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by: N. Parkin and C. R. Flood

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# WELDING CRAFT PRACTICE

Part 1, Volume 1:  
Oxy-acetylene Gas Welding  
and Related Studies

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and

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# **WELDING CRAFT PRACTICE PART 1**

*VOLUME 1: Oxy-acetylene Gas Welding and  
Related Studies*

BY

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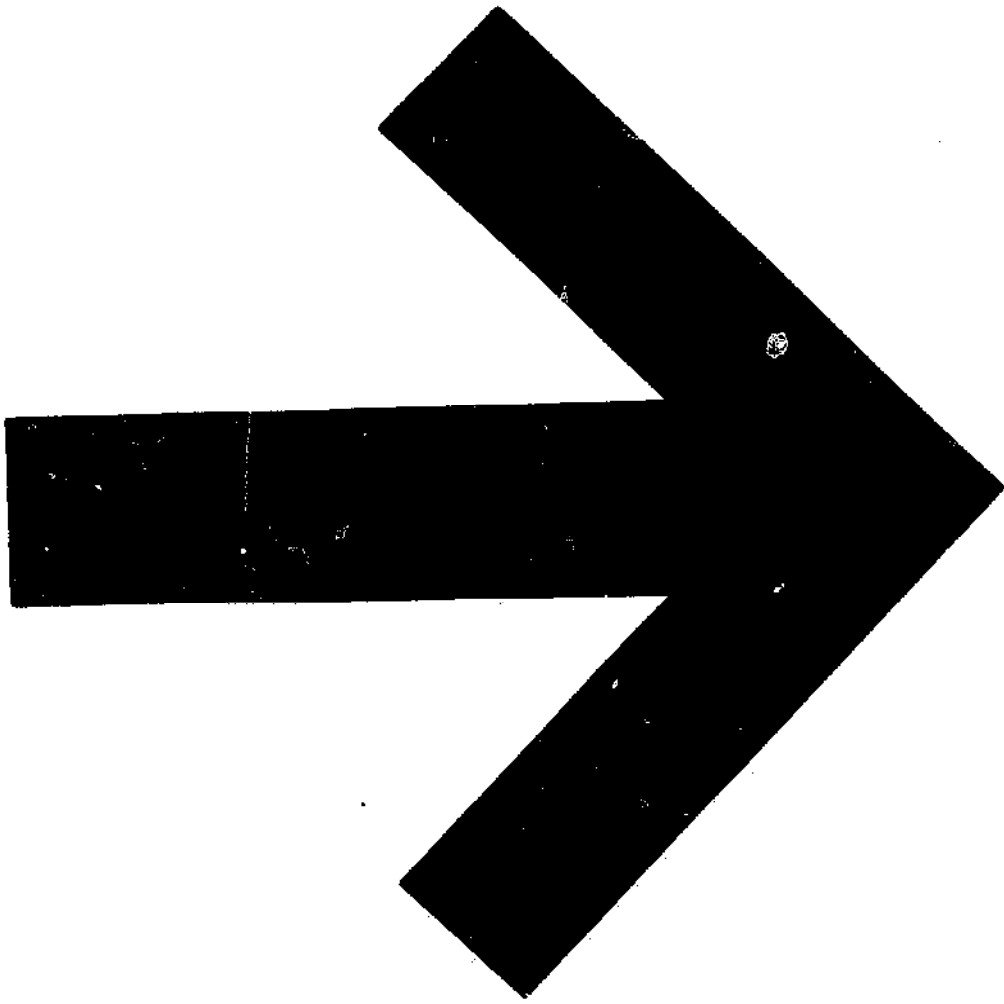
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## Publisher's Foreword

THE Industrial Training Act has resulted in an increase in the number of people now being trained or re-trained. LICET\* books are intended to provide suitable texts which will be easy to read and assimilate for those employed in industry and commerce who are receiving further education and training as a part of their employment. It is hoped that they will be particularly suitable for those attending courses leading to the examination of the City and Guilds of London Institute, the Regional Examining Unions and other examining bodies.

The books are essentially straightforward, simple and practical in their approach and are designed to provide all the basic knowledge required for a particular trade or occupation. They are structured in such a way that the subject is broken down into convenient and progressive components, and are written by authors specially chosen for their expert knowledge and for their practical and teaching experience of their subjects.

Where appropriate, emphasis has been placed on safety training. In some subjects separate manuals on safety and safety training will be provided; in other texts, authors have been encouraged to emphasise safety precautions at relevant points, or to devote a separate chapter to these matters.

LICET books are published in a number of subject divisions, with each division controlled by a specialist editor responsible for selecting authors and providing guidance and advice to both authors and publisher. It is hoped that the series will make an important contribution to further education and industrial training.

ROBERT MAXWELL  
*Publisher*

*vii*

## Introduction

IN A rapidly developing welding industry there is a constant demand for skilled craftsmen capable of producing high-quality work with first-class equipment. The wide range of modern welding work makes it necessary for the operator to be as capable of controlling expensive automatic machines as he is of performing skilful manual welding. The need is for adequately trained personnel with a sound understanding of the various processes and materials to be used, a keen appreciation of the importance of the correct, careful use of equipment and a completely "safety-conscious" outlook.

The two volumes of this book cover the ground necessary for the acquisition of the essential basic skills. Safe working methods, sufficient technology and related studies being included to provide a suitable background to the practical work and form a basis for further, more advanced studies. It is intended for all who wish to learn to weld and the ground covered will enable the beginner to obtain a sound knowledge of the equipment, a keen appreciation of safety and, by means of a graduated series of practical exercises, a good standard of skill.

The intention has been to cover the requirements of the syllabus of the City and Guilds of London Institute, Course 323, Welding Craft Practice (Part I), the relevant information being given for the production and testing of the specimen welds required in this course, and it is hoped that all would-be welders will aim at obtaining a suitable qualification.

Volume 1 deals with Oxygen-Acetylene Processes and Weld Defects, Testing of Welds and Welding Science, Volume 2 with Electric Arc Processes and Elementary Electricity, Classification of

## INTRODUCTION

Electrodes, Welding Symbols, Engineering Drawing, Metal Plate Surface Development and Workshop Calculations.

We wish to express our appreciation to Messrs. Hancock and Company (Engineers) Ltd., Air Products Ltd., Lincoln Electric Company Ltd., Murex Welding Processes Ltd., for allowing the reproduction of photographs and diagrams of their welding equipment.

Material from B.S. 1295; 1959: *Tests for Use in the Training of Welders*, B.S. 1719; Part 1, 1963: *Classification Coding and Marking of Covered Electrodes for Metal-Arc Welding* and B.S. 499; Part 2, 1965: *Welding Terms and Symbols*, is reproduced by permission of the British Standards Institution, 2 Park Street, London, W.1, from whom copies of the complete standards can be obtained.

The student is advised to make a further study of the British Standards referred to.

N. PARKIN

C. R. FLOOD

## CHAPTER 1

# Oxy-acetylene Gas Welding

THIS is a process in which welding heat is produced by the combustion of an acetylene/oxygen gas mixture in a blowpipe which directs the heat in the form of a concentrated flame to the required point causing melting of the parent metal. It is widely used in the welding of most metals and alloys.

### The Gases

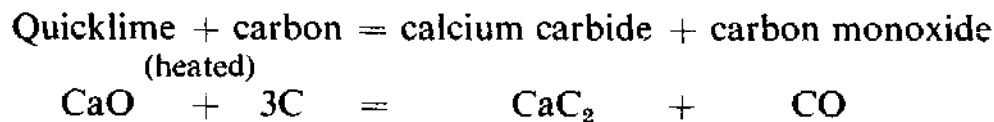
#### *Acetylene*

Acetylene is an inflammable, comparatively heavy gas with a distinctive smell, and it gives the highest flame temperature (3200°C approx.) of any fuel gas. It is unstable and is liable to decompose or detonate at elevated temperatures or at pressures above 15 p.s.i. When mixed with air it forms explosive mixtures in all proportions between 2% and 82%, and when in contact with copper or alloys containing 70% copper, e.g. pipes and valves, it can form violently explosive compounds known as acetylides.

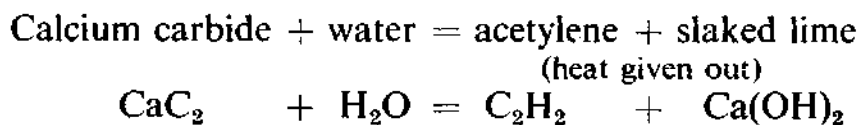
To make it possible for acetylene to be generated and used with safety a comprehensive set of safety regulations is essential and a thorough study must be made of the *Memorandum on Safety Measures Required in the Use of Acetylene Gas and in Oxy-acetylene Processes in Factories* (H.M.S.O., Form 1704) and the recommendations of the British Acetylene Association and the suppliers of gas and carbide.

Acetylene is a "hydrocarbon", or a chemical compound of carbon and hydrogen ( $C_2H_2$ ), and is prepared by the interaction between calcium carbide and water.

Calcium carbide is made by smelting quicklime and coke in a furnace. The result is the formation of a hard grey solid, calcium carbide ( $CaC_2$ ) and carbon monoxide (CO) gas:



Calcium carbide reacts chemically in contact with water to generate acetylene gas:



One pound of calcium carbide produces approximately  $4\frac{1}{2}$  ft<sup>3</sup> of acetylene gas.

#### GENERATION OF ACETYLENE

There are two types of generator:

(a) *Water to carbide*, used when small gas yields or portability are required and ranging in capacity from a calcium carbide charge of several pounds up to 1 cwt.

Generation is brought about by allowing a controlled flow of water to have access to calcium carbide placed in charging trays. The gas is cooled and "washed" by allowing it to pass through the body of water in the container, the washing removing some of the impurities (ammonia and sulphuretted hydrogen). The flow of water to the calcium carbide is controlled by the pressure of generated gas.

*Method of operation* (see Fig. I.1). The flow of water from the outer container (1) to the calcium carbide trays (2) is regulated by the water control valve (3). As gas is generated it passes through the main body of water into the rising gas bell (4) and the pressure of gas gradually lifts the rising bell, allowing the water control valve to close owing to the upward movement of the valve control

## OXY-ACETYLENE GAS WELDING

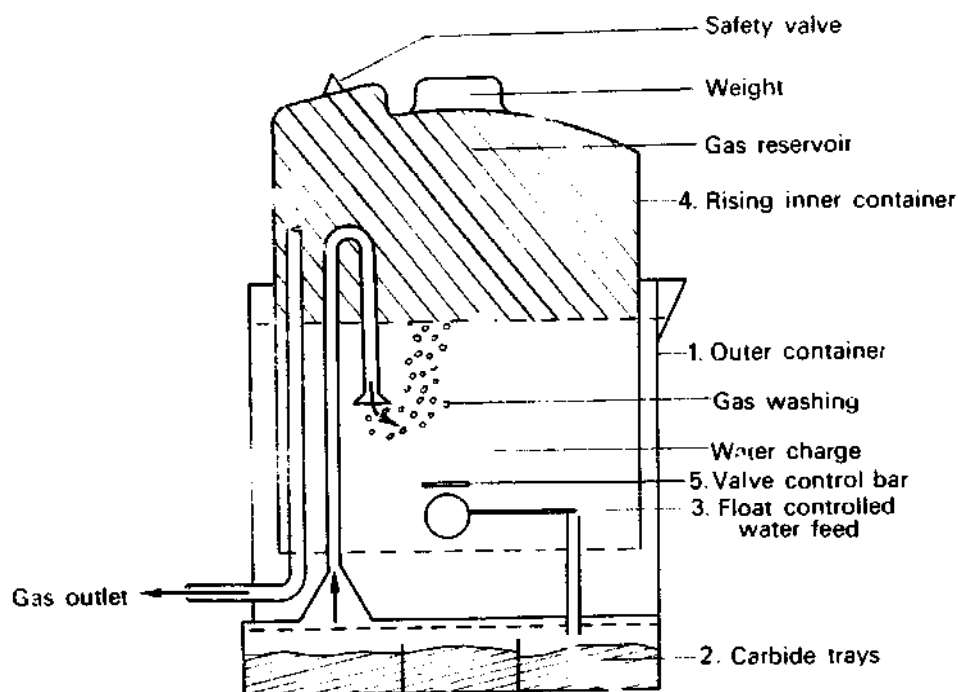


FIG. I.1. Acetylene generator (water to carbide type).

bar (5). The carbide compartment is surrounded by water to absorb the heat given out by the chemical reaction. This is important because gas generated slowly under cool conditions contains a much smaller percentage of impurities. Once the reaction has started in the charging trays it may continue for some time after the demand for gas has ceased, hence the tendency for "over-making" and waste of calcium carbide. After generation is complete the sludge (slaked lime) residue from the calcium carbide must be removed, safely disposed of and the trays cleaned before recharging.

(b) *Carbide to water.* The graded calcium carbide is gravity fed through a feed-control valve into the water contained in the lower part of the apparatus. This method gives more precise control over the rate of gas production, allows complete gasification and cooling of the calcium carbide and (because of its sensitivity to variations in gas demand) prevents "overmaking". The larger static plants are usually of this type and the operation can be



made completely automatic by means of a calcium carbide conveyor feed, a continuous flow of cooling water and water-carried sludge removal.

*Method of operation* (see Fig. I.2). The supply of calcium carbide from the hopper (1) is regulated by the automatic feed valve (2) which is closed or opened by the rise or fall in the pressure of generated gas acting on the feed-control diaphragm (3). Falling into the lower part of the chamber the calcium carbide reacts with the water and the acetylene gas is "washed" and cooled as it passes up through the water into the gas storage chamber (4). The slaked lime residue falls to the bottom of the container and may be discharged through the sludge cock (5) to a settling tank.

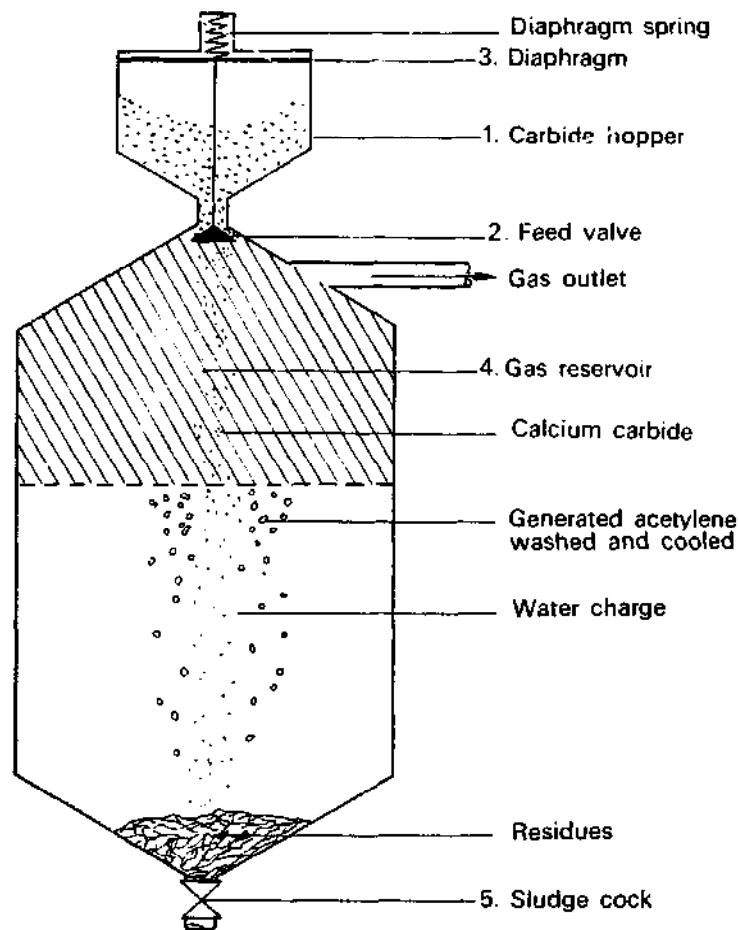


FIG. I.2. Acetylene generator (carbide to water type).

Acetylene produced under the correct conditions is cool and partially purified and may be used for cutting and for some mild steel welding processes. In view of the amount of heat generated by the reaction between calcium carbide and water, ample cooling facilities and a slow production rate are essential features of a good type of generator. Only good-quality calcium carbide (to B.S. 642) should be used. Elevated temperatures in the reaction will seriously affect the purity of the gas and reduce the gas yield per pound of calcium carbide. The outlet temperature of the gas should never exceed 75°C.

Because of the fire and explosion hazards inherent in the process, only generators of a type approved by the British Acetylene Association should be used and the complete installation, including calcium carbide stores and sludge-disposal arrangements, must be in accordance with the appropriate regulations.

#### PURIFICATION OF ACETYLENE

The gas as generated is crude acetylene containing several impurities (ammonia, sulphuretted hydrogen, lime) and if it is to be suitable for all types of welding it is essential that these impurities are removed.

*The acetylene purifier* (see Fig. I.3). The gas from the generator is fed upwards through layers of pumice (1), salts of ferric iron (2) and felt pad (3), issuing at the outlet (4) in a purified state. The contents of the purifier need to be replaced periodically, the frequency of this depending on the volume of gas treated and the proportion of impurities to be removed. It must be emphasised that the emptying and recharging of purifiers must be carried out under the same strict safety precautions as apply to generators.

#### *Oxygen*

Oxygen is a colourless, odourless, active gas which combines readily with other substances, or "oxidises" them. The rusting of iron is an example of the oxidation of a metal. The oxygen is not inflammable but when used in combination with a heated fuel gas

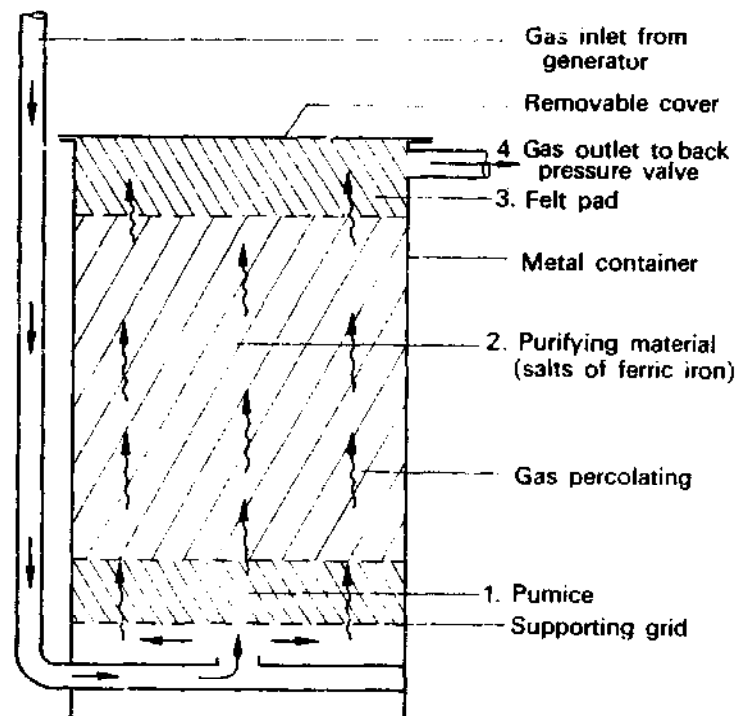


FIG. I.3. Acetylene purifier.

it causes the oxidation of the hydrogen and carbon, which is known as combustion. A fuel gas burnt in air obtains some oxygen from the atmosphere, but the addition of pure oxygen increases the speed of the reaction, giving higher flame temperatures which are due to the more complete combustion of the hydrocarbons.

#### PRODUCTION OF OXYGEN

This gas can be produced in several ways, but the commercial method is by extraction from the atmosphere, approximately one-fifth of which is oxygen. The other gases in the air are nitrogen, carbon dioxide, argon, helium, neon and several other rare gases. Their separation from the mixture provides a wide range of commercially useful gases. These gases are separated by the distillation of liquid air.

After the removal of impurities, compression to 3000 p.s.i.

results in the liquefaction of the gas at a very low temperature. The liquid air is then allowed to evaporate, the various gases "boiling-off" at differing temperatures, leaving a residue of pure liquefied oxygen.

This may be used in its liquid form for "bulk oxygen" supplies, or it can be passed through an evaporator and used for cylindered supplies as a compressed gas. Oxygen is quite stable and safe at high pressures, but it produces violent reactions with grease and oil and should never be used as a substitute for compressed air.

### Systems and Equipment

There are two systems of oxy-acetylene gas welding:

(a) *Low-pressure System* (see Fig. I.4)

The arrangement of the necessary equipment is shown in the diagram and it must be emphasised that the layout, installation and operation of the plant requires expert knowledge. The requirements of the applicable regulations must be fully met with the object of attaining the highest possible standard of safety.

The acetylene is drawn at a low pressure from a local generating plant and supplied to the welding points through heavy-grade mild steel pipes. At each welding point a safety device is provided in the form of a hydraulic back-pressure valve at which the operator takes the acetylene from the outlet side of the valve. It should be appreciated that in the event of a "flash-back" or back pressure occurring in the blowpipe, violent explosions could occur in the generating plant.

*The hydraulic back pressure valve* (see Fig. I.5) is provided to isolate the welding points from the generating plant and prevent this dangerous possibility.

*Method of operation.* The valve is filled with clean water to the level of the levelling cock (1), which is then closed. When the gas inlet (2) and outlet cocks (3) are opened the acetylene passes through the water seal at a low pressure. Should back-pressure occur it causes the gas inlet pipe to be sealed with water (see Fig. I.5) and the remaining body of water extinguishes any flame. The

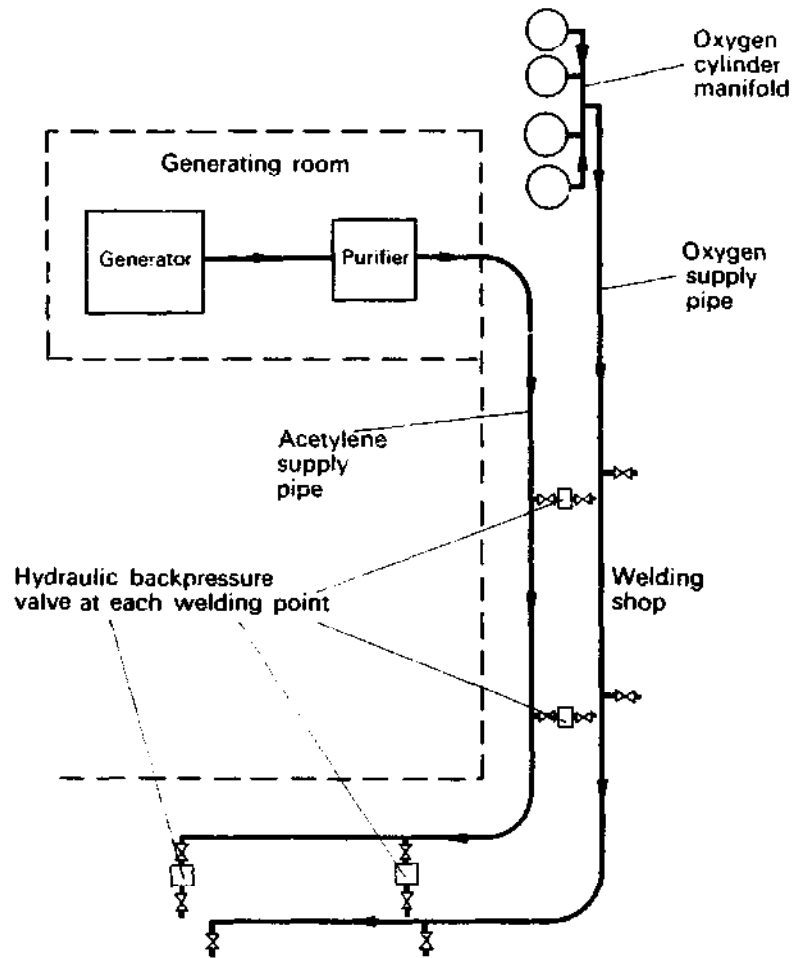


FIG. I.4. Layout for low-pressure system.

excess pressure and any products of combustion are vented to the open air through the water-sealed filling pipe (4). Should a "flash-back" occur, the water level in the valve must be checked before resuming welding. It must also be checked daily before welding starts.

In severe weather the valve should be protected from frost, either by insulation or the use of anti-freeze solution. A frozen valve may be safely thawed out by the application of boiling water, steam or hot cloths; a naked flame must never be used.

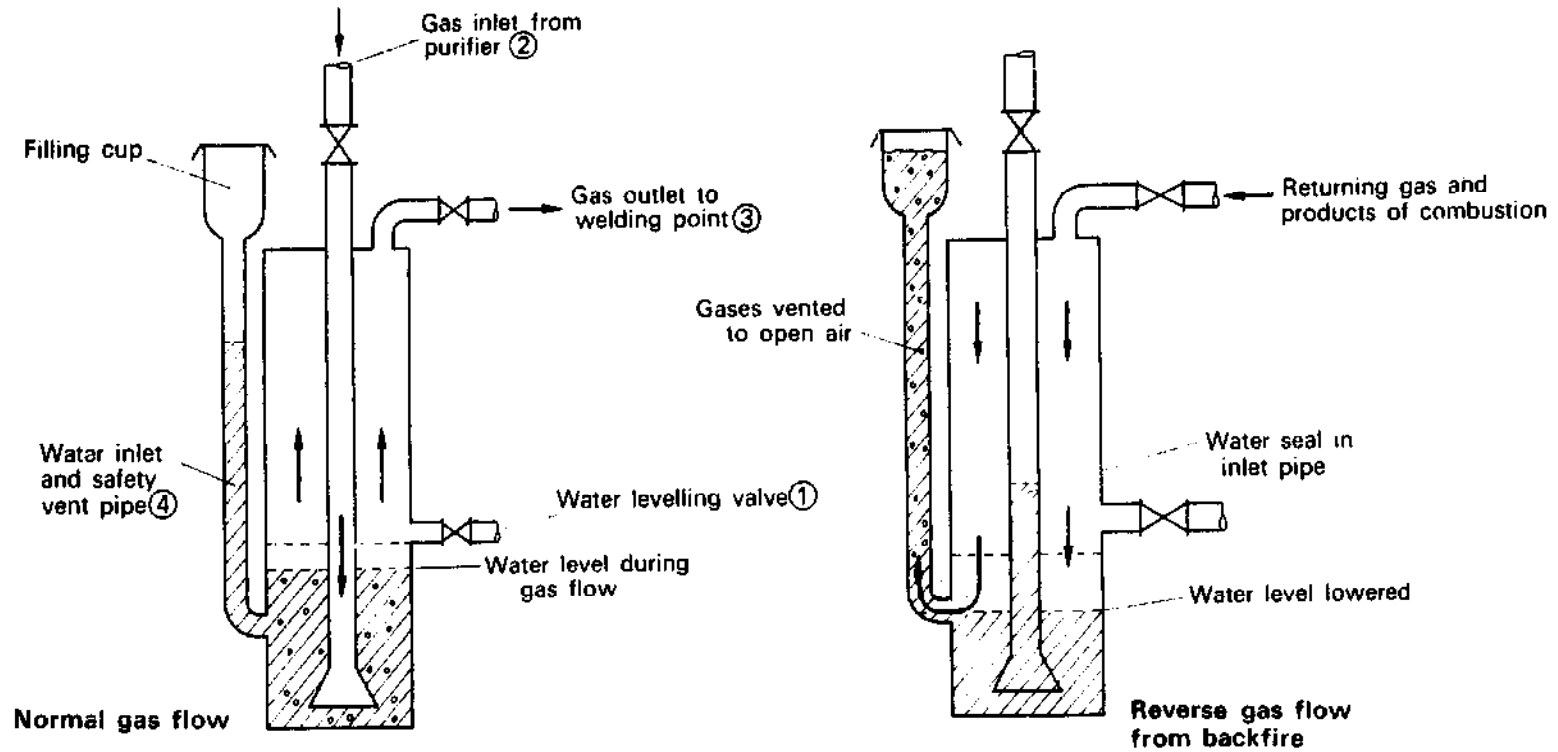


FIG. I.5. Hydraulic back-pressure valve.

THE LOW-PRESSURE BLOWPIPE (see Fig. I.6)

As the acetylene supply is at a very low pressure a special arrangement is necessary in the blowpipe to ensure an adequate and reliable flow of fuel gas.

The principle of operation is shown in the diagram. By passing the higher-pressure oxygen through an injector nozzle (1) in the body (2) of the blowpipe, a partial vacuum is created in the blowpipe body and the acetylene is drawn along and mixed with the oxygen, passing into the nozzle at a velocity sufficient to maintain a stable flame. As the injector size is closely related to that of the nozzle the two are combined in the head of the blowpipe. A set of interchangeable heads is available to cover the required range of work.

It will be apparent from the diagram that, should any obstruction of the nozzle occur, it will result in the oxygen (which is at higher pressure) passing down the acetylene supply pipe and creating a potential hazard. In these circumstances the blowpipe control valves must be closed until the nozzle is cleared. Note this type of blowpipe is also suitable for use with the high-pressure system.

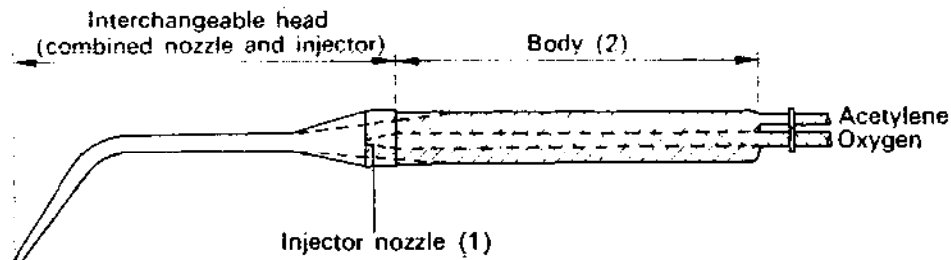


FIG. I.6. Low-pressure blowpipe.

*Oxygen supply.* This will be provided by a cylinder of the compressed gas fitted with an automatic gas pressure regulator to allow a working pressure of 4–8 p.s.i. to be maintained. This and the necessary ancillary equipment are common to both the l.p. and the h.p. systems and will be dealt with in the section on the high-pressure system.

The applications of the low-pressure system are in supplies to fixed points in welding shops and portable plants for site welding. With a static installation of an approved type under the control of a skilled, safety-conscious operator, suitably safe conditions can be achieved; but with portable sets it will always be difficult to maintain reasonable standards of safety.

The main advantage claimed for this system is economy in the cost of acetylene gas as compared with cylindered acetylene, but the actual saving will depend on the type and size of the plant and on the skill of the operator.

#### (b) *High-pressure System*

Both the welding gases are from compressed cylinders, gas-pressure regulators being used to supply the gases at suitable working pressures.

#### DISSOLVED ACETYLENE (see Fig. I.7)

To enable the unstable acetylene to be compressed and stored safely in portable cylinders, the hollow steel cylinder is packed with a porous, absorbent material (charcoal or kapok) which is then charged with liquid acetone. The acetone has a high capacity for dissolving acetylene gas, absorbing 25 times its own volume at atmospheric pressure (1 atmosphere = 14.7 p.s.i.) and 375 times its own volume at 15 atmospheres (the normal fully charged pressure of an acetylene cylinder).

The pure acetylene is introduced into the cylinder in several stages of gradually increasing pressure with "soaking" periods between each stage to allow the acetone time to dissolve the acetylene completely. This procedure is necessary to prevent the formation of pockets of undissolved gas which would be unstable and liable to detonate under adverse conditions. When the gas is completely dissolved in the acetone particles distributed throughout the cellular porous filling, it is stabilised against detonation due to shock or impact and may be used in safety. The processed gas is correctly known as dissolved acetylene (D.A.). When the



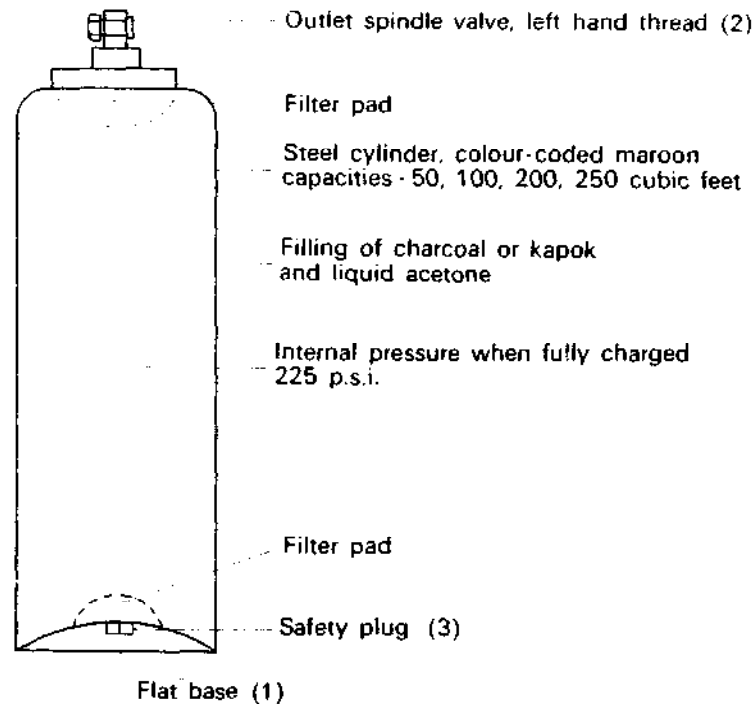


FIG. I.7. The dissolved acetylene cylinder.

cylinder outlet valve is opened acetylene comes out of solution from the acetone at a steady rate, in the same way that carbon dioxide gas escapes from a bottle of mineral water when the cork is released.

The rate of discharge from a cylinder must never exceed one-fifth of the cylinder pressure per hour, otherwise it is likely that the acetone, which is inflammable, will pass from the cylinder into the hoses and blowpipe creating a serious hazard. The maximum discharge rate for a fully charged cylinder is therefore  $\frac{225}{5} = 45 \text{ ft}^3$  per hour.

Because of the liquid content, a D.A. cylinder whether full or empty must always be kept in a vertical position. Any leakage of acetone can create a dangerous situation especially if it occurs in the work area.

Although a "cylinder contents gauge" is provided on the acetylene gas pressure regulator it does not give an accurate indication of the gas content of the cylinder, because the gas is in the dissolved

state. The contents and weight of a full cylinder are shown on the label attached to the outlet. The quantity of gas remaining in a partially used cylinder can be found by weighing it, subtracting this figure from the "full weight" and calculating, on the basis that 1 ft<sup>3</sup> of acetylene weighs 1.1 ounces, the volume of gas used. By subtracting this from the original content given on the label the remaining volume of gas in the cylinder may be determined.

EXAMPLE: Stated weight of full cylinder	219 lb 0 oz
Present weight	212 lb 13 oz
	_____
Weight of gas used =	6 lb 3 oz or 99 oz
Volume of gas used = 99 ÷ 1.1 =	90 ft <sup>3</sup>
	_____
and,	
Volume of gas in full cylinder	= 218 ft <sup>3</sup>
Volume of gas used	= 90 ft <sup>3</sup>
	_____
Volume of gas remaining	= 128 ft <sup>3</sup>
	_____

#### THE ACETYLENE CYLINDER (see Fig. I.7)

The steel shell has a domed, flat base (1) for stability, is fitted with a  $\frac{7}{8}$ -in. B.S.P. thread spindle valve outlet (2) and is painted maroon for identification purposes. [Note the safety plug in the base (3).] The construction and operation of the spindle valve outlet is shown in detail in Fig. I.8. [Note the passage of the gas (1) through the outlet, and the second safety plug (2).] As with other fuel gases the outlet tapping is a left-handed thread. This simple precaution ensures that only a fuel gas regulator can be connected to the cylinder and effectively prevents the accidental misuse of the gas for a non-fuel gas.

#### CYLINDER MANIFOLD SYSTEMS (Figs. I.9 and 10)

Where the total required discharge rate would be above the safe maximum for a single cylinder use must be made of manifolded cylinders. This method consists of interconnecting two or more

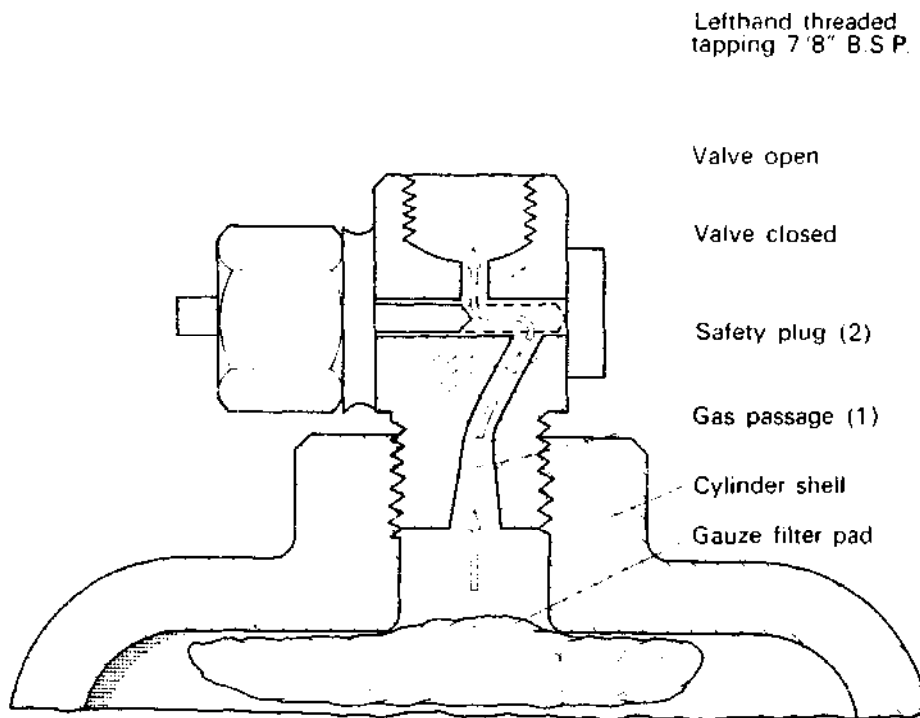


FIG. I.8. Acetylene cylinder outlet.

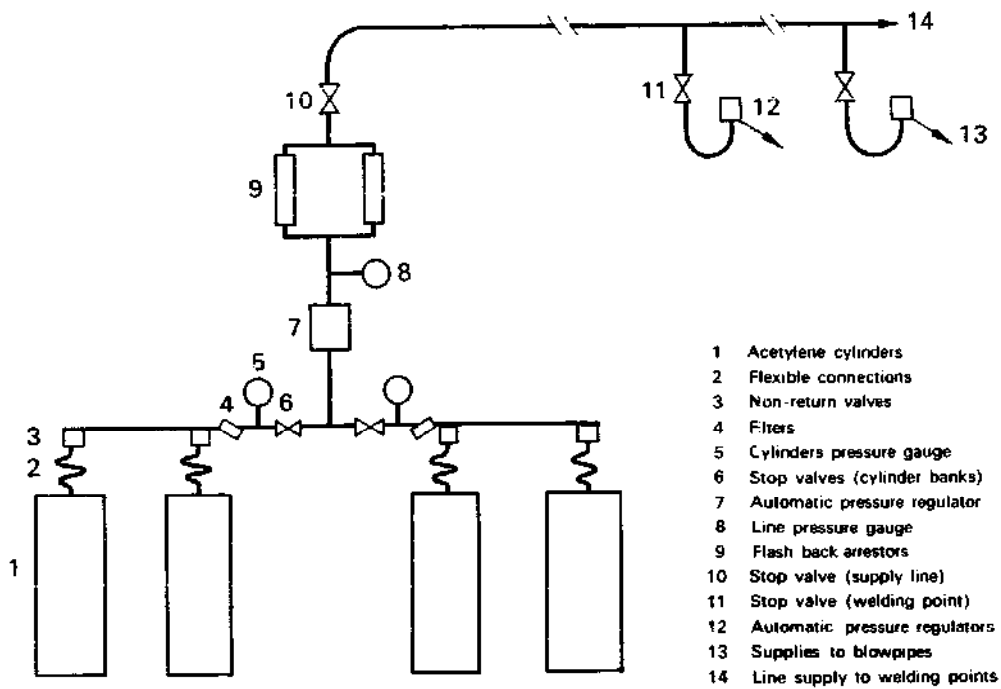
cylinders to supply a common outlet. A manifold of two cylinders will reduce by one-half the discharge rate from a single cylinder. This may be done by using the correct type of fittings, i.e. three-way valve adaptor and connecting arm.

For a permanent installation, serving a number of fixed welding points from a central source of supply, flashback arresters, non-return valves, and main-line control valves and gauges are essential features and the system should be designed and carried out by one of the specialist firms. The principal advantages arising from the use of this system are:

Increased standards of safety as the cylinders can be located outside the welding shop when fire and explosion hazards due to leakages and naked lights are much less likely to occur. The possibility of mechanical damage is also considerably reduced.

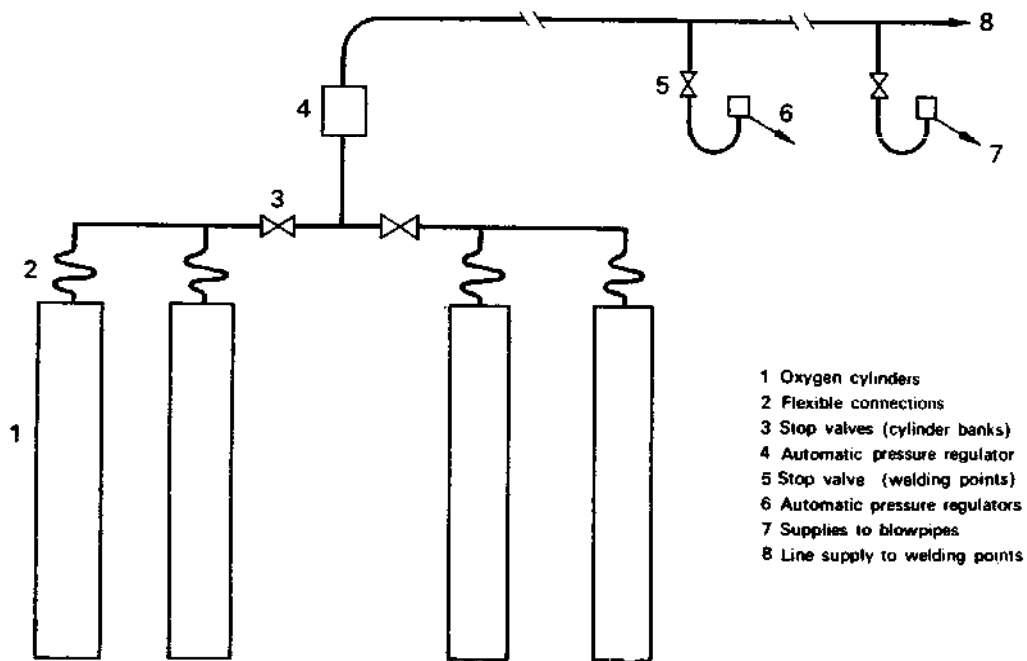
A constant uninterrupted supply of gas can be maintained at each welding point.

OXY-ACETYLENE GAS WELDING



- 1 Acetylene cylinders
- 2 Flexible connections
- 3 Non-return valves
- 4 Filters
- 5 Cylinders pressure gauge
- 6 Stop valves (cylinder banks)
- 7 Automatic pressure regulator
- 8 Line pressure gauge
- 9 Flash back arrestors
- 10 Stop valve (supply line)
- 11 Stop valve (welding point)
- 12 Automatic pressure regulators
- 13 Supplies to blowpipes
- 14 Line supply to welding points

FIG. I.9. Diagrammatic layout of dissolved acetylene manifold.



- 1 Oxygen cylinders
- 2 Flexible connections
- 3 Stop valves (cylinder banks)
- 4 Automatic pressure regulator
- 5 Stop valve (welding points)
- 6 Automatic pressure regulators
- 7 Supplies to blowpipes
- 8 Line supply to welding points

FIG. I.10. Diagrammatic layout of oxygen manifold.

Gas-pressure regulators are not subject to damage in the same way as when used in individual cylinders.

Handling of cylinders is reduced to the minimum. The absence of cylinders from the workshop area gives a welcome increase in available floor space in addition to the greatly improved safety aspect.

### THE AUTOMATIC GAS-PRESSURE REGULATOR

When using compressed gases at relatively high pressures it is necessary to have some means of controlling the gas flow which will allow a low working pressure to be maintained constantly at the blowpipe. The gas-pressure regulator is used for this purpose and two types are available.

1. *Single-stage Regulator* (Fig. I.11). A single adjustable spring-loaded diaphragm is used to control the gas flow. The principle of operation (see Fig. I.12) is:— when the gas pressure on the inlet side (A) of the diaphragm (1) is sufficient to overcome the force exerted by the spring (2), the inlet valve (3) will close and will remain closed until gas is withdrawn from (A) through the outlet. The reduction in pressure in (A) will then allow the spring to move the diaphragm and inlet-valve spindle (4), thus opening the inlet valve. If the tension of the spring can be varied by a fine screw adjustment (5) then gas can be supplied at any pressure within the capacity of the spring.

Owing to the high inlet pressures, it is not always possible with this type of regulator to maintain the fine, accurate control of working pressures necessary in oxy-acetylene welding. The use of the single-stage regulator is therefore usually confined to the control of gases used for manual O.A. cutting, preheating and gas-shielded arc processes.

2. *The Multi-stage Regulator* (see Plates I.1 and 2 and Figs. I.13 and 14) is suitable for all types of welding and cutting as it gives precise control over gas pressures. Reference to Fig. I.14 will show that the same principle of pressure reduction is used as in the single-stage type, but extra stages are introduced to effect the reduction in steps. The spring in the first stage is not adjustable,

OXY-ACETYLENE GAS WELDING

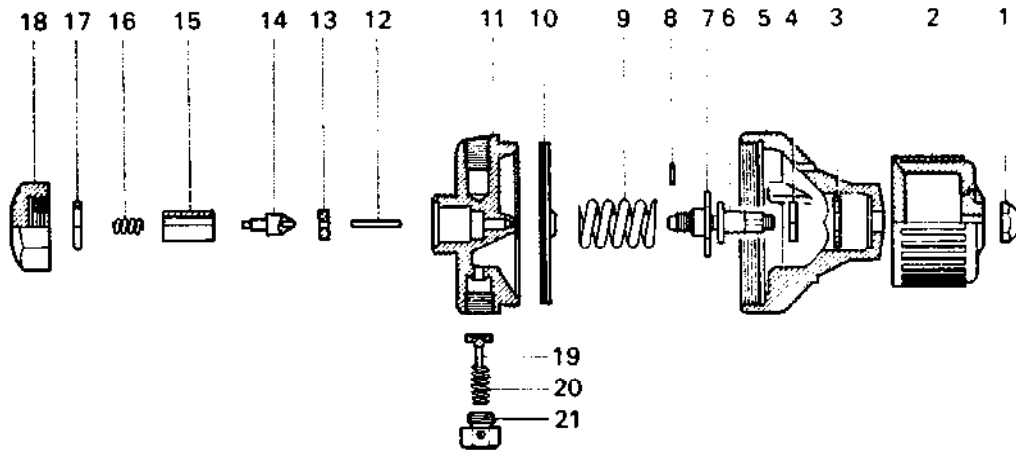


FIG. I.11. Single-stage regulator. (Courtesy, Air Products Ltd.)

- |                              |                        |
|------------------------------|------------------------|
| 1. Cap nut.                  | 12. Valve pin.         |
| 2. Adjusting knob.           | 13. Seat.              |
| 3. Bearing plate.            | 14. Valve stem.        |
| 4. Bearing.                  | 15. Filter.            |
| 5. Bonnet.                   | 16. Plunger spring.    |
| 6. Adjusting screw assembly. | 17. "O" ring.          |
| 7. Adjusting spring button.  | 18. Back cap.          |
| 8. Stop pin.                 | 19. Safety valve stem. |
| 9. Adjusting spring.         | 20. Plunger spring.    |
| 10. Diaphragm.               | 21. Safety valve cap.  |
| 11. Body.                    |                        |

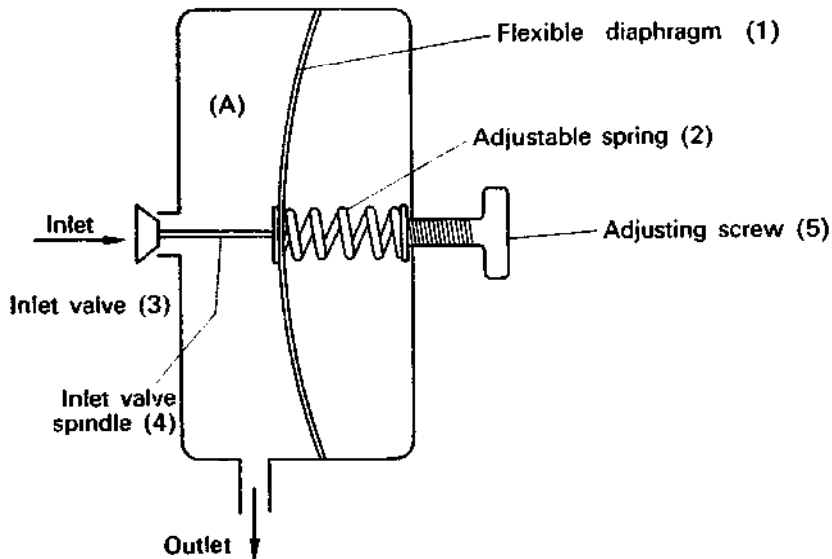


FIG. I.12. Single-stage gas-pressure regulator (principle of operation).

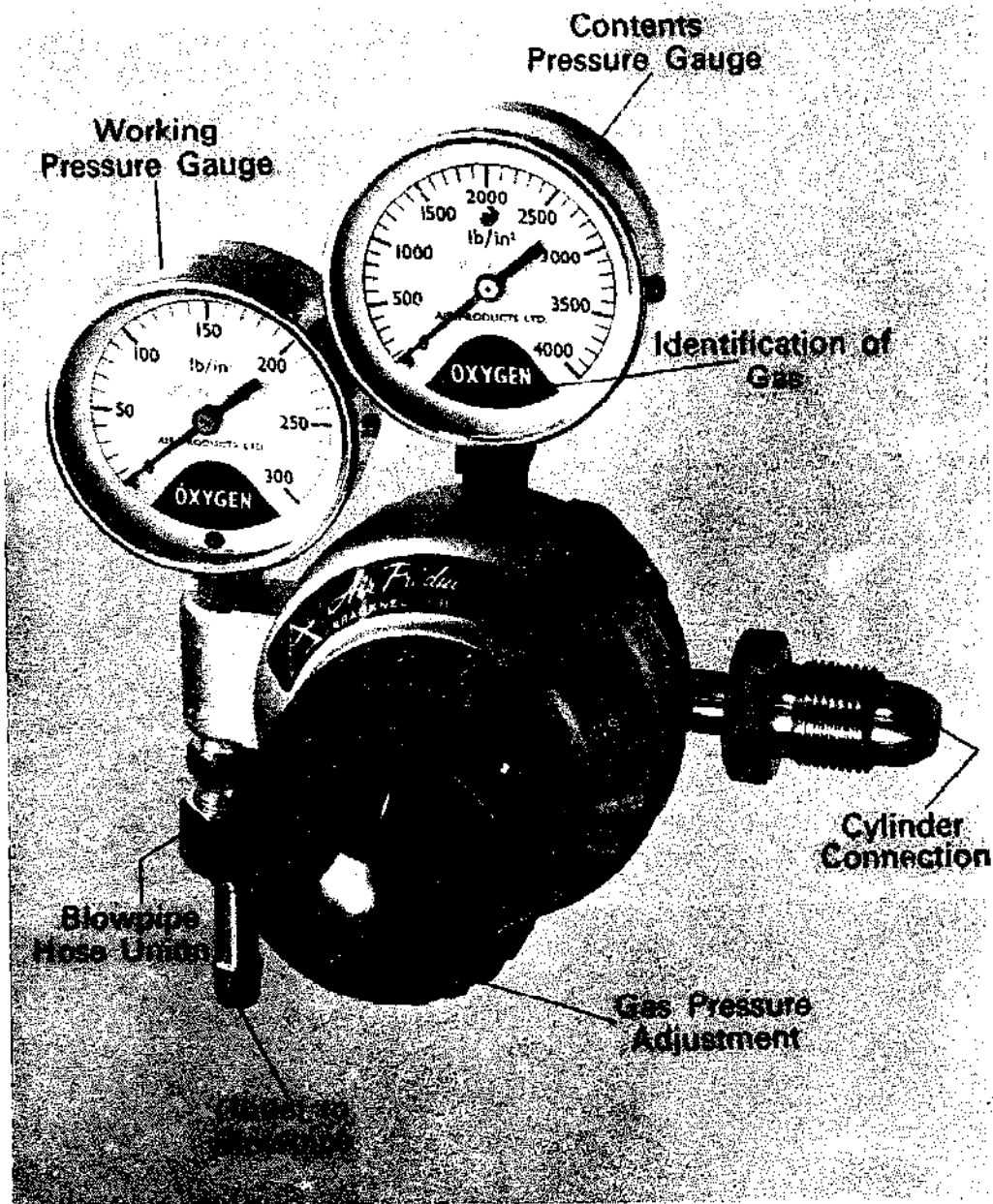


PLATE I.1. Multi-stage gas-pressure regulator.

[Courtesy, Air Products Ltd.]

OXY-ACETYLENE GAS WELDING

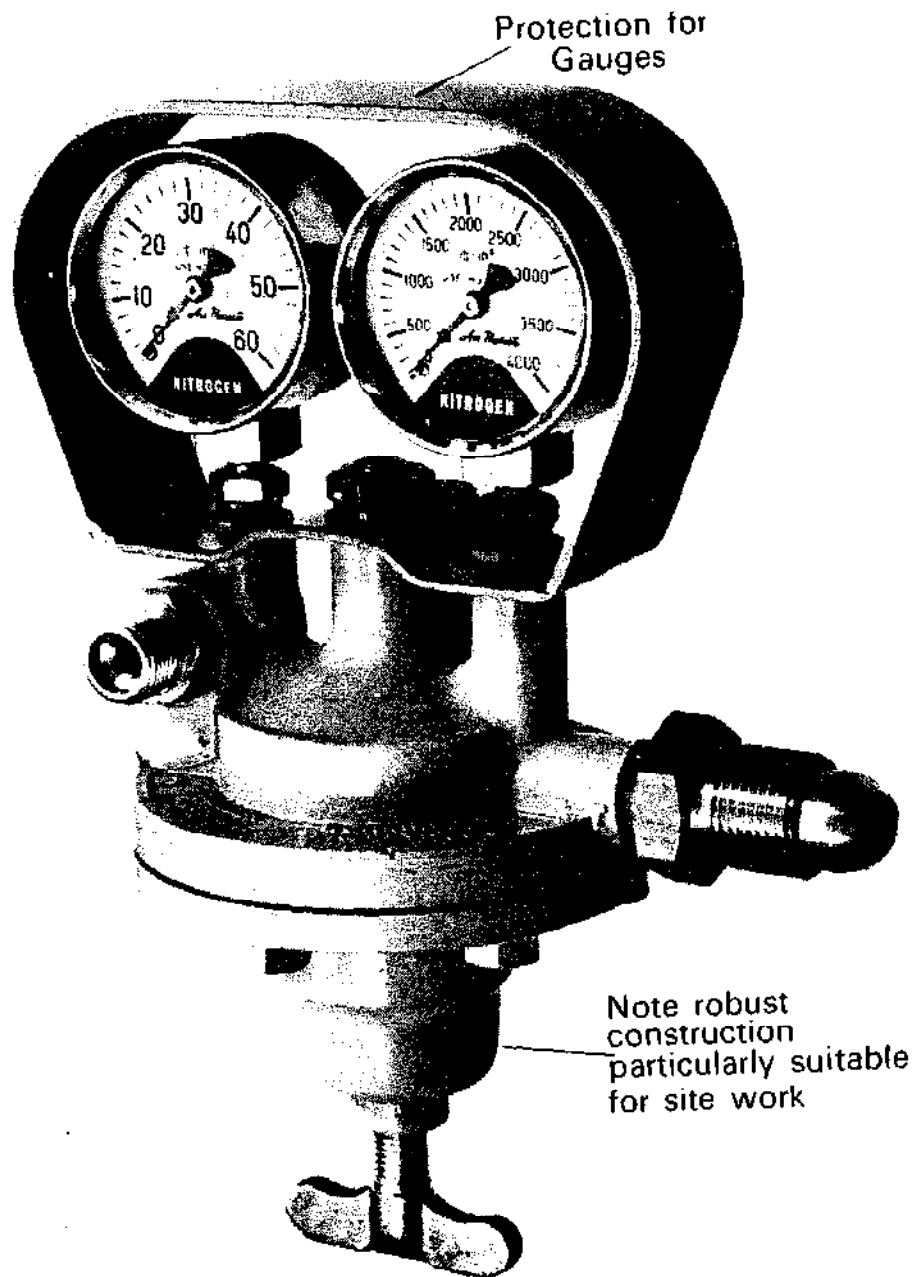


PLATE 1.2. Multi-stage gas-pressure regulator (with protection).

[Courtesy, Air Products Ltd.]



being preset to give an initial reduction from, say, 2000 to 60 p.s.i. The gas is passed at this pressure into the second adjustable stage where it may be varied to give the desired working pressure.

Amongst the various devices incorporated in regulators are filters which prevent the entry of grit and rust into the delicate mechanism, and safety valves designed to relieve excess pressures.

The indicating gauges used consist of a curved Bourdon tube which, under the influence of the internal pressure exerted by the gas, tends to straighten out and, through a delicate rack and

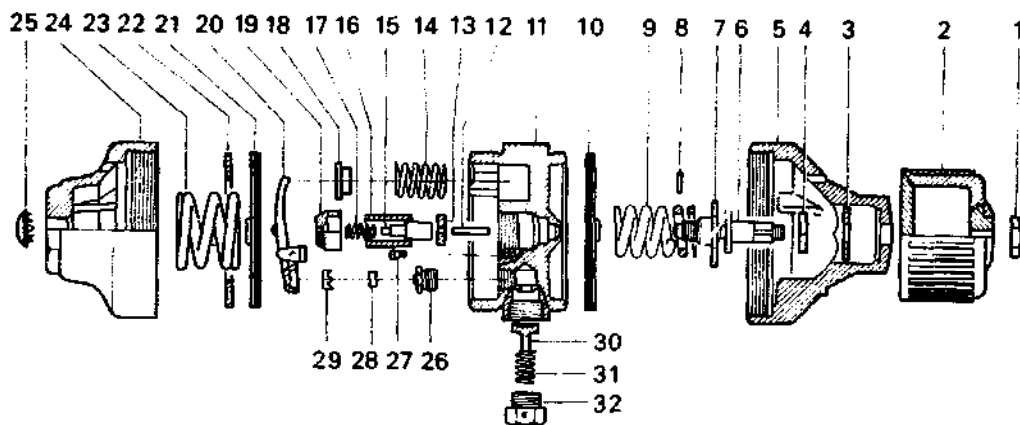


FIG. I.13. Multi-stage regulator. (Courtesy, Air Products Ltd.)

- |                              |                            |
|------------------------------|----------------------------|
| 1. Cap nut.                  | 17. Plunger spring.        |
| 2. Adjusting knob.           | 18. Sealing spring button. |
| 3. Bearing plate.            | 19. Filter retainer.       |
| 4. Bearing.                  | 20. Lever assembly.        |
| 5. Bonnet.                   | 21. First stage diaphragm. |
| 6. Adjusting screw assembly. | 22. Thrust washer.         |
| 7. Adjusting screw assembly. | 23. Interstage spring.     |
| 8. Adjusting screw assembly. | 24. Spring case.           |
| 9. Adjusting spring.         | 25. Spring case plug.      |
| 10. Diaphragm.               | 26. Nozzle.                |
| 11. Body.                    | 27. Bracket screw.         |
| 12. Valve pin.               | 28. Nozzle seat.           |
| 13. Seat.                    | 29. Nozzle seat retainer.  |
| 14. Sealing spring.          | 30. Safety valve stem.     |
| 15. Valve stem.              | 31. Safety valve spring.   |
| 16. Filter.                  | 32. Safety valve cap.      |

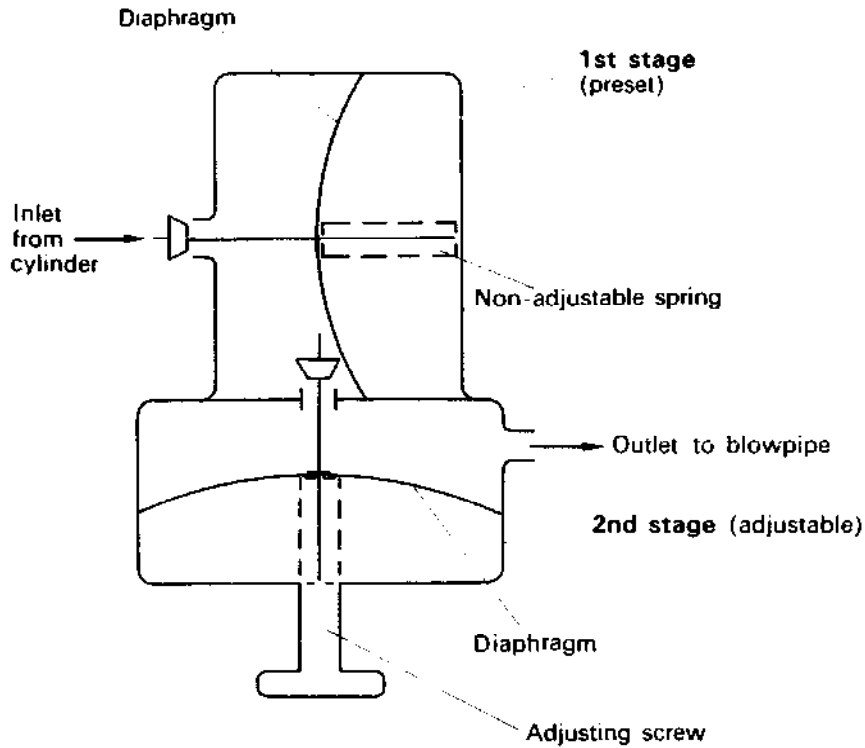


FIG. I.14. Two-stage gas-pressure regulator (principle of operation).

pinion movement, operates a spindle with an attached indicating needle traversing a calibrated scale. The back of the protective metal casing is fitted with a flexible cover and, should the Bourdon tube burst whilst in use, the force of the blast is dispersed through the back of the gauge and not in the operator's face. With the same possibility in mind the transparent front cover is of flexible plastic, not glass. All regulators are clearly marked with the name of the gas and range of pressures for which they are suitable. They must not be used for gases or pressures other than those indicated.

All fuel gas regulators have left-hand threaded cylinder and blowpipe connections, and those of the non-combustible gases have right-handed threads. It will be appreciated that the connection of a fuel gas to a carbon dioxide, argon or air supply line would probably result in a serious accident. Similarly the insertion of a fuel gas regulator into an oxygen or air cylinder could cause damage to the regulator (and to the operator). The differences in

the threaded connections are thus simple, but effective, safety measures to prevent this type of incident.

Regulators must always be treated with great care. Never put them on the welding bench or floor after taking them out of a cylinder. If they are not to be put straight back into service they should be replaced in the maker's carton and stored in a clean cupboard. When disconnected temporarily, e.g. cylinder change-over, place them on a soft, clean cloth in a cupboard. When removing regulators from cylinders always disconnect the gas hoses and use the correct spanners on each connection. Do not move cylinders from place to place with the regulators in position (unless they are secured in a suitable rubber-tired trolley) and do not hang any equipment such as blowpipes, goggles or overalls on the regulators.

It is essential that regulators should be properly maintained in good repair and, if a leakage develops, or if a precise, stable, correctly indicated working pressure cannot be obtained, the faulty equipment should be returned to the manufacturer for skilled servicing. When a leakage is suspected it should be located by the soap and water test, marked and labelled, and taken out of service until repaired. In the case of a fuel gas regulator the test should be carried out in the open air away from the vicinity of naked lights.

#### HIGH-PRESSURE BLOWPIPE (see Fig. I.15 and Plate I.3)

This is designed to mix the acetylene and oxygen, and deliver an intimate mixture of the gases to the nozzle. As the two gases are used at equal pressures the injection principle, as used in the l.p. blowpipe, is unnecessary. Consequently, the h.p. blowpipe is unsuitable for use on the l.p. system.

*Nozzles*, of copper or a copper alloy, are supplied in a variety of sizes designed to cover a specified range of work, and they are identified by a series of progressive numbers increasing with the diameter of the orifice. The most useful system of identification is where the nozzle size corresponds to the hourly gas consumption (e.g. No. 10 nozzle requires 10 ft<sup>3</sup> each of acetylene and oxygen per

hour, giving  $\frac{200}{10} = 20$  hours welding time from a pair of 200 ft<sup>3</sup> gas cylinders), but, as the method of sizing varies amongst the different manufacturers, reference should be made to the data supplied with the equipment.

Nozzles must always be treated with care as even slight damage

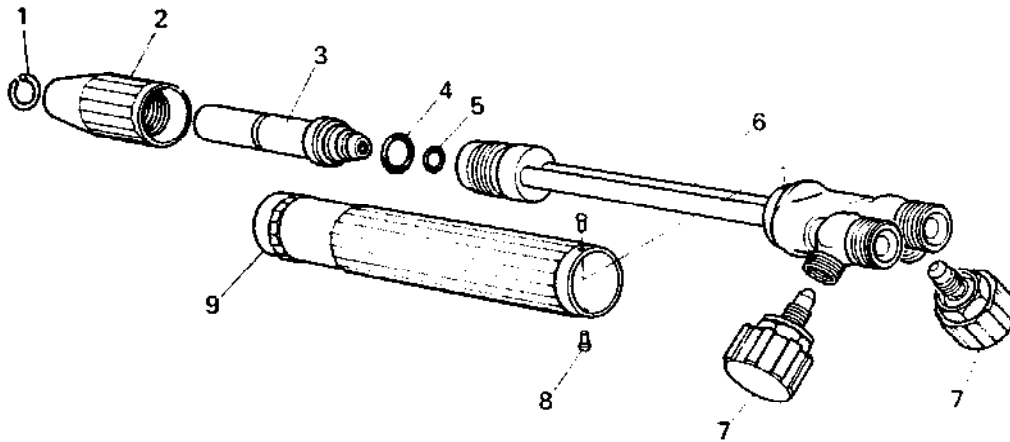


FIG. I.15. High-pressure blowpipe. (Courtesy, Air Products Ltd.)

1. Mixer nut retaining ring.
2. Mixer nut.
3. Mixer.
4. Rear seal ring.
5. Front seal ring.
6. Head, tubes and base assembly.
7. Oxygen and acetylene needle valve stem assemblies.
8. Handle tube retaining pin.
9. Handle tube.



PLATE I.3. High-pressure Oxy-acetylene welding blowpipe.  
[Courtesy, Air Products Ltd.]

will affect performance, making welding more difficult, and may render it dangerous in use; inserting a nozzle with a deformed threaded end will damage the blowpipe. When not in use they should be kept in wooden boxes or racks, or in wallets designed to keep them separate from each other and free from damage. The "storage" of loose nozzles in tool boxes, on benches or shelves or in overall pockets quickly reduces them to a faulty condition.

When the orifice becomes obstructed it should be carefully cleared with the serrated cleaning needles provided; rubbing the nozzle on the bench or the work, and prodding with odd bits of wire are all very effective methods of causing serious damage. As the need arises the built-up deposits should be removed by immersing for several hours in a solution of nozzle-cleaning compound.

*Hoses* are of rubber strengthened by canvas insertion. Those for fuel gas are red with left-handed union connections, whilst the oxygen hose is black with right-handed connections. Standard sizes for welding equipment are  $\frac{3}{16}$ -in. bore with  $\frac{1}{4}$ -in. B.S.P. unions, and  $\frac{5}{16}$ -in. bore with  $\frac{3}{8}$ -in. B.S.P. unions, in lengths of 15, 30, 45, and 60 ft. Flexibility and freedom from kinking are the primary considerations from the operator's point of view, but unfortunately the only material which provides these properties is very vulnerable to damage, being readily combustible and easily cut. Great care must therefore be taken to ensure that the hoses do not come into contact with hot metal or naked flames, and the sharp edges of the work, tools and equipment. A damaged, severed or ignited fuel gas hose is a serious hazard.

Extended lengths of hose are not recommended due to the difficulty of providing adequate protection but, where it is unavoidable, standard lengths of hose may be connected together by hose "couplers". In these circumstances the hoses should be secured in a safe position off the floor and away from sources of heat and moving equipment.

To reduce the danger of flashback, hose-protectors should be fitted at the blowpipe end; this ensures that gas can only flow in one direction—towards the blowpipe. With protected hose of this type the protected end must be coupled to the blowpipe and not

to the regulator. The ends of the hose must be secured to the metal connectors by means of a positive fastening such as a standard hose clip or a "Jubilee" clip. Other methods are a source of danger to the operator and his equipment.

*Goggles* are essential to protect the eyes from ultraviolet and infrared rays, the bright glare of the flame and the hot metal, sparks and drops of molten metal and radiated heat. The frames should completely cover the eyes and the bridge of the nose, be well ventilated, comfortable, light, fire-proof and should conform to B.S. 1542. The elasticated headband should be adjustable. Some types are designed to fit over ordinary spectacles. The lenses should consist of laminated, splinter-proof, tinted filter lenses to B.S. 679 in one of the following shades: light (3/G.W.F.), intermediate (5/G.W.F.), dark (6/G.W.F.). The light tint is normally used for mild steel welding, the darker tints being useful in bronze welding where the glare is brighter. These more expensive lenses are protected by a covering of plain clear glass and when the accumulation of spatter interferes with vision the cheaper covering glass may be renewed, leaving the tinted lenses unaffected.

*A cylinder trolley* holds an oxygen and an acetylene cylinder and makes it possible to transport them in a convenient and safe manner over limited distances, giving portability for site welding. In view of the considerable weight to be carried it should be robustly constructed of stout m.s. angle with a heavy gauge tube handle and chain fastenings for the cylinders. It should be so designed that when it is at rest the cylinders are securely held in the upright position. The provision of rubber tyres considerably reduces vibration and protects equipment from possible damage.

*An equipment box* (Plate I.4) holds a complete set of welding equipment (e.g. blowpipe, nozzles, hoses), and protects it against damage and loss. It may be attached behind the cylinder trolley for site welding.

*Cylinder stands* can be used to hold the smaller oxygen cylinders in an upright position and they give a certain degree of stability, but it must be emphasised that additional, more positive fixing is necessary to eliminate the possibility of a cylinder falling over.

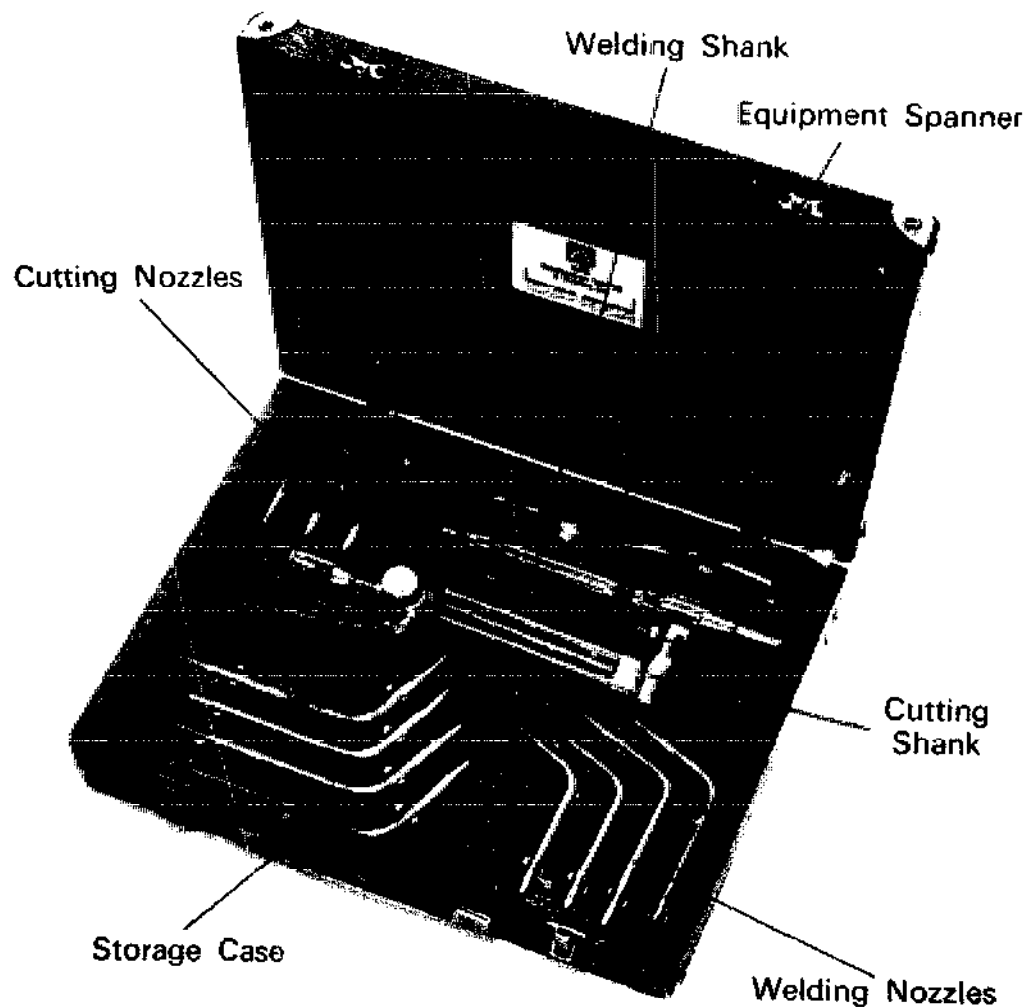


PLATE I.4. Combined welding and cutting outfit.

[Courtesy, Air Products Ltd.]

*Pistol-type spark lighter* is a positive method of igniting a torch, and is preferable, on safety grounds, to naked lights.

*Nozzle cleaners* are supplied to correspond with nozzle sizes and a set should always be available. Their use will prevent the enlargement or deformation of the nozzles which occurs when other methods are used.

*A complete set of spanners* comprises: a single-ended regulator spanner; a combination hose spanner (for hose unions and some nozzles); a spindle valve key (for cylinder outlet valves). To

prevent damage to the equipment it is important that the correct spanners are used with hand leverage only.

A *data card* (or sheet) is supplied with the equipment and should always be available in order that the correct conditions may be used on each type of work.

### *Workshop Layout*

There is a wide diversity of needs in gas welding shops, but certain principles can be laid down which will allow suitable facilities to be provided for any specific needs.

1. *Plate preparation.* The need for cleaning, shaping, bending or cutting the metal must be considered and the necessary equipment located near the welding points. This may include plate or sheet-metal folders, rolls, presses, drills, shears, power saws, oxygen profiling and edge-preparation machines, fixed or portable grinders, sand blasting and degreasing equipment. Floor or bench space should be provided for the stacking of the prepared metal.

2. *Pre-welding assembly.* Facilities may be necessary to allow the component parts to be assembled prior to welding, and this assembly may be divided into a sequence of several stages. The requirements may include jigs, clamps, fixtures, platens, floor plates. Welding points may be necessary to enable the assemblies to be tacked up. The next stage will be either inspection of assembly or stacking of assembled work pieces prior to welding.

3. *Welding operations.* The scale and type of equipment should be appropriate to the volume and nature of the work to be carried out. A choice can be made between low-pressure and high-pressure acetylene, single or manifolded cylinders, cylindered or bulk oxygen supplies. The gas welding points may be at fixed benches or mobile for work on large assemblies. The need for positioners and other work supports should be considered, and provision must be made for the stacking of the welded work before dressing, cleaning and final inspection.

Having decided on the types of equipment and scales of provision, suitable floor space should be allocated to each section. The means of uninterrupted work transfer from one stage to the next



should be considered. This may require the use of overhead cranes, bogies, motorised trucks or conveyor belts, and fixed or mobile cranes, or pulley blocks to lift the work pieces on and off benches, trucks or manipulators. Manual handling should be kept to a minimum.

The necessary skilled men should be available to carry out the duties of inspection and the supervision and maintenance of all equipment. Material, scrap and rubbish storage, and maintenance-staff workshop and store are all necessary to a well-planned shop. The workshop supervisor's office should have a clear view of all parts of the shop.

Adequate natural and artificial lighting with efficient ventilation and means of maintaining a comfortable temperature at all times of the year should be provided.

### **Safety Precautions and Fire Prevention**

It is of primary importance that all work is carried out in a completely safe manner with the maximum protection at all times for both the operator and his equipment. All personnel concerned with welding should be keen to develop a safety-conscious outlook, and the acquisition of a thorough knowledge of welding safety at an early stage in his training will give the operator confidence. Safe working methods should develop into routine practice and an operator who has not developed a completely safe working routine should never be classified as a competent welder.

Attention has already been drawn to the various safety devices incorporated in the equipment, but it is necessary to expand on this and, to complete the picture, the following notes should be studied in conjunction with the comprehensive information contained in the following publications:

1. *Memorandum on Safety Measures in the Use of Acetylene Gas and in Oxy-acetylene Processes* (H.M.S.O., Form 1704).
2. *Health and Safety in Welding* (Institute of Welding).
3. British Standard 349. Colour code for industrial gases.
4. Safety booklets supplied by equipment manufacturers and gas suppliers.

*Compressed Gas Cylinders*

These may give rise to accidents from a variety of causes:

- (a) Mechanical damage to the cylinder shell or outlet may be caused by careless or wrong use and may result in the leakage of gas.
- (b) The gas may come into contact with some other substance, setting up a dangerous reaction, e.g. acetylene and copper, oxygen and oil.
- (c) Heat may come into contact with the cylinder causing a dangerous increase in internal gas pressure, or weakening the cylinder shell.
- (d) Gas leakages may occur, accumulating as explosive mixtures of air and gas in poorly ventilated or confined spaces, or the leakage may ignite at the source.
- (e) The use of defective equipment may cause leakages, back-fires or flashbacks.

The recommended safety precautions aim at preventing such accidents; when they are properly applied and reinforced by the safety devices built in to the equipment they make welding a safe operation at all times.

**THE TRANSPORT, HANDLING AND STORAGE OF CYLINDERS**

They should be transported in a secured position, dissolved acetylene cylinders (full or empty) always being stood upright. Oxygen cylinders may be laid down if more convenient, but if so the stack should not exceed three or four tiers high, and large wedges should be placed at the base of the stack to prevent collapse (see Fig. I.16). Care should be taken that the outlet connections and valves are not damaged. When lifting is not done by hand, cradles, in which a cylinder can be securely held, should be used and if lifting more than a few feet above the ground a cradle is essential. No reliance should be placed on steel ropes, chains, slings, or magnets. The greatest care should be shown at all times during handling and cylinders must never be dropped or bumped.

Although on a firm, level surface a stripped cylinder can

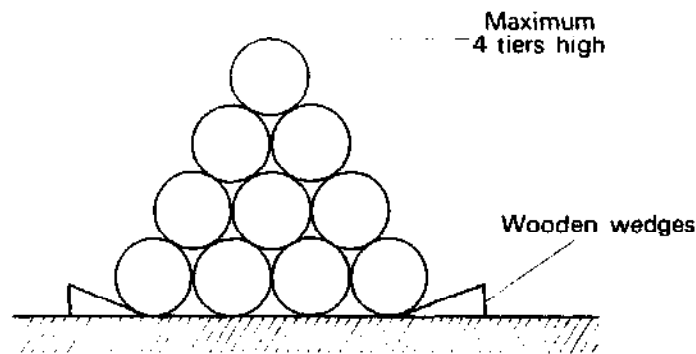


FIG. I.16. Stacking of oxygen cylinders.

conveniently be moved whilst in the vertical position, if the operator maintains the balance with the right hand on the outlet valve and slowly rotates the cylinder on its base, it is preferable to use a cylinder trolley or skid. On uneven surfaces and gradients the trolley is essential. Up or down steps and staircases the single-cylinder trolley should be handled by two men, and if the double-cylinder equipment trolley is in use, the stripped cylinders should be taken up singly.

If it is necessary in site welding to place cylinders on scaffolding, or on any other temporary or permanent elevated structure, careful attention should be paid to ensure that they are adequately supported and securely attached to the structure. It may in some circumstances be preferable to leave the cylinders at ground level, working with extended hoses, but each case must be judged on its merits and the most prudent method selected.

Where more than a single pair of cylinders is in use, suitable facilities should be provided for the storage of both full and empty cylinders. Bulk storage should make separate provision for combustible and non-combustible gases (see Fig. I.17).

The combustible gas store should be situated away from the main work area in an easily accessible position and should consist of a dry, well-ventilated, unheated and fireproof room or enclosure with a strong lockable door displaying the appropriate warning notices. The floor level should be the same as the outside ground level to allow easy movement of cylinders. Electric-light fittings

should be fixed externally, illuminating the store through glass panels. Empty acetylene cylinders should be clearly marked and kept separate from the fully charged ones, e.g. empties on one side of the store and full cylinders on the opposite side.

