THE
SCIENCE & PRACTICE
OF WELDING

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THE SCIENCE & PRACTICE OF WELDING

by

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NOTE ON ILLUSTRATIONS

The 328 figures in the text are not separately listed here, but

Figures 326 and 327 (see p. 396) will be found in a pocket inside the back cover.

PREFACE

The aim of this book is to give, in a convenient form, the basic theoretical principles underlying the various processes of welding and the practical methods of applying them.

It should appeal equally to the practical welder requiring the correct technique for welding metals and alloys, and to the student welder requiring an understanding of the principles of physics, chemistry, metallurgy and electricity as applied to welding, no previous knowledge of these subjects being pre-supposed.

Most of the subject-matter (theoretical and practical) required for the City and Guilds examinations in Electric Arc and Oxy-Acetylene Welding and Welding Science is covered, and therefore the book should prove useful to operators attending technical training classes.

A chapter on Engineering Drawing has been included, since most operators are called upon to read and understand a working drawing or blue print.

The practical procedure given in the sections on electric arc and oxy-acetylene welding has been carried out by the author during many years of welding and the training of operators, and the practical hints given should prove useful.

At the present critical state in our nation's history it is hoped that the book will enable operators engaged on vital war work to obtain a better understanding of their job and thus work toward the ultimate aim of the welding industry, namely, 'more and better welds'.

The author is indebted to the following firms for their co-operation and help in supplying technical information and for the use of photographs and blocks for illustrations:

British Aluminium Co.; British Insulated Cables Co.; British Oxygen Co.; British Thompson-Houston Co.; Buck and Hickman Ltd.; Copper Development Association; English Electric Co.; English Steel

Corporation; Firth Vickers Stainless Steels; Samuel Fox and Co.; General Electric Co.; F. A. Hughes and Co. (Elektron); Laurence Scott and Electromotors Co.; Lincoln Electric Co.; Metalectric Furnaces Co.; Metropolitan Vickers Electrical Co.; Mond Nickel Co.; Murex Welding Processes; Quasi Arc Co.; Shorter Process Co.; Siemens Bros & Co.; Thorn and Hoddle Ltd.

To the City and Guilds of London Institute for permission to publish the questions at the end of the book, and also to Mr H. Darling, A.M.I.M.E. for help in reading of proofs.

A. C. D.

OSWESTRY

May 1941

Chapter I

WELDING SCIENCE CHEMISTRY APPLIED TO WELDING FLUXES

WELDING SCIENCE

States of Matter: SOLIDS, LIQUIDS *and* GASES

In order to understand fully the various states of matter and their relation to each other, we must understand the meaning of the word molecule.

Imagine a cube of a material such as lead. We can cut this up into small parts, and each of these small parts can again be cut up in the same way. We can imagine this cutting process continued until the parts become exceedingly small. Eventually they would become so small as to be incapable of further division, and these smallest particles are termed atoms. They are the 'bricks' of which all materials are made and they have a definite attraction for each other.

Atoms are grouped by nature into molecules and molecules may contain one, two, or more atoms depending upon the substance. In the case of metals, there is only one atom in a molecule.

The molecules, in a solid, are very closely packed and have a great attraction for each other. The closer they are packed, the heavier is the solid, but even in their closest packed state they are in a state of continuous vibration, but they cannot move about at all.

In this state their attraction for each other is very great, and this is why a solid strongly resists attempts to change its shape.

Now, suppose we warm the solid. The molecules become excited, vibrate more and, due to this, have less attraction for each other. Thus, a solid expands when heated. At length a point will be reached when the molecules are sufficiently far away from each other for them to be able to *move about*; at this point the solid changes to a liquid and the change takes place suddenly.

Continue heating the liquid. The molecules become so excited and get so far apart from each other and have such small attraction that they will move about in any direction by themselves. At this point the liquid becomes a gas which, therefore, has no definite size.

Suppose we now enclose the gas in a vessel of given size and continue heating. The molecules will continue to move about with increasing speed as the heat increases, and they will bombard the walls of the vessel, giving rise to greater and greater pressure.

From the foregoing, it can be seen that the three states of matter—solids, liquids and gases—are very closely related, and that by giving or taking away heat we can change from one state to the other. Ice, water and steam give an everyday example of this change of state.

Metals require considerable heat to liquefy or melt them, as, for example, the large furnaces necessary to melt iron and steel.

We see examples of metals in the gaseous state when certain metals are heated in the flame. The flame becomes coloured by the gas of the metal, giving it a characteristic colour, and this colour indicates what metal is being heated. For example, sodium gives a yellow coloration and copper a green coloration.

This change of state is of great importance to the welder, since he is concerned with the joining together of metals in the liquid state (termed fusion welding) and he has to supply the heat to cause the solid metal to be converted into the liquid state to obtain correct fusion.

Heat

Temperature

Thermometers and Pyrometers

The temperature of a body determines whether it will give heat to, or receive heat from, its surroundings.

Our sense of determining hotness by touch is extremely inaccurate, since iron will always feel colder than wood, for example, even when actually at the same temperature.

Instruments to measure temperature are termed thermometers and pyrometers. Thermometers measure comparatively low temperatures, while pyrometers are used for measuring the high temperatures as, for example, in the melting of metals.

In the thermometer, use is made of the fact that some liquids expand by a great amount when heated. Mercury and alcohol are the usual liquids used. Mercury boils at 357° C. and thus can be used for measuring temperatures up to about 330° C.

Mercury is contained in a glass bulb which connects into a very fine glass tube called a capillary tube and up which the liquid expands (Fig. 1).

Fig. 1

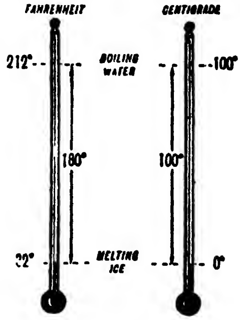


Fig. 2

The whole is exhausted of air and sealed off. The fixed points on a thermometer are taken as the melting point of ice and the boiling point of water at standard pressure (76 cm. mercury).

In the Centigrade thermometer the freezing point is marked 0 and boiling point 100; thus there are 100 divisions, called degrees and shown thus °.

In the Fahrenheit thermometer the freezing point is marked 32 and the boiling point 212, and so it has 180 divisions. The two scales are indicated thus: 100° C. is 100 degrees Centigrade while 100° F. is 100 degrees Fahrenheit (Fig. 2).

For scientific work the Centigrade scale is generally used, while the Fahrenheit scale is generally used in Great Britain.

It is evident that these thermometers will only measure comparatively low temperatures, and to measure high temperatures pyrometers are used. These are electrical in operation.

When a junction of two different metals is heated, the other ends being kept cold, a current will flow across the junction if it forms part of an electric circuit. It is found that with certain metals this current increases uniformly with uniform rise in temperature of the heated end and this is the principle of the thermo-electric pyrometer. The junction of the metals is called the 'couple', and metals available for the couple are iridium, rhodium, platinum, etc., or nickel and nickel-chrome alloys.

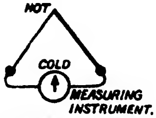


DIAGRAM OF THERMO-COUPLE.

The choice of metals depends on the temperature to be measured. The rare metals, such as platinum and iridium, are used up to 2300° F., while the nickel alloy and nickel couple can be used up to 2500° F. and even 3000° F. if used intermittently, since they do not vaporise as easily as the rarer metals when in contact with gases at high temperature.

In the Platinum Resistance pyrometer the measurement of temperature is achieved by measuring the changes of electrical resistance of a platinum wire.

We have a wire of platinum exposed to the heat source of which the temperature is required. This wire changes in electrical resistance, and as the heat increases its resistance increases proportionally.

This can be measured accurately, and the instruments used indicate the temperature on a scale. This pyrometer is very accurate below 1600° F., but is not used above 2200° F. The Thermo-electric instrument is much more suitable for measuring the temperatures when hardening steel, for example, since the Resistance type will not stand up to *intense* heat *except* for a short time.

Another method of estimating high temperatures between 1700 and 3000° F. accurately to about 35° F. is by means of Temperature Cones. These consist of pyramids made of mineral and metallic alloys, and they have graded melting points. The first melts at, say, 1740° F. and the next at 1780° F., and so on up to 3200° F. Thus, one cone after another melts as the temperature of a source of heat rises and, by observing the last one to melt, we have the temperatures of the source.

The judging of temperatures by colour is usually very inaccurate. If steel is heated, it undergoes a colour change varying from dull red to brilliant white. After considerable experience it is possible to estimate roughly, however, the temperature by this means, but no reliance can be placed on it.

TEMPERATURES OF STEEL BY COLOUR

DEGREES C.	DEGREES F.	COLOUR
500	940	Red (visible in daylight)
800	1470	Cherry red
1000	1830	Bright red
1200	2190	Reddish yellow
1400	2550	White welding heat
1550	2820	Brilliant white

Expansion and Contraction

When a solid is heated, the molecules become excited and vibrate more and more. This causes them to take up more room and thus the solid expands.

Most substances expand when heated and contract again when cooled, as the molecules settle back into their normal state of vibration.

Metals expand by a much greater amount than other solid substances, and there are many practical examples of this expansion in everyday life.

Gaps are left between lengths of railway lines, since they expand and contract with atmospheric temperature changes. Iron tyres are made smaller than the wheel they are to fit. They are heated and expand to the size of the wheel and are fitted when hot. On being quickly cooled, they contract and grip the wheel firmly.

Large bridges are mounted on rollers fitted on the supporting pillars to allow the bridge to expand.

In welding, this expansion and contraction is of the greatest importance. Suppose we have two pieces of steel bar about 2 ft. long. If these are set together at an angle of 90°, as shown, and then welded and allowed to cool, we find that they have curled or bent up in the direction of the weld (Fig. 3).

The hot weld metal, on contracting, has caused the bar to bend up as shown, and it is evident that considerable force has been exerted to do this.

A well-known example of the use to which these forces, exerted during expansion and contraction, are put is the use of iron bars to pull in or strengthen defective walls of buildings.

Plates or S pieces are placed on the threaded ends of the bar, which projects through the walls which need pulling in.

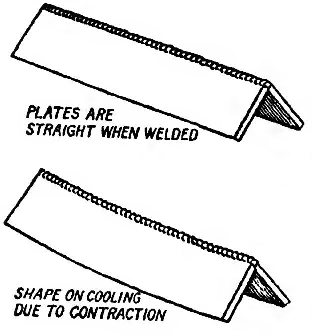


Fig. 3

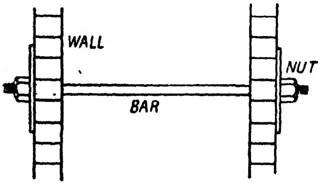


Fig. 4

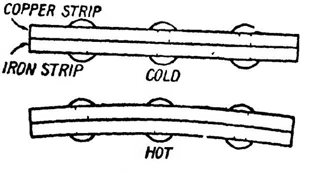


Fig. 5

The bar is heated to redness and nuts on each end are drawn up tight against the plates on the walls. As the bar cools, gradually the walls are pulled in (Fig. 4).

Different metals expand by different amounts. This may be shown by riveting or tack welding together a bar of copper and a bar of iron about 1 ft. long and 1 in. wide. If this straight composite bar is heated it will become bent, with the copper on the outside of the bend, showing that the copper expands more than the iron. (This composite bar is known as a bi-metal strip and is used in electrical engineering for automatic control of temperature, Fig. 5.)

Coefficient of Linear Expansion

The fraction of its length which a bar will expand when heated through one degree rise in temperature is termed its coefficient of linear expansion. (This also applies to contraction when the bar is cooled.) This fraction is very small; for example, for iron it is $\frac{12}{1,000,000}$.

That is, a bar of iron length l would expand by $\frac{12}{1,000,000} \times l$ for every degree rise in temperature. Hence, if the rise was $t°$, the expansion would be $\frac{12}{1,000,000} \times l \times t$.

The fraction $\frac{12}{1,000,000}$ is usually denoted by the letter a. Thus the increase in length of a bar of original length l, made of material whose coefficient of linear expansion is a, when heated through $t°$ is lat.

Thus, the final length of a bar when heated equals its original length plus its expansion, that is:

$$L \quad = \quad l \quad + \quad lat$$

Final length = Original length + Expansion

l — Original length

This can also be written:

$$L = l\,(1 + at)$$

Expansion: l | lat — Length after being heated through $t°$ C.

EXAMPLE

Given that the coefficient of linear expansion of copper is $\frac{17}{1,000,000}$ or 0·000017 per degree C., find the final length of a bar of copper whose original length was 75 in., when heated through 50° C.

Final length = Original length + Expansion, i.e.

$$\text{Final length} = 75 + \left(75 \times \frac{17}{1,000,000} \times 50\right)$$

$$= 75 + \frac{63,750}{1,000,000} = 75\,\frac{6,375}{100,000} = 75{\cdot}06375.$$

The above is equally true for calculating the contraction of a bar when cooled.

TABLE OF COEFFICIENTS OF LINEAR EXPANSION OF METALS PER DEGREE C.

METAL	a	METAL	a
Lead	0·000027	Zinc	0·000026
Tin	0·000021	Cast iron	0·000010
Aluminium	0·000025	Nickel	0·000013
Copper	0·000017	Wrought iron	0·000012
Brass, 60 % copper, 40 % zinc	0·000020	Mild steel	0·000012

Invar, a nickel steel alloy containing 36 % nickel, has a coefficient of linear expansion of only 0·0000009, that is, only $\frac{1}{13}$th of that of mild steel, and thus we can say that invar has practically no expansion when heated.

The expansion and contraction of metal is of great importance to the welder, because, as we have previously shown, large forces or stresses are called into play when it takes place. If the metal that is being welded is fairly elastic, it will stretch, or give, to these forces, and this is a great help, although stresses may be set up as a result in the welded metal. Some metals, however, like cast iron, are very brittle and will snap rather than give or show any elasticity when any force is applied. As a result, the greatest care has to be taken in applying heat to cast iron and in welding it, lest we introduce into the metal, when expanding and contracting, any forces which will cause it to break. This will be again discussed at a later stage.

Coefficient of Cubical Expansion

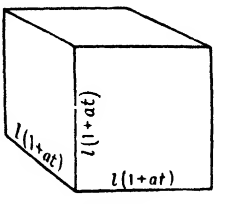


Fig. 6

If we imagine a solid being heated, it is evident that its volume will increase, because each side undergoes linear expansion.

A cube, for example, has three dimensions, and each will expand according to the previous rule for linear expansion. Suppose each face of the cube was originally length l and final length L after being heated through $t°$ C. Let the coefficient of linear expansion be a per degree C.

The original volume was $l \times l \times l = l^3$.

Each edge will have expanded, and for each edge we have:

Final length $L = l(1 + at)$ as before.

Thus the new volume $= l(1 + at) \times l(1 + at) \times l(1 + at)$

$= l^3(1 + 3at)$ approximately.

Thus, Final volume = Original volume $(1 + 3at)$.

That is, the coefficient of cubical expansion may be taken as being three times the coefficient of linear expansion.

Example

A brass cube has a volume of 60 cu. in. and is heated through 65° C. Find its final volume, given that the coefficient of linear expansion of brass = 0·00002 per degree C.

Final volume = Original volume $(1 + 3at)$, i.e.

$$V = 60(1 + 3 \times 0{\cdot}00002 \times 65),$$
$$60(1 + 0{\cdot}0039),$$
$$60 \times 1{\cdot}0039 = 60{\cdot}234 \text{ cu. in.}$$

Quantity of Heat

The quantity of heat in any substance depends upon the substance itself, its mass, and its temperature. Water is taken as the standard substance, and the quantity of heat required to raise a mass M through a rise of temperature $t°$ is Mt units.

$\therefore$ Quantity $= Mt$.

The quantity of heat required to raise 1 lb. of water through 1° F. is termed the British Thermal Unit, written (B.Th.U.). In the Continental System the quantity of heat required to raise 1 grm. of water through 1° C. is termed the Gram Calorie.

Example

The quantity of heat required to raise 10 lb. of water through 50° F. = 500 B.Th.U.

To raise 1 lb. of copper through 1° F. requires 0·094 B.Th.U.

$\therefore$ Quantity of heat in M lb. of copper at $t°$

$= Mt \times 0{\cdot}094$ B.Th.U.

This factor 0·094 is termed the *Specific Heat* of copper.

To raise 1 lb. of aluminium through 1° F. requires 0·215 B.Th.U., that is, the Specific heat of aluminium = 0·215.

Thus the Specific heat

$$= \frac{\text{Quantity of heat required to raise a mass of the substance through a given temperature}}{\text{Quantity of heat required to raise the same mass of water through the same temperature}}.$$

Specific heat is usually denoted by s.

∴ Quantity of heat to raise mass M through $t° = Mst$ units.

EXAMPLE

Find the quantity of heat required to raise the temperature of 20 lb. of cast iron through 30° F., given specific heat of cast iron 0·12.

Quantity of heat $= Mst$

$= 20 \times 0{\cdot}12 \times 30$ B.Th.U.

$= 72$ B.Th.U.

EXAMPLE

Find the quantity of heat required to raise the temperature of 10 grm. of cast iron from 50° C. to 150° C. (Specific heat = 0·12.)

Quantity of heat = Mass of iron × Specific heat × Rise in temperature

$= (10 \times 0{\cdot}12 \times 100)$ gram calories

$= 120$ gram calories.

TABLE OF SPECIFIC HEATS OF METALS

METAL	SPECIFIC HEAT	METAL	SPECIFIC HEAT
Aluminium	0·215	Mild steel	0·115
Tin	0·056	Zinc	0·095
Lead	0·031	Cast iron	0·13
Copper	0·094	Nickel	0·109
Brass	0·092	Wrought iron	0·11

From the foregoing, it can be seen that the greater the specific heat the greater the capacity for heat of the body.

For example, aluminium has a greater capacity for heat than nickel. Water, with a specific heat of 1, has the greatest capacity for heat of all known substances and, thus, all other specific heats will be less than 1.

Melting Point

The melting point of a substance is the temperature at which the change of state from solid to liquid occurs, and this is usually the same temperature at which the liquid will change back to solid form or freeze.

Substances which expand on solidifying have their freezing point lowered by increase of pressure, while others which contract on freezing have their freezing point raised by pressure increase.

The melting point of a solid with a fairly low melting point can be determined by attaching a small glass tube, with open end containing some of the solid, to the bulb of a thermometer. The thermometer is then placed in a container holding a liquid, whose boiling point is above the melting point of the solid, and fitted with a cover, as shown in Fig. 7, and a stirrer is also included. The container is heated and the temperature at which the solid melts is observed. The apparatus is now allowed to cool and the temperature at which the substance solidifies is noted. The mean of these two readings gives the melting point of the solid. By using mercury, which boils at 357° C., as the liquid in the container, the melting point of solids which melt between 100 and 300° C. could be obtained.

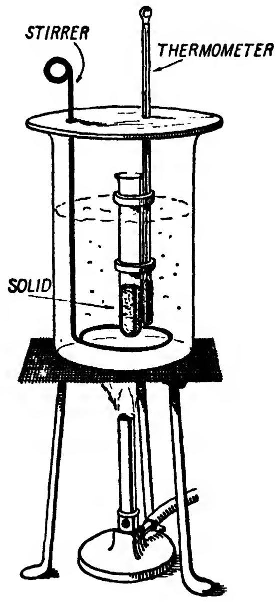


Fig. 7

Determination of the Melting Point by Method of Cooling

The solid, of which the melting point is required, is placed in a suitable container, fitted with a cork or stopper through which a thermometer is inserted (Fig. 8). A hole in the stopper prevents pressure rise. The container is heated until the solid melts, and heating is continued until the temperature is raised well above this point. The liquid is now allowed to cool and the temperature is taken every quarter or half minute. This temperature is plotted on a graph against the time, and the shape of the graph should be as shown in Fig. 9.

If the melting point of a metal is required, the metal is placed in a fireclay or graphite crucible and heated by means of a furnace, and the temperature is measured, at the same intervals, by electrical means which will be described later. The metal, on cooling, begins to solidify and form crystals in exactly the same way as any other solid. The portion *A* shows the fall in temperature of the liquid or molten metal. The portion *B* indicates the steady temperature while solidification is taking place, and portion *C* shows the further fall in temperature as the solid loses heat. The temperature t° of the portion *B* of the curve is the melting point of the solid.

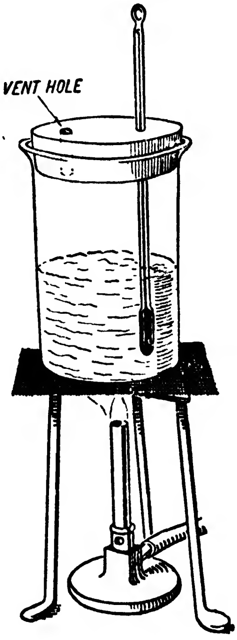


Fig. 8

In practice, we may find that the temperature falls below the dotted line, as shown, that is, below the solidifying temperature. This is due to the difficulty which the liquid may experience in commencing to form crystals, and is called 'super-cooling'. It then rises again to the true solidifying point and cooling then takes place as before (Fig. 10).

This method of determination of the melting point is much used in finding the melting point of alloys and in observing the behaviour of the constituents of the alloys when melting and solidifying.

The melting point of a metal is of great importance in welding, since, together with the capacity for heat of the metal, it determines how much heat is necessary for fusion. The addition of other substances or metals to a given metal (thus forming an alloy) will affect its melting point. Great care has to be taken, therefore, that the melting point of a metal or alloy is known accurately before a suitable welding rod can be designed for welding it. The welding rod usually melts at a slightly lower temperature than the metal itself, and this is particularly the case regarding rods for the welding of aluminium, brass, bronze and copper. The use of bronze in the welding of cast iron is another example of this. The bronze filler rod or electrode melts at a temperature of many hundred degrees below that of

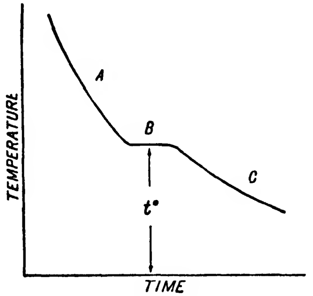


Fig. 9

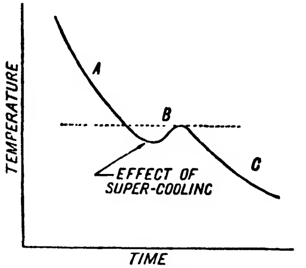


Fig. 10

cast iron. This means that the casting is kept much cooler, does not expand as much and, as a result, there is less risk of distortion and cracking.

Melting Point of Metals	Degrees Centigrade	Melting Point of Metals	Degrees Centigrade
Tin	231·9	Copper	1083
Lead	327·4	Cast iron	1130
Zinc	419·4	Nickel	1452
Aluminium	653·7	Wrought iron	1500

Latent Heat

If a block of ice is placed in a vessel together with a thermometer and heat is applied, it is found that the temperature remains steady at 0° C. or 32° F. until the whole of the ice has been melted. Then the temperature begins to rise. The heat given to the ice has not caused any rise in temperature, but only a change of state, and is called *Latent Heat.* When the change of state is from solid to liquid the latent heat supplied is termed Latent Heat of Fusion. When the change is from liquid to gas it is called Latent Heat of Vaporisation. To change 1 lb. of ice at 32° F. into 1 lb. of water at 32° F. takes 44·4 B.Th.U. This is termed the Latent Heat of Fusion of Ice.

Latent heat of fusion is more important in welding than latent heat of vaporisation, because a comparison of the latent heat of fusion figures gives an indication of the relative amounts of heat required to change the solid metal into the liquid state before fusion.

Since heat must be given to a solid to convert it to a liquid, it follows that heat will be given out by the liquid when solidifying. This has already been demonstrated when determining the melting point of a liquid by the method of cooling. When the change of state from liquid to solid takes place (*B* on the curve) heat is given out and the temperature remains steady until solidification is complete, when it again begins to fall.

Transference of Heat

Heat can be transferred in three ways: Conduction, Convection, Radiation.

Conduction

If the end of a short piece of metal rod is heated in a flame, it rapidly gets too hot to hold (Fig. 11). Heat has been transferred by conduction from atom to atom through the metal from the flame to the hand. If a rod of copper and one of steel are placed in the flame, the copper rod gets hotter more quickly than the steel one, showing that the heat has been conducted by the copper more quickly than the steel. If the rods are held in a cork and the cork gripped in the hand, they can now be held comfortably. The cork is a bad conductor of heat. All metals are good conductors, but some are better than others, and the rate at which heat is conducted is termed the *Thermal Conductivity*.

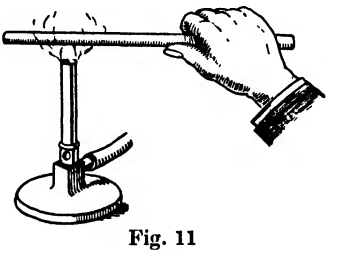


Fig. 11

Thermal Conductivity

To compare the thermal conductivity of metals, three strips, one steel, one brass, one copper, about 9 in. × 1 in. × $\frac{1}{16}$ in. are riveted, as shown in Fig. 12, on to a triangular metal frame with their pointed ends about $\frac{1}{4}$ in. from each other. Their surfaces are coated with wax or candle grease and a coin is stuck in the wax on the end of each strip. Upon heating the pointed ends with a flame, heat is conducted along each bar at different rates and according to their thermal conductivity. We note that the wax melts most quickly along the copper strip and then along the brass strip and much more slowly along the steel strip, and the coins fall from the strips in this order, dropping from the steel strip considerably after the others.

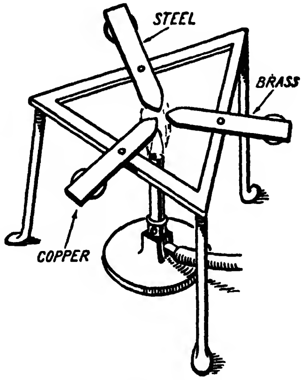


Fig. 12

The thermal conductivity of copper is, therefore, greater than brass and much greater than steel.

The conductivity depends on the purity of the metal, its structure and the temperature.

As the temperature rises the conductivity decreases, but the more a metal is rolled and hammered the closer the structure is made and the greater its conductivity. Impurities in a metal greatly reduce the conductivity.

TABLE OF COMPARATIVE CONDUCTIVITIES
(TAKING COPPER AS 100)

	THERMAL CONDUCTIVITY	ELECTRICAL CONDUCTIVITY
Silver	106	108
Copper	100	100
Aluminium	62	56
Zinc	29	29
Nickel	25	15
Iron	17	17
Steel	13–17	13–17
Tin	15	17
Lead	8	9

The thermal conductivity is closely allied to the electrical conductivity, that is, the ease with which an electric current is carried by a metal. It is interesting to compare the thermal conductivities in the second column. From this we see that in general the better a metal conducts heat, the better it conducts electricity.

The effect of conductivity of heat on welding practice can clearly be seen from the following. A block of copper and one of steel of equal mass are to be welded (Fig. 13).

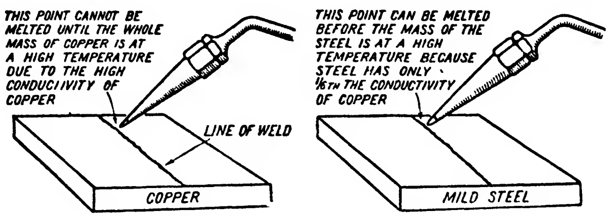


Fig. 13

Mass 1000 grm.
Melting point of copper 1083° C.
Specific heat 0·094.
Heat required to raise block of copper to melting point
= 1000 × 1083 × 0·094 calories
= 101,800 calories.

Mass 1000 grm.
Melting point of steel 1500° C.
Specific heat 0·115.
Heat required to raise block of steel to melting point
= 1000 × 1500 × 0·115 calories
= 172,500 calories.

From the above calculations it is seen that if the two blocks were to be each brought up throughout their mass to melting point, the steel would take *a much greater quantity of heat* than the copper would.

When the heat is applied at one spot, copper being such a good conductor, heat is rapidly transferred from this spot throughout its mass, and we find that the spot where the heat is applied will not melt until the whole mass of the copper has been raised to a very high temperature indeed.

With the mild steel block, on the other hand, the heat conductivity is only about $\frac{1}{8}$th (from the table) that of the copper, that is, the heat is conducted away at only $\frac{1}{8}$th the rate. Hence we find that the spot where the heat is applied will be raised to melting point long before the rest of the block has become very hot.

Because of this high conductivity of copper, it is usual to employ a greater heat, that is, a bigger flame, than when welding the same thickness of steel or iron.

For this reason also, when welding copper, whether by arc or oxy-acetylene, it is always advisable to heat the work up to a high temperature over a large area around the area to be welded. In this way the heat will not be conducted to colder regions so rapidly and better fusion in the weld itself can be obtained.

In welding large copper containers it is usual to have two operators. One heats the area around the weld with a heating flame from the inside of the container, while the other operator performs the welding operation on the outside (Fig. 14).

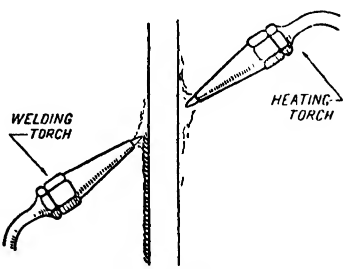


Fig. 14. Illustrating preheating in welding of copper

Cast iron is a comparatively poor conductor of heat compared with copper. If we heat a casting in one spot, therefore, heat will only be transferred away slowly. The part being heated thus expands more quickly than the surrounding parts and, since expansion is irregular, great forces, as before explained, are set up and, since cast iron is brittle and has very small elasticity, the casting fractures. The welding of cast iron is, thus, a study of expansion and contraction and conduction of heat and, to weld cast iron successfully, care must be taken that the temperature of the whole casting is raised and lowered equally throughout its mass. This will be discussed at a later stage.

Convection

When heat is transferred from one place to another by motion of heated particles, this is termed convection. For example, in the hot-water system of a house heat from the fire is transferred by hot water in motion to the storage tank and this is transferred by convection currents (Fig. 15).

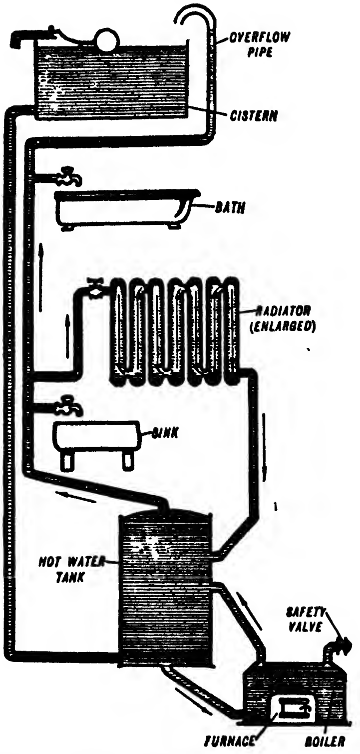


Fig. 15. Heat transferred by convection

In the heat treatment of steel it is often necessary to cool the steel slightly more quickly than if it cooled naturally, in order to harden it. It is cooled, therefore, in an air blast, the heat being transferred thus by convection (Fig. 16).

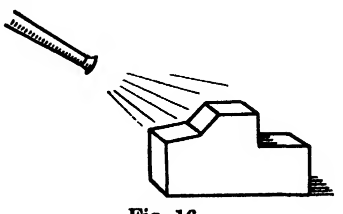


Fig. 16

Radiation

Heat is transferred by radiation as a kind of wave motion through the intervening space.

We sit in front of a fire and it feels warm. There is no physical contact between our bodies and the fire. The heat is being transferred by radiation.

Heat transferred in this manner travels according to the laws of light and is reflected and bent in the same way.

The sun's heat is transmitted by radiation, but the method by which the heat travels through the space is not fully understood. Metal, if allowed to cool in a still atmosphere, loses its heat by radiation and any other bodies in the neighbourhood will become warmed.

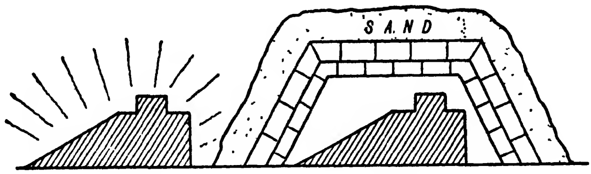


Fig. 17. (*a*) Loses heat quickly from surface by radiation. (*b*) Covering of poor conductor of heat (fire-brick, asbestos and sand) causes heat to be lost slowly and pervents cracking due to unequal contraction

It is evident that the outside of the hot metal will lose heat more quickly than the interior, and we find, for example, that the surface of cast iron is much harder than below the surface, because it has lost heat more quickly.

Great care must be taken in the cooling of work that has been welded because of the rapidity with which the surface cools compared with the interior. With a welded repair to cast iron, for example, the more rapid cooling of the surface will cause this to contract more rapidly than the interior and, as a result of the forces set up inside the casting and the fact that it has little elasticity, it will most probably crack.

This can be prevented by controlling the amount of heat radiated from the surface by enclosing the casting in either a muffle furnace or by covering it with an asbestos sheet and sand, coke or other poor-conducting material.

In this way the heat is lost much more slowly and the cooling period can be extended to 12, 24 or 36 hours at will, thus eliminating any possibility of cracking.

Further details of the muffle furnace and its technique will be found in the section on Cast Iron Welding.

It is now necessary to consider briefly those properties of metals which are of importance in welding. A fuller consideration of many of the points is included in the chapter on Testing of Welds.

Stress, Strain and Elasticity: BEHAVIOUR OF METALS UNDER LOADS

When a force, or load, is applied to a solid body it tends to alter the shape of the body, or deform it.

The molecules of the body, owing to their great attraction for each other, resist, up to a certain point, the attempt to alter their position.

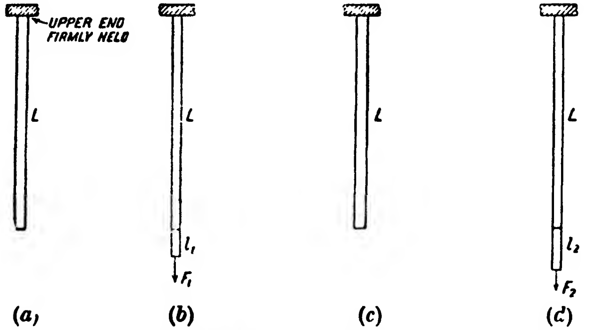


Fig. 18. (*a*) Original length of specimen. (*b*) Extension produced $= l_1$. Elastic limit not reached. F_1 = applied force. (*c*) Force removed, specimen recovers its original dimensions. (*d*) Extension produced $= l_2$. Elastic limit exceeded by application of force. Specimen now remains permanently distorted or set, and does not recover its original dimensions when force is removed. F_2 = applied force

If the applied force is removed before this point is reached, the body will regain its original shape.

This property, which most substances possess, of regaining their original shape upon removal of the applied load is termed *elasticity*.

Should the applied load be large enough, however, the resistance of the molecules will be overcome and they will move and take up new positions. If the load is now removed, the body will no longer return to its former shape. It has become permanently distorted (Fig. 18).

The point at which a body ceases to be elastic and becomes permanently distorted or set is termed the yield point, and the load which is applied to cause this is the yield-point load. The body is then said to have undergone plastic deformation or flow.

Whenever a change of dimensions of a body occurs, from whatever cause, a state of *strain* is set up in that body. Strain is usually measured (for calculation purposes) by the ratio or fraction:

$$\frac{\text{Change of dimensions in direction of applied load}}{\text{Original dimensions in that direction}}.$$

Example

A bar is 100 in. long and is stretched $\frac{1}{4}$ in. by an applied load along its length. Find the strain.

$$\text{Strain} = \frac{\text{Change in length}}{\text{Original length}} = \frac{\frac{1}{4}}{100} = \frac{1}{400}.$$

The magnitude of the force or load on unit area of cross-section of the body producing the strain is termed the *Stress*.

Stress = Force or load per unit area.

Stress may be measured in tons per sq. in., lb. per sq. in. or kilograms per sq. cm. The former is usually used in Great Britain.

When a given load per unit area or stress is applied to a body and it changes its shape within its elastic limits, the ratio $\frac{\text{Stress}}{\text{Strain}}$ is termed the Modulus of Elasticity or Young's Modulus, and is the measure of the elasticity of the body.

(For further details on moduli of elasticity, a text book on strength of materials should be consulted, as it falls outside the scope of this book.)

There are three kinds of simple stress: (1) Tensile or Pull, (2) Compression or Push, (3) Shear.

Tensile Stress

If one end of a rod or wire is fixed firmly and a load is applied to the other end, the rod stretches. This type of load is known as a tensile force or load, and when it is measured on unit area of cross-section of the rod it is termed *Tensile Stress.*

Example

If a load of 10 tons is applied so as to stretch a bar of cross-sectional area ¾ sq. in., find the tensile stress.

$$\text{Tensile stress} = \frac{\text{Load}}{\text{Area of cross-section}} \text{ tons per sq. in.}$$

$$= \frac{10}{\frac{3}{4}} = \frac{10 \times 4}{3} = \frac{40}{3} = 13\tfrac{1}{3} \text{ tons per sq. in.}$$

A machine known as a Tensile Strength Testing Machine, and which will be described later (section Testing of Welds), is used for determining the tensile strength of materials and welded joints.

The specimen under test is clamped between two sets of jaws, one fixed and one moving, and the force can be increased until the specimen breaks.

Suppose a piece of mild steel is placed in the machine. As the tensile stress is increased, the bar becomes only very slightly longer for each increase of force. Then a point is reached when, for a very small increase of force, the bar becomes much longer. This is the yield point and the bar has been stretched beyond its elastic limit.

If the applied load had been reduced before this point was reached, the bar would have recovered its normal size, but will not do so when the yield point has been passed.

As the load is increased beyond the yield point, the elongation of the bar for the same increase of loading becomes much greater, until a point is reached when the bar begins to get reduced in cross-sectional area and forms a waist, as shown. Less load is now required to extend the bar, since the load is now applied on a smaller area, and the waist becomes smaller and the bar breaks. The accompanying diagram (Fig. 19) will make this clear.

As the load is first applied, the extension of the bar is very small, and this needs very accurate measurement, but is proportional to the load. This part of the diagram is, therefore, a straight line *OX*. At the point *X* the extension suddenly becomes much greater than before for a small increase in load. *X* is termed the yield point and the load at this point is termed the yield-point load.

Increase of load produces progressive increase of length to the point *Z*. At this point the waist forms; *Z* is the maximum load. Breakage occurs at *Y* under a smaller load than at *Z*. A

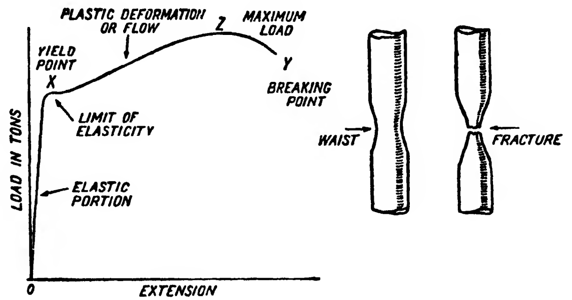


Fig. 19

substance which has a fair elongation during the plastic stage is called ductile, while if the elongation is very small it is said to be brittle.

It is evident that, given a table of tensile strengths of various metals (that is, the maximum force per square inch that they will stand), we can calculate the maximum force or stress that any given section will stand.

TABLE OF TENSILE STRENGTHS IN TONS PER SQ. IN.

Lead	0·8–1·5	Cast iron	6–13·5
Tin	2	Copper	17–25
Zinc	2–3	Brass	8–22
Aluminium	8–11	Wrought iron	16–28·5
Mild steel	25–34	Cast steel	40–54

For instance, a certain grade of steel has a tensile strength of 45 tons per sq. in. What tensile force will be required to break a piece of this steel having a section $1 \times \frac{3}{4}$ in.?

Area of cross-section $= \frac{3}{4}$ sq. in.

Tensile strength $= 45$ tons per sq. in.

$\therefore$ $\frac{3}{4}$ sq. in. section has a tensile strength $= \frac{3}{4} \times 45 = 33\frac{3}{4}$ tons.

It will be noticed that the tensile strength of many of the above metals varies between considerable limits. This is because the tensile strength of a metal depends largely upon the way it is hammered and rolled in manufacture, its heat treatment, its actual composition and the presence of impurities.

In stating the qualities of a particular metal or welding rod, manufacturers usually state:

(1) Yield point (in tons per sq. in.).
(2) Maximum stress (in tons per sq. in.).
(3) Elongation (in inches on a certain length).

The elongation is usually stated on a given length of 8 in. or 2 in. and is the amount an 8 in. or 2 in. length of the metal will elongate when subjected to a load up to its elastic limit. The elongation is often stated as a percentage.

This is, therefore, a direct measure of the elasticity of the metal.

In welded joints it is important that the tensile strength of the joint should be as near as possible that of the surrounding metal. Evidently, therefore, the metal of the weld must also have a tensile strength at least equal to the parent metal, while, if it should be greater, the failure will probably occur not in the joint but in the parent metal itself, if the welding has been carried out correctly.

Proof Stress

Non-ferrous metals, such as aluminium and copper, etc., and also very hard steels, do not show a definite yield point, as just explained, and the load-extension curve is roughly as shown.

For aircraft work, a load which will produce a definite permanent extension (e.g. 0·1 %) is used as the standard measurement. This load is known as the *Proof Stress* (Fig. 20).

Compressive Stress

If the forces applied in the previous experiments on tensile strength are reversed, the body is placed under compression. The applied force now tends to squeeze the atoms together and, since in a solid they are already tightly packed, they will tend to bulge out in other directions when the elastic limit is passed.

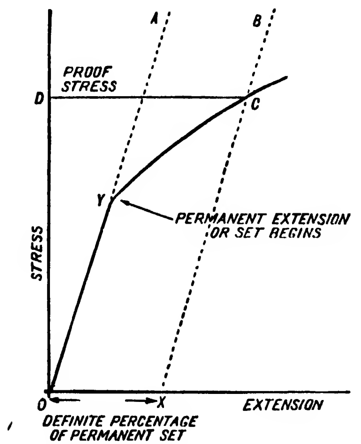


Fig. 20. Load-extension curve of hard steels and non-ferrous metals illustrating proof stress

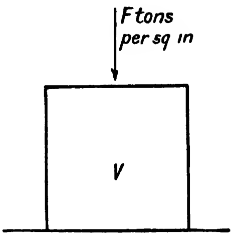


Fig. 21

If a compressive stress of F tons per sq. in. produces a decrease in volume of v in a solid of original volume V (Fig. 21), the

$$\text{Compressive strain} = \frac{v \text{ (Change in volume)}}{V \text{ (Original volume)}}$$

and

$$\frac{\text{Compressive stress}}{\text{Compressive strain}} = \frac{F}{v/V} = \text{Compression modulus of elasticity.}$$

A good example of compressive stress is found in building and structural work. All foundations, concrete, bricks and steel columns are under compressive stress, and in the making or fabrication of welded columns and supports, the strength of welded joints in compression is of great importance. A table of compression stresses is given:

Materials	Compression Stress in tons per sq. in.
Cast iron	40–50
Wrought iron	23
Nickel steel	65
Brass (60/40)	37

Shearing Stress

If a cube has its face fixed to the table on which it stands and a force is applied parallel to the table on one of the upper edges, this force per unit is termed a shearing stress and it will deform the cube, as indicated by the dotted line (Fig. 22). The angle θ through which the cube is deformed is a measure of the shearing strain.

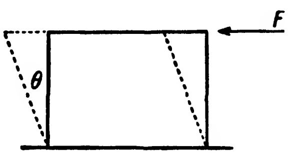


Fig. 22

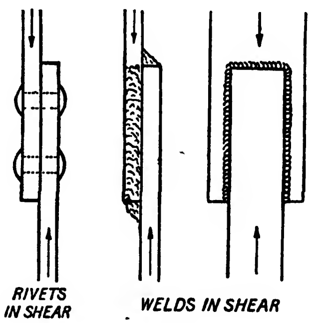


Fig. 23

This is a very common type of stress in welded construction. For example, if two plates are lapped over each other and welded, as indicated, then a load placed on the upper plate places the welds under a shearing stress (Fig. 23). If the load is known and also the shearing strength of the metal of the weld, then sufficient metal can be deposited to withstand the load.

A welded structure should be designed to ensure that there is sufficient area of weld metal in the joint to withstand safely the load required.

Mechanical Properties of Metals and the Effect of Heat on these Properties

Plasticity may be defined as the ease with which a metal may be bent or moulded into a given shape. At ordinary temperatures, lead is one of the most plastic metals. The plasticity usually increases as temperature rises. Iron and steel are difficult to bend and shape when cold, but it becomes easy to do this when heated above red heat. Wrought iron, however, because of impurities in it, sometimes breaks when we attempt to bend it when hot (called hot shortness), and thus increase of temperature is not always accompanied by an increase in plasticity.

Brittleness is the opposite of plasticity and denotes lack of elasticity. A brittle metal will break when a force is applied. Cast iron and high carbon steel are examples of brittle metals. The wrought iron in the above paragraph has become brittle through heating. Copper becomes brittle near its melting point, but most metals become less brittle when heat is applied. Carbon steel is an example; when cold it is extremely brittle, but can easily be bent and worked when hot. Brittle metals require care when welding them, due to the lack of elasticity.

Malleability is the property possessed by a metal of becoming permanently flattened or stretched by hammering or rolling. The more malleable a metal is, the thinner the sheets into which it can be hammered. Gold is the most malleable metal (the gold in a sovereign can be hammered into 4 sq. yd. of gold leaf, less than $\frac{1}{10000}$th thick).

Copper is very malleable, except near its melting point, while zinc is only malleable between 140 and 160° C. Metals such as iron and steel become much more malleable as the temperature rises and are readily hammered and forged.

The presence of any impurities greatly reduces the malleability, as we find that the metal cracks when it stretches.

Order of Malleability when cold

(1) Gold.	(3) Aluminium.	(5) Tin.	(7) Zinc.
(2) Silver.	(4) Copper.	(6) Lead.	(8) Iron.

Ductility. If a bar or wire is drawn out lengthwise, the amount of extension measures its ductility. For a metal to be ductile its molecules must have great power of attraction for each other after the yield point has been passed or breakage will occur. Since the atoms have greater attraction when cold than hot, metals are usually more ductile when cold, and thus wire drawing and tube drawing are often done cold, but not always.

In the wire-drawing operation, wire is drawn through a succession of tapered holes called *dies*, each operation reducing the diameter and packing the atoms more tightly. The brittleness thus increases and the wire must be softened again by a process termed annealing.

Order of Ductility

(1) Gold. (2) Silver. (3) Iron. (4) Copper. (5) Aluminium. (6) Zinc. (7) Tin. (8) Lead.

Tenacity is another name for tensile strength. The addition of various substances to a metal may increase or decrease its tensile strength. Sulphur reduces the tenacity of steel while carbon increases it (see section on Tensile Strength).

Hardness is the property possessed by a metal to resist wear and abrasion. It can be measured on various scales, the most common of which are: (1) Brinell, (2) Scleroscope, (3) Rockwell, (4) Vickers, Diamond Pyramid.

TABLE OF COMPARATIVE HARDNESS (BRINELL FIGURE)

Material	Brinell Figure	Material	Brinell Figure
Lead	6	Brass: Cast	60
Tin	14	Rolled	150–200
Aluminium	37	Cast iron (under surface)	150–200
Zinc	45	Mild steel	125–170
Copper:		Cast iron (on surface)	400–500
Cast	40–45	Nitralloy (nitrarded or nitrided steel)	700–800
Annealed	45–55		
Cold worked	80–100		

On the Brinell scale the number is a comparison of its hardness (see Testing of Welds). The hardness of a metal can roughly be tested by scratching or attempting to file it. Some metals, such as cast iron, are much harder on the surface than just below it.

Hardness decreases with rise in temperature. The addition of carbon to steel greatly increases its hardness, and the operation of rolling, drawing, pressing and hammering greatly affect it.

It will be noted that there is considerable latitude in the higher figures. Copper, for example, varies from 40 to 50 according to the way it is prepared. Copper is hardened by cold working, that is drawing, pressing and hammering, and this also increases its ductility.

The tensile strength of steels can be approximately determined in tons per square inch by multiplying their Brinell hardness figure by 0·21 for hard steels and by 0·23 for those in the soft or annealed condition.

Fatigue

If a metal is subjected to continually varying loads, such as hammering or an alternating push and pull, it may eventually suffer from fatigue.

The atoms, in the face of the continued attempt to break them apart, eventually lose their power of attraction and behave as though they were tired. Metal tyres on railway carriage wheels, subjected to millions of blows by the junctions of the rails, suffer from fatigue cracks. The wheel tapper, with his long-handled hammer, sounds the tyre and, from the sound emitted, coupled with long experience, he can tell whether cracks have developed.

Machines are now made which subject specimens to continually varying forces, that is, alternately pull and push or tensile and compressive, and these machines can subject a specimen in a short time to the amount of alternating stress which would only be met with in years of service.

CHEMISTRY APPLIED TO WELDING

Elements, Compounds and Mixtures

All substances can be divided into two classes: (1) Elements, (2) Compounds.

An element is a simple substance which cannot be split up into anything simpler. For example, aluminium (Al), copper (Cu), iron (Fe), tin (Sn), zinc (Zn), sulphur (S), silicon (Si), hydrogen (H), oxygen (O) are all *elements.*

A table of the elements is given in the Appendix, together with their chemical symbols.

A compound is formed by the combination of two or more elements, and the property of the compound differs in all respects from the elements of which it is composed.

We have already mentioned the occurrence of matter in the form of molecules, and now it will be well to consider how these molecules are arranged among themselves and how they are made up.

If a mixture of iron filings and sand is made, we can see the grains of sand among the filings with the naked eye. This mixture can easily be separated by means of a magnet, which will attract the iron filings and leave the sand. Similarly, a mixture of sand and salt can be separated by using the fact that salt will dissolve in water, leaving the sand. In the case of mixtures, we can always separate the components by such simple means as this (called Mechanical Means).

Similarly, a mixture of iron filings and powdered sulphur can be separated, either by using a magnet or by dissolving the sulphur in a liquid such as carbon disulphide, in which it dissolves readily.

Now suppose we heat this mixture. We find that it first becomes black and then, even after removing the flame, it glows like a coal fire and much heat is given off. After cooling, we find that the magnet will no longer attract the black substance which is left, neither will the liquid carbon disulphide dissolve it. The black substance is, therefore, totally different in character from the iron filings or the sulphur. It can be shown by chemical means that the iron and sulphur are still there, contained in the black substance. This substance is termed a chemical compound and is called Iron Sulphide. It has properties quite different from those of iron and sulphur.

Previously it has been stated that molecules can be subdivided. Molecules are themselves composed of atoms, and the number of atoms contained in each molecule depends upon the substance.

For example, a molecule of the black iron sulphide has been formed by the combination of one atom of iron and one atom of sulphur joined together in a chemical bond. This may be written:

Iron + Sulphur = IRON SULPHIDE (FeS)

The molecules of some elements contain more than one atom. A molecule of hydrogen contains two atoms, so this is written: $H_2 = \overset{\circ}{H} — \overset{\circ}{H}$. Similarly, a molecule of oxygen contains two atoms, thus: $O_2 = \overset{\circ}{O} — \overset{\circ}{O}$.

A molecule of copper contains only one atom, thus: $Cu = \overset{\circ}{Cu}$.

The Atmosphere

Let us now study the composition of the atmosphere, since it is of primary importance in welding.

Suppose we float a lighted candle, fastened on a cork, in a bowl of water and then invert a glass jar over the candle, as shown in Fig. 24. We find that the water will gradually rise in the jar, until eventually the candle goes out. By measurement, we find that the water has risen up the jar $\frac{1}{5}$th of the way, that is, $\frac{1}{5}$th of the air has been used up by the burning of the candle, while the remaining $\frac{4}{5}$ths of the air still in the jar will not enable the candle to continue burning. The gas remaining in the jar is nitrogen. It has no smell, no taste, will not burn and does not support burning. The gas which has been used up by the burning candle is oxygen.

Evidently, then, air consists of four parts by volume of nitrogen to one part of oxygen. That oxygen is necessary for burning is very evident. Sand thrown on to a fire excludes the air, and thus the oxygen, and the fire is extinguished. If a person's clothes catch fire, rolling them in a blanket or mat will exclude the oxygen and put out the flames.

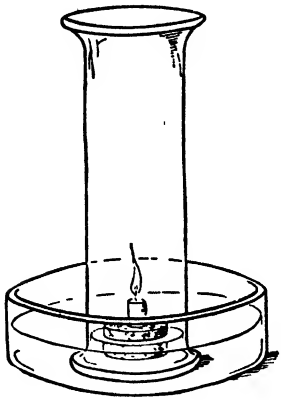


Fig. 24

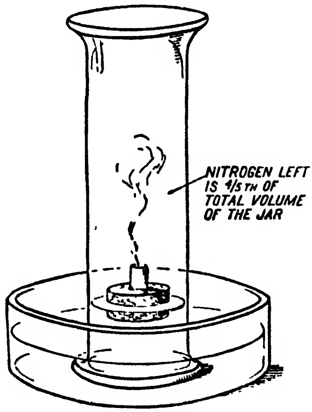


Fig. 25

Oxygen

In view of the importance of oxygen to the welder, it will be useful to prepare some oxygen and investigate some of its properties.

Place a small quantity of potassium chlorate in a hard glass tube (test tube) and heat by means of a gas flame. The substance melts, accompanied by crackling noises. Now place a glowing splinter in the mouth of the tube. The splinter bursts into flame and burns violently (Fig. 26). Oxygen is being given off by the potassium chlorate and causes this violent burning. Use of the glowing splinter is one method of testing for an escape of oxygen, as, for example, from leaky connections to the oxygen cylinder of the oxy-acetylene plant.

Oxygen is prepared on a commercial scale by one of two methods: (1) Liquefaction of air, (2) Electrolysis of water. In the first method air is liquefied by reducing its temperature to about −140° C. and then compressing it to a pressure of 39 atmospheres. The pressure is then reduced and the nitrogen boils off first, leaving the liquid oxygen behind. This is then allowed to boil off into its gaseous form and is compressed into the steel cylinders at 120 atmospheres.

The second method is generally used when there is a plentiful supply of cheap water power for generating electricity. An electric current is passed through large vats containing water, the current entering at the anode (positive) and leaving at the cathode (negative). The passage of the current splits up the water into hydrogen and oxygen. The hydrogen is collected from the

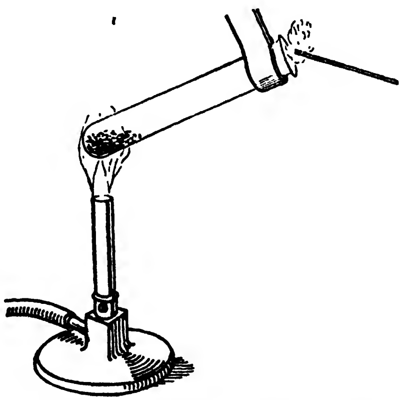


Fig. 26. Test for oxygen, glowing splinter bursts into flame

cathode and the oxygen from the anode, there being twice the volume of hydrogen evolved as oxygen. (This operation is known as electrolysis.) The gases are then dried, compressed and stored in steel containers, the hydrogen being compressed to 120 atmospheres, similar to the oxygen.

Properties of Oxygen

Oxygen is a colourless gas with neither taste nor smell. It is slightly soluble in water, and this slight solubility enables fish to breathe the oxygen which has dissolved.

Oxygen does not burn itself, but it very readily supports combustion, as shown by the glowing splinter which is a test for oxygen.

If a piece of red-hot iron is placed in oxygen it burns brilliantly, giving off sparks. This is caused by the iron combining with the oxygen to form an OXIDE, in this case iron oxide (Fe_3O_4).

Oxidation

Most substances combine very readily with oxygen to form oxides, and this process is termed oxidation.

Magnesium burns brilliantly, forming a white solid powder, magnesium oxide, i.e.

$$\text{Magnesium} + \text{Oxygen} = \text{Magnesium oxide}$$
$$2Mg + O_2 = 2MgO$$

When copper is heated to redness in contact with oxygen copper oxide is formed:

$$\text{Copper} + \text{Oxygen} = \text{Copper oxide}$$
$$2Cu + O_2 = 2CuO$$

Similarly, phosphorus burns with a brilliant flame and forms phosphorus oxide (P_2O_5). Sulphur burns with a blue flame and forms the gas, sulphur dioxide (SO_2).

Silicon, if heated, will combine with oxygen to form silica (SiO_2), which is sand:

$$\text{Silicon} + \text{Oxygen} = \text{Silica or oxide of Silicon}$$
$$Si + O_2 = SiO_2$$

The Rusting of Iron

Moisten the inside of a glass jar so that small iron filings will adhere to the interior surface and invert the jar over a bowl of water, thus entrapping some air inside the jar (Fig. 27).

If the surface of the water inside the jar is observed, it is seen that as time passes and the iron filings become rusty, the surface of the water rises and eventually remains stationary at a point roughly $\frac{1}{5}$th of the way up the jar. From the similar experiment performed with the burning candle it can be seen that the oxygen has been used up as the iron rusts and nitrogen remains in the jar. The rusting of iron is, therefore, a process of surface oxidation.

This can further be demonstrated as follows: Boil some water for some time in a glass tube (or test tube), in order to expel any dissolved oxygen, and then place a brightly polished nail in the water. Seal the open end of the tube by pouring melted vaseline down on to the surface of the water. The nail will now keep bright indefinitely, since it is completely out of contact with oxygen.

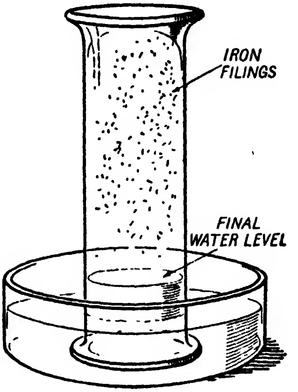


Fig. 27

Oxidation, from the welder's point of view, is the union of a metal with oxygen to form an oxide, i.e.

Metal + Oxygen = Metallic oxide.

Oxygen attacks metals in various ways, depending on:

(1) *The character of the metal.* Magnesium burns very completely to form magnesium oxide, while copper oxidises on the surface.

(2) *Temperature.* Zinc at normal temperature only oxidises slowly on the surface, but if heated to high temperatures it burns with a bright bluish-white flame, forming a white powder, zinc oxide. (This can be observed when welding galvanised articles, since galvanising is a coating of zinc.)

(3) *The amount of surface exposed.* The larger the surface area the greater the amount of oxidation.

(4) *The amount of oxygen present.* Oxidation is much more rapid, for example, in a stream of pure oxygen than in air.

(5) *Presence of other substances.* Iron will not rust if no water is present.

Let us now examine the extent to which the more important metals in welding absorb oxygen.

Iron and Steel. If iron is excessively heated, oxygen is absorbed and oxidation or burning takes place, forming magnetic oxide of iron:

$$\text{Iron} + \text{Oxygen} = \text{Magnetic oxide of iron}$$
$$3Fe + 2O_2 = Fe_3O_4$$

There are two other oxides of iron, ferric oxide (Fe_2O_3) or haematite, which is one of the sources of iron from the earth, and ferrous oxide (FeO), which is a black powder which takes fire when heated in air and forms ferric oxide.

Copper is extremely resistant to atmospheric corrosion, since it forms a film of oxide on its surface. This film is very unlike rust on iron, because it protects the metal and offers high resistance to any further attack. In time the oxide becomes changed to compounds, having a familiar green colour such as sulphate of copper. When copper is brightly polished and exposed to a clean, dry atmosphere it tarnishes and becomes coated with a thin film of cuprous oxide (Cu_2O). If the temperature of the copper is now raised, the amount of oxidation increases proportionally and at high temperatures the copper begins to scale. The black scale formed is cupric oxide (CuO), while underneath this is another film of cuprous oxide (Cu_2O), which has a characteristic red colour.

Aluminium has a great affinity for oxygen and is similar to copper in that it forms a protective coating (of aluminium oxide Al_2O_3) on its surface, which protects it against further attack. The depth of the film of oxide formed will depend upon the amount of corrosion, since the film adjusts itself to the amount of corrosive influences.

As the temperature increases little alteration takes place until near its melting point, when the rate of oxidation increases rapidly. It is the formation of this oxide which makes the welding of aluminium almost impossible unless a chemical (termed a flux) is used to dissolve it.

During the welding process, therefore, combination of the metal with oxygen may:

(1) Produce a gaseous oxide of a metal present in the weld and thus produce blow or gas holes.
(2) Produce oxides which, having a melting point higher than that of the surrounding metal, will form a solid particle or SLAG in the weld metal.
(3) Produce oxides which will dissolve in the molten metal and make the metal brittle and weak. (The oxide in this case may form along the boundaries of the crystals of the metal.)

Some oxides are heavier than the parent metal and will tend to sink in the molten weld. Others are lighter and will float to the top. These are less troublesome, since they are easier to remove.