The non-combustible gas store should for convenience be adjacent to the fuel gas store, following the previous recommendations except that normal electric lighting is sufficient.

Where more than one type of gas is kept in a store (e.g. oxygen and air, carbon dioxide or argon; dissolved acetylene and coal gas or hydrogen) they should stand separately in clearly marked sections.

In view of the dangerous reaction liable to take place, oil and grease, or oily, greasy materials must not be kept in the oxygen store. Similarly, carboys or containers of liquid or solid chemicals, batteries or anything likely to have a corrosive effect on the steel cylinders or react with the stored gases must not be kept in either of the gas stores. Indeed, it should be a strict rule that only gas cylinders are to be placed in the stores.

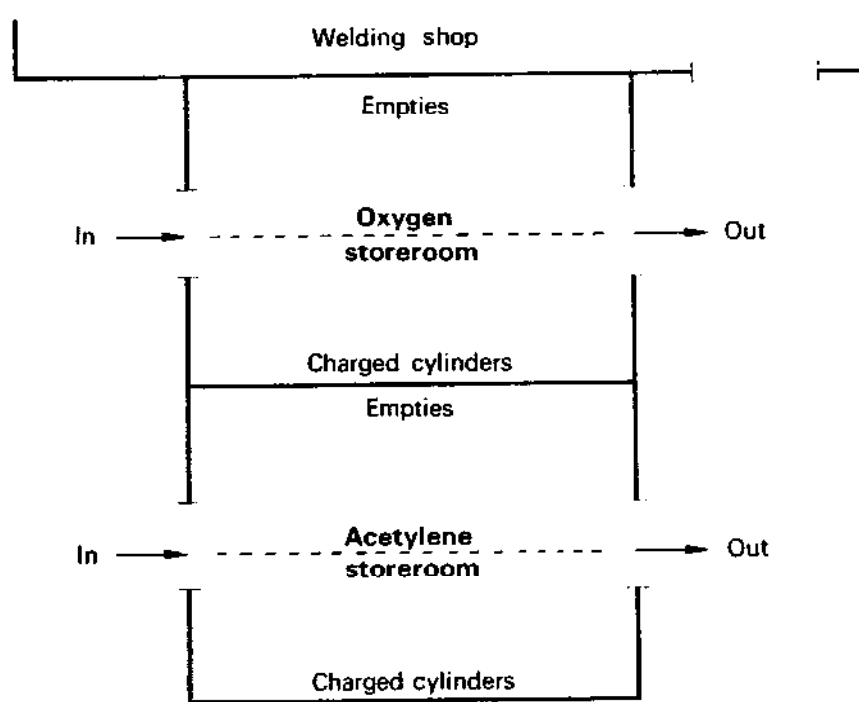


FIG. I.17. Storage of gas cylinders.

When cylinders are put into use they must be protected at all times from water, grit, oil, grease and extreme weather conditions. Water or grit should not be allowed to accumulate in the spindle valve outlet as they can cause serious damage when forced under pressure into the complex mechanism of the pressure-reducing valve. Therefore, even if the outlet may appear quite clean, the valve should always be "snifted" by opening and closing it quickly to ensure complete cleanliness before connecting up equipment.

Gas cylinders, whether in use or not, should be so placed that it is impossible for them to fall or be knocked over; a fallen or toppled cylinder can result in a serious accident. They should never be used as rollers, packings or supports for work or equipment. Wilful misuse of this kind may result in an accident or damage to the cylinder. They should never be placed in contact with electrical equipment such as switchgear, cables or conduit as an electrical fault may cause a flow of current to earth through the metal cylinder with possible dangerous results. They must also be kept away from all sources of heat (e.g. fires, stoves, forges), as any rise in the temperature of the cylinder shell will result in a rapid increase in internal pressure with the possibility that either the cylinder will burst or its contents undergo dangerous changes.

Pure oxygen will react with oil or grease causing it to ignite and where the oxygen is under pressure this combustion will be so rapid that an explosion will occur. Oil, grease or jointing compounds therefore must never be used on any part of the welding equipment. Where a joint will not make tight in a "dry" condition it must be repaired or replaced.

The cylinder outlet should allow easy entry of the regulator connection and where this is not possible, or where obvious damage has occurred, no attempt should be made to apply lubricants, or to "tap out" the threaded outlet or otherwise repair it. The cylinder should be taken out of use, clearly labelled with the fault and the suppliers notified. The only exception to this is where there is a slight leakage from the valve spindle. This can often be remedied by tightening the hexagonal packing gland cover with a spanner. In cases where the leakage cannot be stopped in

this way, or where the spindle valve cannot be completely closed or satisfactorily operated, the cylinder must be taken out of service, as previously mentioned. Leaking cylinders should be stored in a safe place in the open air to await collection and not placed in the cylinder store.

Oxygen cylinders should not be placed near oil-storage containers, machinery, pipe-fitting benches or in any place where there is any possibility of them coming into contact with oil or grease.

The mixing of gases in cylinders and the filling of one cylinder from another are dangerous practices and should never be attempted.

Gases should always be referred to by their correct full names in verbal or written instructions and in cautionary or warning notices. All cylindered industrial gases have the cylinder shell painted a specific colour in order that the contents may be easily and positively identified and it is important that the operator should be familiar with this colour code, which is laid down in B.S. 349 and B.S. 1319. This safety measure is provided to prevent the accidental misuse of gases and as a further precaution all non-combustible gases have right-hand threaded outlet tappings whilst the combustible gases are left-hand threaded. By these means many of the hazards likely to arise, e.g. the use of a fuel gas on an inert gas supply line, are eliminated; though if the colour coding is ignored it is still possible to misconnect any of the non-combustible gases with each other, and similarly with the fuel gases.

Compressed gases must only be taken from a cylinder through a suitably designed automatic gas pressure-reducing valve of one of the types previously described. This is essential in order to prevent hazards likely to arise from the reverse flow of gases or the bursting of hoses due to the full cylinder pressure being imposed on them. The valve must be of the specific type supplied for the particular gas being used and for oxygen, nitrogen, coal gas and hydrogen a minimum inlet working pressure of 3000 p.s.i. is essential; propane and acetylene regulators are designed to function at much lower pressures and must not be used with other fuel gases.

*The Assembly and Use of Equipment*

Equipment of the recommended type supplied by a reputable manufacturer will, if carefully and correctly assembled and handled, give excellent service with no danger to the operator who should ensure that it is always maintained in first-class working order. The correct and safe use of equipment is the primary responsibility of the welder.

**LOW-PRESSURE SYSTEM**

Ensure that the acetylene generator is charged and that gas is available. Fill hydraulic back-pressure valve with water to the correct level and check for correct operation. Place oxygen cylinder upright in stand or on trolley and after "sniffting" the outlet valve insert oxygen regulator, using the regulator spanner with only moderate hand pressure.

Attach the "protected" ends of the oxygen and acetylene hoses to the low-pressure blowpipe inlet connections using the hose spanner. New hoses must be thoroughly blown out to remove dust and french chalk before attaching them to the blowpipe. Close both blowpipe inlet control valves and put the blowpipe in a safe place, whilst connecting the opposite ends of the hoses (acetylene to the hydraulic back-pressure valve outlet and oxygen to the oxygen-regulator outlet). Check that all connections are correctly made before proceeding further.

Insert recommended size of nozzle and turn on acetylene main supply cock. Unscrew oxygen-regulator adjustment until the valve is in the closed position and then, using spindle valve key, slowly open oxygen-cylinder outlet valve. Check cylinder gas content on contents gauge and, if adequate, set the regulator to correct recommended working pressure by screwing in adjuster.

**HIGH-PRESSURE SYSTEM**

The fuel gas supply will now be taken from a cylinder of dissolved acetylene, which will replace the acetylene generator.

Stand the cylinder upright and secure in a safe position away from the welding point and any other naked lights or sources of heat, proceeding as explained previously in regard to the oxygen cylinder. Leave the spindle-valve key in position on the valve at the end of the sequence, as it should not be removed until the acetylene valve is finally closed, in order that any fuel gas leakage may be quickly brought under control. Note that either the low- or high-pressure blowpipe may now be used.

#### TESTING FOR LEAKAGES

With both gases turned on and blowpipe controls closed check carefully for leakages which may arise from loose joints and worn or damaged hoses. Even a slight leak between regulator and blowpipe will be shown by the gradual loss of working pressure on the outlet gauge. Leakage on the regulator and cylinder connections will not affect the gauge readings and on the oxygen supply the only indication will be the noise caused by the issue of the escaping gas. Any acetylene leakage will also be denoted by its distinctive smell.

#### TRACING LEAKAGES

When a leakage is suspected work should not proceed until it has been found and rectified. If the source is not obvious proceed as follows:

*Fuel gases.* Close spindle valve, opening only as necessary to maintain a slight pressure on the equipment. Extinguish all naked lights in the vicinity. Check each joint and the hose from the spindle valve to the blowpipe by brushing on a soapy solution. This is easily made by dissolving a few drops of one of the many common washing-up liquids in clean water, and a supply complete with small brush should always be readily available. The location of any leakage will be positively indicated by the formation of bubbles at the point of issue of the gas.

*Non-combustible gases.* Leave spindle valve open; check joints and hose with soap solution.



### LIGHTING UP BLOWPIPE

Turn on both gas supplies and set correct pressures as before. Slowly open acetylene control on blowpipe until it is purged of air and acetylene is issuing freely (note and remember the pungent smell of the gas), and light at the tip of the nozzle using a spark lighter. The resultant diffused, luminous, but sooty flame is pure acetylene burning in air. Turn up the fuel gas supply until the smoke vanishes from the tail of the flame and the nozzle is now working at its normal capacity with a suitable gas velocity. The flame now, although cleaner, is still of a relatively low temperature. Open the blowpipe oxygen-control valve slowly and note the change in the character of the flame as the oxygen is introduced. The body of the flame turns blue with the formation of a hazy white zone which decreases in size with the development of a small greenish-white cone at the end of the nozzle. Continue increasing the supply of oxygen until the white "feather" of excess acetylene just disappears, leaving a clearly defined inner cone. This is a correctly adjusted neutral flame consuming equal quantities of acetylene and oxygen from the welding gas supplies and a further amount of oxygen from the atmosphere.

*The neutral flame* (see Fig. I.18) is used for the welding of mild steel, but for some metals either a *carburising* or an *oxidising* flame may be necessary. The carburising condition is produced by increasing the supply of acetylene giving the tell-tale feather of excess acetylene. An increase of oxygen will give the sharp pointed bluish cone of the oxidising flame.

Each nozzle may be adjusted over a fairly wide range of flame sizes by increasing or reducing from the original setting, and it will be found that the higher settings of one nozzle size will tend to approximate to the lower settings of the next largest size. Thus a set of nozzles gives a wide choice of flame sizes from which a suitable one may be selected for any particular job.

Flame size should be increased by turning up the fuel gas supply to give a feather of acetylene and then increasing the oxygen supply until the feather disappears, giving a neutral flame of larger size. To reduce flame size: turn down the oxygen supply, again producing the "feather" and then cut down the fuel

gas to remove it. The correct size flame is important in the production of consistently satisfactory welds and adjustments should be made until the flame suits the needs of the operator.

Care should be taken that the flame setting is within the range of the nozzle size in use, for in the higher settings the gas velocity may become too high giving a harsh flame with a sharp, pointed cone. This will agitate the weld pool and make the molten metal difficult to control.

In the lower limits the gas velocity may be insufficient to maintain a stable flame and "lighting back" or backfiring will occur in the nozzle. In each instance a change of nozzle size will give the correct conditions, and when the correct size is in use the flame will be soft and stable.

With the blowpipe lit check that the correct gas pressures are maintained. If they are not, reset at the regulator and readjust the flame.

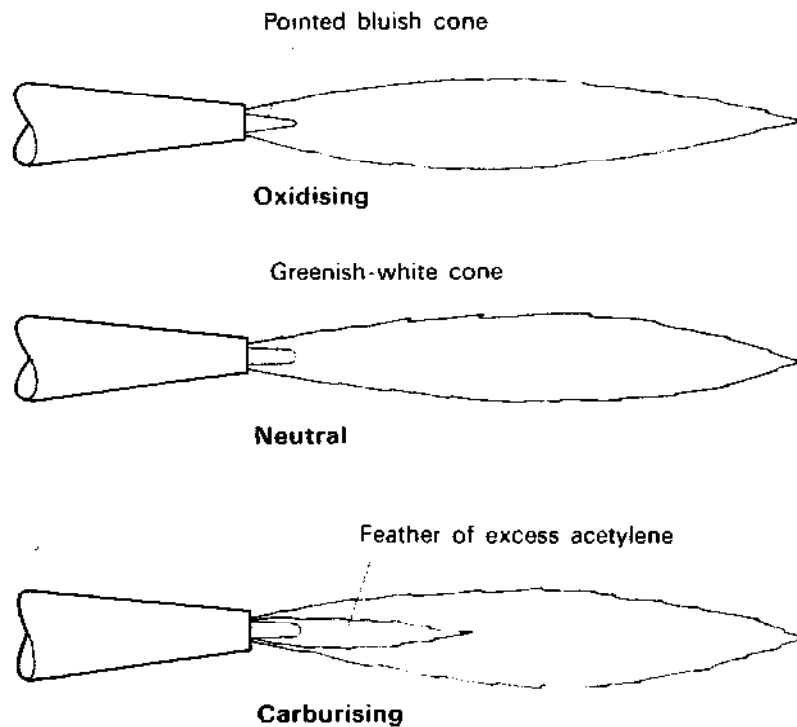


FIG. I.18. Types of flame.

During temporary stoppages of work the blowpipe should be turned off using the blowpipe controls (acetylene first, then oxygen). When welding is finished, or, if the welder is to leave the immediate vicinity of the equipment, it should be completely shut down in the following sequence: (1) close the blowpipe fuel gas control thus extinguishing the flame; (2) shut the oxygen control valve; (3) close outlet valves on both gas cylinders (note: on low-pressure system the main acetylene control cock on back pressure valve must be closed first); (4) relieve gas pressures in equipment by lighting blowpipe and when gases are expended close both valves on blowpipe. Release the tension on the regulator springs by means of the adjusting screws. The working parts in the regulators and gauges are now at rest and all gauges should read zero. If not, check that the cylinder outlet valve is properly closed and then release pressures on equipment as before.

It is most important that the equipment is completely immobilised in this way before it is left, even though the intended absence may be only for a few minutes. The spindle-valve key should be removed from the cylinder and, if welding has finished, the nozzle should be replaced in storage and the hoses neatly coiled and placed with the blowpipe in a safe place.

The following undesirable conditions are liable to arise whilst the blowpipe is in use and the welder should be quick in his reaction and quite sure of the procedure for correction.

*Intermittent backfire* in the nozzle is caused by one of the following factors:

1. Gas pressure set below recommended minimum, giving an unstable flame which has a tendency to "light back" in the nozzle. The correct pressure should be set whilst the blowpipe is alight.
2. Nozzle held too near the work with the inner cone of the flame touching or dipping into the molten weld pool. This obstructs the free flow of gases and produces a minor explosion accompanied by the ejection of droplets of molten metal. Lifting the blowpipe until the inner flame cone is an eighth of an inch away from the surface of the molten metal will

prevent this, and also give much better control of the weld pool.

3. Accumulations of welding spatter, scale and soot on the nozzle end will cause partial or complete blockage of the gas passage, leading to backfiring, reduction of flame size and flame distortion. Where the flame is deflected from the true centre line of the nozzle the result will be lack of fusion at one side of the weld. The bore of the nozzle should be probed, after turning off the blowpipe, with a nozzle cleaner of the correct size.

During prolonged use or with the larger-sized nozzles, and particularly when making tee-fillet welds, the end of the nozzle may become overheated causing the gases to ignite in the mouth of the nozzle and producing a "backfire". The most effective way of cooling is to dip the nozzle into clean cold water, leaving it attached to the blowpipe with the oxygen control opened to give a slight flow of oxygen which will prevent the entry of water into the blowpipe.

Immediately a backfire occurs the operator must determine the cause and take corrective action. Welding carried out with a punctuation of minor explosions is a source of danger to the operator and his surroundings and is indicative of an improperly trained, unskilled welder. Although all backfires should be avoided there is one type, *persistent backfire*, which requires particularly prompt action due to the highly dangerous situation which may arise from it. It is easily recognised by the rapid series of staccato explosions, resembling automatic small-arms fire, in the tip, often followed by the extinction of the flame and the development of a high-pitched squeal in the blowpipe. This is the result of a flashback into the shank of the blowpipe causing the ignition of the gases in the body of the blowpipe and unless it is immediately dealt with it will cause serious damage to the blowpipe. It will be appreciated that this may be followed by the passage of the flame into the fuel hoses, regulator and cylinder with extremely serious consequences. The blowpipe controls must be turned off immediately, the cause of the backfire identified and the fault corrected. If, however, the blowpipe shank has become hot

it must be taken out of use and properly serviced. No attempt should be made to use it until it has been declared to be in sound working order. The fuel hose should also be checked for signs of heating up. If it has been affected it must be removed and either renewed or repaired. When the regulator appears to have been affected it must be taken out of service for a complete check and overhaul.

#### HIGH-PRESSURE SYSTEM

If, in spite of the safety devices incorporated in the equipment, a flashback reaches the acetylene cylinder a situation may develop which will result in the violent explosion of the acetylene cylinder with extremely grave consequences. The flashback, or the products of combustion from it, may initiate the progressive chemical decomposition of the cylinder contents with the evolution of heat and a rapid increase in pressure. The result of this, if allowed to continue unchecked, will be an explosion due either to the detonation of the now unstable contents, or the bursting of the cylinder shell by the excessive pressure.

The only indication of this danger will be the gradual heating up of the top of the cylinder and, therefore, if it feels warm, or hot, or other than quite cool to the touch, calm, prompt and positive action will be necessary to avoid a major accident.

The recommended procedure is:

1. Close the spindle outlet valve.
2. Disconnect and remove the regulator.
3. Take the cylinder outdoors away from the vicinity of other buildings, personnel and naked lights, placing it in an upright position.
4. Immerse the cylinder in cold water, or hose down or spray with cold water.
5. With the face and hands protected open spindle valve fully.
6. Continue cooling until the cylinder is completely empty.
7. Notify gas suppliers immediately and follow their instructions regarding subsequent action.

Note that under no circumstances must the damaged cylinder be returned through the usual channels as an "empty".

Where the cylinder forms part of a manifold or intercoupled system a close check must be made that others are not also in an overheated condition. The outlets of all the fuel gas cylinders must be closed before attempting to remove the defective one(s). The complete installation, pipes, valves, regulators and flashback arrestors must be checked for damage and malfunction by a skilled service engineer before the manifold is put back into operation.

*Hoses* should be examined frequently for cracks, cuts, burnt or worn places, particularly the portions near the hose connectors and those in contact with the floor. Avoid long lengths of extended hoses which will be difficult to supervise and therefore vulnerable to interference or damage. Where extended hoses are essential they must be clipped up clear of the ground and away from vehicles, moving equipment or machinery and sources of heat (e.g. steam pipes, i.c. engines and exhaust pipes).

The correctly coloured hoses must always be used, red for fuel gases and black for non-combustibles. When a fault develops in a hose it must be located and repaired before welding continues. Note that the only two effective methods of repair are either cutting out the defective portion and jointing the remaining sound pieces with a purpose-made hose jointer, or replacing with a new length of hose.

#### LOW-PRESSURE SYSTEM

Where this system is used stringent precautions must again be taken to guard against flashbacks and their effects. As previously mentioned it is essential that the back-pressure valve is correctly maintained and checked daily before welding starts. This is the main protective barrier between the welder and a large volume of acetylene gas and, should a flashback occur, it will effectively prevent a serious accident.

#### *General Fire Prevention in the Workshop and on the Site*

In addition to the hazards likely to arise from the equipment and gases, careful consideration must be given to the effect of the

flame and its resultant heat coming into contact with adjacent combustible materials. Further dangers arise from hot or molten metal and slag, hot stubs of welding rods and sparks all of which may fall or be ejected a considerable distance from the welding point.

In a welding shop the only combustible materials within 30 feet of the welding points should be the gas hoses and the clothing worn by the welder, who should use protection in the form of a leather apron and, depending on the type of work, leather gloves, cap, sleeves, cape, gaiters or spats.

The workshop premises should be of fireproof construction. Concrete, brick or stone floor and walls, steel-framed corrugated asbestos cement or galvanised mild steel-sheeted walls and roofs, roof lights with metal patent glazing bars and reinforced glass, slate or tile coverings on steel roof structures are suitable examples of this type of building. Internal fixtures and fittings should include steel-framed welding benches with brick tops, steel-framed sheet-metal partitions and doors to welding booths, steel cupboards, lockers, shelves, storage boxes and bins. After consultation with the local Fire Service Department the appropriate fire-fighting apparatus in the form of water and sand buckets, fire extinguishers and asbestos blankets should be installed in accessible positions. Attention must be paid to the regular maintenance of this equipment and it should be the specific duty of one individual to ensure that it is always available in first-class order.

Adequate provision must also be made for the escape of personnel should a fire occur. Fire or emergency exits should be clearly indicated in bold lettering and every member of the works' staff must be familiar with the routine to be adopted in the event of an emergency. This routine should be a drill laid down briefly and in simple language, and prominently displayed in all sections of the works.

In the first instance, a full-scale test, or fire drill, should be carried out as soon as possible to ensure that the arrangements are adequate, modifications being made in the light of this experience. Thereafter fire drills should be called at irregular intervals and at unexpected times to familiarise personnel with the routine and to

ensure the smooth operation of this safety measure. In all the foregoing the advice of the local Fire Service department is invaluable and indispensable and should be sought at the earliest possible moment. Combustibles such as wooden benches, boxes, floors, partitions, scaffolding and packings, hemp ropes, clothing, cleaning rags, straw, paper, cardboard, tarpaulin sheets, rubber tyres, hoses and belt drives, inflammable liquids and solids such as petrol, paraffin, grease and plastics may be in the vicinity of the work on site welding and must be moved to a safe position if possible. Otherwise they must be fully protected from damage with coverings of sheet metal or asbestos sheeting.

Where extensive welding or cutting is to be carried out over wooden structures it may be permissible to damp down the woodwork before placing the protective materials in position, but advice should first be sought from the responsible engineer as the swelling and shrinking of the timber may have an undesirable effect on many permanent structures.

During site welding it will be difficult to achieve a high standard of safety, but fire-fighting equipment should be readily available to enable a rapid response to be made to any incident. Each man on the job should have a clear idea of his responsibilities and duties in the event of a fire. The welder should consult the site engineer on the safety aspect before setting-up welding equipment, and thus eliminate what may be unexpected hazards connected with the presence of inflammable, explosive or toxic materials, steam or electrical supplies, and machinery.

In addition to the usual protective clothing an approved type of safety helmet is essential and should be worn at all times.

Each day the scene of work should be closely inspected half an hour to one hour after work has finished to check for the presence of smouldering material.

### *Welding in Confined Spaces*

When working in tanks, drums, boilers or similar vessels special precautions are necessary to give the maximum possible safety for the welder.



If the vessel is not permanently fixed or immovable it must be secured by means of chains, wedges, stays and packings, in such a manner that it will be impossible for it to turn, topple or roll over, or otherwise change its position whilst work is in progress. The immobility of the work piece is of primary importance not only to the welders inside, but also to other personnel in the vicinity. When the vessel is round, cylindrical, or tall in proportion to its base area the risk due to unexpected movement becomes greatly increased and maximum precautions must be taken.

Means of access must first be considered, for ladders and staging may be necessary to give easy and safe access to the interior. Ladders must be in good repair, and preferably of metal construction. They must be secured top and bottom by clamps, bolts or wire ropes. Staging should be constructed by an experienced scaffolder using tubular-metal scaffold poles and fittings and stout scaffold boards. The platforms should be at least four boards wide and have toe and back boards to prevent the accidental fall of tools, equipment and materials. Handrails for personal safety must be provided.

Where the workpiece is not permanently fixed the scaffolding should not be attached to it, but should be stayed and supported from nearby permanent structures to make a scaffold which is independent of the work.

Consideration must also be given to the possibility of mobile equipment such as jib, tower or overhead travelling cranes, or hoists fouling either the work or the staging. There should be no likelihood of contact between electric power wires and the scaffolding or work.

Adequate lighting is essential not only from the safety angle but also to ensure a high standard of workmanship and, where natural light is insufficient, use must be made of a system of artificial lighting. Low-voltage electricity supplying fixed light points which may be small lamps or powerful floodlights, with cables located and secured in safe positions is an efficient and safe method. The use of mains-powered portable inspection hand-lamps on extension leads should not be permitted, for though often convenient it frequently leads to fatal accidents due to short

circuits caused by the cutting or breaking of the cable or its insulation, or by damage to the unearthed lamp and holder.

Where a portable lamp is indispensable a battery-powered type should be used and a choice can be made between the free-standing model which can be placed in a convenient position and the miners' type with lamp attached to safety helmet and battery on the waist belt.

Propane and acetylene floodlights are also effective, but in confined spaces thought should be given to the necessity for ventilating the products of combustion.

With all types of high-powered floodlights the amount of heat generated by the lamps may also create a problem.

Paraffin lamps can provide a wide range of artificial light, but it is never advisable to introduce a reservoir of paraffin, whether pressurised or not, into a confined space. Similarly naked gas or oil flares should never be used. The only naked light in a vessel should be that of the welding blowpipe.

Careful attention should be given to the need for adequate ventilation in partially enclosed vessels. The method adopted should be efficient enough to remove completely all products of combustion from the welding flame(s), all fumes produced by the reaction between the flame and the base metal or coatings, and to supply ample quantities of fresh air to replace that used by the operators in respiration (see Fig. I.19).

Lack of a suitable ventilating system will result in (a) a build up in toxic gases reaching a poisonous level; (b) a reduction in the quantity of oxygen present to the point when respiration becomes difficult or impossible; or (c) a combination of both these conditions. Ventilation must also maintain a reasonable working temperature of, say, 50-55°F inside the vessel, failure in this respect will result in discomfort to the operator, the rapid onset of fatigue and, possibly, collapse through heat exhaustion.

The collapse of the welder will, if welding is in progress at the time, give rise to a fire hazard if the lighted blowpipe comes into contact with clothing, gas hoses or other combustible materials.

A recommended safety precaution is to station an assistant outside the vessel with instructions not to enter under any circum-

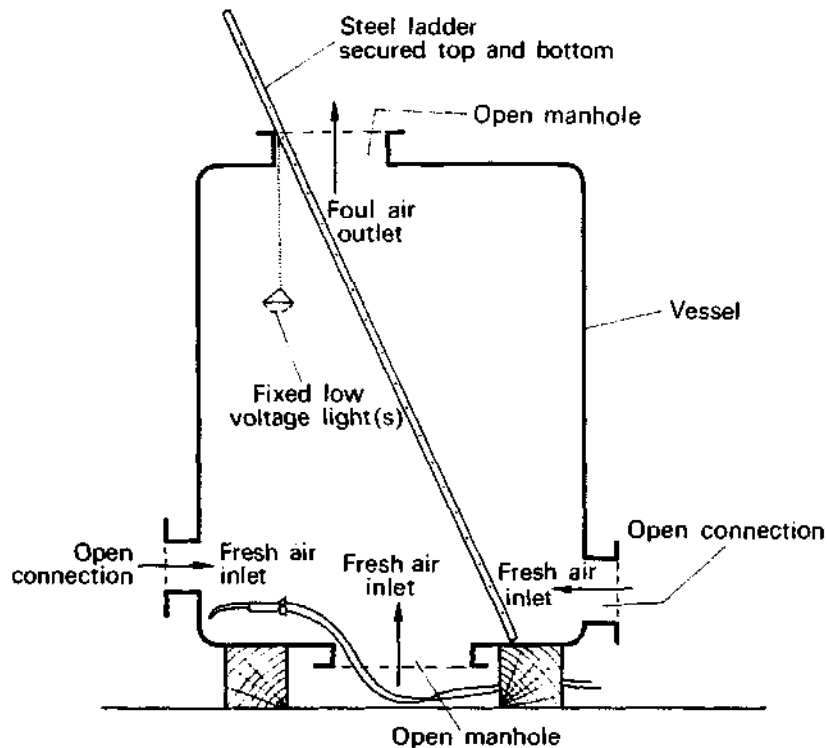


FIG. I.19. Natural ventilation in confined spaces.

spaces. He must be in visual or verbal contact with the welder at all times, conversant with the dangers likely to arise and ready to take immediate action should an emergency arise, e.g. summoning assistance, turning off gas supplies, operating fire extinguishers.

Natural ventilation can be achieved where manholes or other openings are large enough to pass sufficient volumes of air or fumes, and are located in suitable positions at the base and top of the container.

In other instances forced ventilation will be necessary and may be achieved by either introducing a supply of low-pressure air at the base of the vessel to produce a constant upward displacement of fumes through the upper openings (see Fig. I.20), or by drawing out the fumes by an exhaust fan located at the top of the vessel the action of which draws fresh air through the lower openings (see Fig. I.21). Manholes may be available to act as inlets or outlets, but in some cases an opening may have to be cut for the

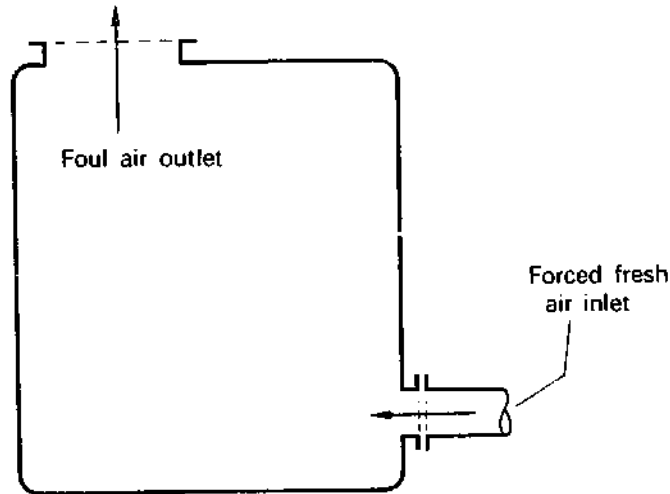


FIG. I.20. Forced air ventilation in confined spaces.

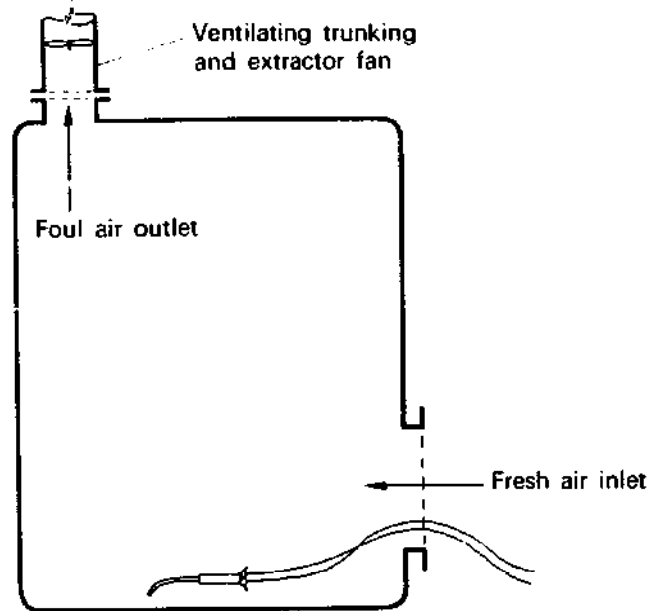


FIG. I.21. Exhaust ventilation in confined spaces.

purpose. [Note that under no circumstances must oxygen be used as a substitute for air in ventilation purposes because its reactions with grease, oil, greasy or oily overalls, and the rapid combustion which takes place in an oxygen-enriched atmosphere, make this a highly dangerous procedure.]

Before the equipment is taken into the vessel, it should be assembled, lighted and thoroughly checked for faults. It may then be passed inside, but the gas cylinder must remain outside at all times. The hoses should be clipped up in position where they are not likely to sustain damage or interfere with free movement of the operator inside. Depending on the size or type of vessel a more suitable procedure is for the blowpipe to be kept outside, and to be lighted and handed in by the assistant as required.

The welder must wear suitable protective clothing: properly fitting overalls, stout boots, leather apron, headgear and goggles are the bare essentials. Leather gloves, sleeves, cape, leggings or gaiters may also be required, depending on the type of work to be carried out.

He should also make certain that his assistant is fully conversant with his duties and aware of the procedure to be followed in the event of an emergency.

During the progress of the work unnecessary materials, equipment or tools should not be allowed to accumulate inside the vessel. Frequent clearing-up sessions will help the work to proceed quickly and safely.

Welding or cutting in or on vessels which have held volatile or toxic substances should be approached with the greatest caution and before attempting work of this nature a close study should be made of the comprehensive recommendations laid down in H.M.S.O. forms 1926 and 386.

The possible dangers include the presence of a concentration of the substance in the air content which will, when inhaled, produce sickness, giddiness or death. Some substances not only produce illness, but also when present in certain concentrations form explosive mixtures with air.

Solid, liquid or gaseous residues may be present which, when exposed to air or heat, may produce inflammable, explosive or poisonous fumes.

Therefore the first steps are to ascertain the nature of the contents and ensure that the interior is thoroughly cleansed before work is started. Where such a vessel is to be entered the welder must consult the engineer concerned who has a joint responsi-

bility to ensure that thorough cleansing and purging have been carried out.

Where the work is to be carried out on the exterior of the vessel the dangers are slightly less, but still considerable.

### *Welding and Cutting Vessels that have held Combustibles*

It is very dangerous to attempt to carry out welding work or flame cutting operations on tanks or other vessels that have contained materials likely to give rise to inflammable or poisonous gases or vapours, unless proper safety precautions are taken. Work should not commence unless the facilities are available to ensure the safety of all personnel.

Vessels and tanks that have contained petrol, oil, gases, paraffin, etc., must all be regarded with suspicion and the necessary safety precautions must be taken. If a vessel has contained an unknown material or liquid, treat it as dangerous and take the necessary precautions.

### METHODS OF PREVENTING ACCIDENTS

These fall under two main headings:

1. Removing the inflammable material.
2. Making the material non-inflammable and non-explosive.

### SMALL TANKS AND VESSELS

*Removing the inflammable material.* This may be carried out by boiling or steaming out the vessel (Fig. I.22).

*For steaming,* first remove all plugs, covers and filler caps, using tools made of a non-sparking material, i.e. bronze. The risk of an explosion using tools that may spark when in contact with the vessel or tank is just as great as the risk from a welding torch or electrode.

After the first operation has been carried out, the vessel must be emptied and left to drain.

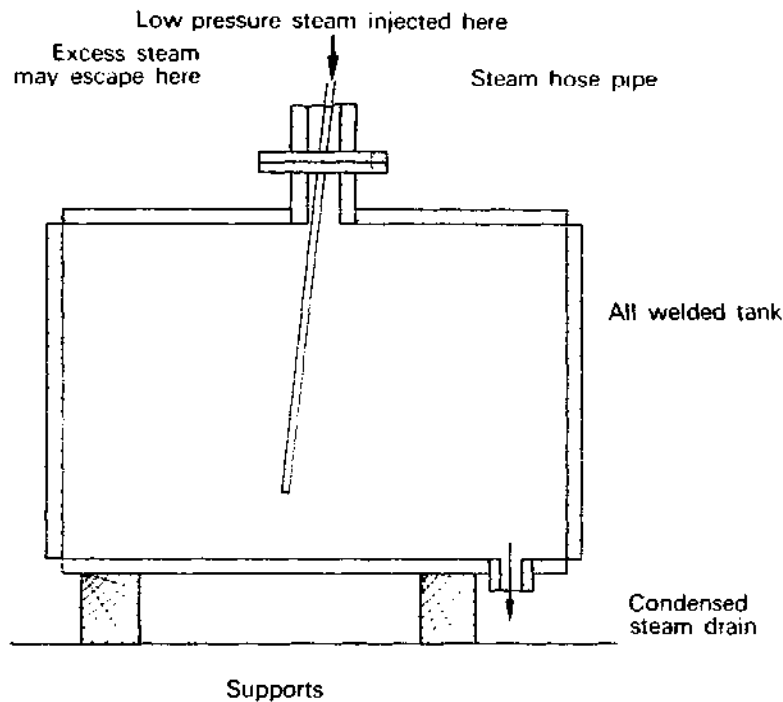


FIG. I.22. Arrangement for steaming out a tank.

Low pressure steam may now be introduced into the vessel making sure that condensed steam is able to drain away and also that there are sufficient outlets from the vessel to prevent any pressure build up. Steaming should be continued until all parts of the vessel feel hot to the touch and continued for one half hour after this. Some vessels may require three or even four hours of steaming.

*For boiling*, the vessel should be opened up, again using non-sparking tools, emptied and allowed to drain. The vessel is then completely immersed in boiling water. It is sometimes an advantage to use water containing an alkaline degreasing agent, but the agent used must be of a type not liable to cause corrosion. Boiling should be continued for at least one hour and for longer periods when necessary.

After steaming or boiling, the vessel should be examined by a responsible person and if necessary chemical tests should be

carried out on the vessel by a qualified person. These tests will ascertain the presence of any traces of inflammable material that may be left in the tank.

**MAKING THE MATERIAL NON-EXPLOSIVE AND NON-INFLAMMABLE**

If steaming or boiling cannot be carried out then other methods must be adopted. The method usually employed is to replace the air in the vessel by either water (Fig. I.23) or an inert gas, but whichever process is used it must remain in the vessel whilst welding or cutting operations are being carried out. This method of ensuring complete safety has its limitations, particularly when using water. Should the repair have to be carried out on a fixed vessel and if the repair is at the bottom, the water method cannot be used for obvious reasons, but if the repair is to the top of the tank then water may suffice.

The inert gases that may be used are nitrogen or carbon dioxide. Gas must be pumped continually into the vessel until the

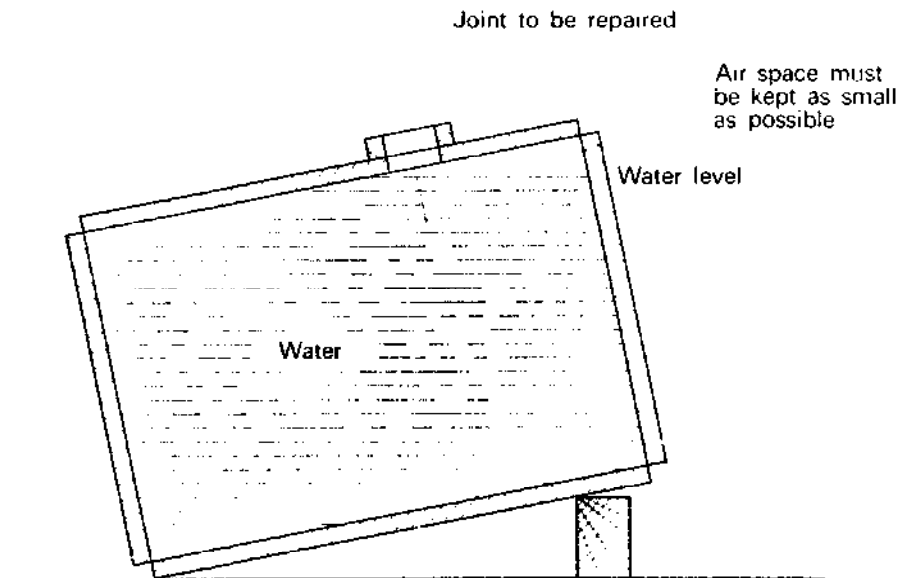


FIG. I.23. Arrangement for filling tank with water.



repair has been completed but care must be taken to ensure that pressure does not build up above a permitted level and a gauge should be fitted for this purpose.

#### **LARGE TANKS AND VESSELS**

It may be necessary to carry out welding or flame cutting operations on very large tanks and vessels that have held inflammable materials. No welder should enter any such vessel until it has been certified safe to do so by a qualified person.

The precautions necessary to make such vessels safe are similar in principle to those described for small vessels, but they have to be carried out on a much larger scale.

When it is necessary to carry out work in large tanks oxygen should never be used to "sweeten" the atmosphere inside the vessel.

## CHAPTER 2

# Basic Welds and Technique

TO WELD is to fuse together materials producing a uniform mass. This fusion may be achieved in some cases, plastics for instance, by the use of solvents to melt the surfaces followed by pressure to unite them firmly. With metals the application of heat, pressure or friction, or a combination of two of these factors is necessary to weld them together.

In oxy-acetylene welding the heat of the blowpipe flame melts the metal and, if the molten edges are allowed to flow together and cool, a joint is produced which has the same composition as the parent metal. During the process it may be necessary to increase the strength of the joint by adding metal from a filler rod of a similar composition to that of the parent metal, thus building up the weld face and producing a reinforcement at the underside of the joint or penetration bead. The majority of metallic welds are of this kind.

### Basic Welds

*The basic types of welds are (a) butt and (b) fillet and all the common joints shown in Figs. I.24, 25 and 26 utilise one or the other.*

### Leftward Technique

#### *Butt Weld*

*The desirable features of a butt weld are (see Fig. I.27)*

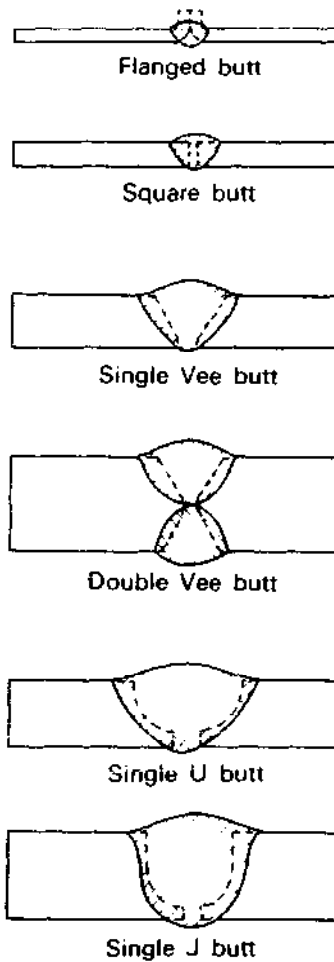


FIG. I.24. Types of welded joints.

Fusion to the full depth of the plate.

Equal fusion along both edges.

Even penetration bead at the root.

Regular reinforcement and suitable profile on weld face.

Correct alignment of plates.

Absence of inclusions and surface defects.

In some types of fillet welds, close-fitting tee or lap joints, for instance, the requirements in regard to full fusion and penetration bead can be ignored, lack of mechanical strength being compensated by either welding the opposite side of the joint or increasing the throat depth of the single weld.

BASIC WELDS AND TECHNIQUE

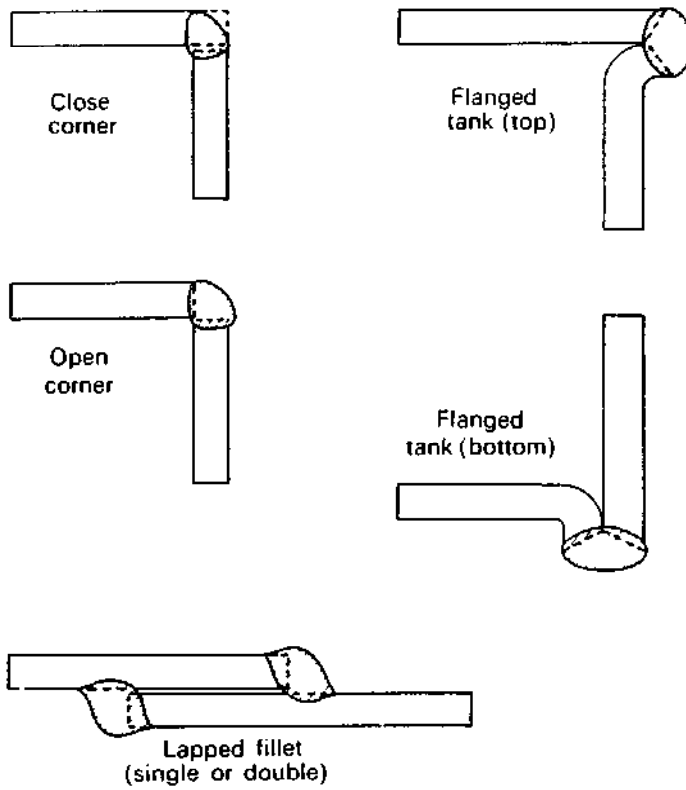


FIG. I.25. Types of welded joints.

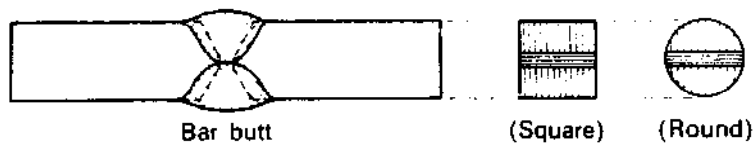
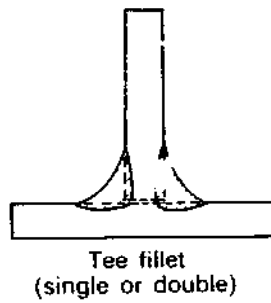


FIG. I.26. Types of welded joints.

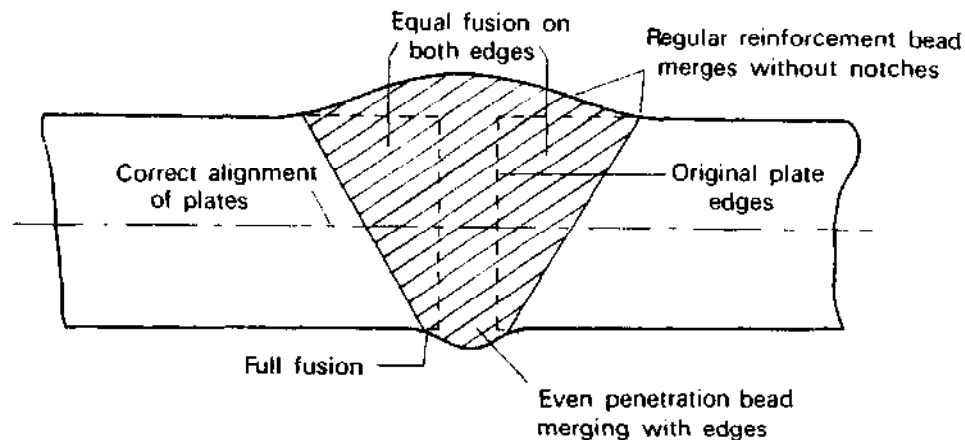


FIG. I.27. Features of a good butt weld.

Where a choice is possible the butt weld is preferable to the fillet weld for it gives much better results in terms of mechanical strength.

#### *Method*

After familiarising himself with all the safety precautions and the correct assembly of equipment, the beginner should practice the lighting of the blowpipe and accurate flame adjustment. The next steps should then be to obtain experience in the control and manipulation of the blowpipe and to acquire what is known as a "sense of fusion". Progress on these lines can best be made by practising straight runs, without filler rod, on thin-gauge plate of, say,  $\frac{1}{16}$  in. thickness.

Fit a number 2 nozzle and, after adjusting the flame to a neutral condition on a medium setting, grasp the blowpipe in a relaxed manner at the point of balance with the right hand. Bring the flame to bear on the plate with the inner cone about  $\frac{1}{8}$  in. from the surface of the metal. The nozzle should be at an angle, pointing along the line of the intended weld and making the recommended angle of  $60^\circ$  to  $70^\circ$  with the plate. The view along the line of the weld should show equal angles of  $90^\circ$  at each side. Suitable results will not be obtained until the nozzle is offered at the correct angles and a few dummy runs with the unlighted blowpipe will be of great help.

Light up again, hold the flame steady at one point and observe the gradual changes in the surface of the metal: the change in colour through black and purple to dull and bright red and, finally, yellow heat. Watch for the glistening of the surface as the metal changes from solid to liquid and note that as the molten pool develops in area it increases in depth also, biting into the thickness of the metal. As soon as the surface of the molten metal starts to sink, begin to move the blowpipe slowly along the intended fusion line and "weave" crosswise to widen the weld pool. Regulate the forward speed so that the size of the weld pool is maintained about  $\frac{3}{16}$  in. wide, for if it increases in size beyond this the molten metal will collapse, leaving a hole and indicating too low a welding speed. The opposite condition is a too high welding speed causing a decrease in weld pool size and a loss of fusion depth. The sideways weave may be varied as necessary to produce the desired width of weld which increases with the thickness of the plate being welded.

At the completion of the first run turn over the practice plate, noting the varying degree of penetration and its relationship to the size and concave shape of the weld pool. This will indicate that the degree of penetration can be judged from the molten pool whilst welding is in progress and welding speed should be varied to suit the observed results.

Adequate fusion occurs when melting has taken place right through the thickness of the plate; that is, when noticeable sinking of the weld pool surface takes place but just before the point of collapse into a hole, with the sunken metal forming the penetration bead.

It is important that the beginner should learn at this stage that the degree of fusion can be estimated accurately from the face side, without stopping work to examine the underside of the plate, and that he should be able to obtain and control penetration in this way (see Fig. I.28).

When one can make satisfactory straight runs at will the filler rod may be introduced using the left hand. The rod,  $\frac{1}{16}$  in. diameter in this case, should lay across the fingers being lightly held, with the thumb opposite the first finger, some 7 to 9 in. from the end to

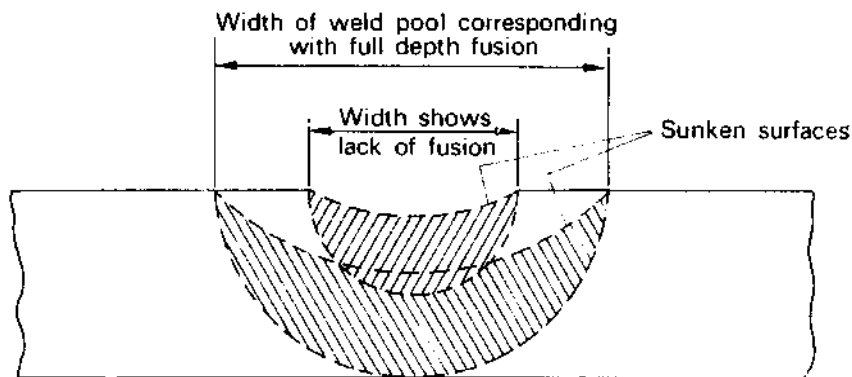


FIG. 1.28. Relationship between weld pool width and fusion depth.

be used. It should be introduced pointing towards the inner cone of the flame and the weld pool so that the molten rod can be deposited in the centre of the pool. The rod must not dip into the pool or touch the inner cone and it may be necessary to lift the nozzle slightly in order to make this possible. The rod must be held so as to make an angle of  $30-40^\circ$  with the surface of the plate, and fed in with a regular in-and-out movement. This action should be practised until it develops into a smooth, automatic movement.

The rod feed rate should be regulated to give a weld bead with satisfactory reinforcement, bearing in mind that it is not the frequency of the rod movement which determines the amount of metal deposited, but the length of time that the rod remains under the flame.

Once the trainee manages to correlate this work of the left hand to that of the right hand, and can regulate his speed and movements in accordance with the observed results he will start to produce satisfactory welds.

Lengthy conscientious practice will now be necessary and the longer the duration of the practice sessions the more definite the progress will be, e.g. a spell of 2 hours will produce greater improvement than four separate periods of half an hour each. To make and maintain good progress regular daily practice is almost essential.

The aim must be, after familiarising oneself with all the basic recommendations, to develop a smooth, regular and leisurely movement which will eventually enable the operator to weld for long periods without strain or fatigue. A "style" will be developed during the very early stages of training and to ensure that it is a good one attention must be paid from the start to such things as:

1. The stance of the feet should be slightly apart with one foot slightly forward and both quite flat on the floor.
2. The position of the head; the back must be straight with the head slightly dropped and held away from the rising heat and fumes.
3. The method of holding the arms; the upper arms should be straight down against the side of the chest with the elbows resting on the hips and the forearms projecting forward at right angles.
4. The means of producing the necessary manipulation of blow-pipe and rod; which should be by forearm movement rather than wrist action. Bear in mind that the essence of gaswelding is a calm, methodical action and a relaxed frame of mind.

The recommendations for downhand butt welds by the leftward technique are given in Table I.1—and the correct conditions should be memorised as each plate thickness is attempted.

Note that:

*Plate edge preparation* is essential if full fusion is to be obtained and although a square edge will suffice up to and including  $\frac{1}{8}$ -in. plate, greater thicknesses will require the edges bevelled.

*Gapping* assists in obtaining adequate fusion and also allows for the inward expansion of the heated plate edges. If the gap is set too wide, welding speed will be greatly reduced due to the extra filler metal required and excessive distortion will arise from the higher heat input and greater weld contraction taking place during cooling (see Fig. I.29).

*Filler rod size* is important and the recommended sizes should be used; as a general rule the rod should be slightly smaller in section than the plate to be welded. Oversize rods will chill the weld pool and thus prevent good fusion. Undersized rods will result in the



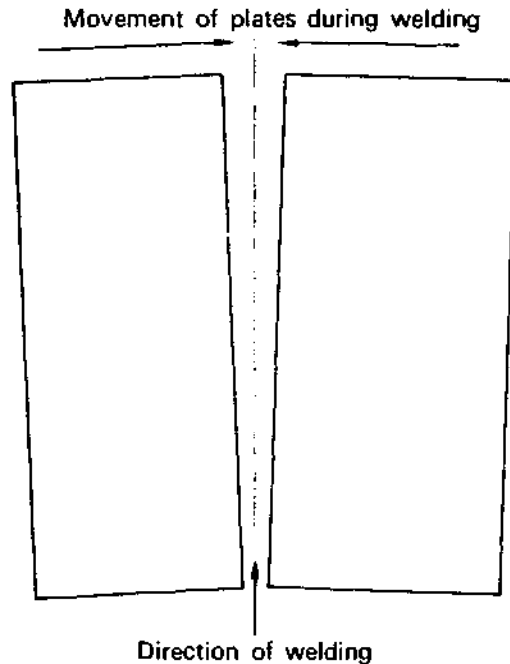


FIG. 1.29. Divergent gap setting.

filler metal being overheated or burnt, and will also call for unreasonably high rates of feed. A choice can be made from the standard rod sizes to cover any particular job.

*Nozzle sizes* given are based on the thickness of the plate to be welded and are an approximate guide. It should be appreciated that the amount of heat required for a weld is determined not only by the thickness of the plate, but also by the mass of metal adjoining the weld, e.g. for a butt weld between the long edges of two pieces of  $1 \times \frac{1}{8}$ -in. mild steel 1 ft long a No. 5 nozzle will be quite adequate, yet a similar weld between  $4 \times \frac{1}{8}$ -in. plate will require a No. 7 nozzle. The selection of the correct nozzle should be done in the first instance in relation to the plate thickness, followed by a plus or minus correction depending on the mass of metal. This correction can only be made accurately after a good deal of experience and the beginner should either seek on-the-spot advice, or proceed on a trial-and-error basis in order to gain experience.

Although the best results are obtained by operating the nozzle at its optimum capacity it is, of course, possible to vary the size

of flame produced by altering the flow of welding gases with the blowpipe controls. Such variations, however, must be of a limited nature to avoid insufficient or excessive gas velocities and the difficulties which accompany them.

Experiment will show that with these variations the set of standard nozzles available provide a complete range of flame sizes in unbroken sequence, i.e. the heat capacity of the upper setting of No. 1 size approaches that of the lower setting of No. 2, and the upper setting of this borders on the lower range of No. 3. It is thus possible to obtain the precise flame size for any job. Bear in mind that when it is necessary to increase the flame size to the upper limits it will be more advantageous to change to the next larger nozzle and use this at the lower setting. This gives a "soft" flame, the benefits of which are a tranquil weld pool and better fusion control. Alterations in flame size should be made in a methodical manner, by small steps, trying each change until the correct conditions are obtained. It must be emphasised that the setting of an accurately sized flame is of the greatest assistance to any welder, however experienced he may be.

Increase in flame size is best done by turning up the acetylene control until a small "feather" of excess acetylene, say  $\frac{1}{8}$ – $\frac{5}{16}$  in. long depending on nozzle size, appears on the inner cone and then increasing the supply of oxygen to remove the feather. To reduce—turn down the oxygen giving the acetylene feather which is then removed by a reduction of the acetylene supply. This method gives an accurate, visual check on the amount of adjustment and ensures that the resultant flame is always a neutral one.

Change nozzle sizes immediately the flame takes on a "harsh" appearance or, alternatively, shows any tendency to "light back".

The gas working pressures given in Table I.1 are adequate to maintain a suitable flame and should always be used, with oxygen and acetylene at equal pressures, on the high-pressure system. Pressures outside the given range will produce either an unstable flame liable to backfire when the pressure is lower, or a harsh flame when the pressure is too high.

*The leftward welding technique* is shown in Fig. I.30. Note the angles that the nozzle and filler rod make with the plate. These

TABLE I.1. DOWNHAND BUTT WELDS IN MILD STEEL  
*Leftward Method*

Plate thickness	Preparation	Nozzle size (c.f.p.h.)	Filler rod size (in.)	O.A. gas pressures (p.s.i.)
20 s.w.g.	Edge flanged-up 90°, no gap	1	none	2 to 3
$\frac{1}{32}$ in.	Edge flanged-up 90°, no gap	2	none	2 to 3
$\frac{1}{16}$ in.	Edge flanged-up 90°, no gap	3	none	2 to 3
$\frac{1}{8}$ in.	Square edge, $\frac{1}{32}$ -in. gap	3	$\frac{1}{16}$	2 to 3
$\frac{3}{32}$ in.	Square edge, $\frac{1}{16}$ -in. gap	5	$\frac{1}{16}$	2 to 3
$\frac{1}{4}$ in.	Square edge, $\frac{3}{32}$ -in. gap	7	$\frac{3}{32}$	2 to 3
$\frac{5}{32}$ in.	Bevelled edge, included angle 80°, $\frac{1}{16}$ -in root gap	10	$\frac{1}{8}$	3
$\frac{3}{16}$ in.	Bevelled edge, included angle 80°, $\frac{3}{32}$ -in. root gap	13	$\frac{1}{8}$	3

angles may be varied within the limits given, but generally the steeper nozzle angle will produce consistently better results. The exact rod angle depends on that of the nozzle, as the rod should always pass under the flame at about right angles to the flame cone.

The method of "weaving" is a matter of choice, but the side to side movement (A) is to be preferred because of the improved view it allows of the molten pool, and also because in more advanced positional work the blowpipe movement need only be slightly modified. If the circular movement is adopted in downhand work the sideways weave must be learned later.

BUTT JOINT,  $\frac{1}{8}$ -IN. THICK MILD STEEL (OXY-ACETYLENE),  
DOWNHAND POSITION, L.W.

MATERIAL:  $4 \times \frac{1}{8}$ -in. mild steel, 7 in. long, two pieces.

Check that the plates are flat and the edges straight and regular. Lay the plates across two pieces of m.s. angle section, separating

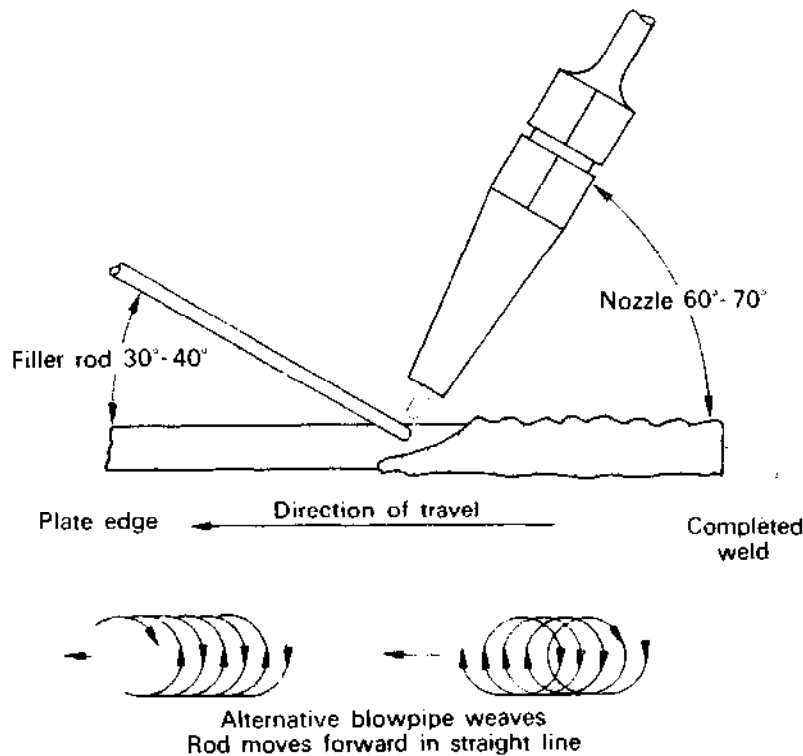


FIG. I.30. Leftward welding technique (side view).

the long edges with a diverging gap of  $\frac{3}{32}$ – $\frac{8}{16}$  in. and keeping them in alignment. Tack weld at, say, 3 in. intervals, making the “tack” with a short weld  $\frac{1}{4}$  in. long penetrating through the plate, but not more than half the plate depth.

Note after tacking that the gap is already noticeably smaller due to the contraction of the heated metal. The final gap must not be less than  $\frac{1}{16}$ – $\frac{5}{32}$  in. otherwise full fusion will be impossible.

The tacks will help maintain the gap and keep the plates in alignment but where movement has taken place during tacking the plates must be realigned by dressing. Where the final gap is insufficient the tacks should be cut and the joint regapped.

Remember that an experienced welder may, if necessary, be able to overcome some of the difficulties caused by incorrect conditions, but the trainee should ensure that every single variable factor is

correctly set and thus provide a minimum of difficulties for himself. Even the experienced operator should stick to the correct conditions as a matter of course.

Once welding commences it will be found that the plate edges expand into the gap, narrowing it, and the two plates at the opposite end of the joint tend to come together with a scissor-like action due to the thermal movement of the metal. The diverging gap makes allowance for this movement (see Fig. I.29).

The weld should be commenced at the right-hand side. Weave the blowpipe steadily with forward movement, developing a suitably sized weld pool and, as settlement occurs, introduce the welding rod with a steady in-and-out movement, starting a forward progression with the blowpipe and producing a regular weave.

The object now is to proceed without interruption at an even speed along the joint, stopping only when the rod is down to the last 6 or 7 in. As the rod shortens rest the end on the cold plate and, lifting the thumb, slide the grip up into a new position.

The welder should have a clear view of the weld pool at all times and should keep a constant watch on the shape and size of the completed weld bead. He should also be on the alert for any changes in the gap dimension in front of the weld and any variations in flame adjustment. On reaching the last 2 in. of the joint flatten the angle of the nozzle to the plate and increase the speed of blowpipe movement and rod feed to compensate for the rapid build-up of heat which will occur at this point.

This is due to the fact that up to this stage there is a large area of parent plate in front of the blowpipe which absorbs a quantity of the heat by conduction from the weld area and from the spread of the outer zone of the flame. Once this area becomes reduced the heat concentration quickly builds up, causing overheating and collapse of the now enlarged weld pool.

An equally suitable means of overcoming this difficulty is to lay another piece of plate of similar thickness and area against the end of the weld which will absorb the heat and allow the weld to be completed without change of rod and blowpipe speeds and angles.

Another method is to stop the weld at the point where the heat

build-up starts, slightly reduce flame size and then complete the weld in the normal way, bearing in mind that on the final half inch or so it will be necessary to lift the nozzle momentarily to shed the still excessive heat.

Starting the weld again after any stoppage should be done with great care to give a sound pick up. Reheat the last half inch of the completed weld to a bright red heat then move forward and produce a molten pool over the last two weld beads. Add a small amount of rod and then move off in the normal way leaving a smooth pick up on the weld face and complete fusion down to the penetration bead. It requires a good deal of care and experience to make a really sound "stop and start" and only careful practice will achieve this.

The completed weld should have a regular neat face with a slightly rounded herring-bone pattern and a continuous root bead of  $\frac{1}{16}$  in. A rounded bead pattern indicates too-slow welding speed and/or lack of heat, whereas a pointed pattern is the result of too high a welding speed and/or excessive heat.

If difficulty is experienced in obtaining thorough fusion and satisfactory penetration, lift the plates slightly at the forward end of the weld giving an angle of 2-4°. This will help to prevent molten metal flowing forward into the gap and interfering with penetration. [Note that the recommended rod and nozzle angles are to the plate, not to the horizontal.]

Each completed weld should be given a critical visual examination and the cause of any fault must be determined and corrective action taken during the next run. It is only by this means that sound progress can be assured. The faults most likely to be found in butt welds include (see Figs. I.31 and 32):

*Misalignment of plates*, which will be due to either faulty setting up or thermal movement. This can be prevented by the correct use of tack welds and by presetting the plates to allow them to move into the desired position.

*Lack of penetration*, which may be due to (a) failure to set and/or maintain an adequate gap, (b) too high a welding speed, (c) incorrect blowpipe manipulation (angles and weave), (d) too small a nozzle size.

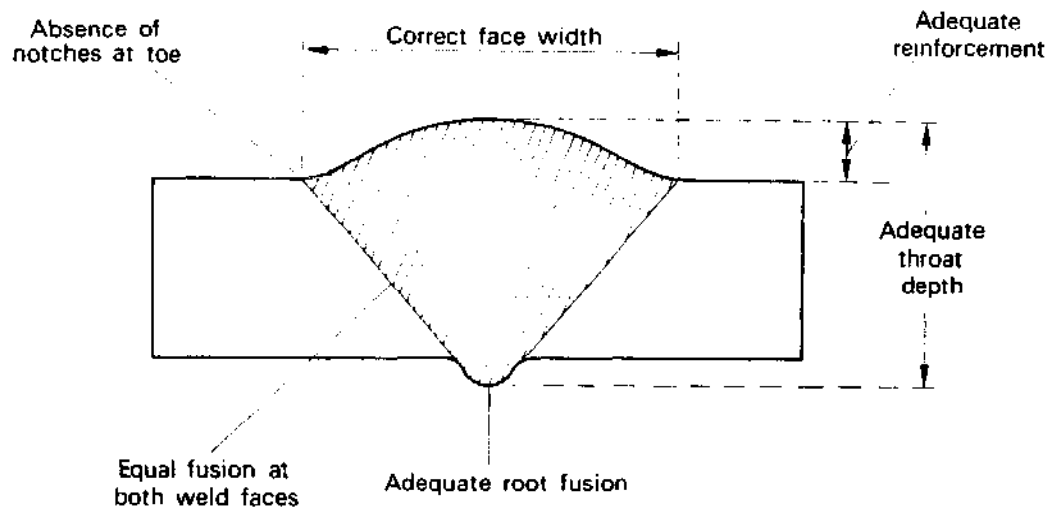


FIG. I.31. Desirable feature of a butt weld.

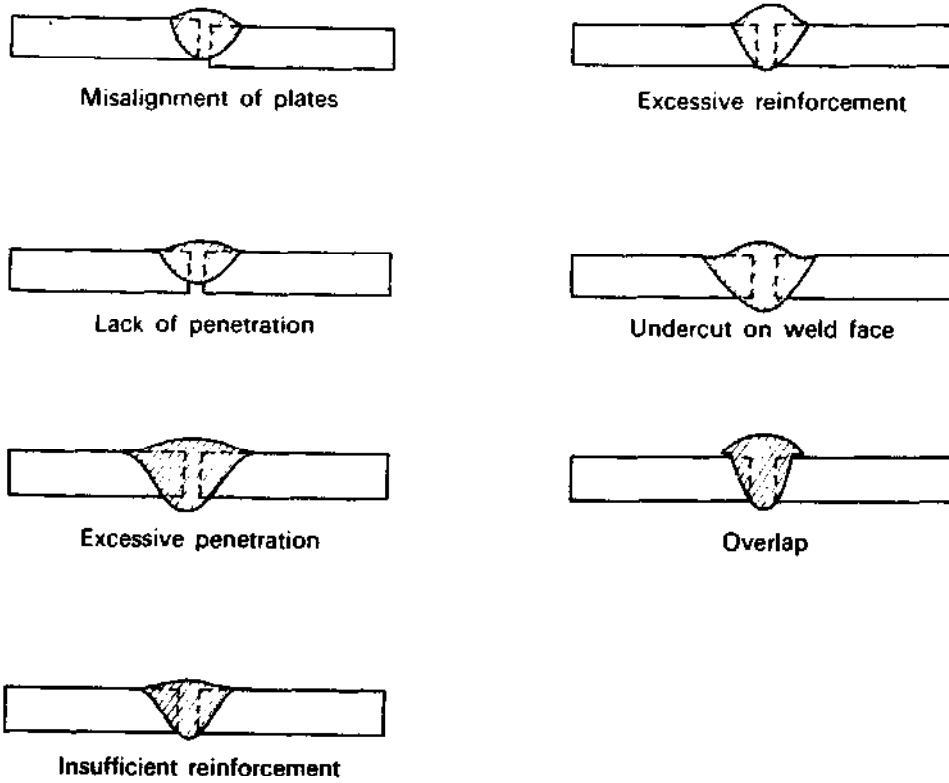


FIG. I.32. Faults in butt welds.

*Excessive penetration*, which may be the result of (a) too large a nozzle size, (b) incorrect blowpipe manipulation, (c) too slow a welding speed, (d) too large a nozzle size.

*Insufficient reinforcement*, which can be caused by (a) inadequate rod size or feed speed, (b) too slow a welding speed, (c) too large a nozzle.

*Excessive reinforcement*, owing to (a) excessive rod feed or size, (b) incorrect blowpipe manipulation, (c) too small a nozzle.

*Undercut along both sides of the weld face*, owing to (a) too large a nozzle, (b) too slow a welding speed, (c) insufficient rod feed.

*Undercut along one side only*, is caused by incorrect blowpipe manipulation (unequal angles to the plate).

*Lack of fusion of weld faces* is caused by the incorrect manipulation of the blowpipe (angles and weave).

*Overlap* is due to (a) lack of welding heat, (b) failure to develop an adequate molten pool before moving off, (c) excessive rod feed.

*Lack of fusion continuity along the weld metal* is the result of (a) failing to melt into the tacks during welding, (b) oversized tacks (too long or too deep), (c) incorrect pick up in "stops and starts".

*Craters in the weld face*, are caused by (a) the overheating of the weld pool, (b) the ejection of metal due to backfires, (c) irregular and insufficient rod feed.

*Harsh, rough appearance of weld face* can be due to (a) oxidising flame, which will cause heavy scaling, or (b) carburising flame, causing carbon deposits.

*Cracking* can be the result of (a) the application of restraint by clamps or jigs, (b) the design of the weldment, (c) incorrect welding procedure.

Note that excessive penetration is often accompanied by insufficient reinforcement and undercut, whilst excessive reinforcement is sometimes an indication of lack of fusion and penetration. Undercut along one side of the weld face often results in lack of fusion along one edge of the weld.

Once a reasonable degree of proficiency has been attained with the  $\frac{1}{8}$ -in. d.h. butt, the next joint to be attempted should be the



$\frac{1}{8}$ -in. downhand open corner weld; this is one of the simpler types of fillet weld. This exercise requires greater accuracy in the line followed by the nozzle and finer control over the width of the weave because any deviations will cause lack of fusion or an overhang of metal at the side(s) of the weld.

OPEN CORNER JOINT,  $\frac{1}{8}$ -IN. THICK MILD STEEL (OXY-ACETYLENE), DOWNHAND POSITION, L.W.

MATERIAL:  $4 \times \frac{1}{8}$ -in. mild steel, 7 in. long, two pieces.

The square-edged plates should be aligned at an angle of slightly less than  $90^\circ$ , gapped  $\frac{1}{16}$  in./ $\frac{3}{32}$  in. and tacked at 3-in. intervals. A No. 5 nozzle will be required. [Note that a sound working rule for nozzle size when welding d.h. open corner fillets is to use one size smaller than that for the equivalent butt weld.] The leftward method should be used and it will be found that blowpipe and filler rod control will improve rapidly during this type of practice. Once a satisfactory joint can be readily produced further practice should follow with  $\frac{1}{16}$ -in. d.h. flanged butt and  $\frac{3}{32}$  in. close corner fillet in the gravity position. Both these joints are made without filler rod and provide an excellent opportunity to develop blowpipe control to a much higher standard. They also demonstrate clearly how much weld quality depends on blowpipe control and manipulation.

Follow on with the  $\frac{1}{16}$ -in. square-edged butt which will present some problems in distortion control and will also require precise control of blowpipe and filler rod. Tacking in this case will need to be closer at, say, 2-in. intervals.

All the preceding joints should now be practised in various thicknesses from 18 s.w.g. to  $\frac{3}{16}$  in. until the procedure is familiar and a reasonable standard is achieved.

### *Fillet Weld*

*The desirable features of a fillet weld (see Fig. I.33) are:*

- Adequate root fusion.
- Adequate fusion of both faces.

- Equal leg length.
- Adequate throat depth.
- Correct profile.
- Correct alignment of plates.
- Absence of inclusions and surface defects.

TEE FILLET JOINT,  $\frac{1}{8}$ -IN. MILD STEEL (OXY-ACETYLENE),  
DOWNHAND POSITION, L.W.

MATERIAL:  $4 \times \frac{1}{8}$ -in. mild steel, 7 in. long, two pieces.

The first step is to practice the close tee fillet joint in the gravity position. The plates should be square edged and close fitting with no gap. Tack into place to an angle of rather more than  $90^\circ$  on the weld side and ensure that the tacks are small and well fused into the plates. The nozzle size may be determined by using one size larger than for the equivalent d.h. butt.

The weld is again carried out by the leftward method with a slight modification of the nozzle angle, i.e. a bigger proportion of

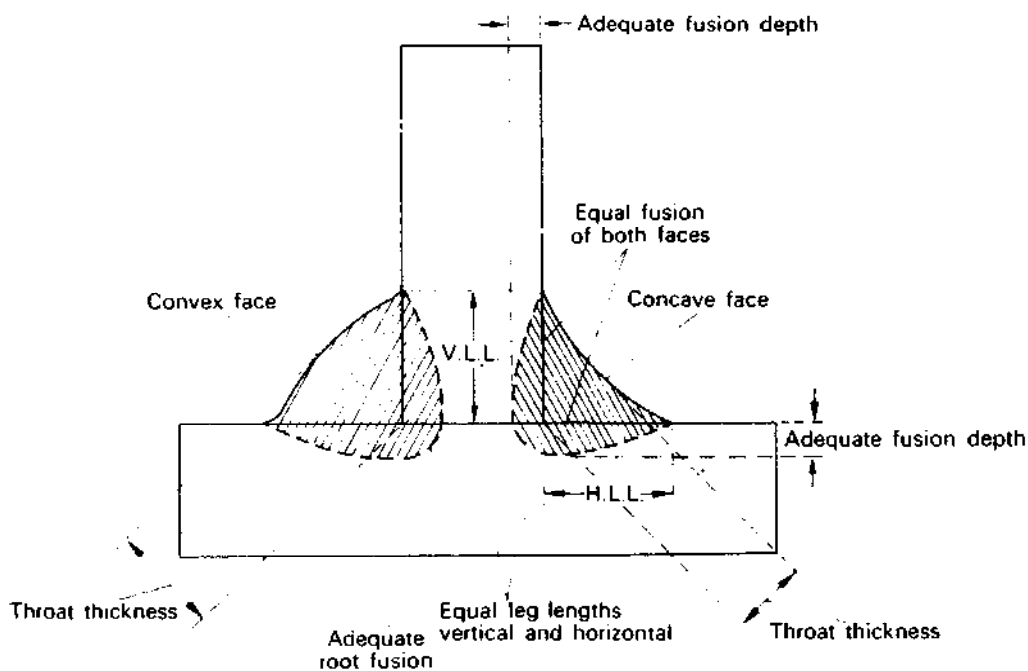


FIG. I.33. Desirable features of a fillet weld.

the available heat must be directed into the base plate, therefore the angle between it and the nozzle is widened up to 5°, and the leading angle is also steepened. This will help to overcome a common fault in tee-fillet welds which is lack of fusion in the face of the base plate and at the root of the weld.

The blowpipe weave should now be kept to a minimum in order to concentrate the heat in the fusion zone and welding should proceed only at the speed at which the weld faces melt and flow together. A really adequate weld pool must be developed before moving off and filler rod added only into the molten pool. A slight inclination of the joint will prevent the forward flow of molten metal and an initial preheat of the base plate will assist considerably in achieving adequate fusion.

Another possible fault is undercut at the sides of the weld face, and when the weld is made in the gravity position the remedies are the same as for butt welds.

When welded in the horizontal-vertical position the fillet joint presents an additional problem, which is the deposition of the filler metal in such a way as to produce a weld of equal leg length. As the filler metal is deposited in molten form it behaves exactly like any other liquid, flowing downwards by gravity to find its own level; therefore, unless modifications are made in procedure the result will be a flattish weld (i.e. unequal leg length) laying on the base plate with severe undercut along the top edge, where the molten plate has flowed downwards.

To overcome this, adjust the nozzle angle between the plates until the two plates melt at equal rates and flow together in a molten pool which lays equally across the intended weld. Add filler metal into the upper part of the weld pool and, although gravity flow will take place, the rapid solidification will result in the formation of a weld bead of equal leg length.

The trainee will probably find that once adequate fusion is obtained undercut will start to appear along the top edge of the weld, but this can be eliminated by working on the above lines. Note that the undercut indicates the correct feed point for the filler rod. This weld will require a good deal of careful practice if a really satisfactory specimen is to be produced (Plate I.5), but



PLATE I.5. Horizontal/vertical close tee-fillet weld—oxy-acetylene.

apart from the application of the correct conditions and the study of the recommendations there is no short cut to proficiency. This joint should also be practiced in various thicknesses from  $\frac{1}{16}$  in. to  $\frac{3}{16}$  in.

Up to this point the testing of completed welds should be limited to visual inspection for, until all visual faults are eliminated, the carrying out of destructive tests such as bend or nick-break merely results in the waste of valuable time which could be more usefully spent in welding. It should be emphasised that whether a welded joint breaks or bends under simple workshop tests is not always a reliable guide to its quality. A defective weld may withstand repeated attempts to break it.

When a good degree of proficiency has been acquired visually, acceptable welds may be submitted to the series of tests laid down in B.S. 1295 (*Training of Welders*) and until a suitable degree of skill is attained the trainee should be occupied in welding to visual standards only as a method of rating his progress.

### *City and Guilds Practical Work*

When attempting the practical work required in City and Guilds Course No. 323, *Welding Craft Practice* (Part 1), the following recommendations should be followed:

*Exercise 4.1* (see p. 57).

*Exercise 5.1* (see p. 62).

*Exercise 6.1* (see p. 62). It will be found that with the bevelled edges of the thicker plates that the root gap can and should be slightly reduced, with  $\frac{3}{16}$  in. and  $\frac{1}{4}$  in. plate the joint should be completed in two runs, paying particular attention to inter-run fusion.

*Exercise 7.1* (see p. 68).

*Exercise 8.1* (see p. 69). The thinner-gauge metal will require closer tacking as the tendency for distortion will be greater.

*Exercise 9.1*. This follows very closely the requirements for tilted tee fillets except that the welding speed will be higher owing to the fact that there is less metal adjacent to the weld area. Thorough fusion of the edge of the upper plate and at the root are essential.

*Exercise 10.1* (see p. 70). With both tee and lap fillets the greater the thickness of plate the more helpful will be an initial preheat of the bottom plate. With the lap joint the edge of the top plate must not be excessively melted away, e.g. with  $\frac{3}{16}$ -in. plate the allowance should not exceed  $\frac{3}{32}$  in. To achieve this it will be found helpful if a chalk line is used as a guide.

*Exercise 11.1* (see following notes on rightward welding).

*Exercise 12.1*. Butt joints in mild steel angle section should be treated as the equivalent butt welds, with special attention being

paid to retaining the correct alignment by the use of presetting and/or clamps. The weld should always be made from the outside of the section and it is advantageous to weld from one edge towards the corner and, after turning the angle, to complete the weld in the same direction. Mitred angle joints should be set up to give a butt weld on top and an open outside corner weld on the corner. Weld the latter first, starting from the edge of the angle, working towards the corner and completing the joint with the butt weld made in the same direction. Tee joints should be carefully prepared and set up to give a butt weld on top and a fillet weld inside the angle. Weld the butt joint first and preheat the corner of the angle before starting the fillet weld. Here again the welds should be made in the same general direction.

*Exercise 13.1.* All solid sections, whether round, square or hexagonal, should be prepared as shown with a double-vee preparation, resembling a chisel point, with root gaps of  $\frac{3}{32}$  in. ( $\frac{3}{8}$  in.)  $\frac{1}{8}$  in. ( $\frac{1}{2}$  in.)  $\frac{5}{32}$  in. ( $\frac{3}{4}$  in.). The leftward technique should be used and each vee welded with a multi-run technique, paying particular attention to thorough root fusion, inter-run fusion, the absence of overheating, and final alignment.