Oxides of wrought iron and steel, for example, melt very much below the temperature of the parent metal and, being light, float to the surface as a scale. Thus, if care is taken in the welding process, the oxide is not troublesome.

In the case of cast iron, however, the oxide melts at a temperature above that of the metal; consequently, it would form solid particles in the weld if not removed. For this reason a 'flux' is used which combines with the oxide and floats it to the surface. In welding copper, aluminium, nickel and brass, for example, a flux must be used to remove the oxides formed (see Fluxes).

The two most common causes of oxidation in welding are by absorption of oxygen from the atmosphere, and by use of an incorrect flame with excess oxygen in gas welding.

Reduction or Deoxidation

Reduction takes place when oxygen is removed from a substance. Evidently it is always accompanied by oxidation, since the substance that removes the oxygen will become oxidised.

The great affinity of aluminium for oxygen is made use of in the Thermit Process of Welding and provides an excellent example of chemical *reduction.*

Suppose we mix some finely divided aluminium and finely divided iron oxide in a crucible or fireclay dish. Upon setting fire to this mixture it burns and great heat is evolved with a temperature as high as 3000° C. This is due to the fact that the aluminium has a greater affinity for oxygen than the iron has, when they are hot, and as a result the aluminium combines with the oxygen taken from the iron oxide. Thus the pure iron is set free in the molten condition. The action is illustrated as follows:

$$\text{Iron oxide} + \text{Aluminium} = \text{Aluminium oxide} + \text{Iron}$$

$$Fe_2O_3 \quad + \quad 2Al \quad = \quad Al_2O_3 \quad + 2Fe$$

This is the chemical action which occurs in an incendiary bomb. The detonator ignites the ignition powder which sets fire to the thermit mixture. This is contained in a Magnesium-

Aluminium alloy case (called Elektron) which also burns due to the intense heat set up by the thermit reaction.

Since oxygen has been taken from the iron, the iron has been *reduced* or deoxidised and the aluminium is called the reducing agent.

NOTE. Hydrogen is an electro-positive element, while oxygen is an electro-negative element. Therefore, oxidation is often spoken of as an increase in the ratio of the electro-negative portion of a substance, while reduction is an increase of the ratio of the electro-positive portion of a substance.

Examples of:

OXIDISING AGENTS	REDUCING AGENTS
(1) Oxygen.	(1) Hydrogen.
(2) Ozone.	(2) Carbon.
(3) Nitric acid.	(3) Carbon monoxide.
(4) Chlorine.	(4) Sulphur dioxide.
(5) Potassium chlorate.	(5) Sulphuretted hydrogen.
(6) Potassium nitrate.	(6) Zinc dust.
(7) Manganese dioxide.	(7) Aluminium.
(8) Hydrogen peroxide.	
(9) Potassium permanganate.	

Acetylene

Acetylene is prepared by the action of water on calcium carbide (CaC_2). The carbide is made by mixing lime (calcium oxide) and carbon in an electric arc furnace. In the intense heat the calcium of the lime combines with the carbon, forming calcium carbide and, owing to the high temperature at which the combination takes place, the carbide is very hard and brittle. It contains about 63 % calcium and 37 % carbon by weight and readily absorbs moisture from the air (hygroscopic); hence it is essential to keep it in airtight containers:

Calcium oxide
or Quicklime + Carbon = Calcium carbide + Carbon monoxide

$$CaO + 3C = CaC_2 + CO$$

The carbon monoxide burns in the furnace, forming carbon dioxide.

When water acts on calcium carbide, the gas acetylene is produced and slaked lime remains:

$$\text{Calcium carbide} + \text{Water} = \text{Acetylene} + \text{Slaked lime}$$
$$CaC_2 + 2H_2O = C_2H_2 + Ca(OH)_2$$

Carbon is of great importance in welding, since it is present in almost every welding operation.

It is a non-metallic element, and is remarkable in that it forms about half a million compounds, the study of which is termed 'Organic Chemistry'.

Carbon can exist in three forms. Two of these forms are crystalline, namely diamond and graphite, but the crystals of a diamond are of a different shape from those of graphite. (Carbon is found in grey cast iron as graphite.)

Ordinary carbon is a third form, which is non-crystalline or *amorphous*.

Carbon forms, with iron, the compound ferric carbide, Fe_3C, known as cementite.

The addition of carbon to pure iron in the molten state is extremely important, since the character of the iron is greatly changed. This is dealt with later.

It is found in organic compounds such as acetylene (C_2H_2), petrol (C_6H_{14}), sugar ($C_{12}H_{22}O_{11}$), ethyl alcohol (C_2H_5OH), etc.

Graphite used to be considered as a lead compound, but it is now known that it is a crystalline form of carbon. It is greasy to touch and is used as a lubricant and for making pencils.

The Oxides of Carbon

Carbon dioxide (CO_2) is found in very small quantities in the atmosphere (0·03 %). It is inhaled by plants and is colourless, but has a faint smell. It is slightly soluble in water (this solution under pressure is known as soda water), heavier than air and is easily liquefied. It is formed when carbon is burnt in air; hence is present when any carbon is oxidised in the welding operation.

$$\text{Carbon} + \text{Oxygen} = \text{Carbon dioxide}$$
$$C + O_2 = CO_2$$

It will not burn, neither will it support combustion, and it is usually prepared by the action of any acid, such as hydrochloric, on limestone (calcium carbonate). It turns lime water milky, and this is the usual test for it. When it dissolves in the moisture in the air or rain it forms carbonic acid, which hastens corrosion on steel (see p. 49).

Carbon Monoxide is formed when, for example, carbon dioxide is passed through a tube containing red-hot carbon:

$$\text{Carbon} + \text{Carbon dioxide} = \text{Carbon monoxide}$$
$$C + CO_2 = 2CO$$

Hence it may be formed from carbon dioxide during the welding process. It is a colourless gas which burns with a blue, non-luminous flame. It is not soluble in water and has no smell and is very poisonous, producing a form of asphyxiation. Exhaust fumes from petrol engines contain a large proportion of carbon monoxide, and it is the presence of this that makes them poisonous.

Carbon monoxide readily takes up oxygen to form carbon dioxide. It is thus a reducing agent and it can be made to reduce oxides of metals to the metals themselves.

Combustion or Burning

The study of combustion is very closely associated with the properties of carbon.

When burning takes place, a chemical action occurs. If a flame is formed, the reaction is so vigorous that the gases become luminous.

Let us first consider the burning of a candle. The wax is sucked up the wick and is vaporised by the flame, thus continuing the burning process.

Since wax is composed of carbon and hydrogen, the products of burning are carbon dioxide and water, and if we examine the flame carefully we find that it consists of three regions. These are indicated in Fig. 28 and consist of (*a*) a dark region around the wick, (*b*) a large, luminous area, and (*c*) an outside region existing around the outside of the flame and which is non-luminous and hard to see.

Region (*a*) is where the vapour is given off, as can be shown by placing a small tube from this region and leading away some of the vapour, which will then burn at the mouth of the tube, as shown.

Region (*b*) is where the hydrogen of the wax burns, and this heat makes the carbon white hot or incandescent.

Region (*c*) is where the burning is completed, but much carbon escapes unburnt, as can be seen if a piece of paper is held above the flame, where it becomes covered with soot.

Hydrogen burns in air with a blue, non-luminous flame.

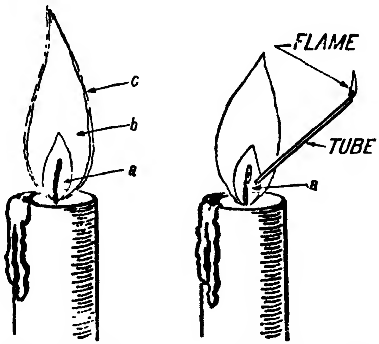


Fig. 28. To illustrate that region (*a*) consists of unburnt vapour

In the oxy-hydrogen flame, hydrogen is burnt in a stream of oxygen. This causes intense heat to be developed, with a flame temperature of about 2400° C.

The oxy-coal-gas flame is very similar, as the coal gas consists of hydrogen, together with other impurities (methane, carbon monoxide and other hydrocarbons). Because of these impurities, the temperature of this flame is much lower than when pure hydrogen is used. The oxy-acetylene flame consists of the burning of acetylene in a stream of oxygen. Acetylene is composed of carbon and hydrogen (C_2H_2), and it is a gas which burns in air with a very smoky flame, the smoke being due, as in the case of the candle, to incomplete combustion of the carbon.

$$\text{Acetylene} + \text{Oxygen} = \text{Carbon} + \text{Water}$$
$$2C_2H_2 + O_2 = 2C_2 + 2H_2O$$

By using, however, a special kind of burner, we have almost complete combustion and the acetylene burns with a very brilliant flame, due to the incandescent carbon. This flame is used for illumination, as in bicycle lamps.

The Oxy-acetylene Welding Flame

When oxygen is mixed with the acetylene in approximately equal proportions a blue, non-luminous flame is produced, the most brilliant part being the blue cone at the centre. The temperature of this flame is given, with others, in the table:

TEMPERATURES OF VARIOUS FLAMES

Oxy-acetylene	...	...	3100–3300° C.
Oxy-hydrogen	...	...	2300–2400° C.
Oxy-coal gas	...	...	2000–2200° C.
Air-acetylene	...	...	2300–2500° C.
Air-coal gas	...	...	1700–1800° C.
(Electric arc	...	...	3500–4000° C.)

This process of combustion occurs in two stages: (1) In the innermost blue, luminous cone; (2) In the outer envelope. In (1) the acetylene combines with the oxygen supplied, to form carbon monoxide and hydrogen.

$$\text{Acetylene} + \text{Oxygen} = \text{Carbon monoxide} + \text{Hydrogen}$$
$$C_2H_2 + O_2 = 2CO + H_2$$

In (2) the carbon monoxide burns and forms carbon dioxide, while the hydrogen which is formed from the above action combines with oxygen to form water:

$$\text{Carbon monoxide} + \text{Hydrogen} + \text{Oxygen} = \text{Carbon dioxide} + \text{Water}$$
$$CO + H_2 + O_2 = CO_2 + H_2O$$

The combustion is, therefore, complete, and carbon dioxide and water (turned to steam) are the chief products of the combustion. This is shown in Fig. 29.

If insufficient oxygen is supplied, the combustion will be incomplete and carbon will be formed.

From this it will be seen that the oxy-acetylene flame is a strong *reducing* agent, since it absorbs oxygen from the air in the outer envelope. Much of its success as a welding flame is due to this, as the tendency to form oxides is greatly decreased. For complete combustion, there is a correct amount of oxygen for a given amount of acetylene. If too little oxygen is supplied, combustion is incomplete and carbon is set free. This is known as a carbonising or carburising flame. If too much oxygen is supplied, there is more than is required for complete combustion, and the flame is said to be an oxidising flame.

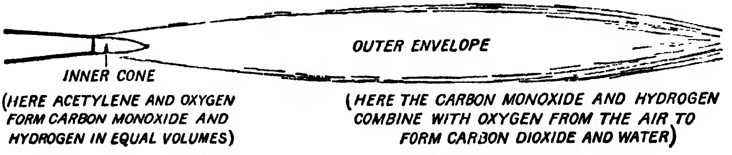


Fig. 29. The oxy-acetylene flame

For usual welding purposes the neutral flame, that is neither carbonising nor oxidising, is required, combustion being just complete with neither excess of carbon nor oxygen.

For special work an oxidising or carbonising flame may be required, and this is always clearly indicated.

Silicon (Si)

Silicon is an element closely allied to carbon and is found in all parts of the earth in the form of its oxide silica (SiO_2). In its free state, silica is found as quartz and sand. Silicon is also found combined with certain other oxides of metals in the form of *Silicates*. Silicates of various forms, including silica, are often used as the flux coverings for arc-welding electrodes and are termed 'siliceous matter'.

Silicon exists either as a brown powder or as yellow-brown crystals. It combines with oxygen, when heated, to form silica, and this takes place during the conversion of iron into steel. Silicon is present, mixed in small proportions with the iron, and, when the air blast is passed through the iron in the molten state, the silicon oxidises and gives out great heat.

Silicon is important in welding because it is found in pig iron (0·1 to 0·5 %), wrought iron (up to 0·1 %) and in carbon and alloy steels (up to 0·3 %). It gives the steel a well-bonded structure.

It is particularly important in the welding of cast iron, because silicon aids the formation of graphite and keeps the weld soft and machinable. If the silicon is burnt out during welding the weld becomes very hard and brittle. Because of this, filler rods for cast iron contain a high percentage of silicon, being known as 'silicon rods'. This puts back silicon into the weld to replace that which has been lost and thus ensures a sound weld.

By mixing silica (sand) and carbon together and heating them in an electric furnace, silicon carbide or carborundum is formed:

Silica + Carbon = Silicon carbide + Carbon monoxide

$$SiO_2 + 3C = SiC + 2CO$$

Carborundum is used for all forms of grinding operations.

Silica bricks, owing to their heat-resisting properties, are used for lining blast furnaces.

Iron has a specific gravity of 7·8, weighs 0·28 lb. per cu. in., melts at 1530° C. and has a coefficient of expansion of 0·0000065 per degree F.

Pure iron is a fairly soft, malleable metal which can be attracted by a magnet.

All metallic mixtures and alloys containing iron are termed ferrous, while those such as copper, brass and aluminium are termed non-ferrous.

Iron combines directly with many non-metallic elements when heated with them, and of these the following are the most important to the welder:

With sulphur it forms iron sulphide (FeS).
With oxygen it forms magnetic oxide of iron (Fe_3O_4).
With nitrogen it forms iron nitride (Fe_4N).
With carbon it forms iron carbide (Fe_3C, called Cementite).
Steel, for example, is a mixture of iron and iron carbide.

Nickel is a greyish-white metal melting at 1450° C., has a specific gravity of 8·8, weighs 0·31 lb. per c. in. and has a coefficient of linear expansion of 0·00000695 per degree F.

It resists caustic alkalis, ammonia, salt solutions and organic acids, and is used widely in chemical engineering for vats, stills, autoclaves, pumps, etc. When molten, it absorbs (1) carbon, forming nickel carbide (Ni_3C), which forms graphite on cooling;

(2) oxygen, forming nickel oxide (NiO), which makes the nickel very brittle, and (3) sulphur, forming nickel sulphide (NiS).

Magnesium and manganese are added to nickel in order to deoxidise it and render it more malleable.

When nickel is added to steel it has a similar effect to that of increasing the rate of cooling and the higher structures can be retained, increasing the strength and toughness. Steels with 0–5 % nickel are strong because they have a finer structure.

Formation of Crystals

We have seen that, as a liquid cools, a point on the cooling curve is reached when the curve becomes horizontal, heat being given out, but no fall in temperature occurring. At this point, crystallisation of the substance begins to take place or the liquid begins to solidify. If, however, the liquid is slow to commence crystallising, the curve may first dip and then rise again, as was shown in Fig. 10, due to the difficulty which the liquid finds in commencing to form crystals.

Small, solid particles are first formed, and they usually take up characteristic shapes. They have flat faces, are symmetrical about a centre line, and are termed 'crystals'. Substances which do not form crystals of a definite shape are said to be 'amorphous' or non-crystalline.

Crystals are in general regular in shape and, though they vary in size, crystals of any one substance are always similar in angular pattern to each other. When broken, crystals break along definite surfaces, called cleavage planes.

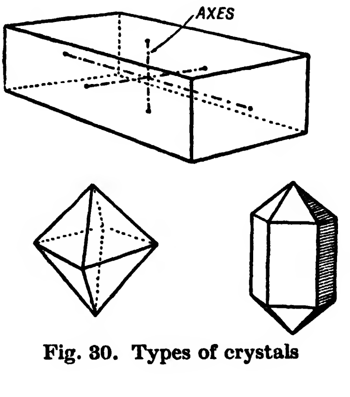


Fig. 30. Types of crystals

The natural behaviour of crystals, when subjected to certain conditions, is to grow, and they do so by absorbing smaller crystals. This is termed crystal growth. The sketches (Fig. 30) show some typical types of crystals. (There are six main groups of crystals and the thick lines, called the axes, are the means by which they are classified.)

Crystals of Pure Metals

When a pure metal is solidifying, the small crystals which form send out arms like the branch of a tree and, from these arms, other arms grow at right angles, as shown in Fig. 31. Eventually these arms meet arms of neighbouring crystals and no further growth outwards can take place. The crystal then increases in size, within its boundary, forming a solid crystal, and the junction where it met the surrounding crystals becomes the crystal or grain boundary. Its shape will now be quite unlike what it would have been if it could have grown without restriction; hence it will have no definite shape like the ones shown in Fig. 30.

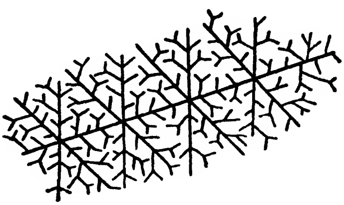


Fig. 31

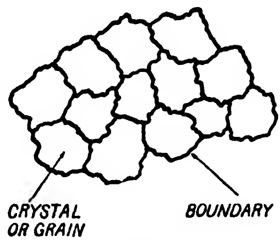


Fig. 32*a*

If we examine a pure metal structure under a microscope we can clearly see these boundary lines separating definite areas (Fig. 32*a*), and most pure metals have this kind of appearance, it being very difficult to tell the difference between various pure metals by viewing them in this way.

This method of crystallisation is termed Dendritic Crystallisation and the above crystal is termed a dendrite (Fig. 32 *b* and *c*). It can be observed when frost forms on the window pane, and this gives a good illustration of the method of crystal formation, since the way in which the arms of the dendrite interlock can clearly be seen. (The frost, however, only forms on a flat surface, while the metal crystal forms in three dimensions.)

Recrystallisation commences at a definite temperature, and if the temperature is increased greatly above this, the grains become much larger in size. Also, the longer that the metal is kept in the heated condition the larger the grains grow. The

Fig. 32*b*. Fir tree (dendritic) crystals in the shrinkage cavity of a large carbon steel casting. The crystals have grown mainly in one direction, but the growth of the lateral arms at right angles to the main axes is clearly seen. (½ actual size.)

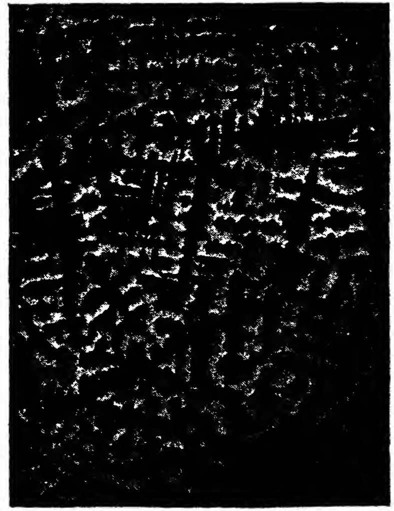


Fig. 32*c*. Portion of a nickel chrome molybdenum steel ingot showing interlocking of the dendrites. In this case crystallisation has started from a series of centres, and the growth of any one dendritic crystal has been restricted by the presence of neighbouring crystals.

rate at which cooling occurs in the case of metals also determines the size of the grains, and the slower the cooling the larger the grains (see grain growth, p. 82 and Fig. 56). Large, coarse crystals or grains have a bad effect on the mechanical properties of the metal and decrease the strength. The size of the grains, therefore, depends on:

(1) The temperature to which the metal has been raised.
(2) The length of time for which the metal is kept at high temperature.
(3) The rate of cooling.

Crystals of Alloys

If one or more metals is added to another in the molten state, they mix together forming a solution, termed an Alloy.

When this alloy solidifies, two things might happen:

(1) It may remain as a solution, in which case we get a crystal structure similar to that of a pure metal.

(2) The two metals may tend to separate out before solidifying, in which case the crystal structure will be a mixture of the crystals of the two metals, intimately mixed together.

Copper-nickel and chromium-iron are examples of the first kind of crystal formation, while lead-tin and copper-zinc are examples of the second kind.

Welding has a very great effect on the structure and crystal form of metals, and the above brief study will enable the reader to have a clearer understanding of the problem.

Effects of Corrosion on Welds in Steel

Corrosion is a chemical action on a metal, resulting in the conversion of the metal into a chemical compound.

The rusting of iron, which we have considered, is a good example. In the presence of air and water, the iron eventually changes into oxides and hydroxides of iron and then into hydrated carbonates.

In addition to this type of attack, the matter which is suspended in the atmosphere also assists corrosion. The very small proportion of carbon dioxide in the atmosphere becomes dissolved in the rain, forming very weak carbonic acid, and this attacks the steel, again forming carbonates. In and near large towns the atmosphere contains a very much larger proportion of suspended matter than in the country. Smoke and fumes contain, among other compounds, sulphur dioxide, which again dissolves in rain to form sulphurous acid. This is oxidised into diluted sulphuric acid, which again attacks the steel, the attack being much stronger than in the case of the carbonic acid.

Near the coast, the salt in the atmosphere forms hydrochloric acid and caustic soda, and severe corrosion occurs in these areas.

In addition to this direct form of chemical attack there is a second type of attack which is at first not so apparent. When two different metals are placed in a conducting liquid, such as a dilute acid or alkali, an electric cell or battery is formed, one of the metals becoming electro-positive, while the other becomes electro-negative. The difference of electrical pressure or voltage between these two plates will depend upon the metals chosen.

In the case of a welded joint if the weld metal is of different structure from the parent metal, we have, if a conducting liquid is present, an electric cell the plates of which are connected together or short circuited. The currents which flow as a result of this are extremely minute, but nevertheless they greatly accelerate corrosion. This effect is called electrolysis, and its harmful effects are now well known.

The deposited metal in the weld is never of the same composition as the parent metal, although it may have the same properties physically. In the welded region, therefore, dissimilar metals exist, and in the presence of dilute carbonic acid from the atmosphere (or dilute sulphuric acid as the case may be) electrolytic action is set up and the surfaces of the steel become pitted. Now if the weld metal is electro-positive to the parent metal, the weld metal is attacked, since it is the electro-positive plate which suffers most from the corrosive effect. On the other hand, if the parent steel plate is electro-positive to the weld metal, the plate is attacked, and since its surface area is much larger than that of the weld, the effect of corrosion will be less than if the weld had been attacked.

Thus, weld metal should be of the same composition throughout its mass to prevent corrosion taking place in the weld itself. It should also be electro-negative to the parent metal to prevent electrolytic action causing pitting of its surface, and it must resist surface oxidation at least as well as the parent metal.

Surface oxidation can be prevented by painting the surface, but oxidation generally occurs in various places, due to the flaking off of the paint at these points.

FLUXES

Fluxes used in Oxy-acetylene Welding

Most metals in their molten condition become oxidised by the absorption of oxygen from the atmosphere. For example, aluminium always has a layer of aluminium oxide over its surface at normal temperature, and has a very great affinity for oxygen. To make certain that the amount of oxidation shall be kept a minimum, that any oxides formed shall be dissolved or floated off, and that welding is made as easy and free from difficulties as possible, fluxes are used. Fluxes, therefore, are chemical compounds used to prevent oxidation and other unwanted chemical reactions. They help to make the welding process easier and ensure the making of a good, sound weld.

The ordinary process of soldering provides a good example. It is well known that it is almost impossible to get the solder to run on to the surface to be soldered unless it is first cleaned. Even then the solder will not adhere uniformly to the surface. If now the surface is lightly coated with zinc chloride or killed spirit (made by adding zinc to hydrochloric acid or spirits of salt until the effervescing action ceases), the solder runs very easily wherever the chloride has been. This 'flux' has removed all the oxides and grease from the surface of the metal by chemical action and presents a clean metal surface to be soldered. This makes the operation much easier and enables a much better bond with the parent metal to be obtained. Fluxes used in oxy-acetylene welding act in the same way.

Brass and Bronze

A good flux must be used in brass or bronze welding, and it is usual to use one of the borax type, consisting of sodium borate with other additions. (Pure borax may be used.) The flux must remove all oxide from the metal surfaces to be welded and must form a protective coating over the surfaces of the metal, when they have been heated, so as to prevent their oxidation. It must, in addition, float the oxide, and other impurities with which it has combined, to the top of the molten metal.

Aluminium and Aluminium Alloys

In the welding of aluminium the flux must:

(1) Attack and dissolve the film of aluminium oxide always present on the surface of the metal.
(2) It must prevent further oxidation during welding.
(3) It must melt at a lower temperature than the metal, so that it will dissolve the surface oxide before the metal melts.
(4) It must be lighter when melted than aluminium, so that it will float any impurities to the surface, where they can be easily removed.

Suitable fluxes for aluminium and aluminium alloys contain lithium chloride, potassium chloride, potassium bisulphate and potassium fluorides, while others may contain chlorides of ammonium, sodium, zinc and tin in addition. The choice of a suitable high-grade flux is essential to ensure success in aluminium welding.

Most aluminium fluxes are very hygroscopic, that is, they absorb moisture very readily from the atmosphere and become useless, and, as they are very expensive, when not in use they should be kept quite airtight.

Since they work by chemical action, it is only necessary to use just sufficient for the purpose. Too much flux is both wasteful and harmful. A good method of ensuring an even supply is by dipping the hot end of the filler rod into the flux and melting the tuft, which clings to the end, along the rod, to form a coating about 4 or 5 in. long. This will ensure approximately the correct supply of flux.

Aluminium flux has a corrosive action if allowed to remain on the aluminium. After welding, therefore, the work should be well scrubbed in hot water to remove all trace of the flux. A 5 % nitric acid solution is also an efficient method of removal.

Suitable fluxes for welding magnesium alloys such as Elektron are similar to those for welding aluminium and largely consist of lithium and potassium chlorides, and may contain in addition alkaline fluorides (potassium, sodium, magnesium), and magnesium, sodium and barium chlorides. They are for the most part hygroscopic and corrosive and thus particular care must be taken to remove completely all traces of them after welding by scrubbing in hot soapy water and then immersing in a 5% sodium or potassium dichromate solution for an hour or more.

Cast Iron

When welding wrought iron and mild steel the oxide which is formed has a lower melting point than the parent metal and, being light, it floats to the surface as a scale which is easily removed after welding. No flux is, therefore, required when welding mild steel or wrought iron.

In the case of cast iron, oxidation is rapid at red heat and the melting point of the oxide is *higher* than that of the parent metal, and it is, therefore, necessary to use a flux which will combine with the oxide and also protect the metal from oxidation during welding. The flux combines with the oxide and forms a slag which floats to the surface and prevents further oxidation. Suitable fluxes contain sodium, potassium or other alkaline borates, carbonates, bicarbonates and slag-forming compounds.

Copper may be welded without a flux, but many welders prefer to use one, to remove surface oxide and prevent oxidation during welding. Borax is a suitable flux, and its only drawback is that the hard, glass-like scale of copper borate, which is formed on the surface after welding, is hard to remove. Special fluxes, while consisting largely of borax, contain other substances which help to prevent the formation of this hard slag.

Commercial fluxes for copper, brass, cast iron and aluminium, etc. contain various small proportions of other chemicals, in addition to the standard basic chemicals mentioned above. This explains why, for example, two fluxes of different make might act with different efficiency, although basically they are the same. These additions are the result of research on the part of the chemists of the firms concerned.

To sum up, we may state, therefore, that fluxes are used:

(1) To reduce oxidation.
(2) To remove any oxide formed.
(3) To remove any other impurities.

Because of this, the use of a flux:

(1) Gives a stronger, more ductile weld.
(2) Makes the welding operation easier.

It is important that *too much* flux should never be used, since this has a harmful effect on the weld.

Electric Arc Welding Fluxes

If bare wire is used as the electrode in arc welding, many defects are apparent. The arc is difficult to manipulate, the resulting weld may lack good fusion, be porous, contain slag, and it also has absorbed oxygen and nitrogen from the air. Because of this, the weld will tend to be brittle and weak. To remedy these defects electrodes are coated with chemicals or fluxes which enable a steadier arc to be maintained, and greatly improve the quality of the weld.

These coatings of flux may be divided into three classes, and in each case the core or rod is centrally situated in the flux so as to obtain even distribution when the flux melts:

(1) Very lightly coated or washed rods.
(2) Medium coated dipped rods.
(3) Heavily coated rods either extruded or spirally wound.

(1) *Lightly coated rods* may be dipped or washed in a chemical such as lime, which merely helps to stabilise the arc and thus make manipulation easier. It does not prevent oxidation and no slag is formed. Consequently, the deposited metal is very like that deposited from a bare wire. If the dipping process is carried out two or three times, a thicker coating is built up and the chemical chosen may produce two effects. It may either produce a thin slag over the molten metal, to some extent excluding the air and preventing oxidation, or it may produce gases (such as hydrogen) which produce a protecting envelope around the arc and prevent the molten weld metal coming into contact with atmospheric gases.

(2) *Medium coated rods* may be dipped or even extruded (forcing a paste on to the rod under pressure). This paste may be of siliceous matter (matter containing silica SiO_2) with various oxides such as iron, manganese or titanium added. The effect of this coating is (i) to produce a much steadier arc and, hence, make the welding operation easier; (ii) to protect the molten metal from the gases of the atmosphere and thus prevent the absorption of oxygen and nitrogen; (iii) to form a slag which floats to the top of the molten pool and forms a coating which prevents oxidation while cooling and which also prevents too rapid cooling. Many well-known and highly successful rods fall into this class.

(3) *Heavily coated rods* may consist, as previously, of a paste of siliceous matter extruded on to the rod, but being much thicker than on the medium coated rod, or it may be of a flux of spirally wound blue or white asbestos which again may be soaked or impregnated with titanium oxide, manganese oxide or with siliceous matter. This latter type of coating provides also a shield around the arc, since the coating melts at a slower rate than the metal core. As a result, we have the following protection for the weld metal:

(i) Shield provided by the coating extending down beyond the molten end of the electrode.
(ii) An envelope of inactive or reducing gases, given out by the chemicals and preventing the atmospheric gases coming into contact with the weld.
(iii) A heavy layer of slag which floats to the top of the molten metal, providing a coating over the weld metal, preventing oxidation and lowering the rate of cooling.

The disadvantage of this type of covering is that the slag formed is heavy and needs chipping in order to remove it, thus involving another operation. Modern electrodes of this class, however, are becoming more and more easy to deslag.

The heavily coated rods of the paste type are also very popular and the slag formed may not be as heavy as with the asbestos covered rods, resulting in easier manipulation during welding and easier deslagging. As with the asbestos coated type, they produce a shield round the arc consisting of the covering which has not melted, an envelope of inactive or reducing gases, set free from the chemicals in the flux, and which prevent oxidation, and a slag covering the hot weld metal.

With these rods, therefore, the arc is made stable, the molten weld is easy to control, penetration and fusion is good and the quality of the deposited metal is not affected by impurities absorbed during the welding process.

Another type of heavily coated rod has the siliceous matter and oxide bound together with a spiral winding of a special form of string to ensure good adhesion, while another asbestos covered rod has a fine aluminium wire running up inside the covering. When this is heated it helps to absorb any oxygen which may be entrapped, owing to the great affinity of the aluminium for oxygen.

The chemical composition of the coating also has a great effect on the electrical characteristics of the arc. If the gases formed when the covering vaporises are conducting, the current will flow easily across from the electrode to the metal and there will be a low pressure (or voltage) across the arc. If, however, a gas such as hydrogen is present, this does not combine with the iron and, as a result, the voltage required across the arc is much greater, since the arc itself is not so conducting. The increased voltage means that more heat is developed in the arc, giving a faster rate of melting. The hydrogen can be given off by a substance in the coating, such as sawdust.

For the arc welding of aluminium and bronze (also copper and brass) the flux must dissolve the layer of oxide on the surface and, in addition, must prevent the oxidation of the metal by providing the usual sheath.

Thus, the flux must have a melting point much higher than those used in oxy-acetylene welding so as to preserve the protecting sheath.

The flux of the aluminium rod is corrosive and also tends to absorb moisture from the air; hence the weld should be well cleaned with hot water on completion, while the electrodes should be stored in a dry place. In fact, all electrodes should be kept very dry, since the coatings tend to absorb moisture and the efficiency of the rod is greatly impaired if the covering is damp.

Chapter II

METALLURGY

Production and Properties of Iron and Steel

Before proceeding to a study of iron and steel it will be well to understand how they are produced.

Iron is found in the natural form as iron ore. These ores are of three main types:

(1) Red haematite or iron oxide (Fe_2O_3), chiefly found in Spain, and red in colour.
(2) Brown haematite (Fe_2O_3 plus water). Not relatively important as it is of poor quality.
(3) Magnetite or magnetic oxide of iron (Fe_3O_4), found in U.S.A., Canada, Norway and Sweden.

These ores contain between 35 % and 65 % of iron and also oxygen, phosphorus, sulphur, silica (sand) and other impurities.

The ore is placed in a blast furnace (Fig. 33), mixed with limestone (called the flux) and coke in the approximate proportion 5 parts ore, 5 parts coke, 2 parts flux. The furnace is started and the blast turned on. As the burning coke oxidises, so the ore is reduced, and it sinks down to the bottom of the furnace, where the temperature is highest. The limestone is decomposed and the iron begins to take in carbon. The molten iron so formed is called pig iron and is run off from the bottom of the furnace into pigs (hence its name).

Cast Iron

Pig iron from the blast furnace is not refined enough for making castings, so in the foundry the iron for casting is prepared as follows: A coke fire is lit at the bottom of a small blast furnace or cupola and then alternate layers of pig iron (broken up into pieces) and scrap and coke together with small quantities of limestone as flux (for purifying and deslagging) are added. When the mass has burnt up the blast is turned on and the molten iron flows to the bottom of the furnace from where it is tapped into ladles or moulds direct. This process greatly improves the quality of the iron. Cast iron is an alloy of many elements, and an average composition is: iron 94 to 98 %, carbon 2 to 4 %, silicon below 3 %, sulphur below 0·2 %, phosphorus below 0·75 %, manganese below 1 %.

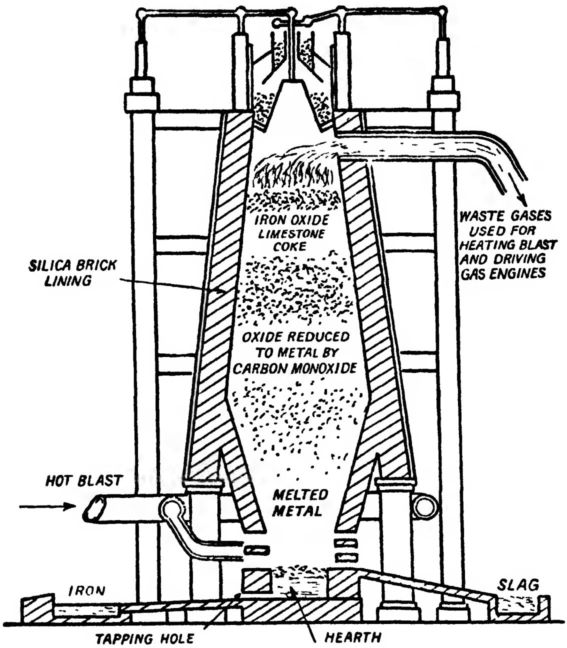


Fig. 33. Blast furnace

The carbon exists in two forms: chemically combined carbon, and free carbon simply mixed with the iron and known as graphite.

The grey look of a fracture of grey cast iron is due to this graphite, which may be from 3 to 3½ %, while the chemically combined carbon may range from 0·5 to 1·5 %. As the amount of combined carbon increases so does the hardness and brittleness increase, and if cast iron is cooled or chilled quickly from a very high temperature, the combined carbon is increased, and the free carbon is reduced. As a result this type of cast iron is more brittle and harder than grey iron, and since it has a white appearance at a fractured surface, it is termed white cast iron. This has from 3 to 4 % of carbon chemically combined.

Cast iron possesses very low ductility, and for this reason it presents difficulty in welding because of the strains set up by expansion and contraction tending to fracture it.

The properties of cast iron can be modified by the addition of other elements. The addition, for example, of chromium gives the cast iron a much closer grain and greatly increases the

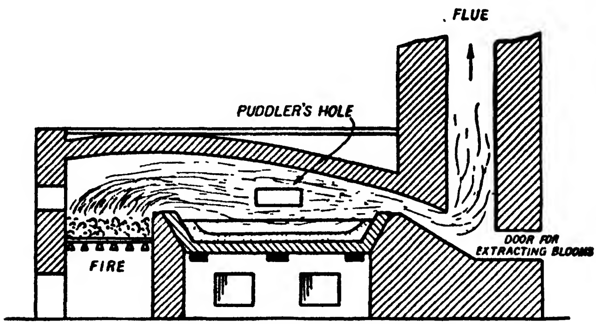


Fig. 34. Puddling furnace

resistance to wear. This type of cast iron is used in automobile engineering for cylinder blocks, the wear on the bore being much less after a given number of miles running than on a corresponding ordinary cast-iron block.

Wrought Iron

Wrought iron is manufactured from pig iron by the puddling process. This consists of the removal of the impurities, such as carbon, sulphur and phosphorus, leaving nearly pure iron.

The pig iron is placed in the puddling furnace (Fig. 34), the temperature of which is kept high enough to melt the pig iron (1180° C.), but not to melt the wrought iron (1520° C.). Oxygen from the air and the 'fettling' (haematite and such substances rich in oxygen) combines with the carbon forming carbon monoxide, and the small particles of pure iron being set free stick together in lumps, since they are not liquid at the temperature of the furnace. These lumps are worked together by the 'puddler' (the operator) into puddle balls, which are then removed. These lumps are then squeezed into blooms and rolled into bars which, however, are not yet suitable for use, since a great deal of slag is entrapped in the iron. The bars are reheated and rolled into bars again, and this is known as refined iron. This operation may be repeated again, and at each operation more slag is removed and the rolling produces a more 'laminated' or layered structure in the iron. If these operations are carried out more than three times, oxidation may take place, the iron becoming 'burnt', and in this condition it is very much less malleable. Scrap iron may be used in place of pig.

Wrought iron consists of: iron 99·5 to 99·8 %, carbon 0·01 to 0·03 %, silicon 0 to 0·1 %, phosphorus 0·04 to 0·2 %, sulphur 0·02 to 0·05 %, manganese 0 to 0·25 %.

It will be noticed that, in the puddling process, the carbon has dropped from 3 to 5 % in the cast iron to 0·01 to 0·03 % in the wrought iron. When broken it shows a fibrous or layered structure, but will bend well and is easily worked when hot. Wrought iron may be defined as a slag-bearing malleable iron which does not harden on cooling. It can be easily welded in the same way as mild steel.

Steel

Steel is manufactured from pig iron by two processes:

(1) **Bessemer Process.** The pig iron is placed in a large vessel called the converter (Fig. 35) in a molten condition, and during the charging operation the converter is horizontal.

While still in this position an air blast is blown from the blast box through holes in the base of the vessel and the converter is moved into an upright position. The pressure of air (20 to 25 lb. per sq. in.) prevents the molten iron flowing out through the holes or blast pipes, and as a result the air blast blows up through the molten metal, oxidising the carbon and other impurities and blowing them out.

In ten tons of molten pig iron, half a ton is carbon, and since this is oxidised in a very short time, great heat is evolved. The oxidation of the silicon present supplies great heat at the beginning of the blow, when a shower of sparks is seen coming from the top of the converter and then the red-yellow flame at the top gradually changes to white. Sparks are ejected at a regular interval as oxidation proceeds and, after about 20 to 25 minutes, the blow is completed, and this is indicated by the flame at the top becoming paler and the sparks becoming less.

The converter is turned horizontal again, the air blast shut off and then a quantity of spiegeleisen or ferromanganese is added to make the steel of the correct carbon content required.

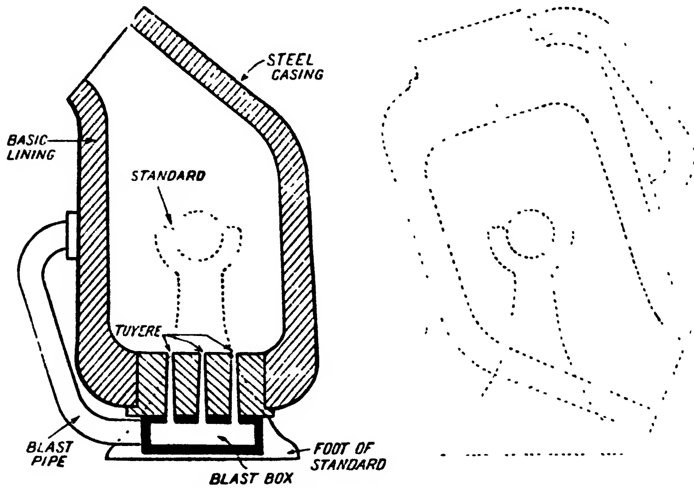


Fig. 35. Bessemer steel converter

The steel is then poured into ingots and these while still white hot are rolled in blooms or billets. The ingots are generally taken to gas-heated 'soaking pits', where they stand until ready to be rolled.

Spiegeleisen is an iron alloy containing up to 30 % manganese and 7 % carbon, while ferromanganese is an iron alloy containing 30 to 80 % manganese and 7 % carbon.

The particular one added depends on the steel required, but both are used (i) to remove any oxygen present and thus prevent the steel becoming brittle by oxidation, and (ii) to supply the necessary carbon.

If too little silicon is present in the pig iron, there is insufficient heat evolved at the commencement of the blow, while too much silicon gives too much heat.

The above process is known as the Acid Bessemer Process and it does not remove any phosphorus or sulphur from the pig iron. This can be removed, however, by the use of a basic lining to the furnace composed of about 60 % lime, and this process is then known as the Basic Bessemer.

The acid and basic processes differ chiefly in that in the acid process carbon and manganese are removed, while in the basic process carbon, silicon, phosphorus and sulphur can be removed.

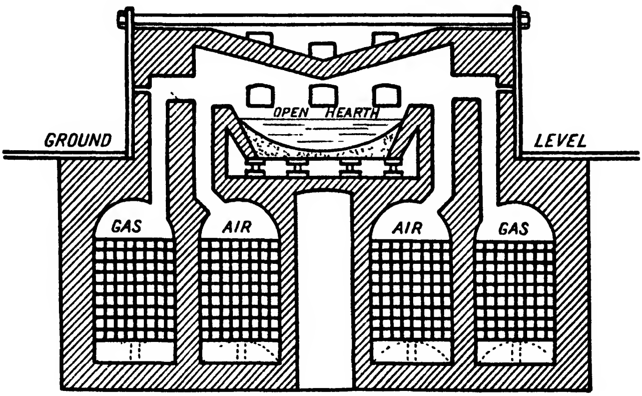


Fig. 36

(2) **The Open-hearth Process** (Siemens-Martin)

In this process the heat required to melt and work the charge is obtained from the burning of a producer gas and air mixture over the hearth. Both gas and air are preheated to high temperature (1200° C.) by passing them through chambers of checkered brickwork in which brick and space alternate. In order that the process shall be continuous a regenerative system is used. There are two sets of chambers each, for gas and air (see Fig. 36). While the gas and air are being heated in their passage through one pair of chambers, the high-temperature waste gases are preheating the other pair ready for the change-over. Pig iron and scrap are fed into the furnace (by mechanical chargers in the larger types), the pig iron being fed in the molten condition if the steel-making furnace is near the blast furnace. The capacity of the hearth may be 30–200 tons, and many of the larger ones are of the tilting type.

When the charge is molten, iron ore is added and oxidation takes place, carbon monoxide being formed, and the carbon content is reduced. The silicon and manganese are also oxidised and thus removed. Finally, deoxidisers (ferromanganese, ferro-silicon, aluminium) are added just before tapping or as the steel is run in the ladle, to improve the quality of the steel.

The acid open-hearth process (silica furnace lining) produces high-grade carbon steels which are suitable for alloying with other elements to produce the large range of alloy steels.

The basic open-hearth process (dolomite furnace lining and lime added to the furnace) produces the normal grades of mild and free-cutting steel, etc.

Crucible Steel or Tool Steel (Cast Steel)

The oldest method of producing this steel is the 'cementation' process, in which bars of wrought iron are covered with charcoal layer over layer in an airtight retort. The retort is placed in a furnace and after a day's heating it attains red heat, and after a further day's heating a bright red heat called 'cementation' heat is attained. It is kept at this heat for several days to ensure that the iron absorbs carbon, i.e. becomes carburised.

In this way carbon enters the iron at the surface and gradually spreads through towards the core.

The retort is then allowed to cool, and on cooling it is found that the surface of the metal has become covered with blisters and hence its name 'Blister Steel'.

This is then heated again and made into small billets. In this process the fibrous structure of the wrought iron has been changed to granular or crystallised structure.

The modern method consists of mixing the wrought iron with charcoal and placing the mixture in an airtight fireclay crucible. This is then placed in the Crucible Furnace and melted down. Other metals can be added to the contents of the crucible to form *alloy* steels, which are to-day of primary importance. The crucible furnace can be electric of the high frequency, resistance or arc type, or gas or oil fired.

The proportion of carbon present in cast steel will determine its properties, and the addition of the other alloying elements produces steels of great varieties and properties.

The advantage of the modern electrical crucible furnace, such as those illustrated, in the making of alloy steel, is that their

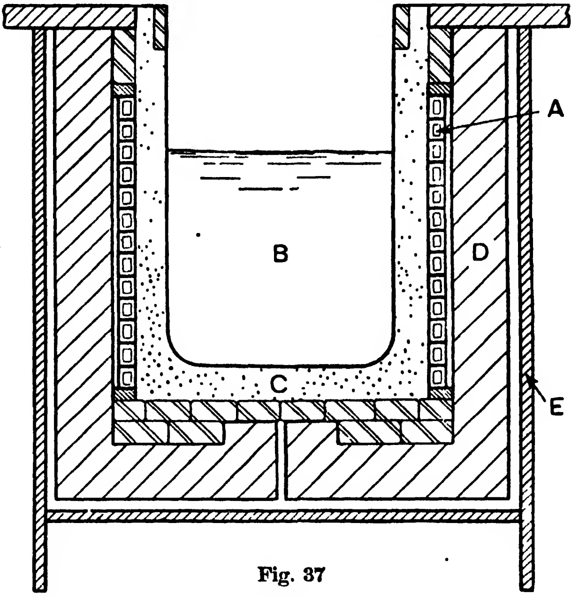


Fig. 37

A Spiral, water-cooled inductor coil.
B Charge to be melted.
C Furnace lining, serving as a crucible and heat insulating the charge from the inductor coil *A*.
D External, laminated silicon steel core, having four or more vertical external legs and bottom yokes.
E Metal case supporting the furnace and enabling it to be tilted for pouring.

temperature can be controlled very accurately and the alloying elements can be added to the molten metal while in the furnace, which is much preferable to adding it while in the ladle.

Cast steel when produced has a fine close-packed structure of black appearance. It is very brittle and inclined to break even when slightly bent, and becomes intensely hard when heated to red heat and water quenched.

A typical high-frequency electric melting furnace is shown in Fig. 37.

An alternating current at a frequency of about 1000 cycles per second is passed through the inductor coil *A* and sets up an alternating magnetic field. This field, passing through the metal composing the charge, causes large currents to flow. These currents generate sufficient heat to melt the charge. In a half

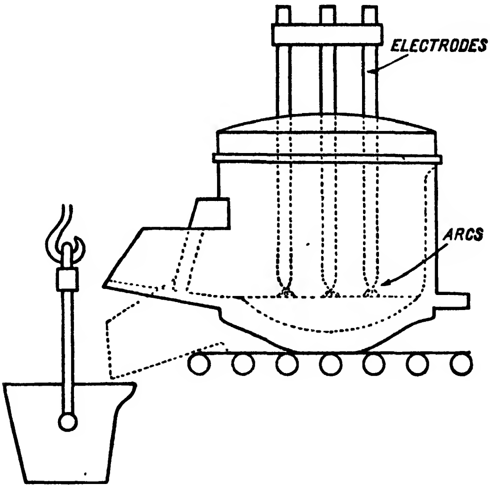


Fig. 38

ton type, for example, the rating is 150 kilowatts and melting time 2–2½ hours, the supply voltage to the coil *A* being about 1200. This type of furnace is used for making high-quality tool and alloy steels.

The heat in the electric arc furnace is generated by carbon arcs struck between carbon electrodes and the charge (as in carbon-arc welding, pp. 291–293).

An oxidising slag covers the charge of suitable steel and the required alloying elements, and the impurities are removed by the slag.

The furnace is tapped by tilting it (Figs. 38 and 39), and this method is very suitable for making steels of the high alloy and stainless types, the capacities being up to 15–20 tons.

Malleable Iron is made from white cast iron by annealing or graphitising. The white cast iron is packed in haematite and is heated to about 900° C. and kept at this for two or three days, after which the temperature is slowly reduced. In this way, some of the combined carbon of the white cast iron is

Fig. 39. Tagliaferri arc furnace for alloy steels

transformed into free carbon or graphite. Malleable castings are used where strength, ductility and resistance to shock are important, and they can be easily machined.

The American 'Blackheart' process is similar to the Réamur or Whiteheart process just described except that bone dust, sand and burnt clay are used for packing in place of iron oxide, the temperature being about 850° C. This converts the combined carbon in the cast iron into temper carbon, and after the treatment they contain little or no combined carbon and about $2\frac{1}{2}$ % graphite. The castings prepared by the former method show a grey fractured surface with a fine grain like mild steel, while those made by the 'Blackheart' process have a black fracture with a distinct white rim.

A typical composition of malleable iron is carbon 1 to 2 %, silicon 0·6 to 1·2 %, manganese under 0·25 %, phosphorus under 0·2 %, sulphur 0·05 to 0·15 %.

Steel Castings are stronger and tougher than either wrought iron, cast iron, or malleable iron. The steel can be prepared by the Bessemer or crucible furnace method for small castings and by the open-hearth process for large castings. The castings are of the same composition as ordinary steel, except that they are cast instead of being rolled. The same procedure is employed in welding cast steel as ordinary steel.

Steel castings are used for cylinder covers, bearing caps, bed-plates, gun mountings, railway and engine equipment, etc.

A typical average composition is: carbon 0·3 to 0·4 %, manganese 0·5 to 0·8 %, silicon 0·1 to 0·3 %, sulphur 0 to 0·05 %, phosphorus 0 to 0·05 %, having a tensile strength of 27 to 37 tons per sq. in.

Manganese Steel Castings are made from steel to which ferromanganese has been added. If un-annealed, they are hard and brittle; but if annealed, they are tough and ductile with a tensile strength of about 40 tons per sq. in.

THE EFFECT OF THE ADDITION OF CARBON TO PURE IRON

We have seen that the chief difference between wrought iron and mild steel is the amount of carbon present. Wrought iron is nearly pure iron containing only 0·01 to 0·03 % carbon, together with impurities such as phosphorus and sulphur. Steel may contain from 0·03 to 2 % carbon, mild or soft steel containing about 0·1 % carbon and very hard razor-temper steel 1·7 to 1·9 %.

The composition of steel is therefore complicated by these variations of carbon content, and is rendered even more so by the addition of other elements such as nickel, chromium and manganese to produce alloy steels. If we examine a microphotograph of a section of wrought iron (Fig. 40), this clearly shows the layered or laminated fibrous structure with dark bands of entrapped slag produced by the rolling process.

Fig. 40. Wrought iron, showing grains of ferrite and slag inclusions. ×100

When carbon is added to pure iron (ferrite, Fig. 41) while molten, a chemical compound termed Iron carbide (Fe_3C) or Cementite is formed. Thus:

Pure iron + Carbon = Iron carbide,

or Ferrite + Carbon = Cementite.

When cementite is formed, however, it mixes intimately with ferrite and forms a mixture called Pearlite, which consists therefore of granules or crystals of cementite embedded in ferrite, i.e.

Mixture of Ferrite and Cementite = Pearlite.

Suppose we now view some steel containing, say, 0·2 % carbon (mild) steel under the microscope (Fig. 42). (The magnification of each is indicated, i.e. ×100 means magnified one hundred times.) We see that it has white areas which are the crystals of ferrite and also dark areas which are pearlite. If these dark areas are now observed under high-power magnification (Figs. 43, 44), it is seen that they have a layered structure like mother-of-pearl and, if illuminated, have the same kind of lustre; hence the name Pearlite.

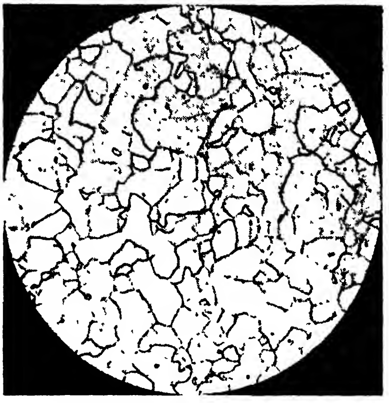


Fig. 41. Ferrite. ×100

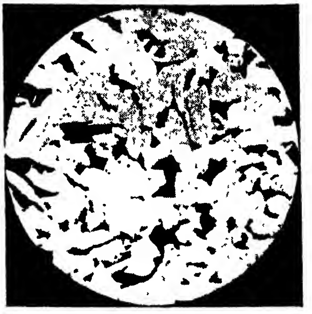


Fig. 42. 0·2 % carbon steel forging normalised, showing pearlite and ferrite. ×100

Fig. 43. 0·8 % carbon tool steel, annealed. ×1000

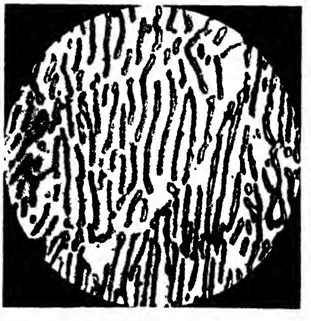


Fig. 44. 0·8 % carbon tool steel, annealed. ×2500

This pearlite has a lower melting point than the ferrite, and because of this, pearlite is termed a Eutectoid, which means having the lowest melting point.

As more carbon is added, more and more pearlite will be formed, until eventually the whole structure of the steel will be of pearlite, and this occurs approximately when 0·9 % (0·87 %) of carbon has been added. Therefore steel containing 0·9 % of carbon is termed Eutectoid Steel, since it consists of all pearlite. Figs. 43 and 44 show a structure of 0·8 % carbon.

The foregoing may be illustrated by Fig. 45:

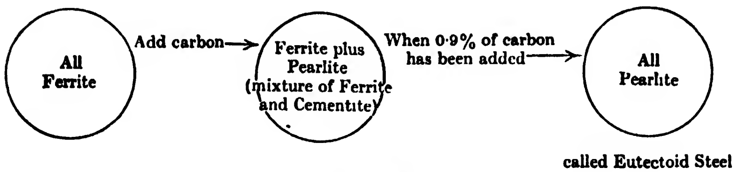


Fig. 45

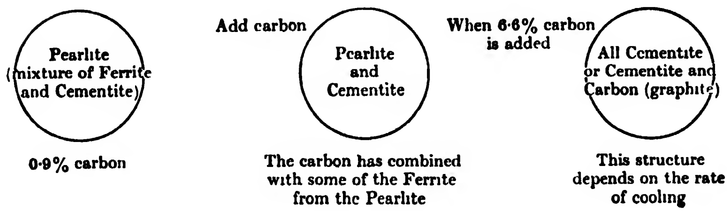


Fig. 46

Evidently the more pearlite in comparison to ferrite in a given steel, the greater will be the area of the dark patches of pearlite compared with the light ones of ferrite. Fig. 47 shows this.

Now consider what occurs when more carbon is added to the eutectoid steel, i.e. the all-pearlite structure. The pearlite is a mixture of ferrite and cementite, so the carbon now added combines with this ferrite and forms more cementite. Thus, as more carbon is added, more cementite is formed and remains in the structure as cementite, while the amount of pearlite becomes less and less.

Eventually when about 6·6 % of carbon has been added, the structure consists entirely of cementite, Fig. 46. Fig. 48 shows the structure of cementite.

A structure of pearlite is soft, ductile and strong, while that of cementite is hard and brittle. Hence steels containing above 0·9 % carbon will be extremely brittle. At about 2 % carbon, the amount of cementite present makes the structure so brittle that we reach the borderline between steel and cast iron,

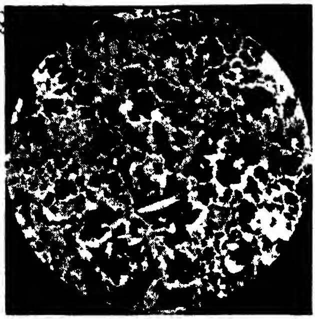


Fig. 47. 0·4 % carbon steel forging, annealed. × 100

Fig. 48. Cementite structure in 1·2 % carbon tool steel, normalised. × 100

although there is not a definite line of demarcation. Above 2 % carbon, the carbon can consist either of cementite or of cementite and free carbon called graphite. The cast iron formed of cementite is the white cast iron, while that of cementite mixed with graphite is the grey cast iron. This is the reason, therefore, why white cast iron is harder and more brittle than the grey variety (see pp. 159–160). This is one of the differences between steel and cast iron. In addition to the cast iron containing 2–4 % carbon, the carbon may be in two forms, as cementite or graphite, whereas in steel it is always in the combined form as cementite.

The following figure will help to make this clear:

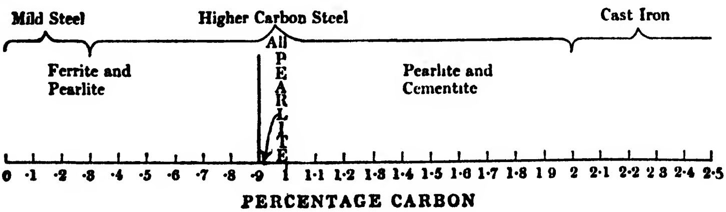


Fig. 49

In the above treatment, we have assumed that the steel has been cooled down slowly from the molten condition after the addition of carbon.

When the ideas of these structures have been firmly grasped, we are in a position to study the changes which occur in these structures when steel of varying carbon content is heated.

Carbon and Alloy Steels

An alloy steel may be defined as a steel which owes its properties to the presence of elements other than carbon—manganese up to 1·5 % and silicon up to 0·5 %.

The purpose of alloy steel is to give the steel a distinct property which in every case is to increase its toughness, hardness or tensile strength, and to give cleaner and more wear-resistant castings.

Phosphorus has a very injurious influence on steel, making it very brittle, and as a result it is never found in greater percentage than 0·03 to 0·04 for steels which have to stand heavy impacts and shock, while for not such important steels, 0·06 % may be allowable. Phosphorus produces 'cold shortness', i.e. liability to crack when cold worked.

Sulphur is also injurious because it produces 'hot shortness', that is, liability to crack when hot. For this reason, the maximum sulphur percentage allowed in a steel is approximately the same as that of phosphorus.

The chief elements which are alloyed with carbon steel are nickel, chromium, manganese, molybdenum, tungsten, vanadium and silicon. The addition of each element produces a different effect, and evidently there is an enormous variety of steels which can be produced by adding varying percentages of the above elements. We shall only consider very briefly the effect produced on the carbon steel by the alloying elements and not attempt to discuss the variety of steels available under each heading.

Carbon Steel

First let us consider the carbon steel before any alloying elements are added. The addition of carbon, as can be seen from the table, greatly affects the property of the steel and varying the percentage from 0·1 to 1·5 is sufficient to change the steel from very soft and malleable to extremely hard. The melting point of steel depends on the percentage of carbon present, decreasing as the carbon content increases, ranging from 1420° C. for mild steel to 1150° C. for hard steel, of 1·5 % carbon. (This is the property on which LINDEWELDING is based.)

CLASSIFICATION OF STEEL ACCORDING TO CARBON CONTENT

APPROX. CARBON CONTENT %	EXAMPLE OF USE
Below 0·1	Dead soft mild steel for pressing, stamping and flanging, solid drawn tubes
0·1 –0·2	Rivets, nails, tubes, strip, bar and plates
0·2 –0·25	Bars, strips, girders, channel and angle sections, drop forgings and parts to be case hardened
0·25–0·5	Shafts, tyres, forgings, boilder shells, spades, etc.
0·5 –0·7	Springs for Automobiles, dies for forging, rails, wire ropes
0·7 –0·8	Setts, engine cylinder liners, hand tools, saws, springs
0·8 –0·9	Cold setts, punches, chisels, shear blades
0·9 –1·1	Cutting tools, milling cutters, screwing dies, wood working tools, punches
1·1 –1·5	Wood working tools, lathe tools, drills, reamers, razors, wire drawing dies

Steel containing from ·7–1·4% carbon is often spoken of as cast steel. It was extensively employed in all cases in which a good cutting surface was required, but it has been largely superseded by the present day range of alloy steels which have a harder cutting surface and are more durable.

Steels for springs generally contain either silicon and manganese (e.g. ·5% carbon, 1·7% silicon, ·7% manganese) or silicon and chromium (e.g. ·5% carbon, 1·2% silicon, 7·5% chromium), and they should be correctly heat treated to develop their maximum tensile strength and elastic properties.

As the carbon content of the steel increases, it becomes increasingly difficult to weld. Steels containing from 0·6 to 1·0 % can be *arc welded* using special electrodes. The study of the welding of alloy steels either by arc or oxy-acetylene is still proceeding; hence the welding of the steels now to be studied is possible in certain cases if the correct procedure is adopted, filler rods or electrodes of the correct composition are used, and the correct heat treatment given on completion of the operation if necessary. The weldability of these steels is discussed on pp. 181–186, 301–306 and 310–311, while a table of typical alloy electrodes available is given in the Appendix, p. 421.