*Exercise 14.1* (see notes on cutting).

*Exercise 15.1* (see notes on rightward technique).

#### THE DISADVANTAGES OF THE LEFTWARD TECHNIQUE

With butt welds in plate thicknesses of over  $\frac{1}{8}$  in. it is no longer possible using a square-edged preparation to obtain full fusion through the depth of the plate and to overcome this difficulty a  $40^\circ$  bevel-edge preparation is used. This gives a vee with an included angle of  $80^\circ$ , presenting the plate edges at such an angle to the flame that sound fusion can be obtained and, although the bevelling increases welding costs, it will still be an economical method provided that the weld can be completed in a single run.

The vee preparation also increases the volume of weld metal necessary to make the joint and above  $\frac{3}{16}$  in. it is not possible to deposit sufficient metal in one run and a multi-run technique becomes necessary. This is undesirable because of the higher costs,

the increased thermal movement and the possibility of lack of fusion between the runs. There is also the tendency for molten metal to be forced forward in the direction of the flame, flowing over the unmelted edges and causing adhesion and incomplete fusion. The narrower the vee the greater this tendency and, although widening the vee helps to counteract this, it also adds to the difficulties by increasing the volume of weld metal required. Some improvement in weld pool control may be brought about by reducing the flame size, but this causes a rapid decline in welding speed as the plate thickness increases. The quality of the weld also tends to deteriorate for it is difficult to obtain a clear view of the bottom of the vee.

It should therefore be understood that whilst plates of over  $\frac{3}{16}$  in. can be welded by the leftward technique the economical limit is  $\frac{3}{16}$  in., and above this thickness the rightward technique should be used.

### **Rightward Technique**

*The rightward technique* is suitable for butt and fillet welds on plate and pipe and the immediate advantages are:

Plate to  $\frac{5}{16}$  in. may be welded with square-edge preparation, eliminating bevelling costs.

The amount of deposited metal, compared with an 80° vee, is reduced by nearly 50% with consequent increases in welding speeds and reduction in rod and gas consumptions.

As a result of this, thermal movement is reduced. Also, the quality of the weld is under the welder's control at all times, because there is an unrestricted view of the weld pool.

The root penetration bead is superior in regularity and profile to that produced in a leftward weld.

Although plate from  $\frac{5}{16}$  in. to  $\frac{3}{8}$  in. will still require a vee preparation, a 60° vee is adequate and, as this gives a 25% reduction in the volume of weld metal compared with the 80° vee of the leftward technique, this is a considerable advantage.

The nozzle size is always larger than would be used for the equivalent leftward weld, giving higher welding speeds.

**BASIC WELDS AND TECHNIQUE**

**TABLE I.2. DOWNHAND BUTT WELDS IN MILD STEEL**  
*Rightward Method*

Plate thickness	Preparation	Nozzle size (c.f.p.h.)	Filler rod size (in.)	O.A. gas pressures (p.s.i.)
$\frac{3}{16}$ in.	Square edge, $\frac{1}{8}$ -in. gap	13	$\frac{1}{8}$	3 to 4
$\frac{1}{4}$ in.	Square edge, $\frac{1}{8}$ -in. gap	18 or 25	$\frac{1}{8}$	3 to 4
$\frac{5}{16}$ in.	Bevelled edge, included angle $60^\circ$ , $\frac{3}{32}$ -in. root gap	25 or 30	$\frac{5}{32}$	4
$\frac{3}{8}$ in.	Bevelled edge, included angle $60^\circ$ , $\frac{1}{8}$ -in. root gap	35	$\frac{3}{16}$	4 to 5
$\frac{1}{2}$ in.	Bevelled edge, included angle $60^\circ$ , $\frac{1}{8}$ -in. root gap	45	$\frac{1}{4}$	6 to 8
$\frac{5}{8}$ in. and over	Double bevelled edge, included angles—upper $60^\circ$ , lower $80^\circ$ , $\frac{1}{8}$ -in. root gap	55	$\frac{1}{4}$	8 to 10

***Butt Weld***

**METHOD** (see Fig. I.34).

It will be noted that the blowpipe, with the nozzle offered to the plate at a flatter angle, precedes the rod along the weld, welding being started at the left-hand end of the weld and moving along the joint in a rightward direction. This change of attitude gives rise to several important advantages:

The majority of the available heat is concentrated at the point of welding, giving quicker fusion.

The completed weld adjacent to the molten pool is maintained at a high temperature, considerably reducing conductive heat losses from the weld pool.

The direction of the flame causes the molten metal to be retained at the weld point and it is prevented from flowing along the vee in front of the fusion zone.



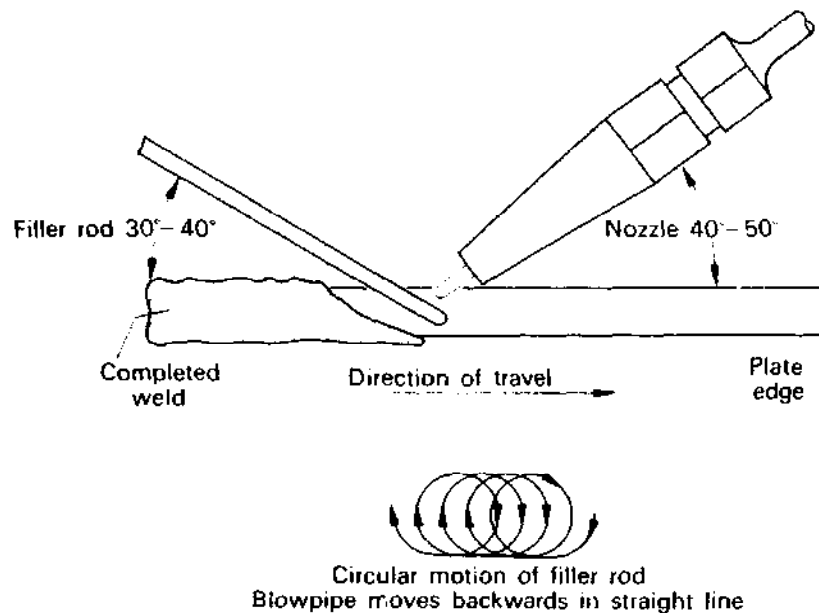


FIG. I.34. Rightward welding technique (side view).

With a more intense heat and the molten pool under strict control, it is possible to deal with a larger volume of molten metal and to produce uniform penetration and adequate build up.

Prolonged practice is necessary to produce consistently good welds and attention should be paid to the following points:

The blowpipe, with the correct nozzle set to give a soft flame, should be held within the given angles of 40–50° to the plate and in a true vertical position between the edges. It should move only in a straight line along the joint with sideways movement, or weave, eliminated.

The tip of the inner flame cone should be held well down, level with the surface of the plate or just below it.

Blowpipe control must be accurate and precise.

The welding rod must be of the correct size and for square-edged plates it should be equal to half the plate thickness. For bevelled-edged preparations half the plate thickness plus  $\frac{1}{32}$  in. will give the correct size, up to a maximum of  $\frac{1}{4}$  in.

Bend the rod near the end in order that it may be comfortably held with the hand out of the heat zone and offer it at 30–40° to the

plate with the feed end parallel with and over the inclined face of the weld pool.

Whilst the correct angle is maintained a continuous, regular and circular movement should be produced by the rod end.

**BUTT JOINT,  $\frac{3}{16}$ -IN. THICK MILD STEEL (OXY-ACETYLENE),  
DOWNHAND POSITION, R.W.**

**MATERIAL:  $3 \times \frac{3}{16}$ -in. mild steel, 7 in. long, two pieces.**

Practice should begin on  $\frac{3}{16}$ -in. mild steel plate set up with square edge preparation and tacked to give a  $\frac{1}{8}$ -in. gap. With other variables set to conform with the data given, develop a weld pool at the left-hand end of the work, at the same time checking and correcting rod and blowpipe angles. [Note how the plate edges are gouged away by the flame.] When correct fusion is obtained a hole will appear at the leading edge of the weld pool and it is essential that this appearance, which may best be described as an "onion shape", is maintained throughout the welding operation. Its presence is proof of the complete fusion of both edges and, although it may be difficult to obtain, the operator must persevere. Once full-depth fusion is achieved start the addition of filler rod and, manipulating the rod correctly, move off along the joint.

With a welder already proficient in the leftward technique the following difficulties will probably arise:

- angle of rod too steep,
- nozzle held too high spreading heat over the plate,
- unnecessary slight weaving of blowpipe,
- incorrect or insufficient rod movement.

A typical rightward butt weld shows a pronounced uniform penetration bead with both edges completely fused, and a rather convex weld face with a roundish bead pattern.

Fillet welds on thick plate are more conveniently done by this technique and should follow the general principles laid down for butt welds, the blowpipe angles being modified to bring about equal fusion of the two edges and, in the H.V. position, to give complete control of the molten metal.

VERTICAL WELDING (see Fig. I.35)

There are several methods of making welds in the vertical position, but "vertical upwards" gives the best results with regard to thorough fusion, satisfactory face reinforcement and a reasonable welding speed. Plate  $\frac{3}{16}$ -in. thickness is welded square edge with one pass at a rate of 6–8 ft per hour compared with the equivalent downhand L.W. butt 12–15 ft per hour.

As can be seen from the diagram (Fig. I.35) this is basically a leftward technique with variations in nozzle angle according to plate thickness, but the molten pool can be kept under strict control for with the recommended blowpipe angles the molten metal cannot be blown over the unfused edges, there is no danger of collapse on the root side, and the force of the flame supports the weld pool on the face side preventing overhang.

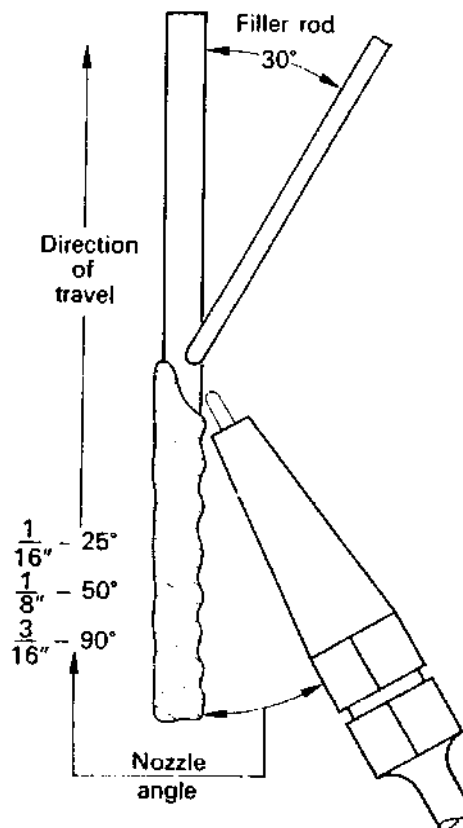


FIG. I.35. Single-operator vertical welding technique (side view).

The main requirements are fine and accurate blowpipe control and a precise flame setting combined with the correct conditions given in Table I.3.

TABLE I.3. VERTICAL BUTT WELDS IN MILD STEEL  
*Single Operator, Vertical Upwards Method*

Plate thickness	Preparation (square edge throughout)	Nozzle size (c.f.p.h.)	Filler rod size (in.)	O.A. gas pressures (p.s.i.)
$\frac{1}{16}$ in.	$\frac{1}{16}$ -in. gap	2	$\frac{1}{16}$	2 to 3
$\frac{3}{32}$ in.	$\frac{1}{16}$ -in. gap	3	$\frac{1}{16}$	2 to 3
$\frac{1}{4}$ in.	$\frac{1}{8}$ -in. gap	5	$\frac{3}{32}$	2 to 3
$\frac{5}{16}$ in.	$\frac{1}{8}$ -in. gap	7	$\frac{3}{32}$	2 to 3
$\frac{3}{8}$ in.	$\frac{1}{8}$ -in. gap	10	$\frac{3}{32}$	3

BUTT JOINT,  $\frac{1}{8}$ -IN. THICK MILD STEEL (OXY-ACETYLENE), VERTICAL POSITION.

MATERIAL:  $4 \times \frac{1}{8}$  in. mild steel, 7 in. long, two pieces.

This is a suitable practice exercise. After tacking-up and fixing firmly in a vertical position, set a soft flame with a No. 5 nozzle and bring the two edges at the bottom of the joint to melting point. Check and correct blowpipe angle. The welding rod should be bent so that the operator may work comfortably and offered to the plate at an angle of  $30^\circ$ . Feed the rod into the molten edges, bridging the gap and develop a molten pool. A tightly controlled semicircular weave will be necessary to maintain fusion to the full depth of the plate on both edges. Once upward progress starts filler metal should be deposited at every alternate weave into the centre of the molten pool. Note the gouging effect of the flame giving the "onion" shape and indicating good fusion. Should the hole in front of the weld pool bridge over or fill up, hold the blowpipe stationary in the centre of the joint until the flame pierces through, re-establishing it. The weave and filler-rod movement should be practised until a smooth synchronised action is developed.

*Vertical tee fillets* (Plate I.6). These will require an increase in nozzle size compared with the equivalent vertical butt weld and a modification of blowpipe angle to produce equal fusion of both faces and to give control over the molten metal. Once a bead has been established as a "platform", the completion of the weld can best be achieved by keeping sideways movement of the nozzle to a minimum and allowing molten filler rod to flow into the top third of the weld pool. Here again incomplete root fusion will be the commonest fault and it can only be overcome by ensuring that both

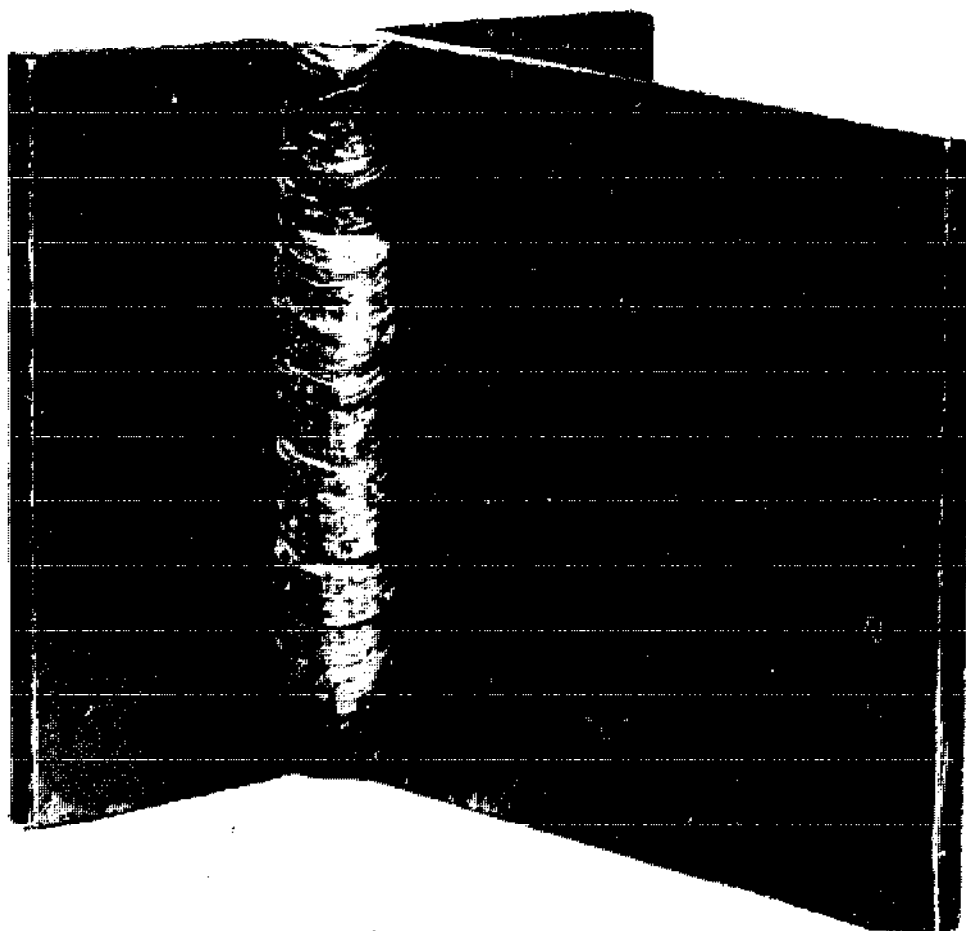


PLATE I.6. Vertical close tee fillet weld—oxy-acetylene.

plate surfaces are gouged away equally by the flame and constant, close observation of the fusion faces will be necessary to achieve it.

The advantages of single operator vertical welding are:

- (i) plates to  $\frac{3}{16}$  in. can be welded with square edge preparation;
- (ii) the edges of both plates are fused full thickness;
- (iii) adhesion is easily avoided;
- (iv) it allows complete fusion and produces a uniform bead on each side of the weld [this is an important point on work where the root side of the weld is inaccessible and therefore not available for visual inspection];
- (v) the amount of filler rod and heat input are less than with any other technique.

*The double-operator vertical method* enables plate from  $\frac{3}{16}$  in. –  $\frac{5}{8}$  in. to be welded with only a square-edged preparation. It requires two operators working simultaneously on opposite sides of the joint and the weld is carried out in an upwards direction (see Fig. I.36). Due to the concentration of heat at the junction of the two flames and the absence of heat loss through the gap, it is possible to use two nozzles with a combined power which is less than would be required of a single one producing the same fusion. Both operators must proceed at the same speed, maintaining the same angles, and the blowpipe flames should be fed from a common gas supply and matched for size before welding starts. Rod and blowpipe angles are constant for all thicknesses, the blowpipes travelling upwards with a slight sideways weave.

This method has the advantages that:

- (i) up to  $\frac{5}{8}$  in. plate can be butt welded with only square-edged preparation;
- (ii) over  $\frac{1}{4}$  in. thickness the welding speed is higher than for the rightward downhand butt;
- (iii) gas and filler rod consumptions are lower than with r.w. method;
- (iv) the weld is completed in one pass;
- (v) each side of the joint has a uniform reinforcement bead;
- (vi) root fusion is more certain.

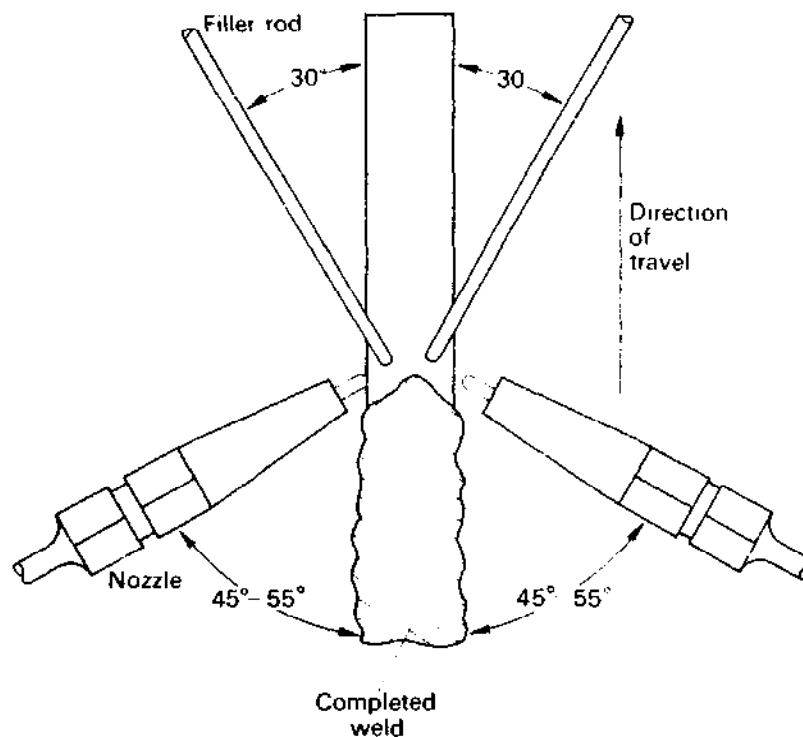


FIG. I.36. Double-operator vertical welding technique.

TABLE I.4. VERTICAL BUTT WELDS IN MILD STEEL  
*Double Operator, Vertical Upwards Method*

Plate thickness	Preparation (square edge throughout)	Nozzle size (c.f.p.h.) (each blowpipe)	Filler rod size (in.)	O.A. gas pressures (p.s.i.)
$\frac{1}{16}$ in.	$\frac{3}{16}$ -in. gap	3	$\frac{1}{16}$	2 to 3
$\frac{1}{8}$ in.	$\frac{1}{8}$ -in. gap	5	$\frac{3}{32}$	2 to 3
$\frac{3}{16}$ in.	$\frac{3}{16}$ -in. gap	7	$\frac{1}{8}$	2 to 3
$\frac{1}{2}$ in.	$\frac{1}{8}$ -in. gap	10	$\frac{5}{32}$	3
$\frac{1}{2}$ in.	$\frac{1}{4}$ -in. gap	13	$\frac{5}{32}$	3
$\frac{3}{8}$ in.	$\frac{1}{8}$ -in. gap	18	$\frac{3}{16}$	3 to 4

The *vertical downwards method* is a conventional rightward technique with welding starting at the upper end of the joint. It relies on the force of the flame and the surface tension of the liquid metal to support the weld pool. Considerable skill is required to obtain thorough fusion and a satisfactory weld face, as only a small quantity of molten metal can be controlled in this position. Usually the "upwards" method will give superior results and is to be preferred.

Another technique which can be adopted for vertical work, but which is particularly useful in the horizontal-vertical and overhead position is the *all-position rightward method*.

It will be found that this will give sound results with material over  $\frac{3}{16}$ -in. thick in all positions, using a relatively small-angled vee, with high welding speeds and reduced distortion. This is, of course, a rightward technique with rod and blowpipe angles modified to give the required control over the molten metal and a clear view of the weld pool at all times, the angles being varied according to the position of the weld (see Figs. I.37, 38, 39).

*Vertical* (see Fig. I.37). The nozzle is held  $10^\circ$  below horizontal and at equal angles between the plates, the rod making an angle

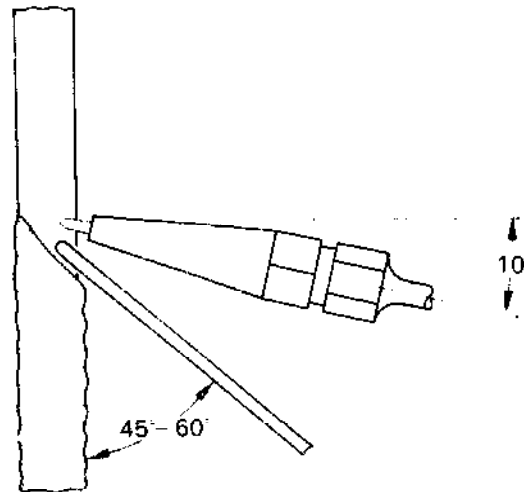


FIG. I.37. All-position rightward technique.  
Vertical position (side elevation).



of  $20\text{--}30^\circ$  with the nozzle. The blowpipe travels upwards with sideways movement kept to a minimum, whilst the cranked rod is manipulated across the weld pool with an intermittent movement towards the root.

*Horizontal-vertical* (see Fig. I.38) (where the joint runs across the vertical plates). The nozzle is again  $10^\circ$  below horizontal with a leading angle of  $80^\circ$  to the plate and makes a steady rightward travel with only sufficient weave to maintain fusion of the edges. The straight filler rod is offered at  $10^\circ$  above horizontal with a trailing angle of  $45^\circ$  to  $60^\circ$  and is fed into the top half of the molten pool with a diagonal crosswise weave, occasionally moving into the root.

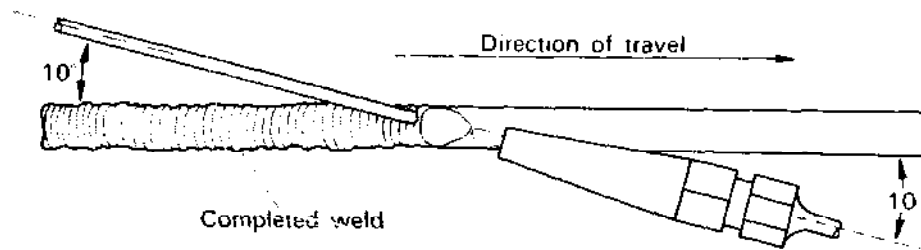


FIG. I.38. All-position rightward technique.  
Horizontal-vertical position (front elevation).

*Overhead* (see Fig. I.39). The nozzle is held  $10^\circ$  from the vertical, pointing slightly forward, and at equal angles to the plate. Sideways movement is restricted to a minimum. The cranked rod lies at an angle of  $45\text{--}60^\circ$  to the plate, weaving across the bottom half of the weld pool with a definite upwards movement into the root after each two cross weaves. This is essential to compensate for the downwards flow of the metal at the root and, although it may be difficult to produce a pronounced convex root bead, it will ensure adequate root penetration.

Compared with the vertical weld, slight reductions in flame size will be necessary in both H.V. and O positions in order to reduce the volume of molten metal to manageable proportions.

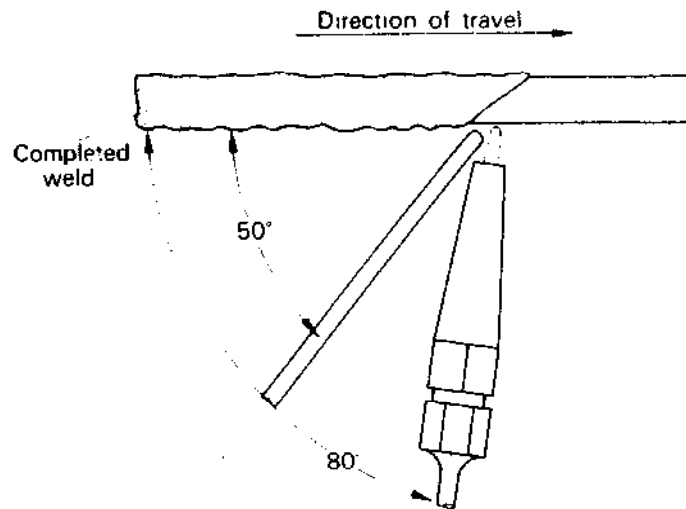


FIG. I.39. All-position rightward technique.  
Overhead position (side elevation).

### PIPE WELDING

This covers a wide range of diameters and wall thicknesses, but several factors are common to all pipe welds. Welding takes place on a constantly changing plane around the pipe with frequent changes of inclination and direction, so that manual dexterity must be of a higher standard than for plate welding. Accurate gap setting is more difficult to achieve and maintain, but lateral alignment of the pipes and matching of the bores is of prime importance. The root of the completed weld cannot be visually inspected so penetration must be accurately controlled at all times. Where the pipe conveys a fluid, e.g. oil or water, a gas, e.g. air or coal gas, a solid, e.g. sand or grain, or a semi-liquid substance such as sludge or wet concrete, any root penetration will reduce the effective flow through the pipe, perhaps causing blockage and must, therefore, be kept within strict limits. Where hot substances such as heated water and steam are conveyed temperature changes will occur in the pipe causing frequent thermal movement and setting up considerable stresses in the joint. Apart from

mechanical stress the joint may be required to withstand high internal pressures as in the case of compressed air and hydraulic lines. In most cases, then, the quality of the weld will need to be of the highest order and will require extremely skilful workmanship to ensure that it fulfils its purpose satisfactorily.

This type of welding should only be attempted after considerable practice in all positions on mild steel plate of equivalent thicknesses.

Mild steel pipe is graded under B.S. into "light", "medium" and "heavy" classifications with coloured-band identifications of brown, blue and red respectively (see Table I.5). In each grade the dimension of the pipe wall varies according to the pipe diameter and as the bore increases the pipe wall becomes thicker; e.g. in the medium pipe the wall thickness ranges from approximately  $\frac{1}{8}$  in. for 1 $\frac{1}{4}$ -in. diameter, to approximately  $\frac{3}{16}$  in. for the 4-in. bore.

TABLE I.5. MILD STEEL PIPE

Size (in., nominal internal diam.)	Grade:	<i>Light</i>	<i>Medium</i>	<i>Heavy</i>
	Colour code:	Brown band	Blue band	Red band
		Wall thickness (in.)		
1 $\frac{1}{4}$		0.104	0.128	0.160
1 $\frac{1}{2}$		0.116	0.128	0.160
2		0.116	0.144	0.176
3		0.128	0.160	0.192
4		0.144	0.176	0.212

The given internal diameters are "nominal bore" only as the outside diameter remains approximately constant for any grade of a given size and differences in wall thickness are compensated for by variations in the actual bore of the pipe. Consequently, two different grades of pipe of the same size will match up externally but have serious inequalities internally (see Fig. I.40).

As the quoted size of a pipe is the nominal bore, its actual outside diameter will always exceed this figure; e.g. 2-in. heavy grade pipe has a wall thickness of  $\frac{1}{8}$  in. and an outside diameter of 2 $\frac{1}{2}$  in.

Inequalities in bore

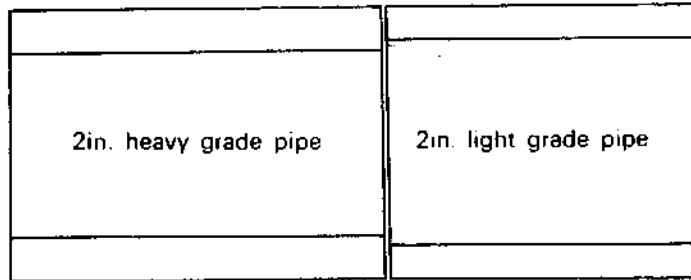


FIG. I.40. Internal differences in tube grades.

**BUTT JOINT, 2-IN. MILD STEEL PIPE (OXY-ACETYLENE),  
ROTATED.**

**MATERIAL:** 2-in. heavy-grade mild steel pipe, 4 in. long, two pieces.

The first joint to be attempted should be the rotated butt in the downhand position. Some useful preliminary practice may be had on the "light" pipe, but a transfer should be made to the medium and heavy grades at the earliest possible moment as these are used exclusively in pipework installations conveying liquids or gases under pressure.

For practice the pieces of pipe, 2 in. diameter, should be not less than 2 in. long and preferably 3-5 in. long, check that both pieces are of the same grade and that the bores match. With both ends cut quite square they should be accurately aligned with the aid of a simple clamp or jig. A straight piece of 1½-in. m.s. angle with feet provides a useful aid to the accurate setting-up of the pieces (see Fig. I.41).

Set a gap slightly wider than that specified (see Table I.6), check that it is constant around the joint and tack at the 2 o'clock position. [In pipe welding it is usual to refer to the different positions on a vertical joint as points corresponding with the position of the hours on a clock, 12 o'clock being at the top, 3 o'clock at the front and so on (see Fig. I.42).]

Rotate the joint and complete the set up with two more tack welds equally spaced around the circumference and made in the 2 o'clock position. This gives three tacks at 120° to each other. The

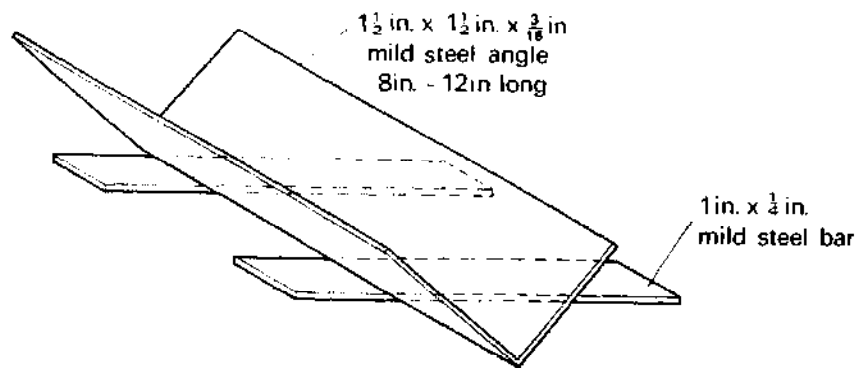


FIG. I.41. Pipe welding jig.

TABLE I.6. VERTICAL BUTT WELDS IN HEAVY-GRADE MILD STEEL PIPE  
*Leftward Method*

Pipe size (in.)	Preparation (bevelled edge, included angle 80° throughout)	Nozzle size (c.f.p.h.)	Filler rod size (in.)	Number of runs	O.A. gas pressures (p.s.i.)
1½	1/16-in. root gap	7	1/8	1	2 to 3
2	1/16-in. root gap	10	1/8	1	3
3	1/16-in. root gap	13	1/8	2	3
4	3/32-in. root gap	13	1/8	2	3

TABLE I.7. VERTICAL BUTT WELDS IN HEAVY-GRADE MILD STEEL PIPE  
*All-position Rightward Method*

Pipe size (in.)	Preparation (square edge throughout)	Nozzle size (c.f.p.h.)	Filler rod size (in.)	Number of runs	O.A. gas pressures (p.s.i.)
1½	1/8-in. root gap	10	1/8	1	3
2	1/8-in. root gap	13	1/8	1	3
3	3/32-in. root gap	18	1/8	1	3 to 4
4	3/32-in. root gap	18	1/8	1	3 to 4

## BASIC WELDS AND TECHNIQUE

**TABLE I.8. HORIZONTAL-VERTICAL BUTT WELDS IN  
HEAVY-GRADE MILD STEEL PIPE**

*Rightward Method*

Pipe size (in.)	Preparation (square edge throughout)	Nozzle size (c.f.p.h.)	Filler rod size (in.)	Number of runs	O.A. gas pressures (p.s.i.)
1½	½-in. root gap	10	⅜	1	3
2	⅝-in. root gap	10	⅜	1	3
3	¾-in. root gap	13	⅜	1	3
4	¾-in. root gap	18	⅜	1	3 to 4

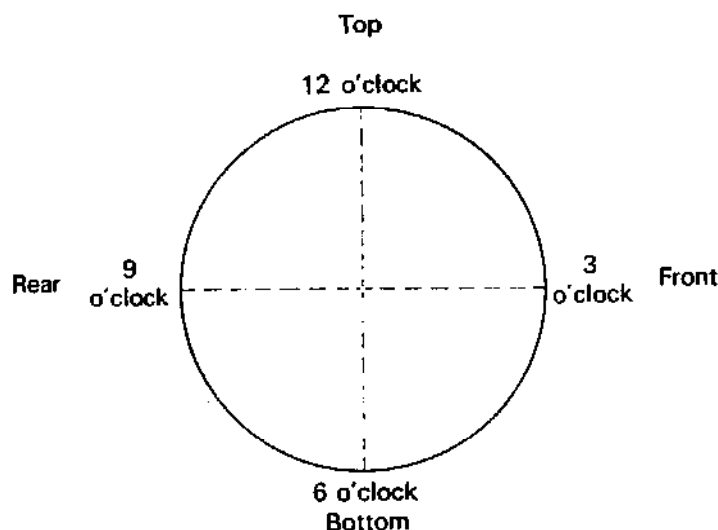


FIG. I.42. Definition of positions in pipe welding.

gap will now have closed slightly, but it must not be less than specified. Check for true alignment. Place the assembly with one of the tacks in the 3 o'clock position and, after melting out the tack, weld to the 1 o'clock position using the vertical upwards method. Rotate the pipe forward to place the end of the weld in the 3 o'clock position and weld again to 1 o'clock, repeating this sequence until the joint is completed.

As the tacks are reached they should be completely melted out, as welding over often results in adhesion and lack of continuity in

root fusion. Picking up the weld again after rotating the pipe must be done with great care, as this method results in four stops and starts in approximately 7 in. of weld and faulty pick up will have a serious effect on the strength of the joint.

When completing the run steps must be taken to produce sound fusion with the start of the weld; i.e. bring it to melting point and maintain root fusion by manipulating the blowpipe with a circular movement, lowering the nozzle slightly and adding filler metal at a slow rate. Avoid leaving a crater on the weld face.

### **Fusion Welding of Cast Iron**

Bearing in mind the composition and properties of cast iron it will be obvious that when heat is applied in fusion welding a number of difficulties will arise.

Its low conductivity rate will allow rapid build up of heat in concentrated areas causing expansion which will be resisted by the mass of the material. The brittle nature of the metal will not allow it to relieve such stresses by bending or twisting and the result will not be distortion, as with mild steel, but the appearance of cracks.

This can best be seen on a piece of  $\frac{1}{8}$ -in. scrap material. Play the outer envelope of the flame over the plate, moving it quickly and evenly over the whole area, and gradually bringing it to red heat. This can be achieved without cracking, as the slow application of heat allows time to diffuse into the metal and expansion takes place at an even rate throughout the plate. Allow to cool slowly, since rapid cooling will cause cracking. Now, using the inner cone of the flame, produce a hot spot in the middle of the plate. This will cause severe cracking due to the heated area expanding whilst the remainder of the plate tends to retain its original size.

Chemical changes will also take place once the metal is brought to a molten state and allowed to cool. When molten the iron and carbon go into solution, forming iron carbide, and if rapid cooling takes place this very hard, brittle substance (also known as cementite) will be retained in the solid state, giving a structure of white cast iron. If, on the other hand, the metal is very slowly cooled the iron and carbon will have the opportunity to separate,

or come out of solution, giving a final structure of soft iron and free graphite, or grey cast iron.

Silicon acts as a graphitiser and the amount present will influence the formation of cementite. It retards the chemical combination of iron and carbon, by retaining the carbon in the form of graphite, and thus preventing the production of cementite. When welding, the use of a "high silicon" cast iron filler rod is essential to provide sufficient quantities of free silicon.

From the practical point of view the aim must be to produce a deposit of soft, grey iron. The formation of cementite will result in an extremely hard, brittle deposit which will probably be unmachinable. Finishing may be unnecessary, depending on the job in hand, but the superior mechanical properties of the grey iron are still desirable.

The oxide formed by cast iron has a higher melting point than the metal and a flux is essential. This will have a sodium carbonate base and will melt under the heat forming a fluid slag which reduces the oxides, chemically cleans the metal, assists in the free flow of molten metal and floats the impurities to the surface of the weld pool.

#### TECHNIQUE (see Figs. I.30 and I.44)

Use the leftward method, with the filler rod at a slightly steeper angle. The nozzle size should be one size larger than for mild steel, though if full preheating has been carried out the same size will be adequate. Set a soft, strictly neutral flame and note that the inner cone should be kept  $\frac{1}{8}$  in. to  $\frac{3}{16}$  in. away from the surface of the weld pool. If it touches the molten metal extremely hard spots will be formed. Using a high silicon filler rod pick up flux on the heated end, bring root and sides of vee to fusion and add filler metal with a puddling movement. Do not use large quantities of flux. The movement of the rod end should be only sufficient to allow the liquid slag and any gases formed to come to the surface, so avoiding inclusions and cavities; the weld pool must not be excessively agitated. After welding is complete, retard cooling by covering the workpiece with fire bricks, asbestos or ashes.



BUTT JOINT,  $\frac{3}{8}$ -IN. THICK CAST IRON (OXY-ACETYLENE),  
DOWNHAND POSITION.

MATERIAL:  $3 \times \frac{3}{8}$ -in. grey cast iron, 6 in. long, two pieces.

Clean the edges of the joint. Bevel to  $45^\circ$  leaving  $\frac{1}{16}$ -in. root face and assemble with  $\frac{1}{8}$ – $\frac{3}{32}$  in. diverging gap ensuring that both plates are in alignment and preset  $2$ – $3^\circ$ . Incline the joint slightly upwards and do not tack. Preheat fully to  $650^\circ\text{C}$  and, using a No. 13 nozzle, set a soft neutral flame. With a  $\frac{1}{8}$ -in.-high silicon filler rod and using the leftward technique commence root run at the lower end of the joint, picking up flux as required on the end of the rod. Wire brush the completed run before starting the filling run with a  $\frac{3}{16}$ -in. rod, maintaining preheat temperature throughout. The completed weld should show a good root bead and a regular face without cavities.

### *Repair Welds*

When a crack is to be repaired, a  $\frac{1}{8}$ -in. hole should be drilled just beyond the visible end of the crack to prevent it running further and the vee preparation and root gap produced by chipping, sawing, filing or grinding. After preheating, weld from the drilled hole to the edge of the casting and avoid the use of tack welds.

There are three methods of preheating applicable to the repair of castings:

1. *Full preheat*, where the whole casting is brought to an even temperature. This will be necessary where welds have to be made on castings of complicated shape, e.g. on the wall of a cylindrical vessel.
2. *Partial preheat*, where one section only is heated in the immediate area of the weld. This may be used when the repair is located in such a position that distortion will not be caused when heat is applied.
3. *Local preheat*, where selected portions of the workpiece are heated to control movement and prevent distortion and cracking in other parts.

### **Bronzewelding and Brazing**

Both these methods use a filler rod with a melting point much lower than that of the parent metal. The fusion of the base metal is not necessary and heat input is lower. The joints can therefore be made more quickly, less distortion is caused, but their mechanical strength is much lower than with the fusion weld. Both methods also have useful applications in the jointing of dissimilar metals which could not be joined by fusion (e.g. copper and mild steel) but they are more widely used in the straightforward jointing of steel (particularly galvanised), copper and also cast iron.

Although both are "hardsoldering" processes (using brass as a solder), their applications differ and they rely on different principles for their strength. The bronze weld uses a large deposit with a relatively small tinned area. The molten filler metal is rather sluggish and quick freezing, allowing it to be used in joints with a wide gap and slight errors in set up. Mechanical strength is provided by a reinforcing bead of filler metal (see Fig. I.43).

A brazed joint requires a thin flowing brass and flux and an accurately prepared, well-fitting set-up with clearances of 0.002–0.006 in. to allow penetration to all parts of the joint by capillary attraction. Appreciable reinforcement is difficult to obtain and strength is imparted by allowing a much larger contact area in the joint faces (see Fig. I.43). The amount of filler metal, which may be fed in from a rod, inserted as a "shim" during assembly of the joint or introduced by dipping the heated joint in a bath of molten brass, is only slightly more than that necessary to tin the joint faces.

In view of these differences it is important that the terms "bronzeweld" and "braze" should not be confused or loosely used. Both the processes can be carried out with the oxy-acetylene flame as the source of heat.

The regulation of heat input is important when melting brasses, as when an alloy containing zinc is heated the zinc, with its depressed melting point, tends to overheat causing rapid oxidation with the formation of zinc oxide. This is given off as white fumes or left as a white deposit on the work [note: the breathing of these fumes will cause sickness and giddiness; an industrial respirator should be worn when working on galvanised material]. As part of

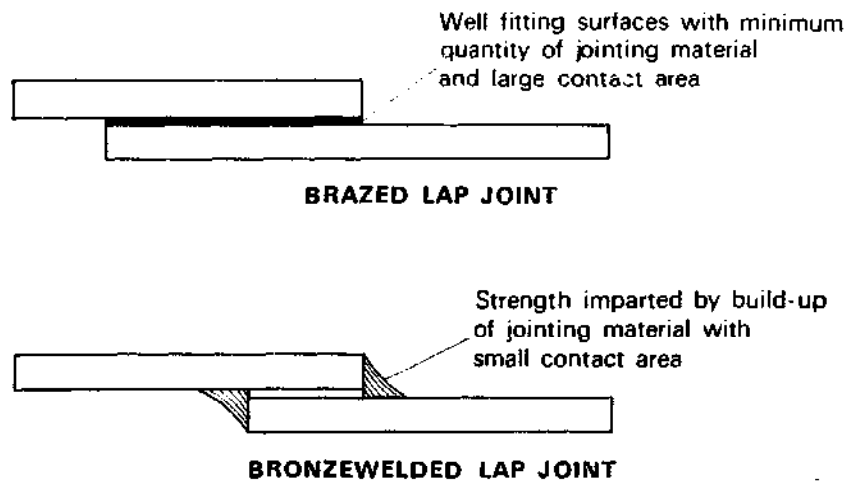


FIG. I.43. Lap joints.

the zinc content has been converted to zinc oxide the filler metal will now be deficient in zinc and no longer suitable for its intended purpose. This will be noticeable in the appearance of the brass which loses its yellow colour to assume a reddish tinge.

Boiling of the liquid zinc also occurs during overheating and many of the faults arising in brazing and bronzewelding are due to these two factors. The correct proportion of zinc as a dissolving agent is essential in the filler metal to allow effective tinning of the surfaces, without which the alloying will be incomplete. Boiling and fuming causes cavities to be formed in the deposit. A slightly oxidising flame will prevent the oxidation of the zinc and enable the joint to be completed without loss of zinc content. Skilful use of the blowpipe will prevent overheating.

The basic essentials of these joints are:

1. The joint must be suitably designed.
2. Preparation—shaping, cleaning, set up—must be correct.
3. Filler rod must have the correct mechanical properties and a suitably low melting point.
4. The joint area must be adequately fluxed.
5. The amount of heat applied must not be excessive.
6. Flux residues must be completely removed after welding.

*Bronzewelded Tee-fillet*

BRONZEWELED TEE-FILLET,  $\frac{1}{8}$ -IN. MILD STEEL PLATE  
(OXY-ACETYLENE), DOWNHAND POSITION.

MATERIAL:  $4 \times \frac{1}{8}$ -in. mild steel plate, 6 in. long, two pieces.

Straighten plates, ensuring good fit-up at the root of the joint, Clean joint faces and tack the plates at the correct angle. Set-up in the downhand position with the joint slightly inclined and using a No. 5 nozzle with a soft, slightly oxidising flame and  $\frac{3}{8}$ -in. nickel-bronze filler rod make the joint in a single run by the leftward technique. Apply flux frequently with the rod to ensure that the tinning area is constantly immersed in a pool of molten flux. The filler metal bonds at red heat so avoid overheating, for at the correct temperature the brass will flow easily over the surface, displacing the flux. Feed in the rod at such a rate that an adequate build up is obtained with leg lengths of approximately  $\frac{7}{16}$ - $\frac{1}{2}$  in. Allow to cool and, after lightly chipping off any heavy flux deposits, scrub off thoroughly in hot water. The completed joint should have an even build up with a regular face pattern and complete tinning on the joint faces. A polished section of the deposit should show complete freedom from porosity. Test to clause 7, B.S. 1724, *Bronzewelding by Gas*.

Galvanised mild steel may be jointed by bronzewelding giving a joint of reasonable strength without the destruction of the zinc coating which occurs in the fusion-welding process. Edge preparation should be by mechanical methods to avoid damaging the zinc. When completed, the edges of the joint should merge into the coating and should not show a zone devoid of zinc.

*Bronzewelding of Cast Iron*

This method is advantageous where a lower heat input is desired to: (1) reduce expansion and contraction; (2) prevent chemical changes in the parent metal; and (3) produce a hard wearing, fully machineable deposit. The mechanical strength of the joint is inferior to that produced by the fusion process, but in the many instances where this is acceptable a repair can be made much

more quickly (see Fig. I.44). Edge preparation should be 45° bevel, giving a vee with a 90° included angle, or, where increased shear strength is necessary, a 90° stepped vee. After cleaning and setting up, preheat to 400°. Recommended nozzle size is one or two sizes smaller than for the equivalent fusion weld in mild steel. Set a soft, slightly oxidizing flame and use a borax-type flux to assist in the tinning of the joint faces. Incline the workpiece to prevent the forward flow of molten metal and use the leftward technique. Depending on the thickness of the parent metal it may require two or more runs to complete the joint. Although chilling or rapid cooling will have little effect on the hardness of the deposit, the movement thus produced may cause the brass to be pulled away from the parent metal. Therefore, the likely effects of expansion and contraction, although less than in fusion welding, should be given careful consideration before the application of heat.

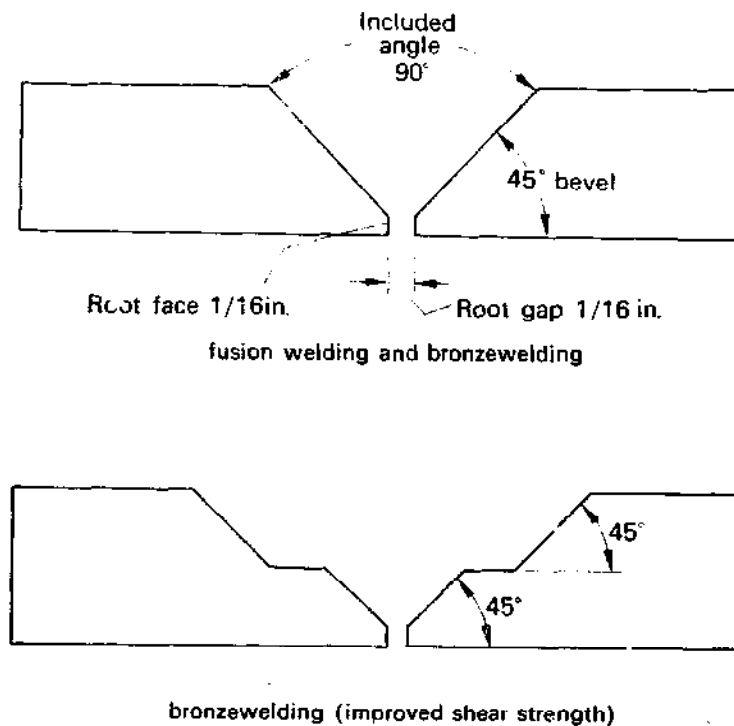


FIG. I.44. Preparation for welding of cast iron.

*Bronzewelded Butt Joint*

BRONZEWELDED BUTT-JOINT,  $\frac{1}{4}$ -IN. THICK CAST IRON  
(OXY-ACETYLENE), DOWNHAND POSITION, LEFTWARD METHOD.

MATERIAL:  $3 \times \frac{1}{4}$ -in. grey cast iron, 6 in. long, two pieces.

Prepare with  $90^\circ$  single vee,  $\frac{1}{16}$ -in. root face. Set up in alignment with  $\frac{1}{16}$ - $\frac{1}{8}$  in. diverging gap presetting to allow for slight contraction of deposit. Using a No. 10 nozzle, preheat and coat the weld faces with flux. Bring the start of the joint to a good red heat and tin both faces with the fluxed  $\frac{1}{8}$ -in. manganese-bronze rod, which should flow easily and cleanly on to the surfaces. Do not overheat. After tinning about an inch, return to the start and commence filling the vee, allowing the filler metal to flow in freely, but avoiding collapse at the root of the joint. Proceed in this manner first tinning, then filling until the joint is completed, maintaining pre-heat temperature throughout. The finished job should have a regular convex build-up and a uniform bead of penetration. Test to clause 7, B.S. 1724.

**Building up Worn Parts**

This covers a wide range of work such as worn shafts, gear-wheel teeth, lugs or projections, cutting tools, rock drill faces, digger bucket faces and teeth.

The worn part may be built up with weld deposits of a similar composition to the parent metal and, after machining and finishing, it can be expected to give the same service as the original.

Alternatively, the deposit may be of an entirely different composition to the base metal and possess superior qualities of hardness or wear-resistance. In this case the repaired part will, if a correct choice of filler rod has been made, give better service than the original.

In the first case the method is a straightforward deposition of welding runs by the fusion process with attention to any preheating or post-weld heat treatment appropriate to the particular metal. Use should be made of carbon fences and supports to produce the desired outline of the deposit and reduce machining to a minimum,

the weld metal being applied in straight, even runs according to the required contour and thickness. On large or complicated parts the need for preheating and the control of thermal movement by the variation of heat input will be appreciated. On a shaft runs should be made alternately around its axis to neutralise any movement and retain it in alignment. On a flat surface deposition of runs will tend to cause the upward bending of the edges of the plate so that if it cannot be preset in an opposite curve it must be restrained by firm clamping.

By the second method varying degrees of corrosion or wear resistance, or hardness can be obtained by employing deposits of medium or high carbon steel, nickel, manganese or stainless steel, and stellites. Bronze or brass can be applied by the usual bronze welding method. An extremely hard deposit can be obtained by using a cast iron filler rod and quenching after welding.

Where any of the steels or stellites are to be deposited on a base of different composition, fusion between the two metals will cause alloying, which completely changes the nature and properties of the deposit and leaves it unsuitable for its intended purpose. Fusion or penetration must be kept to a minimum to reduce this dilution and retain the desirable properties of the deposit.

This can be done by using a carburising flame with an excess acetylene feather about double the length of the inner cone. When the steel base is brought to bright red heat the surface absorbs the available free carbon provided by the carburising flame, reducing its melting point slightly and allowing very shallow surface fusion to occur. This enables the deposit to make a satisfactory bond with the parent metal without excessive admixture of the two metals.

### *Stelliting Technique*

Stellite is a material possessing intense resistance to wear, abrasion and corrosion and retaining these properties at high temperatures. It is an alloy of cobalt, chromium, tungsten and carbon. It may be applied as welding metal or pieces of stellite can be brazed to less brittle workpieces.

Stellite is graded in numbers according to its properties and it is

essential that the correct grade is selected for each particular purpose.

Select a nozzle one size larger than for equivalent steel plate and, using the minimum gas pressures, set a soft, carburising flame with a "feather" 2-2½ times the length of the inner cone. Preheat the surface to 250°C and bring it to surface fusion, melting on the stellite rod. The blowpipe and rod should be held at a flattish angle, 25-30°, to the plate and the inner cone must not touch the molten area. If the stellite bubbles, increase the supply of acetylene until bubbling ceases otherwise blowholes will be left in the deposit. Carbon deposits indicate that the supply of acetylene is excessive and it should be reduced. Do not overheat the parent plate or excessive alloying will occur, destroying the useful qualities of the stellite. When the required area is covered the job must be cooled slowly to avoid cracking of the deposit. This type of hard facing is often applied as a thin coating rather than as a heavy deposit of welding beads.

Cast iron may be satisfactorily stellite in a similar way if a standard cast iron flux is used to deal with the oxides formed. In this case the deposit should be made in two stages, with a thin initial deposit followed by a second heavier layer. This is necessary to overcome the alloying caused by the deeper fusion in the cast iron.

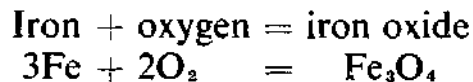


## CHAPTER 3

### Oxygen Cutting of Steels

THIS process utilises the fact that heated iron is easily oxidised and that if it is brought to its combustion temperature (870°C) in the presence of an ample supply of oxygen it will burn in a similar manner to any other combustible, e.g. wood, coal, paper. An iron or steel bar brought to a bright heat in a forge will react vigorously with atmospheric oxygen when withdrawn from the fire. On cooling it will be found that a quantity of the metal has been burnt away and if the process were continued over a sufficient length of time the metal bar would be completely consumed and converted into iron oxide.

This then is a process of oxidation and oxygen cutting is a chemical action. When sufficient oxygen is available the oxide formed will be iron oxide:



This principle is usefully applied in oxy-fuel gas cutting where the metal is quickly brought to its combustion temperature by a large capacity preheating nozzle and a stream of pure oxygen is then directed on to the heated area producing rapid, but localised, combustion or oxidation. The oxide formed is melted and blown through the plate by the force of the high-velocity oxygen jet leaving a clean hole, the size of which corresponds with the diameter of the supplementary oxygen orifice in the nozzle. If the operation is made progressive with the nozzle moving forward in a straight line a section of the plate, corresponding with the width of

the stream of oxygen, will be removed and will produce what is known as a "kerf" cutting the plate into two pieces.

In practice it is found that the metal is removed by the scouring action of the oxygen stream before it is fully oxidised and the slag produced is another iron oxide,  $\text{Fe}_2\text{O}_3$ . It requires about 4.6 ft<sup>3</sup> of oxygen to oxidise completely 1 lb of iron and during this chemical action almost 3000 Btu of heat are given out. Were it not for the heat lost by conduction into the plate, the heat produced chemically would be sufficient once the action was started, to allow the cut to proceed without the assistance of the preheat flame.

For a metal to be cut by the oxy-fuel gas process two conditions must be satisfied:

1. The metal must oxidise freely at a temperature below its melting point.
2. The resultant oxide must melt at a temperature below the melting point of the metal.

Many metals do not satisfy these conditions and cannot be cut by this method, i.e. non-ferrous metals; stainless steels; cast iron. It is applicable to the other steels and irons with excellent results. Whilst no difficulties arise on non-hardenable steels, it will be appreciated that with heat-treatable steels a certain hardening of the edges will occur and steps may be necessary to prevent or correct this condition.

Several fuel gases are suitable for this process including propane, coal gas and acetylene and all produce equally suitable results, the only practical difference being that, owing to their lower calorific values the propane and coal gas use larger preheat nozzles and give slightly slower cutting speeds than the acetylene. Where gas welding work is done it is often more convenient to use the same gas for cutting processes and acetylene is widely used. It also allows quicker starts and higher cutting speeds.

Oxygen cutting is generally divided into four classes:

1. Light, up to ¼-in.-thick material;
2. Medium, up to 8-in.-thick material;
3. Heavy, up to 15-in.-thick material;
4. Very heavy, above 15-in.-thick material.

The upper limit is difficult to fix and the only limitations are those imposed by the capacity of the equipment to supply adequate preheat and sufficient quantities of cutting oxygen at the correct velocities. Steel several feet in thickness has been cut with very heavy equipment.

The oxy-acetylene cutting equipment uses the normal welding gas supplies, but on heavy cutting it may be necessary to use a cylinder manifold to provide the necessary quantities of oxygen and to ensure that acetylene cylinder discharge rates are not exceeded.

All the usual welding safety precautions should be carefully applied and attention must also be paid to the following points:

1. The prevention of fire damage likely to be caused by the ejection of the hot slag.
2. The wearing of adequate protective clothing.

When backfires occur during cutting operations they are usually due to one of the following causes:

1. The preheat flame being set too small.
2. The preheat gas pressures being too low.
3. The nozzle overheating.
4. The nozzle being too near the work.
5. Metal or slag being deposited on the nozzle.
6. The nozzle being the wrong size for the work.

For medium and heavy cutting a special oxygen regulator is used capable of giving the higher outlet pressures necessary. The gas hoses should be the heavy-duty type and all connections must be made in the approved manner.

The cutting blowpipe (see Fig. I.45 and Plate I.7) is provided with three controls, preheat acetylene, oxygen and supplementary cutting oxygen. The preheat gases are mixed at the nozzle and issue through:

1. a single orifice, as in the sheetmetal nozzle;
2. a series of equally sized orifices (Plate I.8);
3. an annular space (Plates I.8 and 9).

In the first, the cutting oxygen outlet is located behind the preheat orifice and in the other types it is positioned in the centre of the preheat gas outlet(s). The body of the blowpipe is of such a

## OXYGEN CUTTING OF STEELS

length that the operator's hands are kept a reasonable distance from the reaction zone. To enable more accurate work to be carried out the following attachments are provided:

1. spade guide—for straight cuts with the aid of a straight edge;
2. roller guide—for straight cuts or irregular curves;
3. trammel bar—for regular curves from a given centre.

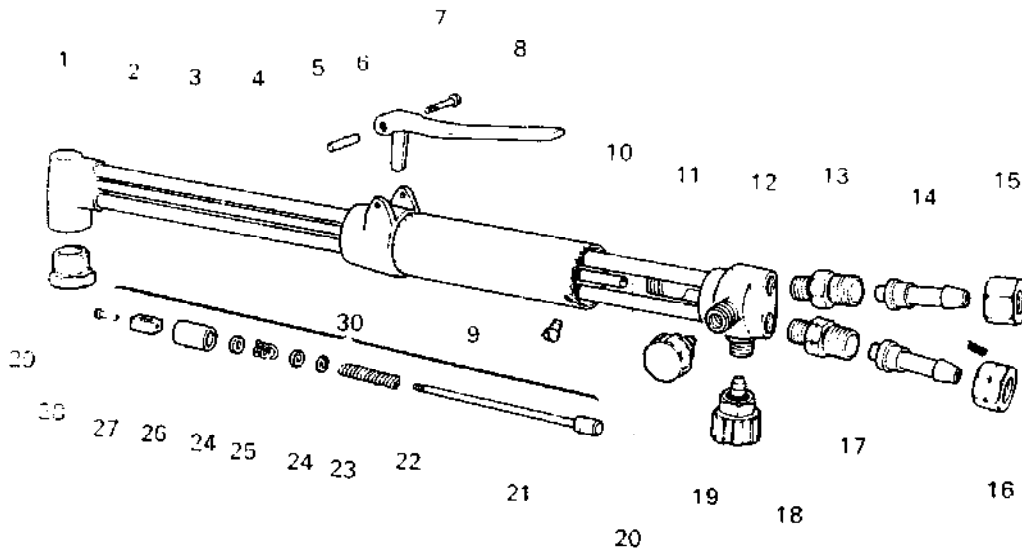


FIG. 1.45. Oxy-acetylene cutting blowpipe

(Courtesy, Air Products Ltd.)

- |                                   |   |
|-----------------------------------|---|
| 1. Torch head.                    | 16. Fuel gas inlet union nut.           |
| 2. Cutting oxygen tube.           | 17. Fuel gas inlet union body.          |
| 3. Heating oxygen tube.           | 18. Fuel gas valve stem assembly.       |
| 4. Fuel gas tube.                 | 19. Oxygen valve stem assembly.         |
| 5. Cutting oxygen lever sleeve.   | 20. Seat assembly.                      |
| 6. Handle cap.                    | 21. Valve stem.                         |
| 7. Cutting oxygen lever screw.    | 22. Spring.                             |
| 8. Cutting oxygen lever.          | 23. Packing washer.                     |
| 9. Handle locating screw.         | 24. Packing.                            |
| 10. Handle tube.                  | 25. Lubricating packing.                |
| 11. Cutting oxygen valve housing. | 26. Packing nut.                        |
| 12. Rear end.                     | 27. Yoke.                               |
| 13. Oxygen inlet union body.      | 28. Yoke adjusting screw.               |
| 14. Hose nipple.                  | 29. Tip nut.                            |
| 15. Oxygen inlet union nut.       | 30. Cutting oxygen valve stem assembly. |

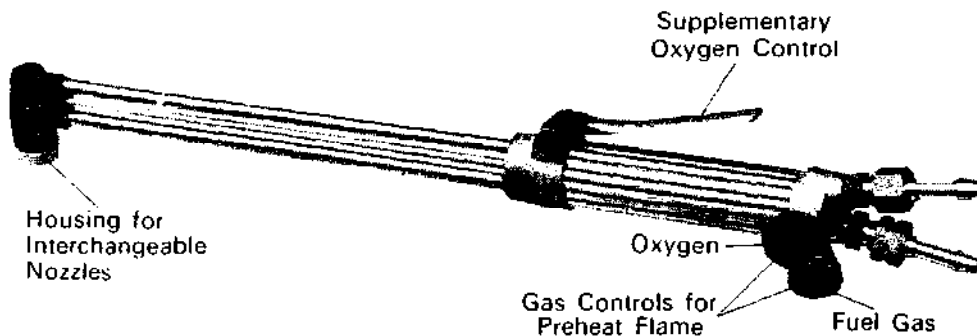


PLATE I.7. Oxy-gas cutting blowpipe.  
[Courtesy, Air Products Ltd.]

The conditions necessary for a good-quality cut are:

1. Correct nozzle size according to plate thickness.
2. Adequate preheat flame.
3. Recommended pressure of supplementary oxygen.
4. Correct distance between nozzle and plate surface.
5. Correct constant speed along the plate.
6. Correct angle of nozzle to plate.
7. Clean, dry plate surface.

## Manual Cutting

### *Method of Operation*

Assemble equipment. Fit recommended nozzle size. Set correct gas pressures. With the cutting oxygen control closed light up the blowpipe as in welding and set a neutral flame. [Note: tinted goggles must be worn when cutting.] Preheat the plate edge at the beginning of desired line of cut and, as it comes up to medium red heat, open cutting oxygen supply and move along the line of cut at a steady speed keeping the nozzle a constant distance from the plate and at equal angles to it. The blowpipe should move at a speed sufficient to prevent melting of the plate by the preheat flame, but if the speed is too high the cut will be lost due to insufficient preheat. Between the two extremes lies the correct cutting speed and only close observation during the operation will enable a good

OXYGEN CUTTING OF STEELS

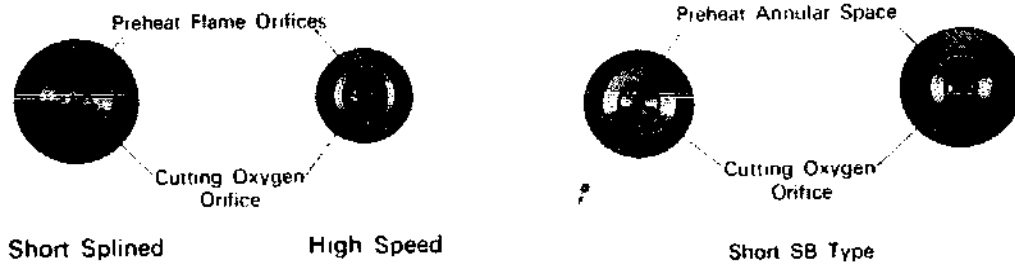


PLATE I.8. Types of oxy-gas cutting nozzles.

[Courtesy, Air Products Ltd.]

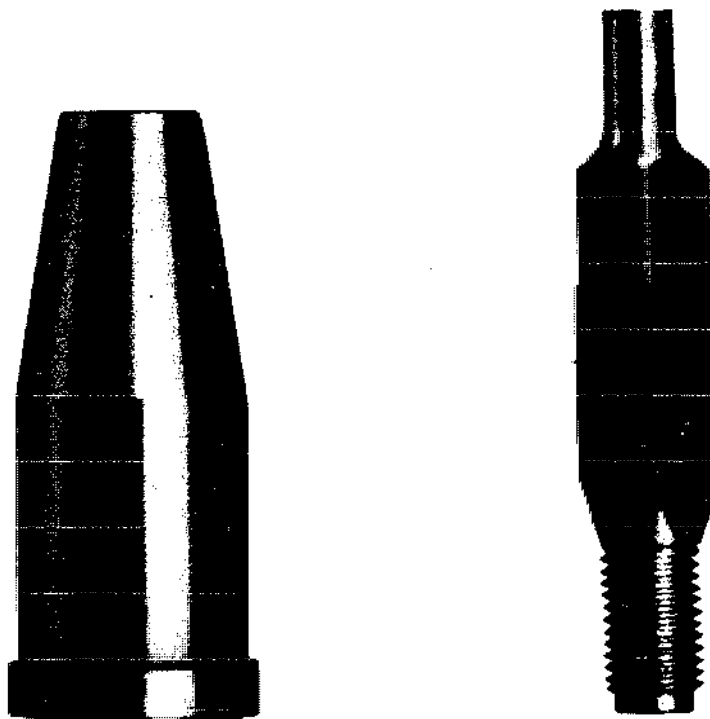


PLATE I.9. Two-piece oxy-gas cutting nozzle.

[Courtesy, Air Products Ltd.]

cut to be made. The quality of the cut edge depends largely on steady, skilful control of the blowpipe and this can only be obtained by practice.

A skilled operator should be capable of producing a cut to an accuracy of  $\frac{1}{16}$  in. on thin plate, either square or bevelled edge, and

except for wirebrushing the edges should need no further preparation for welding.

A close examination of the cut edge will enable definite conclusions to be drawn from any faults present (see Fig. I.46).

1. Top edge slightly rounded with, perhaps, undercut just below and a slightly rounded bottom edge. *Cause*: cutting speed too high.
2. Top edge melted and rounded, with fluting or gouging and heavy scaling on the face and a round bottom edge. *Cause*: cutting speed too low.
3. Slightly rounded and heavy beaded top edge with square face and sharp bottom edge. *Cause*: nozzle too near the plate.

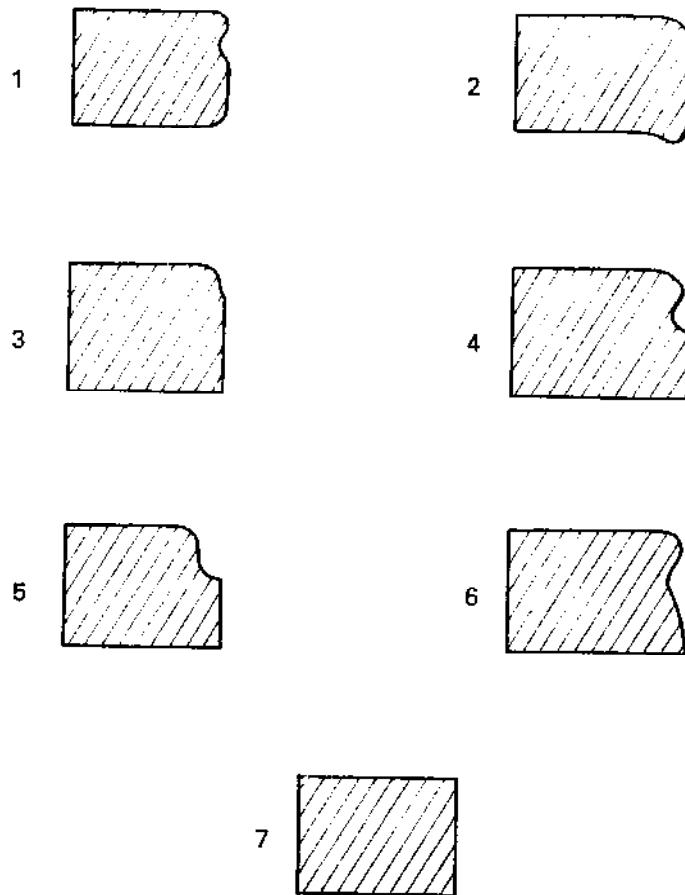


FIG. I.46. Plate edge conditions in oxy-gas cutting.

4. Top edge heavily melted and rounded with undercut showing near the top and the rest of the face square with a sharp bottom edge. *Cause:* nozzle too high above the plate.
5. Kerf wider at the top with a regular bead and undercut, and the rest of the face square. *Cause:* cutting oxygen pressure too high.
6. The top edge rounded, metal falling into the kerf, a smooth face tapered from top to bottom. *Cause:* preheat flame too large.
7. The application of the correct conditions will give a sharp top edge, with a smooth, square face, barely visible drag lines and a sharp bottom edge. Any scale will be light and easily removable.

Where structural sections have to be cut the methods shown in Fig. I.47 should be adopted, following the general principle that the flanges should be cut first and the webs last. Adequate support should be given to the off-cut.

Round sections such as shafts should be cut in the following manner: using a chisel set up a small tongue of metal; preheat with nozzle at right angles to starting point and, when a hot spot forms, open cutting oxygen supply and bring nozzle back into normal cutting position.

To pierce holes in plate or pipe produce a hot spot by preheating and when the cutting oxygen is introduced lift the nozzle  $\frac{1}{2}$  in., tilting it slightly. This will allow slag to be blown out clear of the nozzle and once the plate is pierced the nozzle can be squared up ready for trimming the hole to final shape or continuing the cut along a given line.

The advantage of the oxy-fuel gas cutting process is the speed at which plate and pipe can be cut and prepared compared with sawing, milling and grinding.

### Machine Cutting

Where large amounts of cutting have to be done and where extreme accuracy is desired an oxygen cutting machine should be used. Basically this equipment consists of a cutting blowpipe held



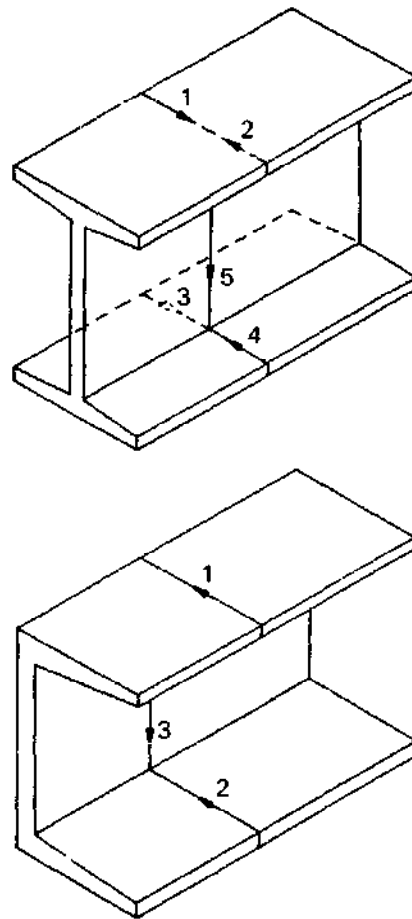


FIG. I.47. Cutting sequences for structural sections.

on an adjustable head with an electrically driven mounting. This either runs along a straight track or is guided by a tracing head (Plates I.10, 11), the drive speed being variable and the nozzle fully adjustable for height and angle. The work is supported under the head in the case of the profiling machine (Plate I.11), which is intended to be installed in a fixed position in the shop. Straight-line cuts are made by allowing the wheeled guide to follow the straight track at the desired speed. When it is desired to cut a profile this can be accomplished by: fitting a knurled steel roller to the guide head; holding it against the edge of a wooden or soft metal template and allowing it to follow the outline; or, fitting a magnetised roller to the head and allowing it to be driven round a

## OXYGEN CUTTING OF STEELS

steel template; or, fitting a tracing wheel to the head which may be guided by hand around the outline of a drawing. There are other more sophisticated methods of control but these lie outside the scope of this work. This machine may also have a number of nozzles controlled by the single head and so be capable of producing several identical profiles at a time using a single template or drawing.

The machine eliminates faults due to variations in manual control and the resultant cut is of high quality. It makes possible the repetition production of intricately shaped identical parts to close tolerances, and with triple nozzles a plate can be cut to size and double-bevelled in one pass. This then is a production machine of great versatility and precision.

The small portable machine (Plate I.12) is driven on the surface of the flat plate either on a track or along a straight edge and is

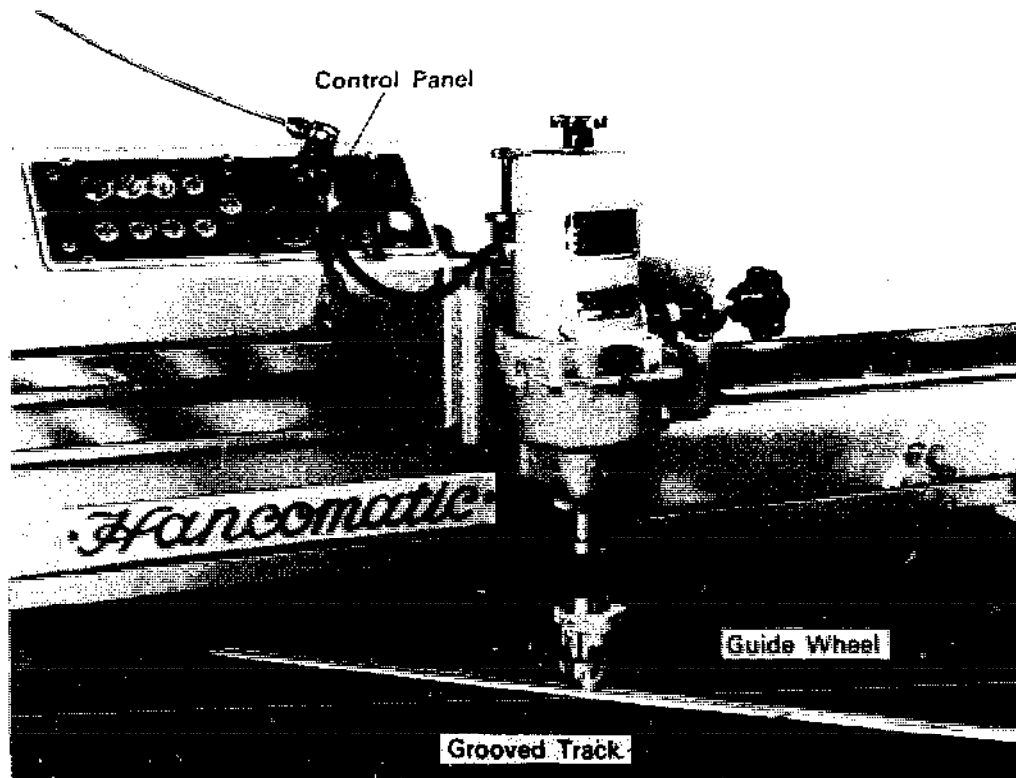


PLATE I.10. Profiling machine tracing head.

[Courtesy, Hancock & Co. (Engineers) Ltd.]

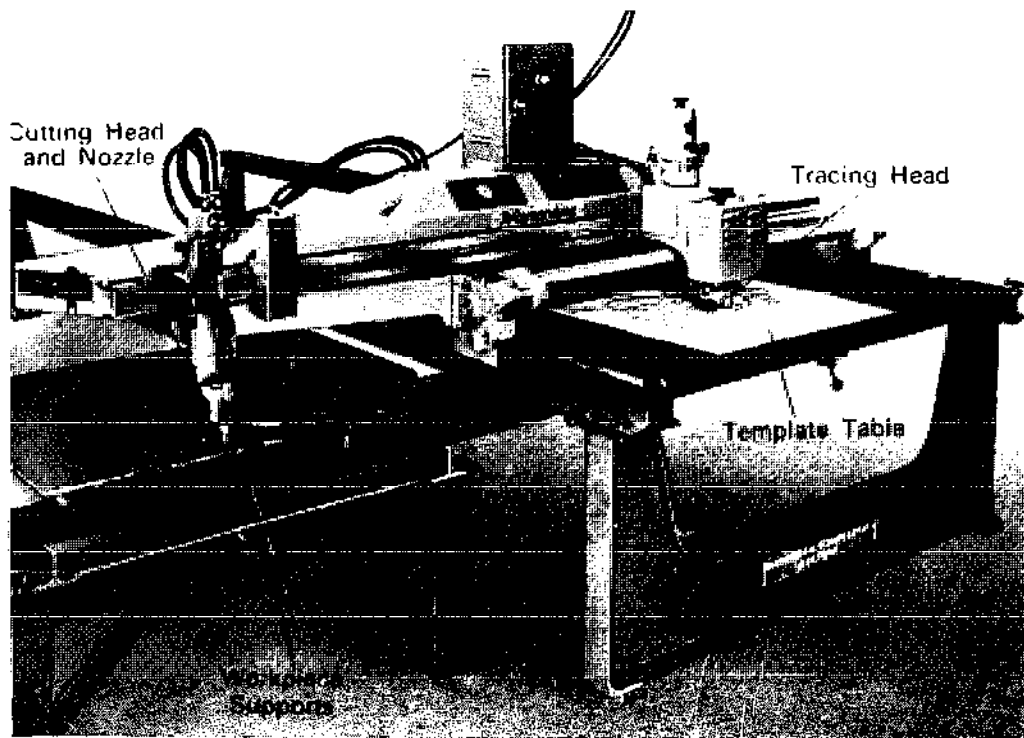


PLATE I.11. Oxy-fuel gas profiling machine.  
[Courtesy, Hancock & Co. (Engineers) Ltd.]

extremely useful in straight cuts and bevel edge preparations. With the attachments it may also be used for curved or circular work. A variation of this machine will climb a vertical plate, so that most plates can be cut *in situ*.

The pipe cutting and bevelling machine (Plate I.13) is portable and can produce square-edged cuts or bevelled edges. There are two main types, one of which moves around the outside of the pipe and the other in which the cutting head remains stationary whilst the pipe is revolved.

### Templates

The type of template used on a profiling machine depends to a great extent on the number of parts to be cut. For a "one-off" job a wooden or aluminium template is often used, being simpler and

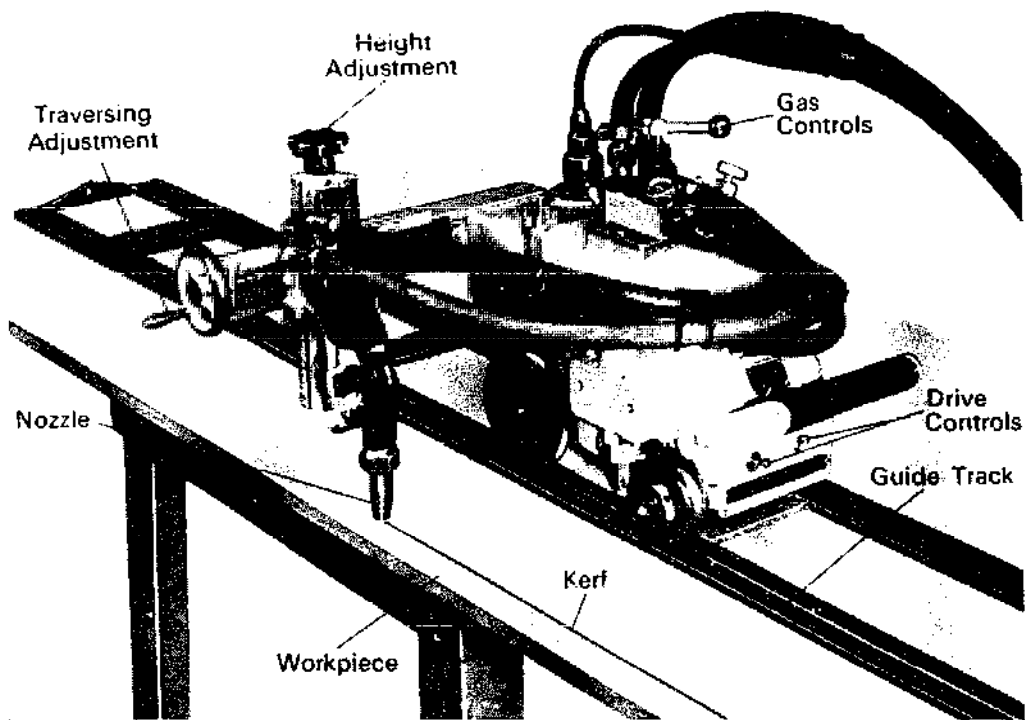


PLATE I.12. Portable oxy-fuel gas cutting machine.