Nickel Steel

When nickel is added to steel, it produces an alloy which has great strength, toughness and resistance to abrasion, and in the same way weld metal containing nickel produces a dense strong tough weld. The nickel when added is absorbed by the ferrite and the temperature of the critical point is lowered by an increasing amount as the nickel content increases. It also reduces the amount of carbon required for the eutectic state.

Nickel steels usually contain from 2 to 4·5 % nickel and from 0·2 to 0·45 % carbon. They are used for armour plate, bridge construction and rails, etc. As previously mentioned, the addition of nickel enables a steel to preserve its austenitic structure on cooling, and they do not suffer from grain or crystal growth on prolonged heating as do plain carbon steels. Hence they are very suitable for heat treatment. Certain percentages of nickel added give a steel with a very low coefficient of thermal expansion. For example, the English Steel Corporation's Nilex, which contains 36 % nickel.

Chrome Steel

Chromium has the opposite effect on steel from nickel because it tends to raise the critical temperature. When the percentage of chromium is low (1 to 2 %), it increases the hardness of the steel, while when the percentage is high, the resistance to corrosion and tarnishing is intense. For example, 4 to 6 % chrome steel is intensely resistant to oxidation and resists crude oil corrosion at high temperatures.

Stainless Steel

This class of steel is an alloy of nickel, chromium and iron. The nickel and chromium form a solid solution with the iron, and this has great corrosion-resisting properties. The group of so-called 'stainless steels' include stainless iron and austenitic and martensitic stainless steel.

Stainless iron is an alloy of chromium, nickel and iron, or simple chromium and iron with a carbon content usually less than 0·15 %. If the carbon content is above this, the alloy is termed 'stainless steel'.

Stainless steels may be divided into the following classes:

(1) Ferritic. These are stainless irons with high chrome (18 %) and low carbon content.

(2) Martensitic. These are alloyed principally with chromium only, are hardenable by heat treatment, are magnetic, very resistant to corrosion, smaller coefficient of expansion than mild steel, thermal conductivity less than mild steel, and are applicable to engineering plant subject to corrosion and stress, e.g. 12–14 % chromium, 0·16 to 0·4 % carbon. This type is used for cutlery, rivets, surgical instruments, valve and pump parts, ball bearings, springs, etc., according to the carbon content.

(3) Austenitic. These are alloyed with chromium and nickel, harden with cold work, do not harden by heat treatment, are non-magnetic, very resistant to corrosion, very ductile, have a greater coefficient of expansion than mild steel, but are inferior to steels of the martensitic group for highly stressed parts, e.g. 16–19 % chromium, 7·5 to 10 % nickel. This group is often termed the 18/8 class, because of the nearness of their composition to these figures. This group is used for chemical, food, textile and industrial plant subject to corrosion; domestic appliances, tables, sinks, shop fittings, etc. If steels of the austenitic group have a content of 25 % chromium and 12 % nickel or over, they are known as the 25/12 class and are classed as heat resisting rather than stainless.

The martensitic group are weldable, but must be heat treated by heating to 650–750° C. and air cooled after welding. (The maker's advice regarding the exact temperature should be followed.)

Types of Stainless Steel

Type	Constituents				Order of Corrosion Resistance (A is highest)	Heat Treatment prior to Test	Maximum Stress (tons per sq. in.)	Remarks	Applications	
	Cr	Ni	C	Other Elements						
Ferritic	16·5–18	—	0·12 max.	—	D	—	84·9	High chrome stainless steel	Used for nitric acid plant or where riveted structures are preferred	Not hardenable
Martensitic	12·2–14	—	0·16–0·2	—	E	Harden and light temper Harden and full temper	98·7 47·4	Mild stainless steel	Taper pins, hinge pins, surgical instruments, scissors and small forgings	Slightly hardenable by heat treatment
Martensitic	12·5–14	—	0·2–0·26	—	E	Harden and light temper Harden and full temper	100 46·8	Stainless steel, general	Valve and pump parts not in contact with non-ferrous metals or graphite packing, and precision instruments	Hardenable by heat treatment
Martensitic	12·5–14	—	0·26–0·35	—	E	Harden and light temper Harden and full temper	105 47·1	Stainless steel cutlery	Cutlery and sharp-edged tools	Hardenable by heat treatment
Austenitic	17·5–18·5	7·5–8·5	0·12 max.	—	B	Soften Cold work	46·1 97·5	Austenitic stainless steel, standard	Chemical, textile, food, and other industrial articles subject to corrosive process, shops and architectural decoration, domestic appliances	Not hardenable by heat treatment but by cold work
Austenitic	17·5–18·5	7·5–8·5	0·06 max.	—	B	Soften	44·7	Austenitic stainless steel (for thin sheet welding finely polished)	Similar to above, where highly polished welded articles are required to work under less severe corrosive conditions	Not hardenable by heat treatment but by cold work
Austenitic	13·5–15	11–14	0·12 max.	—	C	Soften	37·6	Austenitic stainless steel (for cold work)	Cooking utensils, hollow ware, table ware, sinks, vessels, tanks, shop fittings, etc.	Not hardenable by heat treatment but by cold work
Austenitic	17·5–18·5	7·5–8·5	0·07 max.	Titanium	B	Soften Cold work	48·5 94·2	Austenitic stainless steel (low carbon); weld decay proof	Welded structures not heat treated after welding, especially those in textile and chemical trade	Not hardenable by heat treatment but by cold work
Austenitic	18–19	9–10	0·12 max.	Titanium and molybdenum	A	Soften	41·3	Austenitic stainless steel (very acid resisting); weld decay proof	For very strongly corrosive condition in textile and chemical trades	Not hardenable by heat treatment but by cold work

(To face p 74)

The austenitic (18/8) group comprise such well-known steels as: Staybrite, Silver Fox 620 and 20, Anka, Maxilvry and the United States types such as Nevastain, Allegheny Metal and Uniloy, etc.

These steels are weldable, but need not be heat treated unless the finished article will meet corrosive conditions. If corrosive conditions are encountered and they have not been heat treated after welding, weld decay (see later) will occur. Heat treatment consists of raising to 950–1100° C., depending on the steel, and then water quenching.

Weld Decay

The austenitic stainless steels have one great drawback. When heated to between 500 and 900° C., carbon is absorbed by the chromium and chromium carbide is precipitated along the grain boundaries. As a result the chromium content of the adjacent metal near the grain boundaries is so reduced that its resistance to corrosion is greatly weakened. This range of temperature is encountered during welding, and a zone at this temperature exists near the weld and runs parallel to the weld. This zone is now non-resistant to corrosive attack and when corrosion occurs in service it is termed 'weld decay', although no decay occurs in the weld itself but in a zone near the weld. This trouble can be eliminated by heat treatment, the welded part being heated to 950–1100° C. and water quenched. The necessity for heat treatment is a great drawback, as in many cases the parts welded are too large for heat treatment. The difficulty, however, has been overcome in another way. The metal titanium has a greater affinity for carbon than chromium, and when added to the stainless steel as an alloying element, it prevents the formation of chromium carbide along the grain boundaries and thus there is no deficiency of chromium in these regions and no weld decay occurs.

Steels containing titanium, specially recommended for welding purposes, are: Staybrite F.D.P., Silver Fox 22 and 25, Weldanka, etc. When these are welded with rods of similar chrome-nickel content and containing a high proportion of titanium, the resulting weld is free from weld decay when exposed to corrosive action. Considerable titanium is lost during the welding process, and hence the proportion of titanium in the welding rod must be high to allow for this. The metal columbium is equally as effective as titanium in preventing decay and little is lost in the welding process. It is now being used in place of titanium. Molybdenum and tungsten are also alloyed with stainless steel to improve its physical properties.

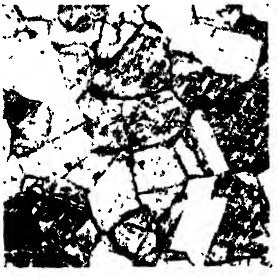


Fig. 50

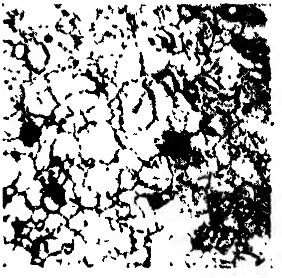


Fig. 51

Fig. 50. Carbide precipitation at the grain boundaries in an 18/8 class stainless steel. The steel is in a state of heat treatment (500–900° C.) in which it is susceptible to intercrystalline corrosion, but it has not yet been subjected to a severe corrosive medium. ×200

Fig. 51. Occurrence of intercrystalline corrosion. The steel is in the same condition as Fig. 50, but it has now been subjected in service to a severe corroding medium. ×200

Fig. 52. Illustrating the effects of intercrystalline corrosion (weld decay) in an 18/8 steel.

If the non-decay-proof austenitic steels do not have to encounter corrosive conditions in service, they can be welded and no heat treatment need be given afterwards. For this reason these steels are most popular for decorative purposes, especially where a high polish is required, since the addition of titanium and molybdenum reduces the degree of finish which it is possible to obtain on the steel surface.

Manganese Steel

Manganese has a great affinity for sulphur and prevents by combining with the sulphur the formation of iron sulphide, this latter being harmful to the steel. The manganese content is usually high, from 10 to 15 %, and this steel has great tensile strength (60 to 70 tons per sq. in.) but its elastic limit is low. It has very great resistance to wear, abrasion and shock, and can therefore be used in all cases where great wear is experienced, as, for example, rolls, dredger bucket lips, mechanical shovel noses, plough shares, etc. Manganese-steel castings harden greatly when cold worked under service conditions. This is termed work hardening. If the percentage of manganese is low (1·5 %), the steel is very brittle. As the content increases, the brittleness increases up to 5½ %, when it is extremely brittle, coming to a maximum at 12 %. Increase of manganese above this makes the steel ductile and hard, sudden cooling increasing the ductility (the opposite effect from carbon steel).

Tungsten Steel

Usually contains 5 to 15 % tungsten and 0·4 to 1·8 % carbon. The tungsten renders the steel self-hardening, i.e. if heated to the correct temperature and allowed to cool when it becomes extremely hard. It can be worked in the usual way when red hot and is used for high-speed metal, cutting tools (tungsten carbide), punch noses, and for making magnets.

Vanadium Steel

Contains 0·2 to 0·25 % vanadium. This greatly increases both the tensile strength and the elastic limit, and also greatly increases the resistance to fatigue. It is used, therefore, for parts subjected to vibration and high stresses; for example, springs, axles and highly stressed gears.

Molybdenum Steel

Is very similar to tungsten steel. The percentage of molybdenum is usually very small, varying from 0·15 to 0·25 %. These steels have a tensile strength of approximately 50 to 60 tons per sq. in., but this can be raised on heat treatment to 70 to 75 tons per sq. in. A typical analysis of a chrome molybdenum steel is given herewith. This gives a non-temper-brittle metal for studs, bolts and similar parts used in high pressure and high temperature steam plant. It does not become brittle during continuous heating. It is also recommended for crankshafts for automobiles and aero engines. Carbon 0·3 to 0·35 %, nickel 0·75 %, silicon 0·35 %, chromium 0·7 to 1·5 %, manganese 0·5 to 0·7 %, molybdenum 1 to 1·5 %.

Nitralloy Steels

These steels contain silicon, manganese, nickel, chromium, molybdenum and aluminium in varying proportion, and their carbon content varies from 0·2 to 0·55 %. They are eminently suited for purposes where great resistance to wear is required. After being hardened, by the process of nitriding or nitrogen hardening them, they have an intensely glass hard surface and are suitable in this state for crankshafts, camshafts, pump spindles, shackle bolts, etc. (see Heat Treatment).

The Effect of Heat on the Structure of Steel

Suppose we heat a piece of steel containing a small percentage of carbon and measure its temperature rise. We find that after a certain time, although we continue supplying heat to the steel, the temperature ceases to rise for a short time and then begins to rise again at a uniform rate. Evidently at this arrest point, termed a critical or "a" point, the heat which is being absorbed, since it has not caused a rise in temperature, has caused a change to occur in the internal structure of steel.

If the heating is continued, we find that a second arrest or critical point occurs, but the effect is not nearly as marked as at the first point. At a higher temperature still, a third critical point occurs similar in effect to the first. For convenience, these three points in order are denoted by ac_1, ac_2, ac_3, but ac_2 is not nearly as important as ac_1 and ac_3 (*c* stands for *chauffage*, French for 'heat').

If the steel is now allowed to cool at a uniform rate, we again have the three critical points corresponding to the three when the steel was heated, but they occur in each case at a slightly lower temperature than the corresponding point in the heating operation. At these points in the cooling operation, the metal gives out heat but the temperature remains steady. These points are denoted by ar_1, ar_2 and ar_3, and again ar_2 is of much less importance than the other two (*r* stands for *refroidissement*, French for 'cooling'). These symbols are internationally used. ac_1 is known as the decalescence and ar_1 as the recalescence point.

Let us now consider briefly the changes which occur at the arrest points. (ac_2 and ar_2 will not be considered, as they are chiefly changes in the magnetic properties of the steel.)

At ac_1 the steel begins to change its structure. If it contains less than 0·9 % of carbon, i.e. it consists of ferrite and pearlite, the pearlite begins to change to a structure termed *austenite*, and this structure then absorbs the ferrite until at the ac_3 line the change is complete, and the structure consists entirely of austenite (Figs. 53 and 62).

If now the temperature is reduced slowly, the austenite gradually undergoes change; these changes consist in the forming of a series of constituents by which the transition from austenite to ferrite and pearlite takes place. The first formed is *martensite*, which is a very hard structure (Fig. 61).

This further changes on cooling into *troostite* (Fig. 60), and this is another step forward in the change of the austenite into the ferrite and pearlite.

Further cooling still produces a change into a constituent termed *sorbite* (Figs. 58, 59), which when viewed under the highest magnification of the microscope appears devoid of any particular structure.

On further cooling, this resolves into ferrite and pearlite (Fig. 57).

The curves given herewith (Fig. 53) will indicate how these points vary with the carbon content of the steel. For example, from the curve we can see that the ac_1 line for a 0·5 % carbon steel occurs at 700° C., while the change is complete, i.e. the ac_3 point is reached at 800° C.

These different structures—austenite, martensite, troostite and sorbite—are important because, with the exception of austenite, they can be retained at normal temperature in a carbon steel by rapid cooling.

When the cooling is rapid, the structures do not have time to change from one to the other, as this takes time, since it is a chemical change.

Since there is no line of demarcation in the change from one structure to another, various heat treatments are given to steels, during which there is accurate control of temperature and quench, and by these methods the structures required are obtained.

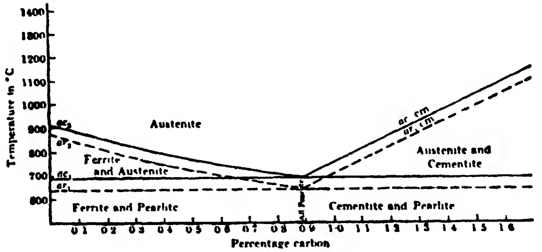


Fig. 53

There is an additional effect in quenching due to the mass of the steel. Upon quenching, the outer layers cool quickly and a higher structure such as martensite may be formed on the surface giving great hardness, while the inner layers or core which cools slowly retains a ferritic pearlitic structure. This effect is used in the 'Shorter' Process of Flame Hardening (p. 398).

Quenching (that is, rapid cooling) the steel in oil from above the ac_3 line retains the troostite, while rapid air cooling, as in an air blast, from temperatures above ar_1 will produce sorbite, which merges into pearlite as the rate of cooling is decreased.

The structures decrease in hardness and tensile strength from austenite downwards. Martensite and troostite are very hard and have great tensile strength, but are brittle and have low impact strength. In sorbite, the hardness and strength are lowered somewhat, but the ductility and impact strength are increased. Pearlite is soft, of fair tensile strength, but is ductile and elastic.

It is not possible to retain the austenite condition in a plain carbon steel. If however nickel, for example, is added to the steel, this austenitic condition can be retained by rapid quenching and, in this way, we have the very important group of steels known as the *austenitic steels*. This accounts for the extreme toughness and tenacity of nickel alloy steels.

Heat Treatment of Steel

Hardening. It will be seen that since the temperatures of the ac_1 and ac_3 lines vary according to the percentage of carbon present in the steel, as a general rule it is advisable to heat a steel to its austenitic condition before commencing any heat treatment. In this way we can be sure that the structure of the steel is homogeneous before beginning the treatment.

The steel must be kept at this temperature just long enough to ensure that the structure has completely changed, but no longer. The steel is then allowed to cool at a uniform rate until just above the ar_1 line and then quenched.

Small tools can, for instance, be heated up to 760° C., allowed to cool to 700° C., and then quenched in water. This results in a fine-grained martensite structure and the steel should be glass hard. Should the article, however, be of complicated shape, cracking or distortion may occur through too vigorous quenching.

It is then advisable to quench in oil or even in hot water. This reduces the risk of distortion and cracking. Steels having very high carbon content, i.e. between 1 and 1·25, tend to form free carbon or graphite if cooled slowly and thus, to prevent this formation, they must be very rapidly quenched.

Annealing. We have considered the various high-temperature structures which can be retained in a steel at low temperatures by means of rapid cooling. When these structures are retained in this way, a state of strain may often exist in the metal. Internal strains may also be set up by hammering, rolling and stretching the metal beyond the elastic limit.

Annealing is the process by which these internal strains are removed; hence it is the opposite process to straining. In addition, the steel is made soft and suitable for machining.

The process consists of heating the metal to a certain temperature and then allowing it to cool very slowly out of contact with the air to prevent oxidation of the surface. After the first softening is obtained, if the annealing is prolonged large numbers of very large crystals are formed. These, as is usual with all crystals, grow in size and decrease in number as the annealing continues. This is known as *crystal growth* or *grain growth* (Figs. 54–56).

As these crystals grow in size, the resistance of the metal to shock and fatigue is greatly lowered; hence over-annealing has the bad effect of promoting grain growth, resulting in reduction in resistance to shock and fatigue.

The annealing temperature should be slightly above the critical ac_3 line and therefore varies with the carbon content of the steel. Low carbon steels should therefore be heated above about 900° C., while high carbon steel should be heated above about 760° C.

The crystals produced depend on the temperature to which the steel is raised, and the growth of the crystals after this formation will depend on how long it is kept at that temperature. Hence to obtain a fine structure, the metal should be heated only just above the 'annealing' temperature and kept there only long enough to ensure that it has been heated right through. The grain produced then will be retained on slow cooling out of contact with the atmosphere; hence great care is necessary to observe the above points.

The annealing of small articles can be carried out roughly by heating to red heat (700 to 800° C.) in the forge and then allowing to cool out in the dying embers.

Normalising. This process consists in raising the steel only slightly above the ac_3 line, keeping it at this temperature for just sufficient time to heat it right through, and then allowing it to cool as rapidly as possible in air. This causes a refining of the structure, since recrystallisation takes place, and a coarse structure becomes much finer, since the steel is not held at the high temperature long enough for any grain (or crystal) growth to take place (see Figs. 54–56).

Tempering. If the steel is made very hard by rapid quenching, such as in water, it becomes very brittle and liable to crack. This tendency can be reduced by tempering, in which the steel is heated to a certain temperature (depending on the result required) and then cooled out. The temperature is indicated by the colours appearing on a polished surface of the steel when heated. If a metal surface is polished so as to make it bright, as it is heated by a flame, colours begin to appear on the polished surface. First yellow, then straw, brown, purple and blue. The temperatures roughly indicated

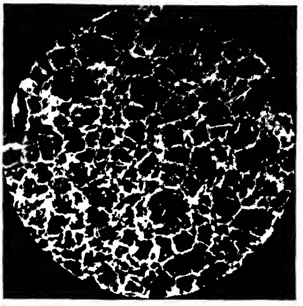


Fig. 54. 0·4% carbon steel normalised at 850° C.

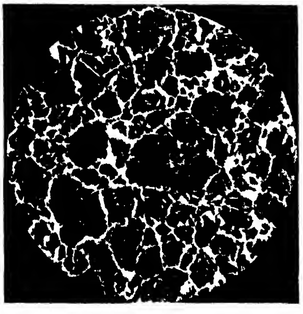


Fig. 55. 0·4% carbon steel normalised at 1000° C.

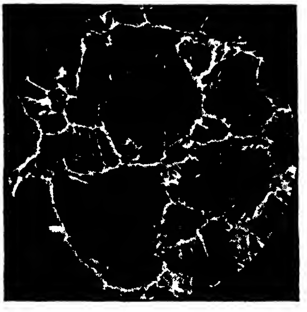


Fig. 56. 0·4% carbon steel normalised at 1200° C.

Figs. 54–56. Illustrating grain growth due to normalising at increasingly high temperatures. × 100

by these 'temper' colours are given herewith. (The colours are due to the thin film of oxide produced on the surface.) Thus if a piece of steel is 'hardened right out', i.e. is quenched in water from above its critical point and then is only slightly heated, it will be found that on quenching again the steel has lost only a little of its hardness, but the higher the temperature to which it is raised, the less the hardness remaining after sudden cooling. The colours can thus be taken as indicating a certain degree of hardness.

Degrees Centigrade	Temper Colour
220	Pale yellow
240	Straw
260	Yellow or light brown
270	Light purple-brown
280	Purple
290	Blue
300	Dark blue

A method often used to obtain a temper on a cutting tool consists of raising the part to bright red heat and then quenching the *cutting end* of the tool in water. The tool is then removed

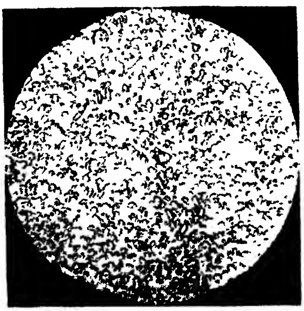


Fig. 57. Spheroidalised pearlite in a 1% carbon tool steel

Fig. 58. Fine grained sorbite in a low alloy steel, hardened and tempered. ×250

and the heat from the part which was not quenched travels by conduction to the quenched end and the temper colours begin to appear. The tool is then entirely quenched, or just the end, when the required colour appears.

In the modern method of tempering, more accurate control of temperature is obtained than by the colour method by heating the parts in oil or molten lead to the required temperature and then quenching.

Overheated Steel. If steel is exposed to too high a temperature or for too long a time to temperatures above ac_3, it becomes overheated. This means that a very coarse structure

Fig. 59. Coarse grained sorbite in a low alloy steel, hardened and tempered. ×250

Fig. 60. Troostite. The white areas are of light etching martensite. ×250

occurs and, on cooling, this gives a similar coarse structure of ferrite and pearlite. This structure results in great reduction in fatigue resistance, impact strength, and a reduced yield point, and is therefore undesirable.

Steel which has been overheated therefore is extremely unsatisfactory. Correct heat treatment will restore the correct structure.

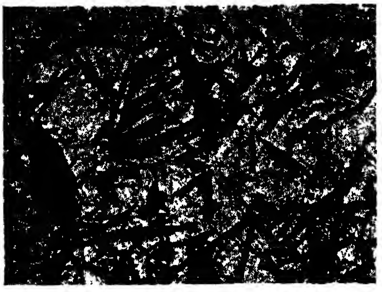


Fig 61. Martensite. ×250

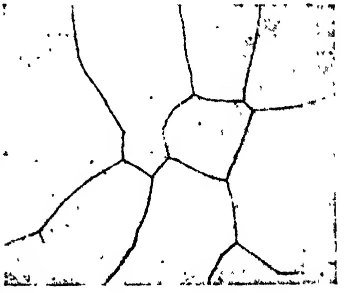


Fig. 62. Austenite. Showing typical polygonal grains of a solid solution in a pure metal. ×250

Fig. 63. Oxidation along crystal boundaries in mild steel which has been overheated and 'burnt'.

Burnt Steel. If steel is heated to a high temperature, this may result in a condition which cannot be remedied by heat treatment and the steel is said to be 'burnt'. This condition is due to the fact that the boundaries of the crystals become oxidised, due to absorption of oxygen at high temperature, and hence the steel is weakened (Fig. 63).

Case-hardening. Case-hardening (and also pack-hardening) is a method by which soft low carbon steel is hardened on the surface by heating it in contact with carbonaceous material (material containing carbon). Parts to be case-hardened are packed in a box and covered with carbonaceous powder, such as charred leather, powdered bone, animal charcoal, or cyanide of potassium (KCN). The box is then placed in the furnace and heated above the critical temperature (that is, above 900° C., depending on the carbon percentage in the steel). The steel begins to absorb carbon at red heat and continues to do so, the carbon diffusing through the surface. The box is then removed from the furnace and the parts on being taken out can either be directly water or oil quenched. Another favoured method is to allow them to cool out slowly, then heat up to about 800° C., and quench in oil or water, depending on the hardness required in the case.

The case-hardening furnace is almost always found nowadays as part of the equipment of large engineering shops. Parts such as gudgeon pins, shackle bolts, and camshafts and, in fact, all types of components subject to hard wear are case-hardened.

The drawback to the process is that, owing to the quenching process, parts of complicated shape cannot be case-hardened owing to the risk of distortion.

The percentage of carbon in steels suited to case-hardening varies from 0·15 to 0·25 %. Above this, the core tends to become hard. The carbon content of the case after hardening may be as high as 1·1 %, but is normally of about 0·9 % to a depth of 40 to 50 thousandths of an inch.

Nitriding or Nitrarding. This process consists of hardening the surface of 'nitralloy steels' (alloy steels containing aluminium and nickel) by heating the steel to approximately 500° C. in an atmosphere of nitrogen. The steel to be nitrarded is placed in the furnace and ammonia gas (NH_3) is passed through it. The ammonia gas splits up, or 'cracks', and the nitrogen is absorbed by the steel, while the hydrogen combines with the oxygen and steam is formed, passing out of the furnace. The parts are left in the furnace for a period depending on the depth of hardening required, because this process produces a hardening effect which decreases gradually from the surface to the core and is not a 'case' or surface hardening. When removed from the furnace, the parts are simply allowed to cool. The nitralloy steel is annealed before being placed in the furnace and the parts can be finished to the finest limits, since the heat of the furnace is so low (500° C.) that distortion is reduced to a minimum, and there is no quenching. Nitralloy steel, after the nitrarding process, is intensely hard (800 to 900 Brinell), and it does not suffer from the liability of the surface to 'flake' as does very hard case-hardened steel.

It is used extensively to-day in the automobile and aircraft industries for parts such as crankshafts, pump spindles, etc.

Let us now consider the effect of the heat supplied, during the welding process, on steel.

During the welding process, the molten metal is at a temperature from 2500 to 3000° C. and the weld may be considered as a region of cast steel. Since regions near the weld may be comparatively cool, it will be possible to find crystal structures of all types in the vicinity, and great changes may take place as the rate of cooling is altered.

There is great possibility, in addition, that oxygen or even nitrogen may be absorbed into the weld itself. We have seen that when oxidation occurs on the crystal boundaries, the impact strength and fatigue resistance of the metal are greatly reduced, and hence a weld which has absorbed oxygen will show these symptoms. The formation of iron nitride (Fe_4N) also makes the weld brittle. The nitride is usually present in the form of fine needle-shaped crystals visible under the high-powered microscope (Fig. 64). The weld must be safeguarded from these defects as much as possible.

Evidently, also, the composition of the filler rod or electrode compared with that of the parent metal will be of great importance, since this will naturally alter the properties of the steel at or near the weld.

If the mass of the parent metal is large and cooling is very quick, the higher crystal structures, such as troostite, may be retained, making the weld tough and strong but brittle, and this will particularly be the case if the carbon content is high.

If, however, cooling is slow, the lower crystal structures are found with smaller crystals, giving a lower strength and decreased hardness, but at the same time a very much increased ductility and impact strength.

Evidently, therefore, the welding of a given joint requires the consideration, as to what properties are required in the finished weld (tenacity, ductility, impact strength, resistance to wear and abrasion, etc.).

When this is settled the method of welding and the rate of cooling can be considered, together with the choice of suitable welding rods.

These considerations are of particular importance in the case of the welding of alloy steels, since great care is necessary in the choice of suitable welding rods, which will give the weld the correct properties required. In many cases, heat treatment is advisable after the welding operation, to remove internal stresses and to modify the crystal structure, and this treatment must be given to steel such as high tensile and chrome steels. The study of welding of these steels is, however, still proceeding (pp. 310–311).

The Effect of Welding on the Structure of Steel

During the welding process, the part of the weld immediately under the flame or arc is in the molten condition, the section that has just been welded is cooling down from this condition, while the section to be welded is comparatively cold. This, therefore, is virtually a small steel-casting operation, the melting and casting process taking place in a very short time and the weld metal after deposition being 'as cast' steel.

As a result we expect to find most of the various structures (martensite, troostite, sorbite, etc.) that we have considered, and the point of greatest interest to the welder is, what structures will remain on cooling. Evidently the structure that remains will determine the final strength, hardness, ductility and resistance to impact of the weld. Since these structures will be greatly affected by the absorption of any elements that may be present, it will be well to consider these first.

Oxygen may be absorbed into the weld, forming iron oxide (Fe_3O_4) and other oxides such as that of silicon. This iron oxide may also be absorbed into the weld from the steel of the welding rod or electrode. If this iron oxide is present in any quantity (as is the case when using bare wire electrode in arc welding, or excess of oxygen in the oxy-acetylene process), oxidation of the weld will occur and this produces great increase in the grain size, which is easily observed on the microphotograph. Even normalising will not then produce a fine grain. This oxygen absorption, therefore, has a bad effect on the weld, reducing its tensile strength and ductility and decreasing its resistance to corrosion. Covered arc-welding electrodes may contain de-oxidising material to prevent the formation of iron oxide, or sufficient silica to act on the iron oxide to remove it and form iron silicate (slag).

Nitrogen. The percentage of nitrogen in weld metal can vary considerably, and the results of experiments performed by Portevin and Séférian have led to the following conclusions:

(*a*) There is very low absorption by the oxy-acetylene process (maximum 0·02 %).

(*b*) Much greater absorption in arc welding (0·15 to 0·20 %) which is influenced by (1) the current conditions that may cause the nitrogen content to vary from 0·14 to 0·2 %, (2) the nature of the atmosphere. By the use of electrodes covered with hydrogen-releasing coatings, e.g. sawdust, the nitrogen content may be brought down to 0·02 %.

(*c*) The thickness of the coating. Use of a very thick covering may reduce the nitrogen from 0·15 to 0·03 %.

Nitrogen is found in the weld metal trapped in blowholes (although nitrogen itself does not form the blowholes) and as crystals or iron nitride (Fe_4N), known as nitride needles (Fig. 64). Nitrogen, however, may be in solution in the iron, and to cause the iron-nitride needles to appear the weld has to be heated up to about 800 to 900° C. The nitrogen tends to increase the tensile strength but *decreases* the ductility of the metal.

Hydrogen may be absorbed into weld metal, since it is slightly soluble in molten steel. When the steel solidifies, the hydrogen gives rise to blowholes of definite type.

Carbon. If we attempt to introduce carbon into the weld metal from the filler rod, the carbon either oxidises into carbon monoxide during the melting operation or reacts with the weld metal and produces a porous deposit. Arc-welded metal cools more quickly than oxy-acetylene weld metal and hence the former may be expected to give a less ductile weld, but the quantity of carbon introduced in arc welding is too small to produce brittle welds in this way.

The effect on the weld metal of the carbon contained in the parent metal is, however, important, especially when welding medium or high carbon steels. In this case, the carbon may diffuse from the parent metal, due to its relatively high carbon

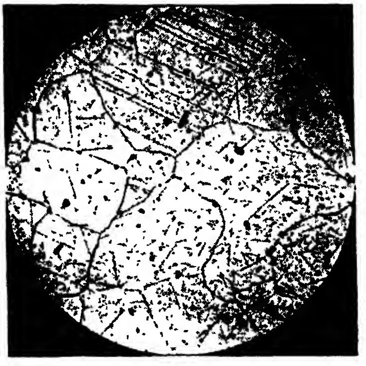


Fig. 64. Nitride needles in ferrite. × 100

content, into the weld metal and form, near the line of fusion of weld and parent metal, bands of high carbon content sufficient to produce hardness and brittleness if cooled rapidly.

The question of change of structure during welding depends amongst other things on:

(1) The process used, whether arc or oxy-acetylene.
(2) The type and composition of the filler rod and, if arc welding is employed, the composition of the covering of the electrode.
(3) The conditions under which the weld is made, i.e. the amount of oxygen and nitrogen present.
(4) The composition of the parent metal.

The change of structure of the metal is also of great importance, as previously mentioned. This will depend largely upon the amount of carbon and other alloying elements present and upon the rate at which the weld cools.

The higher temperature structures, such as martensite and troostite, will be retained only by very rapid cooling, and this will give a brittle and inelastic weld. The carbon content also present in various percentages will influence the weld to a high degree.

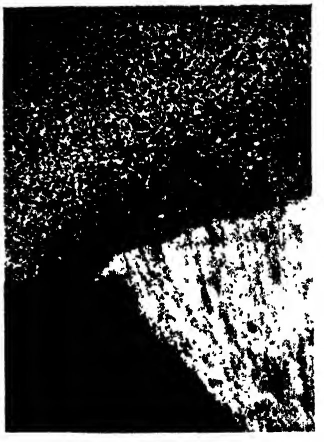


Fig. 65. Crack in weld metal showing structurally altered layer. ×25

A consideration of this subject makes very evident the reason why austenitic alloy steels present such a problem in welding. These steels owe their properties to their austenitic condition, and immediately they are subjected to the heat of the welding process, they have their structure greatly modified. It is nearly always imperative that after welding steels of this class, they should be heat treated in order to correct as far as possible this change of structure. In addition, owing to the number of alloying elements contained in these steels, it becomes very difficult to obtain a weld whose properties do not differ in a marked degree from those of the parent metal. Hence the welding of alloy steels must be considered for each particular steel and with reference to the particular requirements and service conditions. In addition, great care must be taken in selecting a suitable electrode or filler rod.

A further example of structural change is that given by the fact that a multi-run weld is more favoured than a single heavy run in welds on thick sections. Each layer or deposit is then

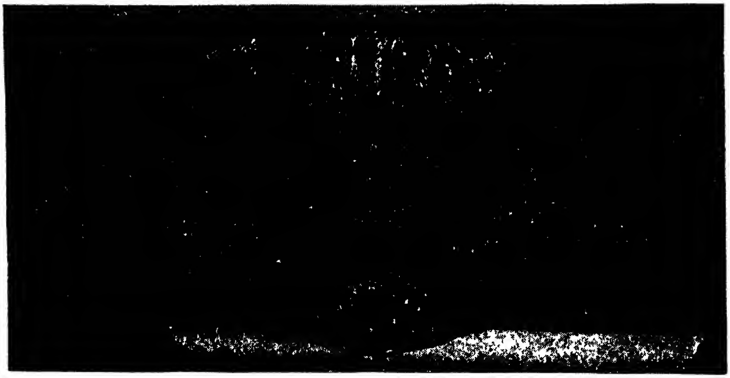


Fig. 66. Effect of welding in the structure of steel

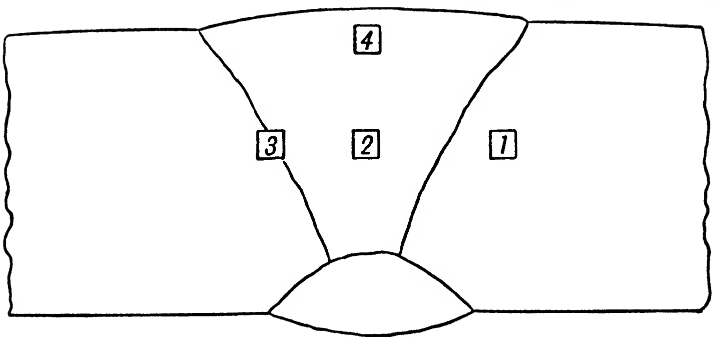


Fig. 66*a*. Section of a flat butt weld in rolled steel plate (×3). 1st run, 8 gauge electrode; 2nd run, 6 gauge electrode; 3rd run, 4 gauge electrode; 4th run, 4 gauge electrode; sealing run, 8 gauge electrode

subjected to the normalising influence due to the heat supplied by the next layer above. As a result, the size of the grains is greatly reduced, that is, a refined weld is produced (Fig. 66). Large grain size often indicates overheating.

The following (microphotographs $\times 75$) are taken from Fig. 66 *a* at the points 1, 2, 3 and 4 as indicated in the figure.

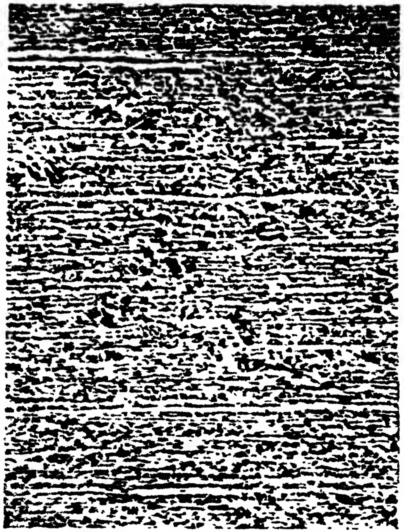


Fig. 66*b*. (1) Rolled steel plate
$\times 75$

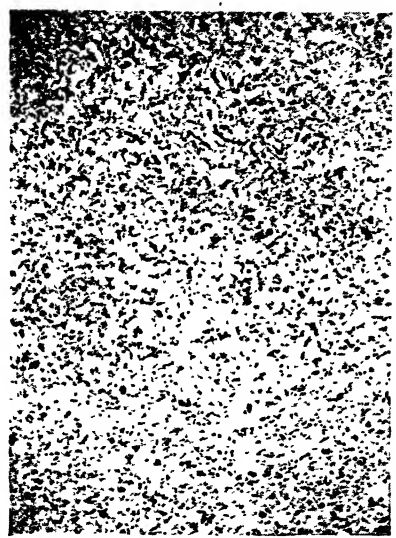


Fig. 66*c*. (2) Weld metal showing refined structure.
$\times 75$

Fig. 66*e*. (4) Top layer.
×75

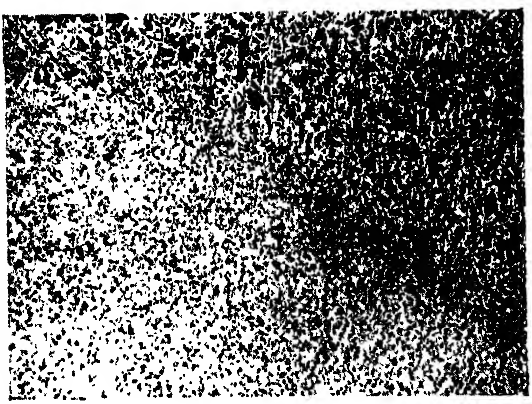


Fig. 66*d*. (3) Junction of weld metal and plate.
×75

The microscope can be used extensively to observe the effect of welding on the structure. When once the observer is trained to recognise the various structures and symptoms, the microscope provides accurate information about the state of the weld. The microscope can indicate the following points, which can hardly be found by any other method and, as previously mentioned, can also indicate fine hair cracks unperceived in X-ray photographs, together with any slag inclusions and blowholes of microscopic proportions. Faults in structure indicated by the microscope using various magnifications are:

(1) True depth of penetration of the weld as indicated by the crystal structure.
(2) The actual extent of the fusion of weld and parent metal (Fig. 65).
(3) The actual structure of the weld metal and its condition (Figs. 65, 66).
(4) The area over which the disturbance due to the heating effect of the welding operation has occurred.
(5) The amount of nitrogen and oxygen absorption as seen by presence of iron-oxide and iron-nitride crystals.

The student should familiarise himself with the microphotographs in various parts of the book and the structures and conditions which they illustrate. The microscope is such a convenient, accurate and relatively quick method of determining the true internal state of a weld structure that its use is imperative wherever welding is employed on any large scale.

Non-Ferrous Metals

Copper is found in the ore copper pyrites ($CuFeS_2$) and is first smelted in a blast or reverberatory furnace, and is then in the 'blister' or 'Bessemer' stage. In this form it is unsuitable for commercial use, as it contains impurities such as sulphur and oxygen. Further refining may be carried on by the furnace method, in which oxidation of the sulphur and other impurities occurs, or by an electrical method (called electrolytic deposition), resulting in a great reduction of the impurities.

In the refining and melting processes, oxidation of the copper occurs and the excess oxygen is removed by reducing conditions in the furnace. This is done by thrusting green wooden poles or tree trunks under the surface of the molten copper, which is covered with charcoal or coke to exclude the oxygen of the air. This 'poling', as it is called, is continued until the oxygen content of the metal is reduced to the limits suitable for the work for which the copper is required.

The oxygen content of the copper is known as the 'pitch' and poling is ended when the 'tough pitch' condition is reached.

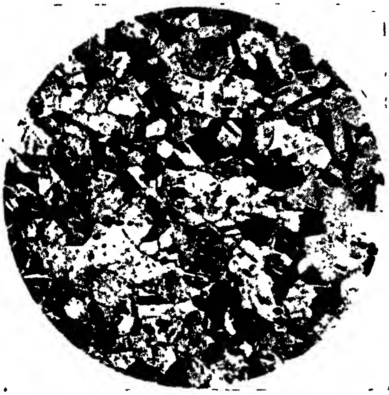


Fig. 67. Cuprous oxide in copper. ×100

Oxygen in Copper. In this condition the oxygen content varies from 0·025 to 0·08 %. The oxygen exists in the cast copper as minute particles of cuprous oxide (Cu_2O), Fig. 67.

The amount of oxygen in the copper is most important from the point of view of welding, since the welding of copper is rendered extremely difficult by the presence of this copper oxide. For welding purposes, therefore, it is much preferable to use copper almost free from oxygen, and to make this, deoxidisers, such as phosphorus, silicon, lithium, magnesium, etc., are added to the molten metal, and they combine with oxygen to form slag and thus *deoxidise* the copper (Fig. 68). The welding of 'tough pitch' copper depends so much on the skill of the welder that it is always advisable to use 'deoxidised copper' for welding, and thus eliminate any uncertainty.

Arsenic in Copper. When arsenic up to 0·5% is added to copper, the strength and toughness is increased. In addition to this, it increases its resistance to fatigue and raises by about 100° C. the temperature at which softening first occurs and enables it to maintain its strength at higher temperatures. For this reason arsenical copper has many applications, including locomotive fire boxes. Arsenic is undesirable in copper intended specifically for welding purposes, since it makes welding more

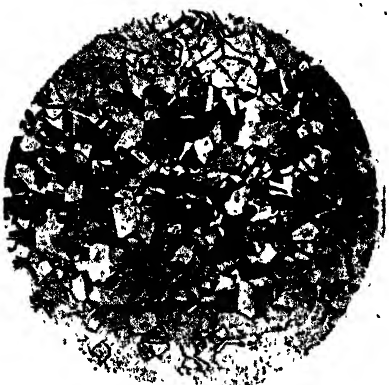


Fig. 68. De-oxidised copper. ×75

difficult. Arsenical copper can be welded by the same method as for ordinary copper, and if care is taken the welds are quite satisfactory. As with ordinary copper, it may be obtained in the de-oxidised or the tough pitch form, the former being the more suitable for welding.

Properties of Copper. Copper is a red-coloured metal having a melting point of 1083° C. or 1981° F., a density of 8·9 grm. per c.c., weighs 0·31 lb. per cu. in. and has a latent heat of fusion of from 41 to 50 calories per gramme, depending upon its condition. The mechanical properties of copper depend greatly on its condition, that is, whether it is in the 'as cast' condition or whether it has been hot or cold worked, 'hammered, rolled, pressed, or forged'.

The tensile strength 'as cast' is about 10 to 11 tons per sq. in. Hot rolling and forging, followed by annealing, modifies its structure and increases its strength to about 14 to 15 tons per sq. in. Cold working by hammering, rolling, drawing and pressing hardens copper and raises its tensile strength, but it becomes less ductile.

Very heavily cold-worked copper may have a tensile strength equal to that of mild steel (30 tons per sq. in.), but it has very little elasticity in this state. The following table indicates the variation of its mechanical properties with its condition:

Condition of Copper	Tensile Strength	Elongation % on a 2 in. Length	Brinell Hardness	Density in grm. per c.c.
As cast	10–11 tons per sq. in.	25–30	40–45	8·5
Cold worked	20–26 tons per sq. in.	5–20	80–100	8·9
Annealed after cold working	14–16 tons per sq. in.	50–60	45–55	8·9

The Temper of Copper. Copper is tempered by first getting it into a soft or annealed condition, and then the temper required is obtained by cold working it (hammering, rolling, etc.). Thus it is the reverse process from the tempering of steel. Soft-temper copper is that in the annealed condition. It has a Brinell hardness of about 50. After a small amount of cold working, it becomes 'half hard' temper, and further cold working brings it to hard temper having a Brinell figure of about 100. Intermediate hardness can of course be obtained by varying the amount of cold working.

Annealing. Copper becomes hard and its structure is deformed when cold worked and annealing is therefore necessary to soften it again. To anneal the metal, it is usual to heat it up to about 500° C., that is, dull red heat, and either quench it in water or let it cool out slowly, since the rate of cooling does not affect the properties of the pure metal. Quenching, however, removes dirt and scale and clears the surface. The surface of the copper can be further cleaned or 'pickled' by immersing it in a bath of dilute sulphuric acid containing 1 part of acid to 70 parts of water. If nitric acid is added, it accelerates the cleaning process. If copper has a surface polish, heating to the annealing temperature will cause the surface to scale, which is undesirable; hence annealing is usually carried out in a non-oxidising atmosphere in this case.

Crystal or Grain Size. Under the microscope, cold-worked copper shows that the grains or crystals of the metal have suffered distortion. During the annealing process, as with steel, recrystallisation occurs and new crystals are formed. As before, if the annealing temperature is raised too high or the annealing prolonged too long, the grains tend to grow. With copper, however, unlike steel, the rate of growth is slow, and this makes the annealing operation of copper subject to a great deal of latitude in time and temperature. This explains why it is immaterial whether the metal cools out quickly or slowly after annealing.

Copper Alloys (Brasses or Copper Zinc Alloys)

Zinc will dissolve in molten copper in all proportions and give a solution of a uniform character. Uniform solution can be obtained when solidified if the copper content is not less than about 60 %. For example, 70 % copper, 30 % zinc consists of a uniform crystal structure known as 'Alpha' solid solution and is shown in Fig. 69. If the percentage of zinc is now increased to about 40 %, a second constituent structure, rich in zinc, appears, known as 'Beta' solid solution, and these crystals appear as reddish in colour, and the brass now has a duplex structure as shown in Fig. 70. These crystals are hard and increase the tensile strength of the brass but lower the ductility. The alpha type brass, which can be obtained when the copper content has a minimum value of 63 %, has good strength and ductility when cold and is used for sheet, strip, wire and tubes. The alpha-beta brass, e.g. 60 % copper, 40 % zinc, is used for casting purposes, while from 57 to 61 % copper types are suitable for hot rolling, extruding and stamping. Hence a great number of alloys of varying copper-zinc content are available. Two groups, however, are of very great importance, as they occur so frequently:

(1) Cartridge brass: 70 % copper and 30 % zinc, written 70/30 brass.
(2) Yellow or Muntz metal: 60 % copper and 40 % zinc, written 60/40 brass.

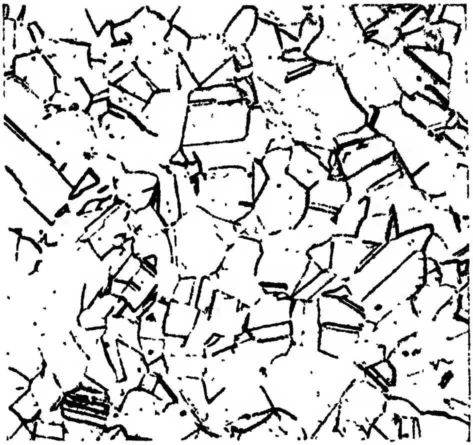


Fig. 69. Rolled and annealed cartridge brass (70/30). This brass has a simple structure, containing only crystals of alpha solid solution, that is zinc dissolved in copper. ×100

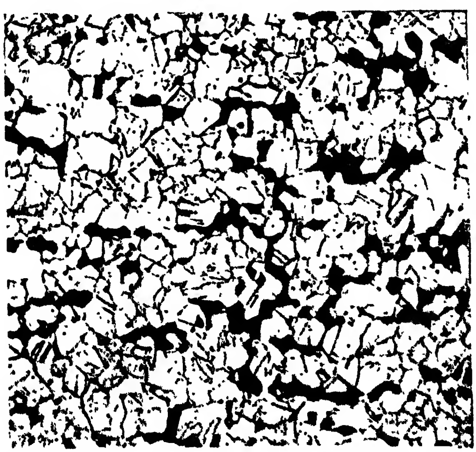


Fig. 70. Rolled and annealed yellow metal (60/40). This brass is a mixture of alpha crystals (white areas), and beta crystals (black areas), richer in zinc. ×100

The following table will illustrate the composition and uses of various copper-zinc alloys:

Name	Composition by Weight		Other Elements	Uses
	Copper %	Zinc %		
Gilding metal	80	20	—	Architectural and decorative metal work
Cartridge brass	70	30	—	For drawn articles, deep pressings and wherever high ductility and strength are required
65/35 brass	65	35	—	Ductile alloy for press work
Yellow or Muntz metal	60	40	—	For brass sheets and articles which do not experience much cold work during manufacture. It works well when hot
Brass for hot stamping casting	58	40½	1½ % lead	Casts well and is easily hot stamped or extended. Machines well
High tensile brass or manganese bronze	58	38	Manganese, aluminium, iron nickel or tin, approximately 4 %	High tensile alloys for casting extrusion bearings, etc.
Phosphor bronze	80 to 90	1 to 10	6 to 8 % tin, 0·3 % phosphorus, iron lead	Gives good castings, bearings, and is very strong

Properties of Brass. Brass is a copper-zinc alloy with a golden colour which can be easily cast, forged, rolled, pressed, drawn and machined. It has a good resistance to atmospheric and sea-water corrosion and therefore is used in the manufacture of parts exposed to these conditions. As the copper content in the brass is decreased, the colour changes from the reddish colour of copper to yellow and then pale yellow.

The density varies from 8·9 to 8·2 grm. per c.c., depending on its composition, and it weighs about 0·308 lb. per cu. in. The heat and electrical conductivity decrease greatly as the zinc content increases, and the melting point is lowered as the copper content decreases, being about 920° C. for 70/30 brass.

Brass for brazing purposes can vary greatly in composition, depending upon the melting point required; for example, three brazing rod compositions are 54 % copper, 46 % zinc; 50 % copper, 50 % zinc (melting at 860° C.) and 85 % copper, 15 % zinc. The choice of the alloy therefore depends on the work for which it is required. For welding brass, the filler rod usually contains phosphorus or silicon, which act as deoxidising agents, that is, they remove any oxygen from the weld.

As the copper content is reduced, there is a slight increase in the tensile strength.

Annealing. Examination of cold-worked brass under the microscope shows that, as with copper, distortion of the crystals has taken place. When its temperature is raised to about 600° C., recrystallisation takes place and the crystals are very small. The rate of growth depends on the temperature, and the higher the temperature the larger the crystals or grains. The annealing time (as with steel) also affects their size. In over-annealed brass, having large crystals, they may show up on the surface after cold working as an 'orange-peel' effect.

Annealing at too high a temperature may also cause pitting or deterioration of the surface by scaling.

Brass can either be quenched out in water or allowed to cool out slowly after annealing. If quenched, the surface scale is removed, but care must be taken with some brasses lest the ductility suffers.

Temper. Brass is tempered in the same way as copper, that is, by cold working. In the annealed condition it is 'soft temper' (60 to 80 Brinell). A little cold working brings it to 'half-hard temper' and further work gives it a 'hard temper' (150 to 170 Brinell). More cold working still, produces a 'spring-hard temper' with a Brinell number of 170 to 180.

Elasticity. The tensile strength of brass varies with the amount of cold working and can be as high as 30 tons per sq. in. At this value, however, it has only half the elasticity of steel having the same tensile strength. Brass, however, is sufficiently elastic to allow of its being used as springs when in the spring hard-temper condition.

Bronzes or Copper–Tin Alloys

The chief bronzes are gunmetal (88 % copper, 10 % tin, 2 % zinc) with a tensile strength of 17 tons per sq. in., phosphor bronze (copper 93 %, tin 7 %, phosphorus 0·3 %), tensile strength 15–20 tons per sq. in. according to whether it is drawn or annealed, and bearing bronze (84 to 88 % copper, 12 to 16 % tin).

Gunmetal was chiefly used, as its name suggests, for Admiralty and Army Ordnance work, but is now used chiefly where resistance against corrosion together with strength is required. Lead bronze has lead added to improve its properties as a bearing surface and to increase its machinability.

Phosphor bronze has largely replaced the older bearing-bronze for bearings owing to its increased resistance to wear. Phosphorus, when added to the copper-tin bronze, helps greatly to remove the impurities, since it is a powerful reducing agent and the molten metal is made much purer.

Bronze welding rods of copper-tin and copper-zinc composition are very much used as filler rods and electrodes in welding. They can be used for the welding of steel, cast iron, brass, bronze and copper, and have several advantages in many cases over autogenous welding since, because of their lower melting point, they introduce less heat during the welding operation. Manganese bronze can be considered as a high tensile brass.

Aluminium

Aluminium is prepared from the mineral *bauxite*, which is a mixture of the oxides of aluminium, silicon and iron.

The aluminium oxide, or alumina as it is called, is made to combine with caustic soda under pressure to form sodium aluminate, thus:

$$\text{Alumina} + \text{Caustic soda} = \text{Sodium aluminate} + \text{Water}$$
$$Al_2O_3 + 2NaOH = Na_2Al_2O_4 + H_2O$$

This clear solution of sodium aluminate is filtered off and, on cooling, it decomposes and aluminium hydroxide is formed. This is heated and water is drawn off leaving a white powder, alumina.

The alumina is then placed in an electric furnace, the heat of which reduces the alumina into aluminium and oxygen, the aluminium being tapped off in a molten condition from the bottom of the furnace. Aluminium prepared in this way is between 99 and 99·5 % pure, iron and silicon being the chief impurities. In this state it is used for making sheets, car bodies, cooking utensils, etc., and for alloying with other metals for castings. In the 99·5 % and over state of purity it is used for electrical work and other work of specialised character.

Properties of Aluminium. Aluminium has a whitish colour very like zinc, but it is extremely light. The density of aluminium is 2·7 grm. per c.c., i.e. it is less, volume for volume, than ⅓rd the weight of copper (8·9 grm. per c.c.), and just more than ⅓rd the weight of iron (7·9 grm. per c.c.); melting-point 659° C.

The density of aluminium alloys is also very small, ranging from 2·7 to 3·0 grm. per c.c.

It can be hammered and rolled into wire and sheets, and casts well, and has extreme ductility. Its tensile strength, however, is low. In contact with air a very thin invisible film of oxide (alumina) forms on its surface. This makes welding difficult and fluxes have to be used to remove it, the flux being a chemical compound which readily attacks and dissolves the oxide.

Annealing. Aluminium can be annealed by heating up to about 350° C. It is held at this temperature for a few minutes only and then is either allowed to cool in air or is quenched in water. A workshop test for the annealing temperature is that a piece of dry stick rubbed on the work becomes charred, or a piece of soap rubbed on it leaves a brown mark at which point heating should be stopped.

Resistance to Corrosion. This property is due to the formation of a film of oxide on the surface, which protects the metal underneath. The thickness of the film depends upon the corrosive condition. In a non-corrosive condition, say indoors, the film is invisible and is extremely thin, but out-of-doors the film may appear on the surface as a grey-coloured coat. This film will not protect the aluminium against many corrosive influences such as sea water. In this case, an electrical treatment called anodising is used which coats the surface with a greyish-white film that is resistant to sea water.

Aluminium is a very good conductor of heat and electricity. Owing to its good thermal conductivity, a considerable quantity of heat has to be applied during welding operations.

Aluminium Alloys

Although its ductility is very great, the tensile strength of aluminium is low and, as a result, its use in the pure form is lessened. By the addition, however, of other elements, such as zinc, copper and silicon, the mechanical properties are greatly altered and the tensile strength greatly increased. The following brief consideration will indicate the great variety of alloys available, each suitable for a special purpose.

Aluminium Casting Alloys: Aluminium-Copper-Zinc

When zinc and copper are added to aluminium, this hardens it, and zinc will alloy in any proportion. Alloys of zinc and aluminium alone, however, are hot short (crack when hot), and as a result are not often used. The addition of copper, however, removes this tendency and we have, as a result, a very useful range of alloys.

One alloy is 3L5 (B.S.S.)—13½ % zinc and 2½ % copper. It is strong and cheap to make and thus is widely used. Its disadvantages are that it is hot short, loses strength at high temperatures, is not very resistant to corrosion, is heavier than other aluminium alloys, and may develop cracks, sometimes after casting. A copper-aluminium alloy (4L11) containing 6 to 8 % copper is very widely used in America, but is not so strong or very resistant to shock.

If silicon is added to the above (copper-aluminium alloy), the strength is increased and the alloy improved for die-casting. An example of this is BA/37.

Aluminium-Silicon Alloys

These alloys contain 10 to 13 % silicon, are fluxed with sodium or other salts when molten, and this gives high strength (as it reduces the grain size), considerable ductility, and high corrosion resistance, and is used on board ship and for chemical plants. When molten it is extremely fluid and contracts by a very small amount in solidifying.

BA/40 contains 7 to 8 % silicon and is stronger than a similar copper alloy 4L11 but not so elastic. It is, however, more ductile and softer.

Heat-treatable Alloys

These alloys are greatly improved by heat treatment and usually contain copper and magnesium. Y alloy is one of the best known of them. As cast it possesses no particular properties, but on heating the casting to 500 to 520° C. for six hours or more and quenching it in boiling water and allowing it to rest for some days, its strength is greatly increased. Y alloy is, however, not easy to cast. (It is used for pistons.) BA/23, containing 1¼ % magnesium and 0·6 % silicon, is another simple alloy which can be heat treated. It is not so strong as Y alloy after treatment, but has greater elongation and higher elasticity.

BA/31, a simple 5 to 6 % copper alloy, can equal the strength of Y alloy by heat treatment. It has greater elongation but lower elasticity.

Aluminium Alloys

The tables on p. 108 give the composition and heat treatment of some of the better-known aluminium alloys for casting and also an example of those suitable for heat treatment.

Aluminium Alloy Sheet

The alloys used for this purpose are in two classes:

(1) Those that acquire their properties by work hardening.
(2) Those that acquire their properties by heat treatment.

Work-hardened Alloys

These can be work hardened to medium and hard temper. BA/60A, containing manganese, has its strength greatly increased by work hardening, changing it from soft temper to hard temper. It can be drawn in all tempers and has a higher resistance to corrosion than most aluminium alloys. It can be welded, but the strength of the weld will be no greater than that of the soft temper of the parent metal.

BA/40D is a silicon alloy not so strong as BA/60A in hard temper but is stronger in soft temper. Since it is stronger than BA/60A in the cast state, it is much better for applications involving welding, the welding operation being easily performed.

Typical Casting Alloys

Name	Composition	Heat Treatment	Tensile Strength sand cast
3L5	Cu 2·5–3 % Zn 12·5–14·5 % Remainder Al	As cast	9–11 tons per sq. in.
4L11	Cu 6–8 % Remainder Al	As cast	7½–9 tons per sq. in.
BA37	Cu 6–8 % Si 2 % Remainder Al	As cast	8½–9½ tons per sq. in.
BA40J	Si 7·5–8·5 % Remainder Al	As cast	9–10 tons per sq. in.
Birma-bright	Mg 3·0–6·0 % Mn 0·75 % Remainder Al	As cast	9 tons per sq. in.

Typical heat-treatable Casting Alloys

		As cast	10 tons per sq. in.
Y alloy (B.S.S.)	Cu 3·5–4·5 % Ni 1·8–2·3 % Mg 1·2–1·7 % Remainder Al	6 hours 500 to 520° C. and quenched. Aged 5 days; or 2 hours boiling water	14–15 tons per sq. in.
RR50	Cu 0·8–2 % Ni 0·8–1·75 % Mg 0·05–0·3 % Fe 0·8–1·4 % Si 1·5–2·8 % Remainder Al	8 to 16 hours at 155 to 170° C. and cooled in air or water	11 tons per sq. in.
Aerial A	Cu 2–4·5 % Cd 0·5–2·5 % Mg 0·2–1·5 % Mn 0·5 % max. Remainder Al	6 hours at 490 to 500° C. and quenched	14–15 tons per sq. in.
Alpax beta	Si 10–13 % Mg 0·6 % max. Mn 0·6 % max.	Not less than 16 hours at 150 to 175° C. and quenched	11 tons per sq. in.