[Courtesy, Hancock & Co. (Engineers) Ltd.]

cheaper to make. In repetition work the accuracy and durability of a steel template and the fact that the magnetic roller can be used more than compensate for its higher cost. The making of a template calls for accuracy in setting out and workmanship if the finished article is to produce pieces of the desired shape and dimensions.

There are four types:

1. *Internal*, where the inside piece is required (Fig. I.48).
2. *Internal*, where the outside piece is required (Fig. I.48).
3. *External*, where the outside piece is required (Fig. I.49).
4. *External*, where the inside piece is required (Fig. I.49).

In each case the outline of the required piece should be drawn full size and, after adjustments to compensate for the size of the roller and the width of the cut, the outline is retraced (Fig. I.50).

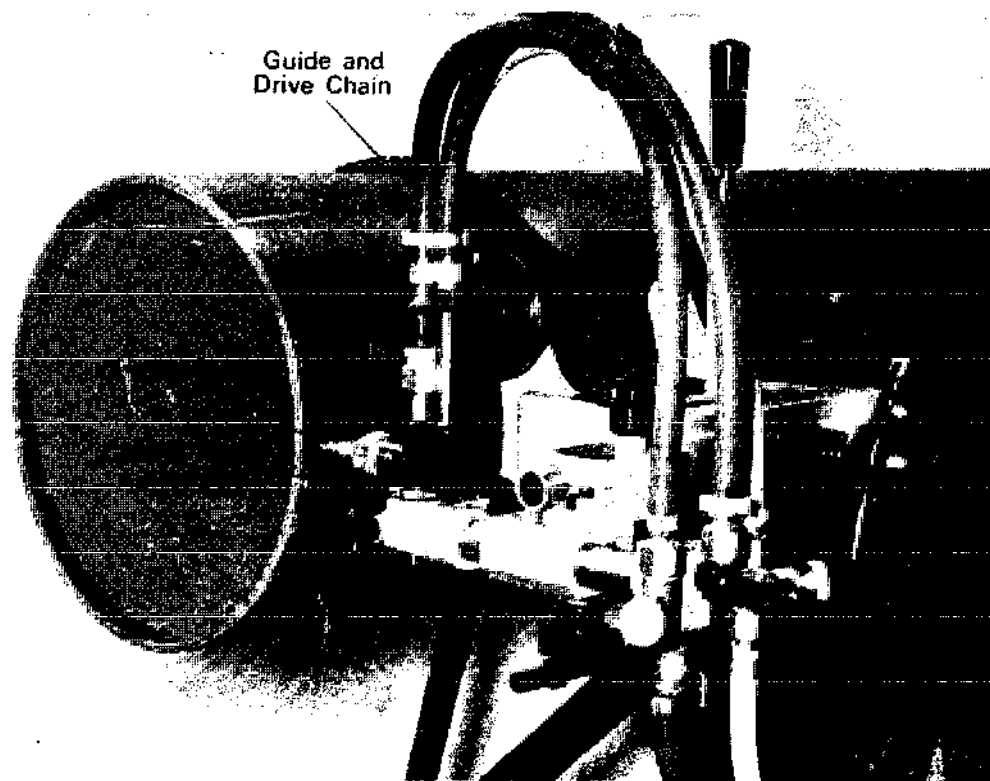


PLATE I.13. Oxy-fuel gas pipe cutter and beveller.

[Courtesy, Hancock & Co. (Engineers) Ltd.]

### Stack Cutting

When oxygen cutting mild steel below  $\frac{1}{8}$ -in. thickness, whether by hand or machine, it is difficult to maintain accuracy and quality and this method has been developed to enable thin plate to be satisfactorily cut with the standard machine. It also makes it possible for the productive capacity of a machine to be increased as a multiple number of identical parts may be cut by each nozzle.

It is based on the fact that if the thin sheets are closely stacked together in a solid mass they can be cut as if they were a solid block of metal and the resultant cut will be accurate and of good quality.

The clean sheets are stacked in a pile and after ensuring that they are in close contact the stack is firmly clamped together, using "G" cramps, dog-leg cramps and wedges, toggle or power

OXYGEN CUTTING OF STEELS

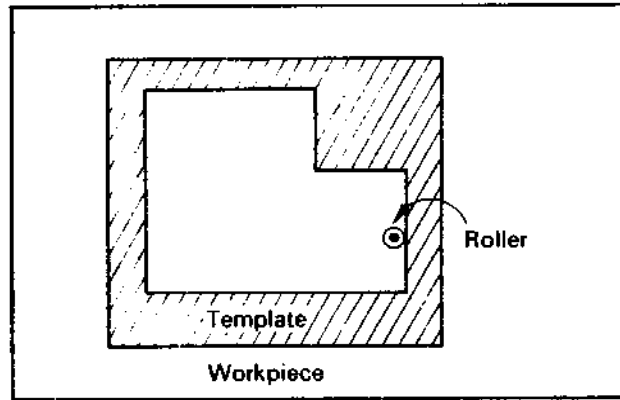


FIG. I.48. Internal template.

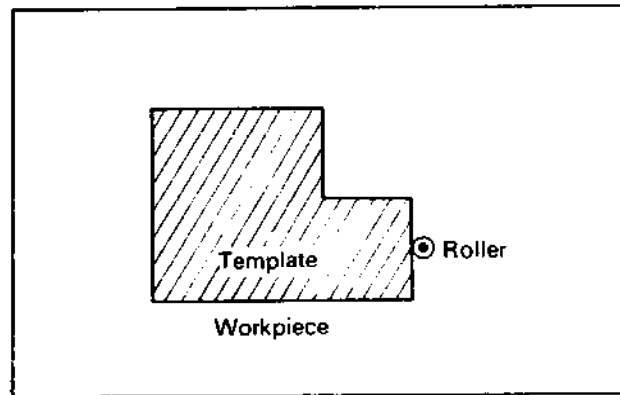


FIG. I.49. External template.

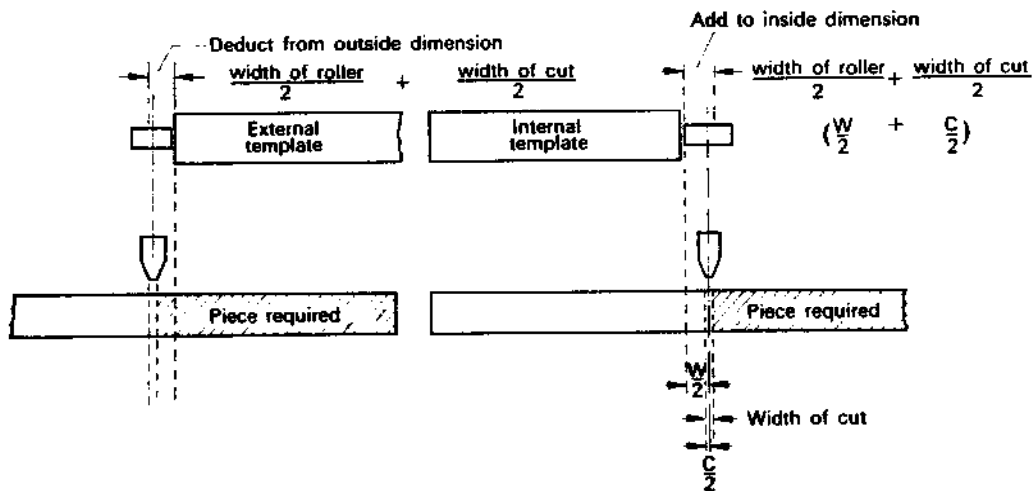


FIG. I.50. Allowances for oxy-gas cutting templates.

clamps. Alternatively the stack may be pressed in a heavy power press and the edges secured by welding, allowance being made for the edges to be discarded as waste.

The quality of cut desired and the permissible tolerance in accuracy will determine the maximum thickness of the stack. With a 2-in. thickness the edge tolerance is  $\frac{1}{32}$  in., increasing to  $\frac{1}{16}$  in. with a 4 in. stack. Above 4 in. accuracy and quality diminish due to the difficulty of maintaining tight clamping.

In practice a 2-in. thick stack could consist of :

- 32 sheets  $\frac{1}{16}$  in. thick,
- or 16 plates  $\frac{1}{8}$  in. thick,
- or 8 plates  $\frac{1}{4}$  in. thick.

## CHAPTER 4

# Inspection and Testing of Welds

WHEN metals are being heated, as happens when welding is taking place, certain changes in the structure of the metal may take place. Other faults may also occur, some of which may be due to the operator, others to the materials being used. It is therefore necessary to be able to examine weldments and to find and correct any faults.

It is not a practical proposition to examine every inch of welding carried out in the workshop and indeed it is not necessary. Only certain items require a 100% inspection, such as boiler and pressure vessels, nuclear power fabrications, bridge structures and oil- and gas-pipe lines. The examination of welds on this type of work is usually carried out by taking X-ray or gamma-ray photographs. It is also usual to examine the welders periodically by giving them certain weld tests.

For a welder to become proficient at his work it is necessary that he should be given the opportunity to examine his own work in detail and to this end there are certain tests that may be carried out in the workshop. It is the aim of this book to deal only with these tests and to mention only briefly the more elaborate and complicated methods of testing.

### Visual Inspection of Welds

Visual inspection of welds may take place both during and after the weld has been completed. During welding the following points may be observed.



*Electric Arc Welding*

1. Check electrodes with the metal being welded.
2. Check welding current, either on welding-set ammeter or by tong-test ammeter, or both.
3. Check angle of electrode.
4. Check arc length.
5. Check speed of travel.
6. Check position of molten pool and slag.

*Oxy-acetylene Welding*

Check the following:

1. Filler rod with the metal being welded.
2. Regulator pressures (with what they should be for the correct size nozzle for the thickness of plate being welded).
3. Blowpipe flame.
4. Angles of filler rod and blowpipe.
5. Speed of travel.
6. Manipulation of rod and blowpipe.
7. Depth of molten metal into parent plate.
8. Type of flux (if used).

The points mentioned above, upon being checked, will give a good indication of the quality of the finished weld. Also, the operator may be corrected whilst welding upon any of the points of detail. This may save the extra work involved in cutting out and making-good bad welds.

Students undergoing practical training may also like to observe each other and discuss any faults arising.

After the weld has been completed a visual examination should be undertaken, checking the following points:

1. Fusion, on face side and reverse side.
2. Undercutting.
3. Reinforcement.
4. Size of fillet.
5. Leg lengths.
6. Smoothness of surface.

7. Pin holes.
8. Stop/start craters.
9. Excessive spatter.
10. Burnt scale.

*Recognition of Defects in Welds as required by B.S. 1295*

British Standard 1295/1959, *Tests for Use in the Training of Welders*, is designed to assist the trainee welder by setting a number of standard test pieces to be examined in accordance with the standard procedure.

It must be stated that should a welder satisfy all the requirements of B.S. 1295 it does not necessarily indicate that he has the ability to satisfy other welding tests as called for in certain other British Standards.

The scope of B.S. 1295 covers tests for trainee welders in manual metallic arc and oxy-acetylene welding in mild steel and the tests are designed so that the progress of a trainee welder may be assessed.

INSPECTION AND ASSESSMENT BEFORE FRACTURE OR SECTIONING OF WELD

*Butt welds. Shape of profile* (Fig. I.51a). The profile of the finished weld should be of a uniform character throughout its length, i.e. the same width and height. It should be convex in shape, free from overlap and show no signs of undercut.

*Fillet welds. Shape of profile* (Fig. I.51b). The profile of the finished weld should be of a uniform character throughout, i.e. the same leg length (unless an unequal leg length is specified). The weld may either be convex or concave, according to the type of filler rod or electrode being used.

*Uniformity of surface.* The face of the weld should be of uniform appearance along its whole length, the ripples should all look alike and not appear distorted. The whole length of the weld must be smooth with no sign of surface protrusions or depressions.



Undercut



Too abrupt reinforcement



Overlap



Incompletely filled joint



Excessively high reinforcement

FIG. I.51(a). Undesirable butt weld profiles.

*Degree of undercut.* Undercut can be seen in both butt and fillet welds. It takes the form of a cut into the parent metal at the extreme edges of the weld. It may show continuously or intermittently along the length of the weld. It is a particularly undesirable fault in that the parent metal at the undercut point is made thinner (e.g. if a tee fillet weld is in  $\frac{3}{8}$ -in. plate and  $\frac{1}{8}$  in. undercut is present, then at the point of undercut the thickness of plate is reduced to  $\frac{5}{16}$  in. thick).

*Smoothness of joint where weld is restarted.* Where welding has stopped and then restarted, the weld should show no signs of a hump or crater. The surface of the weld should appear smooth at the restart point although some slight alteration in colour may indicate a restart.

*Freedom from surface defects.* The surface of the weld should be free from small holes, entrapped slag or burnt-on scale in oxy-acetylene welding.

Small holes may be seen in the weld surface either singly or in groups. Entrapped slag in the weld surface will show up as black holes or as black tubular-shaped marks and a sharp pointed instrument may be used to ascertain whether it is entrapped slag.

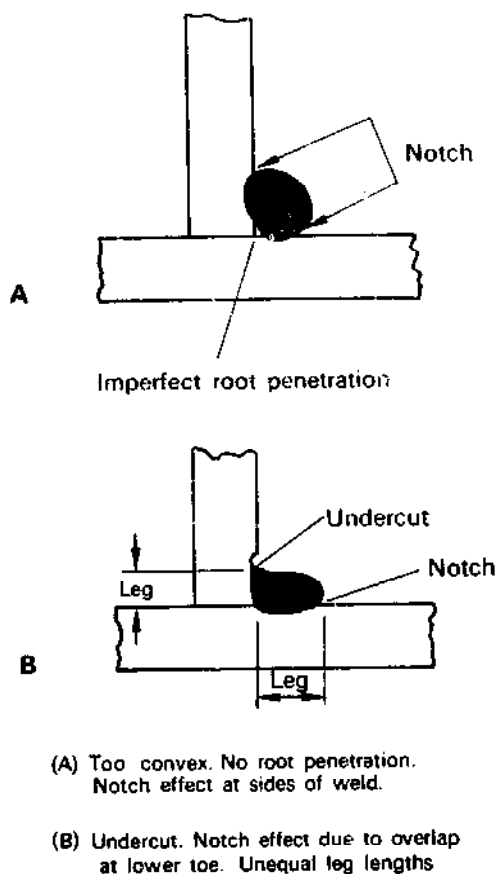


FIG. I.5 (b). Undesirable fillet weld profiles.

*Deposition of runs.* When multi-run welds are deposited, the surface of the weld should not show any deep cavity or groove between each run. The edge of one run must not produce a sharp edge or ridge across another run or a recess in the run.

*Penetration bead.* A penetration bead should be present. The penetration bead of a butt weld can be seen without cutting the weld through and it should appear even along the whole length of the joint. It must not be excessive and of irregular appearance. In general the penetration bead should not exceed  $\frac{1}{8}$  in.

*Inspection of etched sections, bend specimens and weld fractures.* Weld joints when cut through may show the following faults. [The sections must first be etched to show any faults to better effect]:

1. Incorrect profile.
2. Undercutting.
3. Slag inclusions, porosity and cracks.
4. Poor root penetration and other lack of fusion.

*Degree of fusion.* Fusion should be complete over the whole of the weld fusion area and interfusion of weld runs should also be complete.

Lack of fusion may show at the fusion faces and/or between layers of weld metal. Lack of fusion at the joint surface will be indicated by the weld metal not penetrating into the parent plate and the joint will have kept its original form. Between layers of weld metal it will appear as lines.

*Degree of root penetration.* The weld metal should penetrate right through to the root of the joint.

*Non-metallic inclusions and gas cavities.* The weld should have a clean appearance and the weld should be free from voids, porosity, non-metallic inclusions, burnt-on scale and oxide films.

### **Testing**

Some of the points listed above will give a good indication as to the quality of the finished weld, but obviously one cannot see inside the weld; to do this the weld must either be cut or X-ray

photographs must be taken. From this it will be seen that the testing of welds falls into two categories: (1) destructive tests and (2) non-destructive tests.

(1) *Destructive Tests*

The destructive tests may be broken down as listed below.

WORKSHOP TESTING

Bend tests.  
Macroscopic tests.  
Nick-break tests.

LABORATORY TESTING

Mechanical tests.  
Microscopic tests.  
Chemical tests.

WORKSHOP TESTING

Bend tests (Fig. I.52), butt welds in mild steel. The apparatus required to carry out bend tests are: a bending machine, usually hydraulic, and a number of formers and rollers. A workshop usually has a press that can be adapted to carry out bend tests, as it need only be capable of applying an even load on to the specimen under test. (Refer to B.S. 1295, *Tests for Use in the Training of Welders*.)

If it is required to carry out tests on a butt weld in  $\frac{3}{8}$ -in. thick mild steel, the following procedure should be adopted with regard to bend tests.

The specimen (Fig. I.53) should be 12 in. long by 4 in. wide and from it (1 in. from each end) should be cut two pieces  $1\frac{1}{2}$  in. long. These should then be bent over a former, through  $180^\circ$ , having a diameter equal to four times the thickness of the plate. Before bending, the upper and lower surfaces of the weld may be ground flush with the surface of the plate. The sharp corners of the weld may be filed to a radius not exceeding one-tenth of the thickness.

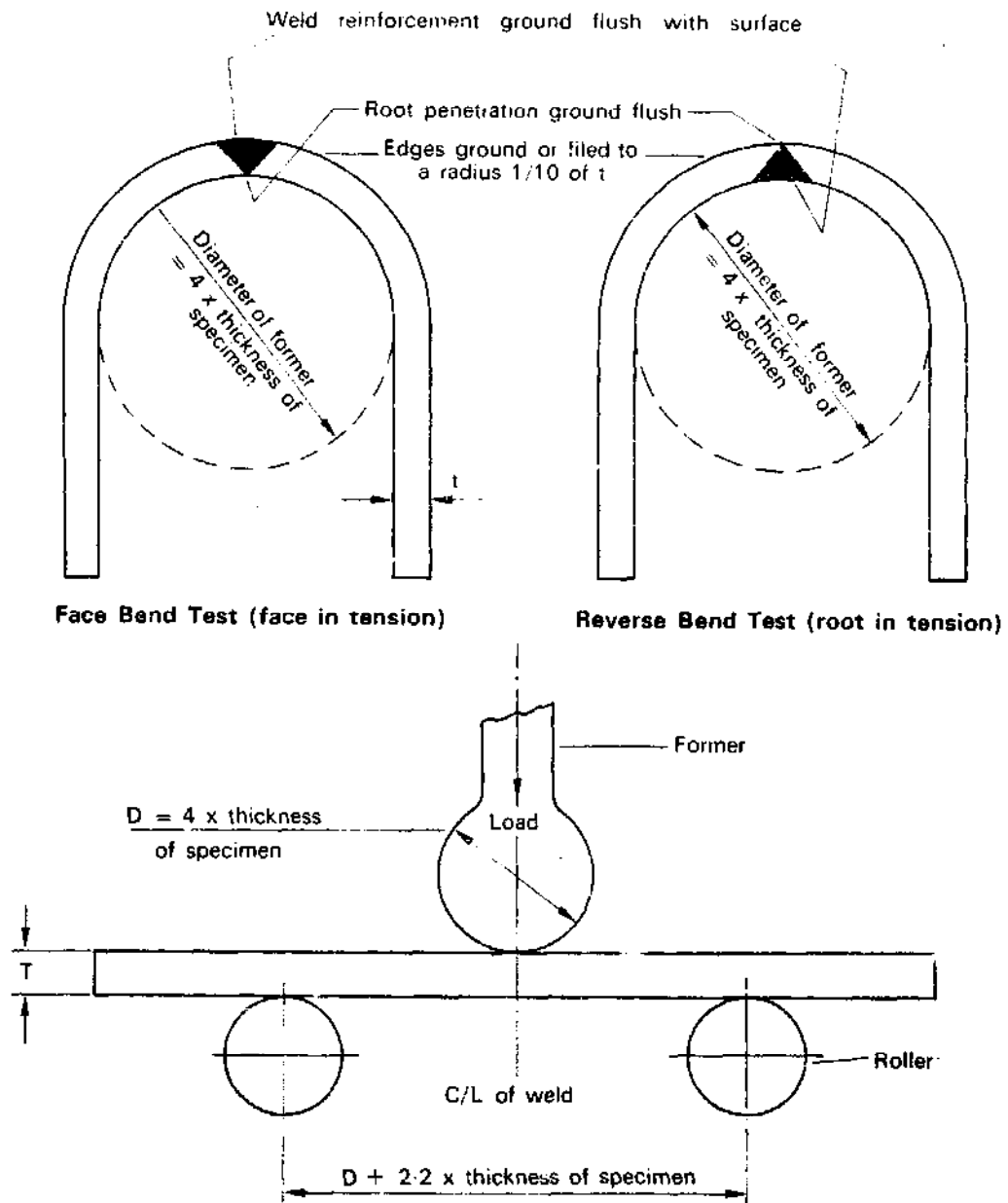


FIG. I.52. Bend tests specimens and arrangement of former and rollers. B.S. 1295.

## INSPECTION AND TESTING OF WELDS

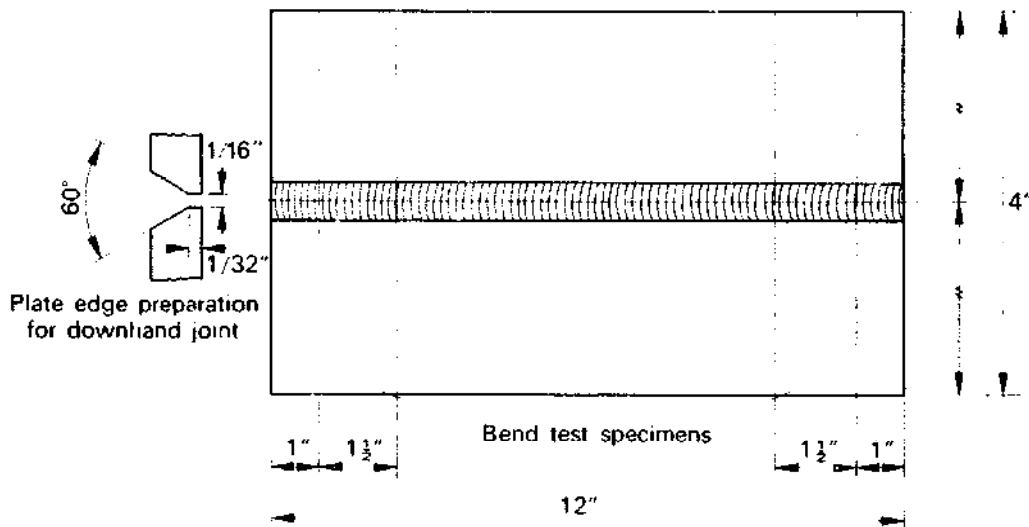


FIG. I.53. Bend test specimens. B.S. 1295.  
For metal arc butt welds in mild steel  $\frac{1}{2}$ -in. and thicker.

One specimen must be bent with the root in tension and the other with the face in tension. These are known as face and reverse bend tests. The bends must show no signs of cracking.

*Bend tests. Butt welds in mild steel tubes* (Fig. I.54) rotated during welding. When it is desired to test specimens from butt welded tubes, the following procedure should be adopted with regard to bend test and nick-break test.

From the weldment two bend tests and one nick-break test specimen (all  $\frac{1}{2}$  in. wide) are required. These must be cut at  $120^\circ$  intervals around the tube, the start of the weld being included in the nick-break specimen. These are best cut on a milling machine using a very thin slit saw. After cutting, the specimens are prepared and bent as described in the previous paragraph on butt weld bend tests.

The nick-break test specimen (Fig. I.55) is prepared by saw cutting each end of the weld to a depth of  $\frac{1}{16}$  in. and saw cutting across the face of the weld to a depth of  $\frac{1}{16}$  in., the specimen is then placed in a vice and broken open. (See paragraph on nick-break testing.)



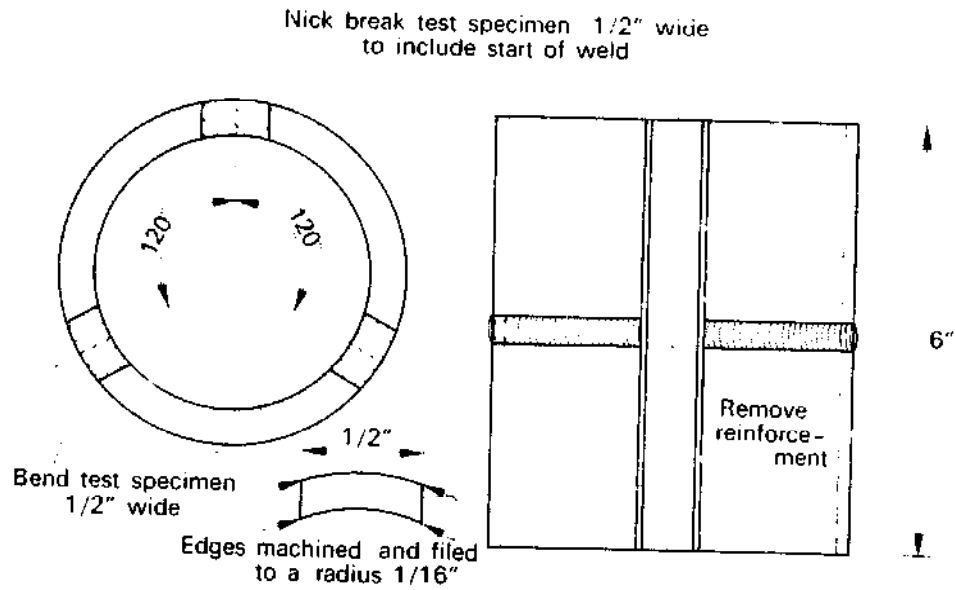


FIG. I.54. Method of obtaining specimens from pipe. B.S. 1295.

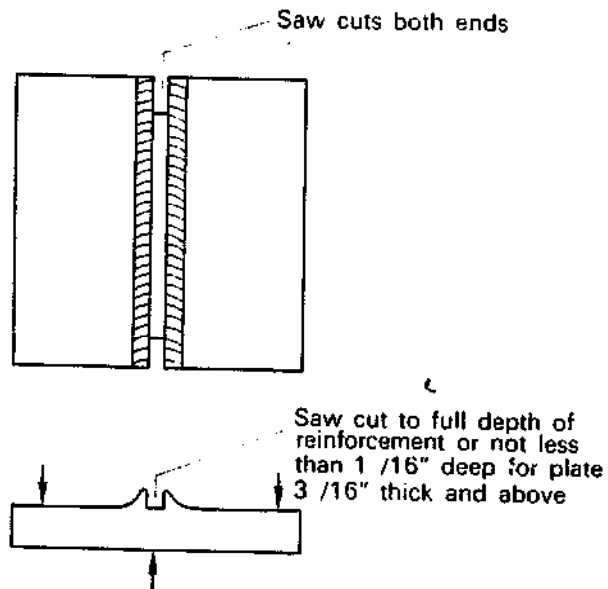


FIG. I.55. Nick-break specimens.

## INSPECTION AND TESTING OF WELDS

*Macroscopic examination. All welds in mild steel.* To prepare a weldment for macroscopic examination, the following procedure should be adopted.

Sawcut through the weld where required. File the specimen until all saw marks and burrs are removed. Polish the weld with a succession of grades of emery cloth, starting with fairly coarse and progressing down to fine. When all marks have been removed by this process the specimen should then be put on a buffing wheel and polished to a mirror finish. Upon inspection any defects will be seen such as pin holes, slag inclusions, gas holes and lack of fusion. To enable the weld metal to be seen even more clearly, etching may be carried out.

### ETCHING

The etching of a weld is the process of coating the weld with a chemical. Etching cannot be carried out successfully unless the specimen has been highly polished. The etching liquids employed depend upon the metal being welded, but for mild steel a 10–20% solution of nitric acid in alcohol will be found adequate. The solution is poured onto the weld and left until the weld metal stands out in contrast to the parent metal. The specimen may then be washed under a running water tap.

The etching of welds may be undertaken in the workshop. A small hand magnifying glass will enable the face of the specimen to be seen in greater detail. To ensure that the specimen does not corrode after etching, coat with oil, vaseline or shellac. (Clear nail varnish will suffice.)

### TEE FILLET TESTING (Fig. I.56), *electric arc over $\frac{1}{8}$ in. thick and above*

The test piece should be 12 in. in length and the material used should be not less than 2 in. in width.

Set up for welding by tack welding in the usual manner (the tack welds may be on the side to be welded). Distortion or misalignment should be corrected before the test weld is deposited.

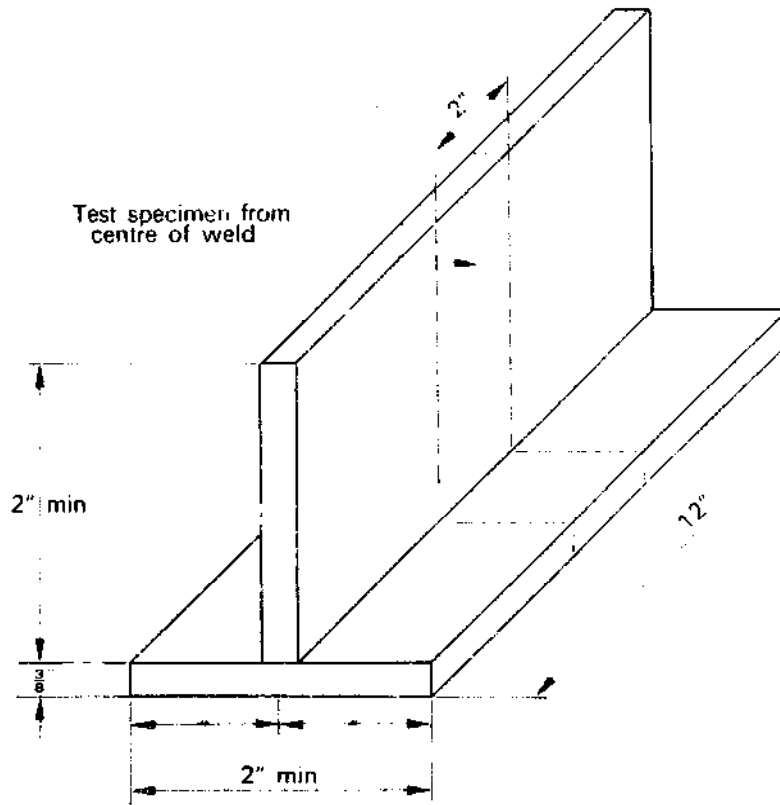


FIG. 1.56. Tee-fillet specimen. B.S. 1295.

The test weld must be of the size  $\frac{1}{4}$  in. or  $\frac{5}{16}$  in. leg length and should be deposited in one run. The only exception to this is the overhead test piece.

After welding, the weld must be examined visibly for shape of profile, i.e. either convex or concave in shape. The central 2-in. portion of the test piece may then be removed and broken open along the weld, which may be accomplished by sawcutting to a depth of  $\frac{1}{16}$  in. along the whole 2-in. length of the weld and then moving one flange of the weld back and forth until it breaks.

The remaining end pieces may be macroetched on the sawn faces, and the degree of penetration may be observed (also slag inclusions, if present).

## NICK TESTING

The nick-break test as called for in the testing of the rotated tube is carried out by sawcutting the specimen as shown in Fig. I.55. A load is applied as indicated by the arrows and the specimen is broken.

The broken weld will show any defects that may be present in the weld, such as slag inclusions, porosity and internal cracks; poor root penetration may also be observed if present.

### (2) *Non-destructive Testing*

These methods may be listed as:

- Magnetic Crack Detection
- Penetrant Ink
- Penetrant Fluorescent
- Ultrasonic
- Radiographic

## MAGNETIC CRACK DETECTION

This a process of weld inspection whereby the weldment is magnetised by the introduction of a very high electrical current, or by placing the weld in a coil. Any cracks or other faults in the weld will distort the magnetic field surrounding the weld and this will show on the surface. By the use of magnetic particles, which are sprayed or brushed onto the weld, the faults will show up by forming a distorted pattern on the surface. The pattern will take the shape of the faults within the weld.

This method of inspection is only of use on magnetic materials and is of particular value in detecting surface cracks and those cracks which may lie just below the surface. For the detection of deeper-lying faults, special equipment is necessary.

If the magnetic field is parallel to the fault there will be no interruption so that it is necessary to magnetise from two directions at 90° to each other.

The surface of the weld must be clean and dry (wire brushing is usually adequate) but roughness of the surface can decrease the sensitivity and also interfere with the powder patterns.

The powder may be either wet or dry. The dry particles are dusted over the weld surface with a spray. It is particularly essential that the particles should be evenly spread over the surface. The wet particles may be suspended in oil, water or paraffin. The wet particles may be sprayed onto the surface or the job may be dipped in the liquid.

Alternating or direct current may be used for magnetisation. Direct current is generally more suitable since it gives greater penetration of the metal being tested. Alternating current is suitable for detecting surface defects.

This type of inspection equipment will detect not only cracks, but also inclusions, porosity lack of fusion and other defects. It may be used in the workshop, on site or in the laboratory. The equipment needed is relatively simple and is not costly. The use of this method of inspection requires some training in the recognition of the patterns produced by certain defects and it is not within the scope of this book to deal with these.

#### PENETRANT INK

This method of inspection is used to detect surface cracks and porosity. It is of particular use on non-magnetic metals where magnetic particle inspection cannot be used.

The method of penetrant dye inspection is carried out in three operations. Firstly, the weld is sprayed (usually pressurised containers are supplied) to remove any oil or grease that may be present on the weld surface. Secondly, the part is sprayed with the dye penetrant. The dye will penetrate into all surface cracks and small holes. Any excess dye is removed from the surface by wiping with a clean cloth. Thirdly, a developer is sprayed onto the surface. This is usually white in colour and is quick drying. The dye will show up on this last substance and any surface defects are clearly seen.

#### PENETRANT FLUORESCENT

This method of inspection is similar in principle to the penetrant ink process except that the dye used is of a very high penetrating

quality and it fluoresces brilliantly when exposed to ultraviolet or black light.

The weld surface is coated with the penetrant either by brushing or spraying, although smaller items may be completely immersed in the fluid. The penetrant has a very low surface tension and by reason of this it is readily able to be drawn into minute surface cracks by capillary action.

The penetrant is washed from the job when penetration is complete. This may be several minutes or even some hours after spraying. Water is used for the washing process and solvents should not be used.

After washing, the part must be dried. Hot air or clean dry air may be used. A developer, either wet or dry, is next applied and the article is placed under a black light, where the imperfections will show up as lines of brilliant colour.

The disadvantage of this method of weld inspection is the need to exclude all daylight and white artificial light whilst the ultraviolet light is being used. For small work this may not be so great a problem because a dark room may be used, but for large fabrications and site work the exclusion of light may present a problem.

#### ULTRASONIC TESTING

The word ultra means "beyond the reasonable" and the word sonic means "sound". The word ultrasonic therefore means "sound beyond the range of the human ear". In ultrasonic testing a sound wave is used to detect imperfections in the weld. The frequencies used are high and beyond human hearing.

The waves are reproduced in the metal under inspection and any faults will reflect the waves to a greater or lesser degree. These signals are shown on a cathode-ray tube. The interpretation of these signals requires a high degree of skill. For this and other reasons (e.g. sensitivity under practical conditions) this method of weld inspection is not so widely used as it might be.

#### RADIOGRAPHIC INSPECTION

Radiographic inspection is carried out using gamma-rays or

**X-rays.** These short wavelength radiations are able to penetrate objects that are not transparent.

Depending upon the density and the thickness of the weld, some of the waves will penetrate whilst other will be absorbed. Should the weld contain an imperfection, such as a blowhole, the radiation beam will have less metal to pass through, because the blowhole is, of course, a void containing no metal, perhaps only gas. The absorption of the rays will vary and if this is measured on a film the image produced contains a shadow, indicating a defect. The shadow film is known as a radiograph. Here again, the interpretation of a radiograph calls for skill and training.

The presence of slag, porosity, cracks and surface defects can be discovered by radiograph as also can incomplete penetration and incomplete fusion of the weld metal with the base metal.

Two sources of radiation are used, X-rays and gamma-rays. The merits of both are not easy to compare, as both have their advantages and disadvantages.

X-rays are obtained from a tube, in which are two elements, one called the cathode and the other the anode. When the cathode is heated electrons are emitted, which bridge the gap between the cathode and the anode and as a result of this X-rays are given off. Gamma-rays are the result of atomic sources of radiation, known as *radioisotopes* and may be cobalt, iridium or caesium. The isotopes are sealed in containers, which are of small diameter. The longer they are the more energy they contain. The wavelengths from gamma-rays are shorter than those from X-rays which means that gamma-rays can penetrate thicker metals.

## CHAPTER 5

### Related Studies

#### Metals and Alloys Commonly Welded

##### *Aluminium*

A non-ferrous metal.

Melting point: 658°C.

Specific gravity: 2.56.

Density approximately 0.1 lb per cubic inch.

Brinell hardness figure: 37.

Tensile strength: 7-15 tons per square inch.

Specific heat: 0.215.

Thermal conductivity figure: 62 (copper as 100).

Electrical conductivity figure: 56 (copper as 100).

Annealing temperature: 350°C.

Aluminium has a silvery-white appearance, but when exposed to the atmosphere it becomes dull grey in colour. It is extremely malleable and ductile and its weight is about one-third that of steel. Pure aluminium is a good conductor of electricity and is used for electrical wiring. It is non-magnetic and as such is invaluable for protecting certain instruments.

Aluminium has a great affinity for oxygen and care must be taken when welding; when gas welding a flux must be used, and when electric welding the gas-shielded-arc process should be employed. Under heating, aluminium does not at any time change colour so that care must be taken when annealing.

Because of its great affinity for oxygen the surface of aluminium



is always covered with a film of oxide. This gives the metal complete immunity from corrosive attack from the atmosphere.

### *Copper*

A non-ferrous metal.

Melting point: 1080°C.

Specific gravity: 8.95.

Density approximately 0.31 lb per cubic inch.

Brinell hardness figure: annealed 45–55, cast 40–45, cold worked: 80–100.

Tensile strength: 10–14 tons per square inch.

Specific heat: 0.094.

Thermal conductivity figure: 100 (using copper as reference).

Electrical conductivity figure: 100 (using copper as reference).

Annealing temperature: 500°C.

Copper is the only metal that is reddish in colour. It is extremely malleable and ductile and is an excellent conductor of both heat and electricity.

When in contact with the atmosphere a green compound forms on the surface, which protects the metal beneath and so prevents further corrosion.

The only grade of copper suitable for welding is the phosphorous deoxidised type and welding may be carried out either by gas, electric arc or the gas-shielded-arc processes.

Overheating of copper must be avoided for when overheating does occur, the metal absorbs oxygen and becomes brittle, giving rise to cracking.

### *Brass*

A non-ferrous alloy.

Melting point: 875–1045°C.

Specific gravity: varies with the composition.

Density: varies with the composition.

Brinell hardness figure: 60–200.

Tensile strength: varies greatly, between 20 and 35 tons per square inch.

Specific heat: varies with the composition.

Thermal conductivity figure: varies with the composition.

Electrical conductivity figure: 10-50 (copper as 100).

Brass is a copper-zinc alloy (of which there are many types), approximate proportions being 2 or 3 copper to 1 zinc. These alloys show great resistance to corrosion, both atmospheric and marine. Welding of these alloys may be carried out using the gas, electric arc and gas-shielded-arc processes.

### *Stainless steel*

A ferrous metal.

Melting point: 1440°C.

Specific gravity: varies with the composition.

Density: varies with the composition.

Brinell hardness figure: 170-210.

Tensile strength: 35-50 tons per square inch.

Specific heat: 0.117.

Thermal conductivity figure: 36 (copper as 100).

Electrical conductivity figure: 13.17 (copper as 100).

Carbon content: minimum 0.06% to maximum 0.35%.

Stainless steel is an alloy containing nickel, chromium and iron and it has great corrosion-resistant properties. So far as welding is concerned, the types of stainless steels considered most suitable for welding come under the heading of austenitic stainless steels.

Welding may be carried out either by the gas, electric arc or gas-shielded-arc processes.

### *Mild Steel*

A ferrous metal.

Melting point: 1450-1500°C.

Specific gravity: 7.8.

Density: 0.28 lb per cubic inch.

Brinell hardness figure: 125-170.

Tensile strength: 25–34 tons per square inch.

Specific heat: 0.115.

Thermal conductivity figure: 13–17 (copper as 100).

Electrical conductivity figure: 13–17 (copper as 100).

Annealing temperature: 900°C.

Carbon content up to 0.25%.

Mild steel is a carbon steel containing iron, carbon, silicon, manganese, sulphur and phosphorus. It is the most widely used of all metals and welding plays a very important part in its use. It is true to say that a number of the intricate, mild steel, fabricated shapes of today would not be possible without welding.

If mild steel can be said to have a disadvantage, as far as general work is concerned, it is its extreme vulnerability to corrosive attack from the atmosphere. Evidence of this can be seen in the rust on vehicle bodies, ships, bridges and other structural steel work.

Rolled mild steel is not very ductile or malleable when compared with aluminium, but nevertheless it can be rolled and pressed into many intricate shapes. Typical analysis of a mild steel is: carbon 0.15%, silicon 0.03%, sulphur 0.05%, phosphorus 0.05%, manganese 0.5%, remainder iron.

### *Medium Carbon Steel*

This carbon steel has all the same characteristics as mild steel with the exception of tensile strength, which increases to 40 tons per square inch. Also, due to an increase in the carbon content (maximum of 0.6%), the hardness is increased. This alloy is not as widely used for welded fabrications as is mild steel.

### *Cast Iron*

A ferrous metal.

Melting point: 1150°C.

Specific gravity: 7.8.

Density: 0.28 lb per cubic inch.

Brinell hardness figure: 400–500.  
Tensile strength: 6–14 tons per square inch.  
Specific heat: 0.13.  
Thermal conductivity figure: 17 (copper as 100).  
Electrical conductivity figure: 17 (copper as 100).  
Carbon content: 2.5–4.0%.  
Annealing temperature: 900°C.

The composition of cast iron is carbon, silicon, sulphur, phosphorus, manganese and iron. It is quite unlike steel in that it is brittle and weak. It cannot be worked into shapes but can only be cast into moulds of the shapes required. The majority of welding operations that are necessary on cast iron are usually to repair broken or cracked castings.

### **Mechanical Properties of Metals**

The mechanical properties of metals can be determined by subjecting them to certain mechanical tests. These tests include hammering, pulling and stretching. It is the amount of hammering and pulling, etc., that the metal can stand, without breaking, that determines some of its mechanical properties.

It is difficult to obtain excellent mechanical properties all in one metal; for example, whilst aluminium has excellent malleability (i.e. it can be formed into shape quite easily, it unfortunately has a low tensile strength (i.e. it cannot withstand a great pulling load). Whilst, on the other hand mild steel has a good tensile property, but low malleability.

Machines are used to test the mechanical properties of metals. Probably the most widely used of these is the tensile testing machine. This machine also tells us certain other properties possessed by the metal under test.

Welded joints and also pure weld metal have to undergo tests to check their mechanical properties. It would be quite wrong to weld a material of 30 tons/square inch tensile with an electrode of lower tensile strength. A certain welded fabrication may have to withstand a certain tensile load during service. To ensure that it

will meet these conditions, weld specimens are made from the material and tensile and other tests are carried out on the specimens.

### *Malleability*

This is the property possessed by a metal to enable it to withstand hammering without showing signs of cracking or fracture.

Gold is the most malleable of metals as it may be beaten into gold leaf less than one ten-thousandth of an inch thick.

Aluminium also has very malleable properties. It may be annealed and quenched in water immediately, without affecting the softness which enables the metal to be hollowed and raised with comparative ease. Copper is also a very malleable metal which may also be annealed, quenched in water and hollowed and raised with the same ease as aluminium.

Both aluminium and copper are, however, prone to work-hardening caused by hammering. They both require frequent annealing.

Iron, compared with aluminium, is not a very malleable metal, but at high temperatures it does become malleable. On cooling, however, its malleability is much less. It also workhardens with constant hammering when the metal is cold.

### ORDER OF MALLEABILITY (Table RS1)

- |              |         |
|--------------|---------|
| 1. Gold      | 4. Lead |
| 2. Aluminium | 5. Zinc |
| 3. Copper    | 6. Iron |

### *Tenacity*

This is the property possessed by a metal to enable it to withstand a pulling force. The ultimate tensile strength of a metal is a measure of the force which breaks the metal under a pulling load.

Tensile strength or tenacity in a metal is a most desirable quality, particularly if the metal is to be used for fabrication purposes. This is because it is the chief property of a metal which

resists distortion or deformation. Such fabrications as pressure vessels, structures, boilers, heavy earth-moving equipment, etc., which undergo tensile or tearing stresses, need to be constructed from metals that possess desirable tensile strength.

To test the tensile strength of a metal, a specimen of the metal (Fig. I.57 (a)) is placed in a tensile strength testing machine. The specimen must be of a uniform nature and the diameter must be accurately measured to give the cross sectional area. The specimen is clamped into the jaws of the machine with one jaw fixed and the other moveable. A pulling load is applied to the specimen. This load is increased gradually and at a certain point the specimen will break. The point at which it breaks is known as the ultimate tensile strength (U.T.S.) of the metal. The tensile test also reveals other properties possessed by the metal.

Let us now consider the tensile testing of a piece of mild steel.

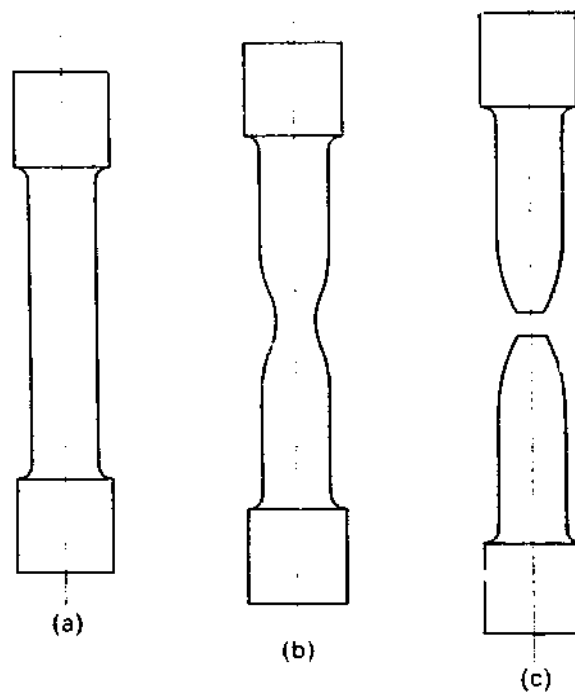


FIG. I.57. Tensile test specimen. (a) Specimen before load. (b) Load applied and as it is increased a "waist" appears. (c) Specimen finally breaks.

The specimen is fixed to the machine and a tensile load is applied. At first the specimen increases in length only very slightly. This increase in length is proportional to the load being applied and it is a measure of the *elasticity* of the metal. The specimen, whilst in this range, would return to its original length. The metal now yields to the pulling force, and it stretches much more rapidly for a smaller increase in load. The specimen now begins to change shape; a "waist" is formed (Fig. I.57 (b)) and the metal finally breaks (Fig. I.57 (c)). From the broken test piece the amount of elongation may be measured. This amount of elongation is a measure of the metal's ductility. The amount the metal has reduced in area, from the original area, may also be measured.

APPROXIMATE TENSILE STRENGTHS (in tons per square inch)  
(Table RS2)

- |                 |                         |
|-----------------|-------------------------|
| 1. Iron: 32     | 4. Zinc: 3              |
| 2. Copper: 18   | 5. Lead: $1\frac{1}{2}$ |
| 3. Aluminium: 8 |                         |

*Ductility*

This is the property possessed by a metal which enables it to be stretched or drawn into wire without breaking.

Metals that are to be drawn out into wire are pulled through a succession of dies, each one smaller than the previous one. During the drawing process, which is usually carried out with the metal at normal room temperatures, the metal becomes hard and brittle and it is usually annealed when the correct wire diameter is reached.

A metal that has good ductile properties may be bent and twisted. If the amount of bending is to be severe then the metal must be sufficiently ductile to allow for stretching at the outside of the bend.

ORDER OF DUCTILITY (Table RS3)

- |              |         |
|--------------|---------|
| 1. Aluminium | 4. Zinc |
| 2. Iron      | 5. Lead |
| 3. Copper    |         |

*Hardness*

This is the property possessed by a metal which enables it to withstand wear and abrasion.

The amount of hardness may be measured by various methods, all of which use the principle that the surface of the metal offers resistance to indentation.

The "Brinell" test uses a steel ball of 10 mm diameter placed under a load of 3000 kg. The metal under test is placed under the steel ball and the indentation formed is measured under a microscope. The Brinell hardness number is then calculated by dividing the applied load by the area of the indentation.

$$\text{Brinell hardness number} = \frac{\text{Load in kg}}{\text{Area of indentation in mm}^2}$$

The Brinell test is inaccurate when testing very hard metals. This is due to the deformation of the steel ball when in contact with the harder metal.

The "Rockwell" test and the "Vickers" test use a diamond-tipped cone instead of a steel ball.

*Brittleness*

This is the property possessed by a metal which will render it liable to easy breaking.

Metals that are brittle have little or no plasticity and, when broken, no appreciable amount of deformation is apparent. Cast metals are very brittle and, when placed under impact, they break very easily. Cast iron is an example of this, although some types are less brittle than others.

*Plasticity*

This is the property possessed by a metal which enables it to be worked into shapes without showing signs of fracture.

If a metal is to be used for deep pressings it is essential that it possesses good plasticity; if not, it will be liable to tearing, particularly at the bottom of the shape. Some metals may show an increase



in plasticity when heated, but some may also show a decrease, rendering them brittle.

### The Structure of Metals

Metals are crystalline, being composed of crystals which form during the change from the molten to the solid state. This structure can be seen on an etched specimen under the microscope and, as each metallic structure is different, the various metals can easily be identified. Figure I.58 (a) shows three common examples. The flat face of the specimen shows only a section across the crystals and it should be appreciated that a crystal is a three-dimensional solid.

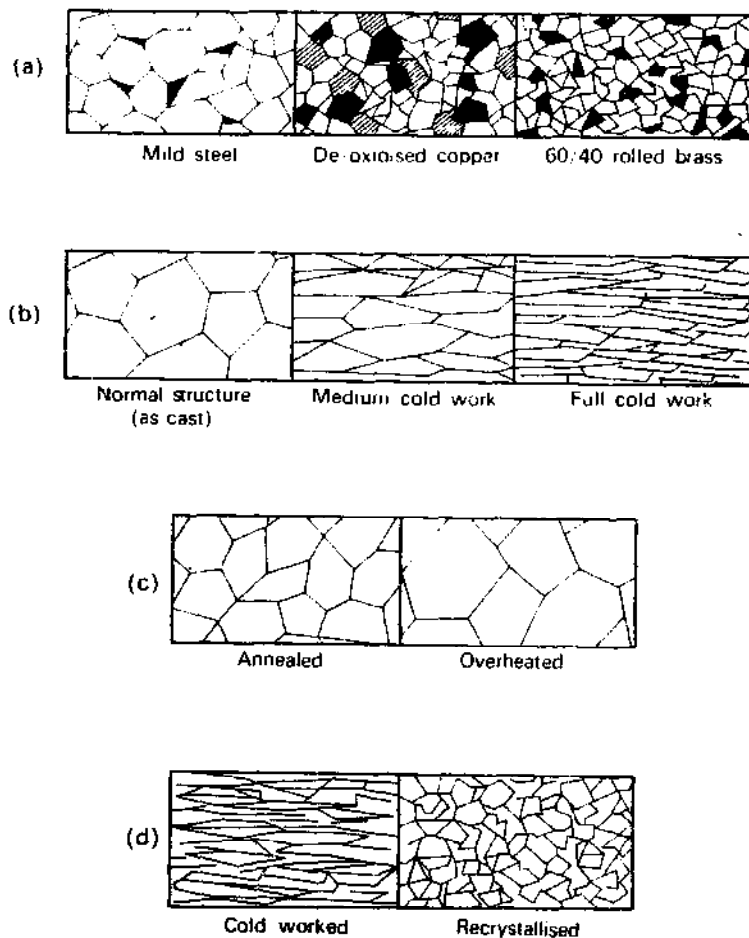


FIG. I.58.

The crystal boundaries are simply the extent of the growth of adjoining crystals, which takes place during solidification, and do not represent "joints" between a series of separate units. This is indicated by the fact that when a metal breaks the fracture often occurs *through* the crystals rather than along the boundary lines.

The application of force or heat can cause a change in the physical shape of the crystal. For example, "cold work" (rolling, forging or drawing) on the metal will result in "workhardening" and this is indicated by the deformed structure shown in Fig. I.58 (b).

Workhardening gives an increase in hardness and tensile strength and a reduction in softness and ductility, which are not desirable qualities in a metal which is to be subjected to further stresses.

Hot working at the correct temperature will allow the normal structure to be retained.

If a workhardened metal is heated to its recrystallisation temperature the deformed crystals start to re-form into new crystals of the normal shape, but smaller size (Fig. I.58 (d)).

This process is known as annealing and reduces hardness and tensile strength, giving an increase in softness and ductility.

If the annealing is carried out at too high a temperature, or over too long a period of time, the crystals will start to increase in size above normal. This is known as "grain-growth", which reduces the strength of the metal (Fig. I.58 (c)).

During cold-working processes, intermittent annealing will allow a great deal of cold work to be carried out whilst retaining the normal grain structure.

### **The State and Structure of Matter**

All matter falls into one of three groups: solid, liquid or gas. A *solid* has a definite shape which can only be altered by the use of force (cutting, pressing). A *liquid* has an indefinite shape which changes easily under the influence of its own weight or atmospheric pressure. Liquids possess surface tension which causes the body of the liquid to be slightly constricted by the pull exerted on it by the

surface of the liquid. In the absence of other influences small quantities of a liquid will always form round drops as the sphere has the smallest surface area of any shape of given volume. Some liquids are able to dissolve solids and gases and are called solvents. Many of them mix freely with each other, although there are exceptions. They are only slightly compressible, i.e. their bulk is only slightly reduced when high pressures are applied. A *gas* is composed of widely separated particles of matter and when not confined in a container will move freely and easily through the air, mixing with it, or diffusing. Gases can be absorbed by some solids and they can sometimes be dissolved in liquids and held in solution. They are highly compressible, i.e. may be squeezed into a smaller volume by the application of pressure. If sufficient pressure is exerted the gas will change into a liquid, or liquefy. When the pressure is released the liquid evaporates or reverts back into a gas.

Under most conditions these substances expand when heated and contract when cooled.

### *Changes of State*

Some substances are commonly seen in two or three different states, e.g. water changes easily to ice or steam with variations in temperature. Metals are altered from solid to liquid by the application of heat and when the molten metal cools the solidification, or freezing, which occurs is the same process as water turning to ice. Metals under extremely high pressure will flow in a similar manner to a liquid. Therefore the physical state of a substance is not permanently fixed, but is dependent on conditions such as temperature and pressure and any change of state is known as a "physical change".

The properties of a substance are determined by its chemical composition and, although it may undergo a physical change, its chemical composition may remain the same, e.g. if pure water is cooled to freezing point the ice formed is still a compound of hydrogen and oxygen; if the ice is melted, the water evaporated and the resulting steam condensed, the final substance will still have the same chemical composition. Similarly, iron whether molten or

solid is unchanged chemically, oxygen as a gas or a liquid is the same substance. *Physical change* does not necessarily involve any alteration in chemical structure.

### *The Structure of Matter*

The smallest natural particle of any substance is known as an atom and when two or more atoms join together a molecule is produced. Many pure substances can exist naturally as separate atoms, but some, particularly amongst the gases, prefer to remain as pairs (or molecules), e.g. hydrogen (H<sub>2</sub>), oxygen (O<sub>2</sub>).

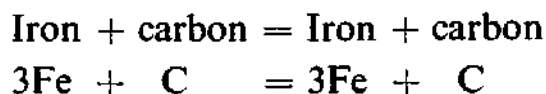
All the pure substances, i.e. those which cannot be further divided into other simpler substances, are known as "elements" and in addition to their chemical name they are given a symbol, e.g. iron, chemical symbol = Fe; carbon = C; oxygen = O.

### MIXTURES

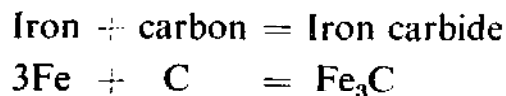
The mixing together of elements does not always result in the formation of new substances, e.g. if iron filings, Fe, and powdered carbon, C, are intimately mixed they can be easily separated by means of a magnet giving the two original substances which are unchanged. This is known as a "mixture".

### COMPOUNDS

If the iron and carbon are again mixed and then heated to melting point it will be found on cooling that some of the carbon will have combined with the iron producing a different, extremely hard substance known as iron carbide (or cementite). This is a chemical compound of iron and carbon and here a portion of the two ingredients has been converted into a different substance. In the mixture the position would be:



whereas in the compound the result would be:



So compounds are chemical combinations of elements producing substances which differ considerably from the original elements. A further example is provided by the two gases hydrogen, H, and oxygen, O, which, when chemically combined in the correct proportions, form a liquid, water, H<sub>2</sub>O. This actually occurs in the gas welding flame and water vapour is given off.

#### CHEMICAL CHANGE

When chemical action takes place with the formation of different substances this is known as a "chemical change".

Not all elements will combine readily to form new substances, but many form compounds quite easily. One of the most important in welding is oxygen, for it is very active, readily forming oxides with the common metals, especially when they are heated. This is possible when the hot metal is in contact with air, as one-fifth of the atmosphere is oxygen.

The oxygen cutting of steel is essentially a chemical process depending on the provision of sufficient oxygen to oxidise the metal.

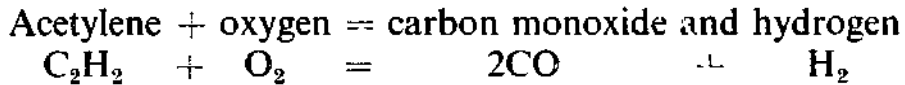
Large quantities of oxygen are necessary for the combustion taking place in the welding flame.

The oxidation of a substance is the chemical combination of oxygen with that substance. If the oxygen can be chemically removed from the oxide the result will be the original substance. This process of de-oxidation, or oxygen removal, is known as "reduction". Substances which act as reducing agents include carbon, hydrogen and carbon monoxide. The oxy-acetylene flame is a "reducing flame", because it consumes large quantities of oxygen, taking some of it from the atmosphere, so that in the area covered by a neutral flame there is no free oxygen available to form oxides with the metal.

THE STRUCTURE OF THE OXY-ACETYLENE FLAME (Fig. I.59).

At the tip of the nozzle in the greenish cone burn equal volumes of acetylene,  $C_2H_2$ , and oxygen, producing carbon monoxide,  $CO$ , and hydrogen. These two gases then burn in the inner envelope with the help of oxygen taken from the air to give the final products of combustion, carbon dioxide,  $CO_2$ , and water vapour. In the outer envelope lies the "reducing zone" where combustion is completed with the atmospheric oxygen.

The chemistry of the combustion is:



Then:

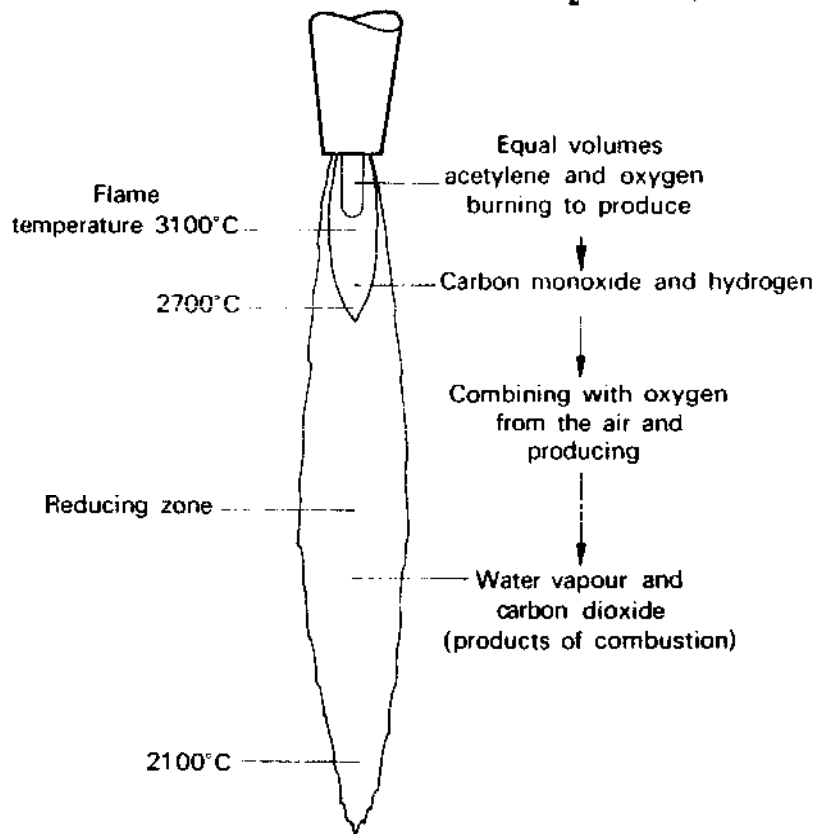
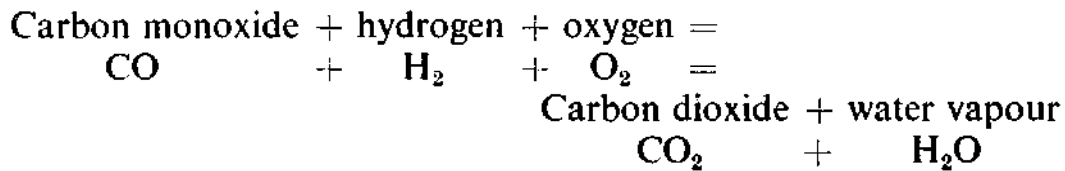


FIG. I.59. Structure of oxy-acetylene flame.

## APPENDIX 1

# Glossary of Welding and General Terms and Abbreviations

### WELDING

**Arc voltage.** The voltage between the electrode and the workpiece.

**Automatic arc welding.** Any welding process whereby the welding wire is automatically fed into the weld and the welding head is completely free from manual control.

**Axis of weld.** Central straight line between the two ends of the weld.

**Base metal.** The metal being welded.


**Butt weld.** A weld joining two pieces of metal, both pieces being in the same plane.


**Chamfer.** The edge of a plate shaped off to form an angle other than a right angle.

**Concave fillet.** A fillet weld with an inward curve.

**Convex fillet.** A fillet weld with an outward curve.

**Deposited metal.** The actual metal deposited by the filler rod or electrode.

**Double "U" preparation.** The edges of the parent metal shaped so that when two edges are brought together  is formed.

**Double vee.** The edges of the parent metal shaped so that when two edges are brought together  is formed.

**Downhand weld.** Weld made in a flat, gravity position.

**Edge preparation.** The shaping of the edges of the parent metal prior to welding.

**Face bend.** Bend test with the face of the weld on the outside of the bend and in tension.

**Filler rod.** Wire or rod added to the weld pool to produce reinforcement.

**Fusion welding.** Welding joint made between metals which are in a molten state without the application of pressure.

## APPENDIX 1

- Fusion zone.** That part of the parent metal which is melted into the weld metal.
- Gapping.** Setting up of plates with a gap between the joint edges.
- Gas-shielded-arc welding.** A process of arc welding whereby a gaseous shield surrounds the molten weld pool.
- Heat-affected zone.** A zone surrounding the weld and the fused metal that is not part of the fused metal.
- Inside corner fillet.** As for an outside corner, but the weld is on the inside of the corner.
- Leading angle.** Inclination of filler rod or blowpipe to the axis of the weld.
- Leg length.** The size of a fillet weld measured across the bottom of the weld and up the side of the weld.
- Longitudinal crack.** A crack in the weld metal extending along the length of the weld.
- Manual welding.** Welding in which the operator is completely responsible for the weld deposition and the means of making the weld is held in the hand.
- Open circuit voltage.** The voltage from or in the welding plant.
- Outside corner fillet.** A weld joining two pieces of metal, in which the inside edge of one piece of the metal is in line with the inside edge of the other, usually at right angles. Welded on the outside of the corner.
- Parent metal.** The metal being welded.
- Parent plate.** The metal being welded.
- Penetration.** The amount of weld metal actually entering the parent metal.
- Pick-up.** Area of interfusion when restarting an interrupted weld run.
- Piping.** Elongated holes in the weld metal caused by the entrapment of gas.
- Plate.** A flat sheet of metal of more than  $\frac{1}{8}$  in. thickness.
- Plug weld.** A weld made through a hole in one component of the workpiece, enabling both components to be joined by filling the hole completely with weld metal.
- Porosity.** Holes in the weld metal caused by the entrapment of gas.
- Preheat.** Heat applied before welding starts.
- Profile.** Outline of weld as seen in section.
- Reinforcement.** The amount of weld metal above the thickness of the parent plates in a butt weld.
- Resistance welding.** Welding carried out under pressure applied to the surfaces in contact, whilst the heat for welding is produced by the passage of an electric current through the surfaces of the metals.
- Root bend.** Bend test with the root of the weld on the outside of the bend and in tension.
- Root concavity.** A shallow groove along the underside of a butt weld.



- Seam welding.** Resistance welding in which the force is applied by wheels and the workpiece is fed between the wheels, which are the electrodes.
- Semi-automatic arc welding.** Any welding process whereby the welding wire is automatically fed into the weld through a gun-type head that is manually controlled.
- Sheet metal welding.** The welding of metal less than  $\frac{1}{8}$  in. thick.
- Single vee.** The edges of the parent metal shaped so that when two edges are brought together a V is formed.
- Slag inclusion.** An entrapment of slag or other foreign matter actually inside the weld metal.
- Spot welding.** Resistance welding in which the force is applied by round bars which are the electrodes.
- Stop and start.** Point at which weld is stopped and restarted during an interrupted run.
- Stove-pipe welding.** A manual arc welding technique for the welding of pipes.
- Submerged arc welding.** A process of arc welding whereby the arc is hidden in a granulated flux, the wire being bare and the flux poured over the arc.
- Tack.** Small temporary weld.
- Tee fillet.** A weld joining two pieces of metal (usually both pieces are at right angles to each other) forming a "T" shape.
- Through penetration.** The amount of weld metal penetrating through to the underside of a butt weld.
- Transverse crack.** A crack in the weld metal across the weld.
- "U" Preparation.** The edges of the parent metal shaped so that when two edges are brought together U is formed.
- Undercutting.** A burning into the parent plate at the weld edges, thereby making the parent metal under thickness.
- Weldment.** Two or more plates joined by welding.
- Weld spatter.** Globules of metal expelled from an electrode and deposited on the surface of the parent plate.
- Weld zone.** The zone containing the weld metal and the heat-affected zone.

#### GENERAL

a.c.	alternating current
alignment	line up of workpieces
alloy	a mixture of metals
ancillary	extra or auxiliary
austenitic	consisting of a solid solution of carbon in iron
Bourdon tube	curved metal tube used in pressure-measurement equipment

## APPENDIX 1

B.S.	British Standard
B.S.P. thread	British Standard Pipe thread
°C	Centigrade scale
calorific value	measurement indicating the amount of heat produced when a specified quantity of a substance is burned
carbon fences	support blocks for molten metal
carboy	large glass bottle with protecting frame
coal gas	town gas
combustion	burning
concave	curving inwards
convex	curving outwards
crater	depressed cavity
cylinder manifold	two or more gas cylinders connected together to give a common supply
d	diameter
D.A.	dissolved acetylene
d.c.	direct current
diaphragm	flexible disc
diffused	intermingled or mixed
drag lines	near-vertical lines produced by oxygen stream on cut edges during oxy-fuel gas cutting
E.A.	electric arc
electrons	electrically charged sub-atomic particles
elongation	lengthening
etch	to cut into the surface
°F	Fahrenheit scale
F.B.	flat bar
ferrous	containing iron
fluorescent	capable of glowing under the action of light
ft, ft <sup>3</sup>	feet, cubic feet
fuse	melt
galvanised	zinc coated
grain growth	enlargement of grain size in metals
G.W.F.	gas welding filter
hardsoldering	soldering with copper/zinc and copper/silver alloys, as in bronze welding, brazing and silver soldering
H.M.S.O.	Her Majesty's Stationery Office
hose coupler	connector for the jointing of rubber hose
hose protector	valve inserted in hose to prevent the reverse flow of gas
h.p.	high pressure
i.d.	inside diameter
in., in <sup>2</sup>	inches, square inches
included angle	angle between two joint faces
inflammable	easily set on fire

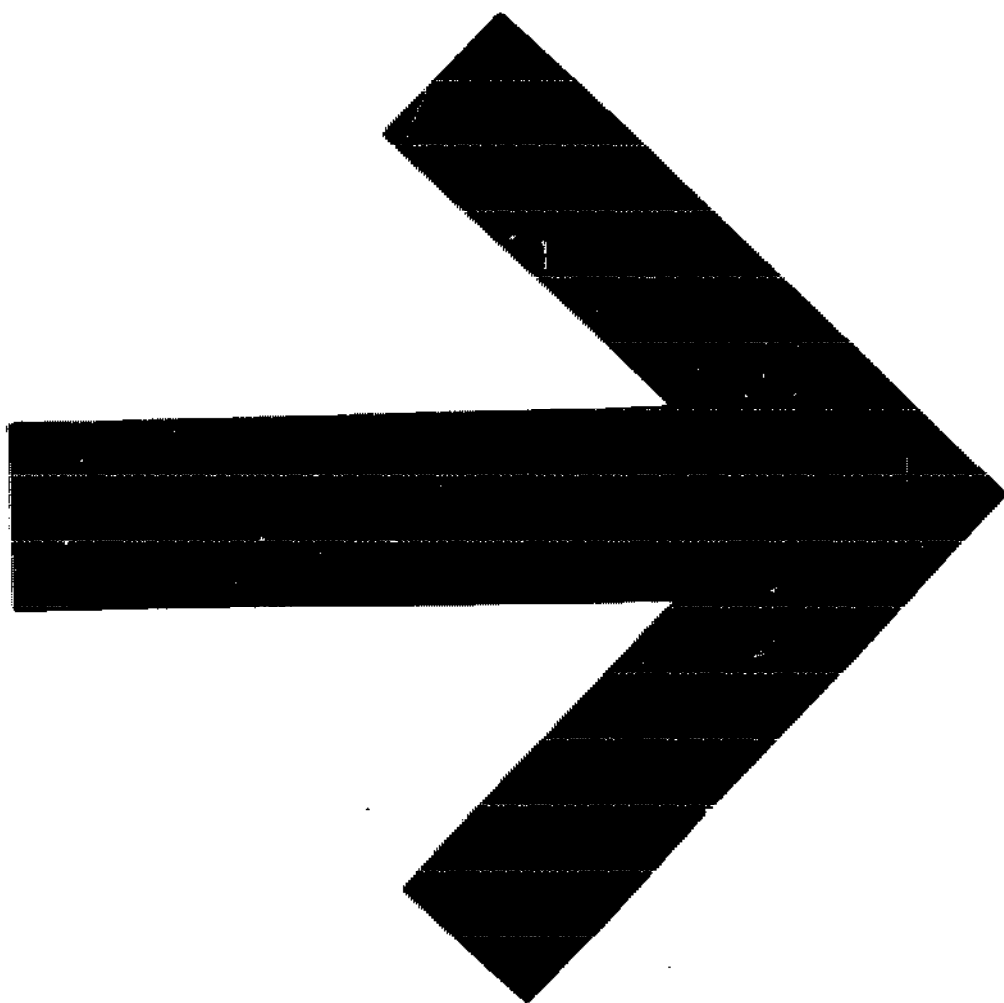
invert	turn upside down
lb	pounds
liquefaction	change into liquid state
l.p.	low pressure
m.a.	metal arc
manipulation	skilful movement
modular	round
multi-stage	consisting of more than one stage
nominal size	approximate measurement
non-ferrous	not containing iron
O.A.	oxy-acetylene
o.d.	outside diameter
optimum	most satisfactory
orifice	hole, aperture
overmaking	gas generated in excess of requirements
oxy-fuel gas	mixture of oxygen and a fuel gas
oxygen-enriched	having a higher than normal oxygen content
peening	dressing with a hammer
plate	metal above $\frac{1}{8}$ in. thick, metal below this thickness is known as "sheet"
positional	in any position other than downhand
prefix	to put in front of
propane	liquefied petroleum gas
protected hose	fitted with hose protector
r	radius
restrain	hold firmly in place
shim	thin metal sheet used as an insert between two surfaces
S.H.W.	safety and health in welding
spheroidal	shaped like a sphere
static installation	equipment permanently fixed in a work place
suffix	letter or syllable appended to a word
t	thickness
technique	manner of execution
thermal movement	expansion and contraction due to changes in temperature
toxic	poisonous
u.t.s.	ultimate tensile strength
velocities	speeds
visual examination	inspection by eye
volatile	evaporating quickly
weave	blowpipe movement across the joint
wt.	weight
yd	yards

## APPENDIX 2

### Revision Questions

#### Welding Technology (Oxy-Acetylene)

1. Describe with the aid of sketches the "leftward" technique of oxy-gas welding.
2. Sketch the correct preparations to be used when making the following mild steel joints by the oxy-acetylene process:  $\frac{1}{8}$ -in. close corner downhand;  $\frac{1}{8}$ -in. lapped fillet H.V.;  $\frac{3}{16}$ -in. butt D.H.;  $\frac{3}{16}$ -in. open corner V;  $\frac{1}{4}$ -in. butt R.W.D.H.
3. List and explain ten safety precautions applicable to oxy-gas welding processes.
4. Sketch and describe the following butt-weld faults: lack of penetration; misalignment of plates; undercut; excessive reinforcement; porosity. Explain how each may arise and how they may be prevented.
5. Explain in detail the oxy-acetylene gas cutting process and give typical applications for hand and machine cutting.
6. Discuss the main safety precautions to be observed when welding in confined spaces.
7. Explain the problems to be overcome in the gas welding of cast iron and show by means of sketches the correct technique for this process.
8. Discuss the following methods of weld testing: non-destructive; destructive. Explain the uses of each method.
9. List the component parts of a low-pressure oxy-acetylene welding system and sketch a typical layout.
10. Explain with the aid of sketches the following welding terms: weld face; root face; fusion face; fusion depth; toe; heel; leg length; root.



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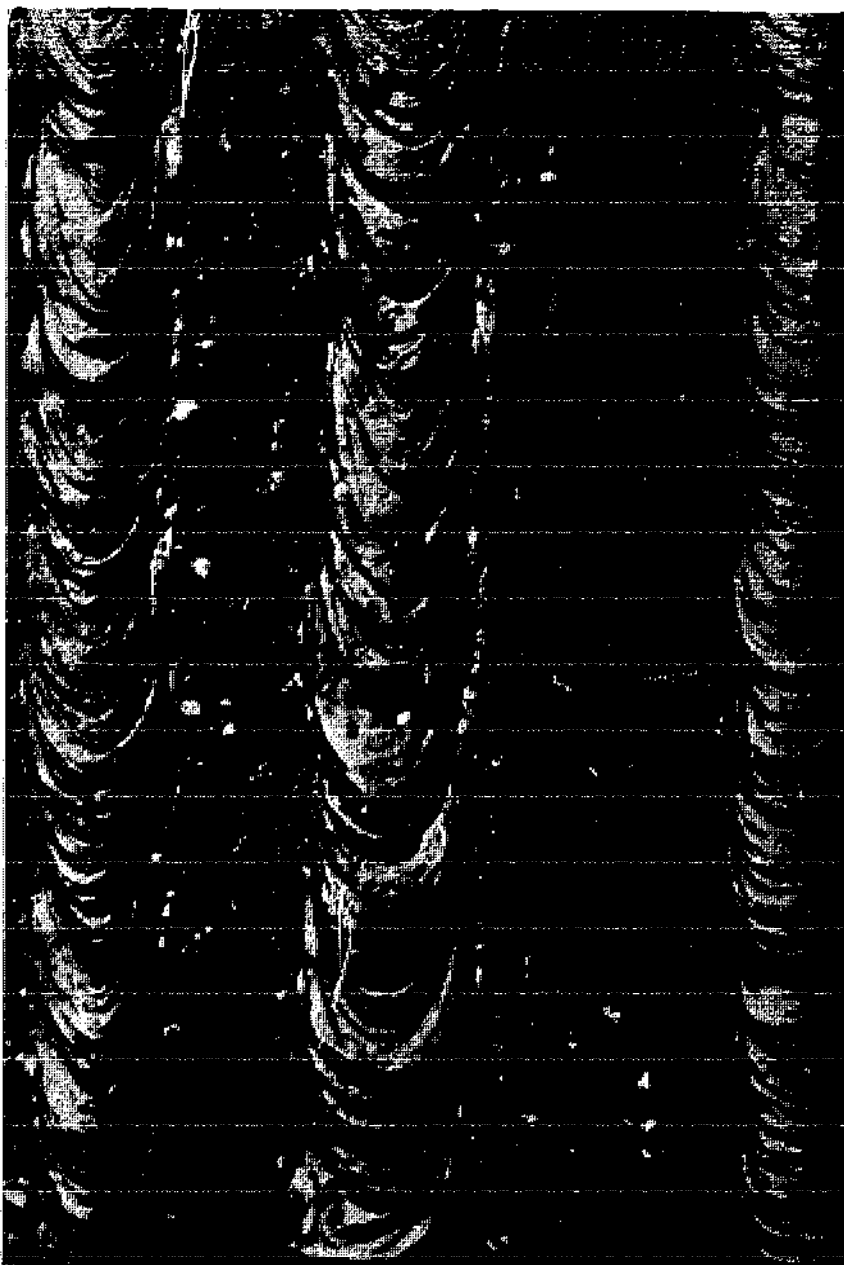
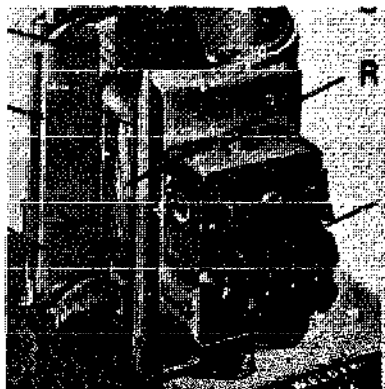
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# Part 1, Volume 2: Electric Arc Welding and Related Studies

**N. Parkin and C.R. Flood**



## **A. Electric Arc Welding**

Plant, Procedure and Equipment  
Method  
Special Techniques

## **B. Related Studies**

Heat and Temperature  
Elementary Electricity  
Engineering Drawing  
Mathematics

**N. Parkin**, M.I.P., M.R.S.H., M.R.P.A., is  
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ENGINEERING DIVISION

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## **WELDING CRAFT PRACTICE *PART 1***

*VOLUME 2: Electric Arc Welding and  
Related Studies*



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*VOLUME 2: Electric Arc Welding and  
Related Studies*

BY

**N. PARKIN, M.I.P., M.R.S.H., M.R.P.A.**  
*Lecturer in Welding and Plumbing  
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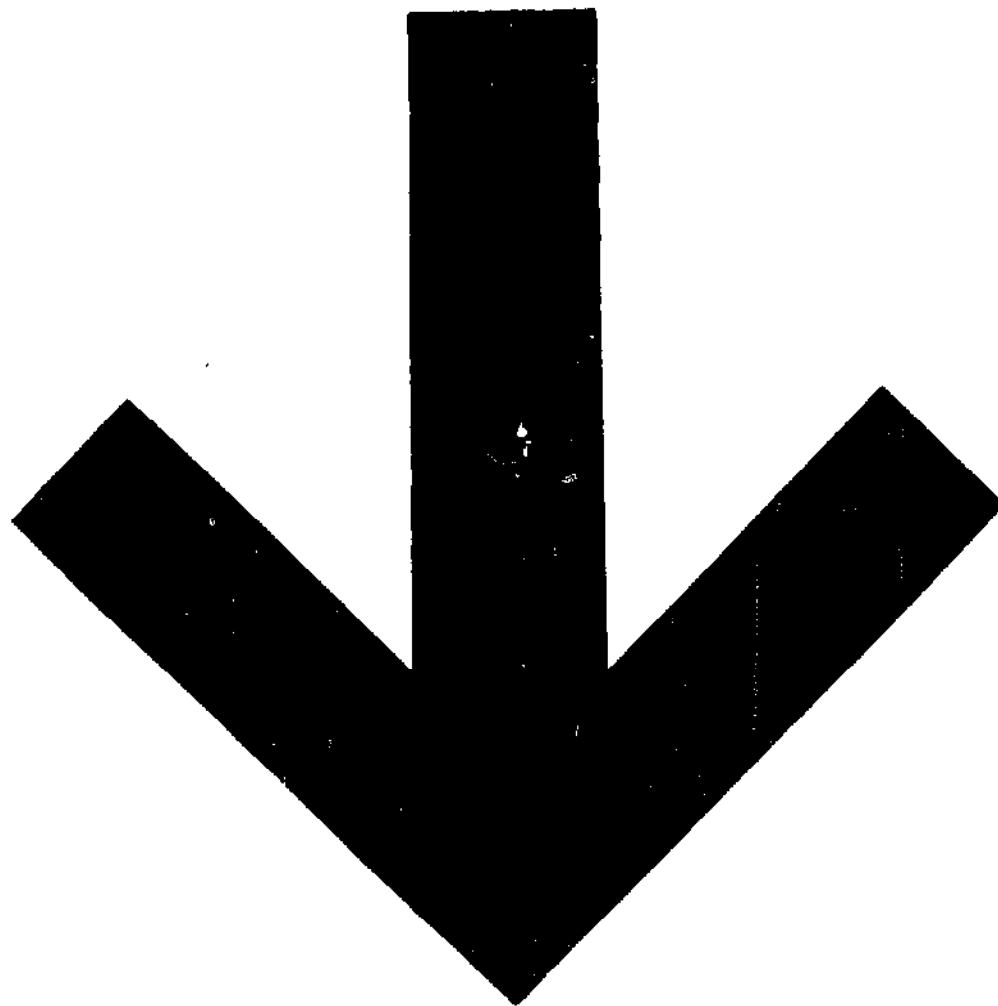
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## **Publisher's Foreword**

THE Industrial Training Act has resulted in an increase in the number of people now being trained or re-trained. LICET books are intended to provide suitable texts which will be easy to read and assimilate for those employed in industry and commerce who are receiving further education and training as a part of their employment. It is hoped that they will be particularly suitable for those attending courses leading to the examinations of the City and Guilds of London Institute, the Regional Examining Unions and other examining bodies.