It has good resistance to corrosion. Its specific gravity, 2·67, is less than that of pure aluminium. MG 7 is stronger and harder than either BA/60A or BA/40D and its resistance to corrosion is high. Welding is not difficult and the strength of the welded joint is high. Specific gravity, 2·63.

Birmabright is a magnesium-manganese alloy having excellent resistance to corrosion and is widely used for lifeboats, speed-boat hulls, etc., and can be used for casting or sheet. Specific gravity, 2·68.

Heat-treated Alloys

Duralumin was one of the first alloys capable of heat treatment to be discovered. It has excellent strength and elongation, and has reasonable resistance to corrosion. If it is desired to expose it to sea water or such type of corrosion, the surface is usually anodised, and this method is used for all aircraft components. An alternative is to use a composite sheet with the duralumin in between two thin sheets of pure aluminium —known as 'Aldural', or 'Alclad'.

Slight variations in the composition for special uses gives Duralumin F, Duralumin G, etc.

Sheet Aluminium Alloy

TYPICAL WORK-HARDENING SHEET ALLOYS

NAME	COMPOSITION	TENSILE STRENGTH
BA/60A	Mn 1·5 % Cu 0·15 % Fe 0·75 % Remainder Al	11 tons per sq. in.
BA/40D	Si 10–13 % Remainder Al	10–11 tons per sq. in.
MG 7	Mg 6·5–10% Mn 0·6% max. Si 0·5% max. Fe 0·75% max. Remainder Al	20–25 tons per sq. in. depending on whether hard or annealed

TYPICAL HEAT-TREATABLE WROUGHT SHEET ALLOYS

NAME	COMPOSITION	HEAT TREATMENT	TENSILE STRENGTH
Duralumin	Cu 3·5–4·5 % Mn 0·4–0·7 % Mg 0·4–0·7 % Remainder Al	Heated to 480 to 500° C. and quenched. Then aged at room temperature for 5 days	25 tons per sq. in.
Hiduminium (RR56)	Cu 1·5–4·0 % Ni 2 % max. Mg 0·3–1·5 % Fe 0·3–1·5 % Remainder Al	Heated to 495 to 535° C. and quenched. 10 to 20 hours at 155 to 185° C.	27 tons per sq. in.
Duralumin G Hiduminium 72 and NA. 245	Cu 3·5–4·8% Mg 0·8–1·8% Mn 0·3–1·5% Remainder Al	Sheets and bars. Heated to 490 ± 10°C. and quenched. Aged at room temperature for 5 days	28 tons per sq. in.

Most aluminium alloys are weldable in the same ways as pure aluminium using a flux (see Welding of Aluminium).

STRESSES AND DISTORTION IN WELDING

Stresses set up in Welding

In the welding process, whether electric arc or oxy-acetylene, we have a molten pool of metal which consists partly of the parent metal melted or fused from the side of the joint, and partly of the electrode or filler rod.

As welding proceeds this pool travels along and heat is lost by conduction and radiation, resulting in cooling of the joint. The cooling takes place with varying rapidity, depending on many factors such as size of work, quantity of weld metal being deposited, thermal conductivity of the parent metal and the melting point and specific heat of the weld metal (Fig. 71).

As the weld proceeds we have areas surrounding the weld in varying conditions of expansion and contraction, and thus a varying set of forces will be set up in the weld and parent metal.

When the weld has cooled, these forces which still remain, due to varying conditions of expansion and contraction, are called ***Residual Stresses*** and they are not due to any external load but to internal forces.

These stresses will cause a certain deformation of the joint. This deformation can be of two kinds:

(1) Elastic deformation.
(2) Plastic deformation.

If the joint recovers its original shape upon removal of the stresses, it has suffered elastic deformation. If, however, it remains permanently distorted, it has suffered plastic deformation. The process of removal of these residual stresses is termed ***Stress Relieving.***

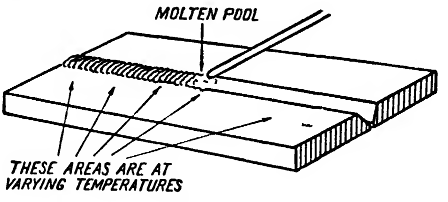


Fig. 71

Stresses are set up in plates and bars during manufacture due to rolling and forging. These stresses may be partly reduced during the process of welding, since the metal will be heated and thus cause some of these stresses to disappear. This may consequently reduce the amount of distortion which would otherwise occur.

Stresses, with their accompanying strains, caused in the welding process, are thus of two types:

(1) Those that occur while the weld is being made but which disappear on cooling.
(2) Those that remain after the weld has cooled.

If the welded plates are free to move, the second stress causes distortion. If the plates are rigid, the stresses remain as residual stresses.

Thus we have to consider two problems. How to prevent distortion, and how to relieve the stress.

Distortion is dependent on many factors, and the following experiment will illustrate this.

Take two steel plates about $6 \times 1\frac{1}{2} \times \frac{5}{16}$ in. Deposit a straight layer of weld metal with the arc across one face, using a small current and a small electrode. This will give a narrow built-up layer. No distortion takes place when the plate cools (Fig. 72).

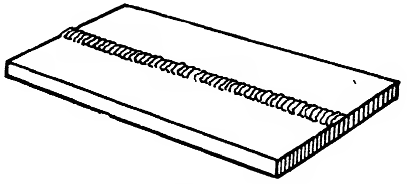


Fig. 72

Now deposit a layer on the second plate in the same way, using a larger size electrode and a heavier current. This will give a wider and deeper layer.

On cooling the plate distorts and bends upwards with the weld on the inside of the bend (Fig. 73). In the first operation the

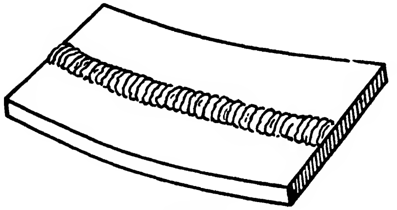


Fig. 73

quantity of heat given to the plate was small, due to the small mass of weld metal laid down. Thus, contraction forces were small, and no distortion occurred. In the second operation, much more weld metal was laid down, resulting in a much higher temperature of the weld on the upper side of the plate. On cooling, the upper side contracted therefore more than the lower, and due to the pull of the contracting line of weld metal, distortion occurred. Evidently, if another layer of metal was laid on the second plate in the same way, increased distortion would occur. Thus from experience we find that:

(1) An increase in speed tends to increase distortion because a larger flame (in oxyacetylene), and a larger diameter electrode and increased current setting (in electric arc) have to be used, increasing the amount of localised heat.

(2) The greater the number of layers of weld metal deposited the greater the distortion.

Let us now consider some typical examples of distortion and practical methods of avoiding it.

Two plates, prepared with a V joint, are welded as shown. On cooling, the plates will be found to have distorted by bending upwards (Fig. 74).

Fig. 74

Again, suppose one plate is set at right angles to the other and a fillet welded in the joint as shown. On cooling, it will be found that the plates have pulled over as shown and are no longer at right angles to each other (Fig. 75).

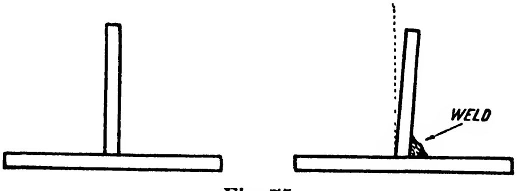


Fig. 75

This type of distortion is very common and can be prevented in two ways:

(1) Set the plates at a slight angle to each other, in the opposite direction to that in which distortion will occur so that, when cool, the plates are in correct alignment.

(2) Clamp the plates firmly in a fixture or vice so as to prevent their movement.

Since we have seen that the amount of distortion depends on several factors, such as speed of welding and number of layers, the amount of bias to be given to the plates in the opposite direction will be purely a matter of experience.

If the plates are fixed in a vice or jig, so as to prevent movement, the weld metal or parent metal must stretch or give, instead of the plates distorting. Thus there is more danger in this case that residual stresses will be set up in the joint.

A very familiar case is the building up of a bar or shaft. Here it is essential to keep the shaft as straight as possible during and after welding so as to reduce machining operations.

Evidently, also, neither of the two methods of avoiding distortion given above can be employed.

In this case distortion can be reduced to a minimum by first welding a deposit on one side of the shaft, and then turning the shaft through 180° and welding a deposit on the opposite diameter. Then weld on two diameters at right angles to these, and so on, as shown in Fig. 76. The contraction due to layer 2 will counteract that due to layer 1, layer 4 will counteract layer 3, and so on.

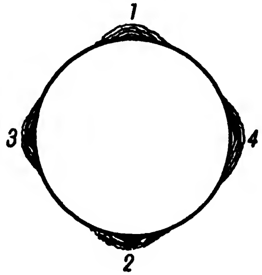


Fig. 76

If two flat plates are being butt welded together as shown, after having been set slightly apart to begin with, it is found that the plates will tend to come together as the welding proceeds.

This can be prevented either by tack welding each end before commencing welding operations, clamping the plates in a jig to prevent them moving, or putting a wedge between them to prevent them moving inwards (Fig. 77).

The disadvantage of tack welding is that it is apt to impair the appearance of the finished weld by producing an irregularity where the weld metal is run over it on finishing the run.

Step welding or back stepping is often used to reduce distortion. In this method the line of welded metal is broken up into short lengths, each length ending where the other began. This has the effect of reducing the heat in any one section of the plate, and it will be seen that in this way when the finish of step 2 meets the beginning of step 1 we have an expansion and contraction area next to each other helping to neutralise each other's effect (Fig. 78).

In the arc welding of cast iron without preheating, especially where good alignment at the end of the welding process is essential, beware of trying to limit the tendency to distort while

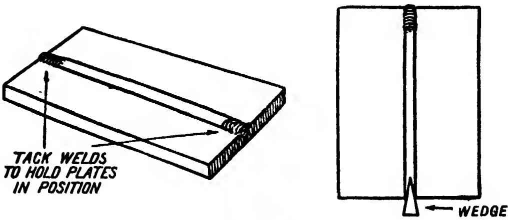


Fig. 77

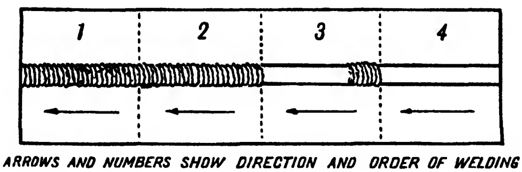


Fig. 78

welding, by tacking too rigidly, as this will frequently result in cracking at the weakest section, often soon after welding has been commenced.

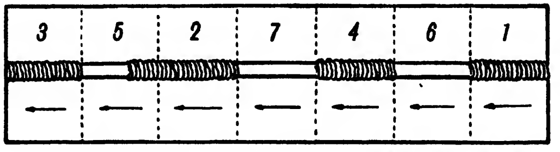
Rather set the parts in position so that after welding they have come naturally into line and thus avoid the setting up of internal stresses.

Practical experience will enable the operator to decide how to align the parts to achieve this end.

In *skip welding* a short length of weld metal is deposited in one part of the seam, then the next length is done some distance away, keeping the sections as far away from each other as possible, thus localising the heat (Fig. 79). This method is very successful in the arc welding of cast iron.

To avoid distortion during fillet welding the welds can be done in short lengths alternately on either side of the leg of the T, as shown in Fig. 80, the welds being either opposite each other as in the sketch (*a*) or alternating as in the sketch (*b*).

It is evident that a great deal can be done by the operator to minimise the effects of distortion.



ARROWS AND NUMBERS SHOW DIRECTION AND ORDER OF WELDING

Fig. 79

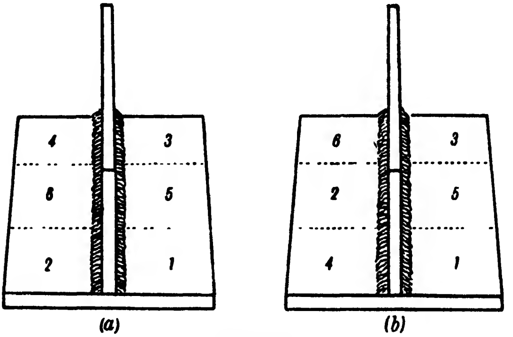


Fig. 80

In the case of cast iron, however, still greater care is needed, because whereas when welding ductile metals there is the elasticity of the parent metal and weld metal to cause a certain yielding to any stresses set up, cast iron, because of its lack of elasticity, will easily fracture before it will distort, unless the greatest care is taken.

This has previously been mentioned in the effects of expansion and contraction.

In the welding of cast iron with the blowpipe, preheating is always necessary unless the casting is of the simplest shape. The casting to be welded is placed preferably in a muffle furnace and its temperature raised gradually to red heat. An excellent furnace can be improvised using fire-bricks, sheet metal plate and some large gas jets, as shown in the sketch. (See also p. 161.)

The welding is performed while the casting is red hot.

(In the case of the furnace shown in Fig. 81 the necessary fire bricks can be removed and the casting welded without removing it from the furnace.)

The casting is then replaced and cooling is allowed to take place for 12, 24 or 36 hours, according to its size and shape.

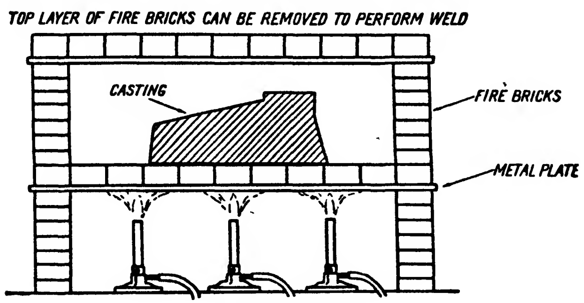


Fig. 81

As a result of this gradual increase and decrease of temperature the stresses due to expansion and contraction are reduced to a minimum.

(In the furnace in the sketch the cooling time can be adjusted by covering it with an asbestos sheet and then covering all over with sand.)

For smaller jobs preheating may be carefully carried out by two or more blowpipes and the casting allowed to cool out in the hot embers of a forge.

Residual Stresses and Methods of Stress Relieving

In addition to these precautions, however, the following experiment will show how necessary it is to follow the correct welding procedure to prevent fracture. Three cast-iron plates are placed as shown in Fig. 82 and are first welded along the seam *A–B*. No cracking takes place, because they are free to expand and contract.

If we now begin at *D* and weld to *C*, that is, from the free end to the fixed end, cracking will in all probability occur; whereas, if we weld from *C* to *D*, no cracking occurs.

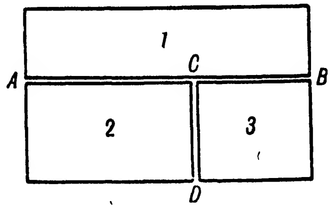


Fig. 82

When we weld from *D* to *C* the ends *D* and *C* are rigid and thus there is no freedom in the joint. Stresses are set up in cooling, giving tendency to fracture. Welding from *C* to *D*, that is, from fixed to free end, the plates are able to retain a certain amount of movement regarding each other, as a result of which the stresses set up on cooling are much less and fracture is avoided. Thus always weld away from a fixed end to a free end in order to reduce residual stress.

Peening

Peening consists of lightly hammering the weld and/or the surrounding parent metal in order to relieve stresses present and to consolidate the structure of the metal. It may be carried out while the weld is still hot or immediately the weld has cooled.

A great deal of controversy exists as to whether peening is advantageous or not. Some engineers advocate it because it reduces the residual stresses, others oppose it because other stresses are set up and the ductility of the weld metal suffers. If done reasonably, however, it undoubtedly is of value in certain instances. For example, in the arc welding of cast iron the risk of fracture is definitely reduced if the short beads of weld metal are lightly peened *immediately* after they have been laid. Care must be taken in peening hot metal that slag particles are not driven under the surface.

Heat Treatment

In this method of stress relieving, the work which has been welded is heated up in a furnace to a given temperature and then allowed to cool slowly or comparatively quickly, according to the conditions under which it is to operate. Welded vessels to withstand high pressures (pressure vessels) and parts of machinery which have to withstand constant shock are examples of welded structures which are heat treated to relieve stresses.

The usual method now used for pressure vessels and machinery parts consists in heating the part to between 590 and 650° C., allowing it to remain at this temperature for some time, and then allowing it to cool gradually. The question whether heat treatment is necessary or not will depend entirely upon the type of welded structure and the conditions under which it must operate.

If these conditions are strenuous and the weld will operate under highly stressed conditions, then heat treatment is indicated.

The following is a summary of the foregoing chapter:

Methods of Reducing Distortion

(1) Decrease the welding speed, using the smallest flame (in oxy-acetylene) and the smallest diameter electrode and lowest current setting (in electric arc) consistent with correct penetration and fusion of weld and parent metal.
(2) Run small layers of deposited metal.
(3) Line up the work to ensure correct alignment on cooling out of the weld.
(4) Use step back or skip method of welding.
(5) Use wedges or clamps.

Methods of Reducing or Relieving Stresses

(1) Weld from fixed end to free end.
(2) Peening.
(3) Heat treatment.

Finally, the following is a summary of the chief factors responsible for setting up residual stresses:

(1) Heat present in the weld depending on:
  (*a*) Flame size and speed in oxy-acetylene welding.
  (*b*) Current and electrode size and speed in arc welding.
(2) Qualities of the parent metal and filler rod or electrode.

(3) Shape and size of weld.
(4) Comparative weight of weld metal and parent metal.
(5) Type of joint and method used in making weld (tacking, back stepping, etc.).
(6) Type of structure and neighbouring joints.
(7) Expansion and contraction (whether free to expand and contract or controlled).
(8) Rate of cooling.
(9) Stresses already present in the parent metal.

Chapter III

THE PRACTICE OF OXY-ACETYLENE WELDING

There are two systems of oxy-acetylene welding in general use: (1) High pressure, (2) Low pressure.

In the high-pressure system, the oxygen and acetylene are supplied from steel cylinders, in which they are stored in compressed form. The pressure is reduced as required by means of reducing valves and the gases are mixed in approximately equal proportions in the blowpipe shank, being finally passed into the nozzle or tip of the pipe to be burnt.

In the low-pressure system the acetylene is supplied from a generator at low pressure. It is purified, dried and passed to the blowpipe. The oxygen is supplied, as in the high-pressure method, from high-pressure cylinders through a reducing valve and the blowpipe is designed so that the high-pressure oxygen injects or drives the low-pressure acetylene along to the blowpipe tip to be burnt.

In certain cases, where an increase in pressure of the low-pressure acetylene is required, as for example if the supply pipes are rather small for the volume of gas to be carried, high-pressure generators and boosters are available. The maximum pressure of generated acetylene allowed in England is 9 lb. per sq. in., and since high-pressure generators normally operate at about 20 lb. per sq. in., they are only used in special cases.

The gas can, however, be 'boosted' or blown after generation by small compressors, and this method gives a steady reliable supply, especially for automatic welding. Many safety devices are necessary with this method to prevent accidents.

Oxygen and Acetylene

The oxygen for both high- and low-pressure systems is supplied in solid drawn steel cylinders at a pressure of 120 atmospheres or 1800 lb. per sq. in. The cylinders are rated according to the amount of gas that they contain, the 100 c. ft. size being very popular.

The volume of oxygen contained in the cylinder is approximately proportional to the pressure; hence for every 1 cu. ft. of oxygen used, the pressure drops about 18 lb. per sq. in. This enables us to tell how much oxygen remains in a cylinder. The oxygen cylinder is provided with a valve threaded right hand and is painted black. On to this valve, which contains a screw-type tap, the pressure regulator and pressure gauge are screwed. The regulator adjusts the pressure to that required at the blowpipe. Since grease and oil can catch fire spontaneously when in contact with pure oxygen under pressure, they must never be used upon any account on any part of the apparatus. Leakages of oxygen can be detected by a glowing splinter, which will either glow brighter or burst into flame according to the size of the leak, or by the application of a soap solution when the leak is indicated by the soap bubbles.

In the high-pressure system the acetylene is stored in steel cylinders similar to the oxygen cylinders. Acetylene gas, however, is unstable when compressed to high pressures, and because of this it is contained in the bottles dissolved in a chemical called acetone; hence the name 'dissolved acetylene'.

The acetone is contained in a porous spongy mass of a substance such as charcoal, asbestos, kapoc or other such material. Acetone can absorb 25 times its own volume of acetylene at normal temperature and pressure and for every increase of one atmosphere pressure (15 lb. per sq. in.) it can absorb an equal amount.

The pressure of the acetylene is usually about 225 lb. per sq. in. and the cylinders may contain 50, 100, 200 or 250 cu. ft. The gas leaves the cylinder through a valve after passing through a filter pad. The valve has a screw tap fitted and is screwed left hand. The cylinder is painted maroon and a regulator (also screwed left hand) is necessary to reduce the pressure to 2–7 lb. per sq. in. as required at the blowpipe.

The amount of dissolved acetylene in a cylinder cannot be determined with any accuracy from the pressure gauge reading since it is in the dissolved condition. The most accurate way to determine the quantity of gas in a cylinder is to weigh it, and subtract this weight from the weight of the full cylinder, which is usually stamped on the label attached to the cylinder. The volume of gas remaining in the cylinder is calculated by remembering that 1 cu. ft. of acetylene weighs 1·1 oz.

As long as the volume of acetylene drawn from the cylinder is not greater than ⅕th of its capacity per hour, there is no appreciable amount of acetone contained in the gas; hence this rate of supply should not be exceeded. For example, a 200 cu. ft. cylinder can supply up to 40 cu. ft. of gas per hour. The advantages of dissolved acetylene are that no licence is required for storage of the cylinders, there is no fluctuation of pressure in use, and the gas is always dry, clean and pure, resulting in a reliable welding flame. Acetylene is highly inflammable and no naked lights should be held near a leaking cylinder, valve or tube. Leaks can be detected by smell or by soap bubbles. If any part of the acetylene apparatus catches fire, immediately shut the acetylene valve on the cylinder. The cylinders should be stored and used in an upright position.

Low-pressure System

In this system the acetylene is generated in a low-pressure generator by the action of water on carbide of calcium. The generators are usually of two types: (1) water to carbide, (2) carbide to water.

Fig. 83 shows a typical water to carbide generator of the 'rising bell' type. The outer vessel is filled with water and all taps are turned off. The rising bell *R* is down, and the cross bar *H*, fixed to the rising bell, holds the ball arm down. A charge of carbide is placed in the container *G* (there may be one, two or three such containers, according to the capacity of the plant), and the front tap *T* is turned on. Water flows down the pipe *P* and enters the carbide chamber. Gas is generated, and leaving by the duct *L* enters the rising bell, being washed and cooled as it passes through the water. The rising bell rises and lifts the cross bar *H* up, and the ball arm can now rise and shut off the valve *V*, preventing further water being admitted to the carbide. The acetylene is led out by the pipe *C*, passes through a condensing chamber where any excess water is trapped, and then is led into the purifier. Generation is completely automatic, and the fact that the storage chamber is separated from the generating chamber by a column of water adds to the safety of the apparatus.

One hundredweight of good calcium carbide will produce about 500 cu. ft. of acetylene in a generator of this type.

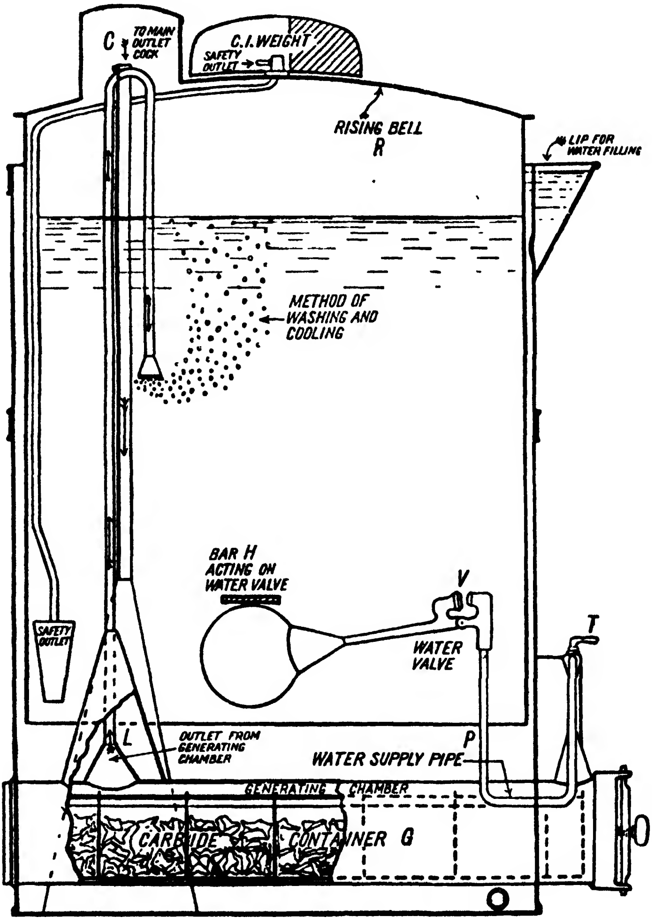


Fig. 88

Fig. 84 illustrates a generator of the carbide to water type. The carbide is contained in the container or hopper *C*, and falls into the water contained in the water container *A*, through the

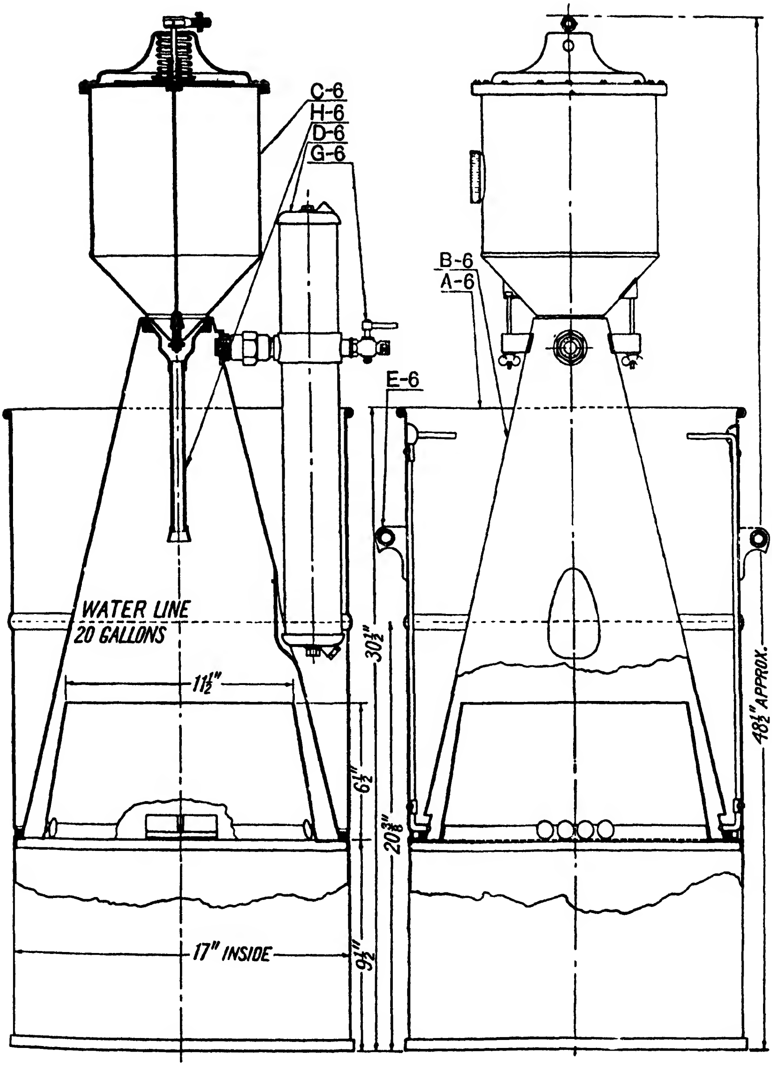

C-6
H-6
D-6
G-6
B-6
A-6
E-6
WATER LINE
20 GALLONS
11½"
6½"
30½"
20⅜"
9½"
17" INSIDE
48½" APPROX.

Fig. 84

cone feed valve. The gas produced forces a certain volume of water out of the gas-holder space into the water container. This creates the necessary working pressure, and at the same time, pressure is exerted on the inside of the flexible diaphragm at the top of the hopper, to which a cone feed valve is fixed, and this lifting action closes the valve.

When gas is used a slight reduction in pressure occurs, and the valve opens, letting in more carbide and generating more acetylene. This design is sensitive in operation and responds to a large or small demand of gas without overmaking or waste of gas.

The dehydrating tube (*H*) prevents condensation reaching the cone feed valve at the base of the hopper. Should a back fire occur and cause a displacement of the water seal, the liquid passes temporarily into an upper chamber and, when the back pressure has subsided, drains back into the normal position again. This is the function of the resealing type hydraulic valve *D*.

Purification of Acetylene

It is important that acetylene used for welding should be free from chemical impurities which are detrimental to the welding process.

Certain impurities are always present in crude acetylene, but the amount depends upon the conditions under which the gas is generated. If generation takes place in a well-designed generator which has a capacity well above the maximum demand likely to be made upon the plant, the gas will be produced at a low temperature and impurities will be kept to a low limit. If, on the other hand, the gas is produced too quickly, considerable heat is generated, which increases the proportion of impurities in the gas. The quality of the carbide also has a great effect on the purity of the gas produced. Carbide which conforms to British Standard Specification No. 642/1935, both as to gas yield and purity, should only be used.

The impurities in crude acetylene consist chiefly of ammonia, hydrides of phosphorus, sulphur and nitrogen, and there are also present water vapour and particles of lime.

A good acetylene generator embodies arrangements for thoroughly washing the gas, and this process will remove most of the ammonia and some of the sulphuretted hydrogen impurities, but to remove the phosphoretted hydrogen it is necessary to pass the gas through suitable chemical purifying materials.

A diagram of a typical purifying vessel is illustratcd in Fig. 85. From this drawing it is clear that gas enters the purifier at the base. After passing through a layer of pumice, which serves to precipitate water vapour, the gas percolates through the purifying material and finally through a layer of filter wool, whence it passes into the service. The filter wool collects any particles of lime or of the purifying material itself and prevents them being carried forward with the gas. Supporting grids are provided for each layer of purifying material to prevent undue loss of pressure, and there is a tap for removing any condensation. To facilitate recharging, the inner receptacle can be lifted right out, and the simple construction of the apparatus ensures easy and efficient operation.

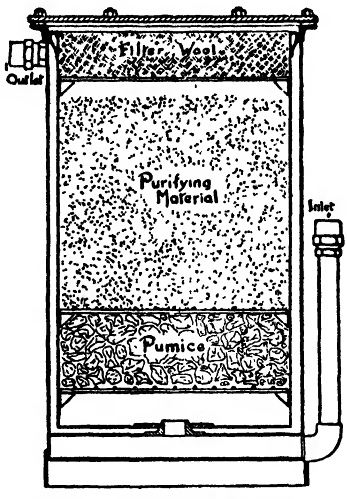


Fig. 85. Diagram of acetylene purifier

To obtain the best results from the purifying material it should be packed evenly and carefully. There should be a total depth of about 10 in., and the purifier should have a diameter sufficient to avoid any restriction of gas flow. Efficient purification will be maintained if the flow of gas is equal to 0·5 cu. ft. per hour per sq. in. in cross-section of the purifier.

A satisfactory purifying material must conform to the following conditions. It must:

(1) Have a minimum corrosive action upon the material of the purifying vessel.
(2) Be non-inflammable, non-explosive, and incapable of forming explosive compounds during use.

(3) Be without action upon the acetylene itself under normal conditions.
(4) Be of a nature to offer the minimum resistance to the flow of the gas, consistent with adequate contact with the gas.
(5) Be capable of absorbing a considerable amount of moisture from the gas without decreasing its purifying power, or increasing its resistance to the flow of the gas.
(6) Should show a pronounced colour change to indicate when the purifying properties are exhausted.

To conform to condition (4), it is the general practice to impregnate a highly porous material, such as good quality kieselguhr or powdered pumice, with a solution of suitable materials capable of oxidising the impurities, and at the same time satisfying other necessary conditions. Active oxidising agents used for acetylene purification can be divided into three main types:

(*a*) Bleaching powder, or hypochlorites.
(*b*) Chromic acids.
(*c*) Salts of ferric iron.

The use of materials of the first class has long been discontinued owing to the danger of explosive interaction between acetylene and the chlorine evolved from the hypochlorites.

Very satisfactory purification can be obtained from the best materials of the second class, but the following objections to their use may be raised:

(*a*) Chromic acid is corrosive.
(*b*) Under normal purifying conditions chromic acid reacts to some extent with acetylene itself, forming acetaldehyde and acetic acid. Some of the latter may be carried forward by the gas and cause corrosion in the pipe lines and blowpipes.

Materials of the third class satisfy all requirements, and when appropriate metal salts are present, such as catalysts, these purifying materials may be regenerated by exposure to air. With this type of purifying material the initial purifying value is as high as that of the chromic acid class, and it has the advantage of being able to be used several times by carrying out the regenerative process described.

The normal method of testing acetylene to ascertain whether it is being efficiently purified is to hold a silver nitrate test paper (a piece of filter paper soaked in a solution of silver nitrate) in the stream of gas for about 10 seconds. If the acetylene is being properly purified, there will be no trace of stain on the silver-nitrate paper.

Hydraulic Back Pressure or Safety Valve

When acetylene is supplied from a low-pressure generator, a back-pressure valve must be used to prevent oxygen or air

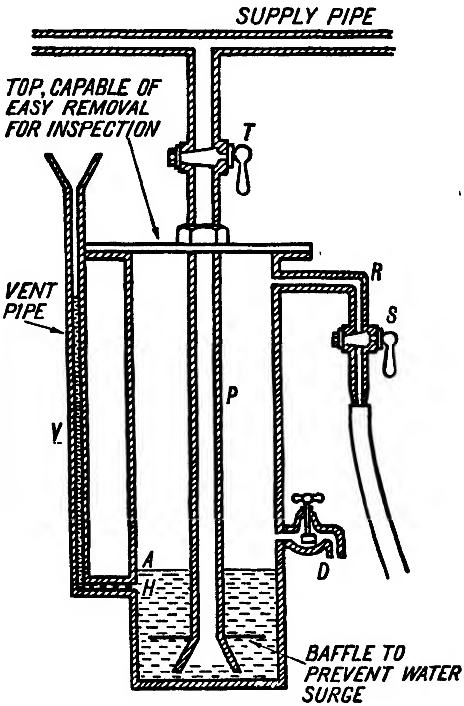


Fig. 86

entering the acetylene generating plant or supply line and thus creating an explosive mixture. Each blowpipe supplied from the main acetylene supply line should have its own back-pressure valve. A typical valve is shown in Fig. 86.

The cylinder can be filled with water via the vent pipe *V* up to the level of the drain cock *D*. Gas is led from the main line through the tap *T*, down the centre pipe *P* and bubbles through the water, eventually leaving by the tube *R* and tap *S*. The pipe *P* has a baffle plate fixed to its lower end. In the event of a back fire, or should a back pressure be set up in the blowpipe line, the water level *A* is depressed and water is forced up the vent pipe until the hole *H* is exposed. The burnt gases in the case of a back fire, or the gases under pressure, thus pass up the vent pipe into the atmosphere and are prevented from getting into the supply line and generator. Since a valve is fitted in each blowpipe, a back fire from one pipe cannot flash back into another.

The water level should be checked up each day and filled to the level of the drain or levelling cock. Excess water can be drained off at this point and at periodical intervals the valve should be dissembled for cleaning and inspection of the inlet pipe for cracks and fractures, as these would render the valve inoperative. Anti-freezing mixtures can be used, if the valve is in an exposed position, to prevent freezing in frosty weather. Glycerine added to the water is a good remedy, the more glycerine that is added, the lower the temperature at which the mixture will freeze.

The Reducing Valve or Pressure Regulator

In order to reduce the pressure of either oxygen or dissolved acetylene from the high pressure of the storage bottle to that required at the blowpipe, a regulator or reducing valve is necessary. Good regulators are essential to ensure the even flow of gas to the blowpipe. A reference to Fig. 87 will make the principle of operation of the regulator clear. The gas enters the regulator at the base and the bottle pressure is indicated on the first gauge. The gas then enters the body of the regulator *R* through the aperture *A*, which is controlled by the valve *V*. The pressure inside the regulator rises until it is sufficient to overcome the pressure of the spring *S*, which loads the diaphragm *D*. The diaphragm is therefore pushed back and the valve *V*, to which it is attached, closes the aperture *A* and prevents any more gas from entering the regulator.

The outlet side is also fitted with a pressure gauge (although in some cases this may be dispensed with) which indicates the working pressure on the blowpipe. Upon gas being drawn off from the outlet side the pressure inside the regulator body falls,

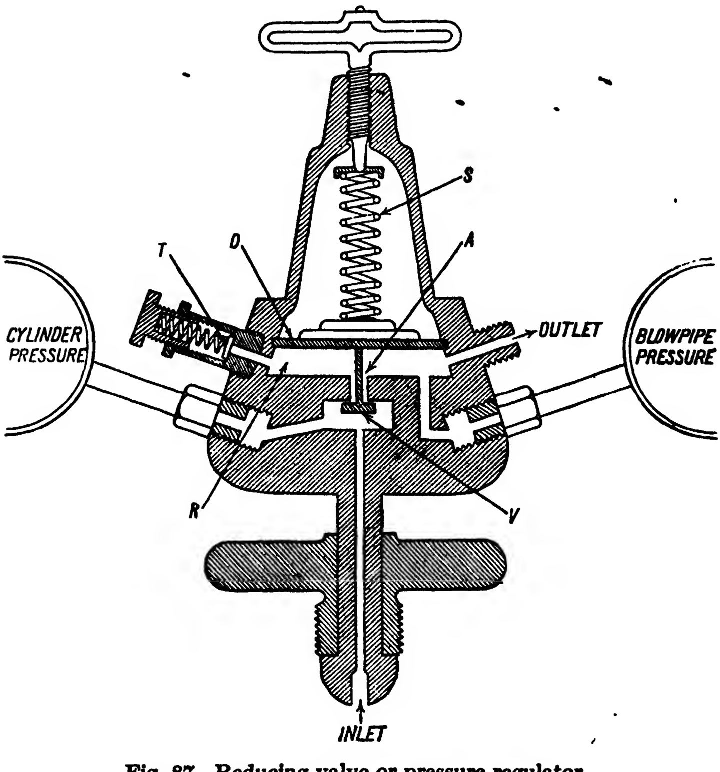


Fig. 87. Reducing valve or pressure regulator

the diaphragm is pushed back by the spring, and the valve opens, letting more gas in from the bottle. The pressure in the body *R* therefore depends on the pressure of the springs and this can be adjusted by means of a screw as shown. A safety valve *T* prevents dangerous pressures being set up in the body of the regulator. The setting of the regulator, as indicated by the pressure of the spring, depends on the work to be done. Some regulators have the spring calibrated in lb. per sq. in. Others have a numbered scale and each number corresponds with a similarly numbered blowpipe tip for which it gives the suitable pressure. On changing a tip the regulator is set with its finger on the tip number on the scale, and final accurate adjustment of the flame made with the blowpipe regulating valves. This is a simple and convenient method. The regulators, graduated in lb. per sq. in., are supplied with a table indicating

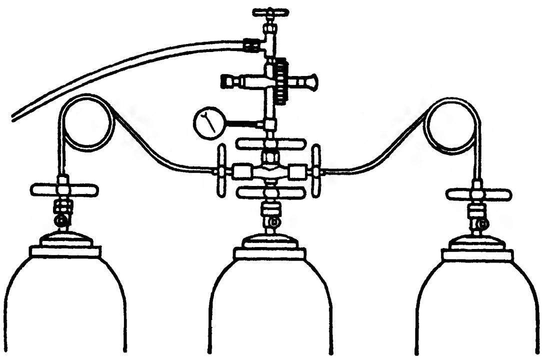


Fig. 88. Method of coupling cylinders for heavy duty

the suitable pressures for various tips, the tips being stamped with their consumption of gas in litres. With practice the welder soon recognises the correct pressures for various tips without reference to the table.

To enable two, three or more cylinders of gas to be connected together as may be required when heavy cutting work is to be done and the oxygen consumption is very great, special adapters are available, and these feed the bottles into one gauge (Fig. 88). In this way a much steadier supply of oxygen is obtained.

Two operators may also be fed from one cylinder of oxygen or acetylene by using a branched gauge with two regulators (Fig. 89). The type of branched gauge which has only one regulator feeding two outlet pipes is not recommended, since any

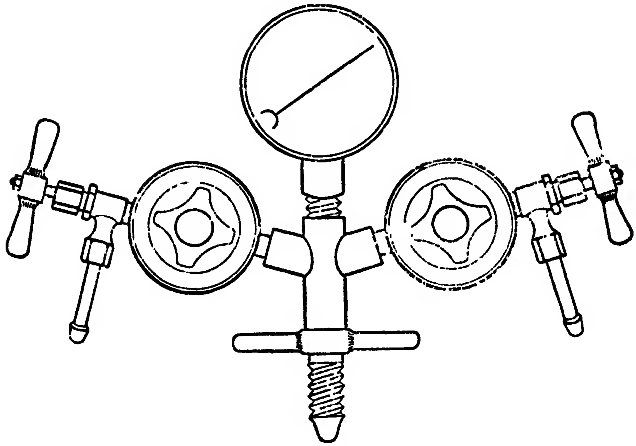


Fig. 89. Two operators fed from one bottle, each has independent pressure control

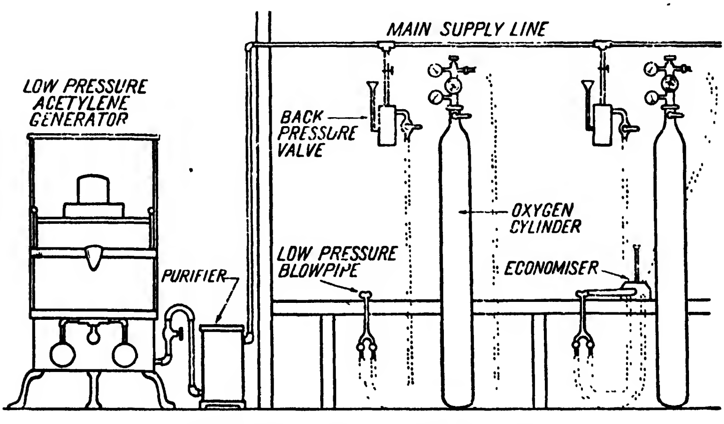


Fig. 90. Sketch of a low pressure layout

alteration of the blowpipe pressure by one operator will affect the flame of the other operator.

Owing to the rapid expansion of the oxygen in cases where large quantities are being used, the regulator may become blocked with particles of ice, causing stoppage. This happens most frequently in cold weather, and can be prevented by use of an electric regulator heater. The heater screws into the cylinder and the regulator screws into the heater. The heater is plugged into a source of electric supply, the connection being by flexible cable.

The Welding Blowpipe or Torch

There are two types of blowpipes: (1) High pressure, (2) Low pressure, and each type consists of a variety of designs depending on the duty for which the pipe is required. Special designs are available for rightward and leftward methods of welding (the

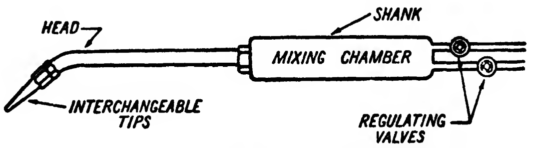


Fig. 91*a*. Principle of high-pressure blowpipe

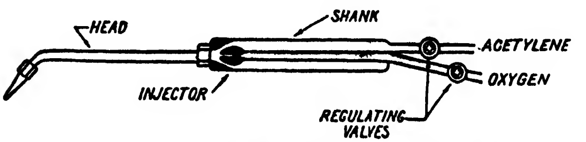


Fig. 91*b*. Principle of low-pressure blowpipe

angle of the head is different in these designs), thin gauge or thick plate, etc., in addition to blowpipes designed for general purposes (see Figs. 92, 93, 94).

The high-pressure blowpipe is simply a mixing device to supply approximately equal volumes of oxygen and acetylene to the tip, and is fitted with regulating valves to vary the pressure of the gases as required (Fig. 91*a*). A selection of tips or nozzles is supplied with each blowpipe, the tips having holes varying in size, and thus giving various sized flames. The nozzles are stamped with their consumption of gas in litres or simply with numbers. Various sizes of pipes are available, from a small light variety, suitable for thin gauge sheet (Fig. 93), to a heavy duty pipe, as shown in Fig. 94. A high-pressure pipe cannot be used on a low-pressure system.

The low-pressure blowpipe has an injector nozzle inside its body through which the high-pressure oxygen streams (Fig. 91 *b*). This oxygen draws the low-pressure acetylene into the mixing chamber and gives it the necessary velocity to preserve a steady flame, and the injector also helps to prevent back firing.

It is usual for the whole head to be interchangeable in this type of pipe, the head containing both nozzle and injector. This is necessary, since there is a corresponding injector size for each nozzle. Regulating valves, as on the high-pressure pipes, enable the gas to be adjusted as required. The low-pressure pipe is more expensive than the high-pressure pipe, but it can be used on a high-pressure system if required.

The illustrations shown on pp. 136–8 are typical of modern blowpipe design.

A very useful type of combined welding blowpipe and metal-cutting torch is shown in Fig. 96. The shank is arranged so that a full range of injector-type heads, or a cutting head, can be fitted as desired. This design is cheaper than for a corresponding separate set for welding and cutting, and the cutter is sufficient for most types of work.

The Oxy-acetylene Flame

The chemical actions which occur in the flame have been discussed on page 42, and we will now consider the control and regulation of the flame to a condition suitable for welding.

Adjustment of the Flame. To adjust the flame to the neutral condition the acetylene is first turned on and lit. The flame is yellow and smoky. The acetylene pressure is then increased by means of the valve on the pipe until the smokiness has just disappeared and the flame is quite bright. This condition gives approximately the correct amount of acetylene for the particular jet in use. The oxygen is then turned on as quickly as possible, and as its pressure is increased the flame ceases to

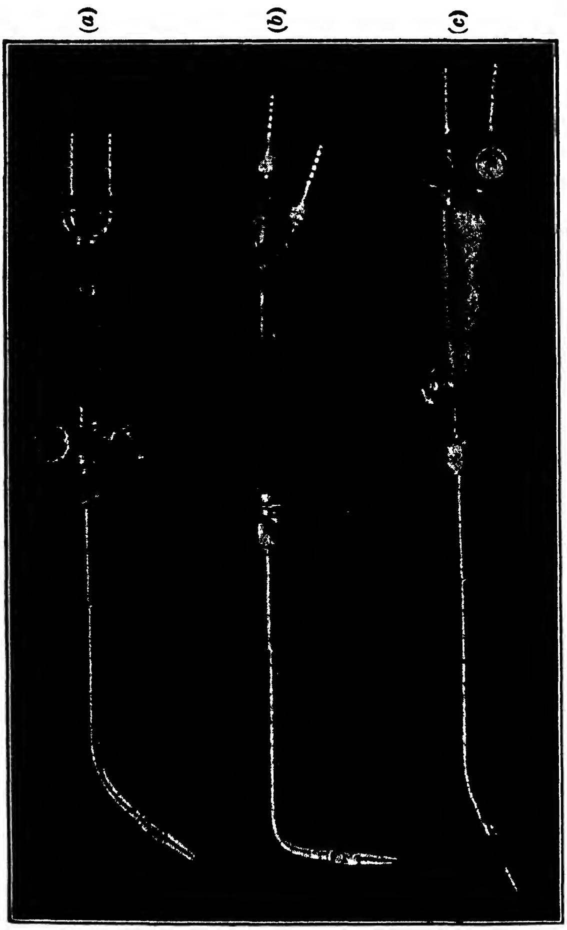


Fig. 92. (*a*) Pipe for leftward welding—nozzle set at 135°. (*b*) Pipe for rightward welding—nozzle set at 90°. (*c*) Pipe for low temperature welding—cast iron and non-ferrous metals.

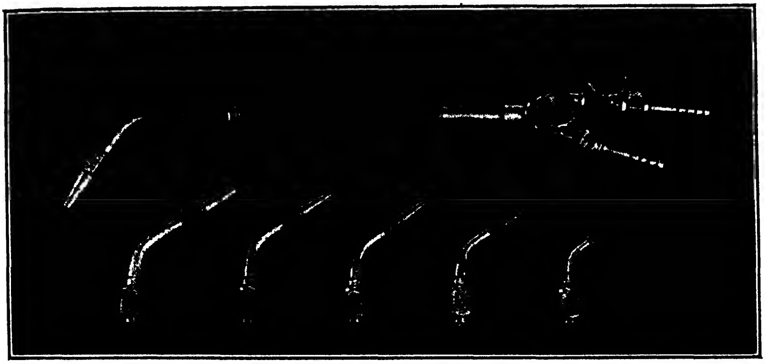


Fig. 93. Light duty low-pressure blowpipe with range of heads. Will weld from thin sheet to ½ in. plate

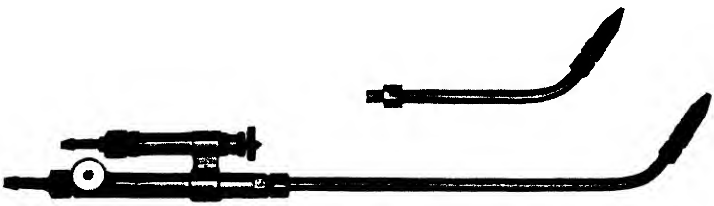


Fig. 94. High-pressure general duty blowpipe with alternative short shank.

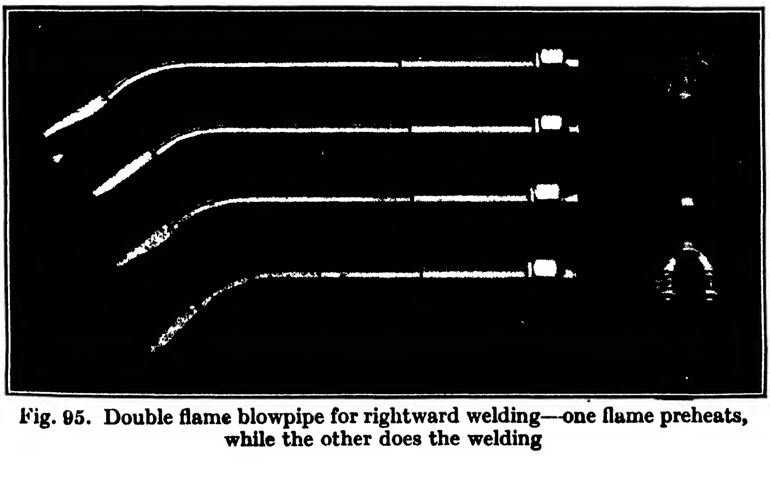


Fig. 95. Double flame blowpipe for rightward welding—one flame preheats, while the other does the welding

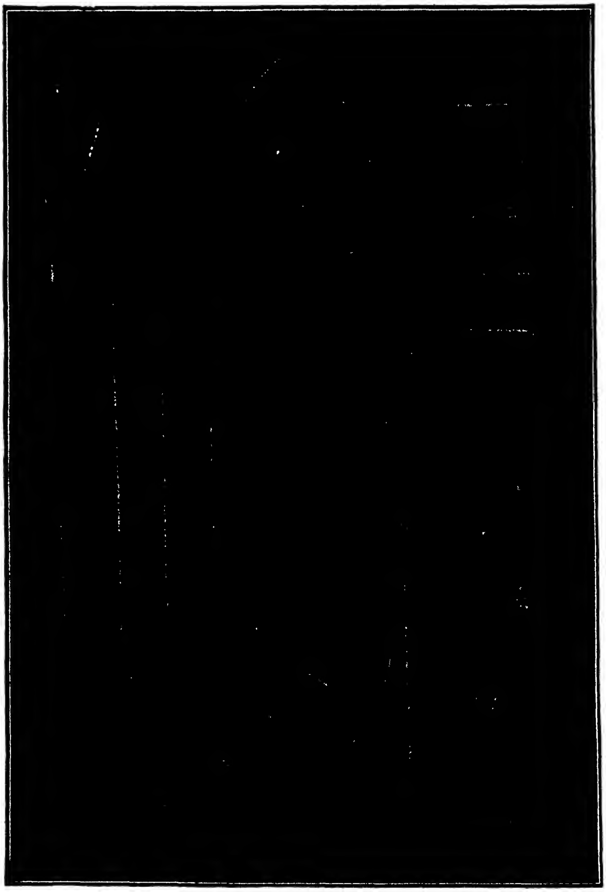


Fig. 96. Combined welding and cutting pipes. Will weld sections from $\frac{1}{16}$ in. to $1\frac{1}{4}$ in. thick and cut steel up to 6 in. thick

be luminous. It will now be noticed that around the inner blue luminous cone, which has appeared on the tip of the jet, there is a feathery white plume which denotes excess acetylene (Fig. 97*a*). As more oxygen is supplied this plume decreases in size until there is a clear-cut blue cone with no white fringe (Fig. 97*b*). This is the neutral flame used for most welding operations. If the oxygen supply is further increased, the inner blue cone becomes smaller and thinner and the outer envelope

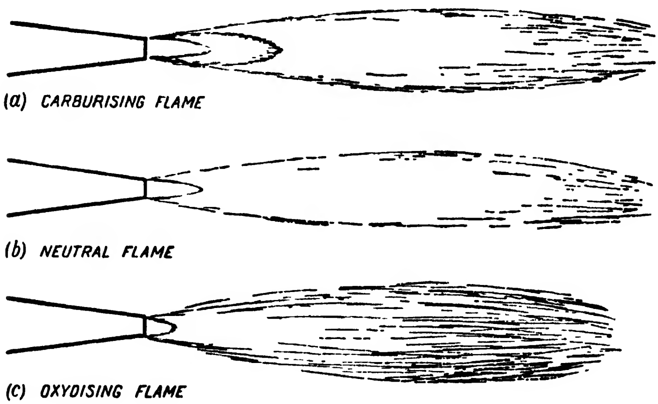


Fig. 97

becomes streaky; the flame is now oxidising (Fig. 97*c*). Since the oxidising flame is more difficult to distinguish than the carbonising or carburising (excess acetylene) flame, it is always best to start with excess acetylene and increase the oxygen supply until the neutral condition is reached, than to try to obtain the neutral flame from the oxidising condition.

Some welders prefer to regulate the oxygen pressure at the regulator itself. The acetylene is lighted as before, and with the oxygen valve on the blowpipe turned full on, the pressure is adjusted correctly at the regulator until the flame is neutral. In this way the welder is certain that the regulator is supplying the correct pressure to the blowpipe for the particular tip being used.

Selection of Correct Tip. As the thickness of the work to be welded increases, the flame will have to supply more heat, and this is made possible by increasing the size of the nozzle or tip. The tip selected may cover one or two thicknesses of plate; for example, a tip suitable for welding $\frac{1}{4}$ in. plate will weld both $\frac{3}{16}$ in. and $\frac{5}{16}$ in. plate by suitable regulating of the pressure valves. This is because the blowpipe continues to mix the gases in the correct proportion over a range of pressures. If, however, one is tempted to weld a thickness of plate with a tip which is too large, by cutting down the supply of gas at the valves instead of changing the tip for one smaller, it will be noticed that explosions occur at the tip when welding, these making the operation impossible. These explosions indicate too low a pressure for the tip being used.

If, on the other hand, one attempts to weld too great a thickness of metal with a certain tip, it will be noticed that as we attempt to increase the pressure of the gases beyond a certain point to obtain a sufficiently powerful flame, the flame leaves the end of the tip. This indicates too high a pressure and results in a *hard* noisy flame. It is always better to work with a soft flame, which is obtained by using the correct tip and pressure. Thus, although there is considerable elasticity as to the thickness weldable with a given tip, care should be taken not to overtax it.

Use and Care of Blowpipe

Oil or grease should upon no account be used on any part of the blowpipe, but a non-oily graphite may be used and is useful for preventing wear and any small leaks.

Back firing may occur at the pipe through several causes:

(1) Insufficient pressure for the tip being used. This can be cured by increasing the pressure.

(2) Metal particles adhering to the nozzle tip. The tip can be freed of particles by rubbing it on a leather or wooden surface. (The gases should be first shut off and then relit.)

(3) The welder touching the platè or weld metal with the tip. In this case the gases should be shut off and then relit.

(4) Overheating of the blowpipe. A can of water should be kept near so as to cool the tip from time to time, especially when using a large flame. Oxygen should be allowed to

pass slowly through the nozzle, when immersed in the water, to prevent the water entering the inside of the blowpipe.

(5) Should the flame back fire into the mixing chamber with a squealing sound, and a thin plume of black smoke be emitted from the tip, serious damage will be done to the blowpipe unless the valves are immediately turned off. This fault may be caused by particles having lodged inside the pipe, or even under the regulating valves. The pipe should be thoroughly inspected for defects before being relit.

In the event of a back fire, therefore, immediately shut off the acetylene valve, and then the oxygen, before investigating the cause.

Blowpipe tips should be cleaned by using a soft copper or brass pin. They should be taken off the shank and cleaned from the inside, as this prevents enlarging the hole. A clean tip is essential, since a dirty one gives an uneven-shaped flame with which good welds are impossible to make.

Technique of Welding

Before attempting any actual welding operations, the beginner should acquire a sense of fusion and a knowledge of blowpipe control. This can be obtained by running lines of fusion on thin-gauge steel plate.

The flame is regulated to the neutral condition and strips of 14 or 16 gauge steel plate are placed on firebricks on the welding bench. Holding the blowpipe at approximately 45° to the plate, with the inner blue cone near the metal surface, and beginning a little from the right-hand edge of the sheet, the metal is brought to the melting point and a puddle formed with a rotational movement of the blowpipe. Before the sheet has time to melt through into a hole, the pipe is moved steadily forward, still keeping the steady rotating motion, and the line of fusion is made in a straight line. This exercise should be continued on various thicknesses of thin-gauge plate until an even line is obtained, and the underside shows a regular continuous bead, indicating good penetration, the student thus acquiring sense of fusion and of blowpipe control.

In the following pages various methods of welding technique are considered, and it will be well to state at this point what constitutes a good weld, and what features are present in a bad weld.

Fig. 98*a* indicates the main features of a good fusion weld, with the following features:

(*a*) Good fusion over the whole side surface of the V.
(*b*) Penetration of the weld metal right through the parent plate.
(*c*) Slight reinforcement of the weld above the parent plate.
(*d*) No entrapped slag, oxide, or blowholes.

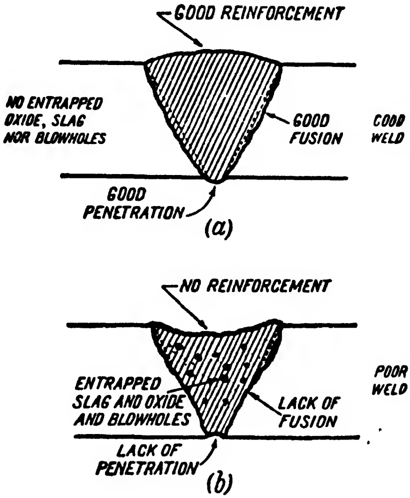


Fig. 98

Fig. 98*b* indicates the following faults in a weld:

(*a*) Bad flame manipulation and too large a flame has caused molten metal to flow on to unfused plate, giving no fusion (i.e. adhesion).
(*b*) Wrong position of work, incorrect temperature of molten metal, and bad flame manipulation has caused slag and oxide to be entrapped and channels may be formed on each line of fusion, causing undercutting.

(c) The blowpipe flame may have been too small, or the speed of welding too rapid, and this with lack of skill in manipulation has caused bad penetration.

(N.B. Reinforcement on the face of a weld *will not* make up for lack of penetration.)

Methods of Welding

We will now consider the following methods of welding:

(1) Leftward or forward.
(2) Rightward or backward.
(3) Lindewelding.
(4) Vertical and overhead.

(Note. The technique for welding both mild steel and wrought iron is the same.)

Leftward or Forward Welding

This method is used nowadays for welding steel plate under $\frac{1}{4}$ in. thick and for welding non-ferrous metals. The welding rod precedes the blowpipe along the seam, and the weld travels from right to left when the pipe is held in the right hand. The inner cone of the flame, which is adjusted to the neutral condition, is held near the metal, the blowpipe making an angle of 60 to 70° with the plate, while the filler rod is held at an angle of 30 to 40°. This gives an angle of approximately 90° between the rod and the blowpipe. The flame is given a rotational, circular, or side to side motion, to obtain even fusion on each side of the weld. The flame is first played on the joint until a molten pool is obtained and the weld then proceeds, the rod being fed into the molten pool and not melted off by the flame itself. If the flame is used to melt the rod itself into the pool, it becomes easy to melt off too much and thus reduce the temperature of the molten pool in the parent metal to such an extent that good fusion cannot be obtained. Fig. 99 will make this clear.