The books are essentially straightforward, simple and practical in their approach and are designed to provide all the basic knowledge required for a particular trade or occupation. They are structured in such a way that the subject is broken down into convenient and progressive components, and are written by authors specially chosen for their expert knowledge and for their practical and teaching experience of their subjects.

Where appropriate, emphasis has been placed on safety training. In some subjects separate manuals on safety and safety training will be provided; in other texts, authors have been encouraged to emphasise safety precautions at relevant points, or to devote a separate chapter to these matters.

LICET books are published in a number of subject divisions, with each division controlled by a specialist editor responsible for selecting authors and providing guidance and advice to both authors and publisher. It is hoped that the series will make an important contribution to further education and industrial training.

ROBERT MAXWELL  
*Publisher*

## Introduction

IN A rapidly developing welding industry there is a constant demand for skilled craftsmen capable of producing high-quality work with first-class equipment. The wide range of modern welding work makes it necessary for the operator to be as capable of controlling expensive automatic machines as he is of performing skilful manual welding. The need is for adequately trained personnel with a sound understanding of the various processes and materials to be used, a keen appreciation of the importance of the correct, careful use of equipment and a completely "safety-conscious" outlook.

The two volumes of this book cover the ground necessary for the acquisition of the essential basic skills and safe working methods, sufficient technology and related studies being included to provide a suitable background to the practical work and form a basis for further, more advanced studies. It is intended for all who wish to learn to weld and the ground covered will enable the beginner to obtain a sound knowledge of the equipment, a keen appreciation of safety and, by means of a graduated series of practical exercises, a good standard of skill.

The intention has been to cover the requirements of the syllabus of the City and Guilds of London Institute, Course 323, Welding Craft Practice (Part I), the relevant information being given for the production and testing of the specimen welds required in this course, and it is hoped that all would-be welders will aim at obtaining a suitable qualification.

Volume 1 deals with Oxygen-Acetylene Processes and Weld Defects, Testing of Welds and Welding Science, Volume 2 with Electric Arc Processes and Elementary Electricity, Classification of

## INTRODUCTION

Electrodes, Welding Symbols, Engineering Drawing, Metal Plate Surface Development and Workshop Calculations.

We wish to express our appreciation to Messrs. Hancock and Company (Engineers) Ltd., Air Products Ltd., Lincoln Electric Company Ltd., Murex Welding Processes Ltd., for allowing the reproduction of photographs and diagrams of their welding equipment.

Material from B.S. 1295; 1959: *Tests for Use in the Training of Welders*, B.S. 1719; Part 1, 1963: *Classification Coding and Marking of Covered Electrodes for Metal-Arc Welding* and B.S. 499; Part 2, 1965: *Welding Terms and Symbols*, is reproduced by permission of the British Standards Institution, 2 Park Street, London, W.1, from whom copies of the complete standards can be obtained.

The student is advised to make a further study of the British Standards referred to.

N. PARKIN

C. R. FLOOD



## **A. ELECTRIC ARC WELDING**

## CHAPTER 1

# Plant, Procedure and Equipment

ELECTRIC arc welding is carried out by transmitting electrical energy from one point to another and then turning the electrical energy into heat. The heat is then used to melt the metal to be welded (generally referred to as the parent metal) and the electrode (sometimes called the filler rod). The melting of the parent metal and the electrode is effected by an arc of high temperature jumping from the electrode across to the parent metal and so giving a source of heat energy (Fig. II.1).

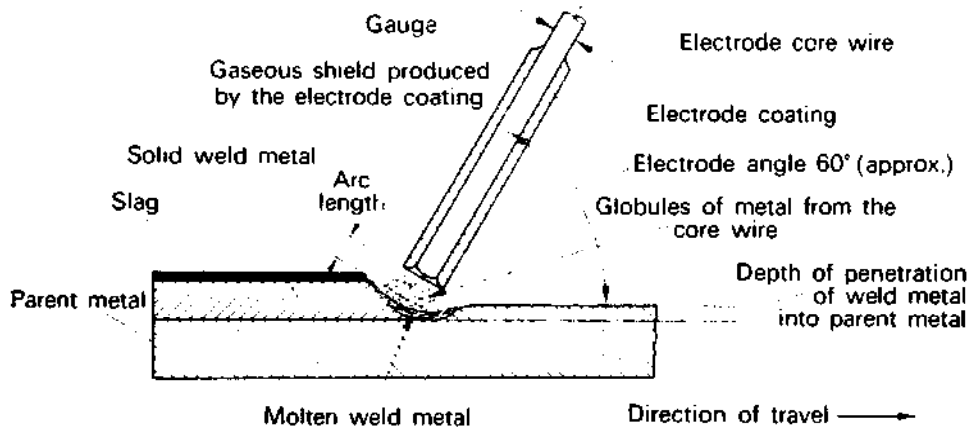


FIG. II.1. Metallic arc welding of mild steel.

To transmit electrical energy efficiently, good conductors are essential. All metals are conductors of electricity, although some are more effective than others. This difference is shown, for

example, by comparing copper and steel: the former is the better conductor of the two, because it wastes less energy. Most electrical wiring is of copper wire.

The chief insulating materials consist of paper, rubber, p.v.c. and oil, and these must resist the flow of electricity. Thus it is possible to wrap a length of copper wire with rubber and pass electrical power along its length, because the rubber coating will confine the flow of electricity along the desired path.

### MANUAL ELECTRIC ARC WELDING PLANT

The term “manual electric arc welding” means arc welding carried out by one man using an electrode in a holder, the operator being entirely responsible for the deposition of the weld metal.

Two types of plant may be used: direct current (d.c.) plants or alternating current (a.c.) plants. The choice of plant depends upon certain factors, but generally both types are suitable for the welding of all metals, except for some non-ferrous metals which require a d.c. plant. A typical arc welding circuit diagram is shown in Fig. II.2.

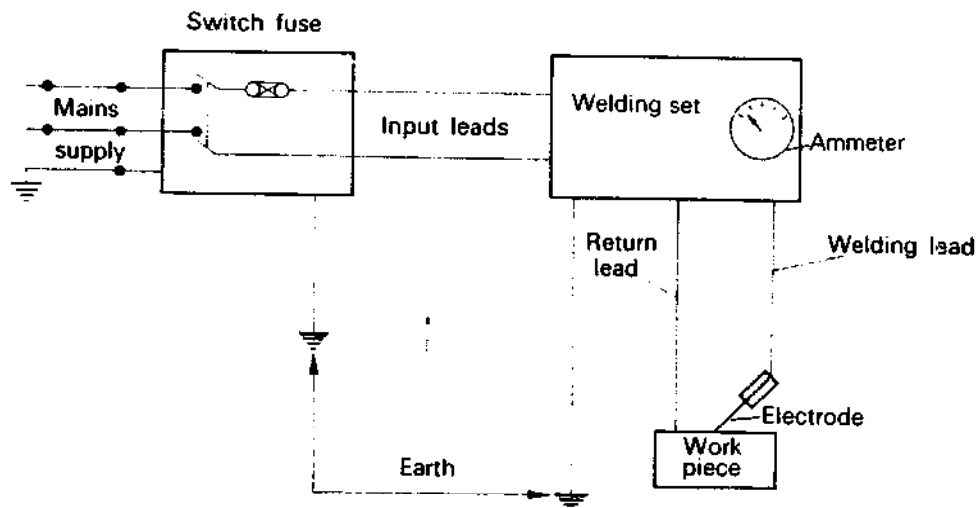


FIG. II.2. Circuit diagram for arc welding.

**A.C. Plants (Fig. II.3; Plate II.1)**

The welding power for a.c. plants is obtained from a step down transformer. This means that the incoming voltage supply, which may be in the nature of 230–250 volts, is stepped down to 80 or 100 volts in the transformer. The transformer is also equipped with a current control regulator, enabling the operator to select the correct current (amp) for the size of electrode being used. The sets may be either air cooled or oil cooled. The air-cooled sets have an electric fan blowing cool air on to the transformer, whilst the oil-cooled sets have the transformer immersed in a thin oil. From the point of view of simplicity and efficiency, the a.c. welding equipment is ideal.

Some of the advantages offered by a.c. over d.c. may be summarised as follows:

1. Cheaper to buy than d.c. sets. The initial cost is approximately one-half of that required for a d.c. set of equivalent rating.

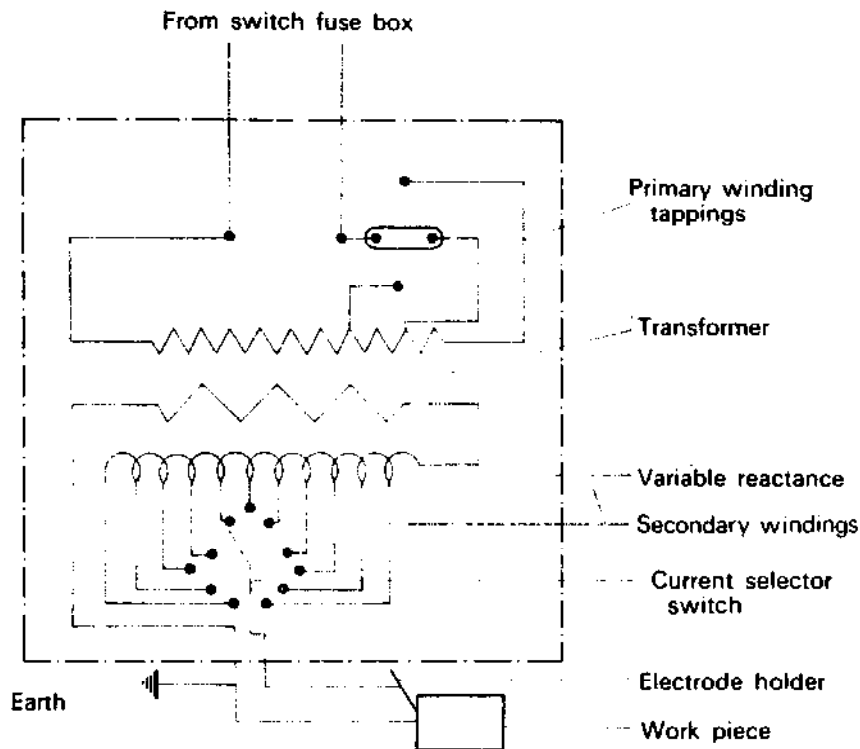


FIG. II.3. Circuit diagram of an a.c. welding transformer.

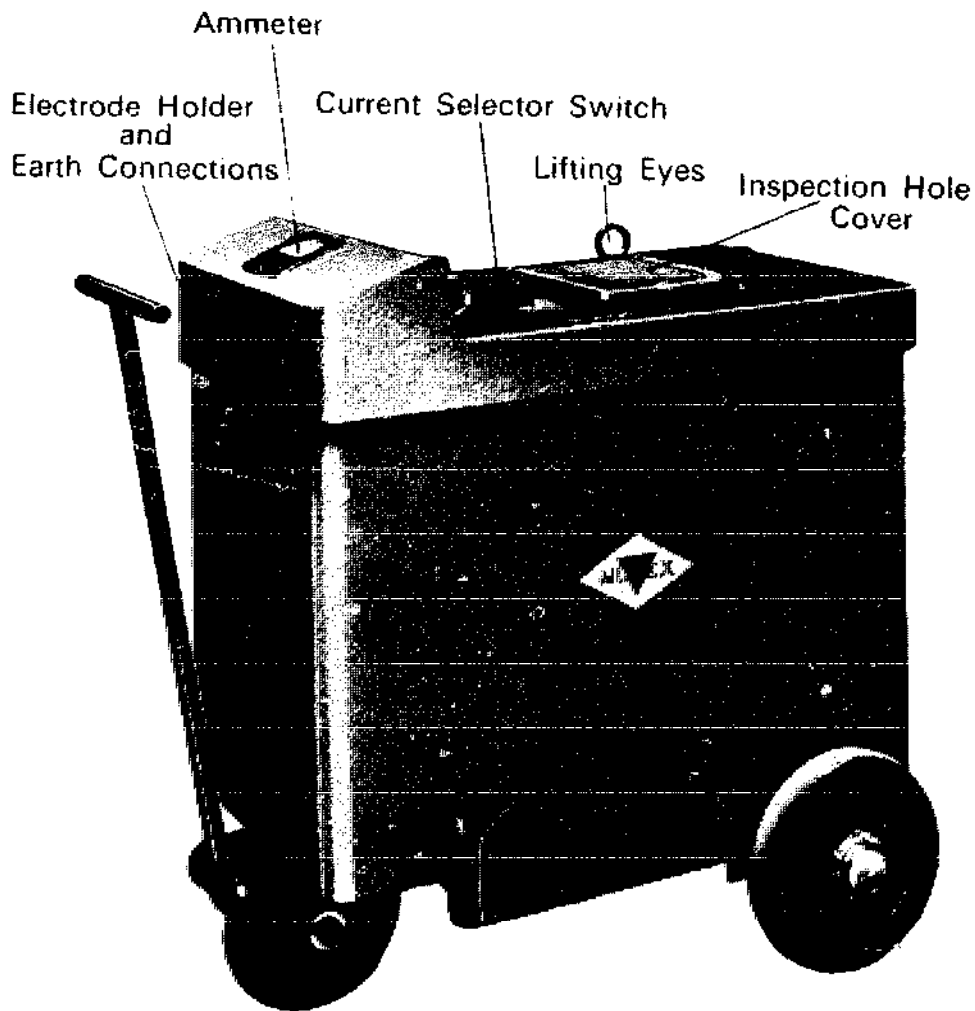


PLATE II.1. a.c. arc welding transformer.  
(Courtesy, Murex Welding Processes Ltd.)

2. Little or no maintenance necessary. This is because there are no moving parts in an a.c. transformer.
3. The phenomenon of "arc blow" does not exist with a.c. (see d.c. plants for an explanation of this).
4. The a.c. transformer may be used in the open without further protection from the weather being necessary.
5. The quality of the weld metal is equal to that of the d.c. process when welding steels.

Some disadvantages are as follows:

1. Non-ferrous electrodes are not so well deposited.
2. Thin gauge sheet metal is better welded with d.c.
3. The electric shock hazard is generally recognised to be more pronounced with a.c. than with d.c.

### **D.C. Plants (Plate II.2)**

Direct current welding power may be obtained from a rectifier or generator set.

A rectifier is a means of changing the a.c. input to d.c. output.

A generator is a machine that generates or "makes" electricity and before this can take place some form of energy is required to drive the machine. This may take the form of a petrol or diesel engine, an a.c. electric motor or even a d.c. electric motor. Where no electrical supply is available (on site or on field repairs) then the petrol or diesel motor is used. When a.c. supply is available it is, of course, most beneficial to use the a.c.-driven generator.

Some of the advantages offered by d.c. sets may be summarised as follows:

1. They can be used to deposit both ferrous and non-ferrous electrodes.
2. Smoother welding giving an advantage when welding thin sheet metal.
3. Safer to use in damp conditions, where the risk of an electric shock is great.

Some disadvantages are as follows:

1. More expensive to purchase than a.c. sets.
2. Periodic maintenance of the plant is necessary, because of the moving parts.
3. Troubles from "arc blow".

### *Magnetic Arc Blow*

This is a condition encountered only with d.c. welding equipment. The arc is forced away from the weld point, notably when

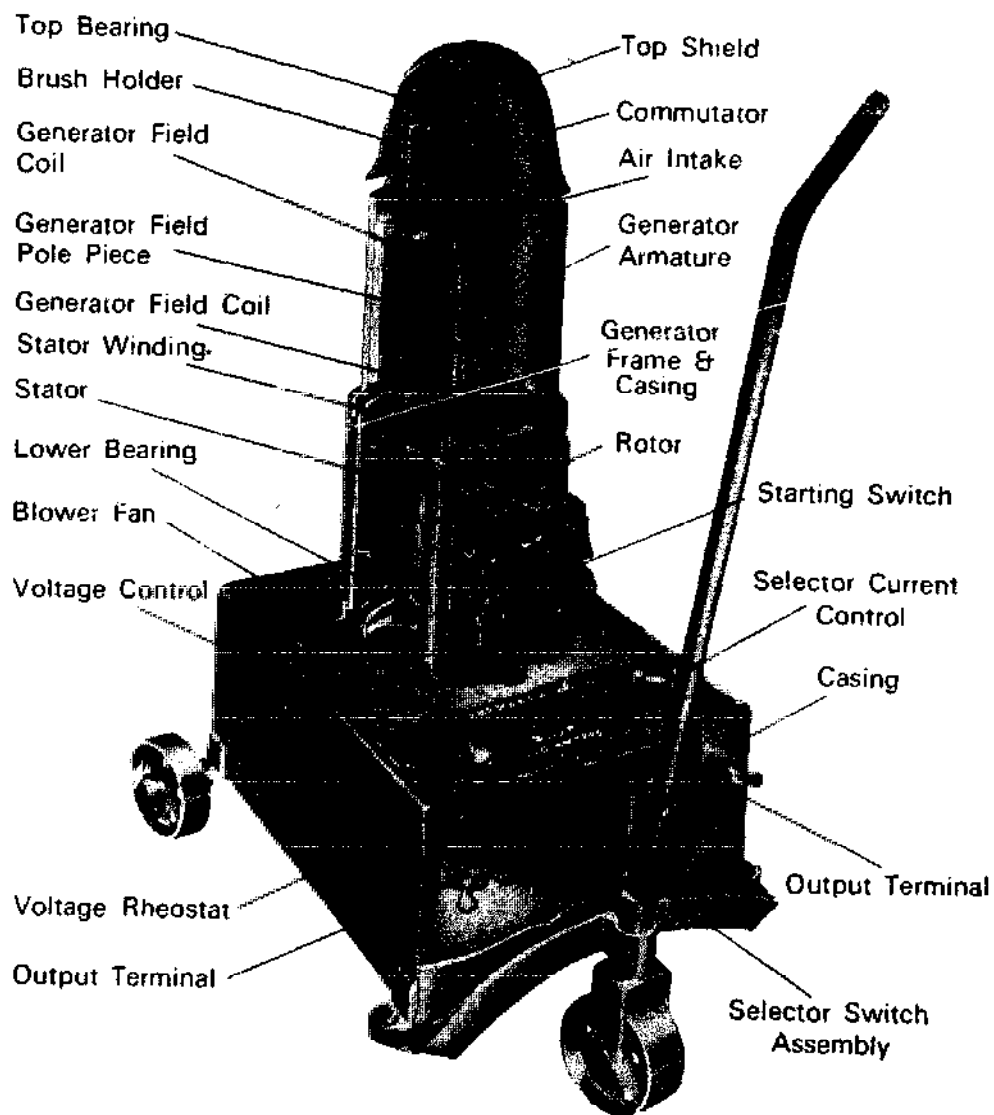


PLATE II.2. d.c. arc welder.  
(Courtesy, Lincoln Electric Co. Ltd.)

welding in corners. The conductors carrying the current, namely, the welding lead from the set and the return lead from the workpiece, are carrying the current in opposite directions, so that a repulsive magnetic force is set up, which in turn affects the d.c. welding arc. The condition seldom occurs, because the various current-carrying conductors are placed in such a way that they do not normally affect each other.

### **Selection of Current Values for Electrode Size**

All welding sets are equipped with the means for selecting a suitable current necessary for the size of electrode being used. Some sets are designed to operate with larger current values than others. Generally the range obtainable is from 15 amp to 600 amp, but for general work a current source of from 20 to 300 amp is considered adequate.

The current regulator on a.c. sets can take the following forms:

#### **1. TAPPED CHOKE**

This consists of a laminated iron core wound with a coil of wire tapped at suitable points. The number of turns on the coil and the number and positions of the tappings regulate the current.

#### **2. MOVING-CORE CHOKE**

This type consists of a coil of wire, connected to the secondary windings on the transformer, on a laminated iron core. The position of the iron core in the coil affects the current regulation.

#### **3. MOVING COIL**

This consists of a special arrangement in the transformer so that the distance between the primary and secondary windings may be varied, thus enabling the current to be varied.



### **Workshop Layout for Electric Arc Welding**

The layout of welding workshops must vary from shop to shop according to the type and size of jobs being carried out, but in general they do fall into a certain near pattern.

For shops carrying out work on fabrications of up to approximately one ton and dimensionally up to 1000 cubic feet (this is  $10 \times 10 \times 10$  ft), the shop may be divided into separate bays with one welding set in each bay. The screens separating each bay should be removable and made of metal (wooden screens are suitable providing they have been fireproofed). Each bay should be complete with a 250/300 amp (either a.c. or d.c.) welding set. A smaller set than this is not really suitable for present-day welding fabrications with the metal thicknesses encountered. A lifting hoist should be available in each bay either electrically-or block-and-chain operated, which will enable the welder to move his particular job without having to rely on the overhead crane, and also to hold the fabrication on the hoist whilst welding, where it must be remembered not to earth through the hoist.

An electrical power point and a compressed air point, for portable grindstones and linishers, are also necessary in each bay. The electrical point may also be used for inspection lamps which may be necessary in confined spaces. A small welding manipulator should also be a feature in each bay, to enable the welder to carry out the majority of the welds on each fabrication in the gravity position.

One or more bays (according to the nature of the work being carried out) should also be equipped with various types of other welding sets such as argon arc, argonaut, gas-shielded arc and oxy-acetylene sets, both for welding and cutting.

Each welder should have his own bench fitted with a vice. The bench, constructed of metal, should have a built-in cupboard for storing drawings, job cards and other paperwork that may be liable to damage from sparks.

So much for each individual welder; now to general shop equipment. A large welding manipulator should be sited outside the welding bays. This is necessary for the larger types of fabrications which cannot be carried on the small individual

manipulators. A large area should also be set aside for very large fabrications, together with a welding set in this area capable of 600 amp, necessary for very heavy platework.

The weld cleaning area should be sited at one end of the shop, and should have ample electrical points for portable cleaning tools such as grinders, finishers, wire brushes and chisels. Figure II.4 shows a layout which is general for the majority of welding shops, and it should be noted that the layout indicates a welding shop as distinct from an assembly shop, although assembly of fabrications can, of course, be carried out in the same shop. It is far better, however, to keep the assembly of jobs to another shop because of the special equipment necessary, such as level tables and surface floor plates. Although the layout indicates single-operator sets, multi-operator sets could be used if necessary. The large manipulator indicated in Fig. II.4 is for the larger fabrications which may lend themselves to this type of apparatus. Only one is shown but others may be necessary according to the shop requirements. Each welding bay is equipped with a small portable manipulator, for work of a few pounds weight only.

#### MANIPULATORS (Fig. II.5)

Every welding job should, if possible, have all joints welded in the gravity position. This means that the joints should be placed in such a manner that when welding is being carried out the weld metal will find its own level. Perhaps another way to describe it would be to say, all positional welding should be eliminated as much as possible. Not only is it quicker, and therefore cheaper, to execute all welds in the gravity or downhand position, but the quality of the welds will be much improved with less chance of weld defects. It is also far less fatiguing on the operator when performing downhand welds than when welding in the vertical up position.

To enable welding to be carried out in the downhand position, welding positioners or manipulators are employed. These may be either power operated or hand operated and they may range from a few pounds weight to 50 tons capacity. They operate on the principle of a revolving table, to which the job is fixed, which

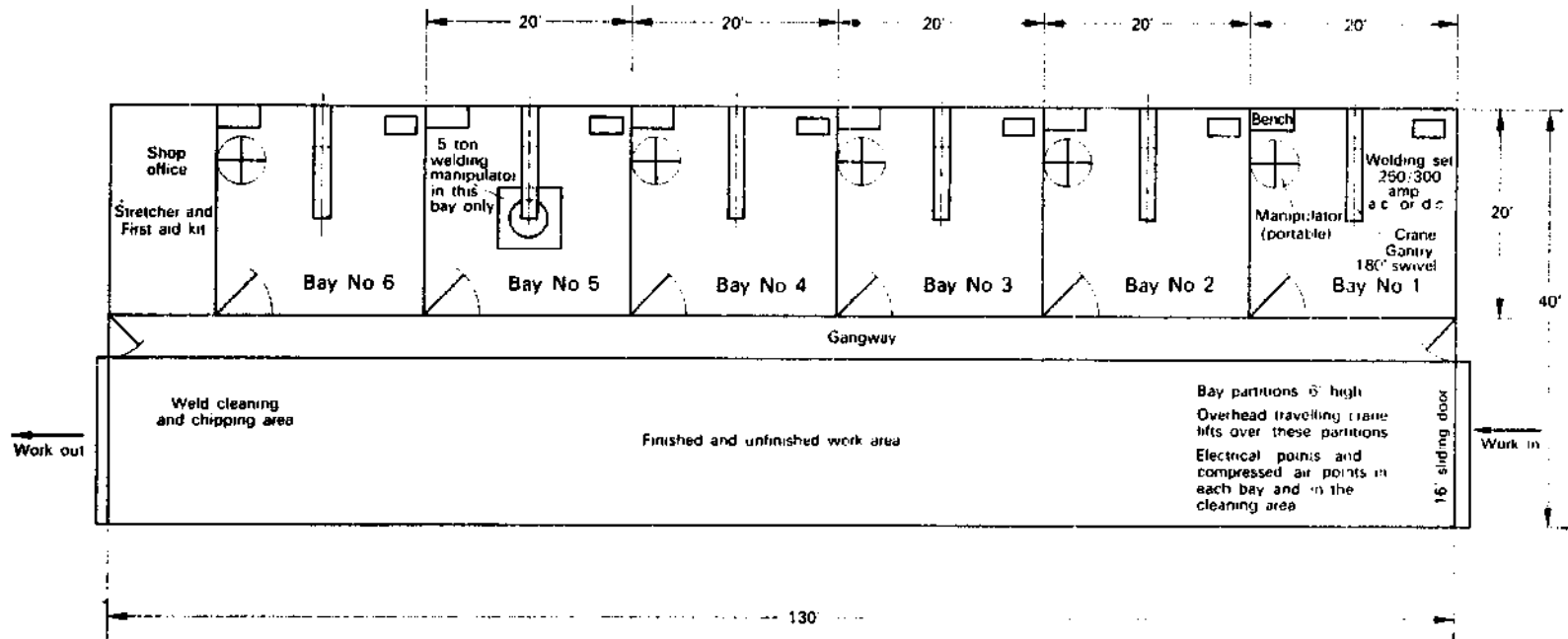


FIG. II.4. Layout for welding shop.

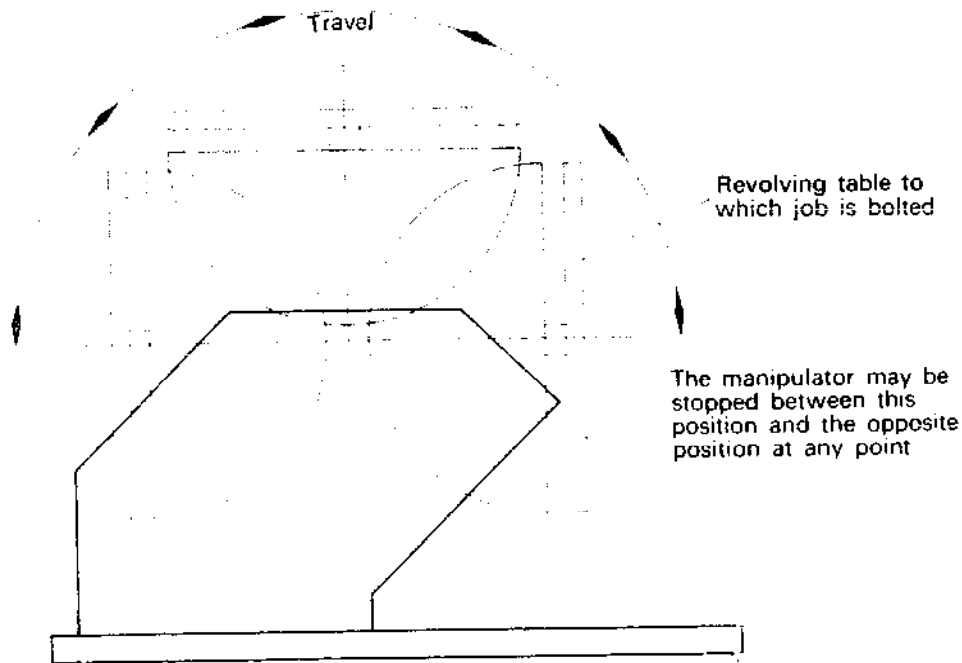


FIG. II.5. Welding positioner.

can be moved from side to side. In fact, the only welds which are not accessible are those which may meet up with the revolving table face.

Before deciding upon the use of a manipulator it has to be decided if the time involved in fixing the job to the manipulator is worth the effort. Obviously, if job movement time is saved, then it is worth the effort, but should it be quicker to move the job around off the manipulator and weld up all joints in the gravity position, then the manipulator may be dispensed with.

### WELDING FIXTURES

A welding fixture or, as it is sometimes named, welding jig, is used for the assembly of welded fabrications. It is employed to ensure the speed and accuracy of welded jobs. Another reason for the use of fixtures is that the assembly may also be carried out by one operator instead of, as is usual, a welder and one other

man. Jobs are only tack welded in fixtures, then removed and welded finally. Should the fabrication be completely welded in the fixture, the fixture would most certainly distort.

An example of a very simple type of welding fixture is illustrated in Fig. II.6. The assembly is of a tube and two plates, one on

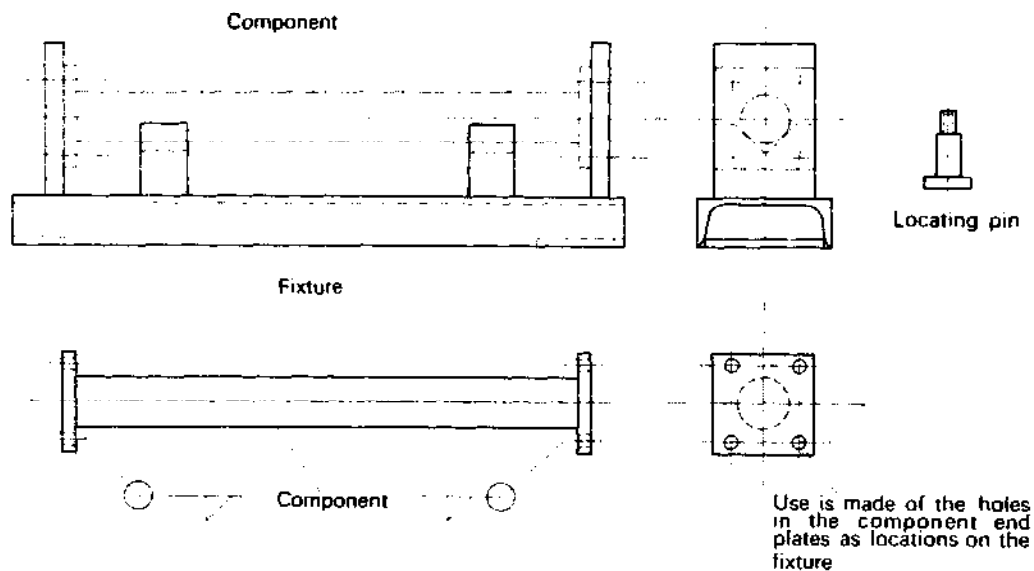


FIG. II.6. Welding assembly fixture.

either end of the tube. The plates are complete with holes and have to be positioned on the tube centre. The end plates are first located on the fixture and the tube is positioned on the fixture saddles. Tack welding takes place and the assembly is then removed for complete welding.

Two important points have to be carefully considered when designing welding fixtures. The first is that the job must be removable from the jig after tacking for it is surprising the number of occasions on which a job has been tacked up in a fixture and then it has been discovered that it cannot be removed from the jig.

The second point concerns the manufacture of the parts. It is essential that there is no variation in sizes, because the fixture, it must be remembered, will only take the correct size part.

### **Ancillary Arc Welding Equipment**

The items of equipment that arrange themselves under this heading are not required for the actual welding operation but are nevertheless necessary for the completion of a good welded joint. Further items associated with safety aspects are dealt with in the section which follows.

#### **CHIPPING HAMMERS**

These are necessary for the removal of slag and spatter and are generally designed with a point at one end and a flat chisel shape at the other and a wooden or metal-tubed handle. The incorrect use of a chipping hammer on a weld can result in the weld face being badly marked.

#### **BRUSHES**

Brushes are necessary for the removal of loose slag and spatter that may be left on the weld after chipping. The brushes are of steel wire, generally with a metal strip protecting the wooden backing.

#### **TONGS**

These are particularly necessary with welding specimens that may only be between 6 in. and 12 in. long. The tongs are required to hold the specimen whilst chipping, brushing and during visual inspection.

#### **MAGNETIC BLOCKS**

These are used to set up plates for tack welding and are so designed that both magnetic sides of the block are at 90° to each other. The magnets should be removed once the plates have been tack welded.

#### *Use of Measuring Equipment in Arc Welding*

It is essential in arc welding that the passage of electricity through conductors can not only be controlled by the use of switches, but that this electricity can also be measured.

The voltage must be known and also the current flowing through the circuit. Electrodes require a certain voltage and a certain current (amperage) to ensure that when the electrode is depositing the weld will be sound.

Welding sets are constructed with an instrument for measuring the current which is usually on the top of the set where it can be easily seen. This instrument is called an ammeter.

The current may also be read by the use of a tong ammeter (Plate II.3). This instrument is clamped around the welding cable and the ammeter records the current passing through the circuit.

The output voltage from the set may also be indicated by the use of another instrument known as a voltmeter. It is not usual to fit voltmeters to a.c. welding sets, but some d.c. sets do have them fitted.

#### AMMETER (Fig. II.7)

An ammeter may be connected at any point in series in an electrical circuit so that the current flows through it. When an arc is struck between an electrode and the workpiece the amount of current flowing in the circuit will be indicated on the ammeter in amperes. The operator cannot, of course, read the ammeter. This must be done by a second person. The needle of the ammeter will not remain absolutely steady, but will fluctuate above and below a mean line. For example, if a 10-gauge electrode is being run out at 117 amperes the ammeter will read between approximately 110 amperes to 125 amperes. This small variation in current is not sufficient in itself to affect seriously the deposited weld metal, but should a large variation in amperes show on the instrument then something is most certainly wrong with the welding set.

#### TONG AMMETERS

If a welding set is not fitted with an ammeter then a portable type of instrument may be used (Plate II.3). This instrument is known as a tong ammeter because of the action of the jaws, which



PLATE II.3. Tong test ammeter.  
(Courtesy, Murex Welding Processes Ltd.)

open when the handles are squeezed and close when pressure on the handles is released. To use this type of ammeter the welding cable must be in the centre of the orifice when the tongs are closed. It is read in exactly the same way as described in the previous paragraph.



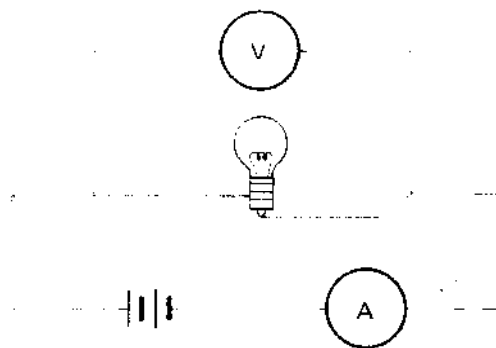


FIG. II.7. Ammeter-voltmeter circuit.

### VOLTMETERS

Some a.c. welding sets have two voltage connections, usually 80 and 100 volts, whilst other types of sets may only have one, but in both the voltage cannot be varied. This is not so with d.c. sets on which the voltage can be varied and so it is sometimes found that d.c. sets are fitted with voltmeters whilst a.c. sets are not.

A voltmeter is an instrument used for measuring the electrical difference across a circuit potential and is sometimes referred to as the "p.d."

A voltmeter has a high resistance and it serves as a by-pass to the main current. If we wish to know the current passing through a lamp and the voltage acting across it, the voltmeter and the ammeter are connected into the circuit as shown in Fig. II.7. A is the ammeter and V the voltmeter.

If carrying out welding operations using a d.c. set and a voltage control (if fitted), set the correct current for the electrode being used and set the voltage to the lowest setting, giving, say, 13 volts across the arc. It will be found that it is almost impossible to maintain an arc and the metal will be deposited in blobs on the plate. Increase the voltage to 24–25 volts and welding will then become possible.

### **Safety Precautions to be observed whilst Arc Welding (Plate II.4)**

It is most essential that the welder should ensure that he is personally adequately protected during arc welding operations.



PLATE II.4. Welding operator dressed in protective clothing.  
(Courtesy, Lincoln Electric Co. Ltd.)

The danger to unprotected skin cannot be too highly stressed. This danger is present in two forms: one from the arc rays and the other from molten metal in the form of spatter. To ensure that the operator suffers no injury it is therefore essential that all skin is covered. Particular attention must be paid in this respect to the eyes, hands, face, arms and neck.

The items of protective clothing and accessories which should be worn are as follows:

*Face Shields.* These are either of the hand-shield or head-shield type, made of a fire-proof material and fitted with a dark glass, protected by a clear glass. The dark glass is specified by B.S. 679. No metal fittings should be incorporated in their design because of the risk of electric shocks.

*Gloves or mitts.* These are made of chrome leather or asbestos. The gauntlet type should always be used with at least a 6 in. to 8 in. covering of the wrist and arm.

*Arm protectors.* Made of chrome leather and designed to protect from the wrist to the shoulder.

*Aprons.* Made of chrome leather, either split or full at the front. The split type does enable more movement during welding in a confined space.

The following protective clothing is rather of a special nature and is usually only worn when carrying out vertical and overhead welding:

*Capes.* Made of chrome leather and designed to protect the shoulders.

*Skull caps.* Made from chrome leather and designed to protect the top of the head.

*Spats.* Usually made from asbestos and designed to protect the top of the foot by ensuring that hot metal does not enter the boot.

#### SCREENING THE ARC

During arc welding it is the responsibility of the operator to ensure that those workmen in close proximity are also screened

from the arc. Should a person near to the arc receive a "flash" it is possible that the pigment of the eye may be burnt, resulting in soreness of the eye for a number of hours. (See memorandum on *Electric Arc Welding*, S.H.W. 329. Ministry of Labour, p. 8, paragraph b).

**Duckboards.** The presence of a wooden slatted duckboard whilst arc welding is in progress minimises the risk of standing on the hot end of a discarded electrode. It also lessens the severity of an electric shock (wood being a poor conductor of electricity). Should the floor be wet, the duckboards will ensure that the operator's feet are not in contact with the water.

#### EARTHING OF ELECTRICAL EQUIPMENT

A good earth is most essential when arc welding, for not only does it ensure a sound weld, but it also lessens the risk of an electric shock to the operator. It is essential that the earth return lead from the welding set goes back to earth through a recognised earth terminal in the ground and not through the operator, as would be the case should the earth terminal be incorrectly connected.

#### Electrodes and Electrode Classification (Fig. II.8)

Manual electric arc welding using the conventional electrode still accounts for approximately 80% of welding. The remaining 20% is taken up by automatic arc welding and semi-automatic

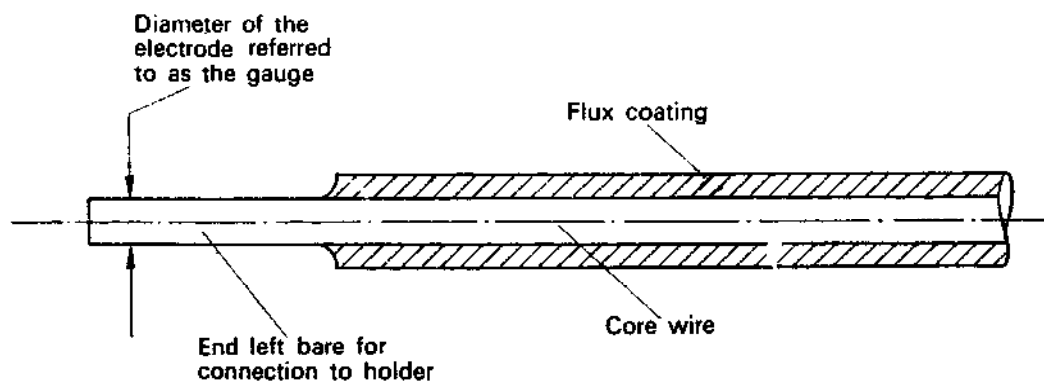


FIG. II.8. Diagram of a "stick" electrode.

arc welding. The electrode as used for manual arc welding is referred to as a *stick electrode*, to distinguish it from a *continuous-wire-coil electrode*. Other names given to an electrode include, *rod* and *filler wire*; but the correct technical term is *electrode*.

A manual arc welding electrode consists of a core wire surrounded by a flux coating, except for approximately  $1\frac{1}{4}$  in. at one end. This area of core wire is left uncoated for the purpose of contact with the electrode holder. The core wire is the only part of the electrode that is actually left behind in the welded joint as weld metal (excluding the iron powder type). The electrode coating has a number of functions to perform during and after welding which are as follows:

1. To stabilise the arc.
2. To aid fluidity of the molten metal.
3. To float any impurities in the molten weld metal to the top of the molten pool.
4. To form a hard surface on top of the weld, which is known as slag and which slows down the rate of cooling and protects the deposited weld metal. It also improves the appearance of the weld surface.
5. To provide a gaseous shield over and around the molten pool of weld metal and so prevent contamination from the atmosphere.

The size of the electrode, called the gauge, is the diameter of the core wire only and does not include the flux coating. Electrodes are manufactured in the following gauge sizes: 16G, 14G, 12G, 10G, 8G, 6G and 4G. The smallest number refers to the largest diameter. Above the 4G size electrode diameters are denoted by fractions and are as follows:  $\frac{1}{4}$  in. dia.,  $\frac{5}{16}$  in. dia. and  $\frac{3}{8}$  in. dia. This last size is the largest diameter electrode manufactured.

The manufacture of electrodes is covered by certain British Standards (see page 23).

Certain defects in welds may occur owing to some fault in the electrodes and for this reason it is essential that electrodes should

be correctly stored and that packets of electrodes should not be left lying around in the workshop when not in use. An electrically heated storage cupboard is necessary for the safe storage of electrodes and this should be thermostatically controlled so that when the desired temperature is reached the electric supply is switched off and when the temperature drops to a certain level it is again switched on. Storing in an oven such as this prevents the electrode from becoming damp. Should electrodes become damp they should on no account be used because of the danger of weld defects. Electrodes that have become damp, however, may be dried, but the advice of the electrode manufacturer must be sought before drying, because overheating can change the characteristics of the coating entirely.

Attention should also be paid to the possible causes of damage to the flux coating on electrodes. Cardboard cartons should not be stacked more than 4-5 high and packets should not be allowed to drop on to metal plate or the shop floor. Any electrodes found to have damaged coatings must not be used.

*Weld defects produced by defective electrode coatings.* Electrodes that may be damp or have a damaged coating may produce defects in welds, some of which may not be visible on the surface of the weld. One of these defects is porosity or piping: when the defect appears as small holes on the weld surface this is known as *porosity*, but when it appears below the surface and is elongated in shape it is called *piping*. Both are caused by the entrapment of gas and the gas is produced by the electrode when it is damp.

### *Classification of Electrodes*

Electrodes are manufactured to certain standards and to cover all the types of electrodes manufactured, a set of British Standard specifications is in force.

These specifications are as follows:

B.S. 639. Specification for covered electrodes for the metal-arc welding of mild steel and medium tensile steels.

B.S. 2493. Molybdenum and chromium-molybdenum low alloy steel electrodes for manual metal-arc welding.

B.S. 2926. Chromium-nickel austenitic steel electrodes for manual metal-arc welding.

B.S. 1719; Part 1: 1963: *Classification, Coding and Marking of Covered Electrodes for Metal Arc Welding* deals with the following points with regard to electrodes:

1. Manufacturing method.
2. Type of flux covering.
3. The welding positions of the electrode.
4. Current requirements.
5. Voltage requirements.
6. Special characteristics.

A coding system is used to indicate certain characteristics of the electrodes with reference to the six points mentioned above. Each package has printed on it certain letters and figures which indicate certain features of the electrode. There is a difference between classification and the specification. Classification covers the type of electrode and specification covers the requirements of the weld metal deposited.

The six points previously mentioned will now be dealt with in detail.

#### MANUFACTURING METHOD—CODING, PREFIX LETTER

Electrodes may be manufactured by three separate processes, each of which is really a different method of putting the flux covering around the core wire. The three processes are as follows:

1. Solid extrusion.
2. Extruded with reinforcing.
3. Dipped.

Generally speaking, very few manufacturers make electrodes by methods 2 and 3. The method of manufacture must be quoted on each package of electrodes and to this end each of the three methods is given a prefix letter. These are as shown:

*PLANT, PROCEDURE AND EQUIPMENT*

*Prefix letter*

*Method of manufacture*

E

Solid extrusion.

R

Extruded with reinforcing.

D

Dipped.

**TYPE OF FLUX COVERING**

Practically all the mild steel electrodes in present day use come under the heading of one of the classes, of which there are six. Provision has also been made to cover any electrodes not conforming to any of these six under the miscellaneous class.

The classes of electrodes and the type of flux coverings are as follows:

*Class No. 1. Covering having a high cellulose content.*

Cellulose provides a reducing gas shield for the arc. The covering of slag is rather thin and is fairly easy to remove. This electrode is suitable for all mild steel welding and is useful in the flat position for deep penetration welding. Generally, this class of electrode is best suited to direct current welding sets, connected to the positive pole.

*Class No. 2. Coverings having a high content of titania and producing a fairly viscous slag.*

Titania is used in the covering in the form of natural sands known as rutile. The viscous (or *flowing*) slag is also quickly freezing. This type of rod is suitable for butt and fillet welds in all positions, but fillet welds in the horizontal-vertical position are particularly well executed with this electrode. Suitable for a.c. and d.c. welding. When using on d.c. connect to either pole.

*Class No. 3. Coverings containing an appreciable amount of titania and producing a fluid slag.*

The addition of basic materials with the titania yields a much more fluid slag than that produced by the class No. 2 electrode. Welding in the overhead and vertical upwards positions is far



easier than with other types of mild steel electrode. The weld metal deposited with this class of electrode will withstand radiographic (X-ray and gamma-ray) tests more readily than deposits made with a class No. 2 electrode. Suitable for a.c. and d.c. welding. When using on d.c. connect to either pole.

*Class No. 4.* Coverings having a high content of iron oxides and/or manganese oxides and/or silicates producing an inflated slag.

The iron oxides and manganese oxides are used to adjust the fluidity of the slag and its properties. The silicates provide the slag and give strength to the coating. The covering is usually thick, but some varieties may have a thinner coating. This class is used for downhand welding only. The slag produced is fluid and is honeycombed internally with holes, but is easily removed.

Suitable for a.c. and d.c. welding. When using d.c. connect to positive pole.

*Class No. 5.* Coverings having a high content of iron oxide and/or silicates producing heavy, solid slag.

This class of electrode has a very thick coating. These electrodes are used principally for single run fillet welds. The finish of the weld is fine, smooth and even in appearance. These electrodes are known as "touch electrodes" which indicates that when welding the electrode touches the surface of the parent metal. The degree of penetration is low. A heavy solid slag is produced which is sometimes "self-detaching". The fillet shape is concave in profile. The tensile strength is generally lower than that of the other electrode classes.

Suitable for use on a.c. or d.c. welding. When used on d.c. the electrode may be connected to either pole.

*Class No. 6.* Coverings based on calcium carbonate and fluoride.

This class of electrode is suitable for welding in all positions.

The slag produced is fairly fluid and the weld shape is convex to flat in profile. This class of electrode is known as low hydrogen

types and the weld metal deposited has excellent mechanical properties. It also has high resistance to hot and cold cracking.

The electrodes may be used for the welding of high tensile structural steels. The storage of these electrodes is of particular importance in that any moisture content is harmful and if necessary they should be dried before use.

A short arc is necessary when welding in order to achieve maximum soundness of weld deposit. Properly used in this way the weld metal will withstand high radiographic standards.

Suitable for use on a.c. or d.c. welding. When using d.c. connect to the positive pole.

*Class 9.* Any electrode having a covering not specified in the previous six classes.

#### CLASSES—CODING, FIRST DIGIT

The class of the electrode must be quoted on each package of electrodes, and this is indicated by the hundreds digit, i.e. 1 --, 2 --, 3 --, and so on.

#### THE WELDING POSITIONS OF THE ELECTRODES

As previously mentioned in the paragraphs on classes of electrodes, some electrodes are more suitable than others for welding in certain positions. For example, class 4 electrode is suitable for welding in the downhand position only, but a class 3 electrode may be used in any position.

#### WELDING POSITIONS—CODING, SECOND DIGIT

The welding position or positions in which the electrode can be used must be indicated on each package of electrodes, this is shown by the tens digit, i.e. -0 -, -1 -, -2 -, -3 -, and so on.

The numbers referring to certain positions are given in Table II.1.

Where an electrode is shown as being suitable for welding in the vertical and overhead position, it is not generally satisfactory to use electrodes above 6 G. Welding positions may be defined as shown in Table II.2.

TABLE II.1.

Digit	Welding positions
- 0 -	F.V.H.D.O.
- 1 -	F.H.V.O.
- 2 -	F.H.
- 3 -	F.
- 4 -	F.H. (fillet weld only)
- 9 -	Not classified above

TABLE II.2.

Position	Degree of slope	Degree of turn	B.S. 1719 symbol
Flat or downhand	Not exceeding 5°	Not exceeding 10°	F
Horizontal/vertical	Not exceeding 5°	Not exceeding 30°-90°	H
Vertical/up	Not exceeding 80°-90°	Not exceeding 180°	V
Vertical/down	Not exceeding 80°-90°	Not exceeding 180°	D
Overhead	Not exceeding 15°	Not exceeding 115°-180°	O

### WELDING CURRENT REQUIREMENTS

Some types of electrodes are suitable for d.c. and a.c. welding, whilst others may only be suitable for d.c.

### WELDING CURRENT REQUIREMENTS—CODING, THIRD DIGIT

The welding current requirements for the correct operation of the electrode must be stated on each package. The numbers referring to these requirements are as in Table II.3

The letter abbreviations are as in Table II.4.

TABLE II.3.

Digit	Welding current conditions
--0	D +
--1	D + A 90
--2	D - A 70
--3	D - A 50
--4	D ± A 70
--5	D ± A 90
--6	D ± A 70
--7	D ± A 50
--9	Not classified above

### ELECTRODES WITH SPECIAL CHARACTERISTICS

Some electrodes are manufactured possessing certain features which make them suitable for special applications. Generally there are four such electrodes and they are:

1. The deep penetration electrode.
2. The hydrogen-controlled electrode.
3. The iron powder electrode with a metal recovery of 110% to 130% of the core wire weight.
4. The iron powder electrode with a metal recovery of more than 130% of the core wire weight.

TABLE II.4.

Welding current conditions	Symbol
d.c. With electrode positive	D +
d.c. With electrode negative	D -
d.c. With electrode positive or negative	D ±
a.c. With an open circuit voltage not less than 90 volts	A 90
a.c. With an open circuit voltage not less than 70 volts	A 70
a.c. With an open circuit voltage not less than 50 volts	A 50

With reference to the iron powder electrodes, it is possible to deposit more weld metal than there is electrode core wire because the coating of the electrode contains metal powder.

#### ELECTRODES WITH SPECIAL CHARACTERISTICS—CODING, SUFFIX LETTER

Each package containing the electrodes previously mentioned shall have a suffix letter as follows:

TABLE II.5.

Suffix	Definition
P	Deep penetration electrode (B.S. 639)
H	Hydrogen-controlled electrode
J	Iron powder electrode with a metal recovery 110 to 130% of the core wire weight
K	Iron powder electrode with a metal recovery of more than 130% of the core wire weight

*PLANT, PROCEDURE AND EQUIPMENT*

*Standard type of electrode package code label.* Should a package contain class No. 3 electrodes, manufactured by the extrusion process and suitable for welding in all positions using a.c. or d.c., the coding would be as follows:

B.S. 1719 coding		E 317
Quality	Positions	Current conditions
B.S. 639	F.I.H.V.O.	D ± A 50

## CHAPTER 2

# Method

### Striking and Maintaining the Arc

#### WELDING POSITION

Before starting to weld and having made sure that one is wearing the correct protective clothing, that the wooden duck-board is in position, that anyone in the near vicinity is screened from the arc, and that the head-shield or hand-shield dark glass and clear glass is not broken, the next point to consider is one's position. A steady hand is essential and this is not possible if the body is not steady. A sitting position is the most comfortable, but it is well to remember that most welders are employed on shop-floor work and as such are not able to sit on a stool. It is therefore essential that whilst learning one does not sit at the bench all the time. Practice standing with the feet placed apart and the body unsupported whilst bending over the bench. Next, practise leaning against the bench (usually on the left hip for a right-handed person and on the right hip for a left-handed person). Do not hold the body rigid, but relax and try to breathe normally. (It is surprising the number of students who hold their breath when running out an electrode). The electrode holder should be held fairly tightly but not clasped rigidly so that one's control over the electrode is impaired. Do not press the elbow into the body so that the arm is held steady as this is a bad fault which means that the body must move away from the bench as welding proceeds. The arm must be held away from the body and must be manipulated entirely free of body movement. The electrode

holder must be held by the insulated handle and not by the frame, which is also insulated, but may contain small metal screws that are not insulated against electric shock.

Next, consider the welding cable which can drag if not supported. Try winding it one turn around the forearm or lay it across the shoulders. This will take the immediate weight of the cable off the holder. Also, make quite sure that the cable has not entangled itself around the ends of the wooden duckboard or any other projection.

#### INSERTING THE ELECTRODE IN THE HOLDER

It is a simple matter to put the electrode in the holder and does not involve any risk of an electric shock, providing a few minor precautionary measures are taken.

Firstly ensure that the electrode is not wet or damaged in any way and that one's gloves are not wet or damp. Grip the electrode about half-way along its length and squeeze the electrode holder. This will open the tongs, enabling the electrode to be inserted into the correct groove in the tongs. Release the tongs and the electrode will be firmly held in position. Do not bend the electrode, for if this is done the coating may become damaged and as a result the weld metal may become defective. Also, make quite sure that the electrode is in the correct groove for the size in use, because a small size electrode in too large a groove will be loose and will not be controllable once the arc is struck.

#### STRIKING THE ARC

Select a 10-gauge electrode for your first practice at striking the arc. Set the current regulator to 117 amperes. For material use  $3 \times \frac{3}{8}$  in. mild steel flat bar approximately 7 in. long (flat bar is more suitable than plate because it is much easier to cut, either with shears or power saw). Next, direct the tip of the electrode towards the practice plate. Do this a number of times with the current switched off. When the electrode touches the material, quickly draw away to about  $\frac{1}{8}$  in. from the surface. Do not worry



about the correct angle of electrode at this stage. When this exercise has been practised a number of times and one has the "feel" of the electrode, switch the current on and practice striking the arc. Remember to keep the welding screen in front of your eyes and, when the electrode touches the plate, very slightly scratch the surface. When the arc burns quickly draw away to approximately  $\frac{1}{8}$  in. The arc will still continue to burn if the electrode is 1 in. or more away from the surface of the plate but the arc must be kept short in order to control the deposition of the weld metal.

Should the electrode "stick" to the plate, do not snatch and twist to try and free it as this will only result in the piece of flat bar being lifted from the bench still attached to the end of the electrode. The correct procedure is as follows: keeping the screen in front of the face, switch off the welding set at the switch fuse, which should be located on the wall of the welding bay. Then give the electrode holder a sharp twist, which will free the electrode from the plate. The electrode and the plate may be hot, so exercise caution if attempting to touch either of them. Before continuing after the electrode has been freed, inspect it to ensure that the coating at the tip is not damaged, as in most cases the coating will be broken. The arc is very difficult to strike with a bare wire and a fresh electrode should be taken if damage has occurred.

Practise striking the arc only at this stage. Do not attempt to complete a weld.

#### RUNNING OUT THE ELECTRODE

When the art of striking and maintaining the arc has been accomplished the next stage is the practice of straight runs. Use the same size electrode and the same size of mild steel flat bar for this.

The angle of the electrode has now to be considered and for a 10-gauge electrode it is  $30^\circ$  from the perpendicular (Fig. II.9).

The electrode will now melt when the arc is struck and hold for any length of time. Now is the time to move along the plate, but

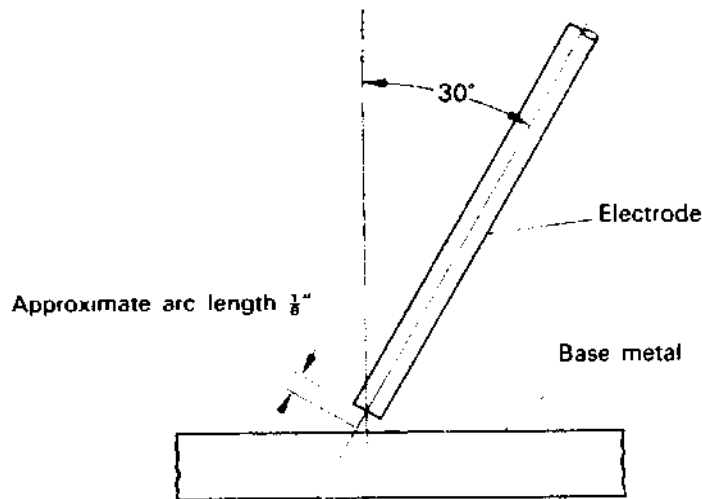


FIG. II.9. Electrode angle arc length.

remember, the electrode is burning off, and speed of movement, arc length and electrode angle have all to be watched very closely.

It is important to maintain the correct arc length and to this end the electrode tip may touch the parent metal, but only very lightly. If too much pressure is applied, or if the tip is completely immersed in the molten pool, the electrode will stick.

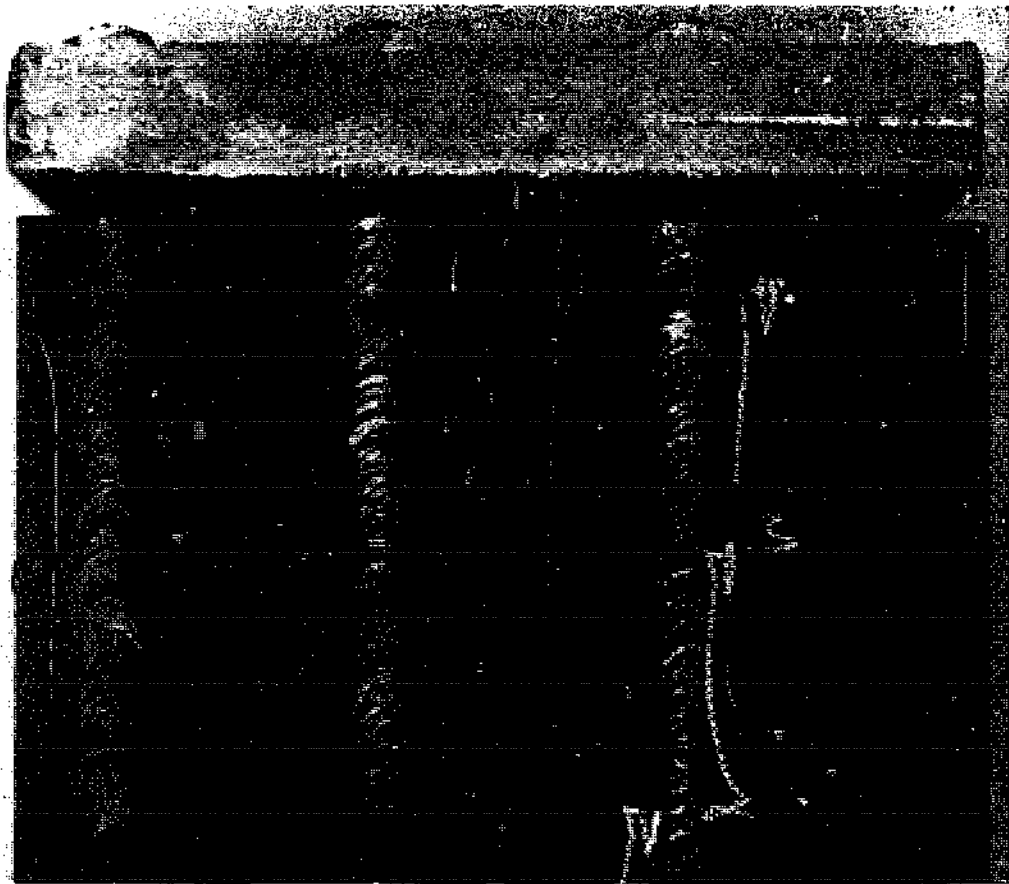
At this stage the difference between the molten metal and the slag must be distinguished. The slag appears a brighter colour than the metal and is more fluid. It is important that the molten slag is never allowed to run ahead of the molten metal.

The slag must be chipped from the deposited run and when doing this always wear goggles or if the welding screen is of the type where the coloured glass may be lowered, leaving the clear glass for eye protection, always use as intended.

### Correct Run and Faults

#### CORRECT DEPOSIT (Plate II.6(a))

A weld correctly executed should show the following visible appearance after removal of slag and wire brushing:



(a) Arc too long

(b) Arc too short

(c) Too slow

PLATE II.5. Welding runs—some common faults.

1. close even surface ripple,
2. a flat contour outline,
3. absence of weld spatter,
4. smooth blend with the parent plate along the weld edge.

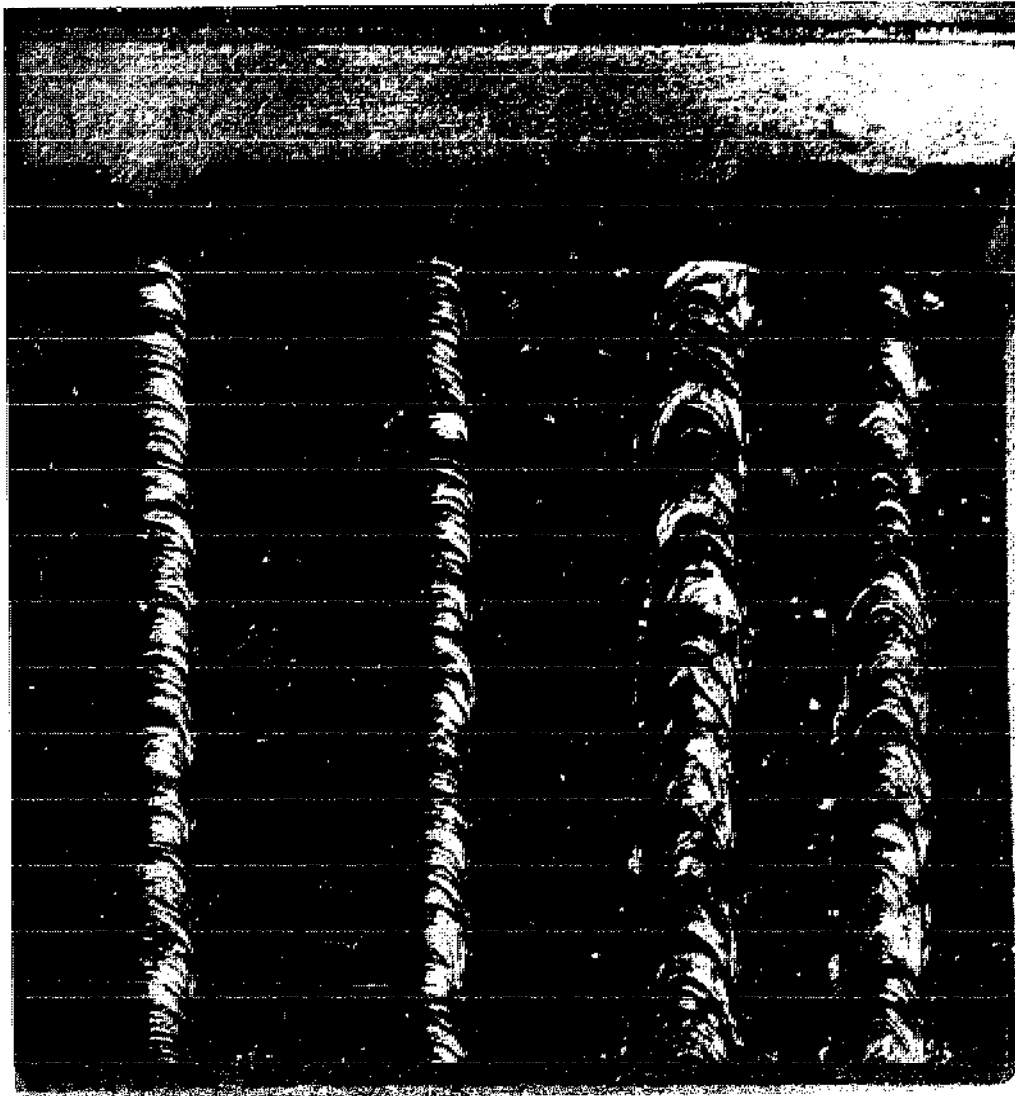
The following incorrect procedures during welding will result in the weld faults as stated.

#### TRAVEL OF ELECTRODE TOO SLOW (Plate II.5(c))

The weld deposit will be too high. This is because too much molten metal has been deposited in one place because of the slow speed of travel.

TRAVEL OF ELECTRODE TOO FAST (Plate II.6(d))

The weld deposit will be too small. This is because too little molten metal has been deposited in one place because of the high speed of travel.



(a) Correct

(b) Low Current

(c) High current

(d) Too fast

PLATE II.6. Welding runs—Correct method and some common faults.

**CURRENT TOO LOW (Plate II.6(b))**

The weld deposit will look uneven in height and width. This is because with too low a current the metal has tended to pile up.

**CURRENT TOO HIGH (Plate II.6(c))**

The weld deposit will be very flat and spread out and undue spatter will be seen on the parent plate. The surface of the weld will show a very long ripple effect. This condition also results in electrode wastage. Undercutting of the plate may also be apparent.

**ARC TOO SHORT (Plate II.5(b))**

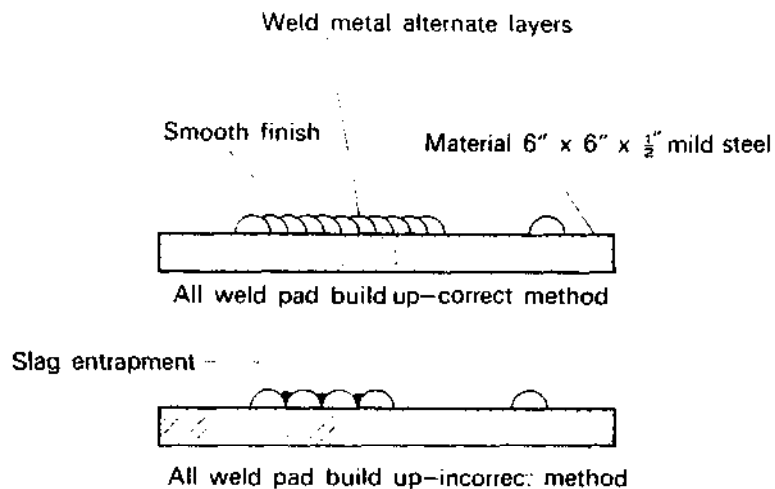
The weld deposit will look very irregular in width and it will have a very uneven surface appearance.

**ARC TOO LONG (Plate II.5(a))**

The weld deposit will have a very uneven appearance, both on the surface and along the sides. Excessive spatter will also be seen.

**BUILDING UP A PAD OF SOLID WELD METAL (Fig. II.10)**

When one has become familiar with striking the arc, depositing straight runs of weld and can recognise and correct the faults



**FIG. II.10. All weld metal pad.**

described in the section on weld faults, the next exercise should be attempted.

This exercise is the laying down on mild steel plate of a solid pad of weld metal and is designed to give practice in starting in the correct position, running the weld straight, stopping in the correct position, cleaning out all slag and preventing the sides from collapsing.

The material required is a piece of mild steel plate  $6 \times 6 \times \frac{1}{2}$  in. Use flat bar if available. Three or four 1-in.-square copper or brass bars 6 in. long, 10-gauge and 8-gauge electrodes.

Mark out a 4-in. square using white chalk in the centre of the plate. This is the size of the pad.

Commence the deposit using 10-gauge electrodes with a current of 117 amperes and firstly weld completely around the four sides of the 4 in. square, remembering after each run to remove the slag and to wire brush vigorously, inspect for faults and correct as necessary.

The layers of weld may now be commenced, each layer to be deposited alternate ways. Every separate run of weld must penetrate approximately one-half of the preceding run. It must not be laid so as to cause a "valley" between the two runs. This is a bad fault that will cause incorrect removal of the slag, which will become entrapped at the bottom of the "valley". Each layer should have a smooth finish completely free from slag and spatter.

When the pad is approximately  $\frac{1}{4}$  in. high change to 8-gauge electrodes. The current setting must be altered to 160 amperes.

It will now be found that the edges of the pad are becoming increasingly difficult to stop from running over and, to counteract this, one of the copper or brass bars should be placed along the edge of the pad and the weld deposited against this. A straight, clean edge will result. Brass and copper become hot very quickly and several bars should be available for use so that when one is in use the remainder are cooling.

When the pad has reached a thickness of approximately  $\frac{5}{8}$  in., stop welding, clean with a wire brush, allow to cool and then saw

cut in halves. When cut in halves, file smooth, polish with emery cloth, buff up on a cloth wheel, and etch with 20% nitric acid in water or spirit. The weld metal will show up in contrast to the parent plate and thus the degree of penetration of weld metal into the parent plate may be observed. Any blow holes and slag inclusions will also be visible. (A section on macroscopic examination is included in Volume 1, page 125.)

### Butt Welds in Mild Steel

*(Using electrodes other than deep penetration types)*

A butt weld is the welding together of two pieces of parent metal whilst both are laying together in the same plane. It is not sufficient just to bring the two edges of the plate together and then weld (this is only possible on the thinner materials). The edges of the plates may have to be chamfered, or "prepared". The types and shape of the *preparation* depends upon the thickness of plate (Figs. II.11, 12, 13).

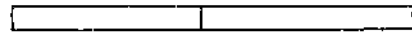
Preparation of the edges is necessary to ensure maximum penetration of the weld metal through to the under side of the plates. For example, if one were to attempt to butt weld two pieces of mild steel plate together  $\frac{5}{8}$  in. thick, using manual metallic arc welding, without preparing the edges beforehand, the force of the arc would only be sufficient to penetrate for approximately  $\frac{3}{32}$  in. If welded from both sides, this would only give  $\frac{3}{16}$  in. of penetration, leaving  $\frac{7}{16}$  in. of unwelded plate. This condition would be most unsatisfactory from the point of view of joint strength.

The edges of plates may be prepared for welding by either flame cutting, machine tool cutting, machine grinding or hand grinding. Flame cutting is the quickest and cheapest method and the finished surface in most instances is quite satisfactory for welding. Machine tool cutting is expensive and the time required to set up the job makes the whole operation very expensive. The finished surface may be neat and smooth in appearance, but this

METHOD

type of surface is not really necessary for most welding operations. Grinding of the plates is a long and expensive process and is seldom considered.

The preparation of plate edges by flame cutting is usually carried out using a profile burning machine or with a straight line burning machine. (These are dealt with in Volume 1, page 100.)



Less than  $\frac{1}{8}$ " Close butt - No gap



$\frac{1}{8}$ " to  $\frac{1}{4}$ " No preparation -  $\frac{1}{16}$ " to  $\frac{1}{8}$ " gap



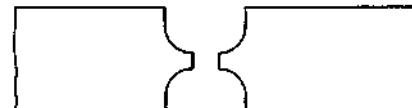
$\frac{1}{4}$ " to  $\frac{3}{4}$ " 60° single "Vee" -  $\frac{1}{16}$ " to  $\frac{1}{8}$ " gap  
Root face  $\frac{1}{32}$ "



Over  $\frac{3}{4}$ " 60° double "Vee" -  $\frac{1}{16}$ " to  $\frac{1}{8}$ " gap  
Root face  $\frac{1}{32}$ "



Over  $\frac{3}{4}$ " Single "U" -  $\frac{1}{16}$ " to  $\frac{1}{8}$ " gap  
Root face  $\frac{1}{32}$ "



Over  $\frac{3}{4}$ " Double "U" -  $\frac{1}{16}$ " to  $\frac{1}{8}$ " gap  
Root face  $\frac{1}{32}$ "

FIG. II.11. Plate edge preparation for butt welds in mild steel.



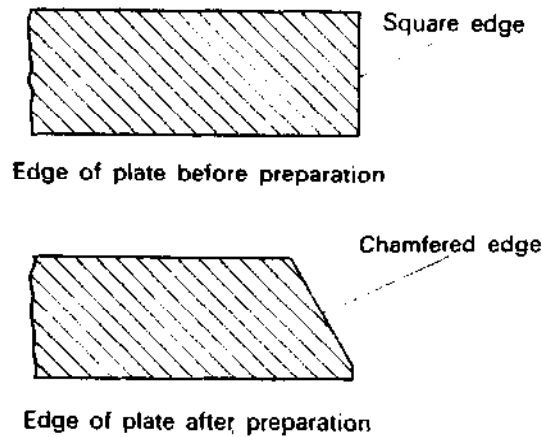
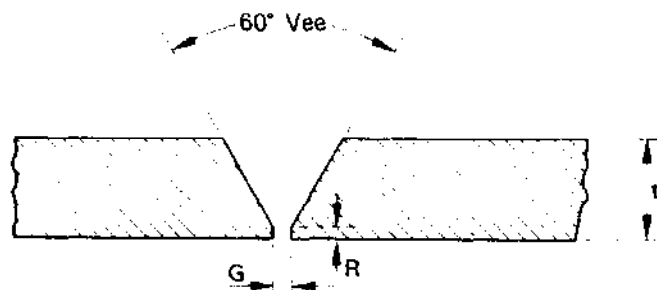


FIG. II.12. Plate edge preparation.

BUTT WELD,  $\frac{3}{8}$ -IN. THICK MILD STEEL (MANUAL ARC), DOWNHAND POSITION

MATERIAL:  $3 \times \frac{1}{8}$ -in. thick mild steel flat bar, 13 in. long, two pieces.

This weld piece is to be tested in accordance with B.S. 1295 test MA/T2. Thoroughly wire brush both edges of the plates and flatten on the anvil if necessary. Set up for welding with a  $\frac{1}{16}$ -in. gap. Preset the plates as shown in Fig. II.14a. Tack weld at both ends and in the centre, using a 12-gauge electrode at approximately 92 amp. Remove slag and wire brush tacks. The tack



"t" = Plate thickness  
"G" = Gap at the root  
"R" = Width of the root face

FIG. II.13. Plate prepared and set up for butt welding.

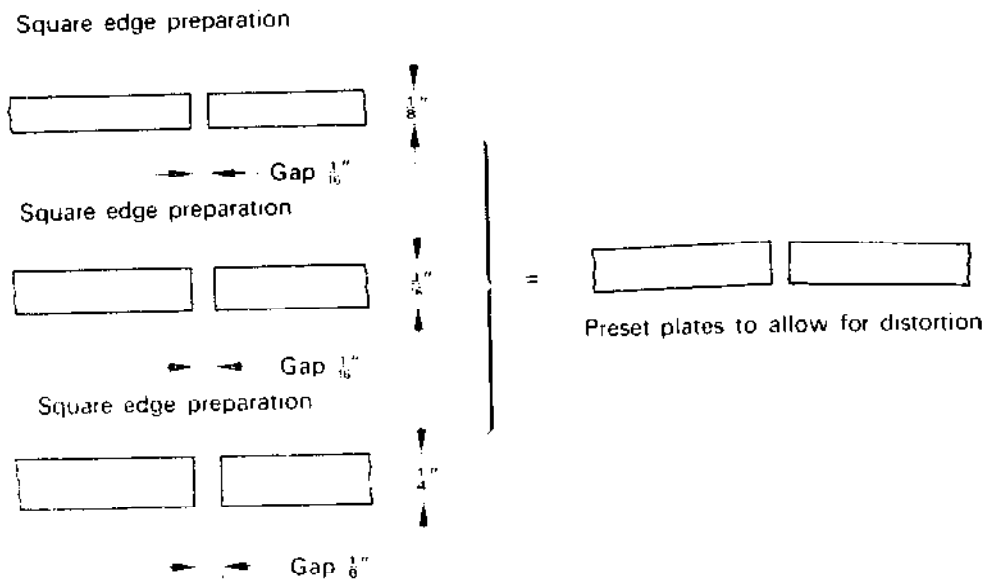


FIG. II.14a. Square edge preparation and gap settings.

welds should be  $\frac{3}{4}$  in. long and maximum penetration should be ensured, particularly with the centre tack. Weld the joint using a 10-gauge electrode at approximately 108 amp. Remove slag and wire brush completed weld. Weld one side only. An even bead of penetration should appear on the underside of the weld. Cut the test piece and test as specified in B.S. 1295 test MA/T3. (Note B.S. 1295 states that test MA/T2 must be prepared prior to welding; in order to obtain a perfect weld, in  $\frac{1}{8}$ -in. thick mild steel this is not necessary and a square edge butt may be used.)

**BUTT WELD,  $\frac{3}{8}$ -IN. THICK MILD STEEL (MANUAL ARC), DOWNHAND POSITION**

**MATERIAL:**  $3 \times \frac{3}{8}$ -in. thick, mild steel flat bar, 13 in. long, two pieces.

This weld piece is to be tested in accordance with B.S. 1295 test MA/T2. Prepare one edge of each plate with a  $30^\circ$  single chamfer. A  $\frac{1}{32}$ -in. root face may be obtained by running the sharp edge of the chamfer along a grinding wheel. Remove any loose scale and oxide by wire brushing. Set up for tack welding with a  $\frac{3}{32}$ -in. gap,

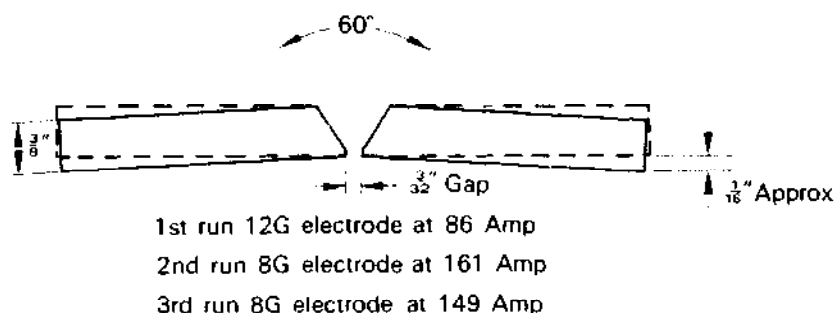


FIG. II.14b. Set up of plates for butt weld.

as shown in Fig. II.14b. Preset as shown in Fig. II.14b. Tack weld at each end and in the centre, using a number 12-gauge electrode at approximately 86 amp. Remove the slag and wire brush the tack welds. The tack welds should be  $\frac{3}{4}$  in. long and it is necessary to ensure maximum penetration, particularly with the centre tack. Commence to weld the joint with the first run using a 12-gauge electrode at 86 amp. Do not weld over the tacks but weld up to them and stop. Follow by one run with an 8-gauge at 161 amp and a final run using an 8-gauge electrode at 149 amp, this run will have to be weaved (see p. 51). An even bead of penetration should be apparent on the underside of the joint and the top side should be of even reinforcement and free from undercut.

### Open Corner Welds in Mild Steel

A corner weld is the bringing together of two pieces of parent metal so that they are at right angles to one another. No edge preparation is necessary for corner welds, other than the normal wire brushing of the edges.

As in the case of butt welds, penetration through to the underside of the joint is very important, and an even bead is necessary to ensure maximum joint strength.

The top side of the weld is also very important, in that it must form a smooth contour with the parent plates, and the thickness of the weld must be the same as the parent plate. Plate II.7 illustrates a corner fillet of smooth contour and good penetration.

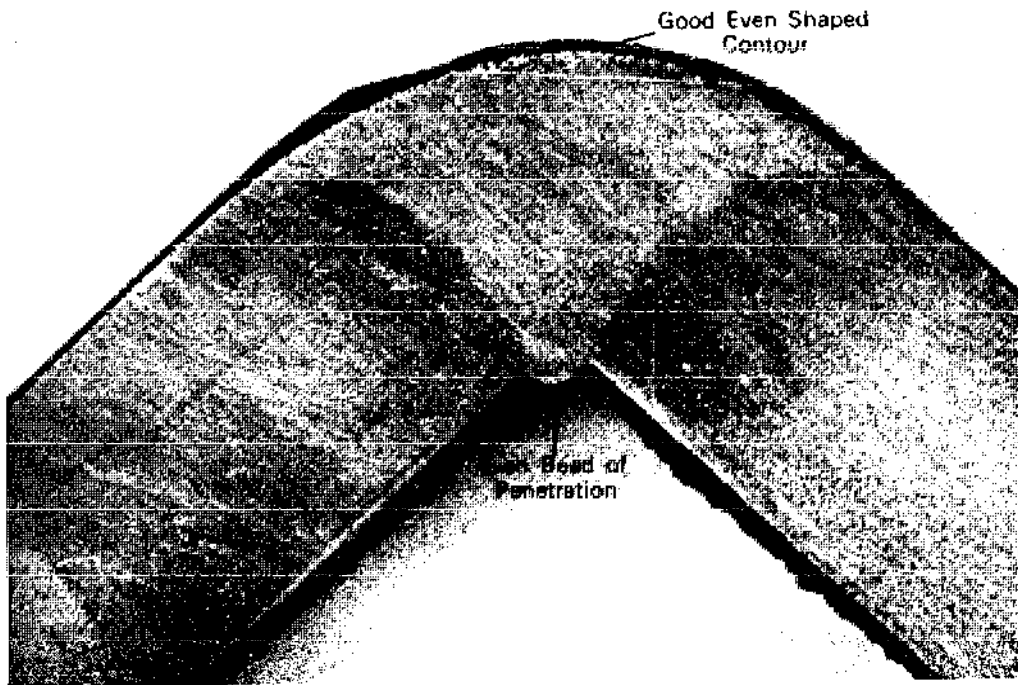


PLATE II.7. Open corner weld,  $\frac{3}{8}$ -in. thick mild steel.

Corner welds are easy to execute, particularly if they can be tilted to the gravity position, and the finish is pleasing to the eye if the weld is laid down correctly.

Figure II.15 illustrates an open outside corner weld set up prior to welding. A slight gap is necessary at the root to ensure maximum penetration. Some joints are required to have an inside fillet, but this is not to be considered at this stage. Against the

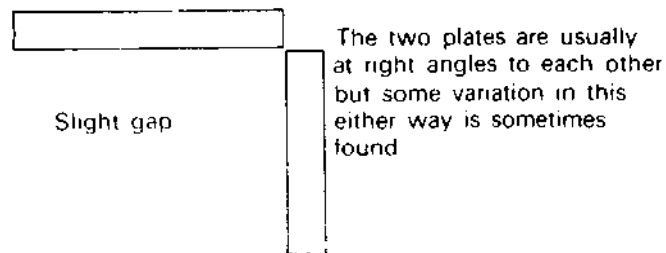


FIG. II.15. Open outside corner joint set up.

use of inside fillets with open corner joints are extra costs coupled with perhaps the difficulty of getting at the inside of the joint.

A simple jig for setting up small corner weld test pieces is shown in Plate II.8. The slots enable adjustments to be made

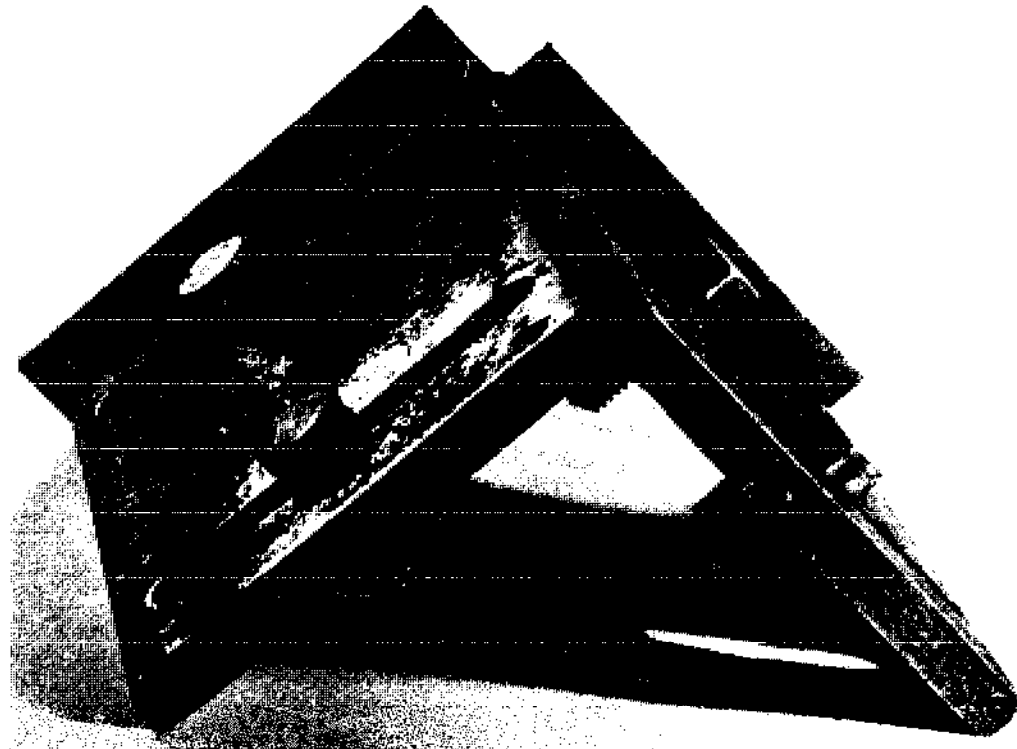


PLATE II.8. Assembly jig for corner joints.

according to the size of material being used and the gap required. The test piece should be removed from the jig prior to welding.

OUTSIDE CORNER JOINT,  $\frac{3}{16}$ -IN. THICK MILD STEEL (MANUAL ARC),  
DOWNHAND POSITION

MATERIAL:  $3 \times \frac{3}{16}$ -in. thick mild steel flat bar, 7 in. long, two pieces.

Thoroughly wire brush the plate edges and flatten on the anvil if necessary. Set up for welding as shown in Fig. II.15. The correct gap setting is very important.

## METHOD

Tack weld at both ends and in the middle, using a 12-gauge electrode with a setting of 80 amp. Thoroughly remove the slag and wire brush. Commence welding the first run, using a 12-gauge electrode at 80 amp. This will ensure an even bead of penetration on the underside of the joint. Remove the slag from the first run and wire brush. Deposit the final run with a 10-gauge electrode at 117 amp (weaving of the electrode is not necessary). Clean the final run by chipping and wire brushing, making quite sure that all excess weld spatter is removed. Saw cut the specimen and macro-etch.

OUTSIDE CORNER JOINT,  $\frac{1}{4}$ -IN. THICK MILD STEEL (MANUAL ARC),  
DOWNHAND POSITION

MATERIAL:  $3 \times \frac{1}{4}$ -in. thick mild steel flat bar, 7 in. long, two pieces.

Thoroughly wire brush the plate edges and flatten on the anvil if necessary. Set up for welding as shown in Fig. II.15. The correct gap setting is very important.

Tack weld at both ends and in the middle, using a 12-gauge electrode with a setting of 80 amp. Remove the slag from the tacks and wire brush. Commence welding the first run, using a 12-gauge electrode at 80 amp, which will ensure an even bead of penetration on the underside of the joint. Remove the slag from the first run and wire brush. Deposit the final run with an 8-gauge electrode at 150 amp (weaving of the electrode is not necessary). Clean the final run by chipping and wire brushing, making quite sure that all excess weld spatter is removed. Saw cut the specimen and macro-etch.

OUTSIDE CORNER JOINT,  $\frac{3}{8}$ -IN. THICK MILD STEEL (MANUAL ARC),  
DOWNHAND POSITION

MATERIAL:  $3 \times \frac{3}{8}$ -in. thick mild steel flat bar, 7 in. long, two pieces.

Use the same procedure as described in the previous examples, but the weld runs are as follows: first run—12-gauge electrode

at 92 amp; second and third run—10-gauge electrode at 117 amp; fourth and final run to be carried out using an 8-gauge electrode at 140 amp. Weaving of the final run is necessary and great care should be taken to ensure an even ripple surface finish by the correct side-to-side motion of the electrode (see p. 51).

### Tee and Lap Joints

#### TEE JOINTS (MANUAL ARC), TILTED POSITION

**MATERIAL:**  $3 \times \frac{3}{16}$  in.,  $3 \times \frac{1}{4}$  in.,  $3 \times \frac{3}{8}$  in., mild steel flat bar, two pieces of each thickness, 13 in. long.

These welds are to be tested in accordance with B.S. 1295 test MA/T8. The edges of a flat bar will be found to be slightly radiused, where an edge is to come in contact with a flat plate to form a tee-fillet joint. This edge will need to be ground flat.

Thoroughly wire brush and flatten the plates as necessary. Set up for welding. [The magnetic blocks will be found to be a great help here, slightly preset (Fig. II.16).] Tack weld on the

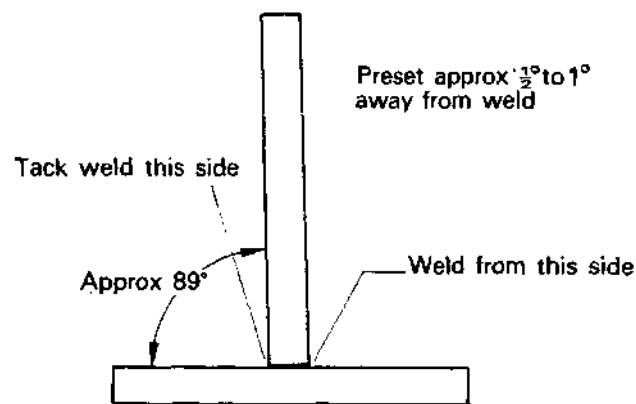


FIG. II.16. Tilted tee-fillet weld.

opposite side to the intended welded joint. One tack at each end will suffice.

Prior to commencing the weld, set up as shown in Fig. II.17.

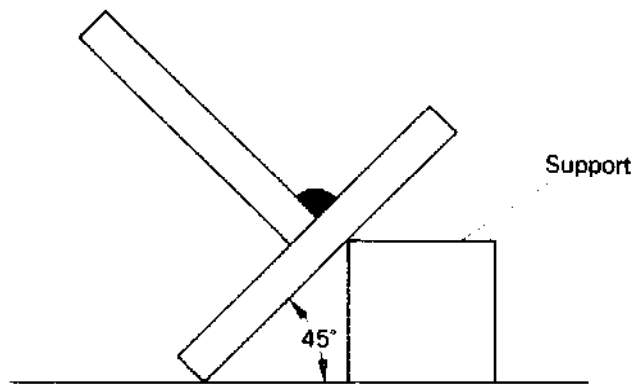


FIG. II.17. Tilted tee-fillet weld. Single run.

The correct positioning of the test piece is important and should the slope be incorrect the weld will be of uneven leg length.

For  $\frac{3}{16}$  in. use a 10-gauge electrode at 108 amp, for the  $\frac{1}{4}$  in. use a 8-gauge electrode at 160 amp, and for the  $\frac{3}{8}$  in. use a 6-gauge electrode at 220 amp. One run for each joint will suffice.

Do not allow the electrode to touch the sides of the plates, as this will cause undercutting. The same will result from too high a current, a common and easily made fault when completing this joint.

Weaving of the electrode is not to be attempted as it is necessary to get the weld as far into the two plates as possible.

#### LAP JOINT (MANUAL ARC), TILTED POSITION, SINGLE RUN

**MATERIAL:**  $3 \times \frac{3}{16}$ -in. mild steel flat bar, 13 in. long, two off.

A lap joint is a joint in which the two plates to be joined overlap one another, thus making it possible to execute two fillet welds.

For the test piece, the overlap needs to be  $1\frac{1}{2}$  in. Thus the finished joint, if 3-in. flat bar is used, will be  $4\frac{1}{2}$  in. wide.

Thoroughly wire brush and flatten the material as necessary. It is important that both plates are absolutely flat so as to ensure a gap-free joint between the two surfaces. The use of small "G"



clamps will suffice to hold the plates whilst tacking. Before commencing to weld set up the test piece as shown in Fig. II.18. The correct slope is important because, if the slope is incorrect, an uneven deposit may result.

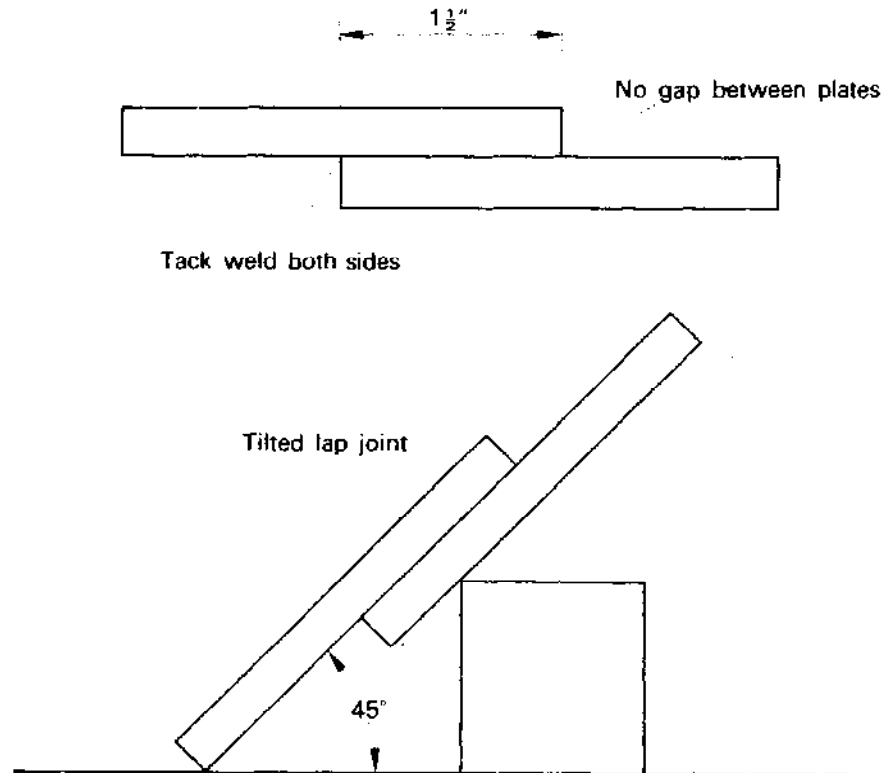


FIG. II.18. Tilted lap joint.

The joint is to be completed in one run, and for this use an 8-gauge electrode at 140 amp (weaving is not necessary and it is most important to ensure good penetration). "Bridging" of the two plates with penetration of each is not sufficient—the penetration must be complete into the root.

The edge of the completed weld must be straight, and the weld must not overlap into the top plate in an uneven manner.

Saw cut both ends, file and etch the weld. Saw cut a specimen 2 in. wide and break open. Inspect for defects.

## LAP JOINT (MANUAL ARC), TILTED POSITION, MULTI-RUN

MATERIAL:  $3 \times \frac{3}{8}$ -in. mild steel flat bar, 13 in. long, two off.

Carry out the same preparation and setting up technique as outlined for the previous test piece.

This joint is to be completed in three runs, all with an 8-gauge electrode at 140 amp. The first run is to be deposited in the root of the joint and maximum penetration again is essential. The second run is to be made above and to the left of the first run, and here the correct penetration and even line into the top plate has to be ensured. The third run is deposited below and to the right of the first and second runs (an even weld line and maximum penetration into the lower plate is essential—see Fig. II.19).

Saw cut and etch as detailed in the previous test piece.

## Weaving

The process of weaving should not be attempted until the practising of straight runs has been completed.

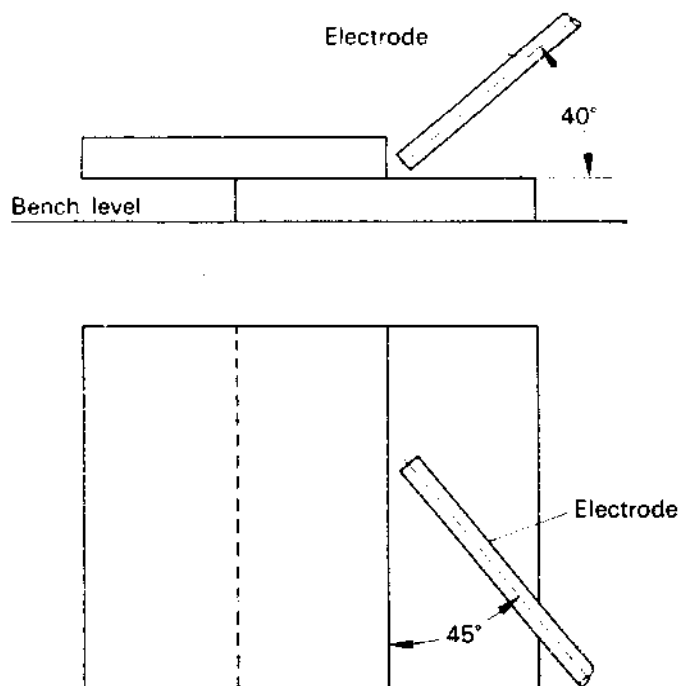


FIG. II.19. Electrode angles for lap joints and tee fillets.

Weaving is the method employed to cover a larger surface area with weld metal than is normally covered by a single straight run. If a  $\frac{3}{4}$ -in. thick mild steel single vee butt joint is considered, it will be found that the vee at the top is approximately  $\frac{7}{8}$  in. wide. This width cannot be covered with a single straight run using manual arc welding, for it would require three or four single runs of weld, which would give an uneven appearance and would also be detrimental to the strength of the joint.

Weaving, therefore, is a method of finishing off a weld, giving it a nice appearance and at the same time ensuring maximum joint strength.

There are several methods employed in making a weave, the most common of which is an ordinary side-to-side motion employed on downhand welds. Weaving is not an easy art to acquire and needs much practice; a badly executed weave not only looks of poor appearance but also may be the result of weld failure at a later date, if not corrected.

The faults most common to weaving are: incorrect finishing at the end of each weave leaving a gap between weaves; entrapped slag caused by excessive overlapping of weaves; and uneven surface ripples caused by incorrect manipulation of the electrode.

### *Methods of Weaving*

#### SIDE-TO-SIDE MOTION FOR DOWNHAND (FLAT) POSITION (Fig. II.20(a))

Commence the weld to one side of the joint and move to the opposite side, holding the weld at this point for a matter of a few seconds only and at the same time moving back into the corner very slightly. Then move across to the opposite side of the weld and repeat the sequence. Failure to hold in the corner and to move back slightly will result in a poor weave.

#### CIRCULAR MOTION FOR DOWNHAND (FLAT) POSITION (Fig. II.20(b))

Commence the weld to one side of the joint and move down and round to the opposite side of the weld and back round the top

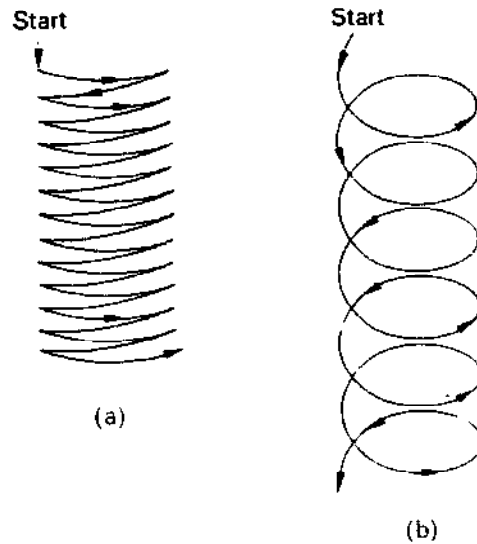


FIG. II.20. Downhand weave: (a) side-to-side method, (b) circular method.

of the previous weld so completing a circle. Great care must be taken when employing this method not to trap slag in the weld.

### Butt Welded Joints in Pipes

*(Rotated. Up to 5½ in o.d. pipes)*

The method of welding butt joints in pipes that are being rotated during welding is much the same as the welding of downhand butt welds in flat plates.

The method of rotation may be by hand or by machine. When a machine is used, the machine rotating at a fixed speed, welding may be completed in one without stopping, provided that the circumference of the pipe can be welded with one electrode; if not, the only stopping times are to fix a fresh electrode. If the pipe has to be rotated by hand, many stops will have to be made to bring the pipe up to just past top dead centre to enable all the weld to be deposited in the downhand position.

It is this constant stopping and restarting that requires the welder to execute care and skill because defects in the weld are

likely to occur at the restart positions if care is not taken. The slag at the end of each run must be removed and the weld wire brushed. The restart should then be made in such a position on the end of the previous run that it will not cause a lump to protrude which would make subsequent runs of weld uneven at the points of protrusion. If difficulty is experienced in restriking the electrode (and some makes of electrodes are difficult to restrike) have a piece of plate handy so that the restrike may be carried out on this and the electrode tip, whilst still hot, transferred to the pipe joint for the next run. Remember, a bad restrike will most probably result in porosity.

The pipe edge preparation is a  $70^{\circ}$  to  $75^{\circ}$  included angle with a root face of  $\frac{1}{16}$  in. to  $\frac{3}{32}$  in. and the gap between the two pipes approximately  $\frac{3}{32}$  in. to  $\frac{1}{8}$  in. Set the two pipes up on self-aligning pipe rollers to facilitate rotation of the job.

The first run is deposited with a 12-gauge or 10-gauge electrode and over-penetration into the pipe bore is to be avoided—it must not exceed  $\frac{1}{16}$  in. The subsequent runs may be carried out with a 10-gauge or 8-gauge electrode. The number of runs required to complete the joint will depend upon the thickness of the tube, but this should be approximately  $\frac{3}{16}$  in. to  $\frac{1}{2}$  in. thick.

The weld should then be examined and tested as described in “Weld Testing”, Volume 1 p. 123. The nick-break test should be taken from the weld start.

### **Technique for Vertical Welding (Upwards) (Figs. II.21, 22)**

Students of welding will find that to weld vertically upwards will require more skill than that necessary for downhand flat welding. The need to practice this technique continuously is essential if one is to master the vertical upwards welding method. The welder will experience more fatigue because of the necessity to hold the arm in one position and at the same time remain steady. Also, the electrode tip is more difficult to control in this position.

For the first practice at vertical upwards welding a “tee” fillet should be set up, using  $\frac{3}{8}$ -in.-thick mild steel (two pieces 6 in.

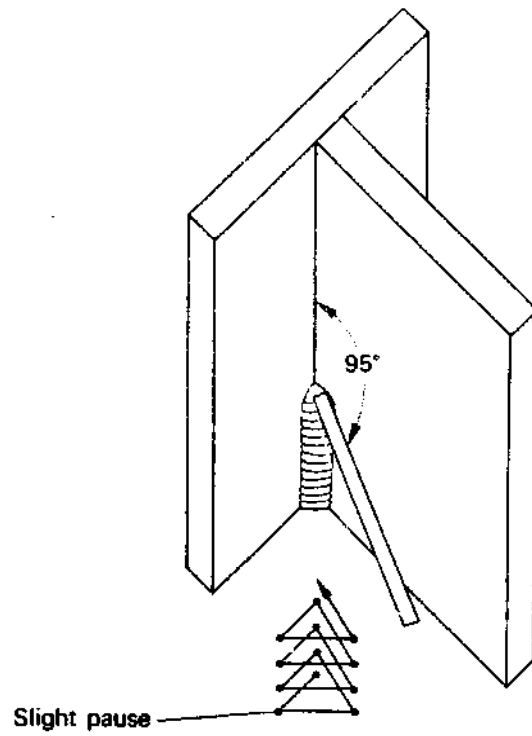


FIG. II.21. Electrode angle and weave for vertical welding.

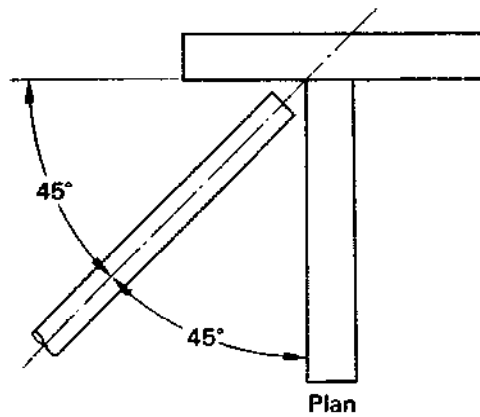


FIG. II.22. Electrode angle for vertical welding.

long by 3 in. wide). Tack weld the "tee" in the downhand position. Clamp the piece in a bench stand and sit on a stool for the initial practices. At a later date, clamp the pieces in a floor stand and practise welding standing up.

After ensuring that the metal surface is thoroughly free from dirt and scale, select a 10-gauge electrode.

Here a word about special vertical welding electrodes. Most electrode manufacturers do supply special electrodes for vertical welding and, although almost all electrodes may be used for downhand and vertical work, an electrode designed for vertical welding should be used for preference. The coating of these special electrodes is of such a nature that the weld metal and the slag remain as they should and do not run away down the joint.

The current conditions for vertical welding are lower than those required for downhand welding and it is recommended that a small-gauge electrode be used.

For the first run on the test piece set the current for the 10-gauge electrode at 95 to 100 amperes. Strike the arc and commence to weld, holding the electrode at an angle of 95° from the top of the joint. Do not weave as no side-to-side movement is necessary, but keep the arc length as short as possible. Move up the joint fairly slowly and do not dwell on what the weld is going to look like, but concentrate on moving upwards and keeping the arc short and free from wander. When the run is complete, chip off the slag and wire brush clean. Do not expect the run to look as smooth in appearance as downhand welds—it never will on vertical work, although as one goes on practising the welds will get better in finish.

For the second run, use the same gauge electrode at 95 to 100 amperes, but this time a side-to-side motion or weave is necessary. Remember to keep the arc short and, when weaving, the movement must come from the whole of the arm. Do not move the wrist, which is required to remain steady so as to ensure a short arc. The side-to-side movement is in the form of a triangle and, to begin the second run, strike the arc in the centre of the first run and move the electrode tip slightly downwards and to the left. This will now bring the electrode to the edge of the first run and

on the left hand plate. A slight pause is now necessary before moving over to the right-hand side of the joint and a pause is now necessary before moving back to the centre of the first run slightly above the deposited weld. This completes the triangle and the whole process is carried out again until the weld is completed. A word of warning here. It is most essential that a slight pause is made at either side of each weave, for if this is not done the weld will be incomplete at these points.

Remember the following points and correct as necessary. Ensure correct amperage; electrode angle approximately  $95^\circ$  from top of joint; electrode to be directed well into the joint and half-way between each plate; pause in the corners and use a triangular weave.

Should the restriking of each new electrode prove difficult, the following method may be adopted. Strike the arc approximately  $\frac{1}{4}$  in. below the finish of the previous electrode and when a stable arc has been established move on to the start of the weld. This method will leave some excess weld metal on the completed weld at each start point, but this may be chiselled off, to reduce the risk of porosity when welding subsequent runs.

#### BUTT WELDS IN THE VERTICAL (UPWARDS)

The plates for vertical butt welds are prepared for welding in exactly the same way as for downhand butts. A  $60^\circ$  inclusive vee with a chamfer on the reverse side is prepared and the gap setting is  $\frac{3}{32}$  in. The first run is made in the small chamfer on the reverse side. This may be performed in the vertical downwards position. This first downwards run is easy to perform and some of the slag will penetrate through to the other side of the vee and must be removed before welding commences on the front face.

The weld is completed by exactly the same technique as for vertical tee fillet welding.

The final run may be deposited with a small-gauge electrode, the movement from side to side must be adhered to, but the pause at each corner need not be so long as when depositing the previous runs.



VERTICAL WELDING (DOWNWARDS), “STOVEPIPE” TECHNIQUE (Fig. II.23)

The “Stovepipe” technique is used for the butt welding of pipes, i.e. pipes that cannot be rotated and therefore have to be welded in position. Many cross-country oil and gas pipe lines are welded using this technique.

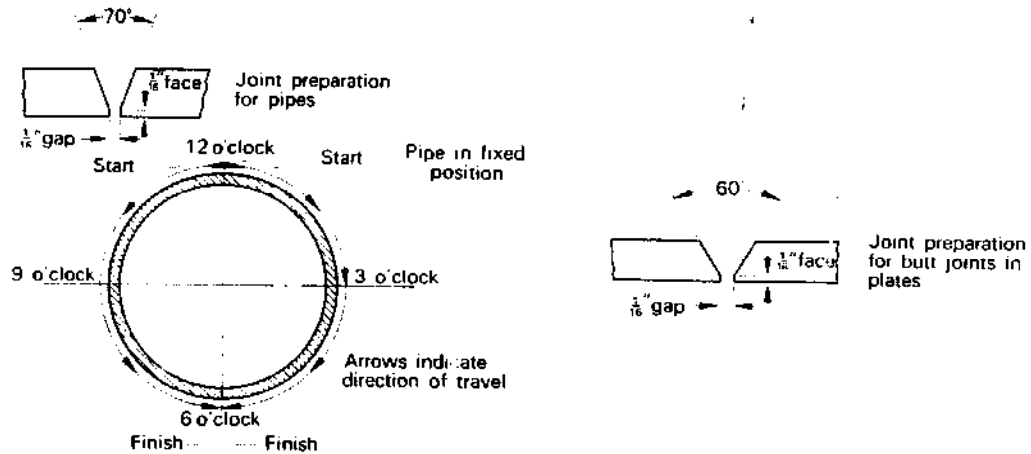


FIG. II.23. Stovepipe welding.

The preparation recommended for the joint is 70° included angle vee, a root face of  $\frac{1}{16}$  in. and a  $\frac{1}{16}$ -in. root gap.

The electrodes used should conform to B.S. 1719 class 1. This type of electrode is most suitable because of its deep penetrating characteristics, its thin slag coating and the fact that it may be used in all welding positions. The last fact mentioned is most important, because when using the “stovepipe” technique, the welding position changes during welding from almost downhand at the start, to overhead at the finish.

The weld is commenced at the top dead centre of the pipe and this is referred to as the 12 o'clock position. The joint is welded downwards finishing at bottom dead centre, the 6 o'clock position. The same procedure is then repeated on the opposite side of the pipe. The first run in the joint is referred to as the “Stringer Bead” and it is laid by “dragging” or touching the electrode against the

root of the joint. The weld is deposited without weaving, and the electrode is held at an angle of  $60^\circ$  to the line of travel.

The second run, known as the "Hot Pass", is made commencing at the 12 o'clock position and finishing at the 6 o'clock position. The same gauge electrode is used and the touch or "Drag" technique is still practised, the angle of electrode remaining the same as for the first run, i.e.  $60^\circ$ .

The third run, or "Filler Bead", is deposited by normal open arc methods, that is, an arc length of approximately  $\frac{1}{8}$  in. The weld is commenced at the 12 o'clock position with the electrode at an angle of  $90^\circ$  to the line of travel. When the 3 o'clock position is reached (9 o'clock on the opposite side) the weld position starts to become overhead and the angle of the electrode must be corrected to  $130^\circ$  to the line of travel.

Upon completion of the third run the weld should be inspected for shallow depressions, which will normally occur at the 2 o'clock to 5 o'clock positions and the 7 o'clock to 10 o'clock positions. If necessary, any shallow depressions should be filled with weld metal by a single pass run, using an open arc and with an electrode angle of  $90^\circ$  to the line of travel.

The final run, referred to as the "Capping Bead", is made with the electrode held at an angle of  $90^\circ$  to the horizontal. A side-to-side weaving technique is employed, and upon approaching the positions previously referred to, the angle of the electrode is increased to  $130^\circ$  to the line of travel.

### City and Guilds Work

When attempting the practical work required in *City and Guilds Course, No. 323, Welding Craft Practice (Part 1)*, the following recommendations should be followed:

#### *First Year of Course*

*Exercise 3.2* (see pp. 32–38).

*Exercise 4.2* (see pp. 34–40).

*Exercise 5.2* (see pp. 38–40).

*Exercise 6.2* (see pp. 40–44). The  $\frac{3}{16}$ -in. edge preparation and gap setting as in Fig. II.14 and two runs with an 8-gauge electrode at 140 amp will be necessary. The  $\frac{1}{4}$ -in. edge preparation and gap setting is as shown in Fig. II.14 and two runs are again necessary, both with a 6-gauge electrode at 210 amp.

*Exercise 7.2* (see pp. 44–48).

*Exercise 8.2* (see pp. 48–49).

*Exercise 9.2* (see pp. 49–51).

*Exercise 10.2.* Carry out the same preparation and setting-up technique as for Exercise 9.2, but the test pieces are to be welded in the horizontal-vertical position. (The specimen is not tilted, but lies flat on the bench.) The weld runs are the same as for Exercise 9.2, but the electrode angles are as shown in Fig. II.19.

*Exercise 11.2* (see pp. 40–44). The  $\frac{1}{4}$ -in. specimen should be prepared as shown in Fig. II.11. The  $\frac{1}{2}$ -in. test specimen should be chamfered as shown in Fig. II.11. The gap settings are also shown. The joint will require the first run to be deposited with a 10-gauge electrode at 108 amp and the subsequent runs with an 8-gauge electrode or 6-gauge electrode. The final run will have to be weaved. The  $\frac{3}{4}$ -in. specimen may be completed in exactly the same way as the  $\frac{1}{2}$ -in. specimen, with either single vee or double vee preparation.

*Exercise 12.2* (see pp. 38–40). Carry out as detailed on page 39, but 8-gauge and 6-gauge electrodes are to be used and the pad thickness should be from  $\frac{3}{8}$  in. to  $\frac{1}{2}$  in.

*Exercise 13.2.* Prepare the round bar with a double-vee preparation. A  $60^\circ$  include angle on each vee is necessary, and this type of preparation on round bar is referred to as a “Chisel-point Preparation”. Set up the two parts in vee blocks with a  $\frac{1}{8}$ -in. gap between the two faces (the *root faces*) which should be  $\frac{1}{32}$  in. wide. Use 10-gauge electrodes throughout the whole welding operation, placing alternate runs in each vee to minimise distortion. When the weld metal is level with the diameter of the bar, the runs may be made longitudinally to give a smoother and neater finish to the weld. A word of warning here with regard to slag cleaning: it is a most important feature of this specimen that

all slag should be thoroughly removed. Because a large number of runs have to be laid down the job does become tedious, but do not let this interfere with correct cleaning.

*Exercise 15.2* (see pp. 58–59). The “Stove Pipe” technique of vertical downwards welding is described earlier. This same method may be used for vertical downhand butt welds.

### *Second Year of Course*

At least five specimen welds must be completed by the electric arc process during the second year and must also be tested by the student.

*Exercise 1.2* (see pp. 38–40). This test piece is carried out using 8-gauge electrodes at 130 amp. The beads must be straight with no weaving. Use the same technique as described for test No. 5.2 with regard to the deposition of the runs. Copper bars are not necessary to prevent the sides from collapsing. The ultimate test of a good surface finish is that when looked at from above (when the pad is lying flat on the bench), it should be indistinguishable from a pad that has been executed in the downhand position.

*Exercise 2.2.* The plate edge preparation is the same as for butt welds in the flat position. The first run should be carried out with a 12-gauge electrode at 80 amp. Slag must be thoroughly chipped out before the second run is commenced. The existing runs are made by welding upwards and the final run must be of a good finish. A side-to-side movement with a slight pause each side is necessary. The arc must be kept short with each layer laid on the step of the preceding layer.

*Exercise 3.2* (see pp. 54–57). The vertical welding of lap joints should be carried out in the same manner as that described for fillet welds.

*Exercise 4.2* (see pp. 54–57).

*Exercise 5.2.* (see pp. 54–57). The open outside corner joints in the vertical position in  $\frac{1}{4}$ -in. and  $\frac{3}{8}$ -in. plate should be set up with a  $\frac{1}{8}$ -in. to  $\frac{1}{16}$ -in. gap between the plates. The first run on both test pieces is carried out with a 10-gauge electrode at 70 amp. The  $\frac{1}{4}$ -in. specimen should require two runs and the  $\frac{3}{8}$ -in. specimen

*WELDING CRAFT PRACTICE—PART 1, VOL. 2*

three runs, all with an 8-gauge electrode, with the exception of the first run.

*Exercise 6.2* (see pp. 53–54).

*Exercise 7.2* (see pp. 54–57).

*Exercise 8.2* (see pp. 65–70).

*Exercise 9.2* (see pp. 65–70).

*Exercise 10.2* (see pp. 63–65).

## CHAPTER 3

# Special Techniques

### Building up Worn Parts with Mild Steel Electrodes (Fig. II.24)

Sometimes it is possible to build up worn parts of machinery with weld metal thereby saving time and money. The technique is particularly useful for worn shafts, oversize bores, worn-down blades and many other applications too numerous to mention here. The building up of a part by weld metal may also be used

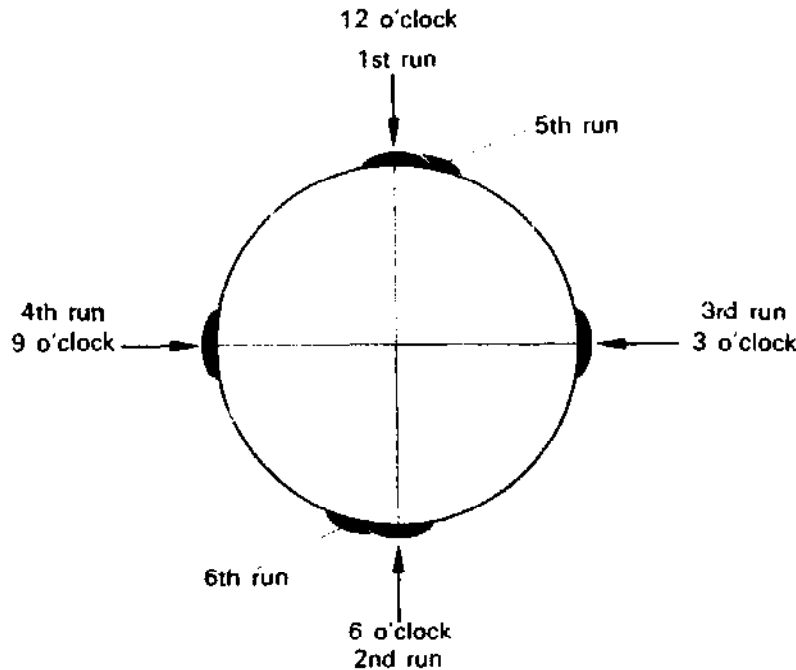


FIG. II.24. Building up a worn shaft.

on items that may have been incorrectly machined during manufacture, in this way a costly item may be saved from the scrap box. (See also Volume 1, page 97.)

Before commencing work on old worn parts, all grease and dirt must be removed. This should be carried out by a thorough wire brushing or grinding and if necessary immersion in a degreasing agent. Any protruding edges or unwanted metal in the way of the new weld metal should also be removed.

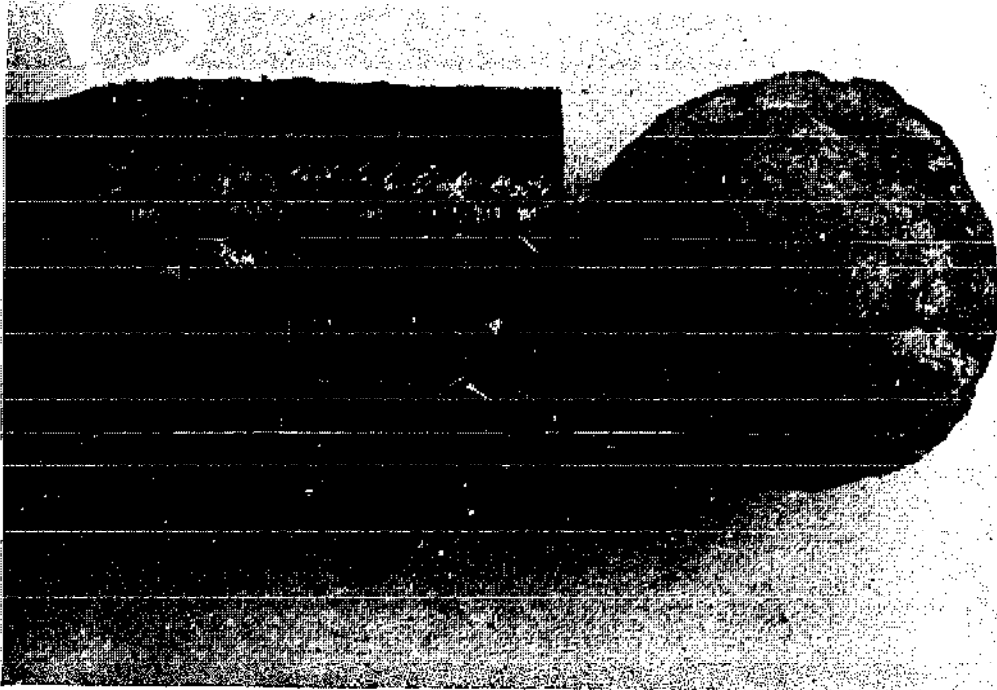
Examine the surface for any deep voids or cracks and deal with these before building up the part. Cracks must be gouged out to a point beyond their depth and then welded. Welding over a crack on the surface is wrong and should on no account be carried out because of the possibility of the crack still being present beyond the depth of weld penetration.

The probable effects of the heat causing distortion must now be considered. If a shaft is to be built up, distortion may take place, depending on its diameter and length. However, it is always the safest policy to assume that distortion will occur and to take the necessary steps to minimise it.

The welding has to be carried out so that the heat input is minimised and also so that the heat is spread out over the whole area of the part to be built up. The heat input may be reduced to a minimum by the use of large-gauge electrodes and also by working on the shaft at intervals. This will enable the welds to cool. Commence the weld at 12 o'clock with a single run along the length of the worn area. Commence the next run at 6 o'clock to counteract the pull from the first run and to help to even the heat distribution. Run number three is laid down at 3 o'clock and run number four at 9 o'clock. This sequence is carried on until the shaft has been completely built up over the whole area to the required thickness of weld. The welding technique for the laying down of the runs should be the same as for building up the solid pad of weld metal (see p. 38).

A word of warning here about quantity of weld metal. Ensure that the build up of parts that have to undergo machining afterwards is adequate. A great deal of time and therefore expense will be incurred if the job has to be removed from a machine

because it will not "clean up" and it has to be returned for spots of weld here and there where it will not machine up correctly.



**PLATE II.9.** Build up of worn shaft.

If stress relieving of a shaft is necessary after welding, it is important that the shaft is supported in such a way as to ensure that it will not sag. It must be supported on sufficient vee blocks along its whole length or lie flat on a good surface. Remember that a great deal of thought may go into the control of distortion and it may be wasted by incorrect support of the shaft during stress relieving.

### **Electric Arc Welding Cast Iron**

The types of cast iron available today are many and various and the term cast iron is used to describe a range of compositions that may vary very widely indeed.



Types of cast iron include the more common grey cast irons, white cast iron, blackheart and whiteheart malleable cast irons and various other types, including the type known as nodular or spheroidal graphite cast iron.

The problem of welding any one of this wide variety of cast irons is complicated by the fact that most of them are lacking in ductility. Because of this, local preheating and stresses set up during welding are much more marked than those set up during the welding of mild steel. Also, residual stresses are contained within the cast iron and these may be aggravated by welding.

Because many cast irons have a high carbon content certain precautions have to be taken after welding to ensure slow cooling. If allowed to cool too rapidly a hard deposit may result and render the cast iron liable to cracking.

In spite of the foregoing, a large number of cast iron welds are carried out successfully, but there is always a chance of failure. The risk of a failure is well worth taking, however, because the welding of cast iron can save an enormous amount of expense.

Various types of electrodes may be used to weld cast iron depending upon the requirements of the finished weld. An electrode of a copper-nickel alloy will result in a soft weld, because the alloy will bond thoroughly with the casting and the absorption of carbon does not harden the deposited metal. If a ferritic electrode with a low carbon content is used (the carbon content is approximately 0.1%) the resultant weld metal will be hard, because the parent metal (of 3-4% carbon content) will dilute with the weld metal and an increase in the carbon content will result. At the junction of cast iron and weld metal a decrease in the carbon content takes place. Somewhere between the centre of the weld, which is a low carbon area, and the unaffected parent metal, which is high carbon, a zone exists where the carbon content is 0.9%. This zone is extremely hard and is not machineable.

An electrode of nickel-iron alloy will give a machineable deposit, which will fuse very readily with the cast iron and will in fact give a stronger bond than the copper-nickel alloy. The welding of spheroidal graphite cast iron may be carried out very successfully using this type of alloy.

## FACTORS AFFECTING WELDING OF CAST IRON

1. The deposited weld metal will contract on cooling and the contractional stresses set up at this stage must be kept within the weld metal and the parent metal adjacent to the weld if cracking is to be avoided. Owing to the low ductility of cast iron, new fractures may also occur, during or after welding, which may be some distance away from the weld.

2. When using electrodes of mild steel composition carbon will be absorbed from the cast iron into the weld metal, resulting in a hard, brittle weld. This condition can be relieved by slow cooling of the weld. Welds of a less brittle nature may be obtained by using electrodes of such a composition that they will not combine with carbon to form hard deposits (nickel, monel and bronze are typical examples). As an alternative to these types of electrode, the mild steel deposit may be rendered less hard by using a deposit of a special electrode between the cast iron and the mild steel weld metal. This is known as a "buffer" or "buttering" layer (Fig. II.25).

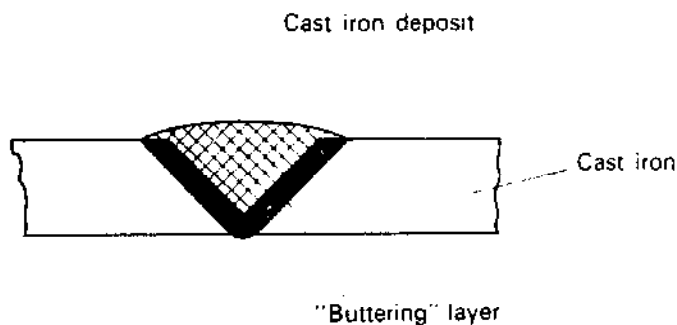


FIG. II.25. "Buttering" of cast iron.

3. The zone of heat in the cast iron adjacent to the weld metal will become very hard if the rate of cooling is rapid, and in fact will become white iron. This is due to the formation of martensite.

In view of these factors and their effects it is necessary to pre-heat most castings, although some electrodes may be used on cold castings. Here the experience and skill of the welder is needed to decide the correct method.

### PREHEATING OF CAST IRON

Preheating is generally only necessary on castings of complicated shape, or which are liable to fracture easily, although if the heat input is kept to a minimum even complicated castings may be welded without preheating.

If preheating has to be undertaken, any one of the following methods may be used:

1. Preheating locally to slow down the rate of cooling at the weld junction.

2. Preheating of the whole casting so as to release internal locked-up stresses and also to help slow down the rate of cooling of the weld. Above 450°C a slight increase in ductility occurs and as the temperature is increased the ductility will also increase. This increase in ductility will reduce the risk of distortion and the risk of cracking.

3. Preheating may also be employed to expand a part of the casting in order to counteract the contractional stresses caused by welding another part of the same casting. Figure II.26 shows an example of this method of preheating.

When preheating has to be carried out it must be applied slowly to allow a uniform distribution of heat to cover the casting. Heat may be effected by furnace or by gas torch.

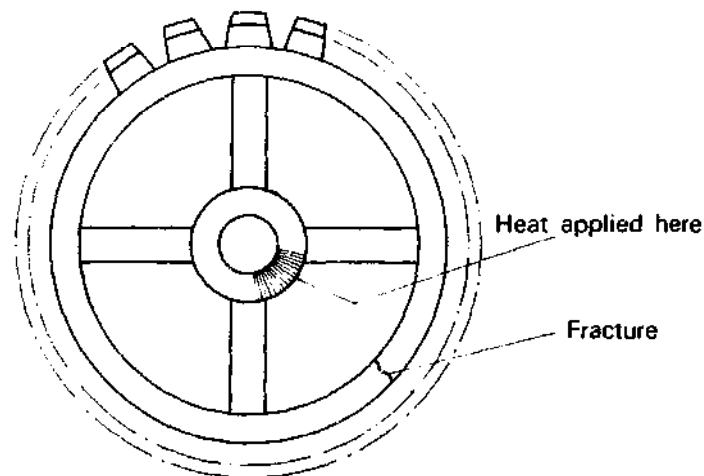


FIG. II.26. Indirect preheating of a fractured cast iron gear wheel.

### SLOW COOLING OF THE CASTING

Slow cooling of the casting after preheating and welding is essential if the risk of cracking is to be reduced. To slow down the cooling rate, cooling may be carried out in the furnace or under asbestos blankets. Warm dry sand may also be used to cover the casting.

### Welding Procedure for Electric Arc Welding Cast Iron

The type of joint preparation will depend upon the thickness of metal. For very heavy sections the double-vee preparation should be used, which will enable deposits to be made on one face and an equal amount deposited on the other face, in sequence, helping to balance the heat input. Where the single vee is used, the job may have to be offset to allow for distortion. Whatever the type of preparation, it must ensure perfect penetration and fusion of the electrode and parent metal. For this reason the root of the weld must be easily accessible.

Welding may be carried out using either the "step-back", "block" or "scattered" methods. In "block" welding, the weld metal is deposited to the full thickness of the metal as it progresses forward. This method ensures that heat is maintained in a certain area during welding. The "step-back" method reduces the movement of the parts being welded and is of particular value when these are of unequal thickness. The procedure for "step-back" welding is as shown in Fig. II.27. The "scattered" method is similar in technique to the "step-back" method and it has the effect of distributing the heat input over a wider area than either of the other two methods.

If the casting has been preheated large-gauge electrodes should be used and the weld deposit should be of maximum cross-sectional area to help the weld withstand the stresses set up on cooling. Should the casting be welded cold, the heat input must be kept to an absolute minimum and to this end the smallest gauge electrodes must be used. The length of weld runs must be kept to a minimum, not longer than 2 in., and the "scattered" or planned wandering method should be employed. Weaving should

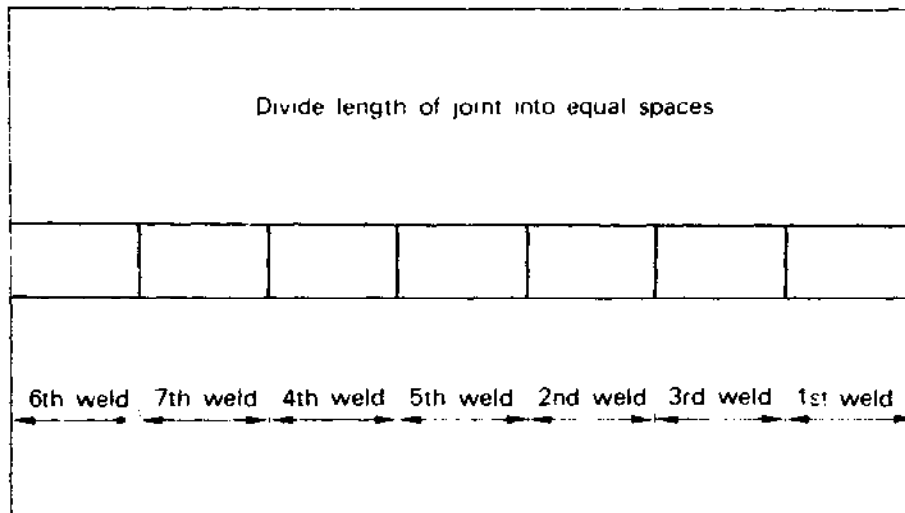


FIG. 11.27. Step-back welding.

not be employed and narrow beads only must be deposited, the casting being allowed to cool at intervals.

#### PEENING OF THE WELD

Contractional stresses may be reduced by lightly hammering each weld run. This should be done immediately after deposition. This has the effect of expanding the weld bead and by so doing compensates for the contraction. Peening of the weld is best accomplished whilst the metal is red hot. Should peening take place when the metal is cold work hardening may result and the mechanical properties of the weld affected.

#### Carbon Arc Welding

Carbon arc welding was the original system of electric arc welding and was called "Bernardo's" process, after its inventor.

The process employs a bare carbon electrode which is struck on the parent metal, causing an arc, or the arc may be struck between two carbon electrodes. When the single carbon is used it is connected to the negative pole of a d.c. set, but when using twin carbons, alternating current must be used to ensure an equal rate of burning at each electrode.

The process may be either manual or automatic. The main problem associated with the process is contamination of the weld by the atmosphere and, in consequence of this, its use has been superseded by the covered electrode. In more recent years, however, the process has been used with a gaseous shield surrounding the arc, which prevents contamination of the molten metal by harmful elements in the atmosphere.

Welds may be made with or without a filler rod and, when learning to weld with the carbon arc, runs should be made firstly without filler rods and then with a filler rod.

Light-gauge mild steel may be welded by this process. The sheets should be prepared for butt welding by flanging the edges and then fusing the two flanges into one by the use of the carbon electrode, generally without a filler rod.

Thicker plates may also be welded by preparing the edges of the plates in the usual way and welding with the carbon arc, using a filler rod, in a similar manner to gas welding.

When welding without a gaseous shield surrounding the molten metal, a flux should be applied to prevent contamination. Other methods of protection may also be employed such as a powder flux fed automatically on to the joint, a paste flux painted on to the joint or a fibrous strip core fed into the weld area. This last method leaves a hard slag covering the weld.

Cast iron may be welded by using a carbon arc and a machinable deposit will be made by proper manipulation of the arc and filler rod. This is partly due to the slower cooling of the casting. The carbon arc may also be used to prevent rapid cooling by playing it about the casting.

Compared with gas welding this process is cheaper because welding is faster; also distortion is reduced due to the arc giving a more localised heat.

### **Atomic Hydrogen Welding**

In this welding process the heat source is an a.c. arc, burning between two tungsten electrodes. The arc is shielded by hydrogen. The resultant heat from the flame is far in excess of that obtainable

by any other gas flame, the temperature being approximately 4000°C.

Hydrogen is a good reducing agent and, as a result, the weld metal is surrounded by a reducing gas preventing contamination from atmospheric gases.

The arc is struck by allowing the two tungsten electrodes to touch and then to separate slowly. As soon as the arc is struck the hydrogen is ignited and an intense, fan-shaped flame extends from the electrode tips. The arc may be broken by extending the gap between the electrodes or by switching off the electrical supply, which also shuts off the gas supply.

Welding is carried out in a similar manner to gas welding, although strips of metal may be placed in the joint rather than use a filler rod. This is particularly the case when automatic welding by this process.

The plates to be welded are prepared in the usual way, but, owing to the intense heat, welding is quicker. The welds produced are clean, ductile and free from scale. The process is employed for the welding of high carbon steels, but it may also be used for the welding of non-ferrous metals and alloys.

### **The Gas-shielded Arc Processes**

The most harmful elements to the molten metal when welding are those contained in the atmosphere, the greatest danger being the presence of oxygen. In the early days of welding, when bare wire was the only method used, the presence of these harmful gases greatly affected the welded joint. To overcome these troubles the covered electrode was introduced and also the powder fluxes for use with bare wire, both designed to protect the weld metal from atmospheric contamination.

A more recent innovation is the use of a gaseous shield surrounding the arc and the molten metal. The presence of a gas shield prevents oxidation and the formation of nitrides.

One of the gases used is argon, a gas found in the atmosphere, which is "inert". It has no smell or taste, it is non-toxic, it will not

burn nor will it support combustion. It does not readily combine chemically with other elements.

Another gas used for shielding the arc is carbon dioxide ( $\text{CO}_2$ ), which is found in very small quantities in the atmosphere but is also produced by various other methods. If dilute hydrochloric acid is poured on to chalk, limestone or marble carbon dioxide will be given off. The gas has no taste or smell, will not support combustion, it will not burn and is colourless.

Some gas-shielded arc processes do employ a combination of two or more gases when welding some metals, but the details of these processes do not fall within the scope of this book.

The welds produced by the use of a gaseous shield are free from slag, are generally of a pleasing surface finish and are quick and easy to perform. If one has mastered the manual electric arc and gas welding processes the learning of the manual gas-shielded arc welding techniques is a comparatively simple matter.

### **The Argon Arc Process**

This is a manual or automatic process, using an electric arc torch with a tungsten electrode and a filler rod, with argon gas as the shield. It is particularly suitable for the welding of aluminium and its alloys, magnesium, stainless steel, copper and nickel chrome alloys.

The equipment consists of three main items : torch, electrical supply and the argon.

The torch is constructed of a non-conductive material with a shield surrounding the tungsten electrode made of a ceramic material (Fig. II.28). The torch may be either water- or air-cooled; for sets up to 300 amp it is water-cooled, but below 150 amp air-cooling is sufficient. The cooling of the torch is important in that it prevents the ceramic shield from cracking under the intense heat. The tungsten electrode is fitted into the end of the torch with approximately  $\frac{1}{8}$  in. protruding beyond the end of the ceramic shield. Different diameter electrodes are required according to the thickness of the material being welded.

For the welding of aluminium, aluminium alloys and magnesium



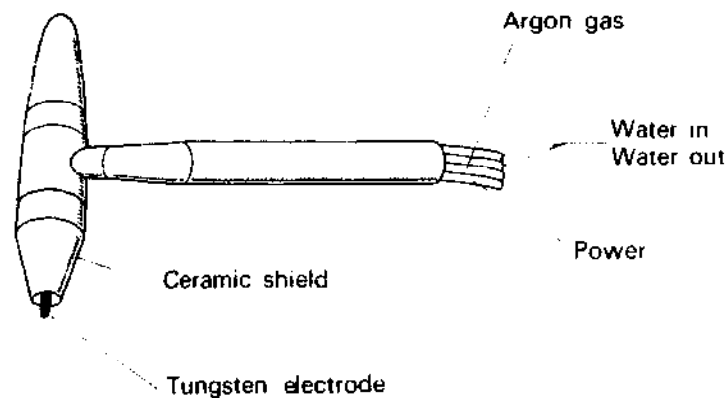


FIG. II.28. Argon arc welding torch.

alloys, a.c. equipment is used, while d.c. equipment is used for stainless steels, nickel chrome alloys and copper, the torch being connected to negative polarity.

The a.c. equipment consists of a transformer with an open circuit voltage of 100 volts, a suppressor unit to suppress the direct current component caused by the inherent rectification of the tungsten electrode and an aluminium workpiece. This phenomenon is present in all a.c. arcs when electrodes of dissimilar metals are used.

When welding with the argon arc, the tungsten electrode must not be allowed to touch the workpiece, for, if contact is made, contamination of the electrode will result. To overcome the necessity of striking the arc without resorting to contact with the metal to be welded, a high-frequency current is superimposed upon the welding current, which has the effect of causing high-voltage pulses at the electrode tip, sufficient to cause an arc between the workpiece and the electrode without direct contact.

The d.c. equipment consists of a motor generator or a rectifier as the power source, and a high-frequency unit is also employed. The argon gas is supplied in cylinders, which are painted blue, of 165 ft<sup>3</sup>, at 1980 p.s.i. pressure or 132 atmospheres. A regulator is used to reduce the pressure required for welding and a flow-control valve is also incorporated in the equipment. The conservation of argon is most important because of its high cost, so that

incorrect use can result in the welding operation becoming very expensive.

The welding technique and the filler rods, preparation of metals before welding and the many other factors concerned with argon arc welding are not intended for this book and indeed are not necessary for the student following the course of study that this book covers.

## **Cutting**

### **CUTTING WITH THE METALLIC ARC**

In this process, covered metal electrodes are used, connected to either an a.c. or d.c. power source, d.c. being preferred. The electrode coating prevents the core wire from touching the metal being cut and so short-circuiting of the arc is prevented.

The electrode holder may be the same as that used for manual metallic arc welding. The electrodes range in size from  $\frac{1}{8}$  in. dia. to  $\frac{1}{4}$  in. dia. and when using the large diameter electrodes the holder should be of the heavy-duty type.

The action of the arc causes melting of the plate and, in consequence of this, the finished surface of the cut is rough and is not suitable for welded fabrications without machining or grinding.

The technique of cutting is with a sawing motion of the electrode as the metal is melted off.

This process is not suitable for bevelling or gouging and it would be true to say that the process has been superseded by more efficient methods of plate cutting and that it is not widely used in industry.

### **CUTTING WITH THE CARBON ARC**

The carbon arc may be used for the cutting of steel, but the finished cut is of a ragged appearance and in no way resembles a flame cut edge, so that the carbon arc should only be employed for cutting where the finished edge is of little importance.

In this process, use is made of the high temperature of the arc to melt the steel and by so doing cut the plate. Rather than a

cutting process, therefore, it is a method in which the metal melts and falls away. A high direct current is necessary and this is particularly so when cutting very thick plates, in which the cut should be started where the melted metal can flow away easily, for if the melted metal cannot flow away, a build-up of partly solid and partly-melted metal will ensue.

Carbon or graphite rods are used well down in the cut to ensure melting of the lower depths of the metal.

Cast iron cannot easily be cut by the carbon arc because of the presence of graphite in the cast iron and under these circumstances it is not recommended.

#### CUTTING WITH THE AIR CARBON ARC

In this process of metal cutting, a carbon electrode is used to melt the metal and a jet of air is blown on to the arc to help in the quick removal of the melted metal. The process may be used for cutting, gouging and bevelling.

The electrical power source may be either a.c. or d.c. and when using d.c. the torch is connected to the positive pole.

The electrodes are of carbon or graphite or a combination of both, usually coated with copper, to allow the use of higher currents and also to minimise the heat radiation, which is rather high when using uncoated carbon electrodes.

Table II.6 indicates the currents required for the carbon electrodes.

TABLE II.6.

Diameter in inches	Current in amperes
$\frac{5}{32}$	75-150
$\frac{3}{16}$	150-200
$\frac{1}{4}$	200-250
$\frac{5}{16}$	250-325
$\frac{3}{8}$	325-425
$\frac{1}{2}$	425-550
$\frac{5}{8}$	550-700

Ordinary compressed air is used at a pressure of 80–100 p.s.i. The pressures are important and should be used for all thicknesses of metal because lack of air pressure will result in an unclean surface after cutting. On very heavy sections higher pressures will be found to be more effective.

The torch, which is similar to an ordinary manual metallic arc welding torch, is fitted with a control for regulating the flow of air. The jets of air are directed to converge at the point of arcing. Some torches have a self-aligning, rotating head which permits the torch to be used in all positions. The air may also be used to cool the torch.

Before commencing to arc it is most important to check that the air supply is on, that the electrode is connected to the positive pole and, if using d.c., that the current setting is correct and that the correct size carbon is being used.

The cut is commenced by directing the carbon at a point half-way through the thickness of the material. The carbon is held at an angle of 45° and the cut is carried out with a sawing motion of the carbon.

The removal of pads, bosses, hard surfacing and other unwanted projections may be carried out with the carbon arc. This technique is referred to as “flushing”. The method of manipulation of the carbon is a side-to-side weave whilst moving forward, at the same time washing to the required depth. The smoothness of the finished surface depends a great deal upon the steadiness of the operator’s hand.

Bevelling or chamfering plate edges may be accomplished with the carbon arc. With the carbon at an angle of 90° to the torch, draw the torch towards the operator with a smooth movement; a jerky motion must be avoided if a smooth surface is required.

Gouging or grooving is carried out using the following technique. The torch is held so that the carbon slopes back from the direction of travel and the air blast must be behind the carbon. Strike the arc and progress along the plate so that the molten metal is pushed away from the groove. Keep the arc short and maintain a steady rate of travel in keeping with the removal of

the metal. Here again a steady hand is essential if a smooth finish is required.

Many applications may be found for this process amongst which are: removing defects from castings, removing defective welds, preparation of plate edges for welding, cutting stainless steel, a variety of jobs on plant maintenance.

### CUTTING WITH THE OXYGEN ARC

This is a process wherein the cutting of metal is effected by means of the chemical reaction of oxygen with the metal being cut at high temperatures. The necessary temperature required to maintain the chemical reaction is supplied by means of an arc between an electrode and the metal being cut.

Cutting, piercing and gouging may be carried out using this process on both ferrous and non-ferrous metals. The edges as cut are not as smooth as are gas-cut edges and some machining may be necessary.

The electrical power source may be either a.c. or d.c. For rapid cutting d.c. is preferred with the torch connected to the positive pole.

The electrodes are of coated tubular steel core, two sizes being available ( $\frac{3}{16}$  in. and  $\frac{5}{16}$  in.) with an internal diameter of  $\frac{1}{8}$  in. and  $\frac{1}{8}$  in. respectively. When being used for underwater cutting the electrodes are further covered with a thermoplastic coating which renders them waterproof for several hours of immersion.

The oxygen supply is the same as that used in oxygen welding and oxygen cutting.

When using this process, the "touch" technique is applied. The rod is touched on the plate and is not withdrawn and the electrode coating melts off at a slower rate than the core wire and by so doing a constant arc length is maintained.

For piercing operations the following technique is employed. The electrode tip is scratched on the metal, as for welding, and the arc is held whilst the oxygen is switched on. When the metal begins to melt the rod is pushed into the plate as fast as the hole is formed.

### *SPECIAL TECHNIQUES*

For cutting, the arc is struck without sticking to the plate, the oxygen is released and the rod is dragged along the plate in a forward direction. The angle of the rod and the speed of travel are adjusted according to the thickness of the plate.

For gouging, the arc is struck, the oxygen is released and the rod is held almost parallel to the surface of the plate. The direction of travel is away from the gouge already cut and into the molten pool.

The oxygen arc cutting process was originally developed for underwater cutting and later used for cutting in air. Almost any thickness of metal may be cut in mild steel, low alloy steels, stainless steel, cast iron and non-ferrous metals.

## **B. RELATED STUDIES**

Metals very readily give up or take in heat. As an example, in the hot sun, a metal roof would feel much hotter than the surrounding woodwork, but actually both would be at the same temperature. In very cold weather it would be the other way about.

When a piece of metal is heated it may change in various ways:

1. It may expand.
2. A change of composition or physical state may take place.
3. Its colour may alter.
4. The temperature of the metal may rise.

### *Latent Heat*

The term latent heat means the heat used to cause a change of state. When water is heated until it boils and the heat is continued after boiling, the temperature of the water does not rise, but if heating of the water is continued, the vessel will eventually boil dry. The water in fact has turned to steam and a change of state has taken place, although some of the steam will, of course, condense and return as water.

There are two changes of state that may take place with a substance, viz. from solid to liquid and from liquid to vapour. The two forms of latent heat that produce these changes are latent heat of fusion and latent heat of vaporisation.

The latent heat of fusion is defined as the quantity of heat required to change a unit mass of a solid into a liquid at the same temperature.

The latent heat of vaporisation is defined as the quantity of heat required to change a unit mass of a liquid into vapour at the same temperature.

### *Quantity of Heat*

The quantity of heat is the amount of heat required to raise the temperature of a substance. As an example, suppose that a tank full of water is at 20°C and it is necessary to raise this to 60°C, the amount of heat required to do this can be calculated and is



known as the quantity of heat. The amount of heat required to raise the temperature of a substance not only depends upon the number of degrees of temperature rise, but also upon the substance and its weight. It will be found that if we require to raise the temperature of a certain amount of water and the same amount of sulphuric acid through the same number of degrees, it would require "three times as much heat for the water as for the acid".

The units in which quantities of heat are measured are based upon the heat required to raise, by 1 degree, a unit amount of water. The type of unit used depends upon the quantity of water in the unit and the temperature scale used. The units usually employed are as follows:

#### THE CALORIE

This is the amount of heat required to raise the temperature of one gram of water by 1 degree Centigrade.

#### THE CENTIGRADE HEAT UNIT (Chu)

This is the amount of heat required to raise the temperature of one pound of water by 1 degree Centigrade.

#### THE BRITISH THERMAL UNIT (Btu)

This is the amount of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

#### *Specific Heat*

Previously, only the heating of water has been mentioned in connection with quantity of heat. It is now necessary to discuss the heating of other substances.<sup>3</sup>

By experiment it has been determined that given equal weights

of copper and water, both at the same temperature, the water contains much more heat than the copper. If a piece of copper weighing 1 lb is heated up and placed in 1 lb of cold water, it will be found that the water temperature will rise because it will extract heat from the copper. If 1 lb of water at high temperature is added to 1 lb of water with a low temperature, the resultant temperature of the 2 lb of water would be considerably higher than that of the 1 lb of colder water. In fact it will be found that the cold water in the second instance will have been able to extract more heat from the hot water than the water did from the copper in the first instance.

In a similar manner the heat which could be extracted from any substance can be compared with that which could be extracted from the same weight of water at the same temperature. Water is taken as the basis of comparison. Experiments have been conducted and the heat required to raise the temperature of a given weight of a substance has been found and has been compared with the amount of heat required to raise the same weight of water by the same amount. This comparison is known as the specific heat and it can be expressed as:

$$\text{Specific heat of a substance} = \frac{\text{Heat required to raise temperature of 1 lb of substance } 1^{\circ}}{\text{Heat required to raise temperature of 1 lb of water } 1^{\circ}}$$

As an example: the specific heat of iron is 0.115; therefore a given weight of iron required 0.115 times the amount of heat required to raise the same amount of water to the same temperature.

It is necessary to know the specific heat of a substance before the quantity of heat needed can be calculated. The quantity of heat required may be found by calculation, as follows:

$$\begin{array}{l} \text{Quantity of} \\ \text{heat required} \\ \text{to raise the} \\ \text{temperature of} \\ \text{a substance} \end{array} = \text{Weight of substance} \times \text{specific heat of} \\ \text{substance} \times \text{temperature rise.}$$

**EXAMPLE.** Calculate the amount of heat required to raise the temperature of 10 lb of aluminium from 15°C to 180°C (specific heat of Aluminium is 0.215).

$$\begin{aligned} \text{Heat required} &= \text{Quantity} \times \text{specific heat} \times \text{temperature rise} \\ &= 10 \times 0.215 \times (180 - 15) \\ &= 2.15 \times 165 \\ &= 354.75 \text{ Centigrade heat units.} \end{aligned}$$

### Temperature

The term temperature is used to indicate the degree of hotness of a body and this may be measured by various instruments and other means, according to the amount of heat involved.

One of the most common forms of measuring temperature is by the thermometer, which relies on the fact that some liquids expand by a great amount when heated. The two most common liquids used are mercury and alcohol. The freezing point of mercury is minus 39°C and it has a boiling point of 357°C (this can be raised above 357°C by filling the thermometer above the liquid with compressed nitrogen).

Alcohol has a freezing point of minus 112°C and a boiling point of 78°C but its expansion is not as uniform as mercury and it does not conduct heat so readily.

For measuring temperatures above 330°C the instruments used are called *pyrometers*.

### THERMOMETER SCALES

In this country the two most commonly used scales are the Centigrade and Fahrenheit scales.

#### CENTIGRADE SCALE (Fig. II.29(a))

The freezing point is called zero (written 0°C.) The boiling point is called 100 degrees Centigrade (written 100°C.) The space between these two limits is divided into 100 parts, each division called a degree Centigrade.

#### FAHRENHEIT SCALE (Fig. II.29(b))

The freezing point is called 32 degrees Fahrenheit (written 32°F) and the boiling point 212 degrees Fahrenheit (written 212°F).

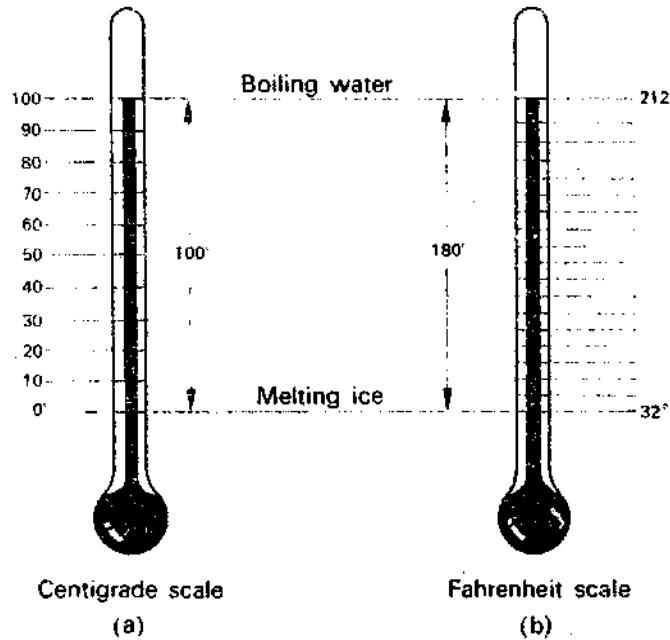


FIG. II.29. Centigrade and Fahrenheit scale.

The space between these two limits is divided into 180 parts, each division called a degree Fahrenheit.

### *Workshop Methods of Temperature Measurement*

Thermometers are of little use in the workshop. For example, if a piece of cast iron needs to be heated to 800°C, a thermometer could not be used, as it cannot be used to measure such high temperatures. Likewise, if the same piece of cast iron needs to be heated to a lower temperature, within the thermometer range, it still would not be convenient or accurate to use a thermometer. And so for temperature measurement in the workshop other methods have to be employed.

### COLLAPSIBLE CONES

These rely on the fact that certain material compositions melt at known temperatures. The material, made up in the shape of

a pyramid or cone, is placed on the job before heating commences and when the correct temperature has been reached, the cone will melt.

### TEMPERATURE CRAYONS

These work on a similar principal to the previous example, but a mark is made with the crayon on the metal before heating, so that when the temperature has been reached the crayon mark will melt.

### OPTICAL PYROMETER

This instrument works by comparing the intensity of light being emitted from a hot body with the intensity of light from an electrically heated wire.

### THERMOELECTRIC PYROMETER (Fig. II.30)

The basic principle of the thermoelectric pyrometer is that when two dissimilar metals are joined and the junction is heated, the other ends being kept cold, providing the junction forms part of an electric circuit, current will flow.

It is found that if certain metals are used, such as iridium, rhodium, platinum, and nickel or nickel-chrome constantan

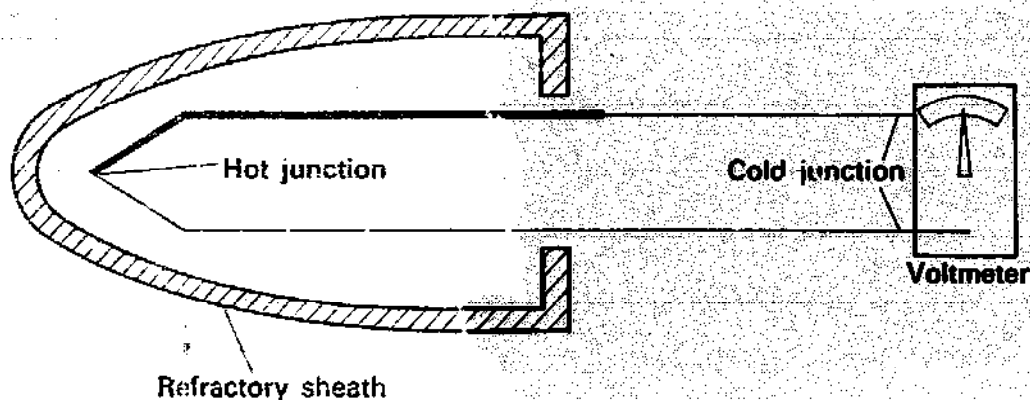


FIG. II.30. Thermoelectric pyrometer.

alloys, the current will increase uniformly with a uniform rise in temperature of the heated end (called the "couple"). For temperatures up to 2300°C the metals used are platinum and iridium, while up to 2500°C nickel alloy and nickel are used.

## Heat Transfer

### *Conduction*

If a piece of steel bar is held in one hand and the free end is heated with a welding torch, it will at first be noticed that the end being held in the hand remains cold. After a period of time, depending upon the length and thickness of the bar, the whole of the bar will be too hot to hold. Heat has travelled along the whole length of the bar. In fact, it has been conducted from the hot end to the cold end. The speed at which the heat travels along the bar will depend upon the type of metal, as some metals conduct heat much more rapidly than others. Copper, for example, will conduct heat almost five times as quickly as steel.

The speed at which a metal is able to conduct heat is known as the thermal conductivity. All metals are good conductors of heat, but some are much better than others. If copper is taken as value 100, on the resulting scale then lead is only 8, whilst silver is 106.

### *Radiation*

One of the simplest examples of transfer of heat by radiation is the ordinary fire. The heat is emitted from whatever is burning in the fire, and if a hand is placed close to the fire it will get hot. It does not have to touch the burning fuel, because the heat is radiating from the fire in heat waves.

During welding, heat is radiated from the blowpipe flame or the electric arc. It is also radiated from the hot metal as the weld progresses. In this respect the effects of excessive heat radiation, or in other words, rapid cooling of the metal after welding, particularly with regard to cast iron, can be harmful. To counteract

this rapid cooling the cast iron must be covered by a substance, or material, that will not give up the heat very quickly (see earlier section in this volume).

### *Convection*

When a substance is heated it expands and becomes lighter per unit volume than when at the lower temperature. Due to the ease with which liquids and gases can move freely within the mass when heat is applied, the heated portion is floated upwards by the greater weight of the cooler fluid, which is in turn heated and displaced upwards. This produces a "circulation" or convection current in which there is a constant upward displacement of the hot, lighter matter by that which is cooler and heavier. If the application of heat is continued the whole of the fluid will eventually reach a uniform temperature.

Use is made of the principle of convection in a hot-water central-heating system (see Fig. II.31). Water heated in the boiler

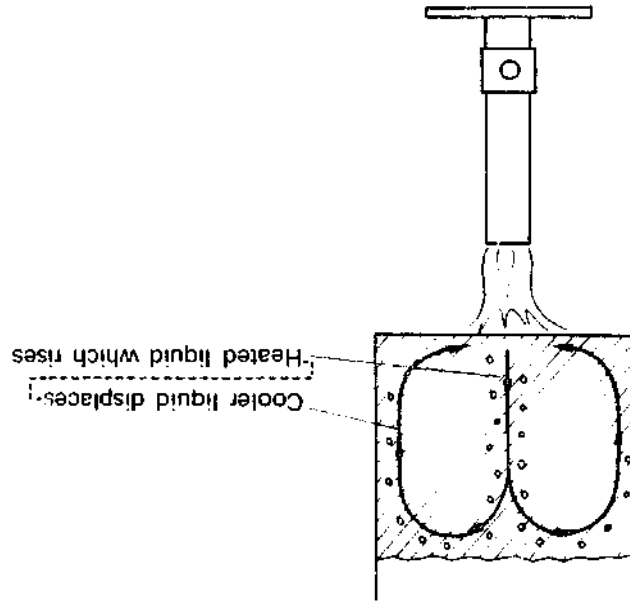


FIG. II.31. Convection currents in liquids.

is displaced upwards through the flow pipe by the cooler, heavier water in the return pipe and circulates freely around the pipe circuit, passing through the radiator. As long as a difference in temperature exists between the water in the flow pipe and that in the return, the circulation continues (see Fig. II.32). The cooler

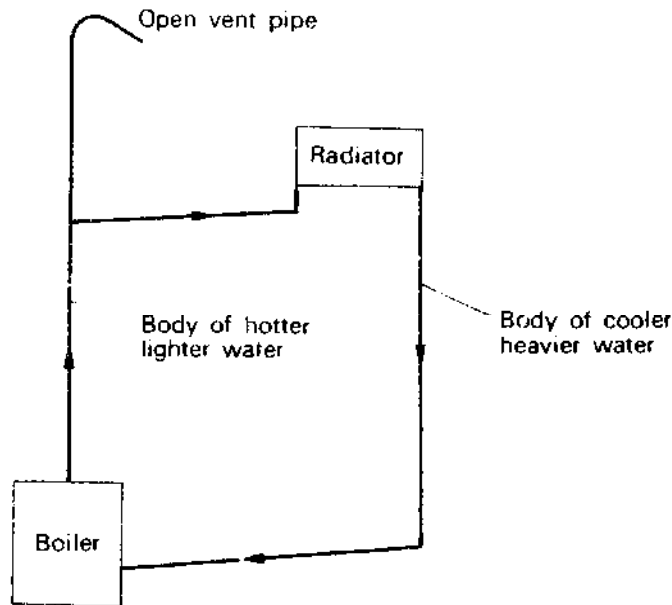


FIG. II.32. Circulation due to convection in hot water system.

air in the room is heated by contact with the hot metal radiator and again convection currents are set up in which the lighter, warm air is displaced upwards by the heavier, cooler air until the whole of the air in the room is warmed. It cools on contact with the ceiling, walls and windows and descends to be reheated. The loss of heat from the radiator to the air means that cooler water is constantly descending into the return pipe and returning to the boiler.