The first exercises in welding with the filler rod are done with the technique just described and consist of running lines of weld on 14 and 16 gauge plate, using the filler rod. Butt welds of thin plate up to $\frac{3}{32}$ in. can be made by flanging the edges and melting the edges down. When a uniform weld is obtained, with good penetration, the exercises can be repeated on plate up to $\frac{1}{8}$ in. thick, and butt welds on this thickness attempted. Above $\frac{1}{8}$ in. thick the plates are bevelled, chamfered, or V'd to an angle of 80 to 90° (Fig. 100). The large area of this V means that a large quantity of weld metal is required to fill it. If, however, the V is reduced to less than 80°, it is found that as the V becomes narrower the blowpipe flame tends to push the molten metal from the pool, forward along on to the unmelted sides of the V, resulting in poor fusion or adhesion. This gives an unsound weld, and the narrower the V the greater this effect.

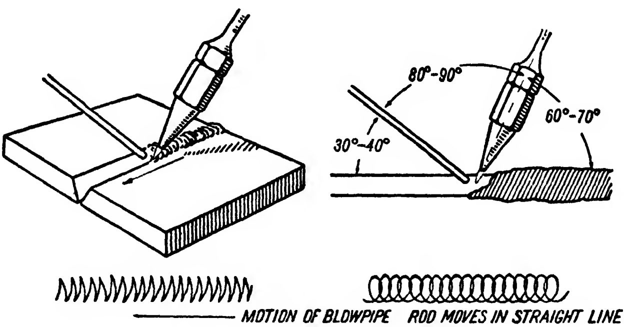


Fig. 99. Leftward welding

As the plate to be welded increases in thickness, a larger tip is required on the blowpipe, and the control of the molten pool becomes more difficult; the volume of metal required to fill the V becomes increasingly greater, and the size of tip which can be used does not increase in proportion to the thickness of the plate, and thus welding speed decreases. Also with thicker plates the side to side motion of the blowpipe over a wide V makes it difficult to obtain even fusion on the sides and penetration to the bottom, while the large volume of molten metal present causes considerable expansion. As a result it is necessary to weld thicker plate with two or more layers if this method is used. From these considerations it can be seen that above $\frac{1}{4}$ in. plate the leftward method suffers from several drawbacks. It is essential, however, that the beginner should become efficient in this method before proceeding to the other methods, since for general work, including the non-ferrous metals (see later), it is the most used.

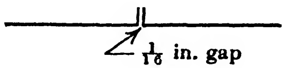
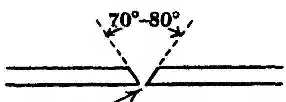
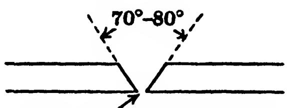
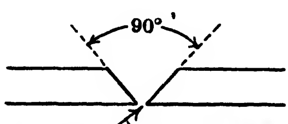
Thickness of Plate		Diameter of Rod	Size of Tip in Litres
$\frac{1}{32}$ in. and $\frac{1}{16}$ in.	 No gap Edges turned up at right angles twice thickness of plate	No rod	50/or $\frac{1}{32}$ in. 100/or $\frac{1}{16}$ in.
$\frac{3}{32}$ in.	 $\frac{1}{16}$ in. gap	No rod	150
$\frac{1}{8}$ in.	 $\frac{1}{16}$ in. gap, no vee	$\frac{3}{32}$ in.	225
$\frac{5}{32}$ in.	 70°–80° $\frac{1}{16}$ in. gap or butt together	$\frac{3}{32}$ in.	350
$\frac{3}{16}$ in.	 70°–80° $\frac{3}{32}$ in. gap or butt together	$\frac{1}{8}$ in.	350
$\frac{1}{4}$ in.	 90° $\frac{3}{32}$ in. gap or butt together	$\frac{1}{8}$ in.	500

Fig. 100. Leftward welding. Preparation of butt joints

The preparation of various thicknesses of plate for butt joints by the leftward method is given in Fig. 100.

Rightward Welding

This method was introduced some years ago to compete with electric arc welding in the welding of plate over $\frac{3}{16}$ in. thick, since the leftward method has the disadvantages just mentioned

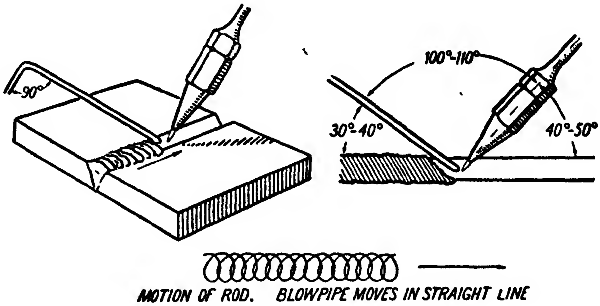


Fig. 101*a*. Rightward welding

Fig. 101*b*. Rightward weld in $\frac{3}{8}''$ m/s plate

on welding thick plate. This method has definite advantages over the leftward method on thick plate, but the student should be quite aware of its limitations and use it only where it has a definite advantage.

In this method the weld progresses along the seam from left to right, the rod following the blowpipe. The rod is given a rotational or circular motion, while the blowpipe moves in practically a straight line as illustrated in Fig. 101. The angle between blowpipe and rod is greater than that used in the leftward method.

When using this method good fusion can be obtained without a V up to $\frac{5}{16}$ in. plate. Above $\frac{5}{16}$ in. the plates are prepared with a 60° V, and since the blowpipe has no side to side motion the heat is all concentrated in the narrow V, giving good fusion. The blowpipe is pointing backwards towards the part that has been welded and thus there is no likelihood of the molten metal being pushed over any of the unheated surface giving poor fusion.

A larger blowpipe tip is required for a given size plate than in leftward welding, because the molten pool is controlled by the pipe and rod but the pipe has no side to side motion. This larger flame gives greater welding speed, and less filler rod is used in the narrower V. The metal is under good control and plates up to $\frac{5}{8}$ in. thick can be welded in one pass. Because the blowpipe does not move except in a straight line, the molten metal is agitated very little and excess oxidation is prevented. The flame playing on the metal just deposited helps to anneal it, while the smaller volume of molten metal in the V reduces the amount of expansion. In addition, a better view is obtained of the molten pool, resulting in better penetration.

It is essential however, in order to ensure good welds by this method, that blowpipe and rod should be held at the correct angle, the correct size tip and filler rod should be used, and the edges prepared properly (Fig. 102). The rod diameter, as will be seen from Fig. 102, is about half the thickness of the plate, being welded up to $\frac{5}{16}$ in. plate, and half the thickness $+\frac{1}{32}$ in. when welding V'd plate. The blowpipe tip is increased in size from one using about 11 cu. ft. per hour with the leftward method, to one using about 13 cu. ft. per hour, when welding $\frac{1}{8}$ in. plate. If too large diameter filler rods are used, they melt too slowly causing poor penetration, and poor fusion. Small rods melt too quickly and reinforcement of the weld is difficult. Rightward welding has no advantage on plates below $\frac{1}{4}$ in. thick and is rarely used below this thickness, the leftward method being preferred.

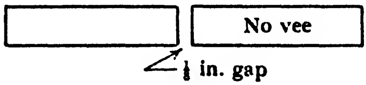
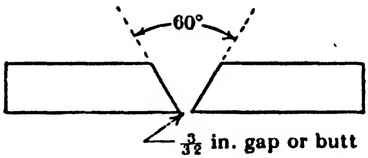
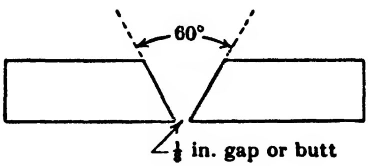
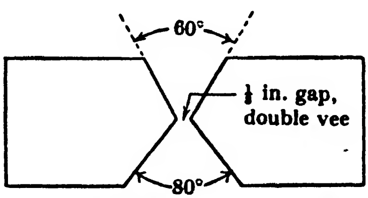
Thickness of Plate		Diameter of Rod
¼ in.		⅛ in.
5/16 in.		5/32 in.
⅜ in.		3/16 in.
½–1 in.	 Both sides must be V or U preparation from 1 in. upwards. Welded in flat position	¼ in.

Fig. 102. Rightward welding. Preparation of butt joints

The advantages of the rightward method on thicker plate may be summarised as:

(1) Less cost per foot run due to less filler rod being used and increased speed.

(2) Welds made much faster.

(3) Less expansion and contraction.
(4) Annealing action of the flame on the weld metal.
(5) Better view of the molten pool, giving better control of the weld.

Its drawback is that since the flame is playing backwards over the weld there is no preheating of the seam. To remedy this, and to make welding faster, the multi-jet blowpipe may be used on thicker sections.

Rightward Welding with Preheating Flame (Multi-jet Blowpipe)

In this method the blowpipe has a double tip. Welding is carried out in the rightward manner with the two flames adjusted to the neutral condition. The right-hand jet now preheats the V and enables the left-hand jet to bring the metal up to welding heat more rapidly (Fig. 103). The jets are normally each smaller

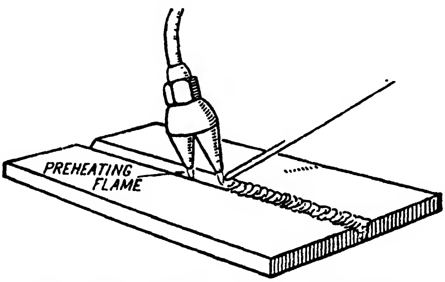


Fig. 103. Two-jet method of welding

than those in the single-jet method, so that the gas consumption is only slightly more (10 %) than before. Because the speed of welding is so much increased, the final cost of the weld is reduced. This method is normally used on plate of $\frac{1}{4}$ to $\frac{1}{2}$ in section and is useful for tank seams, pipe welds, fillet welds, etc. In special cases a three-jet blowpipe can be used, this giving two preheating flames.

Vertical Welding

The preparation of the plate for welding greatly affects the cost of the weld, since it takes time to prepare the edges, and the preparation given affects the amount of filler rod and gas used. Square edges need no preparation and require a minimum of filler rod. In leftward welding square edges are limited to $\frac{1}{8}$ in. and less. In vertical welding, up to $\frac{3}{16}$ in. plate can be welded with no V'ing with the single operator method, while up to $\frac{5}{8}$ in. plate can be welded with no V'ing with the two-operator method, the welders working simultaneously on the weld from each side of the plate. The single-operator method is the most economical up to $\frac{3}{16}$ in. plate.

The single-operator method (up to $\frac{3}{16}$ in. plate) requires more skill in the control of the molten metal than in downhand welding. Welding is performed either from the bottom upwards, and the rod precedes the flame as in the leftward method, or from the top downwards, in which case the metal is held in place by the blowpipe flame. This may be regarded as the rightward method of vertical welding, since the flame precedes the rod down the seam. In the upward method the aim of the welder is to use the weld metal which has just solidified as a 'step' on which to place the molten pool. A hole is first blown right through the seam, and this hole is maintained as the weld proceeds up the seam, thus ensuring correct penetration and giving an even back bead.

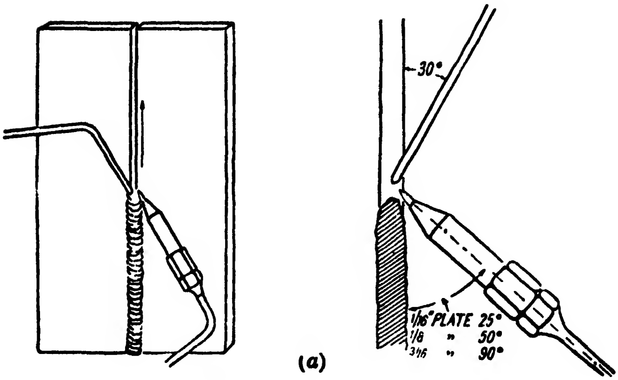
In the vertical welding of thin plate where the edges are close together, such as for example in a cracked automobile chassis, little filler rod is needed and the molten pool can be worked upwards using the metal from the sides of the weld. Little blowpipe movement is necessary when the edges are close together, the rod being fed into the molten pool as required. When the edges are farther apart, the blowpipe can be given the usual semicircular movement to ensure even fusion of the sides.

From Fig. 104 it will be noted that as the thickness of the plate increases, the angle of the blowpipe becomes much steeper.

When welding downwards much practice is required (together with the correct size flame and rod), in order to prevent the molten metal from falling downwards. This method is excellent practice to obtain perfect control of the molten pool.

Double-operator Vertical Welding

The flames of each welder are adjusted to the neutral condition, both flames being of equal size. To ensure even supply of gas to each pipe the blowpipes can be supplied from the same



(a)

(b) Vertical weld in $\frac{1}{4}''$ m/s plate

Fig. 104. Single-operator vertical welding

gas supply. It is possible to use much smaller jets with this method, the combined consumption of which is less than that of a single blowpipe on the same thickness plate. Blowpipes and rods are held at the same angles by each operator, and it is well that a third person should check this when practice runs are being done. To avoid fatigue a sitting position is desirable, while, as for all types of vertical welding, the pipes and tubes should be as light as possible. Angles of blowpipes and rods are shown in Fig. 105.

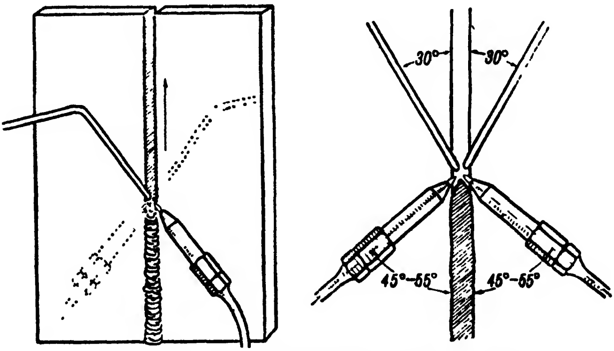


Fig. 105. Double-operator vertical welding

This method has the advantage that plate up to ⅝ in. thick can be welded without preparation, reducing the gas consumption and filler rod used, and cutting out the time required for preparation. When two operators are welding ½ in. plate, the gas used by both is less than 50 % of the total consumption of the blowpipe when welding the same thickness by the downhand rightward method. Owing to the increased speed of welding and the reduced volume of molten metal, there is a reduction in the heating effect, which reduces the effects of expansion and contraction.

Overhead Welding

Overhead welding is usually performed by holding the blowpipe at a very steep angle to the plate being welded. The molten pool is entirely controlled by the flame and, by holding it almost at right angles to the plate, this enables the pool to be kept in position.

Difficulty is most frequently found in obtaining the correct amount of penetration. This is due to the fact that as sufficient heat to obtain the required penetration is applied, the molten pool becomes more fluid and tends to become uncontrollable. With the correct size of flame and rod, however, and practice,

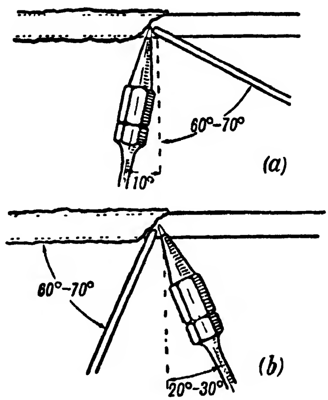


Fig. 106*a*. Leftward overhead welding. Flame is used to position metal melted from the rod into the molten pool

Fig. 106*b*. Rightward overhead welding. Blowpipe has little motion. Rod describes criss-cross movement side to side

this difficulty can be entirely overcome and sound welds made. Care should also be taken that there is no undercutting along the edges of the weld.

A comfortable position and light blowpipe and tubes are essential if the weld to be made is any fair length, as fatigue of the operator rapidly occurs in this position and precludes the making of a good weld.

The position of blowpipe and rod for the leftward technique are shown in Fig. 106*a*, while Fig. 106*b* shows their relative positions when the rightward method is used. The rightward method is generally favoured, but it must again be stressed that considerable practice is required for a welder to become skilled in overhead welding.

Lindewelding

This method was devised by the Linde Co. of the United States for the welding of pipe lines (gas and oil), and for this type of work it is very suitable. Its operation is based on the following facts:

(1) When steel is heated in the presence of carbon, the carbon will reduce any iron oxide present, by combining with the oxygen and leaving pure iron. The heated surface of the steel then readily absorbs any carbon present.

(2) The absorption of carbon by the steel lowers the melting point of the steel (e.g. pure iron melts at 1500° C., while 0·2 % carbon steel melts at 1130° C.).

In Lindewelding the carbon for the above action is supplied by using a carburising flame. This deoxidises any iron oxide present and then the carbon is absorbed by the surface layers, lowering their melting point. By using a special rod, a good sound weld can be made in this way at increased speed.

Let us now consider the method in detail. The standard welding blowpipe is used, with a tip one size larger than for normal welding of the same thickness plate. It is essential to have a 'soft' flame for the work, otherwise the molten metal, owing to the large size of the molten pool, tends to get out of control. The plates are prepared with a 60° V and the rightward method of welding used (a multi-jet blowpipe with preheating jet can be used to advantage). The rightward method is used because the welder must have full view of the molten pool, and the reducing envelope of the flame must play over the metal just deposited, protecting it from the atmosphere, and annealing it, giving the excess carbon time to diffuse throughout the weld, and preventing high carbon-content layers (with their resulting brittleness) from forming.

Flame and Rod. The flame is adjusted to be carburising, so that the feathery white plume, denoting excess acetylene, is from 1 to 1½ times the length of the inner blue cone (see Fig. 107 *a*). The special filler rods contain silicon and manganese, and the size of the rod is slightly larger than that normally used for the same thickness plate, owing to the greater speed of welding.

Technique. The rod and blowpipe are held at a greater angle to each other than in rightward welding, each making an angle of 25 to 30° with the horizontal (see Fig. 107*b*). Owing to the rapid rate at which the surface layers melt or 'sweat', the rod and blowpipe are each moved to and fro along the seam, the blowpipe alternately preheating the V and the rod, as shown in

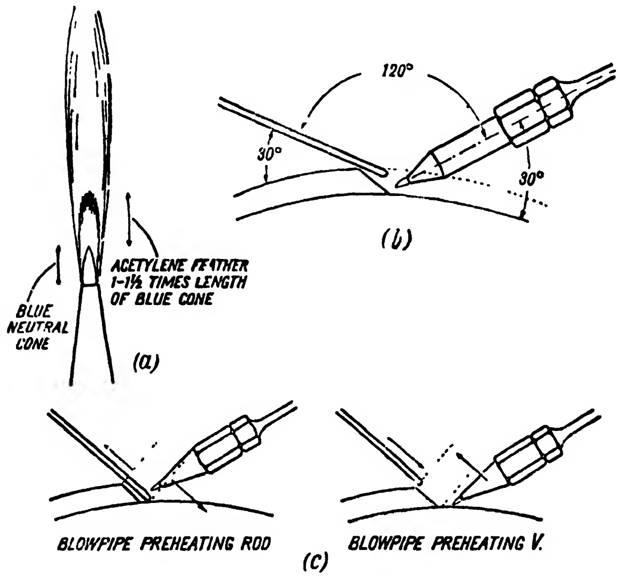


Fig. 107. (*c*) Motion of blowpipe and rod in Lindewelding

Fig. 107*c*. Because of this 'concertina' motion we have a much longer molten pool than in normal welding. In addition, the rod may be given a slight side to side motion, so that it is actually describing an elongated ellipse. The blowpipe is given as little sideways motion as possible to prevent loss of heat. On commencing the weld the flame is applied to the bottom of the V and then to the rod, and thus both are heated. The sides of the V then begin to sweat, and the welding rod is now melted and the molten metal is protected by the fluxing and deoxidising agents in the silicon-manganese filler rod. Weld metal and parent metal thus form an excellent bond with each other, because no oxides exist between the sweating surface and the weld metal.

NOTE. The parent metal is not molten except for the thin surface layer, therefore this method is totally different in principle from the normal fusion weld.

Care should be taken not to puddle the metal or this may cause oxidation of the weld. Reinforcement of the surface of the weld should be slight, and little or no ripple effect should be obtained on the surface.

Lindewelding has the following advantages:

(1) Little loss of carbon compared with the neutral flame method of welding.
(2) No surface oxide is present on the sides of the V to cause poor fusion or adhesion.
(3) Welding speed is greater than with the rightward method of welding.
(4) The weld has great strength and ductility.
(5) The technique is easily learnt.

At present the method is almost exclusively used on pipe work and is performed in the downhand position only. There is no reason, however, why it should not have other applications in the future.

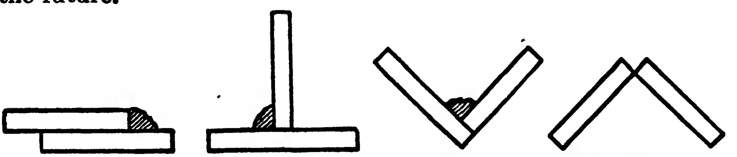
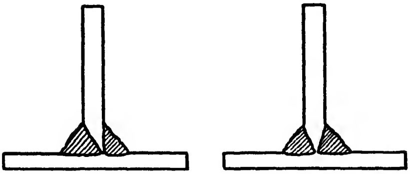


Fig. 108. Types of fillet welds

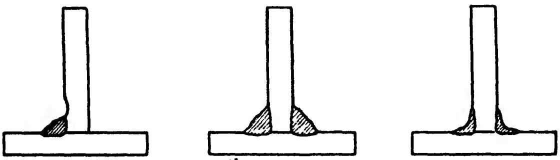
Fillet Welding

In making fillet welds (Fig. 108), care must be taken that, in addition to the precautions taken regarding fusion and penetration, the vertical plate is not undercut as in Fig. 110*a*, and the weld is not of a weakened section as in Fig. 110*c*. A lap weld may be regarded as a fillet, but no difficulty will be experienced with undercutting, since there is no vertical leg.

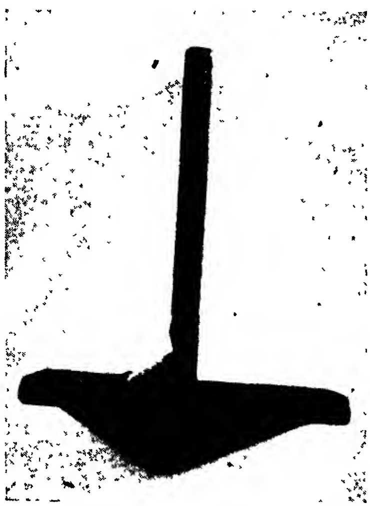


(a) SINGLE V PREPARATION (b) DOUBLE V PREPARATION

Fig. 109



(a) UNDERCUT (b) GOOD WELD (c) WEAK SECTION



(*d*) Fillet weld showing deep undercut

Fig. 110

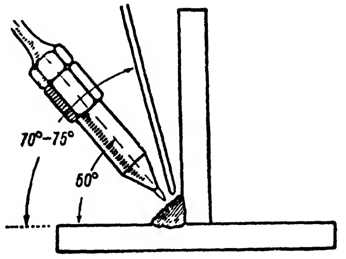


Fig. 111

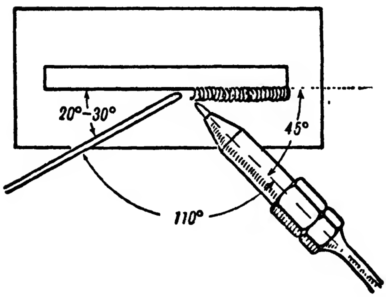


Fig. 112

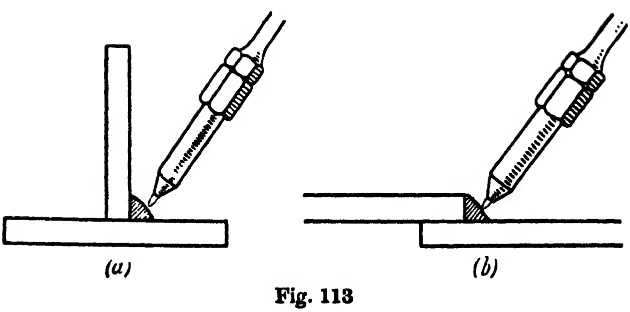


Fig. 113

The blowpipe and rod must be held at the correct angles. Holding the flame too high produces undercutting, and the tip of the cone should be held rather more towards the lower plate, since there is a greater mass of metal to be heated in this than in the vertical plate (Figs. 113*a* and *b*). Figs. 111 and 112 show the angles of the blowpipe and rod, the latter being held at a steeper angle than the blowpipe. Fillet welding requires a larger size tip than when butt welding the same section plate, owing

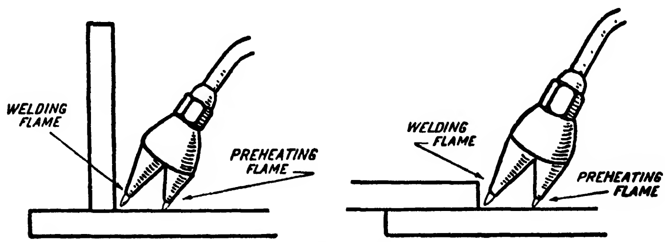


Fig. 114

to the greater amount of metal adjacent to the weld. Because of this, multi-jet blowpipes can be used to great advantage for fillet welding. Fig. 114 shows the position of the multi-jet blowpipe in making two types of weld, a fillet and a lap. The single V (Fig. 109) preparation is used for joints which are subjected to severe loading, while the double V preparation is used for thick section plate when the welding can be done from both sides. The type of preparation therefore depends entirely on the service conditions, the unprepared joint being quite suitable for most normal work.

Cast-Iron Welding (*see also* Bronze Welding of Cast Iron)

Cast iron, because of its brittleness, presents a different problem in welding from steel. We may consider three types—grey, white and malleable.

The grey cast iron is softer and tougher than the white, which is hard and brittle. The good mechanical properties of grey cast iron are due to the presence of particles of free carbon or graphite, which separate out during slow cooling. When the cooling is rapid, it is impossible for the cementite (iron carbide) to decompose into ferrite and graphite; hence the structure consists of masses of cementite embedded in pearlite, this giving the white variety of cast iron with its hardness and brittleness.

The other constituents of cast iron are silicon, sulphur manganese and phosphorus. Silicon is very important, because it helps to increase the formation of graphite, and this helps to

Fig. 115. Oxy-acetylene fusion weld in cast iron. ×100

soften the cast iron. Manganese makes the casting harder and stronger. It has a great affinity for sulphur and, by combining with it, prevents the formation of iron sulphide, which makes the metal hard and brittle. Phosphorus reduces the melting point and increases the fluidity. If present in a greater proportion than 1 % it tends to increase the brittleness. Sulphur tends to prevent the formation of graphite and should not exceed 1 %. It is added to enable the outer layers to have a hard surface (chill casting), while the body of the casting is still kept in the grey state.

The aim of the welder should be always, therefore, to form grey cast iron in the weld (Fig. 115).

Preparation. The edges are V'd out to 90° on one side only up to $\frac{3}{8}$ in. thickness and from both sides for greater thicknesses. Preheating is essential, because not only does it prevent cracking due to expansion and contraction, but by enabling the weld to cool down slowly, it causes grey cast iron to be formed instead of the hard white unmachinable deposit which would result if the weld cooled off rapidly. Preheating may be done by blow-pipe, forge or furnace, according to the size of the casting.

Preheating Furnace

In the absence of a muffle furnace a very useful one can be made as shown in Fig. 17*b*. It is built up of firebricks, and either large Bunsen gas burners or charcoal can be used as the source of heat.

The furnace is built up so as to enclose completely the casting to be preheated and the top covered over with a steel or asbestos sheet. When gas burners are used, the casting should be placed so that it is heated evenly throughout its mass. For example, a cylinder block would be mounted the right way up so that the outside and the inside of the bores were heated by the flames. Upon reaching dull red heat (600–700° C.) the top is removed together with any bricks as required, and the casting turned so that the part to be welded is horizontal. The welding is performed, and the furnace built up again, the top placed on and the casting raised to dull red heat and then allowed to cool out in the furnace for several hours according to size.

When charcoal is used, it is filled around the casting so as to cover it. The top is placed on the furnace but lifted a little so as to allow air to circulate. The charcoal is ignited by the welding torch through spaces in the firebricks at the bottom of the furnace.

Since in this case the heat is more evenly distributed, the casting can be placed so as to be most easily welded. This saves moving it when it is red hot.

After welding, more charcoal is placed round the casting to raise its temperature again, the top placed on, and then the whole is allowed to cool off slowly.

Welds performed in this manner are entirely satisfactory.

When it is desired to protect machined surfaces from oxidation and scaling during welding, as for example the bores of cylinders, they should be coated with a mixture of graphite and oil or grease. This will preserve the machined surface.

Blowpipe, Flame, Flux and Rod. The neutral flame is used, care being taken that there is not the slightest trace of excess oxygen, which would cause a weak weld through oxidation, and the metal must not be overheated. The inner cone should be about $\frac{1}{8}$ to $\frac{3}{16}$ in. away from the molten metal. If it touches the molten metal, hard spots will result. The flux (of alkaline borates) should be of good quality to dissolve the oxide and prevent oxidation, and it will cause a coating of slag to form on the surface of the weld, preventing atmospheric oxidation. Ferro-silicon and super-silicon rods, containing a high percentage of silicon, are the most suitable rods to use.

Technique. The welding operation should be performed on the dull red-hot casting with the rod and blowpipe at the angles shown in Fig. 116 and done in the leftward manner. The rod is

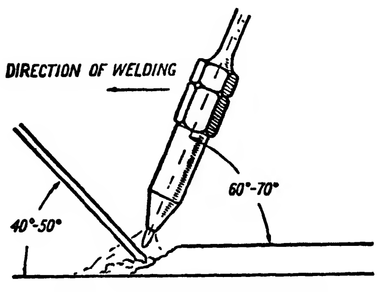


Fig. 116. Cast-iron welding

dipped into the flux at intervals, using only enough flux to remove the oxide. It will be noticed that as the flux is added, the metal flows more easily and looks brighter, and this gives a good indication as to when flux is required. The excessive use of flux causes blowholes and a weak weld. The rod should be pressed down well into the weld, removing a good percentage of the slag and oxide. Very little motion of the blowpipe is required and the rod should not be stirred round continuously, as this means the formation of more slag with more danger of entrapping it in the weld. Cast-iron welds made by beginners often have brittle parts along the edges, due to their not getting under the oxide and floating it to the top.

After Treatment. The slag and oxide on the surface of the finished weld can be removed by scraping and brushing with a wire brush, but the weld should not be hammered. The casting is then allowed to cool off very slowly, either in the furnace or fire, or if it has been preheated with the flame, it can be covered by an asbestos sheet or put in a heap of lime, ashes, or coke, to cool. Rapid cooling will result in a hard weld with possibly cracking or distortion.

Malleable Cast Iron

This is unsuitable for welding with cast-iron rods because of its structure. If attempted it invariably results in hard, brittle welds having no strength. The best method of welding is with the use of bronze rods, and is described under 'Bronze Welding'.

Bronze Welding

By the use of such rods as nickel-bronze, silicon-bronze and manganese-bronze, a sound bond can be made on steel, cast iron, copper, brass, etc., with a much lower temperature (800 to 900° C.) than is usual in fusion welding, since these alloys have a much lower melting point than the parent metal. These bronzes also have a tensile strength of 26 to 28 tons per sq. in., which is greater than that of cast iron, for example.

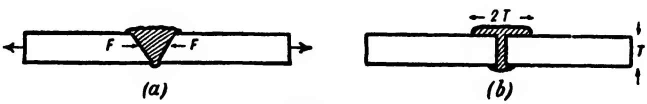


Fig. 117

(*a*) When this specimen is subjected to a tensile pull as shown, the faces *F* of the joint are partly in shear

When the bronze runs on to the metal surface, heated to the correct temperature, it adheres firmly to it, and (to use a soldering term) it is said to 'tin' the surface. For a satisfactory bronze weld it is essential that the metal surface should tin well, and for this reason bronze welding is not possible on burnt or dirty cast iron, since the bronze will not tin the surface.

A weld between bronze and the parent metal has great strength in shear (Fig. 117*a*), and because of this V'ing or bevelling should be done whenever possible. If no V'ing is done, the width of the deposit on the face of the weld should be at least twice the thickness of the plate, and it should penetrate right through and round the edges on the underside (Fig. 117*b*).

A special type of joint has been developed (Fig. 118) to give greatly increased strength, as for example in cast-iron work. This joint makes full use of the strength of the bond between the weld and parent metal when in shear.

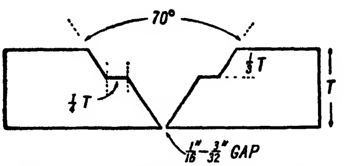


Fig. 118. 'Shear V' preparation

General Method of Preparation for Bronze Welding

All impurities such as scale, oxide, grease, etc. should be removed, as these would prevent the bronze tinning the parent metal. The metal should be well cleaned on both upper and lower faces for at least ½ in. on each side of the joint, so that the bronze can overlap the sides of the joint, running through and under on the lower face.

Bronze welding is unlike brazing in that the heat must be kept as local as possible by using a small flame and welding quickly. The bronze must flow in front of the flame for a short distance only, tinning the surface, and by having sufficient control over the molten bronze, welding may be done in the overhead position. Too much heat prevents satisfactory tinning. We will now consider the bronze welding of special metals.

Cast Iron

Bevel the edges to a 90° V, round off the sharp edges of the V, and clean the casting well. Preheating may be dispensed with unless the casting is of complicated shape, and the welding may often be done without dismantling the work. If preheating is necessary it should be heated to 450° C., and on completion cooling should be as slow as possible as in the fusion welding of cast iron.

Blowpipe, Flame and Rod. The blowpipe may be about two sizes smaller than for the same thickness steel plate, and the flame is adjusted so as to give a slight excess of oxygen. If a second deposit is to be run over the first, the flame is adjusted to a more oxidising condition still for the subsequent runs, the inner cone being usually only about $\frac{3}{4}$ths of its neutral length. The best flame condition can easily be found by trial. Rods of manganese bronze are very suitable, while for extra strength nickel-bronze rods can be used, the bronze flux being of the borax type.

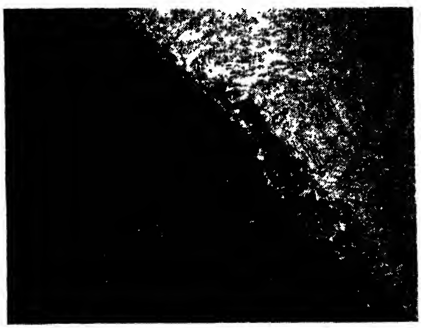


Fig. 119. Bronze weld in cast iron. × 100

Technique. The leftward method is used with the rod and blowpipe held as in Fig. 120, the inner cone being held well away from the molten metal. The rod is wiped on the edges of the cast iron and the bronze tins the surface. It is sometimes advisable to tilt the work so that the welding is done uphill, as shown in Fig. 120. This gives better control. Do not get the work too hot.

Vertical bronze welding of cast iron can be done by the two-operator method, and often results in saving of time, gas and rods and reduces the risk of cracking and distortion.

The edges are prepared with a double 90° V and thoroughly cleaned for ½ in. on each side of the edges. The blowpipes are held at the angle shown in Fig. 121 *a*. Blowpipe and rod are given a side to side motion, as indicated in Fig. 121 *b*, as the weld proceeds upwards, so as to tin the surfaces.

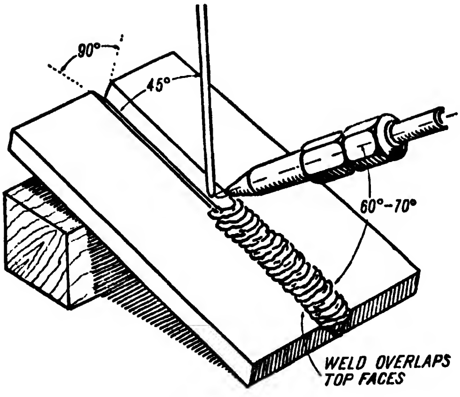


Fig. 120. Bronze welding cast iron

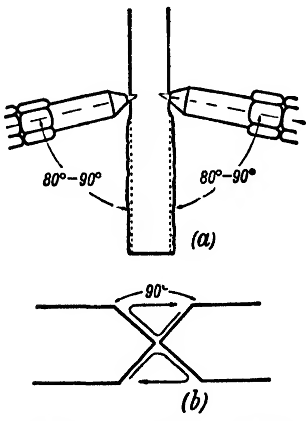


Fig. 121. (*a*) Two-operator vertical bronze welding of cast iron.
(*b*) Showing motion of pipe and rod

If the cast-iron sections are very thick, cleats can be used to position the metal while molten. The cleats may be of $1 \times \frac{1}{4}$ in. up to $1 \times \frac{3}{8}$ in. mild steel and can extend for about $\frac{3}{8}$ in. on each side of the 90° V, the edges of which are rounded. The cleats are curved so as to give a reinforced section to the weld (Fig. 122).

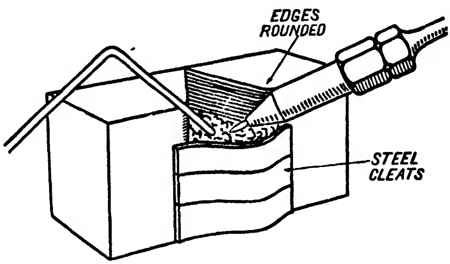


Fig. 122. Bronze welding with cleats

Malleable Cast Iron

The bronze welding of malleable castings may be stated to be the only way to ensure any degree of success in welding them. Both types (blackheart and whiteheart) can be welded satisfactorily in this way, since the heat of the process does not materially alter the structure. The method is the same as for cast iron, using nickel-bronze or manganese-bronze rods and a borax type flux.

Steel

In cases where excessive distortion must be avoided, or where thin sections are to be joined to thick ones, the bronze welding of steel is often used, the technique being similar to that for cast iron, except, of course, that no preheating is necessary.

Galvanised Iron

This can be easily bronze welded, and will result in a strong corrosion-resisting joint, with no damage to the zinc coating. If fusion welding is used, the heat of the process would of course burn the zinc (or galvanising) off the joint and the joint would then not resist corrosion.

Preparation, Flame and Rod. For galvanised sheet welding, the edges of the joint are tack welded or held in a jig and smeared with a silver-copper flux. Thicker plates and galvanised pipes are bevelled 60 to 80° and tacked to position them. The smallest possible nozzle should be used (50 to 70 litres up to 16 S.W.G.) and the flame adjusted to be slightly oxidising. A silicon-bronze rod is very suitable.

Technique. No side to side motion of the blowpipe is given, the flame being directed on to the rod, so as to avoid overheating the parent sheet. The rod is stroked on the edges of the joint so as to tin them. Excessive flux *must* be washed off with hot water.

Copper

Tough pitch copper can be readily bronze welded owing to the much lower temperature of the process compared with fusion welding.

Preparation, Flame and Rod. Preparation is similar to that for cast iron. Copper tubes can be bell mouthed, as in Fig. 123. Special joints are available for multiple branches. The blowpipe tip should be small and will depend on the size of the

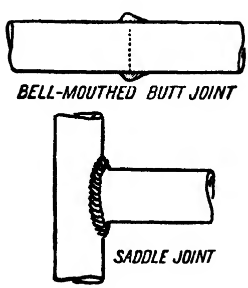


Fig. 123

work or the diameter of the pipe to be welded, and should be chosen so that the bronze flows freely but no overheating occurs. The flame should be slightly oxidising, and if a second run is made, it should be adjusted slightly more oxidising still (inner cone about ¾ths of its normal neutral length). Silicon-bronze rods and a borax type flux are very suitable.

Technique. The method is similar to that for cast iron, and the final difference between the bronze-welded and brazed joint is that the former has the usual wavy appearance of the oxy-

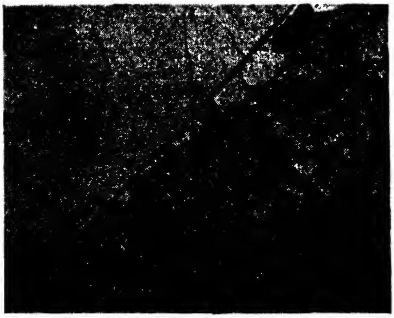


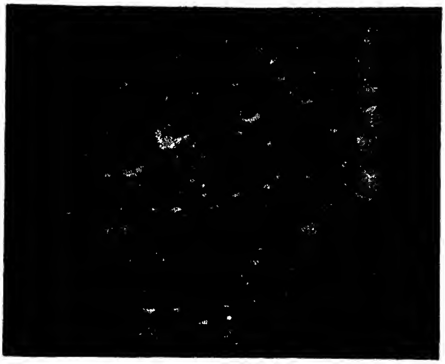
Fig. 124. Bronze weld in copper. × 100

Fig. 125. Bronze weld in copper. × 250

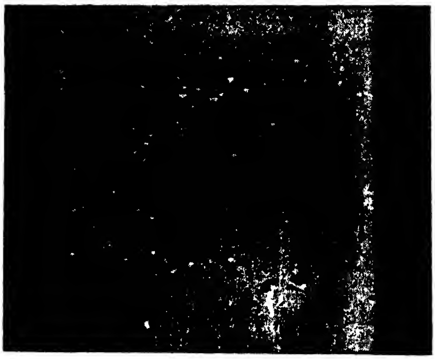
acetylene weld, while the latter has a smooth appearance, due to the larger area over which the heat was applied. The bronze joint is, of course, much stronger than the brazed one.

Brasses and Zinc-containing Bronzes

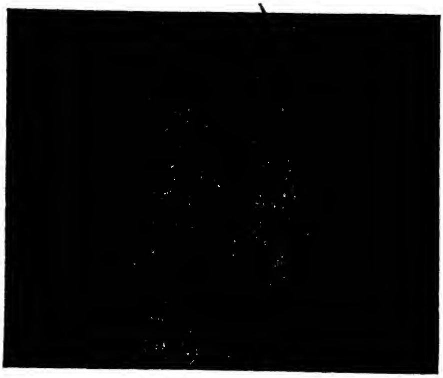
Since the filler rod now melts at approximately the same temperature as the parent metal, this may now be called fusion welding. When these alloys are heated to melting point, the zinc is oxidised, with copious evolution of fumes of zinc oxide, and if this continued, the weld would be full of bubble holes and weak (Fig. 126). This can be prevented by using an oxidising flame, so as to form a layer of zinc oxide over the molten metal, and thus prevent further formation of zinc oxide, and vaporisation.



(*a*) Unsatisfactory brass weld made with neutral flame. Unetched, ×2·5



(*b*) Brass weld made with insufficient excess of oxygen. Unetched, ×2·5



(*c*) Correct brass weld made with adequate excess of oxygen. Unetched, ×2·5

Fig. 126

Preparation. The edges and faces of the joint are cleaned and prepared as usual, sheets above ⅛ in. thickness being V'd to 90°. Flux can be applied by making it into a paste, or by dipping the rod into it in the usual manner.

Rod and Flame. A silicon-bronze rod is most suitable, while a brass rod is used for brass welding, the colour of the weld then being similar to that of the parent metal. Owing to the greater heat conductivity, a larger size jet is required than for the same thickness of steel plate. The flame is adjusted to be oxidising, as for bronze welding cast iron, and the exact flame condition is best found by trial as follows. A small test piece of the brass or bronze to be welded is heated with a neutral flame and gives off copious fumes of zinc oxide when molten. The acetylene is now cut down until no more fumes are given off. If any blowholes are seen in the metal on solidifying, the acetylene should be further slightly reduced. The inner cone will now be about half its normal neutral length. Too much oxygen should be avoided, as it will form a thick layer of zinc oxide over the metal and make the filler rod less fluid.

The weld is formed in the 'as cast' condition, and hammering improves its strength. Where 60/40 brass rods have been used the weld should be hammered while hot, while if 70/30 rods have been used the weld should be hammered cold and finally annealed from dull red heat.

Tin–Bronze cannot be welded using an oxidising flame. Special rods and fluxes are available, however, with which good welds can be made. Urgent repairs may be safely carried out using a *neutral* flame and silicon-bronze rod with borax type flux.

Gilding Metal. For the weld to be satisfactory on completion, the weld metal must have the same colour as the parent metal. Special rods of various compositions are available, so that the colours will 'match'.

Aluminium Bronze can be bronze welded using a manganese-bronze or silicon-bronze filler rod and a flux specially mixed for the purpose. Fusion welding of aluminium bronze can also be performed where it is necessary for the weld to have the same properties and resistance to corrosion as the parent metal. Aluminium-bronze rods and a special flux are used.

Copper Welding

Tough pitch copper (that containing copper oxide, see p. 97) is difficult to weld, and so much depends on the operator's skill that it is advisable to specify deoxidised copper for all work in which welding is to be used as the method of jointing. Welds made on tough pitch copper often crack along the edge of the weld if they are bent, showing that the weld is unsound due to the presence of oxide, often along the lines of fusion. A *good* copper weld, on the other hand, can be bent through 180°

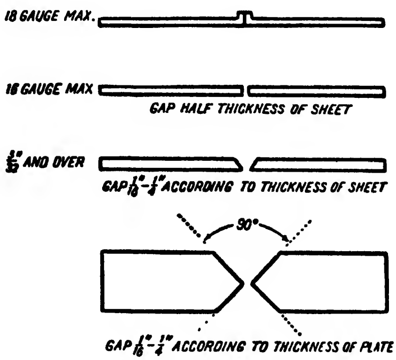


Fig. 127. Preparation of copper plates for welding

without cracking and can be hammered and twisted without breaking. This type of copper weld is strong and sound, free from corrosion effects, and is eminently satisfactory as a method of jointing.

Preparation. The surfaces are thoroughly cleaned and the edges are prepared according to the thickness, as shown in Fig. 127. In flanging thin sheet the height of the flange is about twice the plate thickness and the flanges are bent at right angles. Copper has a high coefficient of expansion, and it is necessary therefore to set the plates diverging at the rate of $\frac{3}{8}$ to $\frac{1}{2}$ in. per ft. run, because they come together so much on being welded. Since copper is weak at high temperatures, the weld should be well supported if possible, and an asbestos sheet between the weld and the backing strip of steel prevents loss of heat.

Tacking to preserve alignment is not advised owing to the weakness of the copper tacks when hot. When welding long seams, tapered spacing clamps or jigs should be used to ensure

Fig. 128*a*. Poor copper weld. Crack developed when bent

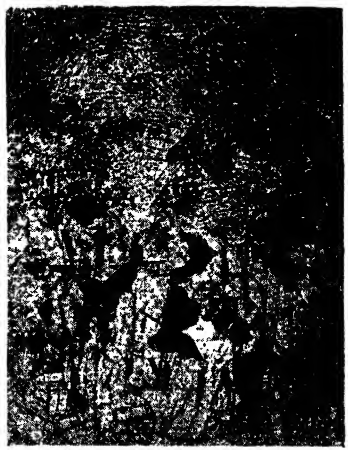


Fig. 128*b*. Oxy-acetylene weld in de-oxidised copper. × 100

correct spacing of the joint, care being taken that these do not put sufficient pressure on the edges to indent them when hot. A very satisfactory method of procedure is to place a clamp *C* at the centre of the seam and commence welding at a point say about one-third along the seam. *A* •——• *D* ——| *C* ————• *B*. Welding is performed from *D* to *B* and then from *D* to *A*.

Because of the high conductivity of copper it is essential to preheat the surface, so as to avoid the heat being taken from the weld too rapidly. If the surface is large or the metal thick, two blowpipes must be used, one being used for preheating. When welding pipes they may be flanged or plain butt welded, while T joints can be made as saddles.

Blowpipe, Flame and Rod. A larger nozzle than for the same thickness of steel should be used and the flame adjusted to be neutral or very slightly carbonising. Too much oxygen will cause the formation of copper oxide and the weld will be brittle. Too much acetylene will cause steam to form, giving a porous weld, therefore close the acetylene valve until the white feathery plume has almost disappeared. The welding rod should be of the deoxidised type, and many alloy rods, containing deoxidisers and other elements such as silver to increase the fluidity, are now available and give excellent results.

The weld may be made without flux, or a flux of the borax type used. Proprietary fluxes containing additional chemicals greatly help the welding operation and make it easier.

Technique. The blowpipe is held at a fairly steep angle, as shown in Fig. 129, to conserve the heat as much as possible. Great care must be taken to keep the tip of the inner cone

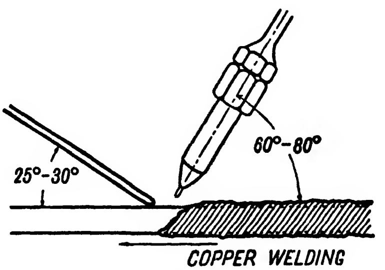


Fig. 129. Angles of blowpipe and rod

$\frac{1}{4}$ to $\frac{3}{8}$ in. away from the molten metal, since the weld is then in an envelope of reducing gases, which prevent oxidation. The weld proceeds in the leftward manner, with a slight sideways motion of the blowpipe. Avoid agitating the molten metal, and do not remove the rod from the flame but keep it in the molten pool. Copper may also be welded by the rightward method, which may be used when the filler rod is not particularly fluid.

The technique is similar to that for rightward welding of mild steel, with the flame adjusted as for leftward welding of copper.

Welding can also be performed in the vertical position by either single or double operator method, the latter giving increased welding speed.

After Treatment. Light peening, performed while the weld is still hot, increases the strength of the weld. The effect of cold hammering is to consolidate the metal, but whether or not it should be done depends on the type of weld and in general it is not advised. Annealing, if required on small articles, can be carried out by heating to 600–650° C.

Aluminium

The welding of aluminium, either pure or alloyed, presents no difficulty (Fig. 130*c*) provided the operator understands the difficulties which must be overcome and the technique employed.

The oxide of aluminium (alumina Al_2O_3), which is always present as a surface film and which is formed when aluminium is heated, has a very high melting point, much higher than that of the molten aluminium, and if it is not removed it would become distributed throughout the weld, resulting in weakness and brittleness. A good flux is necessary to dissolve this oxide and to prevent its formation.

Pure Aluminium

Preparation. The work should be cleaned of grease and scale with a wire brush. Sheets below 20 gauge can be turned up at right angles (as for mild steel) and the weld made without a filler rod. Over $\frac{1}{8}$ in. thick the edges should have a 90° V and over $\frac{1}{4}$ in. thick a double 90° V. Tubes may be bevelled if thick or simply butted with a gap between them. It is advisable always to support the work with backing strips of asbestos or other material, to prevent collapse when welding. Aluminium, when near its melting point, is extremely weak, and much trouble can be avoided by seeing that no collapsing can occur during the welding operation.

Blowpipe, Flame, Flux and Rod. The flame is adjusted to have a very slight excess of acetylene, and the rod of pure aluminium should be a little thicker than the section to be welded. A good flux must be used and should be applied to the rod as a varnish coat, by heating the end of the rod, dipping it in the flux and letting the tuft, which adheres to the rod, run over the surface for about 6 in. of its length. This ensures an even supply. Too much flux is detrimental to the weld.

Technique. The angle of the blowpipe and rod are shown in Fig. 130*a* (a slightly larger angle between the blowpipe and rod than for mild steel), and the welding proceeds in the leftward manner, keeping the inner cone well above the molten pool. The work may be tacked at about 6 in. intervals to preserve alignment, or else due allowance made for the joint coming in

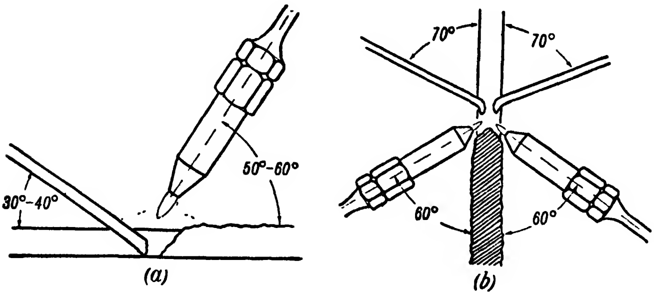


Fig. 130. (*a*) Aluminium welding.
(*b*) Aluminium welding, double operator method

as welded, like mild steel. As the weld progresses and the metal becomes hotter the rate of welding increases, and it is usual to reduce the angle between blowpipe and weld somewhat to prevent melting a hole in the weld. Learners are afraid of applying sufficient heat to the joint as a rule, because they find it difficult to tell exactly when the metal is molten, since it does not change colour and is not very fluid. When they do apply enough heat, owing to the above difficulty, the blowpipe is played on one spot for too long a period and a hole is the result.

The two-operator vertical method may be employed (as for cast iron) on sheets above ¼ in. thickness, the angle of the blowpipes being 50 to 60° and the rods 70 to 80°. This method gives a great increase in welding speed (Fig. 130*b*).

After Treatment. The flux, owing to its corrosive action, *must* be removed by washing and brushing the weld with hot water or with a warm 5 % nitric acid solution, followed by warm-water swill. If this is not carried out, corrosion will certainly occur. Hammering of the completed weld greatly improves and consolidates the structure of the weld metal, and increases its strength, since the deposited metal is originally in the 'as cast' condition and is coarse grained and weak. Annealing may also be performed and is beneficial.

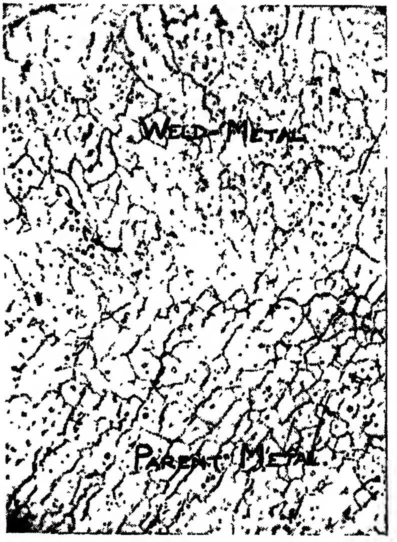


Fig. 130. (*c*) Oxy-acetylene weld in aluminium. × 45

Aluminium Alloy Castings and Sheets

The process for the welding of castings is very similar to that for the welding of sheet aluminium.

Preparation. The work is prepared by V'ing if the section is thicker than ⅛ in., and the joint is thoroughly cleaned of grease and impurities. Castings such as aluminium crankcases are usually greasy and oily (if they have been in service), the oil saturating into any crack or break which may have occurred. If the work is not to be preheated, this oil *must* be removed. It may be washed first in petrol, then in a 10 % caustic soda solution, and this followed by a 10 % nitric or sulphuric acid solution. A final washing in hot water should result in a clean casting. In normal cases in which preheating is to be done, filing and a wire brush will produce a clean enough joint, since the preheating will burn off the remainder.

If the casting is large or complicated, preheating should be done as for cast iron.[1] In any case it is advantageous to heat the work well with the blowpipe flame before commencing the weld.

Blowpipe, Flame, Rod and Flux. The blowpipe is adjusted as for pure aluminium and a similar flame used. The welding rod should preferably be of the same composition as the alloy being welded, but for general use a 5 % silicon-aluminium rod is very satisfactory. This type of rod has strength, ductility, low shrinkage, and is reasonably fluid. A 10 % silicon-aluminium rod is used for Alpax castings, while 5 % copper-aluminium rods are used for the alloys containing copper such as Y alloy and are very useful in automobile, aircraft and chemical industries. The deposit from this type of rod is harder than from the other types. Some of the rods available are: aluminium copper, 5 %; aluminium silicon, 5 %; aluminium silicon, 10–12 %; aluminium copper silicon; aluminium copper zinc; MG5 (AlMg) (DTD308); MG5 (AlMg) (DTD297).

Technique. The welding is carried out as for aluminium sheet, and the cooling of the casting after welding must be gradual.[2]

After Treatment. After welding, the metal is in the 'as cast' condition and is weaker than the surrounding areas of parent metal, and the structure of the deposited metal may be improved by hammering. The area near the welded zone, however, is annealed during the welding process and failure thus often tends to occur in the area alongside the weld, and not in the weld itself. Alloys such as BA/60A and BA/40D are examples of those alloys in which this type of failure occurs, since they do not improve with heat treatment. In the case of heat-treatable alloys, the welded zone can be given back much of its strength

[1] Care should be taken that the casting is not overheated, or collapse may occur. The temperature of the casting when ready for welding can be judged by the discoloration of a piece of white paper rubbed on it, or better still by tapping it. When at the correct heat a "dead" sound (as opposed to the normal ringing sound) should be emitted.

[2] When repairing cracked castings, any impurities which appear in the molten pool should be floated to the top, using excess flux if necessary.

by first hammering the weld itself and then heat treating the whole of the work.

For this to be quite successful it is essential that the weld should be of the same composition as the parent metal. If oxidation has occurred, however, this will result in a weld metal whose structure will differ from that of the parent metal and the weld will not respond to heat treatment. Since many of this type of alloys are 'hot short', cracking may occur as a result of the welding process.

Duralumin, Y alloy, hiduminium, etc. demand great care in welding because of these factors.

If sheets are anodised, the welding disturbs the area and changes its appearance. Avoidance of overheating, localising the heat as much as possible, and hammering, will reduce this disturbance to a minimum, but heat treatment will make the weld most inconspicuous.

Monel Metal and Nickel

Monel is a copper-nickel alloy containing approximately ⅔rds nickel and ⅓rd copper (a belt of ore was found in Canada having this natural composition). The actual composition is nickel 68·4 %, copper 29·14 %, iron 1·19 %, manganese 1·02 %, silicon 0·06 %, carbon 0·12 %, sulphur 0·008 %.

The following procedure will produce sound welds on either monel or nickel.

Preparation. Sheets thinner than 18 gauge can be bent up through an angle of about 75°, as shown in Fig. 131, and the edges melted together. The ridge formed by welding can then be hammered flat. Sheets thicker than 18 S.W.G. are bevelled with the usual 90° V and butted together. For corner welds on sheet less than 18 gauge the corners are flanged as shown, while for thicker plate the weld is treated as an open corner joint (see Fig. 131). Castings should be treated as for cast iron.

Blowpipe, Flame, Rod and Flux. The blowpipe tip should be one size larger than for the same thickness steel plate and the flame adjusted to have a slight excess of acetylene. The oxygen valve is closed slowly until the feathery white plume is very small, or until a small lilac-coloured flame can be seen darting in and out of the blue inner cone when viewed through blue glasses. Powdered *boric acid* (not borax) is the most satisfactory flux, and may be sprinkled along the joint or made

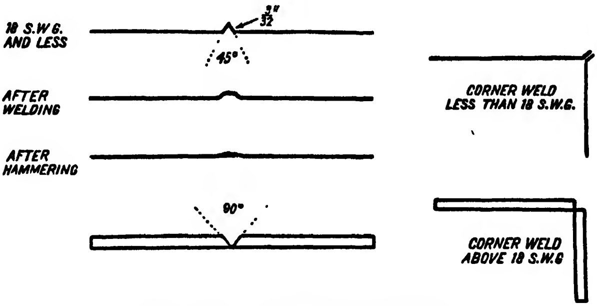


Fig. 181. Preparation of plates

into a solution with alcohol. On applying this solution to the joint with a brush, the alcohol evaporates and leaves a thin film of boric acid. A monel or nickel filler rod of the same thickness as the sheet being welded should be used.

Technique. Welding is done in the leftward manner. Care should be taken that in welding thicker sections the sides of the V do not melt inwards, as this tends to cause the copper and nickel to separate out, due to the heat of the flame. This can be avoided by adding sufficient filler rod into the V. Castings should be allowed to cool off slowly, as for cast iron.

Monel rods can be used for welding cast iron. The monel rod is used with a pure borax flux, and the welding is carried out as for cast iron, using the reducing flame as described for monel and nickel. Preheating is necessary for more complicated castings and the same precautions as for cast iron should be taken.

Inconel is a corrosion-resisting alloy of 80% nickel, 12–14% chromium, and the balance mainly iron. It can be welded in the same way as monel, using an inconel filler rod, a special inconel flux and a slightly reducing flame.

Special Steels: Nickel Clad Steel

This steel is produced by the hot rolling of pure nickel sheet on to steel plate, the two surfaces uniting to form a permanent bond. It gives a material having the advantages of nickel, but at much less cost than the solid nickel plate. It can be successfully welded by the oxy-acetylene process.

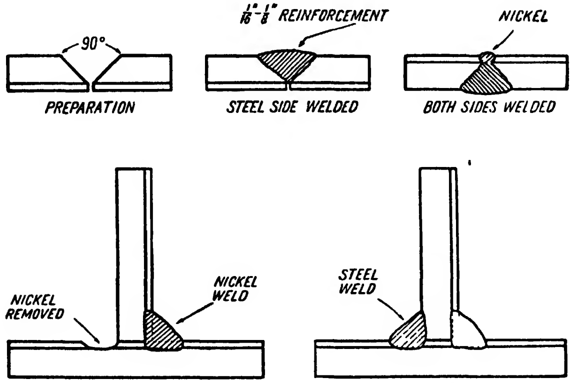


Fig. 132. Double fillet weld. Nickel clad steel

Preparation. The bevelled 90° butt joint is the best type. For fillet welds it is usual to remove (by grinding) the nickel cladding on the one side of the joint, as shown in Fig. 132, so as to ensure a good bond of steel to steel.

Technique. The weld is made on the steel side first, using a mild steel rod and the same technique as for mild steel. The nickel side is then welded, using a nickel rod and a slightly reducing flame as for welding monel and nickel. The penetration should be such that the nickel penetrates and welds itself into the steel weld.

Stainless Steels (see also pp. 74–76 for description of this class of steels)

Stainless steels of the martensitic and austenitic class can be welded by the oxy-acetylene process.

Preparation. Thin gauges may be flanged at 90° as for mild steel sheet and the edges fused together. Thicker sections are prepared with the usual 90° V and the surfaces cleaned of all impurities. The coefficient of expansion of the 18/8 austenitic steels is about 50% greater than that of mild steel, and consequently the sheets should be set diverging much more than for mild steel to allow for them coming together during welding. An alternative method is to tack the weld at both ends first, and then for sheets thinner than 18 gauge tack at 1 in. intervals, while for thicker sheets the tacks can be at 2 in. intervals. Cooling clamps are advised for the austenitic steels. The thermal conductivity is less than for mild steel, and thus the heat remains more localised. Unless care is taken, therefore, the beginner tends to penetrate the sheet when welding thin gauges.

Flame. The flame should be very slightly carburising (excess acetylene), there being the smallest trace of a white plume around the inner cone. The flame should be checked from time to time to make sure that it is in this condition, since any excess oxygen is fatal to a good weld, producing porosity, while too great an excess of acetylene causes a brittle weld.

Rod and Flux. The welding rod must be of the same composition as the steel being welded, the two types normally used being the 18/8 class, and one having a higher nickel and chromium content and suitable for welding steels up to a 25/12 chrome-nickel content. Since there is considerable variety in the amounts of the various elements added to stainless steels to improve their physical properties, such as molybdenum and tungsten in addition to titanium or columbium, it is essential that the analysis of the parent metal be known so that a suitable rod can be chosen. The steel makers and electrode makers will always co-operate in this matter. The rod should be of the same gauge or slightly thicker than the sheet being welded. No flux is necessary, but if difficulty is experienced with some steels in penetration, a special flux prepared for these steels should be used, and can be applied as a paste mixed with water.

Technique. Welding is performed in the leftward manner, and the flame is played over a larger area than usual because of the low thermal conductivity. This lessens the risk of melting a hole in the sheet. The tip of the inner cone is kept very close to the surface of the molten pool and the welding performed exactly as for the leftward welding of mild steel. No puddling should be done and the least amount of blowpipe motion possible used.

After Treatment. Martensitic stainless steels should be heated to 700 to 800° C. and then left to air cool. The non-weld decay proof steels, such as Staybrite, Silver Fox 620 and 20, Anka, etc., should be heated to 950 to 1100° C., depending on the particular steel, and then water quenched, if they are to encounter corrosive conditions, otherwise no heat treatment is necessary. The weld decay proof steels, such as Staybrite F.D.P., Silver Fox 22 and 25, Weldanka, etc., need no heat treatment at all.

The original silver-like surface can be restored to stainless steels which have scaled or oxidised due to heat by immersing in a bath made up as follows: sulphuric acid 8 %, hydrochloric acid 6 %, nitric acid 1 %, water 85 %. The temperature should be 65° C. and the steel should be left in for 10 to 15 minutes, and then immersed for 5 minutes or until clean in a bath of 10 % nitric acid, 90 % water, at 25° C.

Other baths made up with special proprietary chemicals with trade names will give a brighter surface. These chemicals are obtainable from the makers of the steel.

Stainless Iron

The welding of stainless iron results in a brittle region adjacent to the weld. This brittleness cannot be completely removed by heat treatment, and thus the welding of stainless iron cannot be regarded as completely satisfactory. When, however, it has to be welded the welding should be done as for stainless steel, using a rod specially produced for this type of iron.

Hard Surfacing and Stelliting

Surfaces of intense hardness can be applied to steel, steel alloys, cast iron or monel metal, by means of the oxy-acetylene flame. Hard surfaces may be deposited either on new parts so that they will have increased resistance to wear at reduced cost, or on old parts which may be worn, thus renewing their usefulness.

In addition, non-ferrous surfaces, such as bronze or stellite, may be deposited and are described under their respective headings.

The surfaces deposited may be hard and/or wear and corrosion-resisting. It is usual in the case of hard surfaces for the metal to be machinable as deposited, but to be capable of being hardened by quenching (see table of rods available in Appendix, p. 420).

We may divide the methods as follows:

(1) Building up worn parts with a deposit similar to that of the parent metal.

This process is very widely used, being cheap and economical, and is used for building up, for example, gear wheels, shafts, keys, splines, etc.

The technique employed is similar to that for mild steel, using a neutral flame and the leftward method. The deposit should be laid a little at a time and the usual precautions taken for expansion and distortion. Large parts should be preheated and allowed to cool out very slowly, and there are no difficulties in the application.

(2) Building up surfaces with rods containing, for example, carbon, manganese, chromium, silicon to give surfaces which have the required degree of hardness or resistance to wear and corrosion.

These surfaces differ in composition from that of the parent metal, and as a result the fusion method of depositing cannot be used, since the surface deposit would become alloyed with the base metal and its hardness or wear-resisting properties thus greatly reduced.

The method used is similar to that of Lindewelding (q.v.).

Technique. The flame is adjusted to have excess acetylene with the white plume from 2 to 2½ times the length of the inner cone. As explained on p. 154 the heated surface absorbs carbon, its melting point is reduced and the surface sweats. The rod is melted on to this sweating surface and a sound bond is made between deposit and parent metal with the minimum amount of alloying taking place.

This type of deposit, used for its wear-resisting properties, is usually very tough and is practically unmachinable. The surface is therefore usually ground to shape, but in many applications, such as in reinforcing tramway and rail crossings, it is convenient and suitable to hammer the deposit to shape while hot, and thus the deposit requires a minimum amount of grinding. The hammering, in addition, improves the structure.

In the case of the high carbon deposits, they can be machined or ground to shape and afterwards heat treated to the requisite degree of hardness.

Another method frequently used to build up a hard surface is to deposit a surface of cast iron in the normal way, using a silicon cast iron rod and flux. Immediately the required depth of deposit has been built up, the part is quenched in oil or water depending on the hardness required.

This results in a hard deposit of white cast iron which can be ground to shape, and which possesses excellent wear-resisting properties. This method is suitable only for parts of relatively simple shape, that will not distort on quenching, such as cam-shafts, shackle pins, pump parts, etc.

The use of carbon and copper fences in building up and resurfacing results in the deposit being built much nearer to the required shape, reducing time in welding and finishing and also saving material.

When hard surfacing cast iron, the surface will not sweat. In this case the deposit is first laid as a fusion deposit, with neutral flame, and a second layer is then 'sweated' on to this first layer. In this way the second layer is obtained practically free from any contamination of the base metal.

It will be seen, therefore, that the actual composition of the deposit will depend entirely upon the conditions under which it is required to operate. A table of alloy steel rods and uses is given in the Appendix, p. 420.

One of the best known and successful alloys which can be deposited is stellite, an alloy of cobalt, chromium and tungsten with carbon. It has intense resistance to wear and corrosion and preserves these properties at high temperatures, but it is very brittle. By depositing a surface of stellite on a more ductile metal we have an excellent combination.

Tips of stellite can be brazed on to lathe and cutting tools of all types, giving an excellent cutting edge on a less brittle shank. Stellite, however, can be welded directly on to surfaces, and in this form it is used for all types of duty, such as surfaces on shafts which have to stand up to great wear and corrosion, lathe centres, drill tips, etc.

Grade 1 (black tip) is recommended where the surfaces are subjected to abrasive wear, hardness being an essential feature. Grade 6 (red tip) gives a stronger and tougher deposit than grade 1. Can be used for valves, tappet heads, and surfaces subject to heavy shock and impact and also for large areas where grade 1 would be liable to crack. Grade 12 (green tip) gives a tougher deposit than grade 1 and is recommended for building up surfaces subjected not only to abrasion, but shock.

Stelliting Steel

Preparation. Scale, dirt and impurities are thoroughly removed and the parent metal is preheated. Preheating and slow cooling are essential to avoid cracking.

Small jets of water, playing on each side of the weld, can be used to limit the flow of heat and reduce distortion, when building up deposits on hardened parts such as camshafts.

Flame and Rod. A flame with an excess of acetylene is used, the white plume being about 2 to $2\frac{1}{2}$ times the length of the inner blue cone. Too little acetylene will cause the stellite to foam and bubble, giving rise to blowholes, while too much acetylene will cause carbon to be deposited around the molten metal. The tip should be one size larger than that for the same thickness steel plate, but the pressure should be reduced, giving a softer flame. For small parts $\frac{3}{16}$ in. diameter stellite rods can be used, while thicker rods are used for larger surfaces. Too much heat prevents a sound deposit being obtained, because some of the base metal may melt and mix with the molten stellite, thus modifying its structure.

Technique. The flame is directed on to the part to be surfaced, but the inner cone should not touch the work, both blowpipe and rod making an angle of 25–35° with the plate. When the steel begins to sweat the stelliting rod is brought into the flame and a drop of stellite melted on to the sweating surface of the base metal, and it will spread evenly and make an excellent bond with the base metal. The surfacing is continued in this way.

After Treatment. The part should be allowed to cool out very slowly to prevent cracks developing.

Stelliting Cast Iron

Preparation. Clean the casting thoroughly of oil and grease and preheat to a dull red heat.

Technique. Using the same type rod and flame as for stelliting steel, it is advisable first to lay down a thin layer and then build up a second layer on this. The reason for this is that more of the surface of the cast iron is melted than in the case of steel, and as a result the first layer of stellite will be diffused with impurities from the cast iron.

The flame is then played on the cast iron and the rod used to push away any scale. A drop of stellite is then flowed on to the surface, and the flame kept a little ahead of the molten pool so as to heat the cast iron to the right temperature before the stellite is run on. Cast-iron flux may be used to flux the oxide and produce a better bond.

Magnesium Alloys: Elektron. Wrought Alloys

Magnesium alloys are well known under their trade name of elektron, and the chief types suitable for welding are those known as AM503 and AZM. The alloy A4 is weldable but much less easily than AM503. AM503 contains aluminium, zinc, manganese, copper, silicon, with the remainder magnesium (see appendix for actual compositions), and is recommended for welding purposes. It is a sheet-metal alloy suitable for all types of aircraft work and can readily be beaten, bent and flanged.

AZM is less easily welded than AM503 and is used for structural purposes and highly stressed parts, being available as rods, bars, sections, sheets and forgings. It contains a much higher percentage of aluminium than AM503 and no silicon nor copper.

The density of these alloys compared with aluminium and a typical aluminium alloy can be seen from the following table. It will be observed that their weight is only roughly $\frac{5}{8}$ths of that of an equal volume of duralumin.

Alloy	Density	Specific Heat	Ultimate Stress in tons per sq. in.
Elektron: AM503	1·8	0·24	12–17
AZM	1·83	0·24	18–22
Aluminium	2·7	0·21	5–9
Duralumin	2·85	0·23	25–26

When a change of section occurs in magnesium alloys, they are more liable to fatigue failure than aluminium alloys; hence great care must be taken during welding that penetration occurs right through the joint, and that no scratches, slag inclusions and blowholes are present, or failure will occur at the reduced section thus introduced. In addition, they are liable to crack during welding and working, and if the metal is to be worked before or after welding, this should be done hot to avoid this danger of cracking, the temperatures for hot working being 270 to 330° C. for AM503 and 270 to 300° C. for AZM.

AM503 does not suffer from this liability to crack as much as AZM and is therefore more suitable for welding purposes. If AZM is being welded, the seams should be short (6 to 8 in.). Tubular designs with short welds have great strength and lightness.

Magnesium burns fiercely in air and readily oxidises. In welding the alloys, however, the conductivity of the metal enables the heat to be removed sufficiently rapidly to prevent burning. If a fire does occur, water should not be used, since

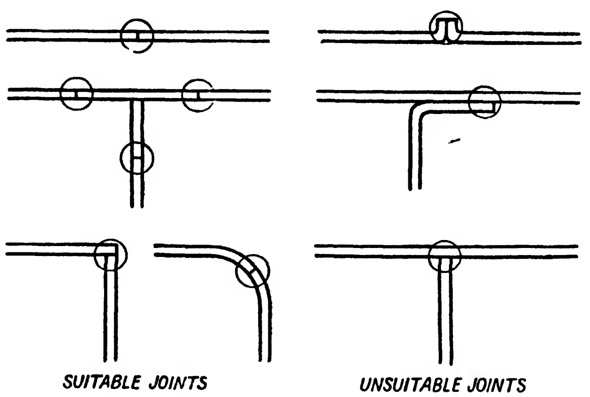


Fig. 133

hydrogen is evolved and forms an explosive mixture with the air. Asbestos sheets and sand are the best methods of extinguishing a magnesium alloy fire.

To reduce corrosion on the alloys under working conditions the surfaces are chromated, that is, are coated with a film of chromate which acts as a protective coating and gives the surface a brassy look.

The oxy-acetylene flame is the most suitable method of welding and the acetylene must be free from all impurities. The surface oxides must be removed by fluxes before welding, and these also help to prevent further oxidation. These fluxes usually consist of a base of magnesium chloride with additions of other metallic chlorides specially compounded for elektron, and they attack the metal very rapidly. Great care must therefore be taken in the design of the welded joints so that no flux can become entrapped in the joint and result in serious corrosion. Lapped and T joints should not be used, and welded tubes should have a means provided by which the interior can be thoroughly washed out when welding is finished. Examples of suitable and unsuitable joints are shown in Fig. 133.

Preparation. The method of preparing butt joints of various thicknesses is given in Fig. 134. The edges should be thoroughly cleaned of all grease and scale and the chromated surface removed from the line of welding leaving a bright surface. Owing to the liability to cracking when hot, the parts to be welded should be well supported by jigs or clamps.

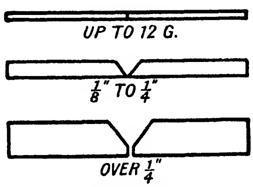


Fig. 134

AM503 must only be welded to itself and AZM similarly only to itself. Never weld AM503 to AZM. The filler rod *must* be of the same composition as the parent metal, i.e. AM503 or AZM. Suitable rod sizes are:

Gauge of Sheet	Size of Rod
20–14	$\frac{1}{16}$ in. diam.
$\frac{3}{32}$–$\frac{5}{32}$ in.	$\frac{1}{8}$ in. diam.
$\frac{5}{32}$–$\frac{1}{4}$ in.	$\frac{1}{4}$ in. diam. (seldom used)

Flux. The powdered flux (see p. 52) should be mixed with the liquid type to a creamy consistency and only a little prepared at a time, as it is hygroscopic and rapidly deteriorates. It should be applied by a brush to the welding rod and both sides of the joint (application to the heated rod will give a more uniform layer). The alloy should be tacked with about twice the number of tacks as for aluminium and then the work trued up again and refluxed if necessary.

Flame. The following table gives the approximate high pressure tip sizes for various thicknesses of sheets. The flame should be adjusted to be slightly reducing (excess acetylene), the white plume denoting excess acetylene showing clearly. The tip must give a clear and pointed flame and not be 'spread'.

Gauge of Sheet	Size of H.P. Tip	Gauge of Sheet	Size of H.P. Tip
18–22	50 litres	7 and 8	350 litres
14–18	75–100 litres	5 and 6	500 litres
11–12	150 litres	3 and 4	750 litres
9 and 10	225 litres	($\frac{1}{4}$ in.)	
($\frac{1}{8}$ in.)			

Technique. Welding may be done preferably by the leftward method and holding the flame as shown in Fig. 135. The flame preheats the work and little movement of blowpipe or rod is advised.

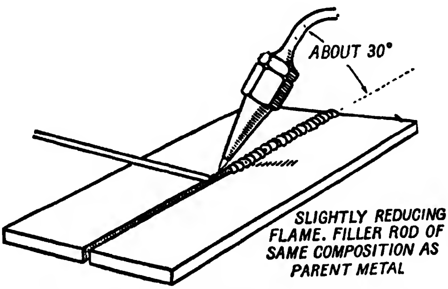


Fig. 135. Welding magnesium alloys

Long seams may be started a little away from the ends and these portions welded up afterwards, all tacks being fused well into the joint. Too slow a speed of welding will result in holes in the seam, while too fast a speed will result in poor fusion. Overheating the metal will cause discoloration of the surface, and results in a porous condition of the metal, and should be avoided. The less flux included in the weld the better, and for this reason with thick section sheets and castings the deposit may be built up well above the normal level, since slag and flux tend to accumulate in the upper layers, and these can then be removed by machining and chipping. This built up section should never be hammered back into the weld itself.

After Treatment. The weld should be allowed to cool, then brushed vigorously in hot soapy water to remove *all* traces of flux and then immersed in a hot 5% solution of potassium dichromate in water for at least an hour. Any parts left after welding and before chromating should be left totally immersed in this solution. Welds made in AM503 can be improved by hammering while hot. Welds in AZM should not be hammered hot, as cracks are liable to be set up in it.

After finishing, the weld should be minutely examined for cracks since, as before stated, the presence of these would greatly reduce the fatigue resistance.

A weld made in accordance with the above procedure is similar to the alloy in the 'as cast' condition, and its ductility is lower than that of the annealed metal. There is also a reduction in tensile strength of about 25% compared with the parent metal. Finally, the surface should be chromated after cleaning, and the finish made with a primer of zinc chromate in an oil base, followed by zinc oxide in a nitrocellulose base.

Casting Alloys

Elektron castings can be welded successfully by using the special rod (AZ102) and flux designed for the purpose.

Preparation. Support the casting on bricks and prepare by V-ing to 90°. Preheating should be done to 250–300° C. (test by discoloration of white paper when rubbed on casting) in a very slow furnace, preferably of the open coal gas type. Too rapid preheating may cause collapse.

Flux and Rod. The opposite side of the weld from the V should be painted with the flux made into paste form as for wrought alloys, and the rod of AZ102 should be warmed and its tip dipped into the flux as in normal welding operations using flux.

Flame. Use a similar flame to that for welding AM503 (slightly carbonising) and in general observe the same precautions and conditions as for welding aluminium.

Technique. Keep the direction of the blowpipe as in Fig. 135, and excess flux which is detrimental to the weld will be blown away by the flame if the manipulation is correct. Direct the flame on to the bottom of the V until molten, and then add filler rod, keeping the flame steady over the molten pool and not moving it from side to side nor up and down.

After Treatment. The casting must be allowed to cool slowly and should then be cleaned by washing and scrubbing with a wire brush in Bath No. 1; then wash, scrub and immerse for one minute in Bath No. 2; then boil for half an hour and scrub in Bath No. 1.

The contents of these baths are as follows:

No. 1. Dissolve about 15% of Potassium Dichromate in water, keep in a galvanised iron container and use hot.

No. 2. Add 10–15% concentrated nitric acid to cold water. Dissolve some Potassium Dichromate in a small quantity of hot water and add to the acid solution until it assumes a dark brown colour. This should be used cold in an aluminium, slate or wood container and the operators should wear rubber gloves.

If the above baths are not available, the flux may be removed by scrubbing the casting while still warm in hot water.

After removal of the flux the casting should be annealed wherever possible.

To tell the difference between an aluminium and an elektron casting, drop a few spots of ammonium chloride (sal-ammoniac) solution in water on each. The elektron casting will give off bubbles of gas where the solution has fallen, whereas there is no reaction on the aluminium casting.

General Precautions

The following general precautions should be taken in welding:

(1) Always use goggles of proved design when welding or cutting. The intense light of the flame is harmful to the eyes and in addition small particles of metal are continually flying about and may cause serious damage if they lodge in the eyes.

(2) When welding galvanised articles the operator should be in a well-ventilated position and if welding is to be performed for any length of time a respirator should be used. (In case of sickness caused by zinc fumes, as in welding galvanised articles or brass, milk should be drunk.)

(3) In heavy duty welding or cutting and in overhead welding, asbestos or leather gauntlet gloves, ankle and feet spats and protective clothing should be worn to prevent burns. When working inside closed vessels such as boilers or tanks, take every precaution to ensure a good supply of fresh air.

(4) In welding or cutting tanks which have contained inflammable liquids or gases precautions must be taken to prevent danger of explosion. One method for tanks which have contained volatile liquids and gases is to pass steam through the tank for some hours according to its size. Any liquid remaining will be vaporised by the heat of the steam and the vapours removed by displacement.

Smaller tanks such as fuel tanks on automobiles and aircraft which have similarly contained volatile liquids can be thoroughly drained and then blown through with compressed air, introducing the air supply into any corners and pockets in the tank. They can then be allowed to stand in the open air for several hours and afterwards blown through again, after which they are ready for welding.

Tanks should never be merely swilled out with water and then welded; many fatal explosions have occurred as a result of this method of preparation. Carbon dioxide in the compressed form can be used to displace the vapours and thus fill the tank, and is quite satisfactory but is not always available. Tanks which have contained heavier types of oil, such as fuel oil, tar, etc., present a more difficult problem since air and steam will not vaporise them. One method is to fill the tank with water, letting the water overflow for some time. The tank should then be closed and turned until the fracture is on top. The water level should be adjusted (by letting a little water out if necessary) until it is just below the fracture. Welding can then be done without fear as long as the level of the water does not drop much more than a fraction of an inch below the level of the fracture.

The welder should study the Home Office memorandum *Safety measures for the use of Oxy-Acetylene equipment in Factories*, and memorandum on the *Repair of drums or tanks which have contained petrol or other inflammable liquid.*

Chapter IV

ELECTRIC ARC WELDING

ELEMENTARY ELECTRICAL PRINCIPLES

Introduction: Sources of Electrical Power

The principal sources of electrical power of interest to the welder are (1) Batteries and accumulators, (2) Generators.

Batteries generate electrical energy by chemical action. Primary batteries, such as the Leclanché (used for flash lamps and radio high-tension supply), continue giving out an electric current until the chemicals in them have undergone a change, and then no further current can be given out.

Secondary batteries or accumulators are of two types: (i) the lead acid, and (ii) the nickel-iron alkaline. In the former, for example, there are two sets of plates, one set of lead peroxide and the other set of lead, immersed in dilute sulphuric acid (specific gravity 1·250, i.e. 4 parts of distilled water to 1 part of sulphuric acid). Chemical action enables this combination to supply an electric current, and when a current flows from the battery both the lead peroxide plates and the lead plates are changed into lead sulphate, and when this change is completed the battery can give out no more current. By connecting the battery to a source of electric power, however, and passing a current through the battery in the opposite direction from that in which the cell gives out a current, the lead sulphate is changed back to lead peroxide on one set of plates and to lead on the other set. The battery is then said to be 'charged' and is ready to supply current once again.

It may be also noted here that when two different metals are connected together and a conducting liquid such as a weak acid is present, currents will flow, since this is now a small primary cell. This effect is called 'electrolysis' and will lead to corrosion at the junction of the metals (see p. 49).

Generators can be made to supply direct current or alternating current as required and are described later. For welding purposes generators of special design are necessary. When welding with alternating current, 'transformers' are used to transform or change the pressure of the supply to a pressure suitable for welding purposes.

The Electric Circuit

The electric circuit can most easily be understood by comparing it to a water circuit. Such a water circuit is shown in Fig. 136*a*. A pump drives or forces the water from the high-pressure side of the pump through pipes to a water meter *M* which measures the flow of water in gallons. From the meter the water flows to a control valve the opening in which can be varied, thus regulating

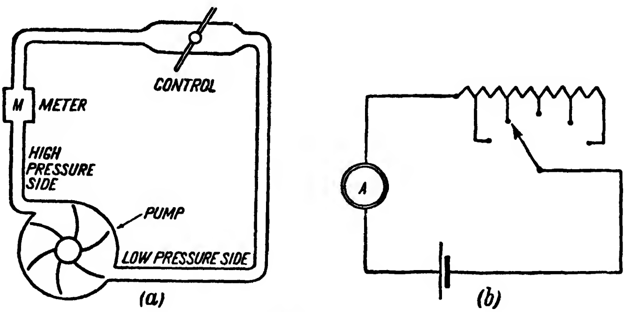


Fig. 136

the flow of water in the circuit. The water is led back through pipes to the low-pressure side of the pump. We assume that no water is lost in the circuit. Fig. 136*b* shows an electric circuit corresponding to this water circuit. The chemical action in the battery (a generator can be used if desired) supplies the force to drive the current of electricity around the circuit. The pressure available at the terminals of a battery when no current is flowing is called the Electro-Motive Force (E.M.F.). The current is carried by copper wires or cables, which offer very little obstruction or resistance to the flow of current through them, and the current flows from the high-pressure side of the battery (called the positive or +ve pole) through a meter which corresponds to the water meter. This meter, known as an ampere meter or ammeter, measures the flow of current through it in amperes (amps. for short), just as the water meter measures the flow of water in gallons. This ammeter may be connected at any point in the circuit so that the current flows *through* it, since the current is the same at all points in the circuit. From the ammeter the current flows through a copper wire to a piece of apparatus called a 'resistance'. This consists of wire usually made of an alloy, such as manganin, nichrome or eureka, which offers considerable obstruction or resistance to the passage of a current.

The number of turns of this coil in the circuit can be varied by means of a switch, as shown in the figure. This resistance corresponds to the water valve *V* by which the flow of water

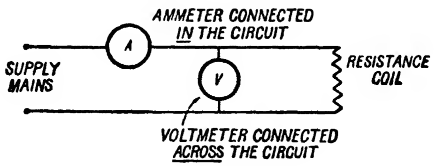


Fig. 137

in the circuit is varied. The more resistance wire which we include in the circuit, the greater is the obstruction to the flow of the current and the less will be the current which will flow, so that as we increase the number of turns or length of resistance wire in the circuit, the reading of the ammeter, indicating the flow of current in the circuit, becomes less. The current finally flows through a further length of copper wire to the low-pressure (negative or −ve) side of the battery.

In the water circuit we can measure the pressure of water in lb. per sq. in. by means of a pressure gauge. We measure the difference of pressure between any two points in an electric circuit by means of a voltmeter, which indicates the difference of pressure between the two points in volts. Fig. 137 shows the method of connection of an ammeter and a voltmeter in a circuit.

Fall in Potential—Voltage Drop

Let us consider the circuit in Fig. 138 in which three coils of resistance wire are connected to each other and to the battery by copper wires as shown, so that the current will flow through each coil in turn. (This is termed connecting them in *series.*) Suppose that the current flows from the +ve terminal *A* through the coils and back to the −ve terminal *H*. Throughout the circuit from *A* to *H* there will be a gradual fall in pressure or *potential* from the high-pressure side *A* to the low-pressure side *H*. Let us place a voltmeter across each section of the circuit in turn and find out where this fall in pressure or *voltage drop* occurs. If the voltmeter is first placed across *A* and *B*, we find that no difference of pressure or voltage drop is registered. This is because the copper wire connecting *A* to *B* offers very little obstruction indeed to the passage of the current, and hence, since there is no resistance to be overcome, there is no drop in pressure.

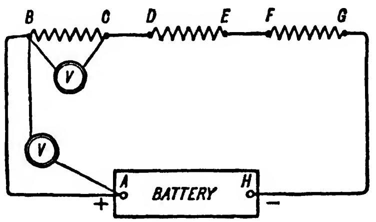


Fig. 138

If the voltmeter is placed across *B* and *C*, however, we find that it will register a definite amount. This is the amount by which the pressure has dropped in forcing the current against the obstruction or resistance of *BC*. Similarly, by connecting the meter across *DE* and *FG* we find that a voltage drop is indicated in each case, whereas if connected across *CD*, *EF*, or *GH*, practically no drop will be recorded, because of the low resistance of the copper wires.

If we add up the voltage drops across *BC*, *DE* and *FG*, we find that it is the same as the reading that will be obtained by placing the voltmeter across *A* and *H*, that is, the sum of the voltage drops in various parts of a circuit equals the pressure applied.

The question of voltage drop in various parts of an electric circuit is important in welding. Fig. 139 shows a circuit composed of an ammeter, a resistance coil, and two pieces of carbon rod called electrodes. This circuit is connected to a generator or large supply battery, as shown. When the carbons are touched together, the circuit is completed and a current flows and is indicated on the ammeter. The amount of current flowing will evidently depend on the amount of resistance in circuit.

If now the carbons are drawn apart about $\frac{1}{8}$ in., the current still flows across the gap between the carbons in the form of an arc. This is the 'carbon arc', as it is termed. We can control the current flowing across the arc by varying the amount of resistance *R* in the circuit, while if a voltmeter is placed across the arc, as shown, it will register the drop in pressure which occurs, due to the current having to be forced across the resistance of the gap between the electrodes. We also notice that

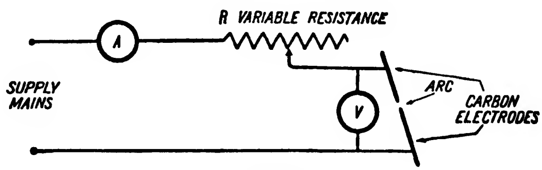


Fig. 139

the greater the distance between the electrodes the greater the voltage drop. The metallic arc used in arc welding is very similar to the carbon arc and is discussed fully later.

It has been mentioned that copper wire offers little obstruction or resistance to the passage of a current. All substances offer some resistance to the passage of a current, but some offer more than others. Metals, such as silver, copper and aluminium, offer but little resistance, and when in the form of a bar or wire the resistance that they offer increases with the length of the wire and decreases with the area of cross-section of the wire. Therefore the greater the length of a wire or cable, the greater its resistance; and the smaller the cross-sectional area, the greater its resistance. Thus if we require to keep the voltage drop in a cable down to the lowest value possible as we do in welding, the longer that the cable is, the greater must we make its cross-sectional area. Unfortunately, increasing the cross-sectional area makes the cable much more expensive and increases its weight, so evidently there is a limit to the size of cable which can be economically used for a given purpose.

Series and Parallel Grouping

We have seen that if resistances are connected together so that the current will flow through each one in turn, they are said to be connected in series (Fig. 140*a*). If they are connected so that the current has an alternative path through them, they are said to be connected in parallel or shunt (Fig. 140*b*).

A battery is generally denoted by a long thin line representing the +ve plate and a short thick line representing the −ve plate. If cells of a battery are connected so that the +ve of one cell is

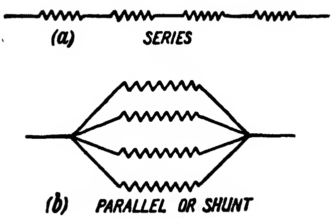


Fig. 140

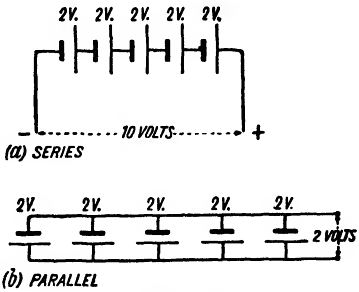


Fig. 141

connected to the −ve of the next, and so on, as in Fig. 141*a*, the cells are connected in series and the pressure available at the terminals is the sum of the pressures of all the cells connected in series. If the cells are grouped by connecting the +ve terminals together, and the −ve terminals together, as in Fig. 141*b*, the cells are said to be connected in parallel and the pressure available at the terminals is simply the pressure of one cell. The current which can be given out now, however, is the sum of the currents which could be given out by each cell.

Conductors and Insulators

Substances may be divided into two classes from an electrical point of view: (1) Conductors, (2) Insulators.

Conductors. These may be further divided into (*a*) good conductors, such as silver, copper and aluminium, which offer very little obstruction to the passage of a current, and (*b*) poor conductors or resistances, which offer quite a considerable obstruction to the passage of a current, the actual amount depending on the particular substance. Iron, for example, offers six times as much obstruction to the passage of a current as copper and is said to have six times the resistance. Alloys, such as manganin, eureka, constantin, german silver, no-mag and nichrome, etc., offer much greater obstruction than iron and have been developed for this purpose, being used to control the current in an electric circuit. No-mag, for example, is used for making resistance banks for controlling the current in motor and arc welding circuits, etc., while nichrome is familiar, since it is used as the heating element in electric fires and heating appliances, the resistance offered by it being sufficient to render it red hot when a current flows. Certain rare metals, such as tantalum, osmium and tungsten, offer extremely high obstruction, and if a current passes through even a short length of them in the form of wire they are rendered white hot. These metals are used as filaments in electric-light bulbs, being contained in a bulb exhausted of air, so as to prevent them oxidising and burning away.

Insulators. Many substances offer such a great obstruction to the passage of a current that no current can pass even when high pressures are applied. These substances are called insulators, but it should be remembered that there is no such thing as a perfect insulator, since all substances will allow a current to pass if a sufficiently high pressure is applied. In welding, however, we are concerned with low voltages. Amongst the best and most familiar insulators are glass, porcelain, rubber, shellac, mica, oiled silk, empire cloth, oils, resins, bitumen, paper, etc. In addition, there is a series of compounds termed synthetic resins (made from phenol and formalin), of which 'bakelite' is a well-known example. These compounds are easily moulded into any desired shape and have excellent insulating properties. The insulating properties of a substance are greatly dependent on the presence of any moisture (since water will conduct a current at fairly low pressures) and the pressure or voltage applied. If a person is standing on dry boards and touches the +ve terminal of a supply of about 200 volts, the −ve of which is earthed, very little effect is felt. If, however, he is standing on a wet floor, the insulation of his body from the earth is very much reduced and a severe shock will be felt, due to the much larger current which now passes through his body. As the voltage across an insulator is increased, it is put in a greater state of strain to prevent the current passing, and the danger of breakdown increases.

All electrical apparatus should be kept as dry as possible at all times. Much damage may result from wet or dampness in electrical machines.

A cable to conduct an electric current consists of an inner core of copper, usually consisting of many strands of wire, covered by an insulating sheath. The insulation may be of (1) Pure or Vulcanised India Rubber, denoted by V.I.R., or (2) Manila paper soaked in resinous oils (termed impregnated paper) covered with a lead sheath. This type of cable is known as Paper Insulated Lead Covered, or P.I.L.C. Bitumen insulated cables are seldom used nowadays. Rubber insulated cables are usually used for lower voltages, while the P.I.L.C. type are used for the higher voltages, the lead sheath being absolutely free from any holes that would allow moisture to penetrate into the paper insulation and ruin the cable.

For welding purposes the cable connecting the generator to the electrode holder is of very flexible construction and consists of hundreds of strands of fine copper wire wrapped with a paper covering and then enclosed in a pure tough rubber sheath (Fig. 142). In some types of cable the centre insulating sheath is of pure rubber, and is further covered with a taped or braided cotton covering and served over all with an insulating sheath of tough rubber. This provides a flexible yet tough and wear-resisting insulation capable of standing up to the hard work usually met with in welding operations. The cable from the generator to the work is sometimes of the same type, but to save expense it may be of a less flexible type.

The area of the copper conductor in the cable will depend upon the maximum current which it is required to carry. The table indicates the usual sizes for various currents. Since the resistance of a cable increases with its length, the table is based on a cable length of 100 to 150 ft. If longer cables have to be used the size must be increased accordingly, otherwise the voltage drop will be excessive, as previously explained. Two cables may be connected in parallel, where convenient, so as to carry the current between them. The effective size of this combination is that of the two

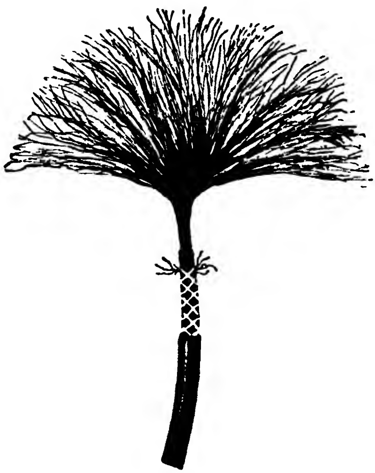


Fig. 142

areas of copper added together, that is, if one has a sectional area of ½ sq. in. and the other ¼ sq. in., when connected in parallel, this is equivalent to a cable of ¾ sq. in. sectional area.

Current Rating amps.	Sectional Area sq. inch.	Total Thickness of Insulation inch.	Number and Diameter of Wires inches	
			"Flexible" Conductors	"Extra Flexible" Conductors
200	·06	.100	248/·018	1330/·0076
300	·075	·100	313/·018	1680/·0076
400	·100	·100	416/·018	2200/·0076
500	·120	·125	482/·018	1105/·0120
600	·150	·125	610/·018	1358/·0120

Note. 248/·018 indicates 248 conductors of ·018 in. diameter.

Ohm's Law

Let us now arrange a conductor so that it can be connected to various pressures or voltages from a battery, say 2, 4, 6 and 8 volts, as shown in Fig. 143. A voltmeter *V* is connected so as to read the difference of pressure between the ends of the conductor, and an ammeter is connected so as to read the current flowing in the circuit. Connect the switch first to terminal 1 and read the voltage drop on the voltmeter and the current flowing on the ammeter, and suppose just for example that the readings are 2 volts and 1 ampere. Then place the switch

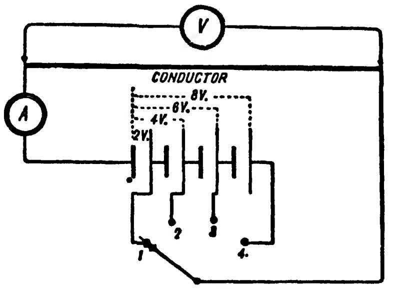


Fig. 143

on terminals 2, 3 and 4 in turn and read current and voltage and enter them in a table, as shown on p. 204. The last column in the table represents the ratio of the current flowing to the voltage applied, and it will be noted that the ratio is constant, that is, it is the same in each case, any small variations being due to experimental error.

In other words, when the voltage across the conductor was doubled, the current flowing was doubled; when the voltage was trebled, the current was trebled, and so on. This result led the scientist Ohm to formulate his law, thus: The ratio of the steady pressure (or voltage) across the ends of a conductor, to the steady current (or amperes) flowing in the conductor, is constant (provided the temperature remains steady throughout the experiment, and the conductor does not get hot. If it does, the results vary somewhat). Ohm called this constant the ***Resistance*** of the conductor. In other words, the resistance of a conductor is the ratio of the pressure applied to its ends, to the current flowing in it.

Voltage or Pressure Drop	Current Flowing in Amperes	Ratio: $\frac{\text{Voltage}}{\text{Current}}$
2	1	$\frac{2}{1}=2$
4	2	$\frac{4}{2}=2$
6	3	$\frac{6}{3}=2$
8	4	$\frac{8}{4}=2$

If now a difference of pressure of 1 volt applied to a conductor causes a current of 1 ampere to flow, the resistance of the conductor is said to be 1 ohm, that is, the ohm is the unit of resistance, just as the volt is the unit of pressure and the ampere the unit of current.

That is
$$\frac{1 \text{ volt}}{1 \text{ ampere}} = 1 \text{ ohm},$$

or, expressed in general terms,

$$\frac{\text{Voltage}}{\text{Current}} = \text{Resistance}.$$

Another way of expressing this is

$$\text{Voltage drop} = \text{Current} \times \text{Resistance}.$$

A useful way of remembering this is to write down the letters thus: V/IR (V being the voltage drop, I the current, and R the resistance). By placing the finger over the unit required, its value in terms of the others is given. For example, if we require the resistance, place the finger over R and we find that it equals V/I, while if we require the voltage V, by placing the finger over V we have that it equals $I \times R$. The following typical examples show how Ohm's law is applied to some useful simple calculations.

Example

A pressure of 20 volts is applied across the ends of a wire, and a current of 5 amperes flows through it. Find the resistance of the wire in ohms.

By Ohm's law, $V = I \times R$,

i.e. $20 = 5 \times R$ or $R = 4$ ohms.

Example

A welding resistance has a resistance of 0·1 ohm. Find the voltage drop across it when a current of 150 amperes is flowing through it.

By Ohm's law, $V = I \times R$,

i.e. $V = 150 \times 0{\cdot}1 = 15$ volts drop.

Power is the rate of doing work, and the work done per second in a circuit where there is a difference of pressure of 1 volt, and a current of 1 ampere is flowing, is 1 *Watt*, that is,

$$\text{Power in Watts} = \text{Volts} \times \text{Amperes}.$$

1000 watts are termed 1 *Kilowatt.*

The watt is the unit of electrical power in a circuit, while the horse-power is the unit of mechanical power. It is useful to remember the connection between electrical power and mechanical power, which is given by

$$746 \text{ watts} = 1 \text{ horse-power}.$$

Example

A welding generator has an output of 80 volts, 250 amperes. Find the output in horse-power.

$$80 \text{ volts, } 250 \text{ amperes} = 80 \times 250 \text{ watts} = \frac{80 \times 250}{746} \text{ horse-power}$$

$$= 26{\cdot}8 \text{ horse-power}.$$

This is the actual *output* of the machine. If this generator is to be driven by an engine or electric motor, the power required to drive it would have to be much greater than this, due to frictional and other losses in the machine. A rough estimate of the power required to drive a generator can be obtained by adding on one-half of the output of the generator. For example, in the above,

Estimate of power required to drive the generator

$$=26{\cdot}8+13=40 \text{ H.P. approx.}$$

It is always advisable to fit an engine which is sufficiently powerful for the work required, and this approximation indicates an engine which would be sufficient for the work, including overloads.

Energy has practically the same meaning as 'work', the terms being interchangeable, and represents the work that may be done by a force. Thus the watt hour, which is a unit of electrical energy, measures the work that may be done by a power of 1 watt in 1 hour.

The practical unit of energy is 1000 watt hours, or 1 kilowatt hour, usually termed 1 Board of Trade Unit. The B.o.T. unit is the unit of electrical energy for consumption purposes, and is the unit on which supply companies base their charge.

Example

An electric motor driving a welding generator is rated at 25 H.P. Find the cost of running this on full load, per day of 6 hours, with electrical energy at ½*d.* per unit.

25 H.P. $=25\times746$ watts $=18{,}560$ watts $=18{\cdot}56$ kilowatts.

Energy consumed in 6 hours $=18{\cdot}56\times6=111{\cdot}9$ kilowatt hours or units.

Therefore cost per day at ½*d.* per unit $=4s.\ 8d.$

For reference purposes the following absolute definitions of the ampère, volt and ohm are included.

The *ampère* is that steady current which, flowing through a neutral solution of silver nitrate in water, deposits silver at the rate of ·001118 gm. per second.

The potential difference between the ends of a conductor is one *volt* if 10,000,000 (10^7) ergs of work are done when one ampère flows for one second.

The *ohm* is the resistance of a column of mercury 106·3 cms. long and 1 sq. mm. in cross-sectional area at a temperature of 0° C.

The Simple Electric Circuit of the Welding Arc

If an electric arc is to be operated from a source of constant pressure, a resistance must be connected in series with it, in order to obtain the correct voltage drop across the arc and to control the current flowing in the circuit. This series resistance can be of the variable type, so that the current can be regulated as required. The ammeter *A* in Fig. 144 indicates the current flowing in the circuit, while the voltmeter V_1 reads the supply voltage, and voltmeter V_2 indicates the voltage drop across the arc. By placing the switch *S* on various studs, the resistance is varied, and it will be noted that one section of the resistance marked *X* cannot be cut out of circuit. This is to prevent the arc being connected directly across the supply mains. If this

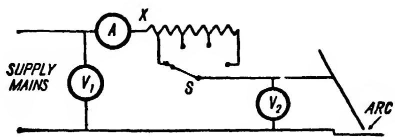


Fig. 144

happened, since the resistance of the arc is fairly low, an excessive current would flow and the supply mains would be 'short circuited', and furthermore the arc would not be stable.

The loss of energy in this series resistance is considerable, since a voltage of about 50 to 60 is required to strike the arc, and then a voltage of about 25 to 30 is required to maintain it. If then, as in Fig. 145, the supply is 60 volts and 100 amperes are flowing in the arc circuit, with 25 volts drop across the arc, this means that there is a voltage drop of 35 volts across the resistance. The loss of power in the resistance is therefore (35×100) watts $= 3{\cdot}5$ kilowatts, whereas the power consumed in the arc is (25×100) watts $= 2{\cdot}5$ kilowatts.

In other words, more power is being lost in the series resistance than is being used in the welding arc. Evidently, therefore, since the 60 volts is required to strike the arc, some other more economical means must be found for the supply than one of constant voltage.

Modern welding generators are designed so that there is a high voltage of 50 to 60 volts for striking the arc, but once the arc is struck, this voltage falls to that required to maintain the arc, and as a result only a small series resistance is required to control the current, and thus the efficiency of the operation is greatly increased. This type of generator is said to have a 'drooping characteristic'.

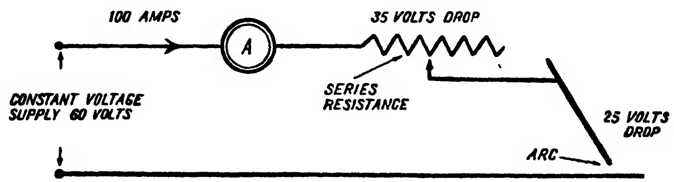


Fig. 145

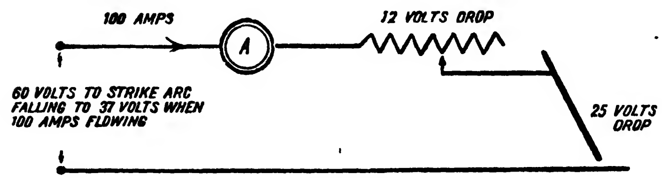


Fig. 146

This can be illustrated thus: Suppose the voltage of the supply is 60 when no current is flowing, that is, 60 volts is available for striking the arc; and suppose that the voltage falls to 37 volts when the arc is struck, the voltage drop across the arc again being 25 and a current of 100 amperes is flowing (Fig. 146). The power lost in the resistance is now only (12×100) watts or $1\frac{1}{5}$ kilowatts, which is just less than one-half the loss in the previous example, when a constant voltage source was used.

A diverter is often used in place of a series resistance in some machines. It consists of resistances R_1, R_2, R_3, R_4 connected in parallel, as shown in Fig. 147. R_1 is constantly in circuit, and with the switches S_2, S_3 and S_4 open, all the current flows through R_1. When the switch S_2 is closed, an alternative path is opened for the current to flow through, and consequently more current can flow. Similarly, when S_3 and S_4 are closed, an alternative path is offered to the current in each case and the current is increased. When all the switches are closed, the current in the circuit is a maximum.

We have up to the present considered only circuits using direct current as a source of supply. In the case of welding with alternating current, the circuit is similar, except that instead of the series resistance, a series choke or reactance is used, serving the same purpose.

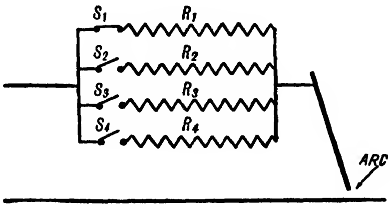


Fig. 147

Contact Resistance. Whenever poor electrical contact is made between two points the electrical resistance is increased, and there will be a drop in voltage at this point, resulting in heat being developed. If bad contact occurs in a welding circuit, it often results in insufficient voltage being available at the arc. Good contact should always be made between cable lugs and the generator and the work (or bench on which the work rests). The metal plate on the welding bench to which one of the cables from the generator is fixed is often a source of poor contact, especially if it becomes coated with rust or scale. When attaching the return cable to any point on the work being welded, the point should always be scraped clean before connecting the cable lug to it, and in this respect, especially for repair work, a small hand vice, bolted to the cable lug, will enable good contact to be made with the work when the jaws are lightly clamped on any desired point, and this is especially useful when no holes are available in the article to be welded.

Generation

We will now proceed to an elementary study of the direct-current welding generator.

Magnetic Field

Pieces of a mineral called lodestone or magnetic oxide of iron possess the power of attracting pieces of iron or steel and were first discovered centuries ago in Asia Minor. If a piece of lodestone is suspended by a thread, it will always come to rest with its ends pointing in a certain direction (North and South); and if it is rubbed on a knitting-needle (hard steel), the needle then acquires the same properties. The needle is then said to be a magnet, and it has been magnetised by the lodestone. Modern magnets of tungsten and cobalt steel are similar, except that they are magnetised by a method which makes them very powerful magnets.

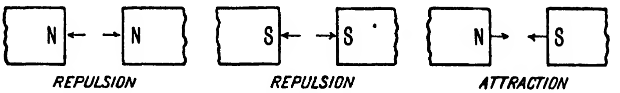


Fig. 148

Suppose a magnetised knitting-needle is dipped into some iron filings. It is seen that the filings adhere to the magnet in large tufts near its ends. These places are termed the poles of the magnet. If the magnet is now suspended by a thread so that it can swing freely horizontally, we find that the needle will come to rest with one particular end always pointing northwards. This end is termed the north pole of the magnet, while the other end which points south is termed the south pole.

Let us now suspend two magnets and mark clearly their north and south poles, then bring two north poles or two south poles near each other. We find that they repel each other. If, however, a north pole is brought near a south pole, we find that they attract each other, and from this experiment we have the law: Like poles repel, Unlike poles attract.

If we attempt to magnetise a piece of soft iron (such as a nail), by rubbing it with a magnet, it is found that it will not retain any magnetic properties. For this reason hard steel is used for permanent magnets.

Iron filings provide an excellent means of observing the area over which a magnet exerts its influence. A sheet of paper is placed over a bar magnet and iron filings are sprinkled over the paper, which is then gently tapped. The filings set themselves along definite lines and form a pattern. This pattern is shown in Fig. 149. The area over which the influence of a magnet is felt is termed a magnetic field and the lines along which the filings set themselves, and which represent the direction of action of the force, due to the magnet at that point, are termed

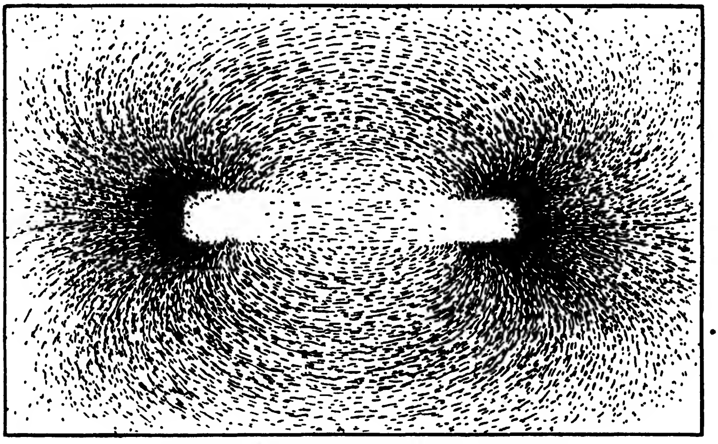


Fig. 149. Magnetic field of a bar magnet

lines of force. It should be noted that the iron filings map represents the field in one plane only, whereas the field exists in all directions around the magnet. Fig. 150 shows the field due to two like poles opposite each other and clearly indicates the repulsion effect, while Fig. 151 shows the attraction between two unlike poles.

The number of lines or tubes of magnetic force which thread or pass through a given area is termed the magnetic flux.

Magnetic Field due to a Current

If a magnetic needle (or compass needle) is brought near a wire in which a current is flowing, it is noticed that the needle is deflected, indicating that there is a magnetic field around the wire. If the wire carrying the current is passed through the centre of a horizontal piece of paper and an iron filing map

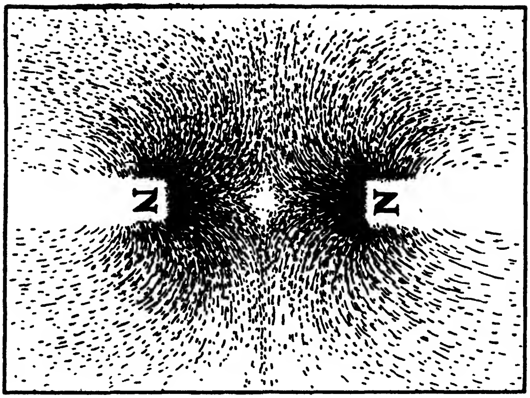


Fig. 150. Repulsion between like poles

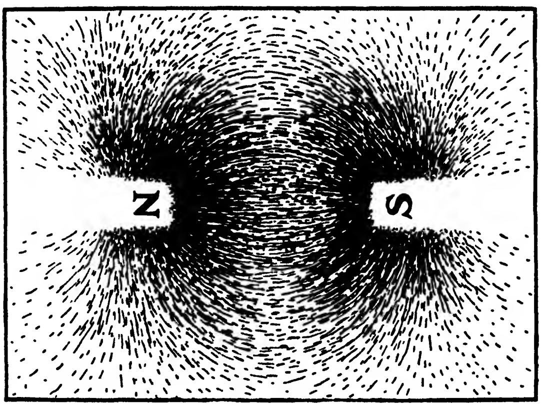


Fig. 151. Attraction between unlike poles

made, it can be seen that the magnetic lines of force are in concentric circles around the wire (Fig. 152).

Two wires carrying currents in the same direction will attract each other, due to the attraction of the fields, while if the currents are flowing in opposite directions, there is repulsion between the wires.

The magnetic field round a wire carrying a current is used to magnetise pieces of soft iron to a very high degree, and these are then termed electro-magnets.

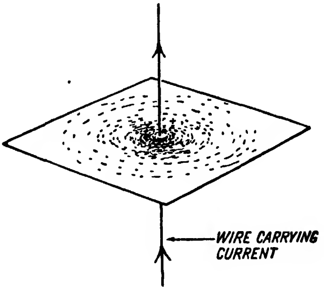


Fig. 152

Many turns of insulated wire are wrapped round an iron core and a current passed around the coil thus formed. The iron core becomes strongly magnetised, and we find that the greater the number of turns and the larger the current, the more strongly is the core magnetised. This is true until a point termed 'saturation point' is reached, after which neither increase in the number of turns nor in the current will produce any increase in intensity of the magnetism.

That end of the core around which the current is passing clockwise, when we look at it endways, exhibits south polarity, while the end around which the current passes anti-clockwise exhibits north polarity (Figs. 153, 154).

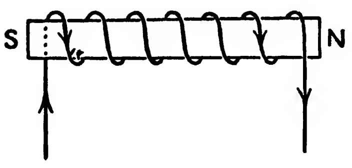


Fig. 153

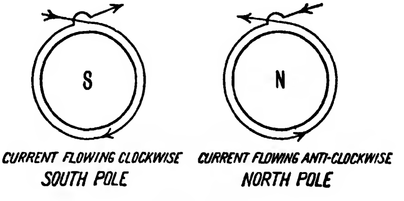


Fig. 154

Magnetic Field of a Generator

The magnetic field of generators and motors are made in this way. The outside casing of the generator, termed the yoke, has bolted to it on its inside, the iron cores called *pole pieces*, over which the magnetising coils, consisting of hundreds of turns of insulated copper wire, fit. To extend the area of influence of the field, pole shoes are fixed to the pole pieces (or made in one with them), and these help to keep the coils in position. Generators may have 2, 4 or more poles, and the arrangement of a 2 and 4 pole machine is sketched in Fig. 155.

It will be noticed that a north and south pole always comes alternately, thus producing a strong field where the conductors on the rotating portion of the machine are fixed. The magnetic circuit is completed through the yoke. The coils are connected

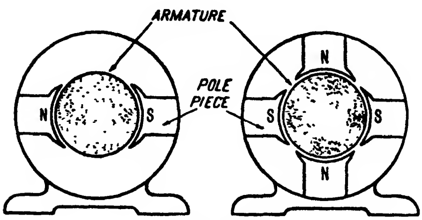


Fig. 155

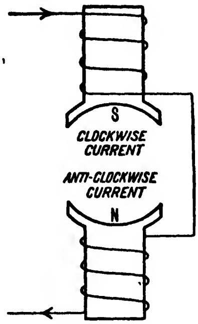


Fig. 156

so that the current passes through them alternately clockwise and anti-clockwise when looked at from the inside of the generator, so as to give the correct polarity (this can be tested by using a compass needle), and the current which flows through the coils is termed the magnetising or *excitation* current (Fig. 156).

The larger the air gap between the poles of an electro-magnet the stronger must the magnetising force be to produce a given field in the gap. This means that the greater the gap between the pole pieces of a machine and the rotating iron core, called the armature, the greater must the magnetising current be to produce a field of given strength. For this reason the gap between pole pieces and rotating armature must be kept as small as possible, yet without any danger of slight wear on the bearings causing the armature to foul the pole pieces (the machine is then said to be pole bound). In addition, this gap should be even at each pole piece all round the armature. Excessive air gaps result in an inefficient machine.

Generation of a Current by Electrical Machines

The following explanation of the principle of operation of a generator is an outline only and will serve to give the operator an idea of the function of the various parts of the machine.

For a current to be generated we require, (1) A Magnetic Field, (2) A Conductor, (3) Motion (producing change of magnetic flux).

The magnetic field causes a magnetic flux to be set up, and the conductor is surrounded by this flux. Any change of flux caused by the change in position of the conductor or by change in value of the field will cause a current to be generated in the conductor.

Generation of Alternating Current

Let us consider the first case. N. and S. (Fig. 157) are the poles of a magnet and *AB* is a copper wire whose ends are connected to a milliammeter. (This is an instrument that will measure currents of the order of $\frac{1}{1000}$ amp.) If the conductor *AB* is moved upwards, we find that the needle of *A* swings in one direction, while if *AB* is moved downwards, it swings in the opposite direction. By moving *AB* up and down, we generate a current that flows first in one direction, *B* to *A*, and then in the other direction, *A* to *B*. This is termed an alternating current, and the current is said to be induced in the conductor.

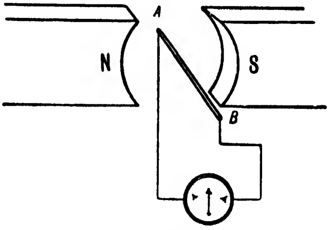


Fig. 157

NOTE. The rule by which the direction of the current in a conductor is found, when we know the direction of the field and the motion, is termed Fleming's Right-Hand Rule. This can be stated thus 'Place the thumb, first finger and second finger of the right hand all at right angles to each other. Point the first finger in the direction of the field from N. to S. and turn the hand so that the thumb points in the direction of motion of the conductor. Then the second finger points in the direction in which the current will flow in the conductor.' Fig. 158 makes this clear.

Instead of moving the conductor up and down in this way, the method used for generation is to make it in the form of a coil of several turns and rotate the conductor, and if the coil is wound

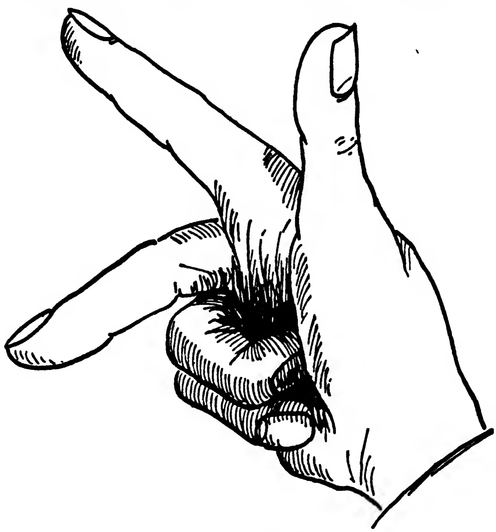


Fig. 158. Fleming's right-hand rule

on an iron core, the field is greatly strengthened and much larger currents are generated.

The ends of the coil are connected to two copper rings mounted on the shaft, but insulated from it, and spring-loaded contacts called brushes bear on these rings, leading the current away from the rotating system (see Fig. 159).

From the brushes *X* and *Y*, wires lead to the external circuit, which has been shown as a coil of wire, *OP*, for simplicity.

When the coil is rotated clockwise, *AB* moves up and *CD* down. By applying Fleming's rule we find that the current flows from *B* to *A* in one conductor and from *C* to *D* in the other, as shown by the arrows (Fig. 160*a*). The current will then leave the machine by slip ring *Y* and flow through the external circuit from *O* to *P* and return via slip ring *X*.

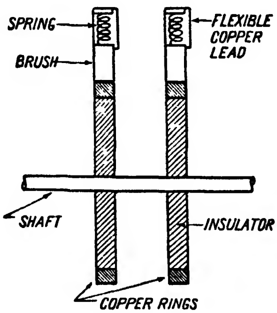


Fig. 159

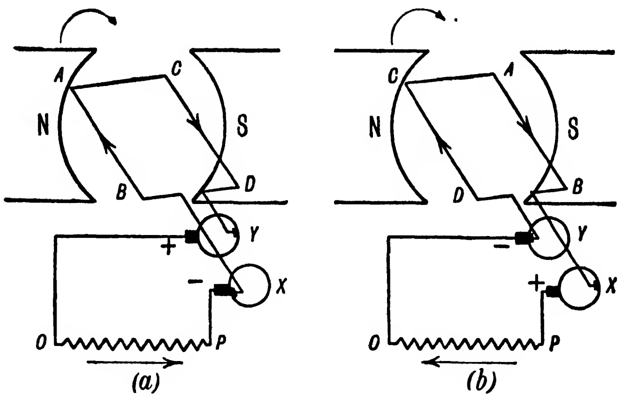


Fig. 160

When the coil has been turned through half a turn, as shown in Fig. 160*b*, *AB* is now moving down and *CD* up, and by Fleming's rule the currents will now be from *D* to *C* in one conductor and from *A* to *B* in the other. This causes the current to leave by slip ring *X* and flow through the external circuit from *P* to *O*, returning via slip ring *Y*. If a milliammeter with centre zero is placed in the circuit in place of the coil *OP*, the needle of the instrument flicks to one side during the first half turn of the coil and to the other side during the second half turn.