An applied example would be as follows: if it is desired to ventilate an enclosed space in which welding is to be carried out, the outlet for the warm fumes must be at the top and the cooler, fresh air inlet at the bottom. This will promote a natural circulation of air within the space (see Fig. II.33).



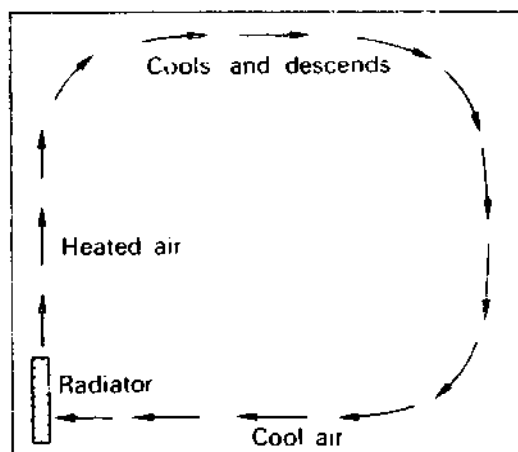


FIG. II.33. Circulation due to convection in heated room.

## Expansion

### EXPANSION OF METALS WHEN HEATED

Most solids expand when heated and metals are no exception. In fact, metals expand by a much greater amount than most other solids. This expansion of metals is a particular nuisance as far as welding is concerned, as it is this that causes distortion. Sometimes allowances can be made when setting up a job prior to welding for the movement and expansion when heated. But, let us take the example of a six-sided tank: when this is being welded the metal expands and, because all six sides are locked, it has only one direction in which it can expand and this causes the sides to buckle and bow.

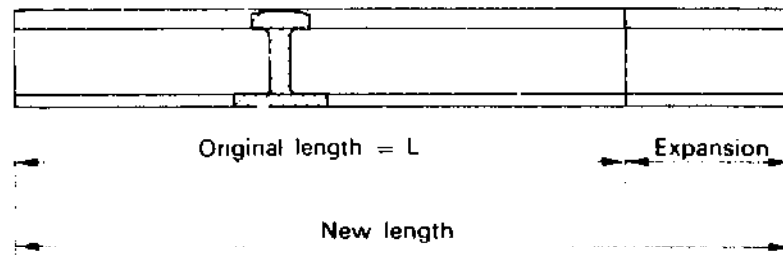
The expansion of metals can also cause serious trouble to engines, if steps are not taken to cool the hot parts. The internal combustion engine, if allowed to overheat, would eventually seize up. The pistons would expand, the block would expand at a different rate and movement would not be allowed to take place.

On the other hand, the expansion of metals can be used to advantage, as in the case of mercury in the thermometer. The method of fixing a metal rim on to a wooden wheel is a further example, for the metal ring or band expands when heated and is fitted over the wheel. When cold, it contracts and grips the wooden wheel.

COEFFICIENT OF EXPANSION

The amount by which a metal will expand when the temperature is increased from 0°C to 1°C or (32°F to 33°F) has been determined by experiment and is known as the coefficient of expansion.

When calculating the increase in length of a metal bar (for example, a railway line) it may be necessary to know the expansion at a certain temperature (Fig. II.34). Before calculations can



- (1) The length of the rail before heating =  $L$
- (2) The coefficient of linear expansion of the metal =  $a$
- (3) The new temperature minus the original temperature =  $t$

$$\text{expansion} = L \times a \times t$$

$$\text{Length after heating} = \text{original length} + \text{expansion}$$

FIG. II.34. Linear expansion of a rail.

be started the “Coefficient of Linear Expansion” of the metal must be determined.

Should the increase in volume of a block of metal at a certain temperature need to be calculated, its “Coefficient of Cubical Expansion” of the metal has to be known.

When calculating the increase in area of a sheet of metal, which will not only expand in length but also in width, it is necessary to know its “Coefficient of Superficial Expansion”.

COEFFICIENT OF LINEAR EXPANSION (Fig. II.34)

From Table II.7 it will be seen that the coefficient of linear expansion of aluminium is 0.000022. This means that if a 1-in.

TABLE II.7. COEFFICIENT OF LINEAR EXPANSION OF METALS

Metal	Expansion per degree Centigrade	Expansion per degree Fahrenheit
Aluminium	0.000022	0.000012
Iron and steel	0.000011	0.000006
Copper	0.000017	0.000010
Brass	0.000019	0.000011
Zinc	0.000026	
Cast iron	0.000010	
Nickel	0.000013	
Wrought iron	0.000012	

length of aluminium bar is heated  $1^{\circ}\text{C}$ , it will expand by 0.000022 in. Therefore, to calculate the expansion of a length of metal the formula is:

Original length  $\times$  coefficient of expansion  $\times$  temperature rise

and New Length = Original length + expansion.

**EXAMPLE.** Given that the coefficient of linear expansion of copper is 0.000017 per degree Centigrade, find the final length of a bar of copper, whose original length is 80 in. at  $40^{\circ}\text{C}$ , when heated to  $90^{\circ}\text{C}$ .

$$\begin{aligned} \text{Expansion} &= \text{original length} \times \text{coefficient of expansion} \times \text{temperature rise} \\ &= 80 \times 0.000017 \times (90 - 40) \\ &= 80 \times 0.000017 \times 50 \\ &= 0.068 \text{ inches.} \end{aligned}$$

$$\begin{aligned} \text{Final length} &= \text{original length} + \text{expansion} \\ &= 80 + 0.068 \\ &= 80.068 \text{ inches.} \end{aligned}$$

EXAMPLE (Fig. II.34). A length of steel railway line is 220 ft long at 60°C. The sun increases this temperature to 95°C. What is the amount of expansion?

From table: Coefficient of expansion of steel = 0.000011 per °C.

$$\begin{aligned}
 \text{Expansion} &= \text{original length} \times \text{coefficient of expansion} \times \text{temperature rise} \\
 &= 220 \times 12 \text{ to bring to inches} = 2640 \text{ inches} \\
 &= 2640 \times 0.000011 \times (95 - 60) \\
 &= 2640 \times 0.000011 \times 35 \\
 &= 1.0164 \text{ inches.}
 \end{aligned}$$

### COEFFICIENT OF CUBICAL EXPANSION

When a cube of solid metal is heated, its volume will increase since each side of the cube will undergo linear expansion. Although the cube has six sides the increase in volume will be three times the linear expansion. Since each side has one other side parallel to it, for the purpose of simple calculations only three sides need to be considered. Reference to Fig. II.35 will clarify this point.

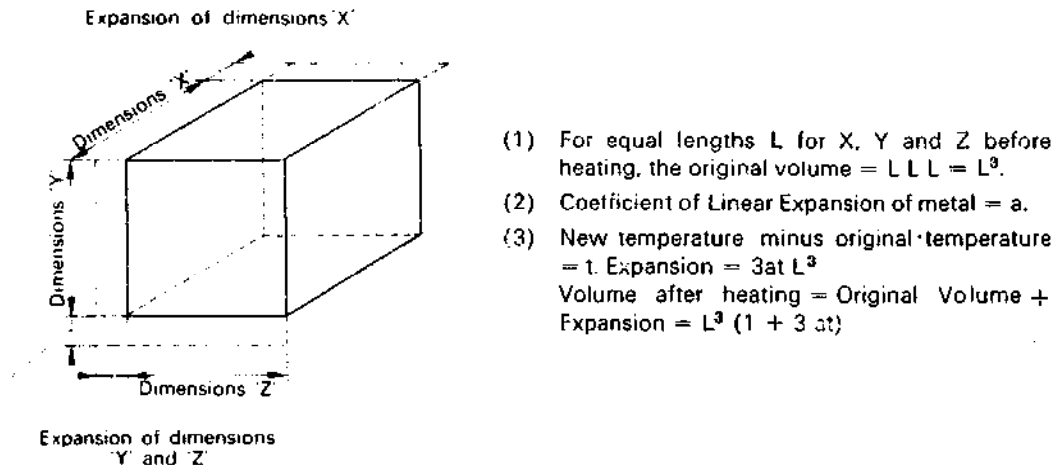


FIG. II.35. Expansion of a cube of metal.

EXAMPLE. A solid brass cube of size  $3 \times 3 \times 3$  in. is heated through  $60^\circ\text{C}$ . Find its final volume.

Coefficient of linear expansion of brass is  $0.000019$  per deg.C.

Original volume of cube:  $3 \times 3 \times 3 = 27$  cubic inches.

Each of the three dimensions will expand, and for each dimension we now have:  $3 (1 + 0.000019 \times 60)$  inches

$$\begin{aligned} \therefore \text{New volume} &= 3^3 (1 + 3 \times 0.000019 \times 60) \\ &= 27 (1 + 3 \times 0.000019 \times 60) \\ &= 27 (1 + 0.00342) \\ &= 27 \times 1.00342 \\ &= 27.09234 \text{ cubic inches.} \end{aligned}$$

From the example it will be seen that the formula for cubical expansion gives for the final volume.

$$L^3 (1 + 3 at)$$

or the original volume multiplied by  $(1 + 3 at)$ ,

where  $a$  = coefficient of linear expansion of metal,  $t$  = temperature rise.

## CHAPTER 5

# Elementary Electricity

### The Electric Circuit

A study of water flowing along a pipe will serve to illustrate the electric circuit. To make water flow along a pipe in sufficient quantities it must be forced. This is done by using pumps and the force with which the water is pushed is expressed in p.s.i. The amount of water being pushed, say in 1 minute, would be expressed in gallons. Somewhere in the water circuit will be a control valve which can be used to limit the flow of water in the circuit. A large amount of water can pass at very low pressure along a pipe of large diameter or the water could be forced at very high pressure through a pipe of very small diameter.

Figure II.36 shows a water circuit and Fig. II.37 shows an electrical circuit. The water meter in the water circuit corresponds to the ammeter in the electrical circuit, while the water pump is equal to the battery or generator and the control valve in the water circuit is shown in the electrical circuit as a switch for various tappings according to the amount of current required.

To study this in a little more detail, suppose the method used to produce the electricity is a diesel-driven generator. Whilst this is working, electricity is being driven around the circuit. This is known as *current* and the force that causes this to flow is called the electromotive force (expressed as "e.m.f."). The units of e.m.f. are volts. Instead of pipes as in the water circuit, the electric current flows along wires, usually copper, and this current is measured in amperes. The current passes through the ammeter, which measures the flow, just as the water meter measures

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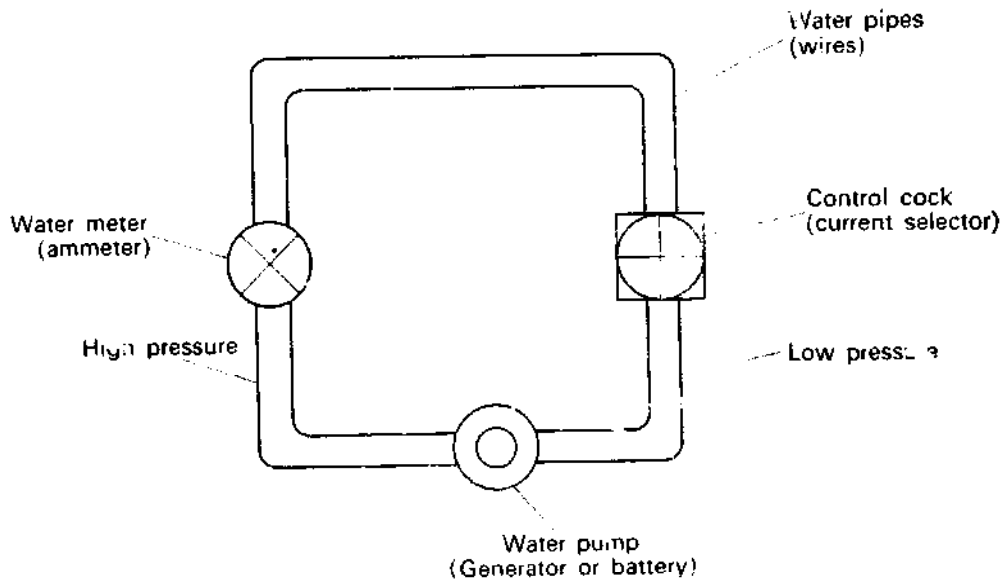


FIG. II.36. Water circuit.

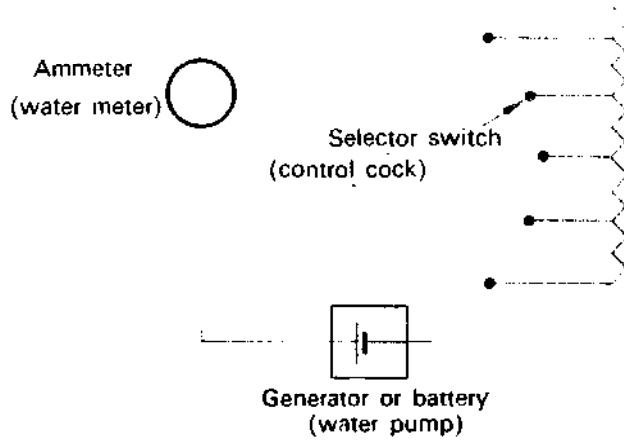


FIG. II.37. Electrical circuit.

the flow of water. After passing through the ammeter, the current passes along the wires to a switch which may control the current which will flow in the circuit, just as the control valve in the water circuit controls the flow of water.

Electricity will not flow unless the circuit is complete and if it is broken the current will cease to flow. If the broken ends of the wire are connected by a conductor the current will again flow.

## Production of Electricity

### *Primary and Dry Cells*

Electricity may be produced by chemical action, as in the case of the primary cell, which is used for flashlamp and radio batteries.

One type of cell is the Leclanché. This cell consists of a carbon rod placed in a porous container with granulated carbon and manganese dioxide, the whole being sealed with the carbon rod protruding at one end. A rod of zinc is used, separate from the carbon, and both are placed in a solution of ammonium chloride, known as sal ammoniac (Fig. II.38). The two rods which protrude

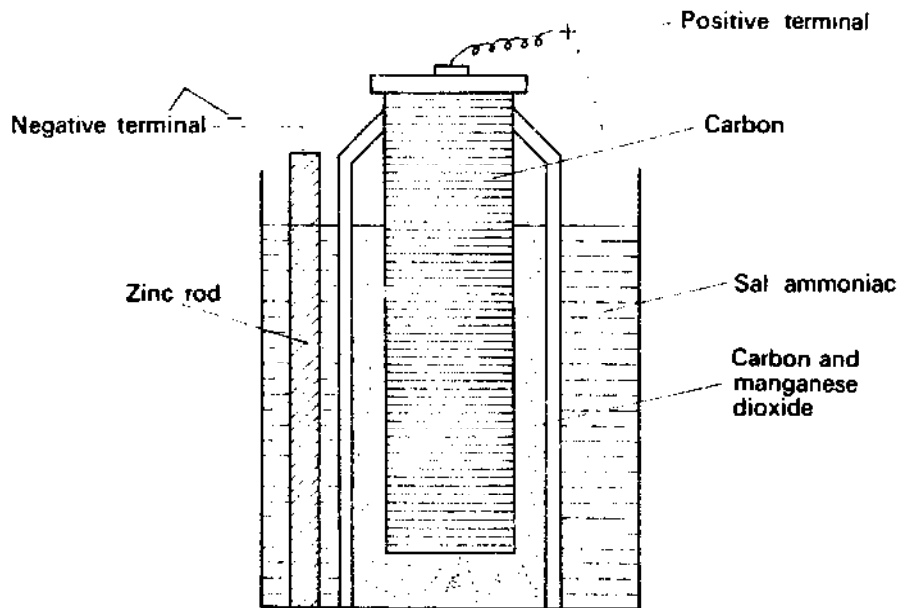


FIG. II.38. The Leclanché cell.



from the top of the container have terminals fitted to them and, when connected in a circuit, electricity will flow. The life of the cell is somewhat short due to the production of hydrogen at the carbon electrode, which causes polarisation, by the hydrogen forming a new pole between the carbon and the zinc. This shortens the life of the cell. This type of cell is best suited for intermittent work such as bell batteries.

A dry cell is much the same as the Leclanché cell, in so far as the carbon rod is surrounded by an outer casing of zinc, which takes the place of the zinc rod of the Leclanché cell. The electrolyte is a paste instead of a liquid and the cell is sealed with pitch. Figure II.39 illustrates a dry cell.

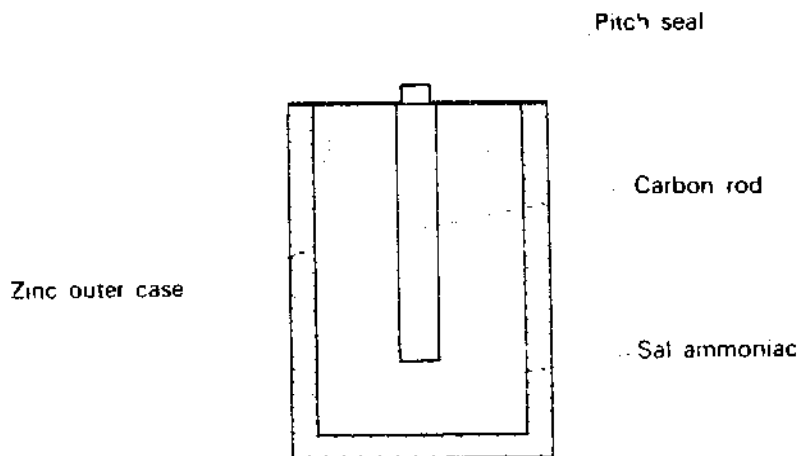


FIG. II.39. Dry cell.

The two types of cells so far discussed cannot be recharged with electricity, but a type of cell known as a secondary cell can be for this. These are called accumulators or storage batteries.

### *The Secondary Cell*

A secondary cell consists of a container, in which are two lead plates immersed in sulphuric acid, the acid being diluted and the lead plates perforated. One of the plates contains lead peroxide

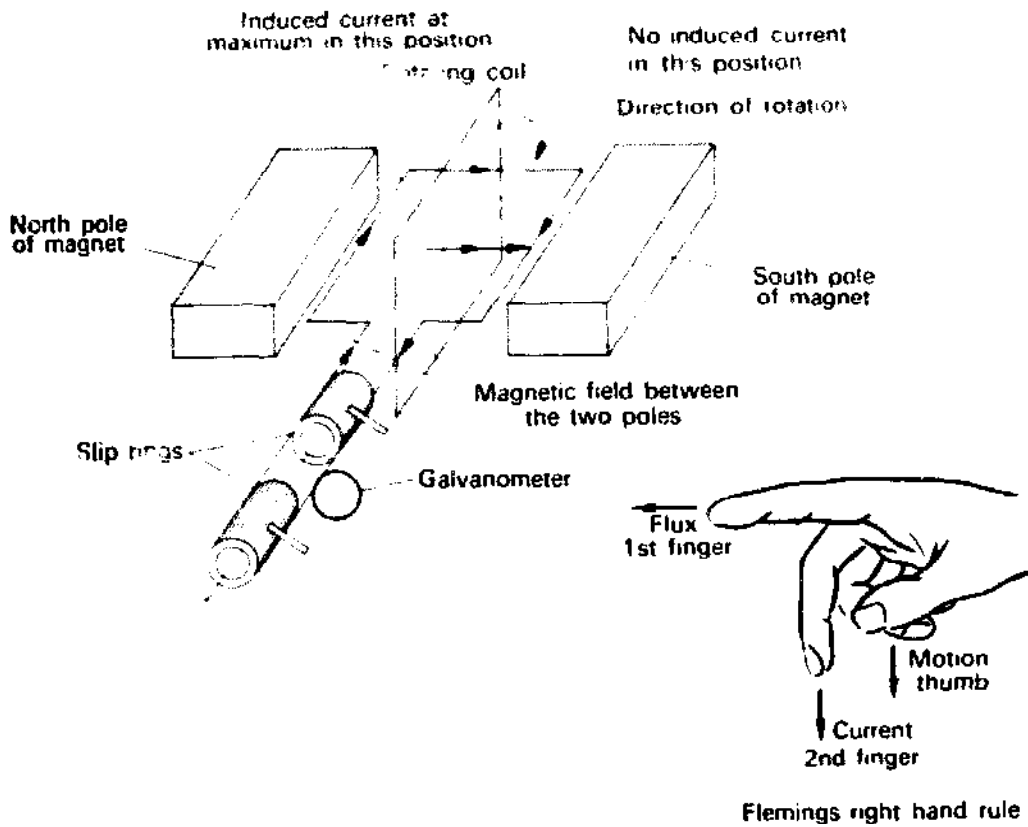
and the other spongy metallic lead. When the cell has run down, these plates contain lead sulphate, and when charged, the lead sulphate reverts back to lead peroxide and spongy metallic lead. The cell will then give out more electricity. This type of cell has an e.m.f. of 2 volts and can give out very high currents. The secondary cell does not store or accumulate electricity, but it has chemical energy which is converted into electrical energy. When all the chemical energy has been exhausted, prompt recharging is necessary. A secondary cell containing a complete charge should show signs of "free gassing" and the specific gravity of the solution should be 1.20–1.220 and not below 1.17. A hydrometer is used to determine the specific gravity of the acid.

### *The Dynamo and the Alternator*

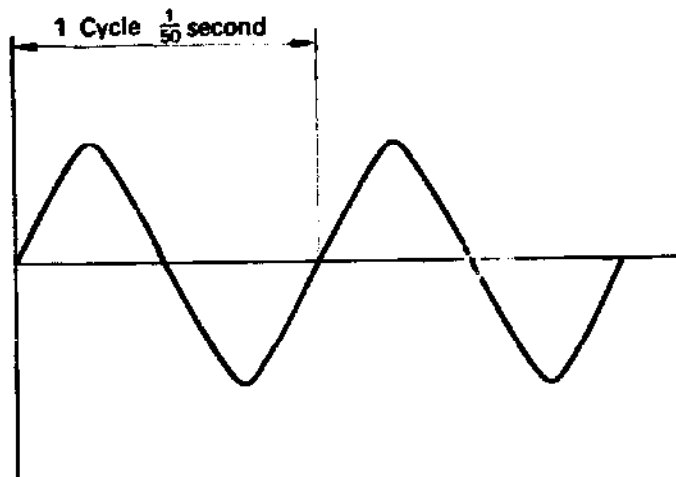
The cells previously mentioned could not be said to be of much use to the welder for actually welding together metals, but they do illustrate the production of e.m.f. The dynamo (d.c. generator) or the alternator (a.c. generator) will produce abundant electricity.

Alternators produce electricity by means of a loop of wire rotating between the poles of a magnet system, so that the wire cuts the lines of magnetic flux. Now if the ends of the wire are connected to two slip rings in contact with carbon brushes and a galvanometer connected to both brushes, the direction of the induced current will be related to directions of flux and motion in the manner shown by the three arrows (Fig. II.40). This is known as *Fleming's right-hand rule* for generators, for if one holds out one's right hand so that the thumb, forefinger and centre finger are at right angles to one another, the thumb indicates motion, the forefinger indicates flux and the centre finger indicates current. When the wire, or coil as it is called, is passing through the horizontal position, the current is at its maximum; in the vertical position the induced current is nil, so that in one revolution of the coil there are two maximum currents and two zero's. The two maximum currents are in opposite directions in the external circuit. Figure II.41 shows this in diagram form. The current produced is said to be alternating and the generator producing

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**FIG. II.40. a.c. generator.**



**FIG. II.41. Alternating current curve.**

it is called an alternator. One complete series of changes (that is two maxima and two zeros) is called a cycle and generally an alternator makes 50 cycles per second

Should the slip rings now be replaced with a split ring and each section isolated by a small gap, still being touched by carbon brushes, the resultant current will be a direct current. The brushes touch each segment of the split ring in turn and thus the connections to the external circuit are reversed. In this case one brush will always be positive and the other negative. Whenever the current changes its direction in the loop each segment moves into contact with the other brush, so that the current is always in the same direction in the external circuit. The current produced with a single coil under these conditions would be unsuitable because it would rise to a maximum and decrease to zero repeatedly (Fig. 11.42).

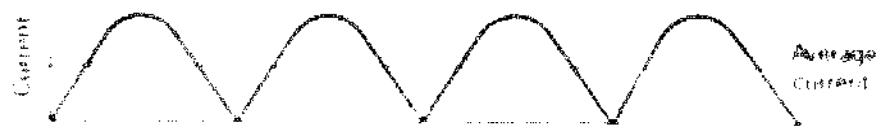


FIG. 11.42. Direct current wave, single coil.

To overcome this difficulty, a number of coils are wound in different directions and each is joined to its own segments of split ring. The resultant current is shown by Fig. 11.43. This arrangement produces the dynamo or d.c. generator.



FIG. 11.43. Direct current curve, two coils.

## Resistance

All metals offer some resistance to the passage of electricity, but some more than others. Electricity is conducted along or through a piece of metal. Again some metals are better conductors than others, the best being silver, with copper next. But even these two metals offer some resistance to the passage of electricity. A simple experiment will show that the current flowing from a battery through a wire will depend on the length of the wire, the thickness and the material of the wire. Using as a source of current two accumulator cells arranged in series, an ordinary flash-lamp bulb connected in turn with the following types and lengths of wire to the cells will show the bulb to have variations of light output.

- (a) 10 yd of 26 d.c.c. (double cotton covered) copper wire,
- (b) 10 yd of 36 d.c.c. copper wire,
- (c) 1 yd of silver wire 36 gauge,
- (d) 2 yd of silver wire 36 gauge.

Wind the wire on to cotton reels with holes bored into the top to receive the ends.

The resistance offered to the passage of electricity can be put to use (e.g. electric fires and resistance welding). In both of these instances the electricity creates heat in the materials to such an extent that they turn red-hot.

The resistance in a wire can be calculated by dividing the voltage by the current. An example is as follows:

A p.d. of 50 volts is applied across the ends of a wire and a current of 5 amp flows through the wire. Calculate the resistance of the wire.

$$\begin{aligned} \text{Resistance} &= \frac{\text{voltage}}{\text{current}} = \text{resistance in ohms} \\ &= \frac{50}{5} = 10 \text{ ohms.} \end{aligned}$$

The term ohm is taken from the name of the scientist who first discovered this relationship. This is known as "Ohm's Law".

### Electrical Power and Energy

The watt is the unit of electrical power. When we know the current, in amp, passing through a wire and also the electrical p.d., in volts, the watts can be calculated by multiplying one by the other, in a d.c. circuit.

The unit of mechanical power is the horse-power and is equal to 746 watts.

An example of watts and mechanical horse-power may be illustrated by the following:

A d.c. welding generator is delivering 100 volts and 300 amperes. Calculate the horse-power output.

$$\begin{aligned} \text{To calculate, Power} &= \text{volts} \times \text{amperes} \\ \therefore \text{horse-power} &= \frac{\text{watts}}{746} \\ \therefore \text{Power} &= \frac{100 \times 300}{746} = 40.21 \text{ horse-power.} \end{aligned}$$

Here it must be stated that if the welding generator must be driven by a motor, the actual horse-power of the motor would have to be approximately 50% greater than the 40.21 horse-power as calculated. This is to allow for frictional and other losses in the motor and the generator.

Estimated horse-power necessary to drive the generator =  $40.21 + 20 = 60$  h.p. approx.

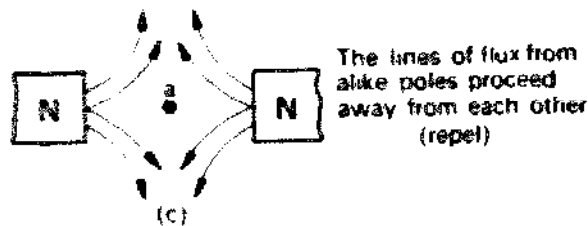
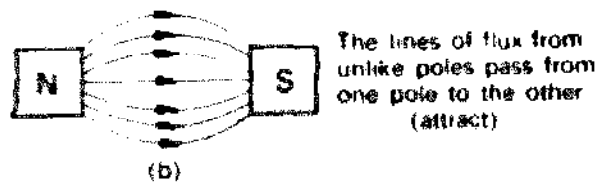
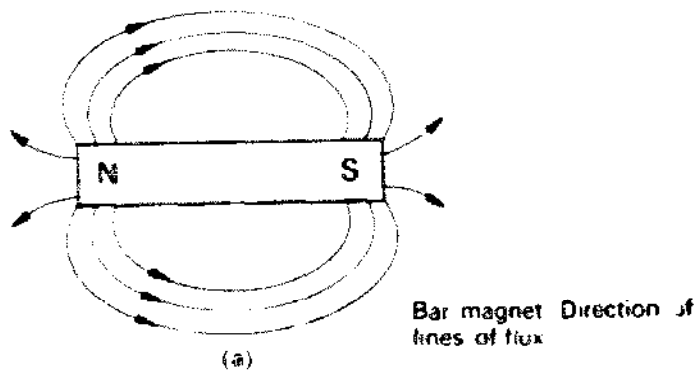
### Kilowatt

There are 1000 watts in one kilowatt. A kilowatt-hour is a useful unit for measurement of electrical energy, used by the Board of Trade and it is the unit used for electricity.

If a 100-watt electric lamp burns for 10 hours, 1 kilowatt-hour of energy is used. Similarly, if an electric fire with three bars, each bar of 1000 watts, is used for 10 hours, then 30 kilowatt-hours is consumed.

**Electromagnetic Induction**

A permanent magnet must be made of hardened steel because soft iron does not retain magnetism. But soft iron is more readily magnetised by induction. To induce magnetism into a piece of soft iron, the iron is placed in a magnetic field, so that the lines of flux pass through the soft iron and it becomes magnetised. The lines of flux of a magnet can be seen by placing iron filings on a piece of paper, holding this over a bar magnet, and gently tapping the paper. The iron filings will arrange themselves into a pattern of lines, representing the magnetic field, in which the lines are the direction of lines of magnetic flux. Figure II.44 shows the general direction of these lines.



a = Neutral point No lines

FIG. II.44. Magnetic fields.

The effect that a magnetic field has on soft iron is utilised in electromagnets. An electromagnet has a core of soft iron with coils of wire wound round it. When the current is switched on the iron becomes magnetised, but when the current is switched off the iron loses most of its magnetism.

An electric current passing along a wire produces a magnetic field around the wire. This may be seen by passing a wire through a piece of paper, sprinkling iron filings on the paper and switching on the current. The iron filings will arrange themselves in a circle of lines around the wire. Figure II.45 illustrates the magnetic field around a wire that is carrying an electric current.

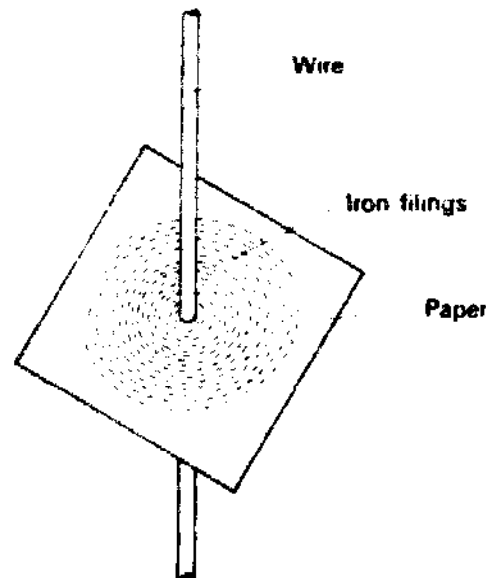


FIG. II.45. Magnetic field around a current carrying conductor.

The student may like to prove the fact that soft iron may be magnetised by an electric current. To do this, wind approximately 2 yards of insulated copper wire around a length of wrought iron. Connect the ends of the wire to the poles of a torch battery, when it will be seen that the iron will pick up steel pins. Disconnect the wires and the pins will drop off.



The electromagnet is used for a variety of purposes in industry, amongst which are generators, electromagnetic hoists and many small instruments.

### The Electric Arc

An electric arc is formed when an electric current is passed between two electrodes across a small gap. This effect is used for electric arc welding by causing the heat generated by this arc to melt the metal and make welding possible. As far as welding is concerned, the electrode carrying the current must always be touched onto the metal to be welded before the arc will flow. This is because of the low voltages used in welding and also because the air gap in between the electrode and the metal is ordinarily non-conducting. Once the "live" electrode has touched the metal, the current flows and, when the electrode is drawn off, a "spark" carries the current across what is at first a very small gap. After this the air in the gap becomes ionized, which makes it conducting, and as a result of this the current continues to flow across the gap.

When using d.c., the arc flows from the  $-VE$  pole to the  $+VE$  pole. Two-thirds of the heat in the arc is generated near the  $+VE$  pole, and the temperature at the point of meeting the plate being welded is approximately  $4000^{\circ}C$ . The remaining third is generated near the  $-VE$  pole.

It is usual to connect the workpiece to the positive pole of the d.c. generator and the electrode to the negative pole in order to melt the greater mass of metal in the base material. On the other hand, certain types of electrodes, because of their heavy coating, may be connected to the positive pole.

With a.c. the same amount of heat is generated at both workpiece and electrode, because the polarity is changing at twice the frequency of the supply.

The arc used in electric arc welding is a low voltage, high current discharge, and it depends for its maintenance upon the bombardment of ions and electrons at the electrode faces. This is caused by electrical energy being converted into heat.

**METAL TRANSFER ACROSS THE ARC GAP**

When an arc is struck between an electrode and parent plate, provided the current is sufficient, the parent plate and the electrode will melt. At the same time the electrode will discharge globules of metal from its tip to the molten pool on the plate. This metal transfer, as it is called, will take place with a.c. or d.c. It will also occur with the electrode held in any position. It is possible to observe metal transfer with the aid of a slow-motion movie film, on which it can be seen that the globules are pear-shaped, with a small "tail" at the point of breakaway from the electrode tip. The size of the globules varies according to the type of electrode and current conditions. Metal transfer from the electrode tip is smooth and controlled, provided all the conditions are right. But too long an arc, incorrect current, incorrect electrode for the type of metal being welded and incorrect rod manipulation will tend to upset the smooth flow of metal from the electrode across the arc.

## CHAPTER 6

# Engineering Drawing

ENGINEERING drawings are produced by a draughtsman to record ideas, so that others can read and understand them. Not the least of those who have to read and understand them is the craftsman on the workshop floor.

To enable mechanical drawings to be read more easily, a certain set of standards is employed and one must understand something of these standards before one can begin to read a drawing.

It is not the purpose of this book to enable readers to become competent draughtsmen and, in view of this, only some of the many aspects of engineering drawing are dealt with in this chapter.

### Equipment

#### DRAWING-BOARD

Drawing-boards must be level and square and to this end most are provided with one special edge for the tee square and a plastic-covered front. Clips and not drawing-pins should be used to hold the paper. The board should be at an angle, if possible, the bottom edge must be level.

#### TEE SQUARE

The most important point regarding tee squares is to ensure that the stock is not loose on the blade. Also make quite sure that the edge of the blade is smooth and level.

### PENCILS

There are many grades of pencil but the student need only have a small number of these; namely a 2H, HB and a 2B.

The 2H is for dimension and construction lines, the HB for lettering and arrow heads and the 2B for any other work requiring a soft pencil. Use a round point or chisel point, but make quite sure that it is sharp.

### SCALE RULE

Use a scale rule because the wooden rules marked in inches are quite useless for accurate drawings to scale. Do not use the scale for drawing straight lines as it is for measuring only.

### ADJUSTABLE SQUARE OR TRIANGLE

An adjustable square will eliminate the need for numerous other set squares. It is easy and quick to use and accurate if adjusted correctly.

### COMPASSES AND DIVIDERS

The range of the types of these instruments is so great that it is sufficient to obtain a pair of compasses that will draw a circle up to 2 in. in diameter and a pair of dividers. The quality also varies greatly, so the student must buy according to his means.

### FLEXIBLE CURVE

A flexible curve consists of a length of lead covered with rubber and it enables points to be joined up to complete a curve. It is of particular value when doing pattern development work.

### Straight-line Constructions and Scales

TO HALVE A STRAIGHT LINE OF KNOWN LENGTH (Fig. II.46).

Draw the line *AB* any length. Using *A* as centre, open compasses to over half of *AB* and arc below and above *AB*. Using the

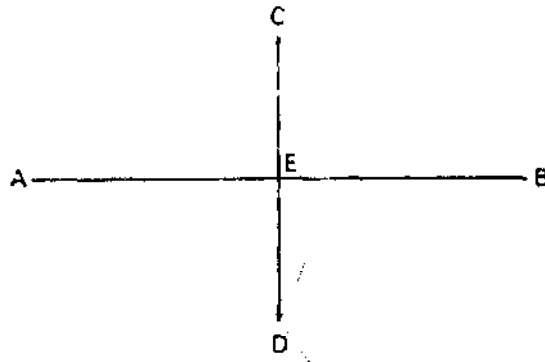


FIG. II.46. To halve a straight line of known length.

same arc length, describe an arc from  $B$  above and below  $AB$ . Where the arcs cross mark them  $C$  and  $D$ . Join  $C$  and  $D$ , this line will cut line  $AB$  at  $E$ .  $AE$  is equal in length to  $EB$ .

TO DRAW A PERPENDICULAR TO A STRAIGHT LINE FROM A POINT NEAR THE END OF THE LINE (Fig. II.47)

Draw a line  $AB$  any length. Position on line  $AB$  a point,  $X$ , near to the end of the line. Position point  $Y$  above line  $AB$ . With  $Y$  as centre, open compasses to radius  $XY$  and describe a circle. Where the circle cuts line  $AB$ , mark a point  $Z$ . Through  $YZ$  draw a line cutting circle at  $O$ . Join  $OX$ .  $OX$  is perpendicular to line  $AB$ .

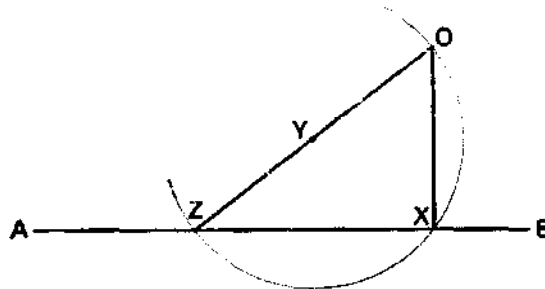


FIG. II.47. To draw a perpendicular line to a straight line from a point near the end of the line.

TO DRAW A PERPENDICULAR TO A STRAIGHT LINE TO A GIVEN POINT AWAY FROM THE LINE AND NEAR TO THE CENTRE OF THE LINE (Fig. II.48)

Draw a line  $AB$  any length. Position a point  $X$  away from the line. With  $X$  as centre, open compasses to a radius greater than

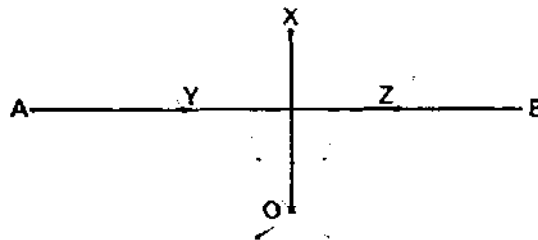


FIG. II.48. To draw a perpendicular line to a straight line to a given point away from the line and near to the centre of the line.

the perpendicular distance from  $X$  to line  $AB$ . Describe an arc to cut line  $AB$  at points  $Y$  and  $Z$ . With  $Y$  as centre, open compasses to a radius greater than half of  $YZ$ . Describe an arc below  $AB$ . With  $Z$  as centre and with the same radius, describe an arc below  $AB$ . Where this arc cuts the previous arc mark point  $O$ . Join  $OX$ .  $OX$  is perpendicular to line  $AB$ .

TO CONSTRUCT A STRAIGHT LINE PARALLEL TO A STRAIGHT LINE (Fig. II.49)

Draw a line  $AB$  any length. From any point on line  $AB$ , but preferably near the end, open compasses to the radius equal to the distance of one line from the other. Describe an arc. Repeat from



FIG. II.49. To construct a straight line parallel to a straight line.

another point at the opposite end of line  $AB$ . Draw a line that just touches the two arcs. This line will be parallel to line  $AB$ .

TO DIVIDE A GIVEN STRAIGHT LINE INTO ANY NUMBER OF EQUAL DIVISIONS (Fig. II.50)

Draw line  $AB$  as the given length. From point  $A$  draw a line at an acute angle to line  $AB$ . Mark point  $X$  at the end of this line.

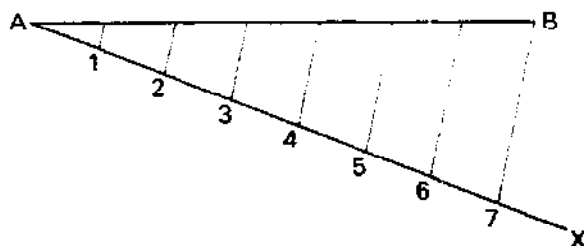


FIG. II.50. To divide a given straight line into any number of equal divisions.

Mark off on line  $AX$  the required number of divisions. Join the last division to point  $B$ . Number up the division points (7 in this instance). Draw lines from each division point parallel to line  $B7$ .

### DRAWING TO SCALE

Many engineering items are far too large to draw full size and it is necessary to draw these much smaller than their actual size.

If an object is drawn so that its dimensions are exactly one-quarter of the actual size, the object is drawn to a quarter scale.

The scale used must always be shown on the drawing and it is usually shown as:

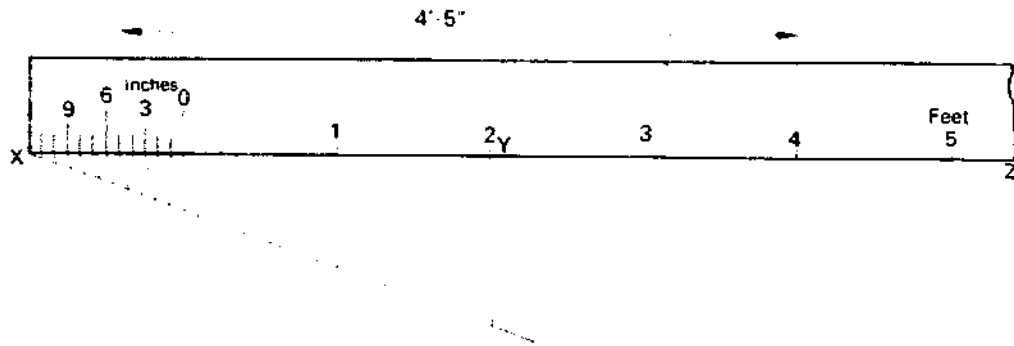
Scale: 3 in. to 1 ft ( $\frac{1}{4}$  full size)

Scale:  $1\frac{1}{2}$  in. to 1 ft ( $\frac{1}{8}$  full size).

**WELDING CRAFT PRACTICE—PART 1, VOL. 2**

**TO CONSTRUCT A SCALE OF 4 IN. TO 3 FT, TO READ UP TO 6 FT (Fig. II.51):**

Draw a line *XZ*. Mark on line *XZ* point *Y* 4 in. from *X*. Divide line *XY* into three equal parts. Each of these parts will



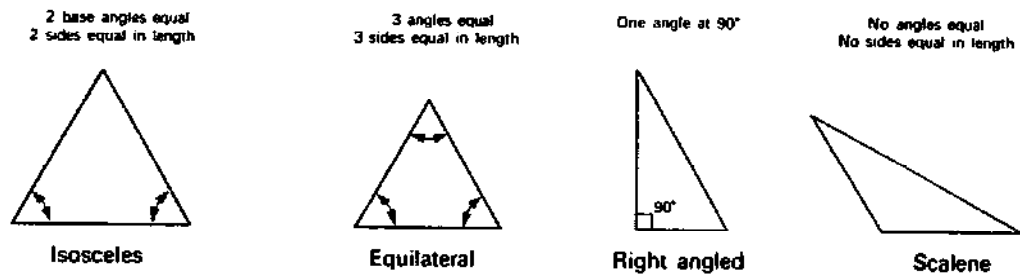
**FIG. II.51.** To construct a scale of 4 in. to 3 ft to read up to 6 ft.

equal 1 ft on the scale. From point *Y* mark off three of these divisions to obtain the required six 1-ft lengths. To obtain inches on the scale, divide the first division into 12 equal parts. Read the scale from left to right. This is illustrated with a specimen reading of 4 ft 5 in.

**TRIANGLES (Fig. II.52)**

**TO CONSTRUCT A TRIANGLE GIVEN THE LENGTH OF THE THREE SIDES (Fig. II.53)**

Mark off side *AB*. Using *A* as centre open compasses to length of side *AC*. Describe an arc. Using *B* as centre open compasses



**FIG. II.52.** Triangles.



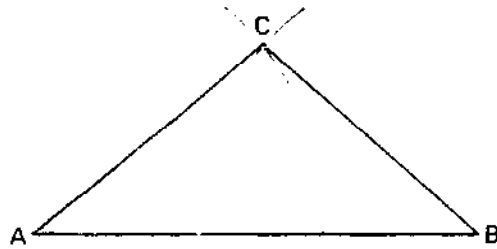


FIG. 11.53. To construct a triangle given the length of the three sides.

to length of side  $BC$ . Describe an arc. Where the two arcs cross mark point  $C$ . Join  $AC$  and  $BC$ .

TO CONSTRUCT A TRIANGLE GIVEN THE APEX ANGLE, THE VERTICAL HEIGHT AND ONE BASE ANGLE (Fig. 11.54)

Using an adjustable square or protractor construct the angle  $a$ . From the base line erect the vertical height on a perpendicular

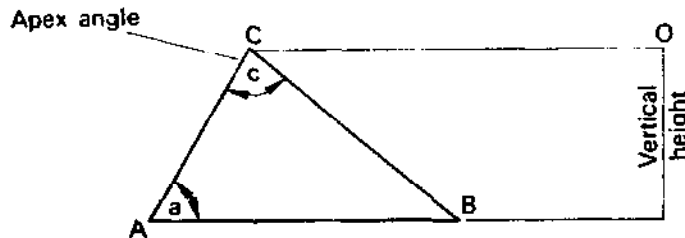


FIG. 11.54. To construct a triangle given the apex angle, the vertical height and one base angle.

line, mark this as point  $O$ . Draw a parallel line from point  $O$  until it meets at point  $C$ . Construct the apex angle  $c$  and join to the base line at  $B$ .

#### ANGLES AND THEIR CONSTRUCTION

When two straight lines meet they form an angle, or the angle is included between the two lines. The straight lines are called the

arms of the angle and where the two lines meet is called the vertex (Fig. II.55).

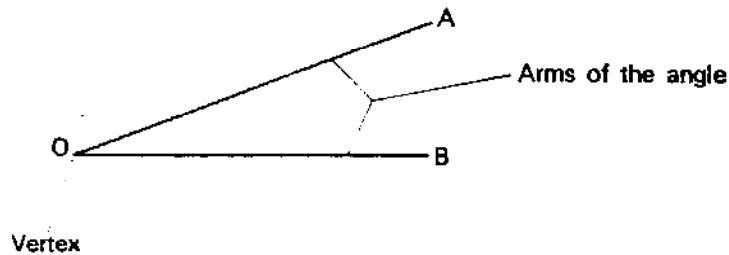


FIG. II.55. Vertex and arms of the angle.

*Acute angles* (Fig. II.56). An acute angle is one that is less than a right angle ( $90^\circ$ ).

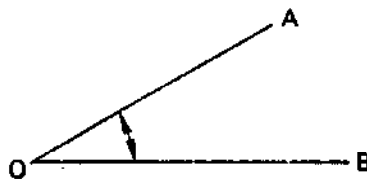


FIG. II.56. Acute angle.

*Obtuse angles* (Fig. II.57). An obtuse angle is one that is greater than a right angle.

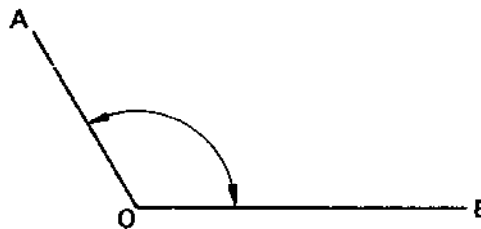


FIG. II.57. Obtuse angle.

*Right angles* (Fig. II.58). When a perpendicular straight line meets a horizontal straight line the resultant angles are right angles.

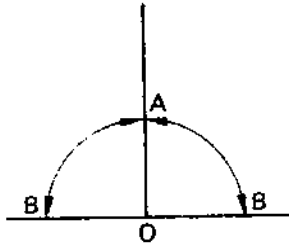


FIG. II.58. Right angle.

*Vertically opposite angles* (Fig. II.59). When two straight lines cut one another as  $AO$  and  $BO$  cut the line  $OC$ , the two angles  $AOB$  and  $COB$  are named vertically opposite (or complementary) angles.

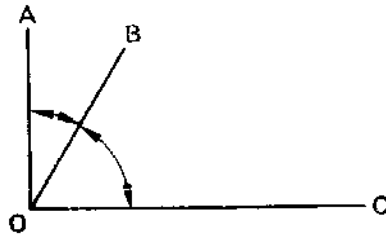


FIG. II.59. Vertically opposite angles.

### QUADRILATERALS

A quadrilateral is a plane (closed) rectilinear figure bounded by four straight lines. (A plane surface having all boundary lines as straight lines is a rectilinear figure).

#### REGULAR QUADRILATERALS

*Rectangle* (Fig. II.60). A rectangle is a quadrilateral having both pairs of opposite sides parallel and one of the angles must be a right angle.

*Square* (Fig. II.61). A square is a quadrilateral having both pairs of opposite sides parallel and one of the angles must be a right angle. Two adjacent sides must be equal in length.

*Parallelogram* (Fig. II.62). A parallelogram is a quadrilateral having both pairs of opposite sides parallel.

*Rhombus* (Fig. II.63). A rhombus is a quadrilateral having both pairs of opposite sides parallel. Two adjacent sides must be equal in length and none of the angles are right angles.

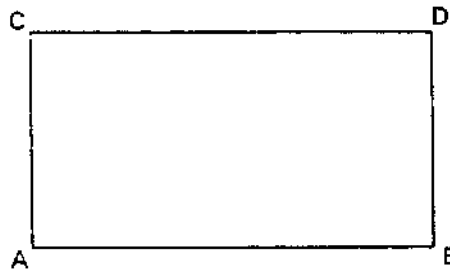


FIG. II.60. Rectangle.

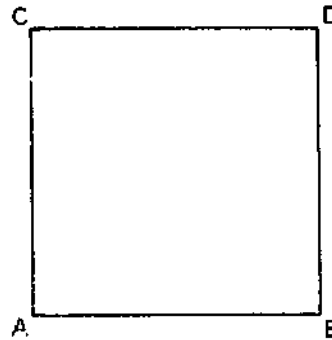


FIG. II.61. Square.

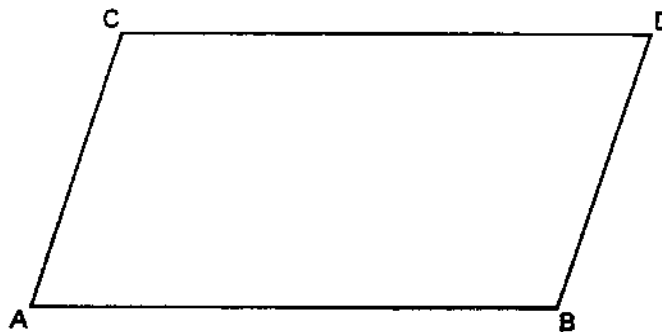


FIG. II.62. Parallelogram.

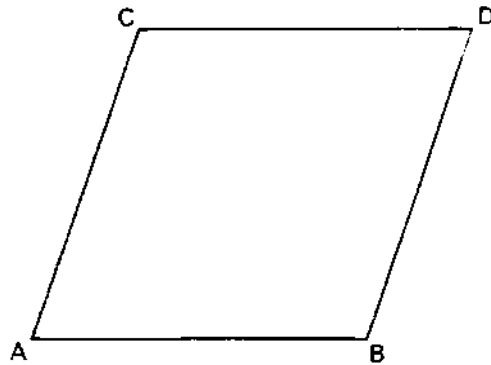


FIG. II.63. Rhombus.

**TO CONSTRUCT A RECTANGLE (Fig. II.60)**

Draw the line  $AB$  to the given length. From point  $A$  draw line  $AC$  to the given length. This line must be at right angles to line  $AB$ . From point  $C$  draw line  $CD$  the same length as  $AB$ . This line must be at right angles to line  $AC$ . Join up points  $DB$ .

**TO CONSTRUCT A SQUARE (Fig. II.61)**

The square is constructed in exactly the same way as a rectangle except that all four sides must be equal in length.

**TO CONSTRUCT A PARALLELOGRAM (Fig. II.62)**

Draw line  $AB$  to the given length. Set adjustable square (or use protractor) to the given angle. Draw a line from point  $A$  and from point  $B$  with both lines at the same angle. Mark off the given length on the line from point  $A$ . Mark point  $C$ . From point  $C$  draw a line parallel with line  $AB$  until it meets at point  $D$ .

**TO CONSTRUCT A RHOMBUS (Fig. II.63)**

The rhombus is constructed in exactly the same way as a parallelogram except that all four sides must be equal in length.

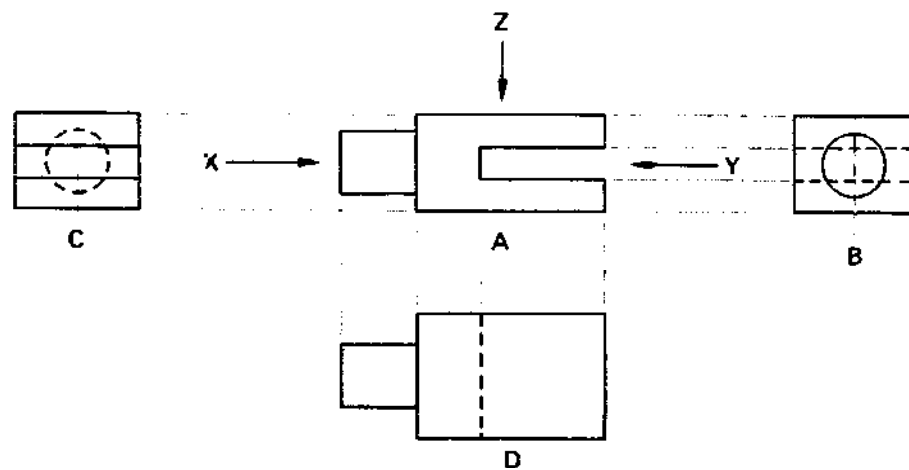
**Projection**

**FIRST-ANGLE PROJECTION**

Figure II.64 shows a small object drawn in first-angle projection. *A* is the elevation of the object, *B* is a view looking on arrow *X*, and *C* is a view looking on arrow *Y*. So it will be seen that the two end views are drawn on opposite sides of their true ends; in other words the view looking on arrow *X* is not drawn on that side of the object, but is actually drawn on the side that arrow *Y* points to. View *D* is the plan view looking in the direction of arrow *Z*.

**TO DRAW THE OBJECT SHOWN IN FIG. II.64 IN FIRST-ANGLE PROJECTION**

Draw the elevation. The elevation is usually drawn looking at the object the correct way up and at its longest side. Project lines from the elevation into the plan view. This is looking in the direction of arrow *Z*. The end elevation looking in the direction of arrow *X* may now be drawn as also may the view looking in the direction of arrow *Y*.



View B = In direction of arrow X

View C = In direction of arrow Y

FIG. II.64. First angle projection.

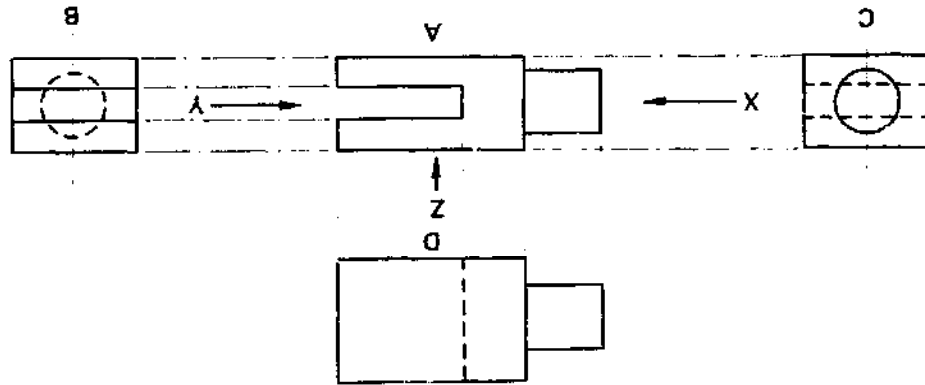
Not all objects require four views and the draughtsman will only draw a sufficient number of views to ensure that a complete description of the object is presented to the craftsman on the shop floor.

THIRD-ANGLE PROJECTION

Figure II.65 shows the same object as in Fig. II.64 but drawn in third-angle projection. *A* is the elevation of the object, *B* is a view looking on arrow *Y*, and *C* is a view looking on arrow *X*. It will be seen that the two end views are both shown at their respective ends and not at opposite ends.

TO DRAW THE OBJECT SHOWN IN FIG. II.65 IN THIRD-ANGLE PROJECTION

Draw the elevation as for first-angle projection. Project lines from the elevation into the plan view, which will be drawn above the elevation. Draw the end elevations looking in the directions of arrows *X* and *Y*.




View B = In direction of arrow *Y*  
View C = In direction of arrow *X*


FIG. II.65. Third angle projection.

### Welding Terms and Symbols

It has been found necessary during the preparation of engineering drawings relating to welded fabrications, to employ a common scheme to indicate what type of welded joint the designer requires.

The scheme of symbols is a method whereby a great deal of unnecessary wording on a drawing may be dispensed with and in its place a sign or symbol may be used. As an illustration of this,

if the joint required is a fillet weld it is indicated by the sign  and the writing of the words "fillet weld" would not be necessary; further to this, if the fillet weld is required on both sides of the

joint, then this would be indicated by the sign , again

eliminating the writing of the words.

The two examples used are simple and easy to understand, but in conjunction with these signs there may be other signs which will require a little more understanding.

A British Standard has been published which has evolved a scheme of welding terms and symbols with the object of including these on drawings, so giving the necessary information concerning the type, size and position of welds in welded joints. This British Standard is 499, *Welding Terms and Symbols, Part 2: 1965, Symbols for Welding*.

#### B.S. 499, PART 2: 1965. INDICATION OF WELDS

The information necessary to indicate the type of weld required has to be shown by the use of (a) a weld symbol, (b) a reference line, (c) an arrow-head, (d) size of the weld, (e) other symbols such as may be necessary (e.g. sealing run, site weld, weld finish).

#### TYPE OF WELD

The British Standard gives twenty-four symbols relating to types of weld (Fig. II.66).



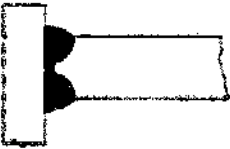












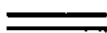


Double-J-butt		
Fillet		
Square butt		
Single-V-butt		
Double-V-butt		
Single-U-butt		
Backing strip		
Spot		

FIG. II.66.

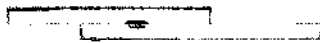

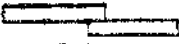



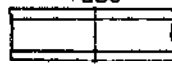


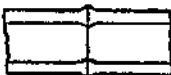



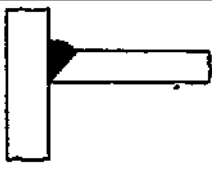

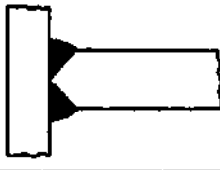
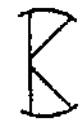
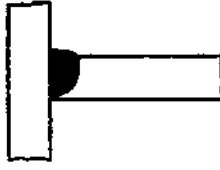

Butch		
Mesh stitch	<p>Before </p> <p>After </p>	
Flash	<p>Bar </p> <p>Tube </p>	
Butt resistance or pressure	 	
Double-U-butt		
Single-bevel butt		
Double-bevel butt		
Single-J-butt		

FIG. II.66 (continued).

ENGINEERING DRAWING

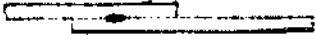
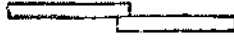






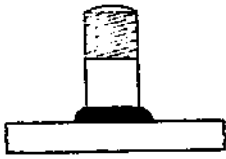

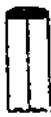





Seam		XXX
Mash seam	<p>Before</p>  <p>After</p> 	
Projection	<p>Before</p>  <p>After</p> 	
Full penetration butt weld by a procedure to be agreed		
Stud		
Edge		
Seal		
Sealing run		

FIG. II.66 (continued).

These symbols refer to the shape of the weld only and do not indicate the number of runs of weld necessary to complete the joint. Nor do the symbols impart any information with regard to the size of root gap or root face if either is in the weld indicated.

### THE REFERENCE LINE

The reference line is the line that carries the weld symbol and it is positioned in a straight line, square across the drawing. The line that carries the arrow-head is positioned at an angle to this line.

The reference line has the welding symbol positioned either above it or below it, either attached to it or away from it.

- |  |  |
|--|--|
| (a) For welds to be made from the arrow side of a joint. | Invert the symbol and suspend it from the reference line (Fig. II.67). |
| (b) For welds to be made from the other side of a joint. | Place the symbol on top of the reference line (Fig. II.68).            |
| (c) For welds to be made on both sides of the joint.     | Place the symbol on both sides of the reference line (Fig. II.69).     |

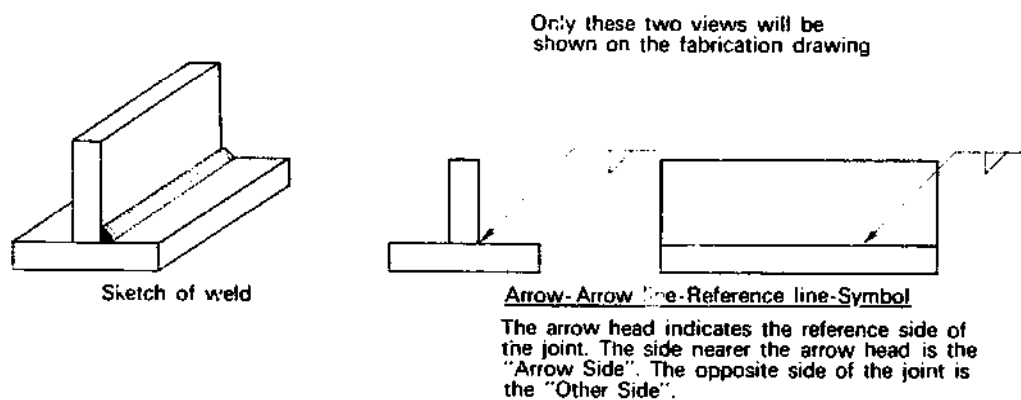


FIG. II.67. Fillet weld from arrow side only.

SIGNIFICANCE OF POSITION OF ARROW-HEAD

The arrow-head as well as indicating the sides of the joint, may also be used to point towards the prepared edge of a plate.

An illustration of this is given in Fig. II.70, where the joint shown is a single-bevel butt joint. The arrow-head is used to indicate the plate to be prepared and the symbol indicates also the side from which the weld is to be made and therefore the wide part of the preparation.

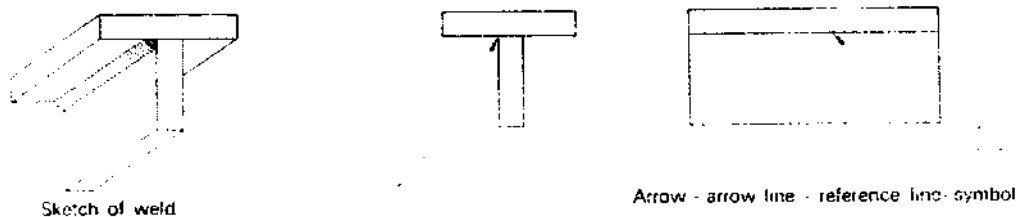


FIG. II.68. Fillet weld.

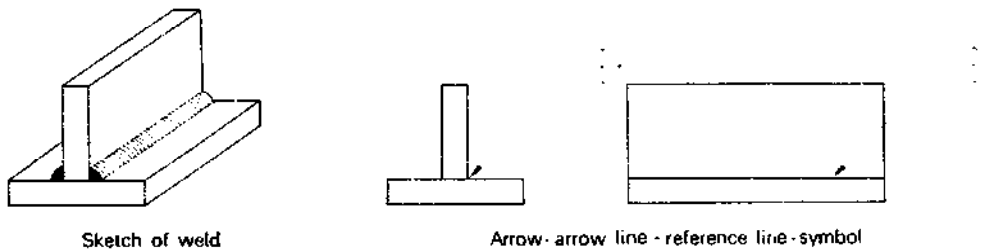


FIG. II.69. Fillet weld from both sides.

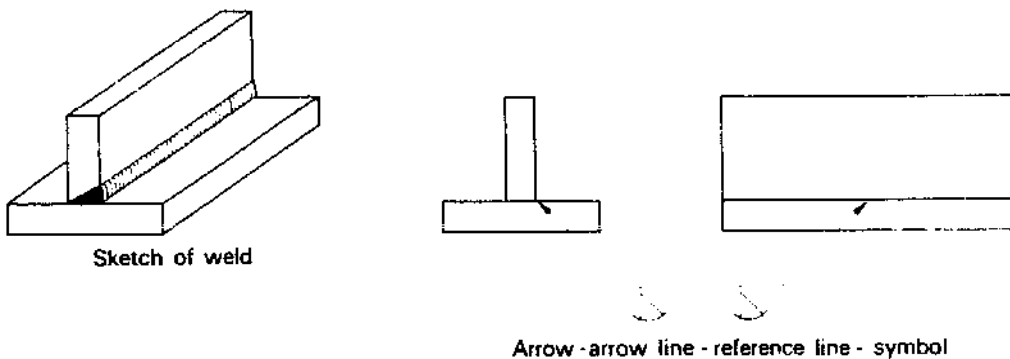


FIG. II.70. Single-bevel butt joint.

In the case of projection welding, the arrow-head must point to the centre line of the weld. The plate which is to carry the projection will be indicated by the symbol which will be shown on the reference line, according to the side of the plate on which the projection is to appear (see Fig. II.67 for reference to arrow side and other side). Figure II.71 illustrates a projection weld.

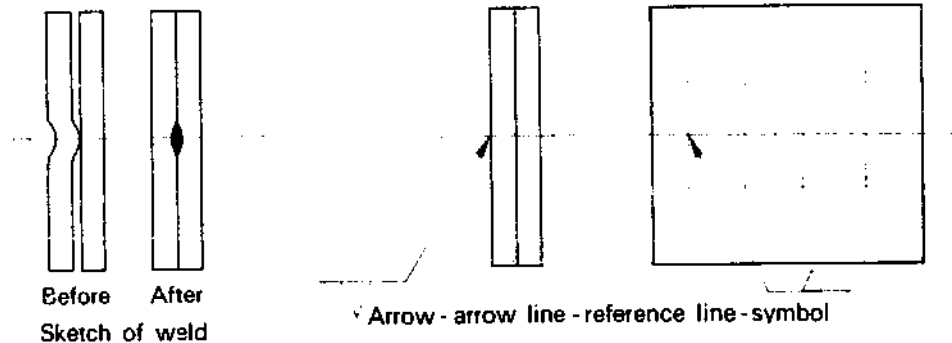


FIG. II.71. Projection welding.

### BACKING STRIPS AND BACKING BARS

A backing strip behind a welded joint may be either permanent or temporary. It may be in the form of a flat piece of bar or it may be a structural member, i.e. a channel section or joist. If the backing strip is to be welded on permanently, it may require either fully welding or tack welding.

The backing strip must be indicated on the drawing in the position in which it is required to be fitted.

Figure II.72 illustrates a backing strip that is to become a permanent part of the welded joint. The joint indicated is a square butt.

Figure II.73 illustrates a backing strip that has to be removed after welding. Here again, the joint indicated is a square butt.

If a backing bar is required, the backing bar symbol will be used, but there need not be any indication of the bar on the drawing. Reference to welding procedure sheets should suffice for this. A mention of procedure sheets may clarify this point:

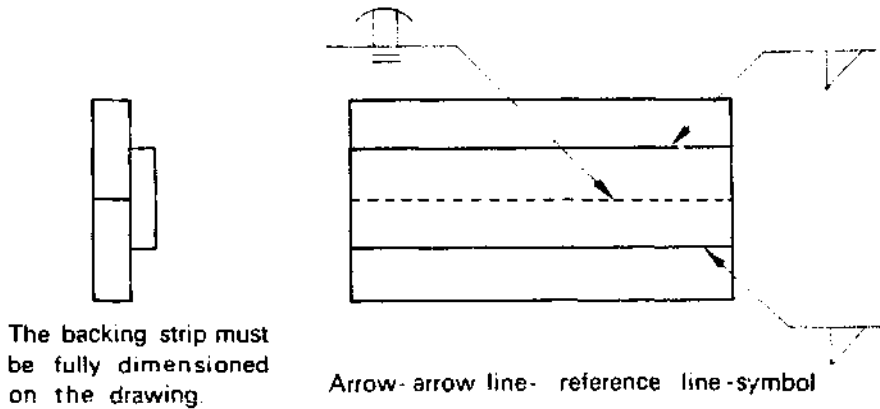


FIG. II.72. Butt weld with permanent backing strip.

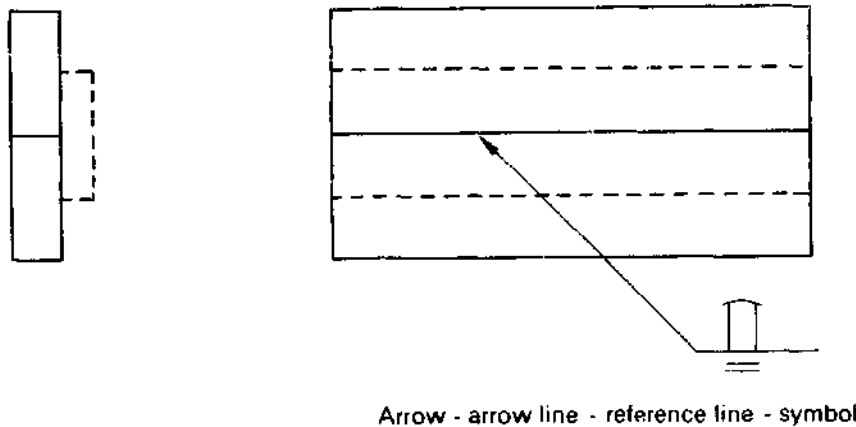


FIG. II.73. Butt weld that is to be removed after welding.

Some drawing and design offices issue a standard set of rules and conditions, which must be read in conjunction with the drawings. This method of procedure eliminates a tedious amount of drawing office work, in that reference need not be made on all the drawings to the welding procedures that are necessary, as the welder need only refer to the set of welding standards.

#### FLUSH FINISH TO WELDS

It is necessary on some welded joints to finish the weld flush with the parent plate. This is usually carried out by grinding or

chiselling, and the required method should be indicated on the drawing, again by reference to standard procedure sheets.

The symbol for indicating a flush finish is a straight horizontal line under the symbol, as shown in Fig. II.74.

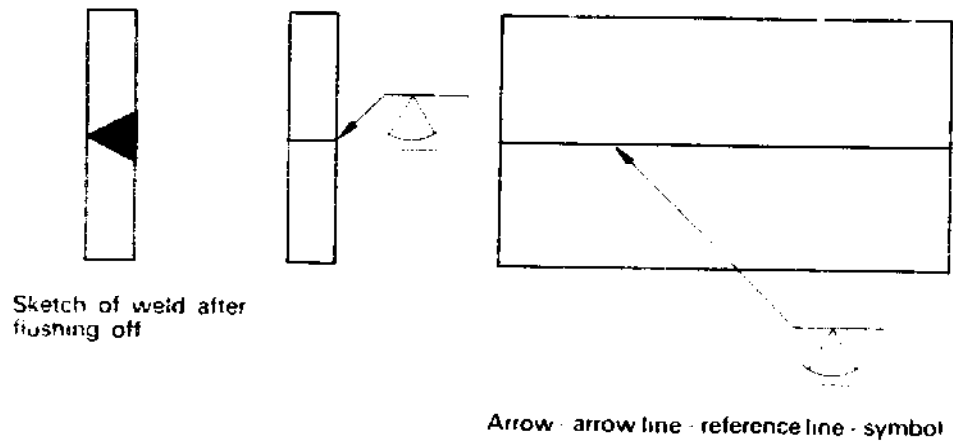


FIG. II.74. Single V butt weld with the weld made flush.

### WELD ALL ROUND

Where a weld is to be made all round a joint, e.g. a round bar on to a flat plate or a length of angle bar to a flat plate, the symbol is a circle at the junction of the arrow line and the reference line. Figure II.75 illustrates a flat plate to angle joint.

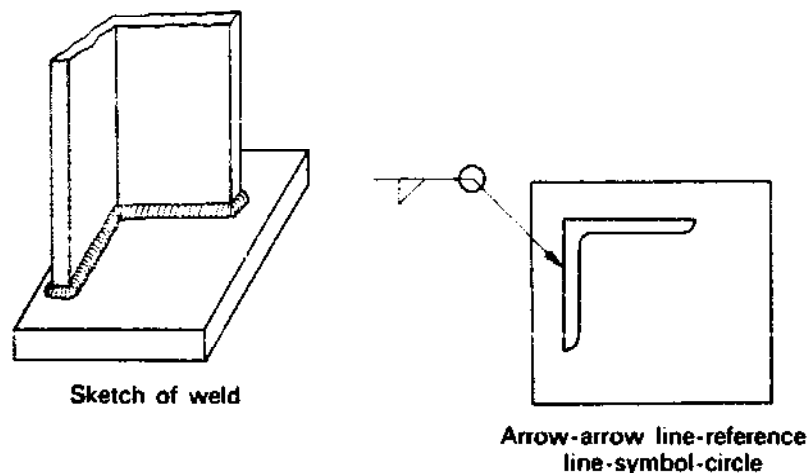


FIG. II.75. Angle welded all round to plate.



## SITE WELDS

It is sometimes necessary to indicate on the drawing that certain pieces of the job are not to be welded in the shop but that they are to be left until the fabrication is being erected on the site.

The symbol for this is a filled-in circle at the junction of the arrow line and the circle line. Figure II.76 gives an illustration of an angle bracket that is to be welded to a joist on the site.

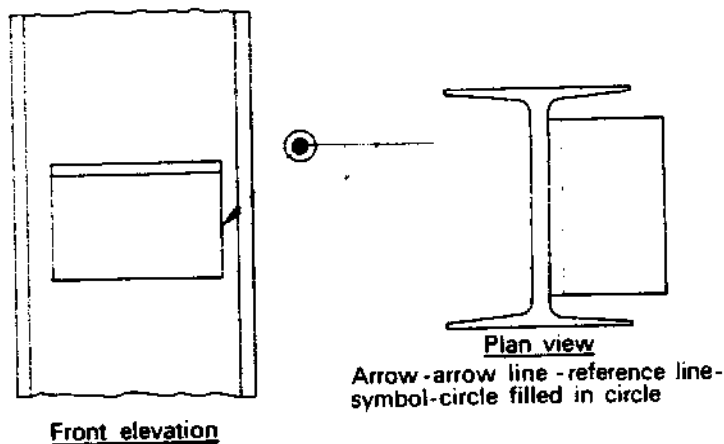


FIG. II.76. Fillet weld to be carried out on site.

### *Weld Dimensions and Relevant Information*

#### LENGTH OF FULL FUSION WELDS

Unless the drawing indicates otherwise, the length of the weld will be continuous along the whole of the joint.

#### INTERMITTENT WELDS

It is sometimes necessary to weld only at regular or irregular intervals along a joint. This is done for several reasons, e.g. to minimise distortion by restricting the heat input or when the load on the welded part is so small that a continuous weld would be uneconomical.

Where regular intermittent welding is required and the joint commences with a weld, this is indicated by the length of each

weld on the right-hand side of the symbol. The unwelded length is shown in brackets next to the welded length.

If the welded joint is to start with a space, the length of the space is shown in brackets between the weld symbol and the length of the weld. Figure II.77 shows a bracket welded intermittently commencing with a weld and Fig. II.78 shows the same bracket, but commencing with an unwelded length.

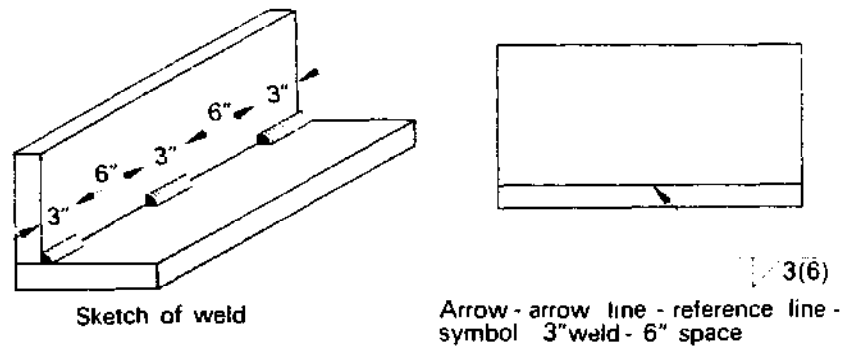


FIG. II.77. Intermittent fillet weld commencing with a weld.

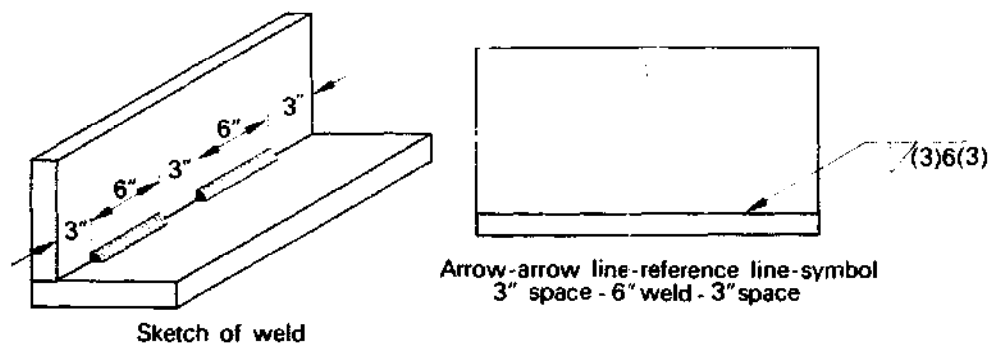


FIG. II.78. Intermittent fillet weld commencing with a space.

### SIZE OF FILLET WELDS

Fillet welds having an equal leg length have the dimension on the left-hand side of the symbol, in inches and fractions of an

inch. Figure II.79 illustrates a number of different sized fillet welds.

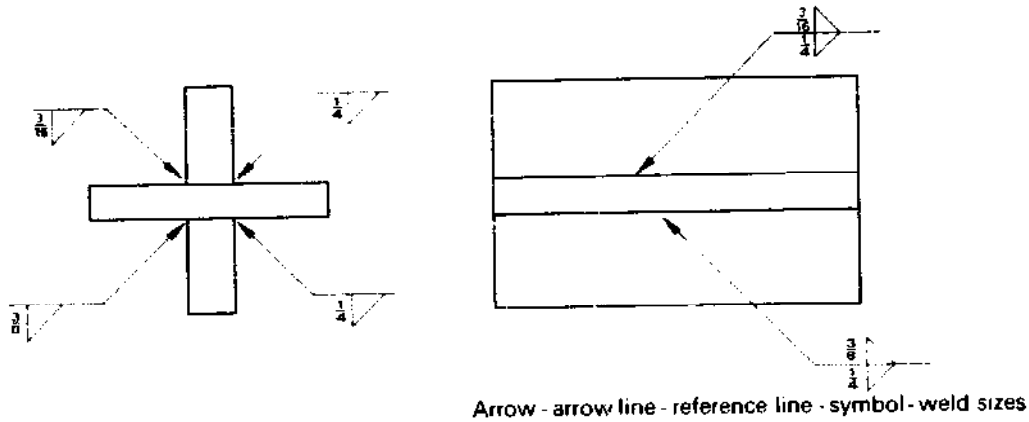


FIG. II.79. Showing sizes of equal leg length fillet welds.