Evidently, therefore, in one revolution of the coil, the direction of the current generated by the coil has been reversed. No current is generated when the coil is passing the position perpendicular to the field, while maximum current is generated when the coil is passing the position in the plane of the field. This can be illustrated thus (Fig. 161):

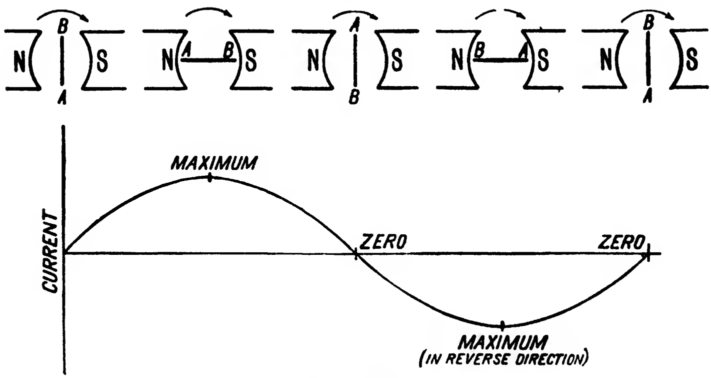


Fig. 161

One complete rotation of the coil has resulted in the current starting at zero, rising to a maximum, falling to zero, reversing in direction and rising to a maximum and then falling again to zero. This is termed a complete *Cycle*, and the number of times this occurs per second (that is, the number of revolutions which the above coil makes per second) is termed the frequency of the alternating current. Alternating currents in this country are usually supplied at 50 cycles per second (written 50∼). In America 60∼ is largely used. Evidently A.C. has no definite polarity, that is, first one side and then the other becomes +ve or −ve.

Generation of Direct Current

By an ingenious, yet simple device called the commutator (current reverser) this generated alternating current can be changed to direct current, that is, to a current flowing only in one direction. Instead of slip rings, two segments of copper are mounted on the circumference of the shaft, as shown in Fig. 162, being separated from each other by a small gap. Brushes bear on these segments as they did on the slip rings

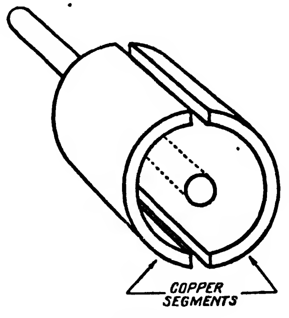


Fig. 162

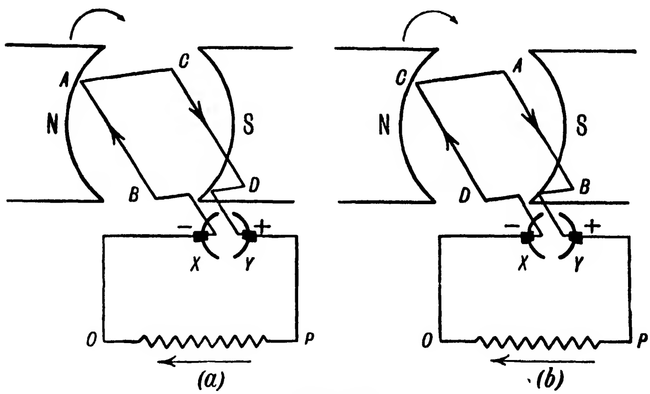


Fig. 163

previously. As the coil rotates, the segments will first make contact with each brush in turn and thus reverse the connections to the external circuit.

In the sketches (*a*) and (*b*), Fig. 163, the conductors are lettered as before, but *AB* is connected to one segment and *CD* to the other. Brushes *X* and *Y* bear on the segments and are connected to the external circuit *OP*. Upon rotating the coil, the current flows in the coil as previously. It leaves by brush *Y* (Fig. 163*a*), flows through the external circuit from *P* to *O* and back via brush *X*. In Fig. 163*b*, when the coil has turned through half a turn, the connections of the coils to the brushes have been reversed by the segments of the commutator and the current again leaves via brush *Y*, through the external circuit in the same way, from *P* to *O*, returning via brush *X*. Thus, though the current in the coil has alternated, the current in the external circuit is uni-directional, or 'direct current' as it is called.

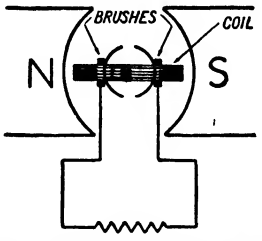


Fig. 164. Maximum current position

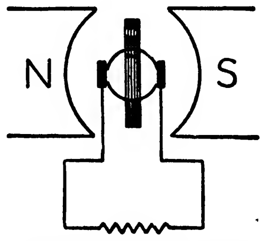


Fig. 165. Zero current

Since the current flows from *Y* to *X*, through the external circuit, *Y* is termed the positive pole and *X* the negative pole.

The brushes pass over the joints or gaps between the segments as the coil passes through the perpendicular position to the field, i.e. when no current is generated; thus there is no spark due to the circuit being broken whilst the current is still flowing (Figs. 164, 165).

The current from a direct current generator with a single coil of several turns, as we have just considered, would be a series of pulsations of current, starting at zero, rising to a maximum and decreasing to zero again, but always flowing in the same direction, as shown in Fig. 166.

If, now, a second coil is wound and mounted on the shaft at right angles to the first coil and its ends connected to a second pair of commutator segments, the maximum current in one coil will occur when the other coil has zero current; and since there are now four commutator segments, each now only extends round half the length that it did previously. The resulting current from the two coils *A* and *B* will now be represented by the thick line; the dotted portion will no longer be collected by the brushes, because of the shortened length of the commutator segment (Fig. 167).

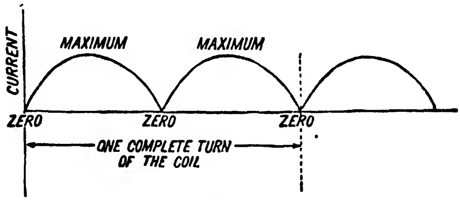


Fig. 166

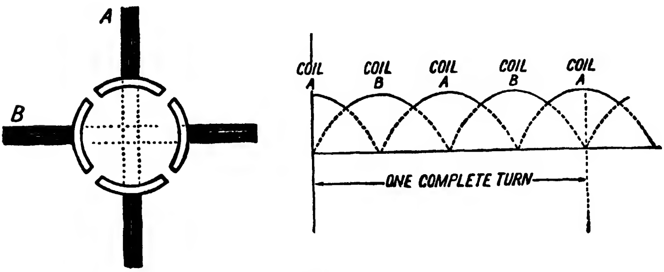


Fig. 167

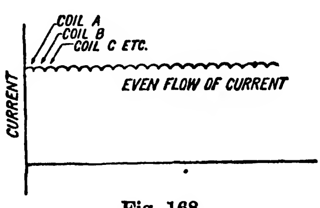


Fig. 168

By increasing greatly the number of coils (and consequently the number of commutator segments, since each coil has two segments), the pulsating current can be made less and less, that is, the effect is a steady flow, as shown in Fig. 168.

It is not necessary here to enter into details of the various methods of connecting the coils to the segments. Full details of these are given in text-books on Electrical Engineering. The voltage of a machine is increased by increasing the number of turns of wire in each coil, while the current output of a machine is increased by increasing the total number of coils in parallel on the machine. The output of a machine can also be increased by increasing the speed of the machine and also by increasing the strength of the magnetic field.

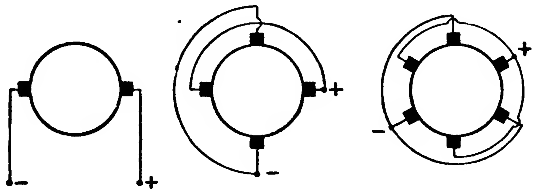


Fig. 169. Connections of brushes

By increasing the number of poles of a machine, its voltage can be increased, while yet keeping its speed the same. Machines of 4 and 6 poles are quite common. In this case there are the same number of sets of brushes as there are poles, i.e. 4 poles, 4 sets of brushes, and so on, and these brushes are connected alternately, as in the sketch, so as to give +ve and −ve poles.

Most welding generators are either 2 or 4 poles. For a given output, the greater the number of poles the slower the speed of the machine.

As a rule a machine is designed to operate at a given speed, but the output voltage is variable by the resistance known as the field regulator (see later).

Description of a Typical Direct-current Generator

A modern direct-current welding generator consists of:

(1) Yoke with pole pieces and terminal box, and end plates.
(2) Magnetising coils.
(3) Armature and commutator (the rotating portion).
(4) The brush gear.

The yokes of modern machines are now usually made of steel plate rolled to circular form and then butt welded at the joint. The end plates, which contain the bearing housings, bolt on to the yoke, and the feet of the machine are welded on and strengthened with fillets. The pole pieces are of special highly magnetisable iron and are bolted on to the yoke. The coils are usually of double cotton-covered copper wire, insulated and taped over all, and they fit over the pole pieces, being kept in position by the pole shoes. The armature shaft is of nickel steel and the armature core (and often the pole pieces also) is built up of these sheets or laminations of highly magnetisable iron, known by trade names such as Lohys, Hi-mag, etc. Each lamination is coated with insulating varnish, and they are then placed together and keyed on to the armature shaft, being compressed tightly together so that they look like one solid piece.

The insulating of these laminations from each other prevents currents (called eddy currents), which are generated in the iron of the armature when it is rotating, from circulating throughout the armature and thus heating it up. This method of construction contributes greatly to the efficiency and cool running of a modern machine. The armature laminations have slots in them into which the armature coils of insulated copper wire are placed (usually in a mica or empire cloth insulation). The coils may be keyed into the slots by fibre wedges and the ends of the coils are securely soldered (or sweated) on to their respective commutator bars (the parts to which they are soldered are known as the commutator risers). A fan for cooling purposes is also keyed on to the armature shaft.

The commutator is of high conductivity, hard drawn copper secured by V rings, and the segments are insulated from the shaft and from each other by highest quality ruby mica.

Brushes are of copper carbon, sliding freely in brush holders, and springs keep them in contact with the commutator. The tension of the springs should only be sufficient to prevent sparking. Excessive spring pressure should be avoided, as it tends to wear the commutator unduly. The commutator and brush gear should be kept clean by occasional application of petrol on a rag, which will wash away accumulations of carbon and copper dust from the commutator micas and brush gear. All petrol must evaporate before the machine is started up, to avoid fire risk. The armature usually revolves on dust-proof and watertight ball or roller bearings, which only need packing with grease every few months. Older machines have simple bronze or white metal bearings, lubricated on the ring oil system. These need periodical inspection to see that the oil is up to level and that the oil rings are turning freely and, thus, correctly lubricating the shaft.

Connections from the coils and brush gear are taken to the terminal box of the machine, and many welding generators have the controlling resistances and meters also mounted on the machine itself.

Connections of Welding Generators

In the following sketches, magnetising coils are shown thus: ɷɷɷɷ, and this represents how ever many coils the machine possesses, connected so as to form alternate north and south poles, as before explained. The armature, with the brushes bearing on the commutator, are shown in Fig. 170.

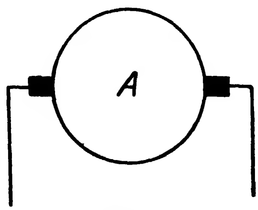


Fig. 170

The current necessary for magnetising the generator is either taken from the main generator terminals, when the machine is said to be self-excited, or from a separate source, when it is said to be separately excited. Welding generators are manufactured using either of these methods.

Separately Excited Machines

These generally take their excitation or magnetising current from a small separate generator, mounted on an extension of the main armature shaft, and this little generator is known as the exciter. Current generated by this exciter passes through a variable resistance, with which the operator can control the magnetisation current, and then round the magnetising coils of the generator. This is shown in Figs. 171 and 177*a*.

By variation of the resistance *R*, the magnetising current and hence the strength of the magnetic field, can be varied. This varies the voltage (or pressure) of the machine and thus enables various voltages to be obtained across the arc, varying its controllability and penetration. This control is of great importance to the welder.

This type of machine gives an almost constant output voltage, irrespective of load, and thus, as before explained, would result

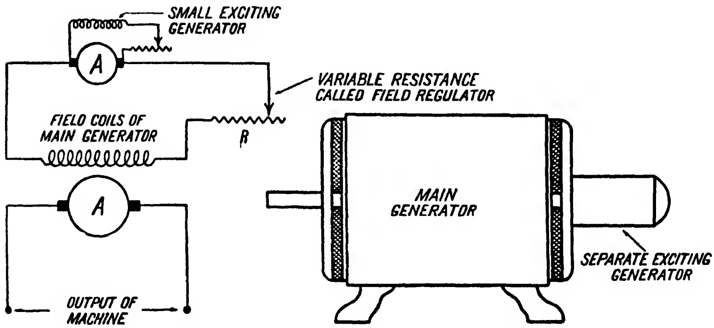


Fig. 171. Simple separately excited generator

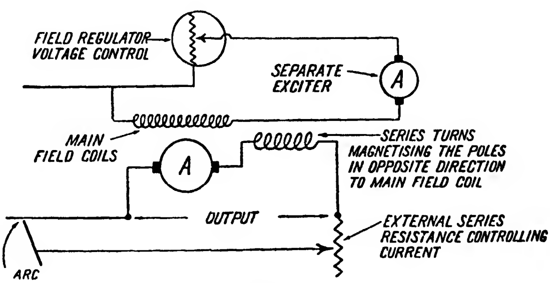


Fig. 172

in large losses in the series resistance, if used for welding. In order to obtain the 'drooping characteristic', so suitable for welding, the output current is carried around some *series* turns of thick copper wire, wound over the magnetising coils on the pole pieces, and this current passes round these turns so as to magnetise them with the opposite polarity from the normal excitation current. Fig. 172 shows how the coils are arranged. Consider then what happens.

When no load is on the machine, the field is supplied from the separate exciter and the open circuit voltage of the machine is high, say 60 volts, giving a good voltage for striking. When the arc is struck, current passes through the series winding and magnetises the poles in the opposite way from the main field and, thus, the strength of the field is reduced and the voltage of the machine drops. The larger the output current the more will the voltage drop, and evidently the voltage drop for any given output current will depend on the number of series turns. This is carefully arranged when the machine is manufactured, so as to be the most suitable for welding purposes.

This type of machine, with control of both current and voltage, is very popular and is reliable, efficient and economical. Because the voltage available at any given instant is only slightly greater than that required to maintain the arc, only a small series resistance is required, this being fitted with the usual variable control.

Self-Excited Machines

The simplest form of this type of machine is that known as the 'shunt' machine, in which the magnetising coils take their current direct from the main terminals of the generator through a field-regulating resistance (Fig. 173).

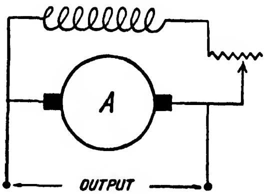


Fig. 173. Connections of a simple shunt machine

There is always a small amount of 'residual' magnetism remaining in the pole pieces, even when no current is passing around the coils, and, when the armature is rotated, a small voltage is generated and this causes a current to pass around the coils, increasing the strength of the field and again causing a greater current to be generated, until the voltage of the machine quickly rises to normal. Control of voltage is made, as before, by the field regulator. This type of machine is not used for welding because its voltage only drops gradually as the load increases and, as before explained, this would cause a waste of energy in the external series resistance.

Again, this machine is modified for use as a welding generator by passing the output current first round series turns wound on the pole pieces, so as to magnetise them with the opposite polarity from that due to the main field, and this results, as before, in the voltage dropping to a great extent as the load increases and, thus, the loss of energy in the external resistance is greatly reduced (Fig. 174). A machine of this type is termed a Differential Compound Machine and shares with the separately excited machine the distinction of being a reliable, efficient and economical generator for welding purposes. The control of current and voltage are exactly as before.

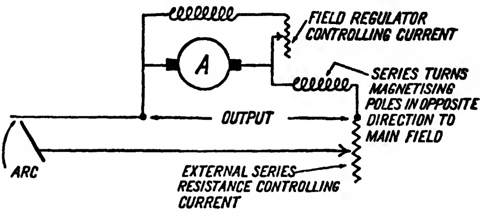


Fig. 174

Certain other modern machines make use of more complicated magnetic circuits, examples of which are given on pp. 229–231.

The rest of the equipment of a direct-current welding generator consists of a main switch and fuses, ammeter and voltmeter. The fuses are of porcelain with copper contacts, across which a piece of copper wire tinned to prevent oxidation is bridged. The size of this wire is chosen so that it will melt or 'fuse' when current over a certain value flows through it. In this way it serves as a protection for the generator against excessive currents, should a fault develop.

On many machines neither switch nor fuses are fitted. Since there is always some part of the external resistance connected permanently in the circuit of these machines, no damage can result from short circuits, and fuses are therefore unnecessary. The switch is also a matter of convenience and serves to isolate the machine from the electrode holder and work when required.

Interpoles, or Commutation Poles

Interpoles are small poles situated between the main poles of a generator and serve to prevent sparking at the brushes. The polarity of each interpole must be the same as that of the next main pole in the direction of rotation of the armature, as in Fig. 175.

They carry the main armature current and, therefore, like the series winding on welding generators, are usually of heavy copper wire or strip.

They prevent distortion of the main field, by the field caused by the current flowing in the armature, and thus commutation is greatly assisted.

Most modern machines are fitted with interpoles, as they represent the most convenient and best method of obtaining sparkless commutation.

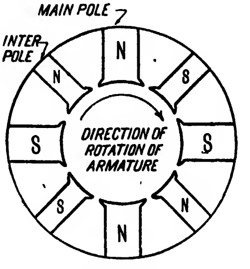


Fig. 175

The following is a summary of the features of a good welding generator:

(1) Fine control of voltage.
(2) Fine control of current.
(3) Excitation must always provide a good welding voltage.
(4) Copper conductors of armature and field of ample size and robust construction, yet the generator must not be of excessive weight.
(5) Well-designed laminated magnetic circuit and accurate armature-pole shoe air gap.
(6) Good ventilation to ensure cool running.
(7) Well-designed ball or roller bearings of ample size and easily filled grease cups.
(8) Well-designed brush gear—no sparking at any load and long life brushes.
(9) Bearings and brush gear easily accessible.
(10) Large, easily placed terminals enabling polarity to be quickly changed (or fitted with polarity changing switch).
(11) High efficiency, that is, high ratio of output to input energy. (60–65 % efficiency is normal for a modern single-operator motor-driven direct current plant.)

For purposes of reference, details of connections and lay out are given of some of the most modern methods of design and excitation of welding generators. These machines represent the most efficient and economical types available.

Cross-Field Excitation, Direct Current Welding Generator

This type of welding generator has a rectangular frame of fairly thin section, to which are bolted the top and bottom main poles, and these contain also the 'commutating' poles (Fig. 176). The main poles are of special shape, with horns which provide a leakage path for the magnetism to the side of the frame.

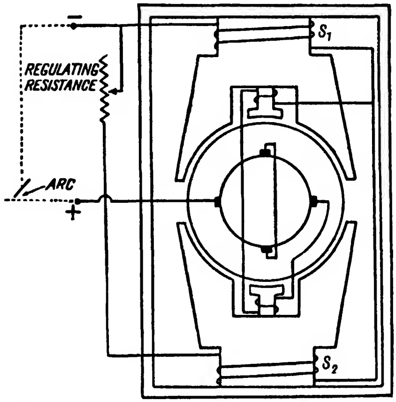


Fig. 176. Two-pole cross-field generator

The field winding consists of two series coils, S_1 and S_2, one on each main pole. These coils are connected in parallel and the regulating resistance is in series with the bottom coil. With all the resistance in the bottom coil circuit, practically all the current flows through the top coil. With the resistance out, the currents are equal through both coils and a current range of about 5 : 1 is obtainable. By means of changing link connections, the resistance can be used as a series-stabilising resistance for currents of 15 to 50 amperes. Short circuits do not cause loss nor reversal of magnetism.

This type of machine gives an arc which is easily struck and which burns steadily and quietly. It is efficient at all loads and gives a steady current supply over all current ranges.

Dual Continuous Control Generator

In the dual continuous control generator, excitation current is supplied by the separate exciting generator shown on the left of Fig. 177*a*, and the control of the excitation current is made by the field rheostat which therefore controls the output voltage of the machine. Interpoles are fitted to prevent sparking and the continuously variable current control is in parallel with the differential series field, the current control being wound on a laminated iron core so as to give a smoothed output. This generator gives a good arc with excellent control over the whole range and is suitable for all classes of work.

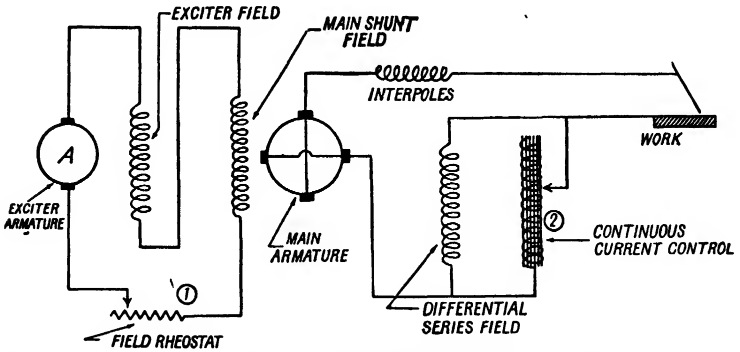


Fig. 177*a*. Welding generator with separate excitation. Regulation of controls (1) and (2) give dual continuous control of voltage and current

'Paradyne' Arc Welding Set

Method of Excitation. The method of excitation employed in the 'Paradyne' is by means of an auxiliary brush arrangement, supplying current to the shunt field windings.

The shunt windings are located on two diametrically opposite poles and are energised from one of the four main brushes, and an auxiliary brush positioned so that its line of commutation is under the slot provided in one of the main poles carrying the shunt windings; in order to obtain good commutation at the auxiliary brush, the slot is relatively wide adjacent to the air-gap. The general arrangement is as shown on the diagram of connections (Fig. 177*b*).

Method of Current Control. Current control is obtained by the combination of a plug and socket selector switch connected to tappings on the series field windings, and a shunt field rheostat for giving fine variation between these tappings. Thus it is possible to obtain variable current control between the minimum and maximum for which any particular machine is designed.

The short-circuit current is limited by means of reverse compound windings on two of the main poles, effecting a reduction in

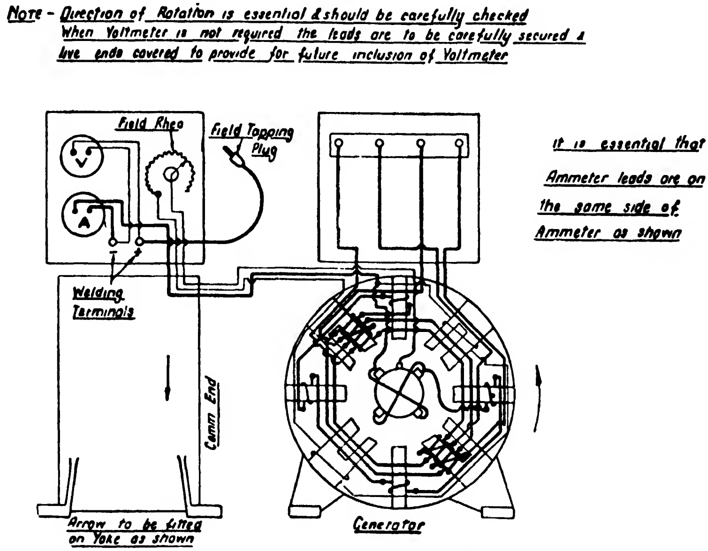


Fig. 177*b*. Diagram of connections for arc welding

the resultant flux crossing the air gap, as the armature current increases. Stability of operation is ensured, since the voltage across the shunt field windings is maintained substantially constant.

Due care is taken in the design stage to ensure that, under transient conditions, the voltage responds immediately to any small change in current, giving an excellent arc.

Static Generator Characteristics

Volt-Ampere Curves. Variation of the open-circuit voltage and the current greatly affect the characteristics of the arc. To understand the effect of this variation of voltage and current, we must consider the volt-ampere curves of the machine.

To obtain the volt-ampere curves of a welding generator:

(1) Set the voltage control to any value.
(2) With arc circuit open, read the open circuit voltage in the voltmeter.
(3) Short circuit the arc.
(4) Vary the current from the lowest to highest value with the current control and, for each value of current, read the voltage. (Voltage will decrease as current increases.)

(Connections of machine are shown in Fig. 178.)

Plot a curve of these readings with voltage and current as axes. This curve is a volt-ampere curve. Any number of curves may be obtained by taking another value of open-circuit voltage and repeating the experiment.

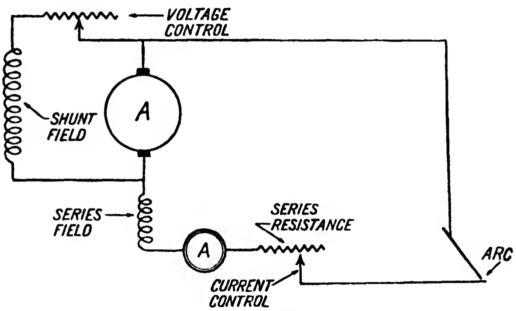


Fig. 178

The following curves (Fig. 179) are the results of typical experiments on a small welding generator.

Suppose Fig. 180 is a typical curve of a welding generator. When welding, the arc length is continually undergoing slight changes in length, since it is impossible for a welder to keep the arc length absolutely constant. This change in length results in a change in voltage drop across the arc; the shorter the arc the less the voltage drop. The volt-ampere curve shows us what effect this change of voltage drop across the arc will have on the current flowing. Suppose the arc is shortened and the drop changes from 25 to 20 volts. From the curve, we see that the current now increases from 108 to 117 amperes.

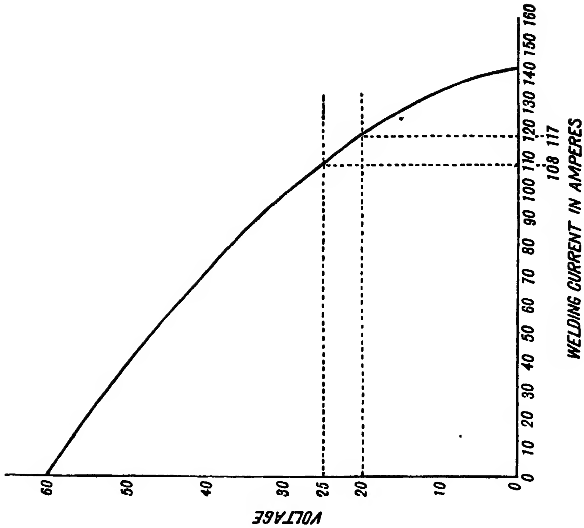


Fig. 180

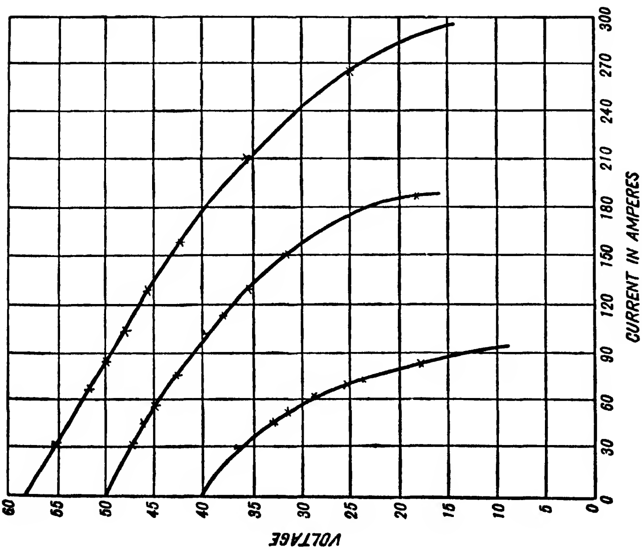


Fig. 179

The steeper the curve is where it cuts the arc voltage value, the less variation in current there will be, and, therefore, there will be no current 'surges' and the arc will be steady and the deposit even. In addition, the current flowing when the machine is short circuited should not exceed 1½ times the maximum welding current. This enables the machine to deal with all short circuits which occur during welding without becoming overheated and risking breakdown.

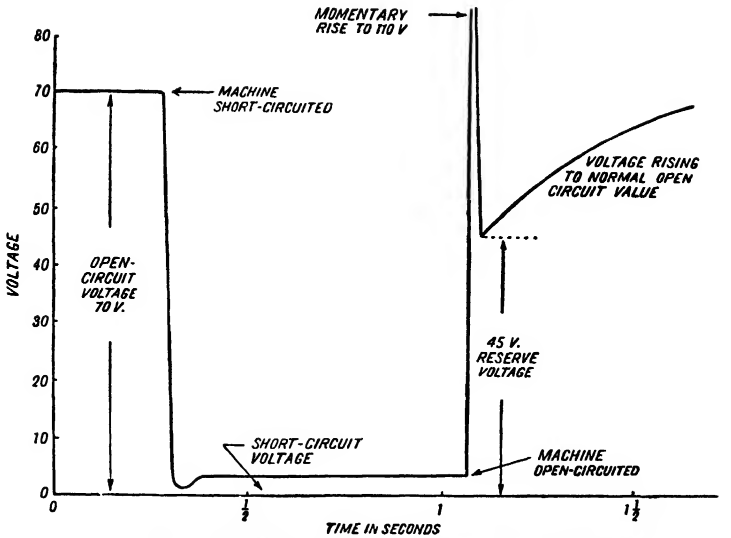
Variation of Current and Voltage Control. Suppose a current of 100 amperes is suitable for a given welding operation. If the current control is now reduced, the current will fall below 100 amperes, but it can be brought back to 100 amperes by increasing the voltage control. The current control may be again reduced and the voltage raised again, bringing the current again to the same value. At each increase of voltage the volt drop across the arc is increased, so we obtain a different arc characteristic, yet with the same current.

This effect of control should be thoroughly grasped by the operator, since by variation of these controls the best arc conditions for any particular work are obtained.

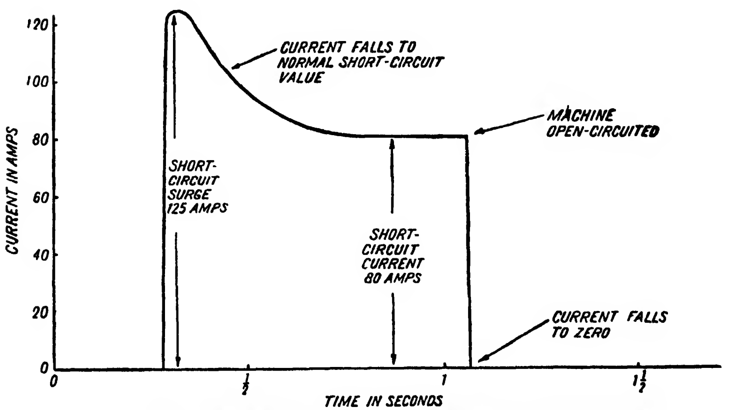
The curves just considered are known as static characteristics. Now let us consider the characteristics of the set under working conditions; these are known as the dynamic characteristics, and they are best observed by means of a cathode-ray oscillograph. By means of this instrument the instantaneous values of the current and voltage under any desired conditions can be obtained as a wave trace or graph, called an oscillograph.

The curves drawn in Fig. 181 are taken from an oscillograph of the current and voltage variation on a welding generator when the external circuit was being short circuited (as when the arc was struck) and then open circuited again.

It will be noticed that the short-circuit surge of current (125 amps.) is about 1½ times that of the normal short-circuit current (80 amps.). This prevents the electrode sticking to the work by an excessive flow of current when the arc is first struck, yet sufficient current flows initially to make striking easy. In addition, when the circuit is opened, the voltage rises to a maximum and then falls to a 'reserve' voltage value of 45 volts and immediately begins to rise to normal. This reserve voltage



CURVE SHOWING VARIATIONS IN VOLTAGE AS MACHINE IS SHORT-CIRCUITED AND OPEN-CIRCUITED



CURVE SHOWING VARIATION OF CURRENT DUE TO ABOVE VARIATION OF VOLTAGE

Fig. 181

ensures stability of the arc after the short circuit which has occurred and makes welding easier, since short circuits are taking place continually in the arc circuit as the molten drops of metal bridge the gap.

Summarising, we may say that a welding generator should possess the following electrical characteristics:

(1) Change in arc length should produce the smallest possible variation in current, so as to prevent surges.
(2) The open-circuit voltage must fall rapidly when the arc is struck, to prevent surge of current causing the electrode to 'freeze' or stick to the work.
(3) Short-circuit current value on a particular current setting should not exceed $1\frac{1}{2}$ times the normal output of that setting.
(4) The reserve voltage should be sufficiently high to ensure a steady, stable arc, free from splutter.
(5) The machine must possess these good characteristics over the whole range of welding current.

Motive Power for Welding Generators

Welding generators may be motor or engine driven. Sets in semi-permanent positions, such as in workshops, are usually driven by direct current or alternating current motors, and these provide an excellent constant speed drive, since the speed is almost independent of the load. The motor and generator may be built into the same yoke, as Figs. 182 and 185, or may be separate machines, as Fig. 183. The first method is mostly used in modern machines, as much space is thereby saved.

Motors of either type should be fitted with no-volt and overload tripping gear. The former automatically switches off the supply to the motor in the event of a failure of the supply and, thus, prevents the motor being started in the 'full on' position when the supply is resumed, while the latter protects the motor against excessive overloading, which might cause damage. This operates by switching the motor off when the current taken by the motor exceeds a certain value, which can be set according to the size of the motor.

Main switch and fuses usually complete the equipment of the motor. The motor-driven set may be mounted on wheels or on a solid bed, depending on whether it is required to be portable or not, and the equipment should be well 'earthed' to prevent shock.

Portable sets for outdoor use are usually engine driven (Fig. 184), and this type of set is extremely useful, since it can

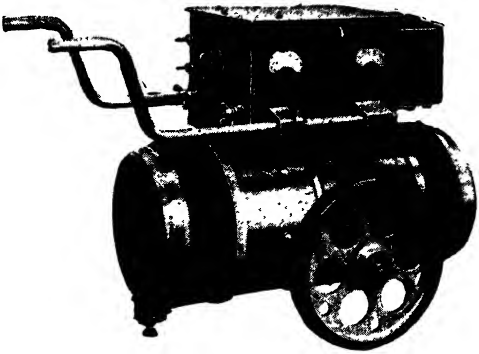


Fig. 182. Portable motor generator arc welding set for one operator

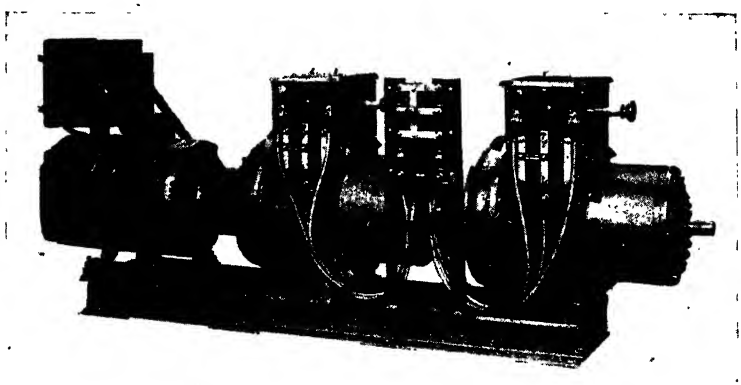


Fig. 183. Motor generator welding set for two operators

be operated independently of any source of electric power. The engines may be of the petrol or diesel type and are usually the four-cylinder, heavy duty type with an adequate system of water cooling and a large fan.

A good reliable governor and one that will regulate the speed to very close limits is an essential feature of the engine. Many modern sets now have an idling device which cuts down the speed of the machine to a tick over when the arc is broken for a period (which can be adjusted by the operator), sufficient for

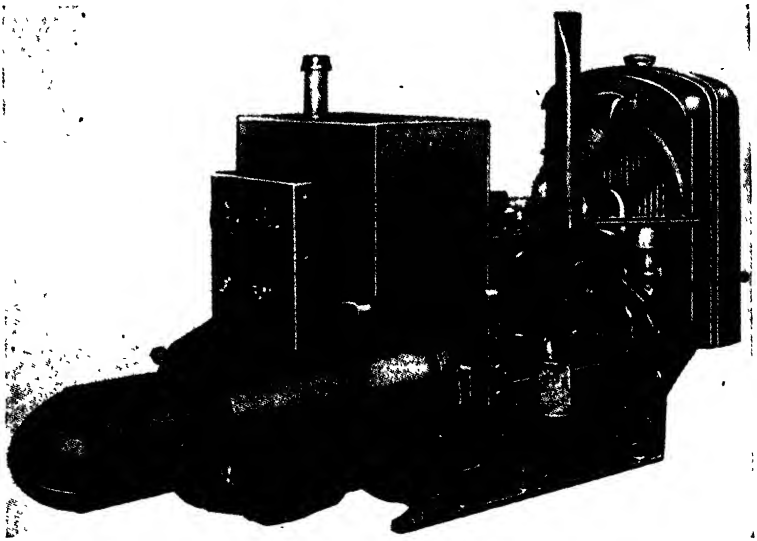


Fig. 184. Engine driven welding set

him to change electrodes and deslag. This results in a considerable saving in fuel and wear and tear and greatly increases the efficiency of the plant.

Direct drive is mostly favoured for welding generators. Belt drive is not very satisfactory, owing to the rapid application of the load when striking the arc causing slip and putting a great strain on the belt, especially at the fastener. Belt-drive sets, however, are used in certain circumstances.

Alternating Current Welding

Welding of steel with coated rods can be done very satisfactorily with alternating current, using a welding transformer, and this method has certain advantages over direct current. The chief of these are:

(1) The welding transformer (dealt with later) and its controller is very much cheaper than the D.C. set of the same capacity.
(2) There are no rotating parts and, thus, no wear and tear and maintenance of plant.
(3) Troublesome magnetic fields causing arc blow are eliminated.
(4) The efficiency is slightly greater than for the D.C. welding set.

Fig. 185a. Portable single operator A.C. motor driven welding set

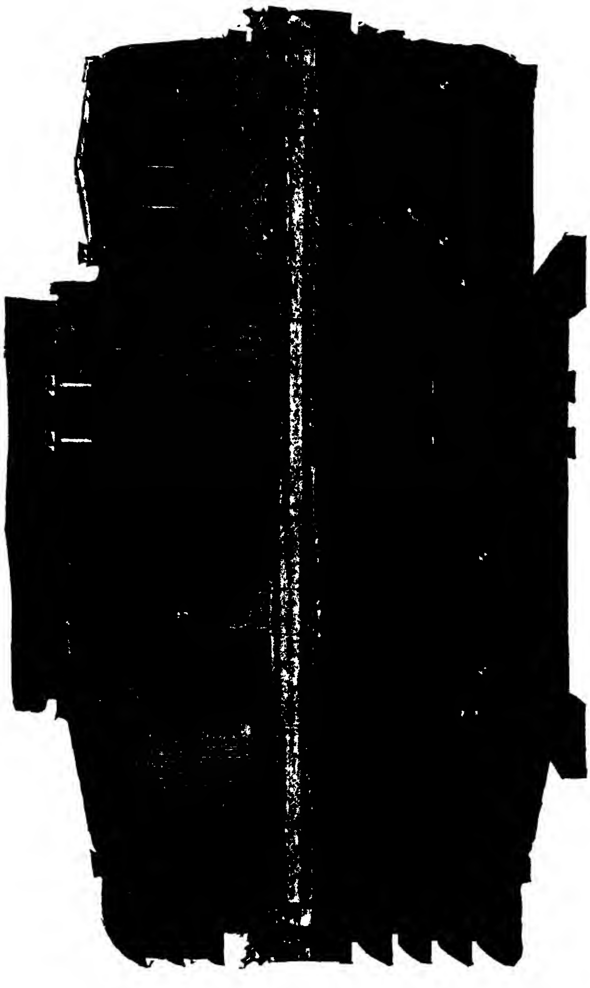


Fig. 185*b*. Sectional view of welding set shown in Fig. 185*a*

Alternating current welding, however, suffers from several disadvantages:

(1) Covered electrodes must be used. The A.C. arc cannot be used satisfactorily for bare wire or lightly coated rods as the D.C. arc.

(2) A higher voltage is used than with D.C., consequently the risk of shock is much greater and in some cases, as for example in damp places or when the operator becomes hot and perspires, as in boiler work, A.C. welding can become definitely dangerous, unless care is taken.

(3) Welding of cast iron, bronze and aluminium cannot be done anything like as successfully as with D.C.

The final choice of an A.C. or D.C. set will depend on the full consideration of the above factors. A.C. multi-operator sets are, however, much cheaper than D.C. sets for the same number of operators and, because of this lower initial cost, have been largely installed in shipyards and large works, where the welding of steel plate is mostly carried out.

The Transformer

The supply for arc welding with alternating current (A.C.) is usually from 80 to 100 volts, and this may be obtained directly from the supply mains by means of a transformer, which is an instrument that transforms or changes the voltage from that of the main supply to a voltage of 80 to 100 suitable for welding. Since a transformer has no moving parts, it is termed a 'static' plant.

The action of the transformer can be understood most easily from the following simple experiment, first performed by Faraday.

An iron ring or core (Fig. 186) is wrapped with two *insulated* coils of wire, *A* (called the primary winding) is connected to a source of alternating current, while *B* (called the secondary winding) is connected to a milliammeter with a centre zero, which will indicate the direction of flow of the current in the circuit. With each revolution of the coil of the A.C. generator, the current flows in the primary first from *X* to *Y* and then from *Y* to *X*, and a magnetic field is set up in the iron core which rises and falls very much in the same way as the hair spring of a watch. This rising and falling magnetic field producing a change of magnetic flux in the circuit, generates in the secondary coil an alternating current, the current flowing in one direction through the milliammeter when the current in the primary is from X to Y and then in the opposite direction when the current in the primary flows from Y to X.

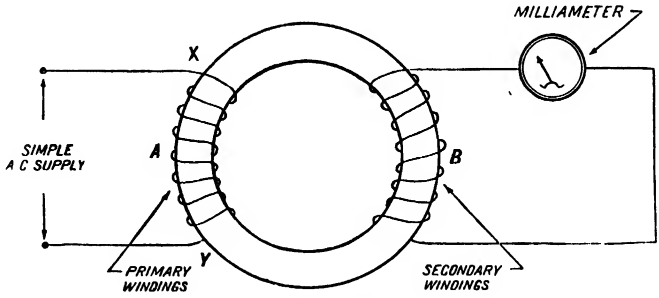


Fig. 186

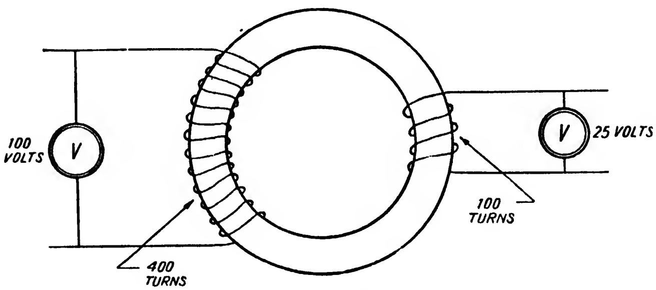


Fig. 187

There is no electrical connection between the two coils, and a current generated in the secondary coil in this way, by a current in the primary, is said to be *induced.* Note that we again have the three factors necessary for generation as stated on page 215: a conductor, a magnetic field and motion. In this case however it is the change in magnetic flux which takes the place of the motion of the conductor, since this latter is now stationary.

Now let us wind a similar ring (Fig. 187) with 400 turns on the primary and 100 turns on the secondary, connect the primary to an alternating supply of 100 volts, and connect a voltmeter across each circuit.

It will be found that the voltage across the secondary coil is now 25 volts.

$$\text{Ratio of } \frac{\text{Primary turns}}{\text{Secondary turns}} = \frac{4}{1},$$

$$\text{Ratio of } \frac{\text{Primary voltage}}{\text{Secondary voltage}} = \frac{4}{1}.$$

Thus we see that the voltage has been changed in the ratio of the number of turns, or

$$\frac{\text{Primary turns}}{\text{Secondary turns}} = \frac{\text{Primary volts}}{\text{Secondary volts}}.$$

This is a simple transformer, and since it operates off one pair of A.C. supply wires, it is called a Single Phase Transformer. The voltage supplied *to* the transformer is termed the input voltage, while that supplied *by* the transformer is termed the output voltage. If the output voltage is greater than the input voltage, it is termed a step-up transformer; while if the output voltage is less than the input, it is a step-down transformer. Transformers for welding purposes are always step down, the output voltage being about 85 volts. Some single-operator transformers have two output tappings of 85 and 95 volts, the higher voltage being suitable for light gauge sheet welding (Fig. 188). The input voltage to transformers is usually 440, 400 or 230, these being the normal mains supply voltages.

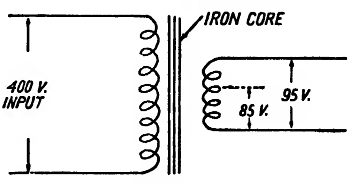


Fig. 188

Since the power output cannot be greater than the input (actually it is always less because of losses in the transformer), it is evident that the current will be transformed in the opposite ratio to the voltage. For example, if the supply is 400 volts and 50 amperes are flowing, then if the secondary output is 100 volts, the current will be 200 amperes (Fig. 189).

Actually, the output current would be slightly lower than this, since the above assumes a 100 % efficient transformer. A transformer on full load has an efficiency of about 97 %, so the above may be taken as approximately true.

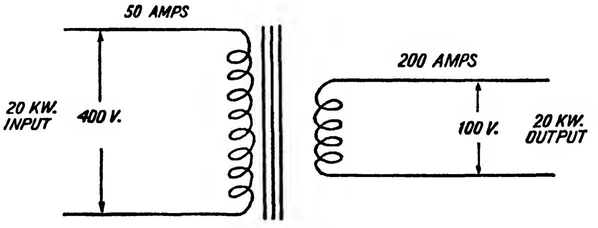


Fig. 189

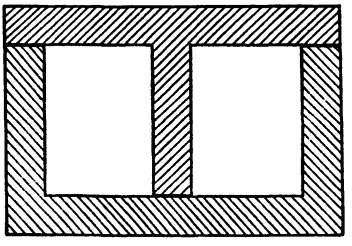


Fig. 190

The iron core of the transformer is made up of laminations bolted together and the coils fit over these (Fig. 190). It will be observed that the magnetic circuit is 'closed', that is, the lines of force do not have to traverse any air gap.

The single-operator welding transformer is made on this principle and is available in sizes up to 450 to 500 amperes. The transformer is housed in an outer casing, in which is also mounted the switch and fuses of the primary circuit.

The transformer may be of the dry type (air cooled) or it may be immersed in oil, contained in the outer container (Fig. 192).

Oil-immersed transformers have a lower permissible temperature rise than the dry type and, therefore, their overload capacity (the extent to which they may be used to supply

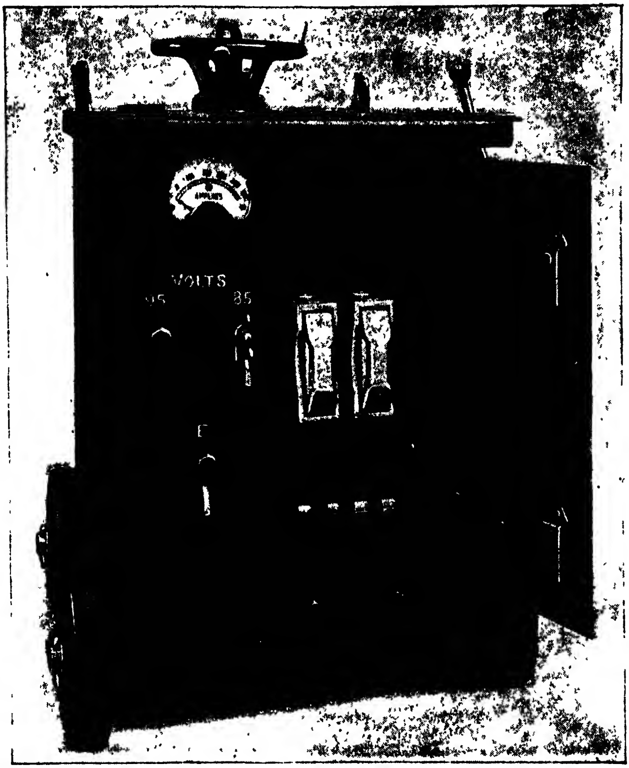


Fig. 191. Transformer, showing ammeter, primary switch, fuses and link board for selection of primary voltages

welding currents in excess of those for which they are rated) is much smaller.

Current regulation may be achieved by two methods. The first consists of movement of a lever, or wheel, which varies the strength of the magnetic field between primary and secondary windings, and in this way a smooth control of current is obtained. The second method is by means of a reactor or choke.

If an ordinary tapped resistance, as used for D.C. welding, is connected in series with a welding transformer, it is found that the arc is difficult to strike. This is because both current and voltage are passing through zero values 100 times per second (on a 50~ supply), and since they pass through these values together, no energy is available at this period for keeping the arc going.

Fig. 192. Single operator transformer welding set giving 200 amperes at 80 volts and 160 amperes at 100 volts

By use of a current regulator, termed a choke or reactor, the current is regulated to any desired value, and in addition the difficulty of striking the arc is overcome (Fig. 193).

The reactor or choke consists of a coil to carry the welding current and it is wound on a laminated iron core. The coil may have tappings connected to a selector switch in order to vary the current, or the iron core may slide in and out, being operated by a handle or hand wheel.

By this means the current is controlled in a similar way to a D.C. circuit, a voltage drop now occurring across the choke and, thus, giving the required voltage across the arc. In addition, the choke, as its name suggests, exerts a choking action on the current and causes it to fall out of step with the voltage and lag behind. As a result, zero values of voltage and

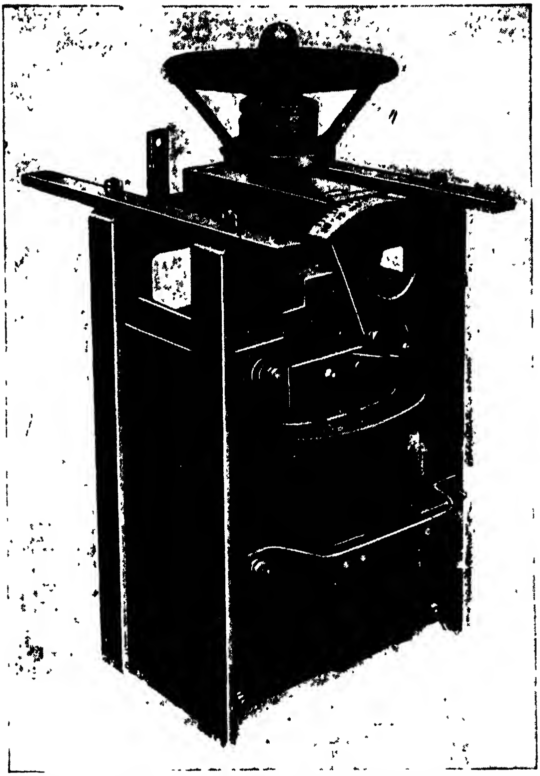


Fig. 193. Current regulator for transformer welding set

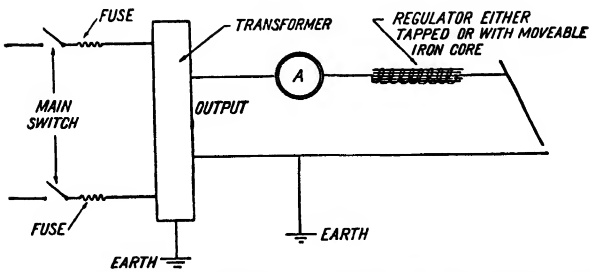


Fig. 194. Connections of a simple single operator (single phase) transformer set

current now do not occur together, and energy is always available at the arc, making it much easier to strike and maintain. Unfortunately this choke or reactance greatly reduces the efficiency of the transformer welding set and brings its operating costs up to that of D.C. welding.

By earthing the cable from work to transformer, liability of shock to the welder is reduced in the event of insulation breakdown between primary and secondary windings.

Three-Phase Welding Supply

For convenience in transmission and distribution, alternating current is supplied on the 'three-phase' system. The alternators have three sets of coils set at an angle of 120° to each other, instead of only one coil as on the simple alternator which we considered. These coils can be connected, as shown in Fig. 195,

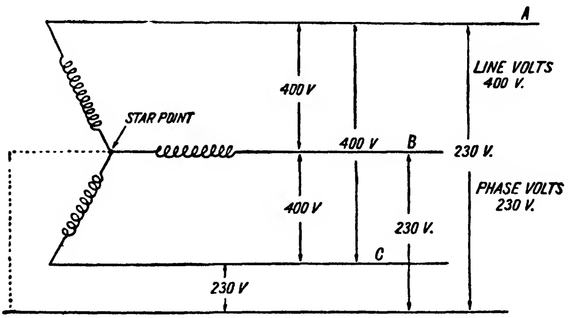


Fig. 195. Three-phase, four wire system

and the centre point, termed the star point, is where the beginning of each coil is connected, and the wire from this point is termed the neutral. *A*, *B* and *C* are the lines. The voltage between *A* and *B*, *B* and *C*, *C* and *A* is termed the line voltage and is usually for supply purposes either 440 or 400. The voltage between any one of the lines and the neutral wire, termed the phase voltage, is only $\frac{1}{\sqrt{3}}$ of the line voltage, that is, if the line voltage is 400 the voltage between line and neutral is $\frac{400}{\sqrt{3}} = 230$ volts.

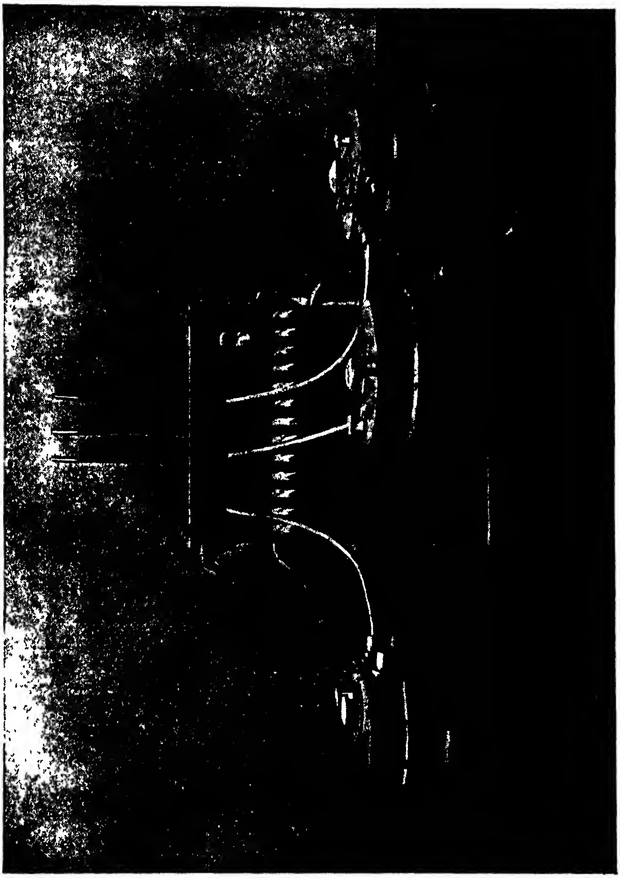


Fig. 196. Three operator set, showing the single three-phase transformer and three welding regulators

Welding supplies for more than one welder are supplied by multi-operator sets from the above type of mains supply.

Evidently a supply may be taken for a single operator from, say, lines *A* and *B*, but this will put all the load on this pair of

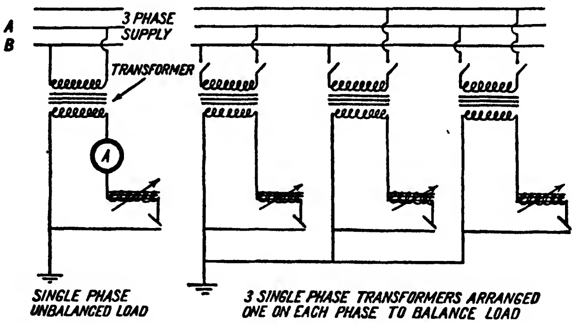
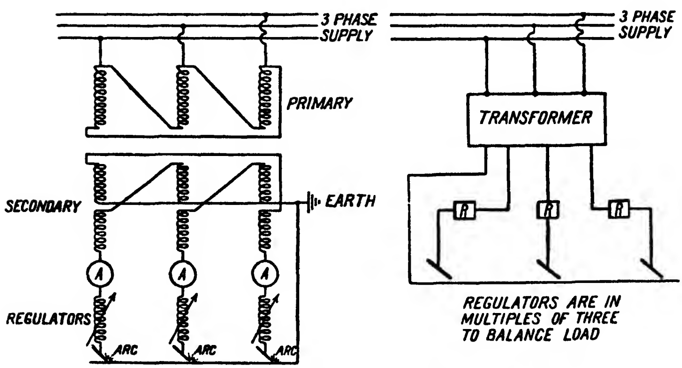


Fig. 197



Internal connections of three-phase transformer to three welding regulators

Lay out of transformer and regulators

Fig. 198

lines, and this load is said to be unbalanced and is not liked by supply authorities, since it upsets the electrical balance of the circuit. To balance the load equally on the three lines, using three single-phase transformers (Fig. 197), is not easy in welding, since the welders are seldom all welding together using the same current, and balance is never fully realised in practice.

By means of a three-phase transformer (Figs. 196, 198), we can obtain a better balancing of load on the three phases, even when only one welder is operating (note method of earthing).

In addition, the three-phase transformer is cheaper to manufacture and instal than three single-phase transformers and, because of this, is invariably found wherever many welders have to be supplied, as in shipyards and engineering works. Each welder has his own current regulator, as in the single-phase set.

High-Frequency Alternating Current Welding

The normal supply frequency for A.C. welding is 50~, but a much more stable arc with better characteristics for welding results from the use of a higher frequency.

Fig. 199. High frequency (motor-alternator) welding set

High-frequency welding sets consisting of a three-phase A.C. motor (operating off the main supply) driving a high frequency, single-phase A.C. generator, contained within the same shell, are manufactured and give an output of from 20 to 500 amperes, having a frequency of from 150 to 240 cycles per second (Fig. 199). Since the motor takes current from a three-phase supply, it is a *balanced* load and the generator has a very steep volt-ampere characteristic. This means, as before explained, that a change in arc volts will produce little change in arc current, and thus we have a steady, stable arc. A set of this type is specially useful for the welding of thin plates or sheets, since the stable arc, free from current variation, eliminates danger of melting through of the sheets. Current control is made, as in the lower frequency transformer sets, by a variable choke or reactor, and sets are available, giving outputs up to 150, 300 and 500 amperes.

The Electric Arc and Welding Accessories

The Electric Arc

An electric arc is formed when an electric current passes between two electrodes separated by a short distance from each other. In arc welding (we will first consider direct-current welding) one electrode is the welding rod or wire, while the other is the metal to be welded (we will call this the plate). The electrode and plate are connected to the supply, one to the +ve pole and one to the −ve pole, and we will discuss later the difference which occurs when the electrode is connected to the −ve or +ve pole. The arc is started by momentarily touching the electrode on to the plate and then withdrawing it to about $\frac{1}{8}$ to $\frac{1}{4}$ in. from the plate. When the electrode touches the plate, a current flows, and as it is withdrawn from the plate the current continues to flow in the form of a 'spark' across the very small gap first formed. This causes the air gap to become ionised or made conducting, and as a result the current is able to flow across the gap, even when it is quite wide, in the form of an arc. The electrode must always be touched on to the plate before the arc can be started, since the smallest air gap will not conduct a current (at the voltages used in welding) unless the air gap is first ionised or made conducting.

The arc is generated by electrons (small negatively charged particles) flowing from the −ve to the +ve pole, and the electrical energy is changed in the arc into heat and light. Two-thirds of the heat is developed near the +ve pole, which burns into the form of a crater, the temperature near the crater being about 3500–4000° C., while the remaining third is developed near to the −ve pole. As a result an electrode connected to the +ve pole will burn away 50 % faster than if connected to the −ve pole. For this reason it is usual to connect medium-coated electrodes and bare rods to the −ve pole, so that they will not burn away too quickly. Heavily coated rods are connected to the +ve pole because, due to the extra heat required to melt the heavy coating, they burn more slowly than the other types of rods when carrying the same current. The thicker the electrode used, the more heat is required to melt it, and thus the more current is required. The welding current may vary from 20 to 600 amperes.

When alternating current is used, heat is developed equally at plate and rod, since the electrode and plate are changing polarity at the frequency of the supply.

Voltage Drop across the Arc. The voltage required to strike a D.C. arc is about 50 to 55 volts, while an A.C. arc requires from 80 to 90 volts. The voltage drop across the arc is 15 to 20 volts when using bare wire or lightly coated rods and maintaining a short arc, necessary with this type of rod. Medium-coated rods with a longer arc length than used for bare wire require from 20 to 25 volts, while certain heavily coated rods require up to 40 volts drop. This voltage drop across the arc determines the amount of penetration and the shape of the deposited bead.