If the fillet has unequal leg lengths then this is shown on the left-hand side of the symbol, as in Fig. II.80. The weld must be shown if the fillet has an unequal leg length, unless the joint makes it quite obvious which size of the leg is to be on which plate.

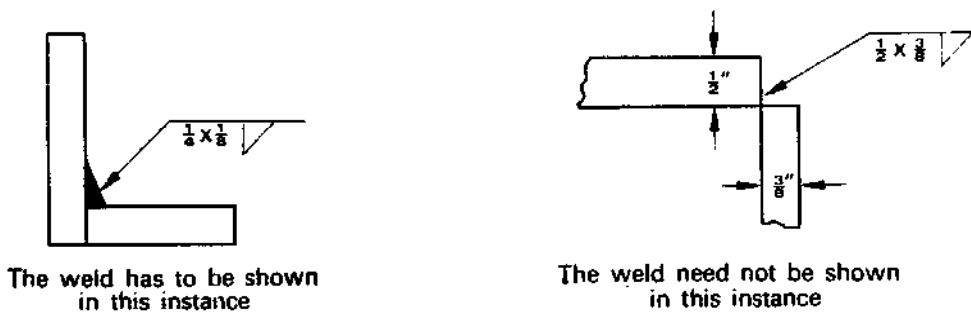


FIG. II.80. Showing sizes and weld representation of unequal leg fillet welds.

JOINTS THAT DO NOT REQUIRE FULL PENETRATION

Some welded joints may not require full penetration, e.g. a butt joint in 1-in.-thick plate may only need to be welded to half of its thickness.

Part-penetrated joints must be shown on the drawing by indicating the depth of penetration on the left-hand side of the symbol. Figure II.81 gives some illustrations of partially penetrated butt joints in thick plates.

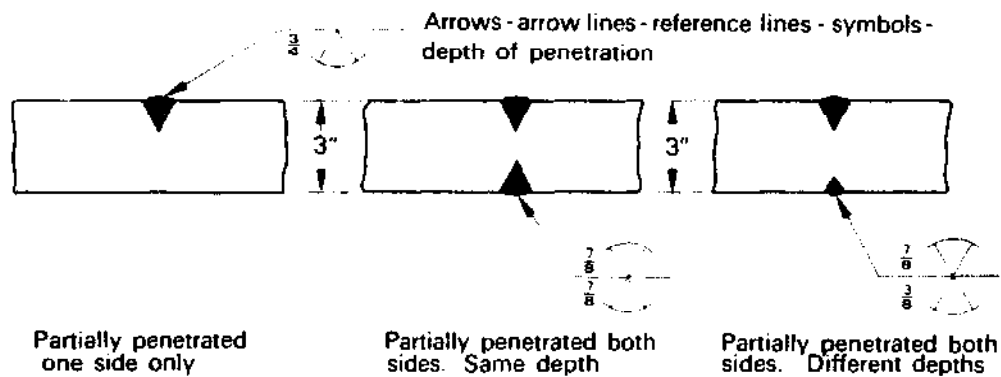


FIG. II.81. Showing partially penetrated butt joints.

Surface Development

Surface development is the art of obtaining the correct shape of an article in the "flat", before it is rolled, bent or moulded to its correct shape. These shapes, when they are developed, are called patterns. They are in fact a pattern of the shape.

Almost all plate fabrications are hollow bodies and the plates or sheets constitute the surface of the article. The surface is shaped into the form required from the flat sheet and it is necessary that the finished job is correct and true to shape. To this end the correct shape of the pattern must be right from the beginning. This process of determining the shape before forming is known as surface development.

## METHODS OF SURFACE DEVELOPMENT

There are three methods by which the surfaces of shapes may be developed, they are:

1. The Radial-line Method.
2. The Parallel-line Method.
3. The Triangulation Method.

The radial-line method is a method in which a series of lines are radiated from a fixed point from different arc lengths and is used for almost all tapering articles, such as cones.

The parallel-line method makes use of a straight line, drawn on the surface of a shape, say a cylinder, with a shaped cross-section, from which are extended parallel lines at right angles to the straight lines on the cylinder to the shape of the surface.

The triangulation method is used to develop such shapes as frustums with a circular base and an oval top. The surface is divided up into triangles and the true sizes of the triangles are transferred to the pattern, side by side, so completing the surface development of the article.

*Examples of Development by the Radial-line Method*

**RIGHT CONIC FRUSTUM (Fig. II.82)**

A right cone is a body having a circular base and tapering uniformly from the base to a point (apex) which lies perpendicularly over the centre point of the base.

Draw the elevation 1-7-9. Mark off line 8-10 at the height of the frustum. Describe a half circle on the base. Divide the half circle into six equal arcs. Mark the points 2 to 6.

*To develop the pattern.* Describe an arc from point 9 as centre and equal to 9-1 in radius. Mark off twelve equal arcs on the arc, number them points 1<sup>1</sup> to 1<sup>2</sup>. Each arc must be equal to one of the arcs on the base half circle. Join up point 1<sup>2</sup> to 9 and 1<sup>1</sup> to 9. Describe the arc 10<sup>1</sup>-10<sup>2</sup>, equal in radius distance 9-10, using point 9 as centre.

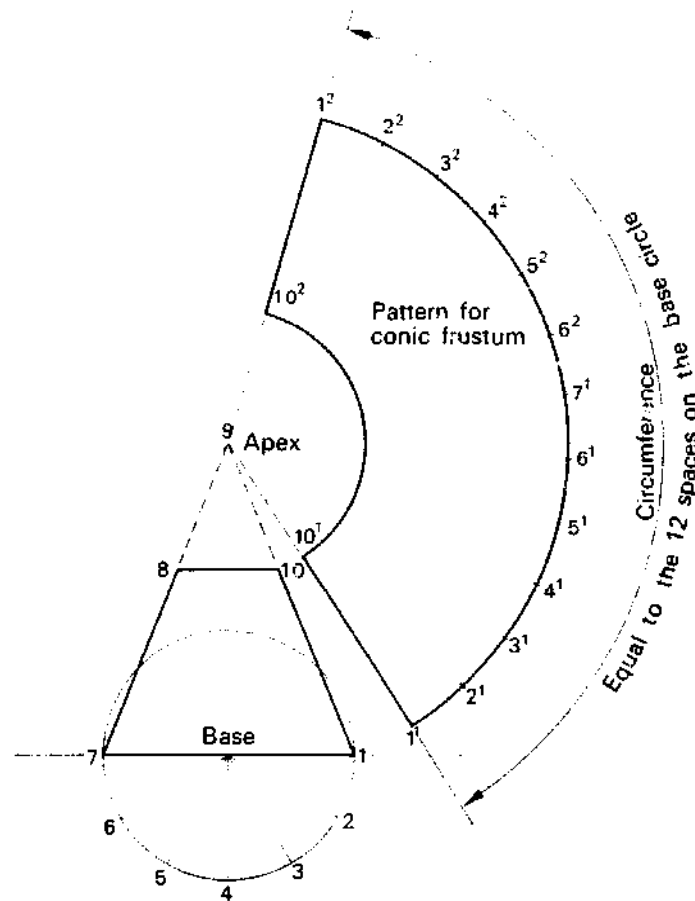


FIG. II.82. Surface development of a right conic frustum.

### RIGHT CONIC FRUSTUM CUT OBLIQUELY (Fig. II.83)

Draw the elevation 1-7-9. Mark off line 8-10 equal to the two heights of the frustum. Describe a half circle on the base. Divide the half circle into six equal arcs. Mark these points 2 to 6. Take each of the points on the base half circle perpendicularly back to the base line and then directly to the point 9 (apex). Where each one of these lines cross the line 8-10 draw a line from each point horizontally to line 1-10.

*To develop the pattern.* Describe an arc from point 9 as centre and equal to 9-1 in radius. Mark off twelve equal arcs on the main arc and number them point 1<sup>1</sup> to 12<sup>1</sup>. Each arc must be equal to one of the arcs on the base half circle. Take each of the points

on the arc  $1^1-1^2$  back to point 9. From point 9 describe arcs from all the points on line  $10-1$ , until they meet their respective lines in the pattern, i.e. point 8 in the elevation meets line  $9-7^1$  in the pattern at point  $8^1$ . Using a curve, join up all the points in the pattern to give the flexible curve  $10^1-10^2$ . Join up points  $1^2$  to 9 and  $1^1$  to 9.

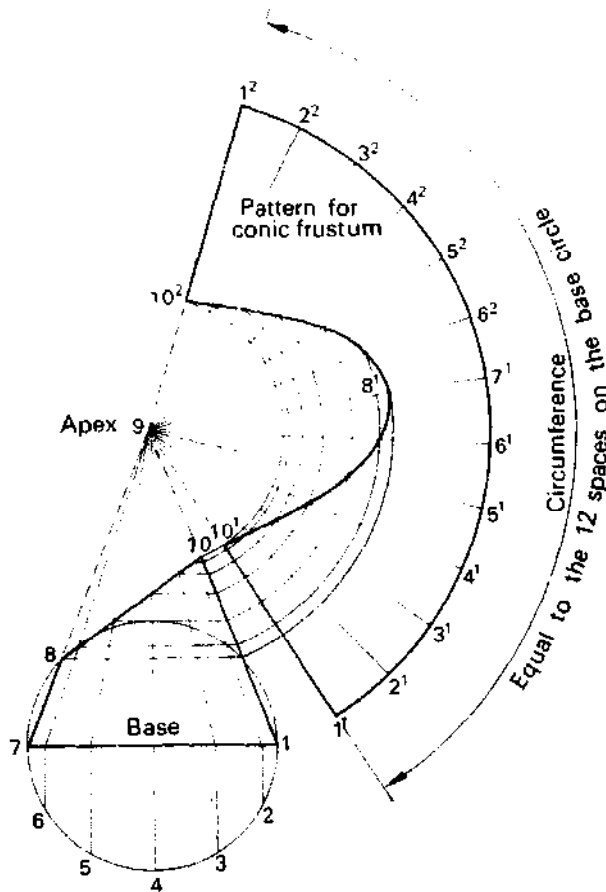


FIG. II.83. Surface development of a right conic frustum cut obliquely.

### *Example of Development by the Parallel-line Method*

#### CYLINDRICAL PIPE ELBOW (Fig. II.84, offset pipe elbow)

Draw the elevation  $1-7-8-9$ . Line  $8-9$  represents the joint line of the offset. Describe a half circle on the base of the pipe. Divide the

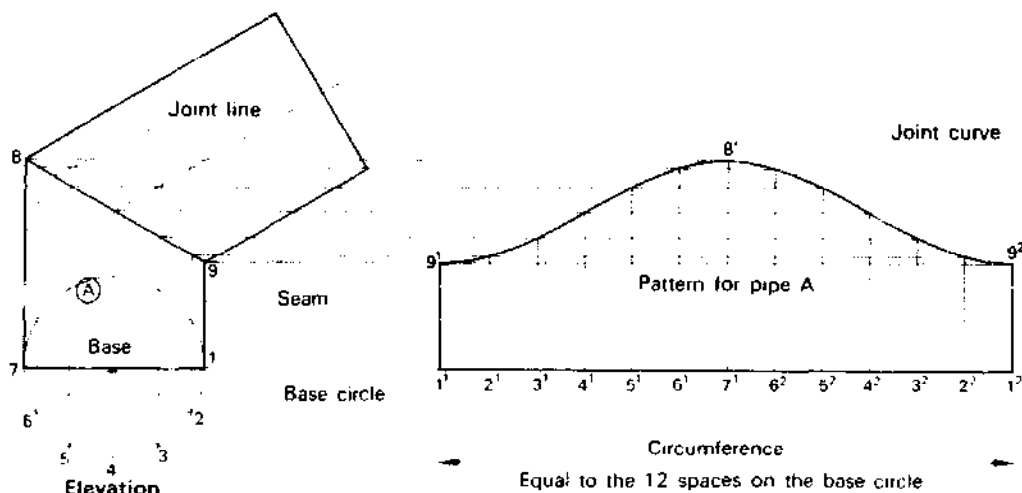


FIG. II.84. Offset pipe elbow.

half circle into six equal arcs and number each point 2 to 6. Take each point on the base half circle back perpendicularly to the line 8-9.

*To develop the pattern.* Draw a line horizontal with the base line and divide this line into twelve equal lengths, numbering them 1<sup>1</sup> to 1<sup>2</sup>. Each length must be equal to one of the arcs on the base half circle. Where each line from the base half circle in the elevation meets line 8-9 draw a line horizontally from each point to meet its respective line in the pattern. When all points have been plotted on the pattern, join up all the points to form the joint curve.

#### CYLINDRICAL PIPE ELBOW (Fig. II.85, right-angle pipe elbow)

Draw the elevation 1-7-8-9. Line 8-9 represents the 45° joint line. Describe a half circle on the base of the pipe and divide the half circle into six equal arcs, numbering each point 2 to 6. Take each point on the base half circle back perpendicularly to the line 8-9.

*To develop the pattern.* Draw a line horizontal with the base line and divide this line into twelve equal lengths; numbering them 1<sup>1</sup> to 1<sup>2</sup>. Each length must be equal to one of the arcs on the



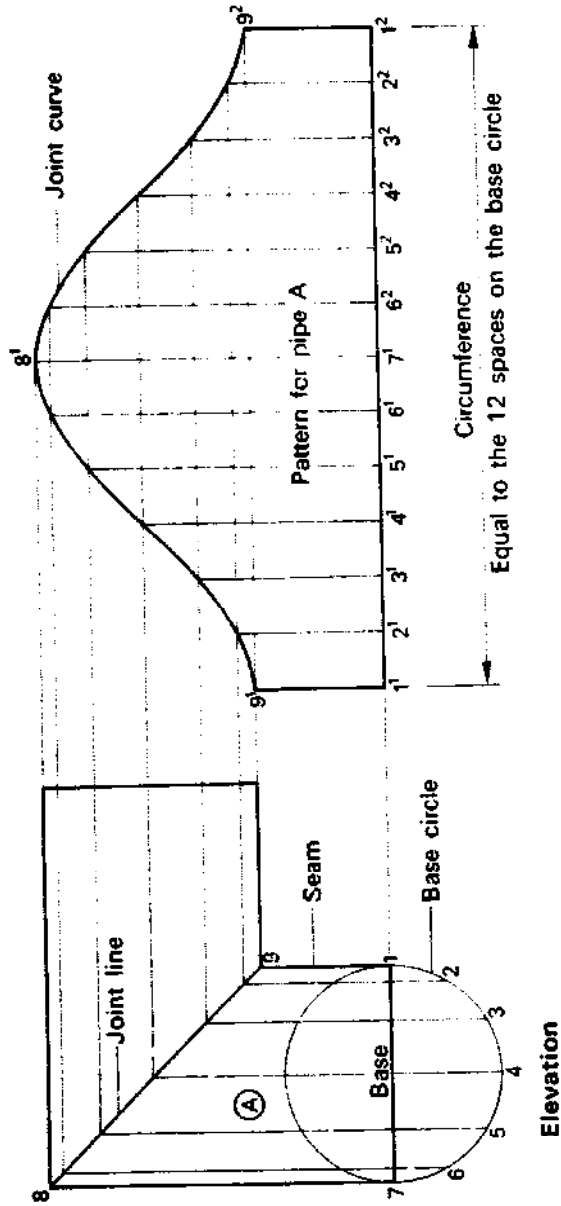


Fig. II.85. Right-angle cylindrical pipe elbow.

base half circle. Where each line from the base half circle in the elevation meets line 8-9, draw a line horizontally from each point to meet its respective line in the pattern. When all points have been plotted on the pattern, join up all the points to form the joint curve.

**SQUARE PIPE ELBOW (Fig. II.86, right-angle elbow)**

Draw the elevation 1/4-2/3-7/8-5/6. Line 7/8-5/6 represents the 45° joint line. Draw the plan 1-2-3-4.

*To develop the pattern.* Draw a line horizontal with line 2/3-1/4. Mark off on this line four lengths, equal to the four lengths in the plan. Mark the points 1<sup>1</sup> to 1<sup>2</sup>. From point 5 in the elevation, draw a horizontal line into the pattern until it meets line 1<sup>1</sup> and 1<sup>2</sup>. From point 7 in the elevation, draw a horizontal line into the pattern until it meets line 2<sup>1</sup>. From point 8 in the elevation, draw a horizontal line into the pattern until it meets line 3<sup>1</sup>. From point 6 in the elevation draw a horizontal line into the pattern

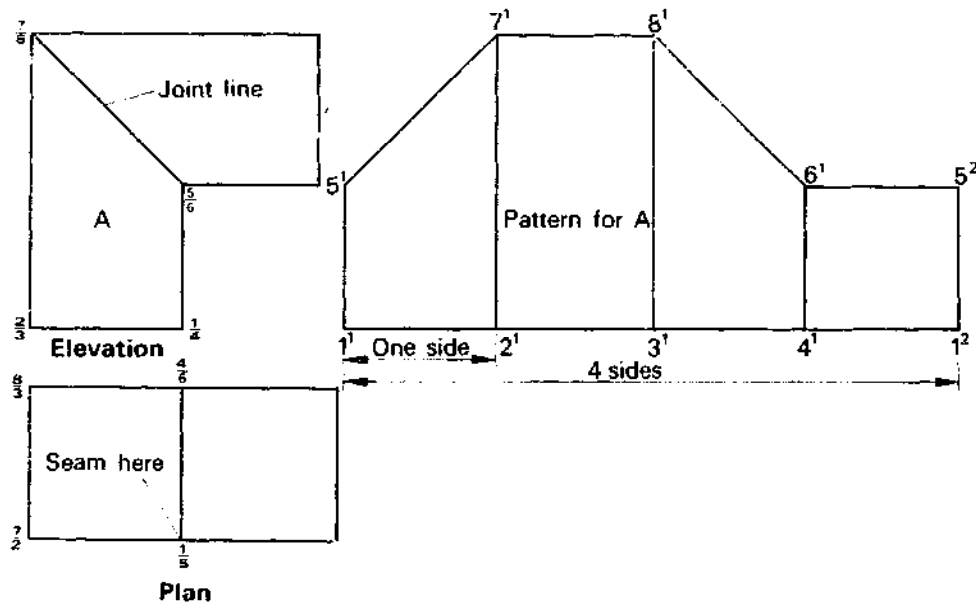


FIG. II.86. Square pipe elbow.

until it meets line 4<sup>1</sup>. Join up all the points in the pattern with straight lines to form the joint line.

**RIGHT-ANGLE PIPE TEE (Fig. II.87, pipes of equal diameter)**

Draw the elevation 1-7-8-9-10. Draw a half circle on the base of the pipe. Divide the half circle into six equal arcs and number each point 2 to 6. Take each point on the base half circle back perpendicularly to the joint line 8-9-10.

*To develop the pattern.* Draw a line horizontal with the base line and divide this line into twelve equal lengths, numbering them 1<sup>1</sup> to 1<sup>2</sup>. Each length must be equal to one of the arcs on the base half circle. Where each line from the base half circle in the elevation meets the joint line 8-9-10, draw a line horizontally from each point to meet its respective line in the pattern. When all the

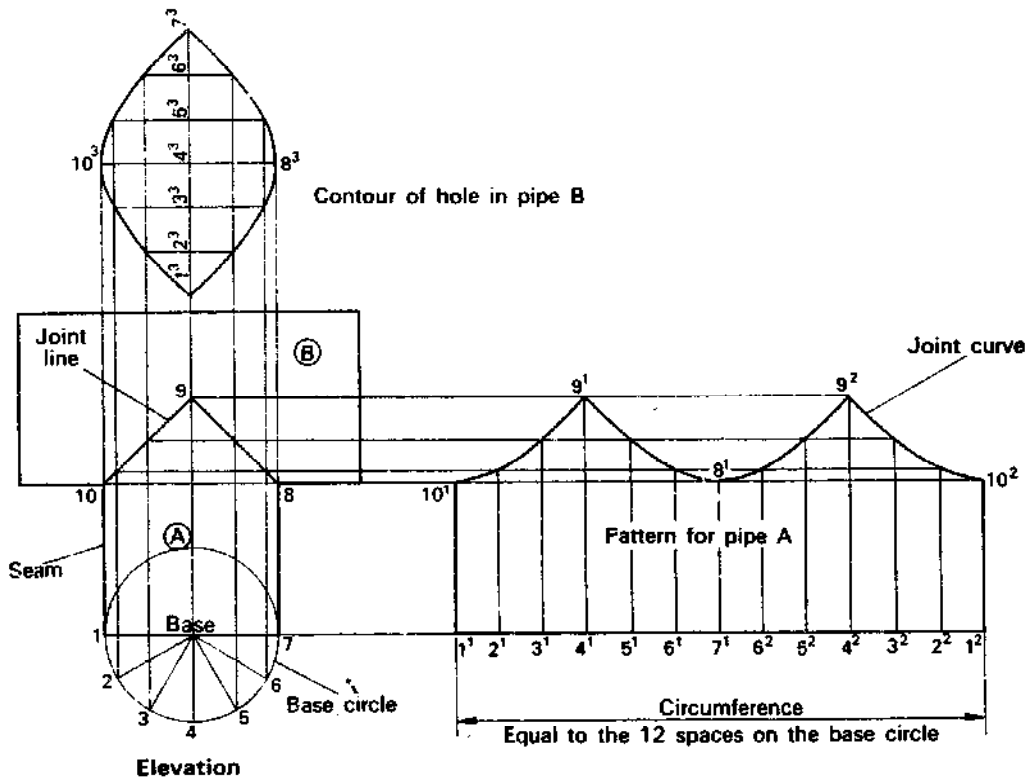


FIG. II.87. Right-angled pipe tee.

points have been plotted on the pattern, join up all the points to form the joint curve.

#### TO DETERMINE THE HOLE SHAPE

Draw a perpendicular line from point 9 in the elevation. Mark 6 lengths on this line, each length being equal to the length of each arc on the base circle. Number them  $1^3$  to  $7^3$ . Draw horizontal lines through all the points on line  $1^3-7^3$ . Draw perpendicular lines from all points on the joint curve until they meet their respective horizontal line in the hole pattern. When all the points have been plotted, join them up to form the hole contour.

#### *Example of Development by the Triangulation Method*

##### SQUARE TO SQUARE TAPERING ON CENTRE (Fig. II.88)

Draw the elevation  $1/2-3/4-A/B-C/D$ . Draw the plan  $1-2-3-4$   $A-B-C-D$ . Place the seam at  $SS$ .

*To develop the pattern.* Draw the height line and the base line, corresponding to the height of the vessel and the base line  $1/2-3/4$ .

Mark out the distance  $1'-2'$  equal to  $1-2$  from the plan. This is a true length line and does not need to be triangulated. All the sides of the top square and the bottom square are true lengths and do not require triangulation.

Place the point of the compasses on point 1 in the plan and open them to the distance, point  $1-B$ . Transfer this distance to the base line and, from the point on the base line, triangulate it against the vertical height. Transfer this distance into the pattern, describing an arc from point  $1'$  equal to this distance.

Place the point of the compasses on point 2 on the plan and open them to the distance, point  $2-A$ . Transfer this distance to the base line and, from the point on the base line, triangulate it against the vertical height. Transfer this distance into the pattern describing an arc from point  $2'$  equal to this distance. (It is the same length as line  $1'-B'$ .)

Place the point of the compasses on point 1 in the plan and open to the distance, point  $1-A$ . Transfer this distance to the

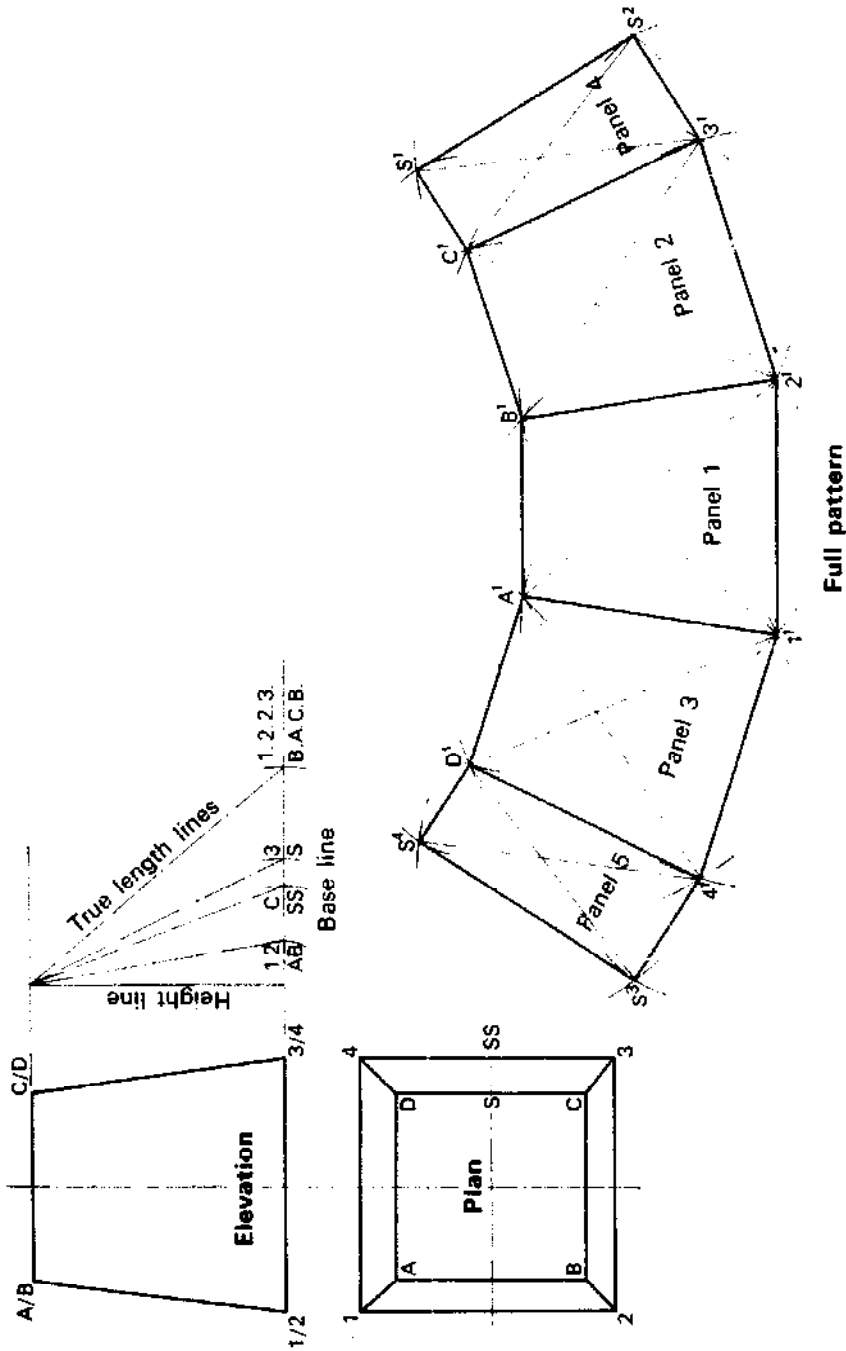


FIG. II.88. Square to square tapering on centre.

base line and from the point on the base line triangulate it against the vertical height. Transfer this distance into the pattern, describing an arc from point 1' equal to this distance. Where this arc crosses arc 2'-A', join to point 1'.

Place the point of the compasses on point 2 in the plan and open to the distance, point 2-B. Transfer this distance to the base line and from the point on the base line triangulate it against the vertical height. Transfer this distance into the pattern describing an arc from point 2' equal to this distance. Where this arc crosses arc 1'-B' join to point 2'. This completes this first panel.

Transfer the true distance 2-3 from the plan to the pattern, by describing an arc from 2' equal to this distance. Also transfer the true distance B-C from the plan to the pattern by describing an arc from B equal to this distance.

Place the point of the compasses on point 2 in the plan and open to the distance, point 2 to C. Transfer this distance to the base line and from the point on the base line triangulate it against the vertical height. Transfer this distance into the pattern, describing an arc from point 2' equal to this distance. Where this arc crosses the arc from point B', join up to B'. This is point C'.

Place the point of the compasses on point 3 in the plan and open to the distance, point 3-B. Transfer this distance to the base line and from the point on the base line triangulate it against the vertical height. Transfer this distance into the pattern, describing an arc from point B' equal to this distance. Where this arc crosses the arc from point 2', this is point 3'. This completes panel 2.

Panel 3 is completed in exactly the same way as described for panel 2.

Transfer the true distance C-S from the plan to the pattern by describing an arc from point C' equal to this distance.

Transfer the true distance 3-SS from the plan to the pattern by describing an arc from point 3' equal to this distance.

Place the point of the compasses on point 3 in the plan and open to the distance, point 3-S. Transfer this distance to the base line and from the point on the base line triangulate it against the vertical height. Transfer this distance into the pattern, describing an arc from point 3' equal to this distance. Where this

arc crosses the arc from point  $C'$ , join up to  $C'$ . This is point  $S'$ .

Place the point of the compasses on point  $C$  in the plan and open to the distance, point  $C$ - $SS$ . Transfer this distance to the base line and from the point on the base line triangulate it against the vertical height. Transfer this distance into the pattern, describing an arc from point  $C'$ . Where this arc crosses the arc from point  $3'$ , join up to  $3'$ . This is point  $S^2$ . This completes panel 4.

To complete the full pattern, develop panel 5 exactly as described for panel 4.

## CHAPTER 7

# Mathematics

### Fractions

A vulgar fraction is one such as  $\frac{3}{16}$ ,  $\frac{3}{8}$ ,  $\frac{3}{4}$ , or  $\frac{11}{16}$ . A vulgar fraction is a number that can be expressed as a numerator over a denominator, i.e.:

$$\frac{\text{Numerator}}{\text{Denominator}} = \frac{\text{Number of parts to be taken}}{\text{The number of parts into which the whole has been divided}}$$

A proper fraction is one whose numerator is less than the denominator, i.e.  $\frac{3}{8}$  is a proper fraction.

An improper fraction is one whose numerator is greater than the denominator, i.e.  $\frac{21}{8}$  is an improper fraction. To convert an improper fraction into a mixed number, divide the denominator into the numerator. Taking  $\frac{21}{8}$ , the conversion is to  $3\frac{3}{8} = 3\frac{1}{2}$ , i.e. a whole number together with a proper fraction.

### ADDITION OF FRACTIONS

Before any attempt can be made to add together fractions having different denominators, it is necessary to reduce the denominators to their least common denominator. This is the smallest number into which all the denominators will divide.

**EXAMPLE.** Add together  $\frac{1}{18}$ ,  $\frac{1}{6}$ ,  $\frac{3}{32}$ ,  $\frac{4}{12}$  and  $\frac{5}{6}$ .

Examine the denominators and find the least number into



which all the denominators will go. In this instance the number is 96. Divide each denominator into this number, multiply the result by the numerator and add together.

$$\frac{6 + 12 + 9 + 32 + 80}{96} = \frac{139}{96} = 1\frac{43}{96}.$$

EXAMPLE. Add together  $\frac{3}{12}$ ,  $\frac{5}{20}$ ,  $\frac{8}{15}$  and  $\frac{3}{4}$ .

Lowest common denominator is 60.

$$\frac{15 + 15 + 32 + 45}{60} = \frac{107}{60} = 1\frac{47}{60}.$$

#### SUBTRACTION OF FRACTIONS

To subtract fractions the same method is applied as for addition, but the numerators must be subtracted.

EXAMPLE. Subtract  $\frac{5}{8}$  from  $\frac{15}{16}$ .

Lowest common denominator is 96.

$$\frac{90 - 80}{96} = \frac{10}{96} = \frac{5}{48}.$$

#### MULTIPLICATION OF FRACTIONS

Multiplication of fractions is carried out by multiplying all the denominators to obtain the final denominator and by multiplying all the numerators to obtain the final numerator.

EXAMPLE. Multiply  $\frac{1}{2}$  by  $\frac{3}{4}$  by  $\frac{4}{12}$ .

$$\frac{1 \times 3 \times 4}{2 \times 4 \times 12} = \frac{12}{96} = \frac{6}{48} = \frac{3}{24} = \frac{1}{8}.$$

EXAMPLE. Multiple  $\frac{3}{4}$  by  $\frac{4}{5}$  by  $\frac{3}{8}$ .

$$\frac{3 \times 4 \times 3}{4 \times 5 \times 8} = \frac{36}{160} = \frac{18}{80} = \frac{9}{40}.$$

WELDING CRAFT PRACTICE—PART 1, VOL. 2

In these examples "cancelling-out" could be used. To cancel out: any one numerator and any one denominator that contain a common factor may be divided by this factor.

Thus in the second example the fours will cancel each other,

$$\frac{3}{\cancel{4}} \times \frac{\cancel{4}}{5} \times \frac{3}{8} = \frac{3 \times 3}{5 \times 8} = \frac{9}{40}$$

EXAMPLE. Multiply  $\frac{7}{8}$  by  $\frac{5}{6}$  by  $\frac{3}{10}$  by  $\frac{3}{4}$ .

$$\frac{7}{8} \times \frac{\cancel{5}}{\cancel{6}} \times \frac{\cancel{3}}{\cancel{10}} \times \frac{3}{4} = \frac{7 \times 1 \times 3 \times 3}{8 \times 2 \times 2 \times 4} = \frac{63}{128}$$

Divide the 9 and 6 by 3 and the 5 and 10 by 5.  
The other figures cannot cancel.

DIVISION OF FRACTIONS

To divide one fraction by another, invert the divisor and then multiply the fractions.

EXAMPLE. Divide  $\frac{7}{8}$  by  $\frac{2}{3}$ .

Invert the divisor, which becomes  $\frac{3}{2}$ , and then multiply.

$$\frac{7}{8} \times \frac{\cancel{3}}{\cancel{2}} = \frac{7 \times 1}{2 \times 3} = \frac{7}{6} = 1\frac{1}{6}$$

Decimals

When working with vulgar fractions, one is likely to find oneself becoming involved with denominators that are large and not easy to manipulate. Therefore, if we could make use of denominators of numbers 1, 10, 100, 1000, etc., the calculations would be much simplified. The decimal system does just this and to indicate the

difference between whole units and fractions of units a small dot or point is placed immediately after the last figure representing whole units.

Thus 2 is written as 2,  
 $\frac{2}{10}$  is written as 0.2,  
 $\frac{2}{100}$  is written as 0.02,  
 $\frac{2}{1000}$  is written as 0.002,  
 $1\frac{2}{10}$  is written as 1.2.

8678.934 would be built up as shown:

8 thousands,	.	decimal point,
6 hundreds,	9	tenths,
7 tens,	3	hundredths,
8 units,	4	thousandths.

Some of the more commonly used fractions expressed as decimals are:

$$\begin{array}{ll} \frac{3}{4} = 0.75 & \frac{5}{8} = 0.625 \\ \frac{1}{2} = 0.5 & \frac{3}{8} = 0.375 \\ \frac{1}{4} = 0.25 & \frac{1}{8} = 0.125 \end{array}$$

#### ADDITION AND SUBTRACTION OF DECIMALS

Addition and subtraction of decimals is carried out in the same way as with whole numbers and care must be taken to ensure that the decimal points are placed exactly under each other.

EXAMPLE. Add together 8.64, 9.73, 5.6, 75.273 and 0.025

$$\begin{array}{r} 8.64 \\ 9.73 \\ 5.6 \\ 75.273 \\ 0.025 \\ \hline \text{Total } 99.268 \\ \hline \end{array}$$

**WELDING CRAFT PRACTICE—PART 1, VOL. 2**

**EXAMPLE.** Subtract 4.25 from 7.34.

$$\begin{array}{r} 7.34 \\ 4.25 \\ \hline 3.09 \\ \hline \end{array}$$

**EXAMPLE.** Add 573.245 and 263.764 and subtract from this total 247.864.

$$\begin{array}{r} 573.245 \\ +263.764 \\ \hline 837.009 \\ -247.864 \\ \hline 589.145 \\ \hline \end{array}$$

**MULTIPLICATION OF DECIMALS**

Decimals are multiplied in exactly the same way as whole numbers. When the product has been obtained, the number of figures to the right of the decimal point in both the multiplier and the multiplicand must be counted. Beginning at the right of the product, count off this number and then insert the decimal point.

**EXAMPLE.** Multiply 475.25 by 3.25.

$$\begin{array}{r} 475.25 \text{ (multiplicand)} \\ 3.25 \text{ (multiplier)} \\ \hline 142575 \\ 95050 \\ 237625 \\ \hline 1544.5625 \text{ (product)} \\ \hline \end{array}$$

There are two figures to the right of the decimal point in the multiplicand and two to the right of the decimal point in the multiplier, making a total of four. Count four figures from the right in the product and insert the decimal point.

**DIVISION OF DECIMALS**

To divide decimals, if the divisor is a whole number, division is carried out as in ordinary long division. The decimal point is placed in line with the point in the number to be divided.

**EXAMPLE.** Divide 435.75 by 3.

145.25 answer to 2 decimal places.

$$\begin{array}{r}
 3 \overline{) 435.75} \\
 \underline{3} \phantom{00} \\
 13 \phantom{00} \\
 \underline{12} \phantom{00} \\
 15 \phantom{00} \\
 \underline{15} \phantom{00} \\
 007 \phantom{00} \\
 \underline{6} \phantom{00} \\
 15 \phantom{00} \\
 \underline{15} \phantom{00} \\
 00
 \end{array}$$

If the divisor contains a decimal, it must be changed to a whole number by moving the decimal point to the right. The decimal point in the dividend must also be moved the same number of places.

**EXAMPLE.** Divide 5625.24 by 278.4.

$$5625.24 \div 278.4 = 56252.4 \div 2784$$

$$\begin{array}{r}
 20.2056 \text{ answer to 4 decimal places.} \\
 2784 \overline{)56252.4000} \\
 \underline{5568} \\
 5724 \\
 \underline{5568} \\
 15600 \\
 \underline{13920} \\
 16800 \\
 \underline{16704} \\
 96
 \end{array}$$

### Percentages

A percentage is another way of expressing a part as a fraction of a whole unit. If the whole unit is 100, then 5 per cent is 5. In other words, 5 is a fraction of 100, expressed in another way. The term "per cent" is denoted by the sign %.

The percentage of any number can be calculated as follows:

$$\frac{\text{Part of the whole number}}{\text{The whole number}} \times 100.$$

EXAMPLE. What percentage is 57 of 95?

$$\begin{aligned}
 & \frac{\text{Part}}{\text{Whole}} \times 100\% \\
 & = \frac{57}{95} \times 100 \\
 & = 60\%
 \end{aligned}$$

### Ratio and Proportion

#### RATIO

When comparisons are made between two quantities with the same units such as feet, inches, shillings, pounds, etc., this is

known as a ratio. Numbers may be related to each other in various ways and the number of times that one number may be contained in another number is known as ratio.

If the ratio between 3 pence and 30 pence is calculated the answer is 1:10, but if the ratio between 4 bricks and 8 pigs is required the result is meaningless. If the ratio is to make any sense at all, the quantities being compared must be of the same kind. If the value of the bricks and pigs were known, then the ratio between the two values could be calculated.

The following will help to understand ratio more clearly. Refer to Fig. II.89 where the strip of metal is 16 in. long and is folded

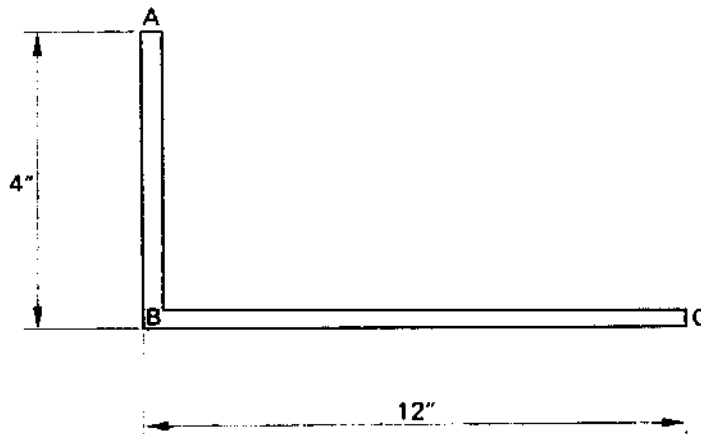


FIG. II.89.

at the 12-in. mark. The sides are 4 in. and 12 in. long and it can be said that the sides are in the ratio of 4 to 12, expressed as 4:12.

One part is  $\frac{4}{16}$  of the whole length while the other part is  $\frac{12}{16}$  of the whole. The number 16 is arrived at by adding 4 and 12. The numbers 4 and 12 are both divisible by 4 and the ratio may be expressed simply as 1:3. This indicates that sides *AB* and *BC* are in the ratio of 1 to 3. The side *AB* is  $\frac{1}{4}$  of the whole and the side *BC* is  $\frac{3}{4}$  of the whole. The number 4 (the denominator) is found by adding the terms of the ratio. By examining the fractions before and after cancelling it will be seen that they are the same, i.e. side  $AB = \frac{4}{16} = \frac{1}{4}$  and side  $BC = \frac{12}{16} = \frac{3}{4}$ , both of the whole.

EXAMPLE. A piece of flat mild steel bar 4 ft 0 in. long has to be cut up in the ratio of 6 to 4. Find the length of each part.

Total number of parts	$= 6 + 4$	$= 10$
One part	$= 48 \text{ in.} \div 10$	$= 4.8 \text{ in.}$
Four parts	$= 4 \times 4.8$	$= 19.2 \text{ in.}$
Six parts	$= 6 \times 4.8$	$= 28.8 \text{ in.}$
		—————
Check total		48.0 in.
		—————

Answer: 28.8 in. and 19.2 in.

EXAMPLE. A welding electrode core wire is made up of iron, copper and carbon in the ratio of 20:3:2 by weight. What weight of each is needed to make up 100 lb of the wire?

Total number of parts	$= 20 + 3 + 2$	$= 25$
Weight of iron	$= \frac{20}{25}$ of 100	$= 80 \text{ lb}$
Weight of copper	$= \frac{3}{25}$ of 100	$= 12 \text{ lb}$
Weight of carbon	$= \frac{2}{25}$ of 100	$= 8 \text{ lb}$
		—————
Total weight		100 lb
		—————

Answer: iron 80 lb; copper 12 lb; carbon 8 lb.

### PROPORTION

Referring back to Fig. II.89, if it were necessary to fold another piece of metal 8 ft long so that it has sides in the same ratio as the piece 16 in. long, it would be folded as follows:

Side *AB* is  $\frac{1}{4}$  of 8 ft  $= 2$  ft.  
 Side *BC* is  $\frac{3}{4}$  of 8 ft  $= 6$  ft.

One flange would be 2 ft long and the other would be 6 ft long. The flanges would be in the ratio 1:3. This piece has the same proportions as the first.

EXAMPLE. A certain size of bolt costs 12s. 6d. per 100. If 560 of these bolts are required what is the total cost?



100 bolts cost 12s. 6d. or 150 pence,  
 1 bolt costs  $1\frac{1}{2}d.$ ,  
 560 cost  $1\frac{1}{2} \times 560 = 840$  pence,  
 $840 \text{ pence} = \frac{840}{12} = 70s.$  or £3 10s. 0d.

Answer: £3 10s. 0d.

The calculation shown above is called the unitary method. The cost of one of the articles is first found and then multiplied by the total number required.

The foregoing example may be worked out by the method called the fractional method.

150 pence for 100 bolts.

For 560 bolts:  $150 \times \frac{560}{100} = 5.6 \times 150 = 840d. = £3 \text{ } 10s.$

When calculating by the fractional method, the nature of the proportion must be known. The problem was one of direct proportion, for as one of the values increases so does the other. Likewise, if one decreases so does the other.

On the other hand, we have indirect proportion where one value increases and the other decreases.

**EXAMPLE.** If 10 men spend 6 days to complete a job, in what number of days will 15 men complete the same job?

6 days require 10 men,  
 x days require 15 men.

∴ less time will be required

$$\text{i.e. } x = 6 \times \frac{10}{15} = 4 \text{ days.}$$

## Area

### CALCULATION OF RECTANGULAR AND SQUARE AREAS (Fig. II.90a)

A rectangle can be "X" number of units long and "Y" number of units wide, but each of the four corners must be a right angle

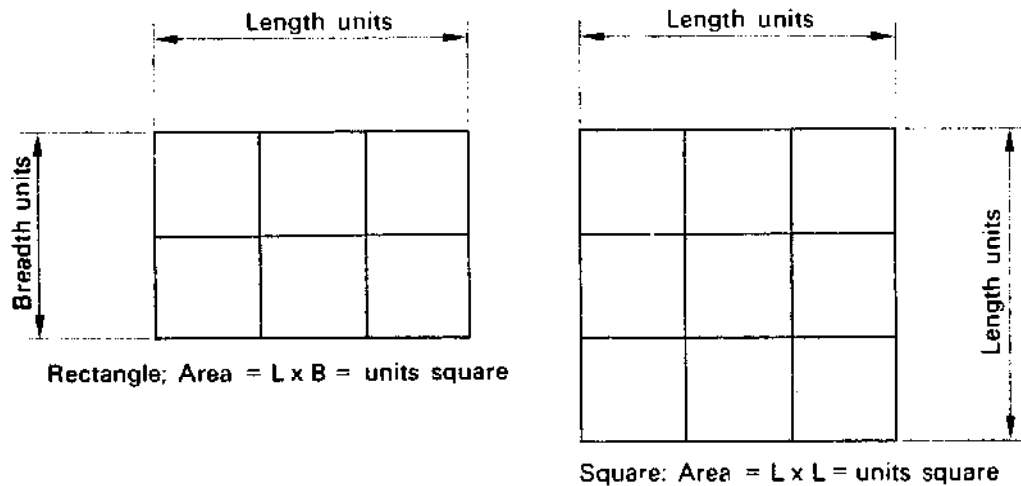


FIG. II.90a.

(90° square). The area is the whole surface within the four lines or edges of the rectangle and is known as the *surface* area.

Generally a rectangle is referred to dimensionally as length and breadth, or L. and B., and the surface area is found by multiplying the length by the breadth.

EXAMPLE. Find the surface area of a rectangle whose dimensions are: Length 4 ft and breadth 3 ft.

$$\begin{aligned}\text{Surface area} &= \text{length} \times \text{breadth} \\ &= 4 \times 3 \\ &= 12 \text{ square feet.}\end{aligned}$$

The answer will always be in square units of measurement (see Fig. II.90a). Terms cannot be multiplied together without first expressing them in similar units.

The area of a square is found by multiplying both measurements. This will be equivalent to length times length, since to qualify as a square both measurements must be the same (see Fig. II.90a).

CALCULATION OF WEIGHTS OF SQUARE AND RECTANGULAR SHEETS OF METAL

Tables are usually supplied by the manufacturers which give the weights per square foot for sheets of metal of certain thicknesses, and the total weight of any size sheet may then be calculated easily by employing the method explained in the previous paragraph.

EXAMPLE. Calculate the weight of a rectangular sheet 4 ft 6 in. long by 3 ft 3 in. wide, if the metal weighs  $2\frac{1}{2}$  lb per square foot.

Bring all measurements to similar units; in this case to decimals.

$$4 \text{ ft } 6 \text{ in.} = 4.5 \text{ ft, } 2\frac{1}{2} \text{ lb} = 2.5 \text{ lb, } 3 \text{ ft } 3 \text{ in.} = 3.25 \text{ ft.}$$

$$\text{Area} = 4.5 \times 3.25 = 14.625 \text{ ft}^2,$$

$$\text{Weight} = 14.625 \times 2.5 = 36.563 \text{ lb.}$$

EXAMPLE. An open-topped water tank measures 3 ft long  $\times$  2 ft 4 in. wide  $\times$  4 ft deep. Calculate the weight of the tank if made from material weighing 5 lb per square foot. (Ignore all joint allowances.)

Bring all measurements to similar units. In this case to decimals.

$$2 \text{ ft } 4 \text{ in.} = 2.333 \text{ ft}$$

$$\text{Areas of plates} = 2 \text{ off at } 3 \text{ ft} \times 4 \text{ ft} = 24.0 \text{ ft}^2$$

$$2 \text{ off at } 2.333 \text{ ft} \times 4 \text{ ft} = 18.664 \text{ ft}^2$$

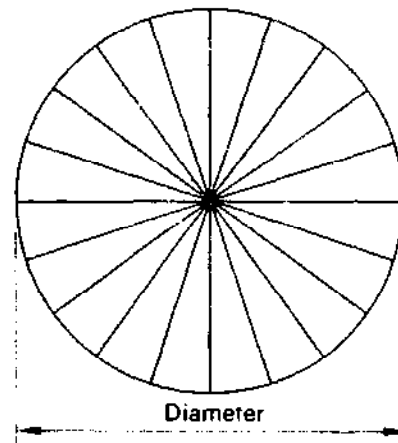
$$1 \text{ off at } 3 \text{ ft} \times 2.333 \text{ ft} = 6.999 \text{ ft}^2$$

Total	49.663 ft <sup>2</sup>
-------	------------------------

$$\text{Weight} = 49.663 \times 5 = 248.315 \text{ lb.}$$

CALCULATION OF CIRCULAR AREAS (Fig. II.90b)

The formula for calculating the area of a circle is  $\pi r^2$  or  $\frac{\pi d^2}{4}$ . Consider a circle divided into a large number of sectors. If the sectors were cut out and placed side by side, they would form a parallelogram, the length of which would be equal to approximately half the distance around the outside of the circle. The width of the parallelogram would approximately equal half the distance across the centre of the circle.



$r$  = radius which is half the diameter

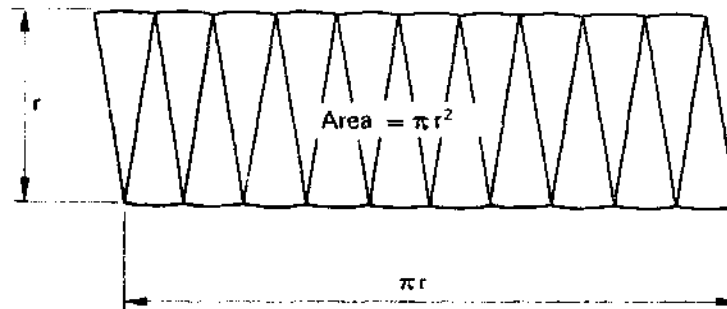


FIG. II.90b. Calculation of circular areas.

The area of the parallelogram = radius  $\times \frac{2\pi r}{2} = \pi r^2$ .

The diameter is twice the radius  $r = \frac{d}{2}$ .

Substituting, area of circle =  $\pi \left(\frac{d}{2}\right)^2 = \frac{\pi d^2}{4}$

$\therefore$  Area of circle =  $\frac{\pi d^2}{4}$  or  $\pi r^2$

EXAMPLE. Calculate the area of a circle whose diameter is 10 in.

$$\text{Area} = \pi r^2 = 3.142 \times 5 \times 5 = 78.55 \text{ in.}^2$$

$$\text{or Area} = \frac{\pi d^2}{4} = \frac{3.142 \times 10 \times 10}{4} = 78.55 \text{ in.}^2$$

EXAMPLE. Calculate the weight of a 14.53 in. diameter disc, if made from metal weighing 5.20 lb per square foot.

$$\text{Area} = \pi r^2 = \frac{3.142 \times 7.265 \times 7.265}{144} = 1.152 \text{ ft}^2.$$

$$\text{Weight} = 5.20 \times 1.152 = 5.987 \text{ lb.}$$

If a circle within a circle is now considered (Fig. II.91) the area between them is called an *annulus* and the formula for the area of a circle can be used to find the area of the annulus.

Referring to Fig. II.91.

$$\begin{aligned} \text{Area of large circle} &= \pi R^2 \\ \text{Area of small circle} &= \pi r^2 \\ \text{Area of annulus} &= \pi R^2 - \pi r^2 \end{aligned}$$

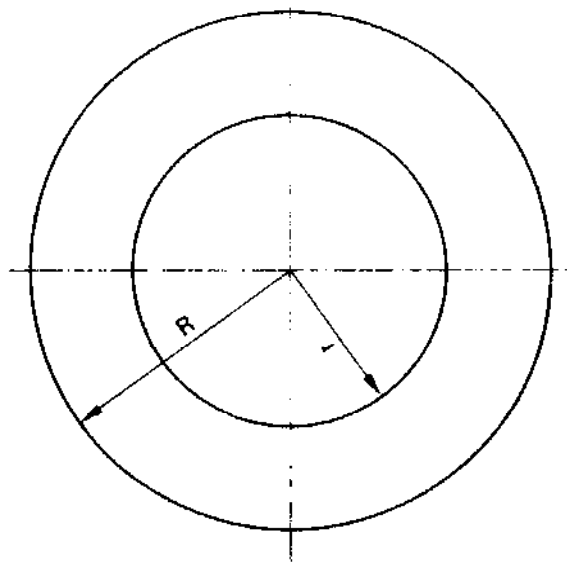


FIG. II.91. An annulus.

As  $\pi$  is common to both, the area of an annulus may be expressed as  $\pi(R^2 - r^2)$ .

EXAMPLE. A flange connection to an outlet pipe is 18 in. outside diameter and 15 in. inside diameter; calculate the weight of the flange if made from metal weighing 5.20 lb per square foot.

Area of flange (annulus) = Area of large circle – Area of small circle

$$\begin{aligned}
 &= \pi(R^2 - r^2) \\
 &= 3.142 (9^2 - 7.5^2) \\
 &= 3.142 (81 - 56.25) \\
 &= 3.142 \times 24.75 \\
 &= 77.76 \text{ in.}^2
 \end{aligned}$$

Weight of flange

$$\begin{aligned}
 &= \frac{77.76}{144} \times 5.20 \\
 &= 2.808 \text{ lb.}
 \end{aligned}$$

### CALCULATION OF TRIANGULAR AREAS

Triangles are three-sided figures, the sides of which may all be of a different length, but the three angles of which always add up to 180°.

Triangles are given different names according to their shape (Fig. II.92).

- (a) Right-angled triangles, are so called when any one angle is a right angle (90°).

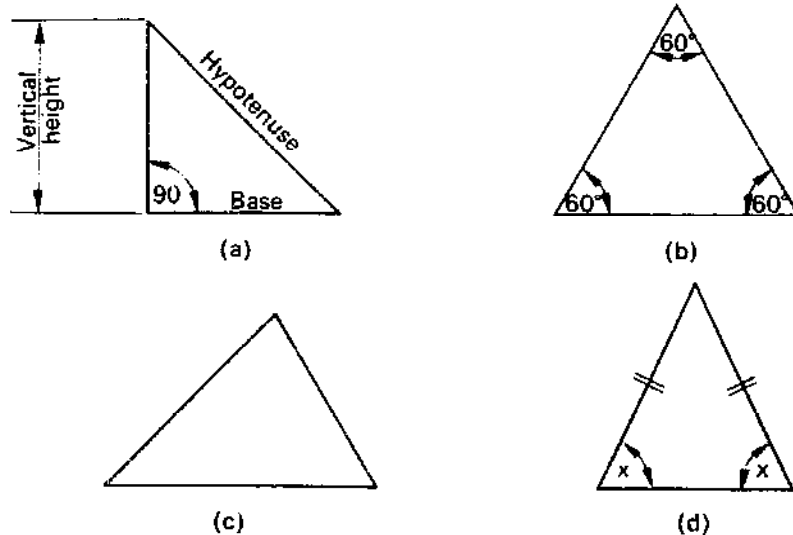


FIG. II.92.

- (b) Equilateral, are so called when all the sides and angles are equal.
- (c) Scalene, are so called when all the sides and angles are unequal.
- (d) Isosceles, are so called when any two sides and angles are equal.

Any one of the three sides of a triangle may be given the name vertex. The opposite side to a vertex is called the base. In a right-angled triangle the longest side is opposite to the right angle and is called the hypotenuse.

The height of a triangle is the distance in a straight line, at right angles to the base, to the top point of the triangle. This is called the vertical height.

The area of a triangle may be calculated as:

$$\frac{\text{base length} \times \text{vertical height}}{2}$$

or half the base  $\times$  height.

EXAMPLE. A triangle has a 12-in. base and a vertical height of 8 in. Calculate the surface area.

$$\begin{aligned} \text{Area} &= \frac{\text{height} \times \text{base}}{2} \\ &= \frac{8 \times 12}{2} = 48 \text{ in.}^2 \end{aligned}$$

EXAMPLE. Calculate the weight of fifty triangular blanks, each having the following dimensions:  $8\frac{1}{2}$ -in. base,  $10\frac{1}{4}$ -in. height, if made from material weighing  $3\frac{1}{2}$  lb per square foot.

$$\begin{aligned} \text{Area of one triangle} &= \frac{\text{height} \times \text{base}}{2} \\ &= \frac{8.5 \times 10.25}{2} = 43.5625 \text{ in.}^2 \end{aligned}$$

$$\text{Total area} = \frac{43.5625 \times 50}{144} = 15.125 \text{ ft.}^2$$

$$\text{Weight of 50} = 15.125 \times 3.5 = 52.935 \text{ lb.}$$

### Volume

The amount of metal contained in a block is measured in cubic units. The amount of free space in a hollow object, such as a bottle, is also measured in cubic units. The amount of solid material is known as the volume, whereas the amount of space inside a hollow object is known as its capacity. The capacity of a tank may be 100 cubic feet, which means that 100 cubes exactly 1 foot cube, will fit inside the tank.

### VOLUME OF SQUARE AND RECTANGULAR PRISMS

A prism of size 4 in. long  $\times$  3 in. wide  $\times$  3 in. deep will have a volume 36 in.<sup>3</sup> Figure II.93 illustrates how this volume is arrived

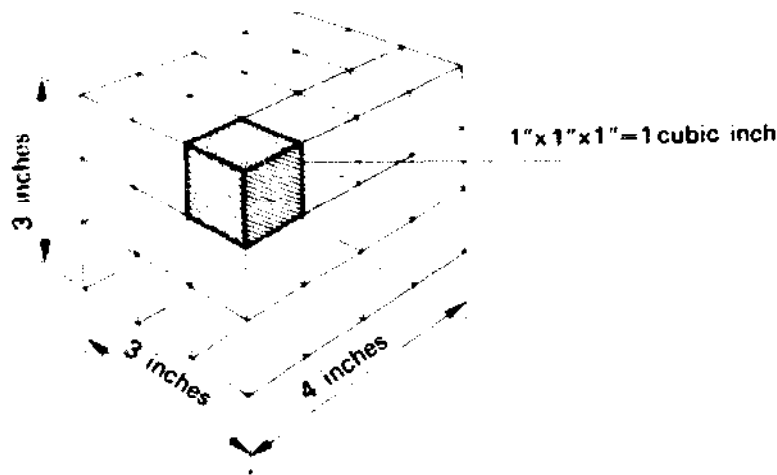


FIG. II.93. Cubes contained in a body.

at. The 36 cubes of  $1 \times 1 \times 1$  in. can be seen in the sketch, and from this it can be seen that the volume is arrived at by multiplying the length by the breadth by the depth—in this case,  $4 \times 3 \times 3 = 36$ .

Therefore the volume of the prisms =  
length  $\times$  breadth  $\times$  depth  
and the volume of a cube =  
length  $\times$  length  $\times$  length = length<sup>3</sup>.



The unit of measurement is in inches and therefore the volume is in cubic inches. Had the unit of measurement been in feet, the volume would have been in cubic feet.

The units of measurement in all cases of calculation of volume must be the same. To calculate the volume of a tank of size 3 ft × 32 in. × 4 ft, all measurements must be brought to the same units, in this example to inches. But the volume of the tank could be expressed in cubic feet by dividing the cubic inches by 1728, because there are this number of cubic inches in a cubic foot, i.e.  $12 \times 12 \times 12 = 1728$ . The answer to the problem would be 32 ft<sup>3</sup>.

Therefore, the volume of the prism has been obtained by multiplying first the units  $4 \times 3 \times 3 = 36$  and the value of the units (inches × inches × inches) = cubic inches or in.<sup>3</sup> The length multiplied by the breadth is the end area.

$$\begin{aligned} \text{Therefore volume of a prism} &= \text{length} \times \text{breadth} \times \text{depth} \\ &= \text{end area} \times \text{depth} \end{aligned}$$

#### CAPACITIES OF RECTANGULAR, SQUARE AND CYLINDRICAL VESSELS

Before one can attempt to calculate how much a vessel will hold, it is necessary to know the weight of the substance, i.e. how much does a cubic foot of the substance weigh.

The following units are important:

- 1 gallon of water weighs 10 lb,
- 1 cubic inch of water weighs 0.036 lb,
- 1 gallon occupies 277.4 in.<sup>3</sup>,
- 1 cubic foot of water weighs 62.4 lb.

**EXAMPLE.** A rectangular tank of size 6 ft long × 3 ft wide × 2 ft deep is filled with water. The water is then drained off at the rate of 2 gallons per minute. How long does the tank take to empty?

$$\begin{aligned} \text{Volume of tank} &= \text{end area} \times \text{depth} \\ &= 6 \times 3 \times 2 \\ &= 36 \text{ ft}^3. \end{aligned}$$

Capacity of tank = Volume  $\times$  wt of water per ft<sup>3</sup>  $\div$  wt. of gallon of water

$$= \frac{36 \times 62.4}{10} = 224.7 \text{ gallons.}$$

$$\text{Time to empty} = \frac{224.7}{2} = 112.3 \text{ minutes.}$$

EXAMPLE. Calculate the capacity of an open-topped tank of size 3 ft long  $\times$  1 ft 6 in. wide  $\times$  22 in. deep.

$$\begin{aligned} \text{Capacity} &= \text{length} \times \text{breadth} \times \text{depth} \\ &= 3 \text{ ft} \times 1 \text{ ft 6 in.} \times 22 \text{ in.} \end{aligned}$$

Bringing to inches, Capacity = 36  $\times$  18  $\times$  22 in.

$$\therefore \text{Capacity} = \frac{36 \times 18 \times 22}{1728} = 8.25 \text{ ft}^3.$$

#### VOLUME OF A CYLINDER WITH CIRCULAR CROSS-SECTION

To calculate the volume of a cylinder the formula, end area multiplied by the depth, may still be used. Hence the volume of a cylinder with circular cross-section is:

$$\begin{aligned} \text{Volume of cylinder} &= \text{end area} \times \text{depth} \\ &= \pi r^2 \times L, \end{aligned}$$

where  $r$  = the radius and  $L$  = the length or depth, or,

$$\begin{aligned} \text{Volume of cylinder} &= \text{end area} \times \text{depth} \\ &= \frac{\pi d^2}{4} \times L, \end{aligned}$$

where  $d$  = diameter of the cylinder.

EXAMPLE. Calculate the volume of a cylinder of size 9 in. diameter  $\times$  10 in. long.

$$\begin{aligned} \text{Volume of cylinder} &= \text{end area} \times \text{depth} \\ &= \pi r^2 \times L \\ &= 3.142 \times 4.5 \times 4.5 \times 10 \\ &= 636.2 \text{ in.}^3 \end{aligned}$$

EXAMPLE. A cylindrical tank of size 10 in. diameter  $\times$  1 ft 6 in. deep is filled with water. What is the capacity of the tank in pints?

$$\begin{aligned} \text{Volume of vessel} &= \text{end area} \times \text{depth} \\ &= \pi r^2 \times L \\ &= 3.142 \times 5^2 \times 18 \\ &= 3.142 \times 5 \times 5 \times 18 \\ &= 1414 \text{ in.}^3, \end{aligned}$$

1 gallon of water occupies 277.4 in.<sup>3</sup>,

1 pint of water occupies  $\frac{277.4}{8}$  or 34.67 in.<sup>3</sup>,

$$\text{Tank capacity} = \frac{1414}{34.67} = 40.78 \text{ pints.}$$

### The Metric System of Linear Measurement

The units of inches, feet, yards, etc., as they have been used in this country for a long while are troublesome and sometimes difficult to remember, i.e. 12 inches in 1 foot, 3 feet in 1 yard, 22 yards in 1 chain, and so on. Now if all the units were to divide and multiply themselves by tens, etc., the same arithmetical sum would suffice for all calculations concerned with any of the measures.

TABLE II.8. LINEAR MEASURE (LENGTH)

British	Metric
12 inches = 1 foot	10 millimetres (mm) = 1 centimetre (cm)
3 feet = 1 yard	10 cm = 1 decimetre (dm)
22 yards = 1 chain	10 dm = 1 metre (m)
10 chains = 1 furlong	10 m = 1 dekametre (dm)
8 furlongs = 1 mile	10 dm = 1 hectometre (hm)
	10 hm = 1 kilometre (km)
<i>Also:</i>	<i>or</i>
100 links = 1 chain	100 cm = 1 metre
5½ yards = 1 pole	1000 mm = 1 metre
6 feet = 1 fathom	1000 m = 1 kilometre

Within the metric system the metre is the unit of measurement from which all the others are derived. The use of prefixes is employed here, i.e. centi-, deci-, kilo-, etc.

In the metric system, reduction from one unit to another is calculated by multiplying or dividing by 10 or some power of 10. This is carried out by moving the decimal point to the left or the right according to whether one wishes to divide or multiply.

EXAMPLE. Express 3500 centimetres in metres.

Since there are 100 centimetres in 1 metre we must divide by 100, and 100 divided into 3500 = 35.00, or the decimal point is moved two places to the left.

Answer: 35 metres.

EXAMPLE. Express 763 centimetres in metres.

$$\frac{763}{10^2} = 7.63.$$

Answer: 7.63 metres.

EXAMPLE. Express 6800 millimetres in metres.

$$\frac{6800}{10^3} = 6.8.$$

Answer: 6.8 metres.

EXAMPLE. Express 1678 metres in kilometres.

$$\frac{1678}{10^3} = 1.678.$$

Answer: 1.678 kilometres.

EXAMPLE. How many pieces of flat mild steel strips, each 33 centimetres long, can be cut from a bar 26.5 metres long?

$$26.5 \text{ metres} \times 10^2 = 2650 \text{ centimetres.}$$

$$\therefore \text{ number of pieces} = 2650 \div 33 = 80 \text{ and } 10 \text{ cm over.}$$

Answer: 80 pieces.

**THE METRIC SYSTEM CONVERSION FACTORS**

The following table indicates the equivalents between the British Linear Measure and the Metric System.

TABLE II.9.

---

1 inch = 2.54 centimetres
39.37 inches = 1 metre
1.0936 yards = 1 metre
0.6214 miles = 1 kilometre

---

**EXAMPLE.** Convert 30.48 centimetres to inches.

$$30.48 \text{ divided by } 2.54 = 12.$$

Answer: 12 inches.

**EXAMPLE.** Convert 90 centimetres to feet and inches.

$$90 \text{ divided by } 2.54 = 35.433 \text{ (to 3 places),}$$

$$\therefore 35.433 \text{ divided by } 12 = 2 \text{ feet } 11.433 \text{ inches.}$$

**EXAMPLE.** Convert 4 feet 8 inches to metres.

$$4 \text{ feet } 8 \text{ inches} = 56 \text{ inches,}$$

$$56 \times 2.54 = 142.24 \text{ centimetres,}$$

$$142.24 \text{ divided by } 100 = 1.4224 \text{ metres.}$$

Answer: 1.4224 metres.

**EXAMPLE.** Convert  $8\frac{5}{8}$  inches to centimetres.

$$\text{To convert } \frac{5}{8} \text{ to a decimal divide } 8 \text{ into } 5 = 0.625,$$

$$\therefore 8.625 \times 2.54 = 21.9075 \text{ centimetres.}$$

## APPENDIX 1

# Glossary of Welding and General Terms and Abbreviations

### WELDING

**Arc voltage.** The voltage between the electrode and the workpiece.

**Automatic arc welding.** Any welding process whereby the welding wire is automatically fed into the weld and the welding head is completely free from manual control.

**Axis of weld.** Central straight line between the two ends of the weld.

**Base metal.** The metal being welded.


**Butt weld.** A weld joining two pieces of metal, both pieces being in the same plane.


**Chamfer.** The edge of a plate shaped off to form an angle other than a right angle.

**Concave fillet.** A fillet weld with an inward curve.

**Convex fillet.** A fillet weld with an outward curve.

**Deposited metal.** The actual metal deposited by the filler rod or electrode.

**Double "U" preparation.** The edges of the parent metal shaped so that when two edges are brought together  is formed.

**Double vee.** The edges of the parent metal shaped so that when two edges are brought together  is formed.

**Downhand weld.** Weld made in a flat, gravity position.

**Edge preparation.** The shaping of the edges of the parent metal prior to welding.

**Face bend.** Bend test with the face of the weld on the outside of the bend and in tension.

**Filler rod.** Wire or rod added to the weld pool to produce reinforcement.

**Fusion welding.** Welding joint made between metals which are in a molten state without the application of pressure.

## APPENDIX 1

**Fusion zone.** That part of the parent metal which is melted into the weld metal.

**Gapping.** Setting up of plates with a gap between the joint edges.

**Gas-shielded-arc welding.** A process of arc welding whereby a gaseous shield surrounds the molten weld pool.

**Heat-affected zone.** A zone surrounding the weld and the fused metal that is not part of the fused metal.

**Inside corner fillet.** As for an outside corner, but the weld is on the inside of the corner.

**Leading angle.** Inclination of filler rod or blowpipe to the axis of the weld.

**Leg length.** The size of a fillet weld measured across the bottom of the weld and up the side of the weld.

**Longitudinal crack.** A crack in the weld metal extending along the length of the weld.

**Manual welding.** Welding in which the operator is completely responsible for the weld deposition and the means of making the weld is held in the hand.

**Open circuit voltage.** The voltage from or in the welding plant.

**Outside corner fillet.** A weld joining two pieces of metal, in which the inside edge of one piece of the metal is in line with the inside edge of the other, usually at right angles. Welded on the outside of the corner.

**Parent metal.** The metal being welded.

**Parent plate.** The metal being welded.

**Penetration.** The amount of weld metal actually entering the parent metal.

**Pick-up.** Area of interfusion when restarting an interrupted weld run.

**Piping.** Elongated holes in the weld metal caused by the entrapment of gas.

**Plate.** A flat sheet of metal of more than  $\frac{1}{8}$  in. thickness.

**Plug weld.** A weld made through a hole in one component of the workpiece, enabling both components to be joined by filling the hole completely with weld metal.

**Porosity.** Holes in the weld metal caused by the entrapment of gas.

**Preheat.** Heat applied before welding starts.

**Profile.** Outline of weld as seen in section.

**Reinforcement.** The amount of weld metal above the thickness of the parent plates in a butt weld.

**Resistance welding.** Welding carried out under pressure applied to the surfaces in contact, whilst the heat for welding is produced by the passage of an electric current through the surfaces of the metals.

**Root bend.** Bend test with the root of the weld on the outside of the bend and in tension.

**Root concavity.** A shallow groove along the underside of a butt weld.

- Seam welding.** Resistance welding in which the force is applied by wheels and the workpiece is fed between the wheels, which are the electrodes.
- Semi-automatic arc welding.** Any welding process whereby the welding wire is automatically fed into the weld through a gun-type head that is manually controlled.
- Sheet metal welding.** The welding of metal less than  $\frac{1}{8}$  in. thick.
- Single vee.** The edges of the parent metal shaped so that when two edges are brought together a V is formed.
- Slag inclusion.** An entrapment of slag or other foreign matter actually inside the weld metal.
- Spot welding.** Resistance welding in which the force is applied by round bars which are the electrodes.
- Stop and start.** Point at which weld is stopped and restarted during an interrupted run.
- Stove-pipe welding.** A manual arc welding technique for the welding of pipes.
- Submerged arc welding.** A process of arc welding whereby the arc is hidden in a granulated flux, the wire being bare and the flux poured over the arc.
- Tack.** Small temporary weld.
- Tee fillet.** A weld joining two pieces of metal (usually both pieces are at right angles to each other) forming a "T" shape.
- Through penetration.** The amount of weld metal penetrating through to the underside of a butt weld.
- Transverse crack.** A crack in the weld metal across the weld.
- "U" Preparation.** The edges of the parent metal shaped so that when two edges are brought together U is formed.
- Undercutting.** A burning into the parent plate at the weld edges, thereby making the parent metal under thickness.
- Weldment.** Two or more plates joined by welding.
- Weld spatter.** Globules of metal expelled from an electrode and deposited on the surface of the parent plate.
- Weld zone.** The zone containing the weld metal and the heat-affected zone.

## GENERAL

a.c.	alternating current
alignment	line up of workpieces
alloy	a mixture of metals
ancillary	extra or auxiliary
austenitic	consisting of a solid solution of carbon in iron
Bourdon tube	curved metal tube used in pressure-measurement equipment



**APPENDIX 1**

B.S.	British Standard
B.S.P. thread	British Standard Pipe thread
°C	Centigrade scale
calorific value	measurement indicating the amount of heat produced when a specified quantity of a substance is burned
carbon fences	support blocks for molten metal
carboy	large glass bottle with protecting frame
coal gas	town gas
combustion	burning
concave	curving inwards
convex	curving outwards
crater	depressed cavity
cylinder manifold	two or more gas cylinders connected together to give a common supply
d	diameter
D.A.	dissolved acetylene
d.c.	direct current
diaphragm	flexible disc
diffused	intermingled or mixed
drag lines	near-vertical lines produced by oxygen stream on cut edges during oxy-fuel gas cutting
E.A.	electric arc
electrons	electrically charged sub-atomic particles
elongation	lengthening
etch	to cut into the surface
°F	Fahrenheit scale
F.B.	flat bar
ferrous	containing iron
fluorescent	capable of glowing under the action of light
ft, ft <sup>3</sup>	feet, cubic feet
fuse	melt
galvanised	zinc coated
grain growth	enlargement of grain size in metals
G.W.F.	gas welding filter
hardsoldering	soldering with copper/zinc and copper/silver alloys, as in bronze welding, brazing and silver soldering
H.M.S.O.	Her Majesty's Stationery Office
hose coupler	connector for the jointing of rubber hose
hose protector	valve inserted in hose to prevent the reverse flow of gas
h.p.	high pressure
i.d.	inside diameter
in., in <sup>2</sup>	inches, square inches
included angle	angle between two joint faces
flammable	easily set on fire

invert	turn upside down
lb	pounds
liquefaction	change into liquid state
l.p.	low pressure
m.a.	metal arc
manipulation	skilful movement
modular	round
multi-stage	consisting of more than one stage
nominal size	approximate measurement
non-ferrous	not containing iron
O.A.	oxy-acetylene
o.d.	outside diameter
optimum	most satisfactory
orifice	hole, aperture
overmaking	gas generated in excess of requirements
oxy-fuel gas	mixture of oxygen and a fuel gas
oxygen-enriched	having a higher than normal oxygen content
peening	dressing with a hammer
plate	metal above $\frac{1}{4}$ in. thick, metal below this thickness is known as "sheet"
positional	in any position other than downhand
prefix	to put in front of
propane	liquefied petroleum gas
protected hose	fitted with hose protector
r	radius
restrain	hold firmly in place
shim	thin metal sheet used as an insert between two surfaces
S.H.W.	safety and health in welding
spheroidal	shaped like a sphere
static installation	equipment permanently fixed in a work place
suffix	letter or syllable appended to a word
t	thickness
technique	manner of execution
thermal movement	expansion and contraction due to changes in temperature
toxic	poisonous
u.t.s.	ultimate tensile strength
velocities	speeds
visual examination	inspection by eye
volatile	evaporating quickly
weave	blowpipe movement across the joint
wt.	weight
yd	yards

## APPENDIX 2

# Revision Questions

### Electric Arc Welding

A.1. Sketch and explain the method of metal transfer which takes place in electric arc welding with coated electrodes.

A.2. Explain with the aid of sketches the correct technique and procedure to be used in multi-run fillet welds on mild steel.

A.3. State the method of classification used for coated electrodes in British Standard 1719-1963.

A.4. List and explain ten safety precautions applicable to electric arc welding.

A.5. Explain the function of jigs and positioners in both "one-off" and repetition work; sketch a simple type of jig.

A.6. Discuss the advantages and disadvantages of a.c. and d.c. welding sets.

A.7. Show by means of neat sketches the correct preparations for the following electric arc welds in mild steel:  $\frac{3}{8}$ -in. open corner, downhand;  $\frac{1}{16}$ -in. butt, downhand;  $\frac{1}{2}$ -in. butt, vertical;  $\frac{3}{8}$ -in. fillet, vertical.

A.8. Discuss the possible effect of weather conditions on welding operations carried out on the site with regard to safety, quality, materials.

A.9. Explain with the aid of sketches the correct technique and procedure to be used in the welding of cast iron.

A.10. Explain how a worn shaft may be built-up by the means of electric arc welding. Discuss the problems likely to arise during this operation.

### Related Studies

B.1. Sketch and describe the following types of oxy-acetylene flames: (a) neutral; (b) carburising; (c) oxidising.

B.2. Explain with the aid of sketches six British Standard welding symbols.

### REVISION QUESTIONS

**B.3.** Find the quantity of heat necessary to raise a cast iron block weighing 10 g from 20°C to 180°C (specific heat of cast iron = 0.12).

**B.4.** Explain three ways by which heat may be transferred and give typical examples.

**B.5.** Explain the terms: tenacity, malleability, ductility, hardness, and compare mild steel and cast iron in respect of these properties.

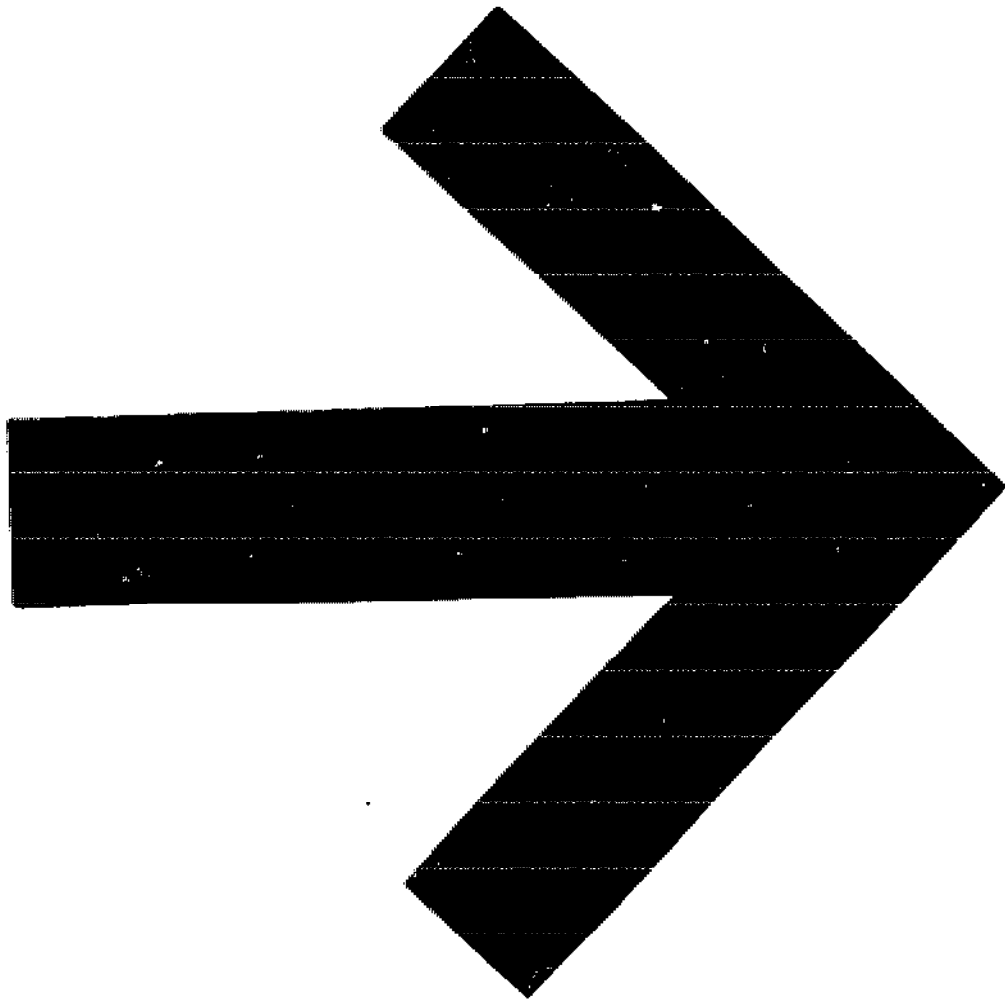
**B.6.** Discuss "chemical" and physical" changes in substances and give examples of each.

**B.7.** Explain the structure of the oxy-acetylene flame and the chemical reactions which take place.

**B.8.** Explain the terms: workhardening and annealing and sketch typical microstructures.

**B.9.** Why is a flux necessary in some types of oxy-acetylene welding? Take an example and explain the functions of the flux.

**B.10.** Explain the electrical terms: a.c., d.c., voltage, current, resistance.



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