An arc cannot be maintained with a voltage lower than 14, and is not satisfactory above 40 volts. The voltage of the supply can be varied at will in the case of a D.C. set to give a higher or lower voltage across the arc, by means of the field regulator. Evidently the greater the voltage drop across the arc (keeping the current constant) the greater will be the heat energy liberated, and in practice it is found that this voltage variation has a great effect on the character of the arc. The welder should familiarise himself thoroughly with the effect of this voltage variation on the deposited metal.

Apart from this direct control of arc voltage which can be obtained with D.C., the voltage across the arc can be increased in two other ways:

(1) By introducing, into the arc stream, gases such as hydrogen, which, being more non-conducting than air, cause a greater voltage to be required across the arc to enable the current to flow.
(2) By increasing the length of the arc.

Many modern electrodes have hydrogen-releasing coatings, such as sawdust, which introduce hydrogen into the arc stream and thus, by raising the voltage across the arc, increase its energy output, resulting in a more rapid rate of welding.

The second method of increasing the voltage drop across the arc, by holding a long arc, has not yet been applied commercially. With the electrode +ve a $\frac{7}{16}$ in. arc is about as long a one that can be maintained, while with the electrode −ve one about 1 in. long can be held. Arcs of this length, however, are almost impossible to maintain for any time, since they are so unstable, and moreover the absorption of oxygen and nitrogen which takes place due to the large areas of molten metal exposed to the atmosphere invariably results in a poor weld. Research work is now progressing in an endeavour to obtain conditions for a long arc that will be easy to maintain and that will be shielded from the effects of the atmosphere. Such an arc is described in the Lessel process of copper welding.

At the present time it is essential that the welder should keep a short arc to ensure sound welds.

Transference of Metal across the Arc Gap. When an arc is struck between the electrode and plate, the heat generated immediately forms a molten pool in the plate and the electrode begins to melt away, the metal being transferred from the electrode to the plate. Little is at present known about the forces which cause the metal to be transferred. The transference takes place whether the electrode is positive or negative and also when it has a changing polarity, as when used on A.C. Similarly, it is transferred upwards against the action of gravity, as when making an overhead weld. Surface tension plays an important part in overhead welding and a very short arc must be held to weld overhead successfully.

If the arc is observed very closely, or better still if photographs are taken of it with a slow-motion cine-camera, it can be seen that the metal is transferred from the electrode to the plate in the form of drops or globules, and these globules vary in size according to the current and type of rod used (bare or coated). Larger drops are transferred at slower intervals compared with smaller drops, and the transference is the same for both A.C. and D.C. arcs. Some types of rods transfer the metal in the form of a fine spray, the drops in this case being exceedingly small. The drops form, elongate with a neck connecting them to the electrode, the neck gets reduced in size until it breaks, and the drop is projected into the molten pool, which is agitated by the arc stream, and this helps to ensure a sound bond between weld and parent metal. Drops of water falling from a tap give an excellent idea of the method of transference (see Fig. 200).

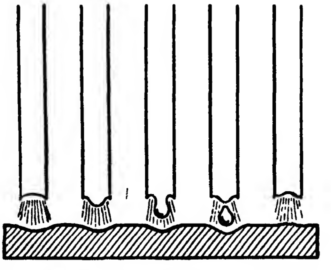


Fig. 200. Transference of metal through the arc

When a bare wire is used as the electrode it is found that the arc is difficult to control, the arc stream wandering hither and thither over the molten pool. The globules are being exposed to the atmosphere in their travel from the rod to the pool and absorption of oxygen and nitrogen takes place even when a short arc is held. The result is that the weld tends to be porous and brittle (Figs. 201, 203).

The arc can be rendered easy to control and the absorption of atmospheric gases reduced to a minimum by 'shielding' the arc. This is done by covering the electrode with one of the various types of coatings previously discussed, and as a result inert gases which will not combine with the molten metal are released from the coverings when they melt. These inert gases form an envelope around the arc and molten pool, completely excluding the atmosphere. The 'shielded' arc coating also melts at a higher temperature than the metal core, and thus the coating always extends a little beyond the core, concentrating and directing the

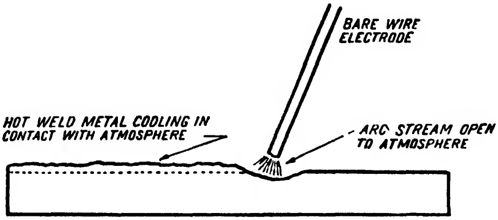


Fig. 201. Bare wire arc. Showing how oxygen and nitrogen are absorbed from the atmosphere. Short arc, voltage drop 15–20 volts. Approx. tensile strength of mild steel deposit 20–26 tons per sq. in. Elongation on 2 in. length 5–12 % little ductility.

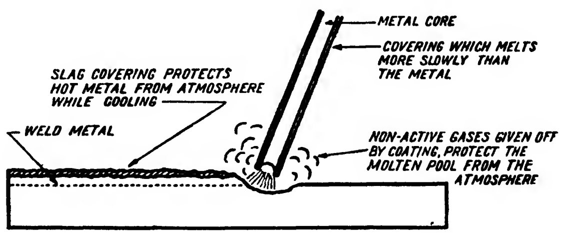


Fig. 202. Shielded arc. Showing how the atmosphere is excluded and the arc made more controllable. Longer arc, voltage drop 20–40 depending on thickness of coating. Approx. tensile strength of mild steel deposit 26–38 tons per sq. in. Elongation on 2 in. length 18–28 % high ductility. In addition the resistance to fatigue, impact and corrosion of the shielded arc deposit is much greater than that of the bare wire deposit.

arc stream, and making the arc stable and easier to control (Figs. 202, 204). The difference in controllability of an arc when using a bare wire compared with a covered rod will be found out by the operator at a very early stage in practical arc welding.

In addition, with a bare electrode, much metal is lost by volatilisation (turning into vapour) during the welding process.

This loss can be greatly reduced by the use of an efficient coating, which may reduce the loss from 25 % to 5 %, thus effecting a great saving.

Arc Blow. We have seen that whenever a current flows in a conductor a magnetic field is formed around the conductor. Since the arc stream is also a flow of current, it would be expected that a magnetic field would exist around it, and that this is so can be shown by bringing a magnet near the arc. It is seen that the arc is blown to one side by the magnet, due to the interaction of its field with that of the magnet (just as two wires carrying a current will attract each other if the current flows in the same direction in each, or repel if the currents are in opposite directions), and the arc may even be extinguished if the field due to the magnet is strong enough. When welding with D.C. it is sometimes found that the arc tends to wander and becomes rather uncontrollable, as though it was being blown to and fro. This is known as arc blow and is experienced most when using currents above 200 or below 40 amperes, though it may be quite troublesome, especially when welding in corners, in between this range. It is due to the interaction of the magnetic field of the arc stream with the magnetic fields set up by the currents in the metal of the work or supply cables. The best methods of correction are:

(1) Weld away from the earth connection.
(2) Change the position of the earth wire on the work.
(3) Wrap the welding cable a few turns around the work, if possible on such work as girders, etc.
(4) Change the position of the work on the table if working on a bench.

In most cases the blow can be corrected by experimenting on the above lines, but occasionally it can be very troublesome and difficult to eliminate. Alternating-current welding has the advantage that since the magnetic field due to the arc stream is constantly alternating in direction at the frequency of the supply, there is no arc blow, and consequently this is very advantageous when heavy currents are being used.

Spatter. At the conclusion of a weld many small particles or globules of metal may sometimes be observed scattered around the vicinity of the weld along its length (see Fig. 216*d*). This is known as 'spatter' and may occur through:

(1) Arc blow making the arc uncontrollable.
(2) The use of too long an arc or too high an arc voltage.
(3) The use of an excessive current.

The latter is the most frequent cause.

Spatter may be caused by bubbles of gas becoming entrapped in the molten globules of metal, expanding with great violence and projecting the small drops of metal outside the arc stream, or by the arc stream being diverted, in the case of a long arc, by the magnetic fields set up, and thus the globules of metal getting projected outside the arc stream.

Spatter can be eliminated by controlling the arc correctly, by reducing current and voltage to the correct values, and by preventing arc blow in the manner previously explained.

Welders' Accessories

Electrode Holder. This is an arrangement which enables the welder to hold the electrode when welding. It has an

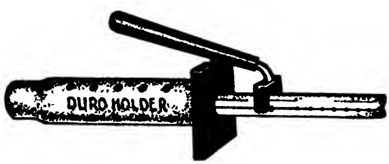


Fig. 203

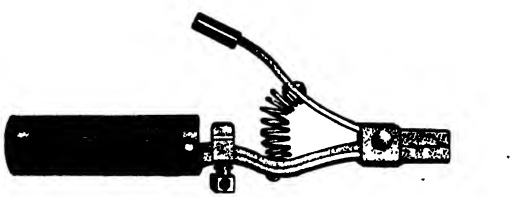


Fig. 204

insulated handle which prevents the hand getting hot due to conducted heat and also prevents any likelihood of electric shocks when working in damp places. The electrode is clamped between copper jaws which are usually spring loaded. A simple movement of the side lever enables the electrode to be changed easily and quickly. The welding flexible cable is attached to the holder by a clamping arrangement, or it may be sweated into a terminal lug. The holder should be light but of robust construction, and electrode changing must be a simple operation. Typical holders are shown in Figs. 203 and 204.

The Electrodes. Metallic electrodes are made in various lengths from 8 to 18 in., and range in size from $\frac{1}{8}$ to $\frac{3}{8}$ in. or more in diameter. Their composition depends entirely upon the work for which they are required, e.g. mild steel, cast iron, bronze, hard surfacing, etc. Bare electrodes are seldom used, because they are so liable to produce unsound welds. Washed, dipped and covered rods have already been described under the

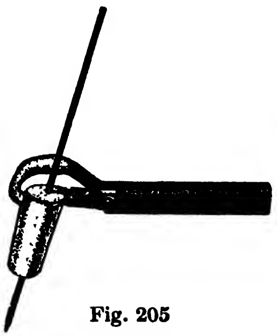


Fig. 205

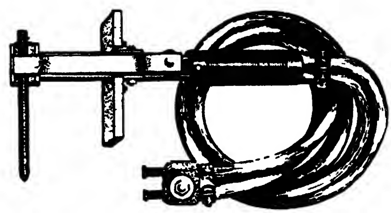


Fig. 206

headings of fluxes, these rods ensuring a sound weld when applied with the correct technique, on the metals for which they are designed. Carbon electrodes are used to strike an arc between a carbon rod and the work, filler rods being added as in oxy-acetylene welding. They are often used for preheating work and are made in diameters from $\frac{5}{32}$ in. upwards. In order to stabilise the carbon arc when using small currents, the feed wire is sometimes wrapped several times round the welding head, as in Fig. 205, and enclosed in an asbestos lagging. This helps to concentrate the arc and make it more easy to control. Special water-cooled carbon electrode holders are available (Fig. 206) for use with larger diameter carbons because of the great heat given out.

Head Shields and Lenses. The rays from the metallic arc are rich in infra-red and ultra-violet radiation, and it is essential that the eyes and face of the welder should be protected from these rays and from the intense brightness of the arc. The welding shield can either fit on to the head (Fig. 207), leaving both hands free, or may be carried in one hand (Fig. 208). It should extend so as to cover the sides of the face, especially when welding is done in the vicinity of other welders, so as to prevent stray flashes reaching the eyes. The shield must be light and, because of this, preferably made of fibre. The lens,

Fig. 207

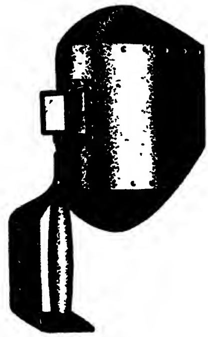


Fig. 208

which fits into an aperture, should absorb at least 99½ % of the infra-red and ultra-violet radiation. A guaranteed lens of this high quality should be insisted upon, as it is the welder's only safeguard against eye trouble, and it should be remembered that the effects of over-exposure of the eyes to the rays may not make themselves fully apparent until many years have passed.

A lens of this type is expensive and is protected from metallic spatter on *both* sides by plain glass, which should be renewed from time to time, as they become opaque and uncleanable, due to spatter and fumes.

Leather or skin aprons are excellent protection for the clothes against sparks and molten metal. Trouser clips are worn to prevent molten metal lodging in the turn-ups, and great care should be taken that no metal can drop inside the shoe, as very bad burns can result before the metal can be removed. Asbestos spats are worn to prevent this. Gauntlet gloves are worn for the same reason, especially in vertical and overhead welding. In welding in confined spaces, such as boilers and fireboxes, the welder should be fully protected, so that his clothes cannot take fire due to molten metal falling on him, otherwise he may be badly burnt before he can be extracted from the confined space.

The welding bench in the welding shop should have a flat top of sheet metal or cast iron, about 4 ft. 6 in. × 2 ft. 6 in. being a handy size. On one end a vice should be fitted, while a small insulated hook on which to hang the electrode holder when not in use is very handy. Another useful accessory is a container, in which to store the various types of welding rods, which must

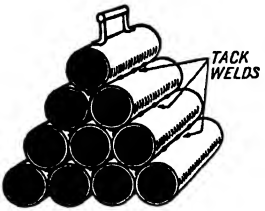


Fig. 209

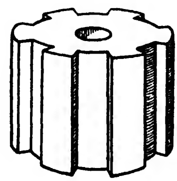


Fig. 210

be kept dry. A suitable one can be made from odd pieces of thin walled steel pipe about 18 in. long and 2 to 3 in. diameter welded together as shown and with a carrying handle on top (Fig. 209).

If welders are to work on adjacent benches, asbestos curtains or metal screens should be arranged between each booth to avoid side glare.

Blocks and rods of carbon to act as 'fences' are very useful. They can be placed in position on a portion of a surface over which weld metal must not encroach. Welding is done and the copper or carbon block effectively prevents the weld metal from running on to the part of the work thus protected. They are especially useful in building up the teeth of gear wheels, since they enable the rough shape of the tooth to be conformed to, and thus reduce the amount of metal which has to be finally removed. Another typical example of their use is the building up of the piston rod of a rock drill on that portion which strikes the drill head itself. On many types there is a central hole through which a rod operates (Fig. 210). When building up this end surface with hard wear-resisting metal, a copper or carbon rod is first placed through the central hole, fitting tightly, and the welding is then performed. On removing the rod the hole is quite clear of any metal deposit, which, if it had flowed in to the hole, would have been almost impossible to remove except by internal grinding.

A pick for deslagging the weld, tongs, hammers, files, chisels and a wire brush complete the essential equipment. A power grinding wheel driven by a flexible shaft is extremely useful for preparing and finishing the work, and is essential in larger shops in order to save time.

Jigs and Fixtures. These are a great aid to the rapid setting up of parts and holding them in position for welding. In the case of repetition work they are essential equipment for economical working. Any device used in this way comes under this heading, and jigs and fixtures of all types can be built easily and quickly and economically by arc welding. They are of convenience to the welder, reduce the cost of the operation, and standardise and increase the accuracy of fabrication.

Jigs may be regarded as specialised devices which enable the parts being welded to be easily and rapidly set up, held, and positioned. They should allow the welded seam to be accessible and must be fairly rigid, but not so rigid that fracture of the part or weld will occur when cooling, and moreover the design must be such that the work can be easily removed after welding.

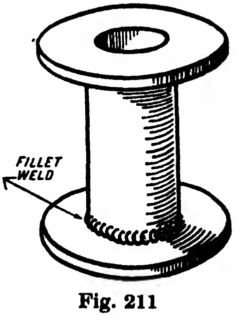


Fig. 211

Fixtures are of a more general character and not so specialised as jigs. They may include rollers, clamps, wedges, etc., used for convenience in manipulation of the work. Universal fixtures are now available, and these greatly reduce the amount of time of handling of the parts to be welded and can be adapted to suit most types of work. An example of a roller fixture is shown in Fig. 304. This enables the tank to be rotated easily when being welded, and this greatly facilitates the operation.

For an elementary example, suppose that flanges have to be welded on to the length of pipe, as in Fig. 211. If accuracy is required in the finished part, great care must be taken that distortion does not occur during welding and cause change in dimensions. If many of these parts are to be turned out, a jig is essential to save time and money. A suitable one is illustrated

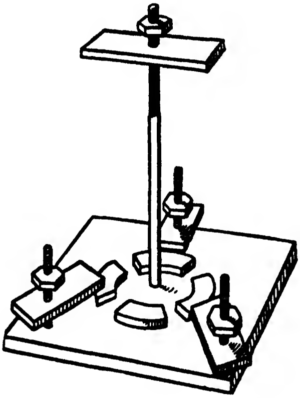


Fig. 212. Jig for fillet welding flanges on to pipes

in Fig. 212, and can be easily fabricated by arc welding, cheaply and quickly. This would reduce the cost and simplify the making of the part. Applications of this type from the simple one considered, to complicated ones, will suggest themselves to the welder in the course of his work, and a collection of such jigs and fixtures is a valuable and essential feature of any welding shop.

Space will not allow of a greater number of illustrations, and their usefulness would be limited, since each part to be fabricated presents its own problem of a suitable jig.

The Practice of Electric Arc Welding

The welder is urged to study the "Home Office Memorandum on Electric Arc Welding."

Electric Arc Welding

In order to assist the operator, the following tables are given, indicating the approximate current values with various types and sizes of electrodes. These tables are approximate only and the actual value of the current employed will depend to a great extent upon the work. In general the higher the current in the range given for one electrode size, the deeper the penetration and the faster the rate of deposit. Too much current leads to undercutting and spatter. Too small a current will result in insufficient penetration and too small a deposit of metal. As a general rule, slightly increase the arc voltage as the electrode size increases.

Full details of currents suitable for the particular electrodes being used are usually found on the electrode packet and should be adhered to; in the following pages it is assumed that, if A.C. is being used, no notice should be taken of the polarity rules, and covered electrodes only should be used.

The technique of welding both mild steel and wrought iron is similar.

Striking and Maintaining the Arc. Using a medium-coated rod (connected to the +ve or −ve pole according to the type of rod) of say $\frac{5}{32}$ in. diameter and with the correct setting of current, the first exercise for the beginner should be in striking the arc and maintaining it. Mild steel plate $\frac{1}{4}$ to $\frac{5}{16}$ in. thick is suitable for the beginning exercises.

There are two methods of striking the arc (Fig. 218). The first consists of jabbing the tip of the rod on to the plate and then lifting it and drawing the arc to about $\frac{1}{8}$ to $\frac{3}{16}$ in. long, while the second method consists of scratching the electrode across the plate with a slight circular motion, so that at the bottom of its travel the arc is struck and further motion of the rod draws the arc to the required length.

Bare Wire, electrode −ve

Arc volts 15–18, increasing with electrode size

Diameter of Rod (in.)	Current in amperes
$\frac{1}{8}$	110–125
$\frac{5}{32}$	140–150
$\frac{3}{16}$	150–175
$\frac{1}{4}$	210–240
$\frac{3}{8}$	250–310

General Purpose Rod, electrode +ve or −ve according to instructions

Arc volts 20–25, increasing with electrode size

Diameter of Rod (in.)	Current in amperes		
	Min.	Max.	Average
$\frac{3}{32}$	50	90	70
$\frac{1}{8}$	60	130	115
$\frac{5}{32}$	100	180	150
$\frac{3}{16}$	150	250	200
$\frac{1}{4}$	200	400	300
$\frac{5}{16}$	250	500	350
$\frac{3}{8}$	300	600	400

Heavily Coated Electrode, generally +ve

Arc volts 20–40, increasing with electrode size

Diameter of Rod (in.)	Current in amperes		
	Min.	Max.	Average
$\frac{5}{32}$	120	180	140
$\frac{3}{16}$	180	250	220
$\frac{1}{4}$	275	375	330
$\frac{5}{16}$	350	500	425
$\frac{3}{8}$	425	600	520

The second method is generally better for the beginner, who is usually troubled with the electrode 'freezing' or sticking to the plate. This is caused by the heavy current flowing when the plate is touched with the end of the rod, melting the end of the rod and virtually welding it on to the plate unless it is drawn

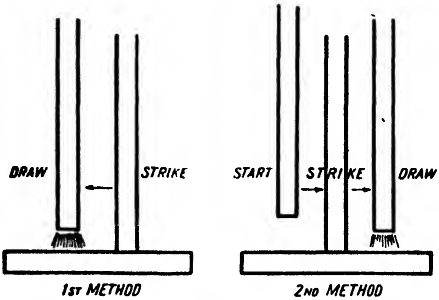


Fig. 218

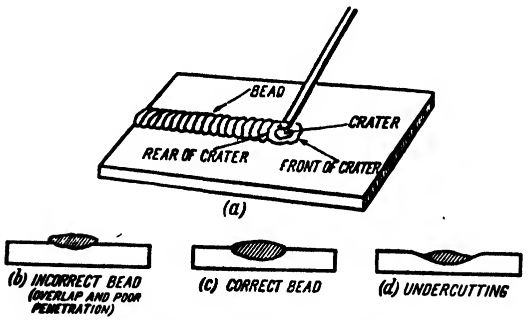


Fig. 218 (*a*), (*b*), (*c*), (*d*)

quickly enough. If the electrode sticks to the plate, it should be freed with a sharp twist; if this fails, the electrode should be released from the holder or the generator switched off. At the instant of striking the arc the operator should place the shield over his face and observe the arc through the lens. When the arc has been drawn, the rod should be held at a steep angle (60–70°) to the plate and then moved slowly and evenly along across the plate towards the operator, keeping the arc a constant fairly short length. No side to side or weaving motion should be attempted. The deposited bead must be continuous, free from holes, even, and must penetrate well into the parent metal. The invariable fault of most beginners is that the rate of travel is too fast, resulting in an irregular bead with poor penetration. If the speed of travel is too slow, too much metal is deposited, the crater is too deep and the electrode tends to become red hot.

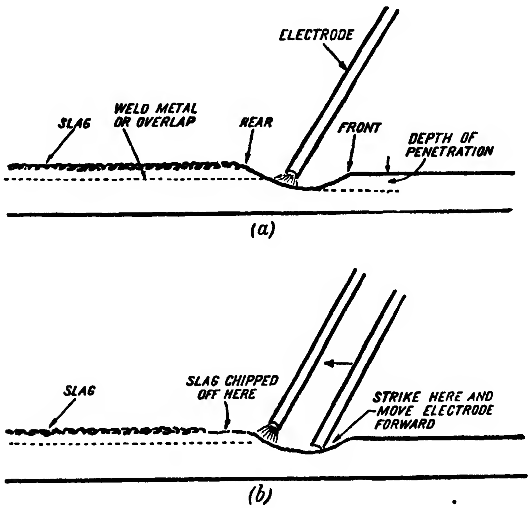


Fig. 214

The molten metal can be observed piling up at the rear of the crater, and this is the best indication as to whether the speed of travel is correct (Fig. 213*a*). The depth of the crater will indicate the amount of penetration, Figs. 214*a* and *b*, while Figs. 213*b* and *c* show incorrect and correct bead sections respectively. Fig. 213*d* indicates undercutting caused by too high a current or too great a welding speed.

It will be noticed that when welding on small masses of metal, the deposited bead rises high above the level of the metal when it is cold. As welding progresses however and the parent metal gets heated up, the penetration becomes deeper and the bead has a lower contour. For this reason the current setting can be higher when welding is commenced and then should be reduced slightly as the metal heats up, resulting in a bead having an even contour throughout its length.

This exercise should be continued until a straight, even, uniform bead about 8 to 10 in. long can be run with good penetration. Then a similar exercise should be performed using a bare wire or lightly dipped rod connected to the −ve pole and holding a shorter arc. The operator will observe that the shorter the arc is, the more easily it is controlled, but the arc is not nearly as easy to control and manipulate as when using the more heavily coated rod. In addition, the bead laid down has not the closeness of texture and its surface has an oxidised appearance.

Bare wire welds are only used in cases where strength and ductility are relatively unimportant.

Next, a heavily coated rod should be tried, connected to the +ve pole and keeping a longer arc than with bare wire. This bead has a much heavier slag deposit, because of the thick coating of the rod, and the operator will have difficulty at first in controlling the slag. He should notice that the molten pool has two distinct colours, one dark and the other light. The dark colour is the molten metal and the light colour the molten slag. Upon no account must the slag be allowed to get in front of the molten metal or blowholes will result, and also the dark-coloured portion must be kept continuous, or else this will result in the slag being entrapped in the metal, causing blowholes. The slag can easily be kept at the rear of the pool, and the best way of ensuring this is to progress at an even rate, keeping a constant arc length. A little practice will ensure excellent beads and, when the slag is chipped off, a bright shining layer of weld metal is exposed to view, completely free from oxidation. With some rods the weld practically deslags itself, and care should be taken that pieces do not fly up into the eyes. In any case chipping should be done, and is performed most easily when the weld has cooled down. The operator will have no difficulty with slag of medium-coated rods.

If a bead is to be continued after stopping, as for example to change an electrode, the end of the bead and the crater must be deslagged and brushed clean and the arc struck at the forward end of the crater. The electrode is then quickly moved to the rear end and the bead continued, so that no interruption can be detected (Fig. 214*b*). This should be practised until no discontinuity in the finished bead can be observed. Since in welding long runs, the welder may have to change rods many times, the

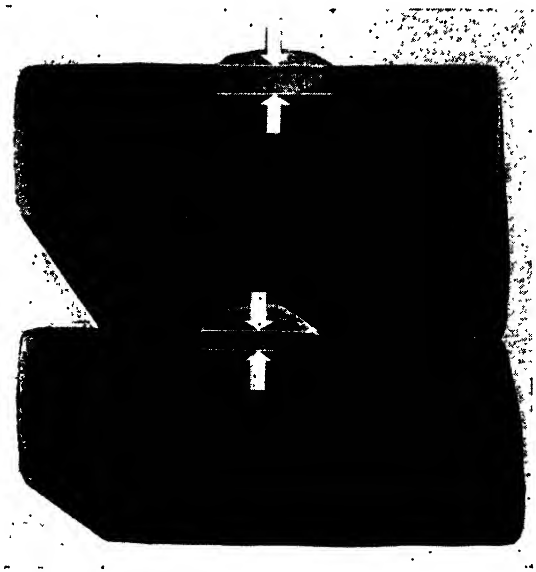


Fig. 215. Illustrating different degrees of penetration in a horizontal bead

importance of this exercise will be appreciated, otherwise a weakness or irregularity would exist whenever the welding operation was stopped.

Beads can now be laid welding away from the operator and also welding from left to right or right to left. A figure of 8 about 5 in. long provides good practice in this and in changing direction of the bead when welding. The bead should be laid continuously around the figure. Little difficulty will be experienced in these exercises when using medium or lightly coated rods, but control of the slag will be found difficult at first when using heavily coated rods. These exercises are useful, because in many cases of fabricated or repair work the welding has to be done in difficult positions and the above methods can be used to advantage.

Control of Current and Voltage

The operator can next familiarise himself with the effect of variation of current and voltage of the arc on the bead. This can be best observed by one operator calling out the reading of the meters while the other operator welds. The machine is set so as to give a voltage of 20 to 24 across the arc, and using a medium-coated rod the current is set at the lowest value. There is poor penetration with a very shallow crater, and the metal heaps up on the plate, producing overlap. The sound of the arc is a splutter more than a crackle. The current is increased until at, say, 110 amperes using a $\frac{1}{8}$ in. rod the crater is deeper (about $\frac{1}{16}$ in.), giving good penetration, the metal flows well, the arc is very easily controlled, and the sound is a steady crackle. Increasing the current well above this produces an excessively deep crater, giving too much penetration (a hole will be blown through the plate if it is insufficiently thick), the arc is fierce and not so easily controlled, while the deposited bead is flat and the electrode becomes red hot. In addition, there is considerable spatter, and the noise of the arc is a loud crackle with a series of explosions (causing the spatter).

If welding with D.C. and the set has the usual voltage control fitted, now set the current at the correct value, as discovered in the previous exercise (say 110 amperes for the $\frac{1}{8}$ in. rod), for the rod being used, and set the voltage control on its lowest setting, giving say 12 volts across the arc. The arc is very difficult, in fact almost impossible, to maintain, and consists of a spluttering in and out, while the metal is deposited in blobs on the plate. The rod tends to stick to the work and the crater formed is very shallow. Increase of voltage improves the arc until at, say, 20 to 24 volts for the rod chosen, the weld has every good characteristic and is easily controlled. Increasing the voltage above this to, say, 30 to 35 across the arc produces a noisy, hissing sound, little penetration and spatter, while the arc is difficult to control and tends to wander. These results are tabulated for convenience of reference, and the accompanying photograph (Fig. 216) shows the appearance of the weld due to the above conditions. The welder should familiarise himself with them.

In A.C. welding the remarks regarding the current apply, but since there is no voltage control the remarks on this may be neglected. The good welder will, however, make a note of all these effects, since he may at any time be called upon to weld with a D.C. set.

Condition of Welding Circuit	Effect
Too low current	Poor penetration; shallow crater; metal heaps up on plate with overlap; arc has unsteady spluttering sound
Too high current	Deep crater; too deep penetration; flat bead; fierce arc with loud crackle; electrode becomes red hot; much spatter
Too low voltage	Rod sticks to work; arc difficult to maintain; spluttering sound as arc goes in and out; metal deposited in blobs with no penetration
Too high voltage	Noisy hissing arc; fierce and wandering arc; bead tends to be porous and flat; spatter
Correct voltage and current and welding speed	Steady crackle; medium crater giving good penetration; easily controlled stable arc; smooth even bead

Weaving

This may be attempted before or after the preceding exercise according to the inclination of the operator. Weaving is a side to side motion of the electrode, as it progresses down the weld, which helps to give better fusion on the sides of the weld, and also enables the metal to be built up or reinforced along any desired line, according to the type of weave used. Weaving is much used to-day, usually much more so in D.C. than in A.C., since the alternations of the A.C. arc tend to produce the same type of effect. Undoubtedly, however, weaving greatly improves the character of the bead, and all welders should learn how to weave. It is especially recommended and required when making welds to stand up to heavy duty, as in pressure vessels and boilers, etc.

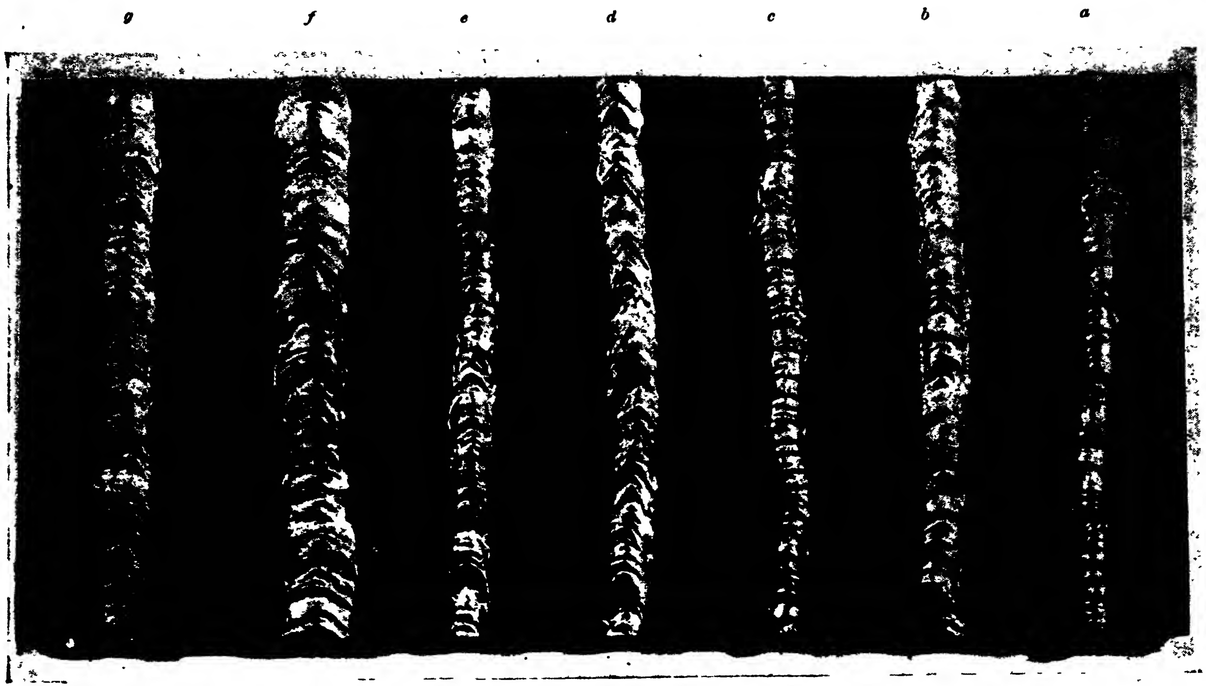

g
f
e
d
c
b
a
Normal bead
Slow rate of travel (wide weave)
Fast rate of travel (used in certain circumstances)
Too much current (note spatter)
Too little current
Too high voltage
Too low voltage

Fig. 216

There are many different methods of weaving, and the method adopted depends on the welder and the work being done. The simplest type is shown in Fig. 217*a*, and is a simple regular side to side motion, the circular portion helping to pile the metal in the bead in ripples. Fig. 217*b* is a circular motion favoured by many welders and has the same effect as Fig. 217*a*. Care should be taken with this method when using heavily coated rods that the slag is not entrapped in the weld. Fig. 217*c* is a figure-of-eight method and gives increased penetration on the lines of fusion, but care must again be taken that slag is not entrapped in the overlap of the weave on the edges. It is useful when reinforcing

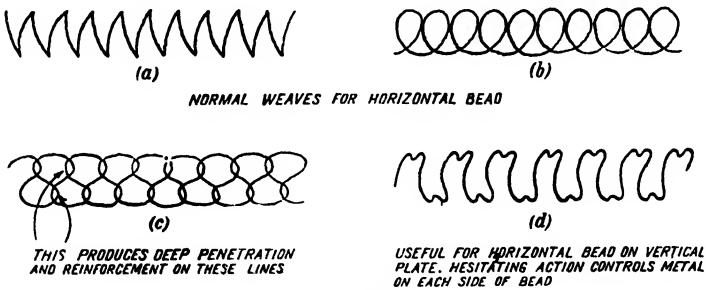


Fig. 217

and building up deposits of wear-resisting steels. Fig. 217*d* is a weave that is useful when running horizontal beads on a vertical plate, since by the hesitating movement at the side of the bead, the metal may be heaped up as required. The longer the period of hesitation at any point in a weave, the more metal will be deposited at this point.

Weaving should be practised until the bead laid down has an even surface with evenly spaced ripples. The width of the weave can be varied, resulting in a narrow or wide bead as required.

At this stage the D.C. welder may also observe the effect of polarity on the bead. Bare wire and lightly coated rods are difficult to deposit, get overheated, and give an uneven bead when connected to the +ve pole, whereas great improvement is noticed at the same current and voltage setting when connected to the −ve pole. Similarly, heavily coated rods connected to the +ve pole run well when used with correct current and voltage setting, while if connected to the −ve pole they are more difficult to control and the metal does not flow well.

Since the polarity evidently depends on the type of coating, the welder should employ the polarity recommended for the rods being used. Vertical and overhead welding, together with the welding of cast iron and the non-ferrous metals, and special steels, are performed with the rod normally positive.

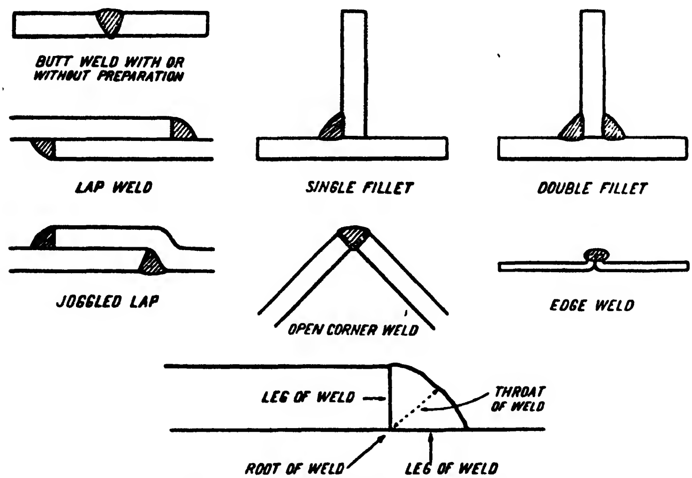


Fig. 218. Types of welded joints

The operator should now be able to proceed to the making of welded joints, and it will be well to consider first of all the method of preparation of plates of various thicknesses for butt welding, as in Fig. 219.

Fig. 218 shows the various types of joints in common use, while the tables on pp. 275 and 276 indicate suitable electrode sizes and number of runs for various thickness plate, together with the approximate weight of electrodes per 1000 ft.

When a weld is made so that the bead is laid horizontally on a flat plate with the hand above the line of the weld, this is called *Down-hand* welding, and wherever possible welding should be done in this position, since it is the easiest from the welder's point of view.

Preparation of Welded Joints

Butt Welds

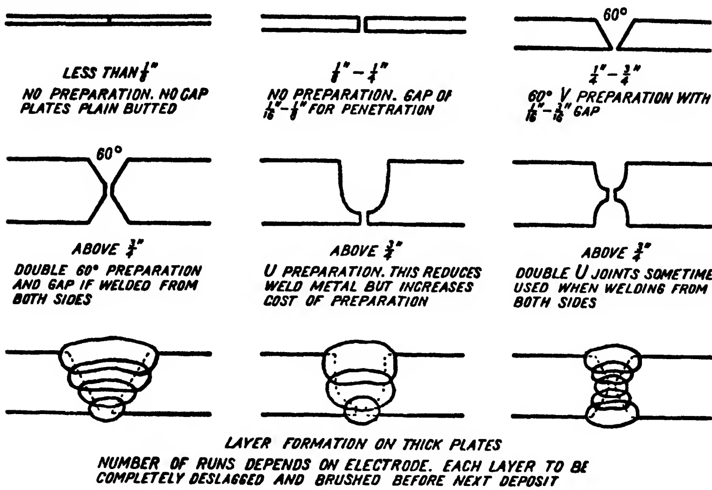


Fig. 219

Butt Weld Data

The following figures may be modified according to conditions, but are approximate for normal work:

Plate Thickness	Method of Preparation	Electrode Size in Order of Runs	Number of Runs
1/16 and 3/32 in.	Butt, no gap	14	One
1/8 in.	Butt, 1/16 in. gap	12 or 10	One
3/16 in.	Butt, 1/8 in. gap	10 or 8	One
1/4 in.	Butt, 1/8 in. gap	8	One
5/16 and 3/8 in.	60° V, 1/16 in. gap	8	Two
1/2 in.	60° V, 1/8 in. gap	10, 8, 6	Three
3/4 in.	U, 3/16 in. gap	8, 6, 4	Three
3/4 in. and above	60° double V, 1/16 in. gap	8, 6, 4	Three or more

DIAMETER AND WEIGHT OF ELECTRODES

S.W. Gauge	Approximate Diameter	Approximate Weight per 1000 ft.
4	$\frac{1}{4}$ in.	165 lb.
6	$\frac{3}{16}$	115
8	$\frac{5}{32}$	85
10	$\frac{1}{8}$	55
12	$\frac{3}{32}$	37
14	$\frac{5}{64}$	23

Full data regarding the length of weld per foot of electrode, welding current, and tensile strength, are given with the particular electrodes being used, and therefore are not included here.

Butt Welding

It will be seen from the table on p. 275 that the size of electrode used will depend on the thickness of the plate being welded. Welds should be made first of all on $\frac{1}{4}$ and $\frac{5}{16}$ in. plate, preparing them correctly with a 60° V, and should be made both with and without weaving. They can be tested roughly for ductility and absence of blowholes by being bent in the vise, and they can also be tested for tensile strength in the testing machine, as described in the section on Testing of Welds.

The operator must get used to breaking open his weld and looking at it, observing any defects, as it is only in this way that good sound welds will be ensured. The effects of distortion can be countered by the methods given in 'Distortion of Welded Joints'.

It is essential that penetration should be right through to the bottom of the V and that an 'underbead', as shown in Fig. 220, should be visible along the whole length of the weld on the underside of the plate.

Open-corner joints can be practised next, a good build up being aimed at, together with fusion right through to the inside of the corner (Fig. 222). This exercise should be done by first tacking (or tack welding) the plates together at the correct angle.

As a rough test of the ductility of the weld, absence of blowholes, and strength of the line of fusion, the joint can be flattened by closing the plates on each other. Weaknesses of a major character will then become apparent.

Butt welds on pipes provide good exercises in arc manipulation. The pipes are prepared in the same way as for plates by V'ing. They are then lined up in a clamp, or are lined up and tack welded in position and then placed across two V blocks. Very

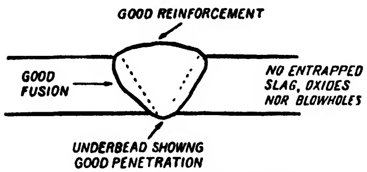


Fig. 220. Good weld

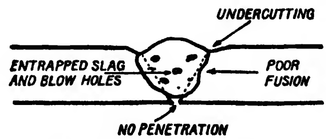


Fig. 221. A poor weld

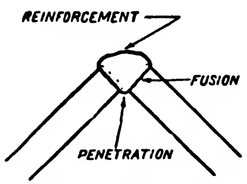


Fig. 222. Open corner joint

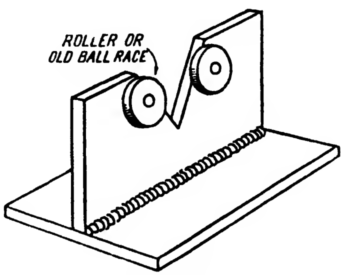


Fig. 223

useful V blocks can be made as in Fig. 223, and the rollers can be plain, or can be old ball races according to inclination, the latter giving smooth rotation of all types of pipes and shafts no matter how heavy.

Using a head shield, so as to leave both hands free, the weld is commenced and the free hand, protected by a gauntlet, is used to keep the pipe rotating, so that the weld is made continuously. If the electrode has to be changed during the weld, great care should be taken to make the bead continuous at this point.

The ends of the pipe can now be plugged and a hydraulic test applied by pump. This indicates the suitability of the weld for pressure vessels.

Padding and Building Up Shafts

This exercise provides a good test of continued accuracy in laying a bead. A plate of $\frac{5}{16}$ to $\frac{3}{8}$ in. mild steel about 9 in. square is chosen and a series of parallel beads are laid side by side

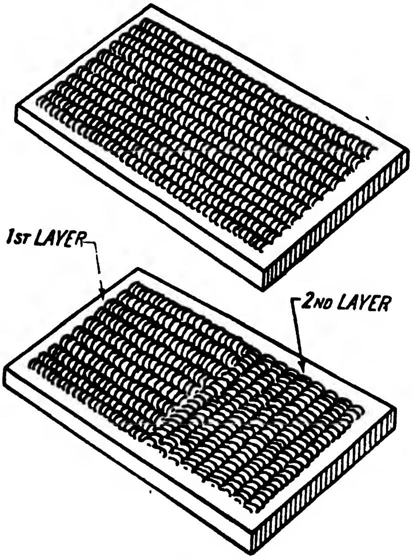


Fig. 224a

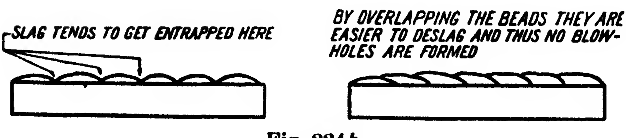
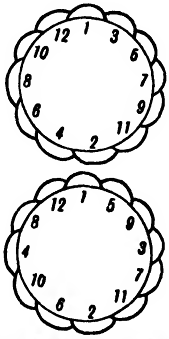


Fig. 224b

across the surface of the plate and so as to *slightly overlap* each other. If the beads are laid side by side with no overlap, slag becomes entrapped in the line where the beads meet, being difficult to remove and causing blowholes Fig. 224*b*. Each bead is deslagged before the next is laid. The result is a built-up layer of weld metal.

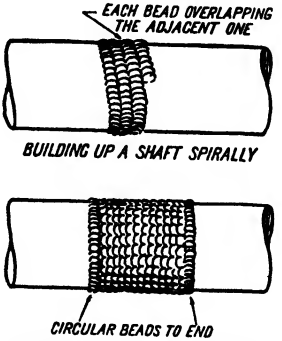
After thoroughly cleaning and brushing all slag and impurities from this layer, another layer is deposited on top of this with the beads at right angles to those of the first layer (Fig. 224*a*), or they may be laid in the same direction as those of the first layer. This can be continued for several layers, and the finished pad can then be sawn through and the section etched, when defects such as entrapped slag and blowholes can at once be seen.

Odd lengths of steel pipe, about ¼ in. or more thick, may be used for the next exercise, which again consists in building up layers as before. The beads should be welded on opposite



ALTERNATIVE METHODS OF LAYING SEQUENCE OF BEADS. EACH BEAD DESLAGGED BEFORE THE OVERLAPPING LAYER IS RUN

Fig. 225*a*



NORMAL METHOD OF BUILDING UP

Fig. 225*b*

diameters to prevent distortion (Fig. 225*a*). After building up two or more layers, the pipe can be turned down on the lathe and the deposit examined for closeness of texture and absence of slag and blowholes. Let each bead overlap the one next to it as previously mentioned—this greatly reduces the liability of pin-holes in the weld metal after being turned down.

The same method exactly is adopted in building up worn shafts (Fig. 225*b*), and a bead may be run around the ends as shown to finish off the deposit. Another method sometimes used consists of mounting the shaft on V blocks and welding spirally. The operator should try both methods.

One further note must be made before proceeding. Shafts are often worn where the bearing surface is, or where the ball races fit, or they may have been turned down undersize in manufacture. In the case of small wear, such as $\frac{1}{32}$ in., it is evident that if the shaft is built up and then turned down again, the thickness of deposited metal remaining is very small, and the bearing surface will be practically on the line of fusion. It is always advisable, in such cases, to turn down the shaft, say a further $\frac{1}{16}$ in., and thus bring the bearing surface well into the deposited metal. This will give much better service (Fig. 226).

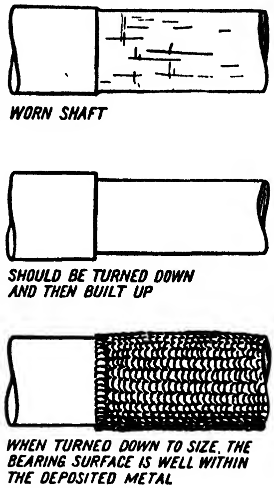


Fig. 226

The following procedure (involving the building up of a pad) is very useful when repairing shafts which have fractured at a large change of section—a very common type of breakdown (Fig. 227*a*). If this is prepared with a double V on the smaller diameter only (Fig. 227*b*), the repair is unreliable owing to the difficulty of ensuring good fusion on the unprepared leg of the V, and double V preparation on both shafts (Fig. 227*c*) is hardly satisfactory owing to the large build up required (as shown by the dotted line) especially if there is a considerable reduction in section at the fracture. This method is, of course, suitable if there is not much change in section at the break.

The most satisfactory and easiest method of repair is to build up a pad on the larger diameter shaft on the position of the break (Fig. 227*d*), the pad being of larger diameter than the smaller shaft to allow for turning or grinding to size. The height of this pad may be $\frac{1}{2}$ to 1 in., depending upon the diameter of the shaft, and this length should then be cut off the smaller shaft to keep the overall length of the shaft the same.

Pad and smaller shaft are now prepared by double V-ing (Fig. 227*e*) and the welding performed, the weld and pad being finally turned and ground to size.

In many repair jobs it is often found that the fit up is poor and that a wide gap often remains to be filled up. The small discarded ends of the electrode, where they were gripped in the holder, can be used to fill up these wide gaps and the whole fused into the weld, resulting in much time being saved.

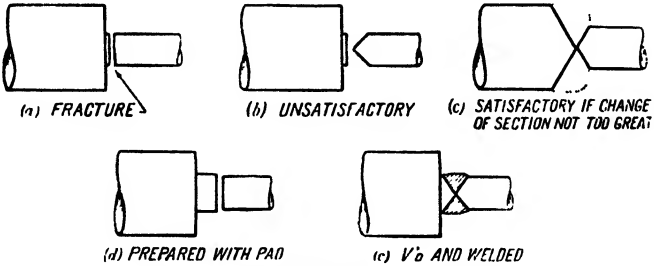


Fig. 227

Lap Welding

Preliminary exercises in lap welding may be made by tilting the plates so that the weld is flat, as shown in Fig. 228. The electrode should point to the centre of the V at 45° to the plate and 60° to the line of weld (Fig. 229). The correct penetration can be obtained in the lower plate which has the greater mass by causing the slight weave to hesitate slightly on this plate. Welds should be then made with the plates flat and the metal controlled so as to get a bead of good section. A wedge inserted at *W* will enable the joint to be broken open for inspection.

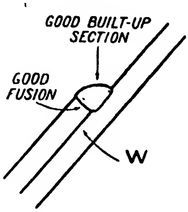


Fig. 228

When a uniform regular bead can be obtained, specimens can be prepared, as in Fig. 294 in the section on Testing of Welds,

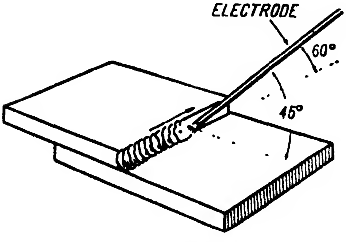


Fig. 229

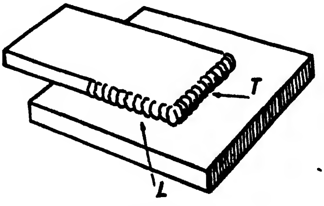


Fig. 230

and tested for strength in shear on the testing machine. Note that a transverse weld at *T* in Fig. 230 is 30 % stronger than the same length of weld made longitudinally at *L*.

Types of Lap Joints. No preparation is normally required for lap welds, and the single joint is used in most cases, since it will stand most loads. The double lap joint is used in cases where heavier loads will be encountered (Fig. 231).

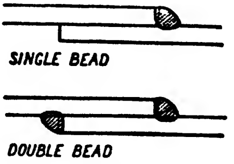


Fig. 231

Fillet Welding

Welds made on an inside corner joint provide good practice for fillet welding (Fig. 236), since the operator thereby gets used to holding and controlling the arc in the more confined space between the two plates. Difficulty is often experienced in making good fillet welds having equal legs and no undercutting. This is because there is a greater mass of metal present near the weld than in a butt joint, and in the case of D.C. welding arc blow may make the arc difficult to control. The weld must penetrate to the bottom of the corner between the plates (Figs. 232, 233, 234), and to ensure this a short arc must be held and the speed of travel must be slow, because of the greater mass of the plates to be heated. Too long an arc and too high a speed of travel will produce undercutting of the vertical plate (Fig. 238). The rod should point at an angle of 35–45° into the corner of the joint, and be held at about 60° or steeper to the line of travel. In most cases weaving is not needed (Figs. 237 *a* and *b*).

Special electrodes for fillet welding help greatly in producing welds having uniform surface, and good penetration with no undercut. Control of the slag often presents difficulties. Keeping the rod inclined at about 60° as before stated helps to prevent the slag running ahead of the molten pool. Too fast a rate of travel will result in the slag appearing on the surface in uneven thicknesses, while too slow a rate of travel will cause it to pile up and flow off the bead. Observation of the slag layer will enable the welder to tell whether his speed is correct or not.

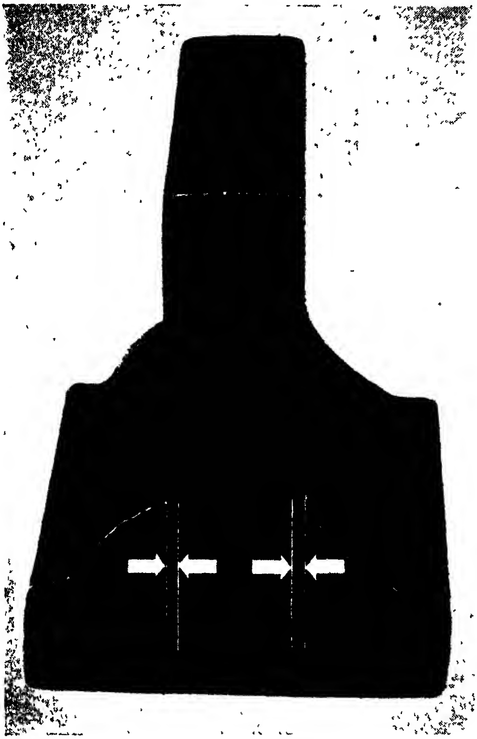


Fig. 282. A double fillet weld showing good penetration. Note the convex bead on left fillet and concave bead on right; this depends on the type of electrode used.

The plain fillet or Tee joint (Fig. 289*a*) is suitable for all normal purposes and has considerable strength. The single V fillet (Fig. 289*b*) is suitable for heavier loads, and is welded from one side only. In thick sections a thinner electrode is used

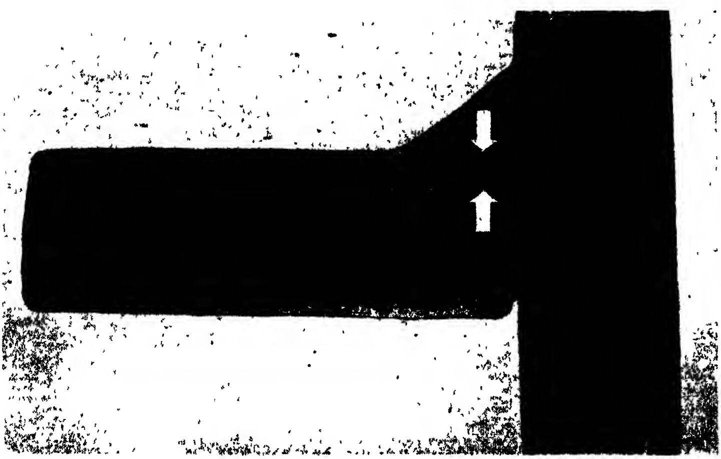


Fig. 233. A fillet weld showing good penetration

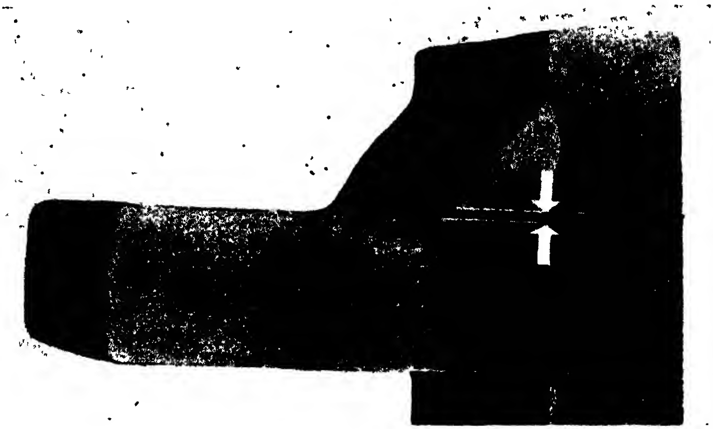


Fig. 234. Showing poor penetration at corner of fillet

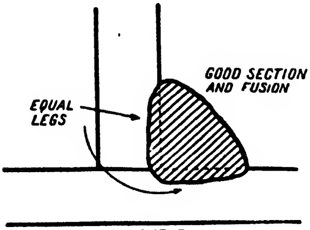


Fig. 235

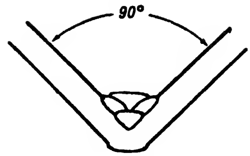


Fig. 236

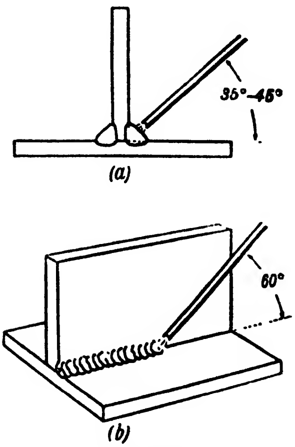


Fig. 237

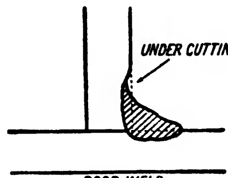


Fig. 238

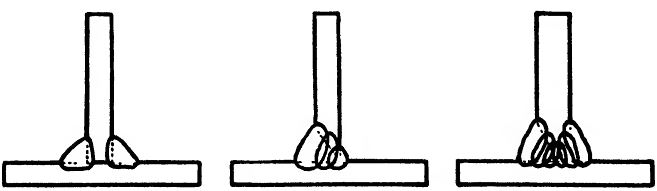


Fig. 239

for the first bead, followed by final runs with thicker rods, each run being well deslagged before the next is laid. Similarly with the double V fillet (Fig. 239c), which is suitable for very thick plates and heavy loads, when the welding can be done from each side.

All practice welds should be either broken open or tested in the machine, as explained in the section on Testing of Welds.

Vertical Welding

All welds inclined at a greater angle than 45° to the horizontal can be classed as vertical welds.

Vertical welding may be performed either upwards or downwards, and in both methods a short arc should be held to enable surface tension to pull the drop across into the molten pool.

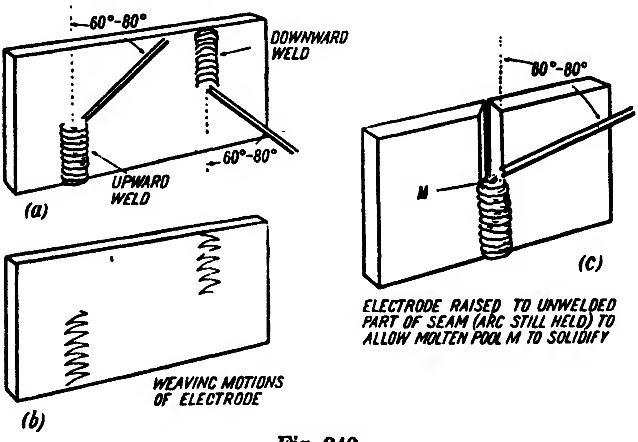


Fig. 240

Electrodes of 10 gauge or smaller are generally used, and special rods having light coatings to reduce difficulties with slag are available. Vertical beads should first be run on mild steel plate, the electrode being held at 60–80° to the plate (Fig. 240).

Downward welding (Fig. 240a) produces a concave bead, and is generally used for lighter runs, since a heavy deposit cannot be laid. If it is, the metal will not freeze immediately it is deposited on the plate, and will drop and run down the plate.

This method, however, is quicker and neater than the upward method, and many welders find it usually easier to weld in this way, and thus produce better welds.

Upward welding (Fig. 240*a*) produces a convex bead, and is used on sections of above ⅜ in. thickness. The metal just deposited is used as a step on which to continue the deposit, and the slag flows away from the pool and does not hinder penetration as it does in the downward method.

In both methods accurate control of the molten metal by using the correct current setting, and keeping a short arc, is essential. In downward welding the weaving motion is exactly similar to that used in downhand welding, but care must be taken that slag does not flow and remain behind the electrode, or this results in blowholes. If it does, lengthen the arc and melt it out, then shorten the arc again and continue. In upward welding, the same side to side motion is used and thus good penetration ensured both at the sides and the bottom of the V. Control of the metal in this method is best obtained by depositing some metal first of all, and then, just as it looks as if the molten metal is going to run out of the pool down the plate, the electrode is raised up the plate, out of the pool, without extinguishing the arc. Fig. 240*c* will make this clear. In this way the heat is reduced, the metal is given time to solidify, and the next layer can be deposited. Progression is thus made in a series of layers. In wider joints on thicker plates, solidification takes place on one side of the weld, while the arc is being weaved to the other side; therefore the above-described method may be dispensed with and welding done in the ordinary manner.

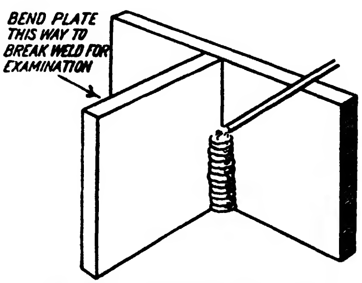


Fig. 241. Vertical fillet weld

Vertical lap and fillet welds are made in exactly the same way as the butt welds just described, and welding can be performed either upwards or downwards. Practice welds should be broken open, so that the degree of penetration into the corner can be observed (Fig. 241).

Horizontal-Vertical Welding

This type of weld is extremely useful for many classes of work, as for example in boiler and firebox reinforcement. As with vertical welding, the greatest factor is correct current value, since if too much heat is introduced, the pool becomes too molten and runs down the side of the plate. A weaving motion is used, keeping a short steady arc, and one free from current variations. It will be noticed that the metal can be piled up at will on the top side or bottom side of the bead according to the time that the rod hesitates at the particular side. The student should aim at a deposit of uniform section, as in Fig. 242, having good penetration with no overlap.

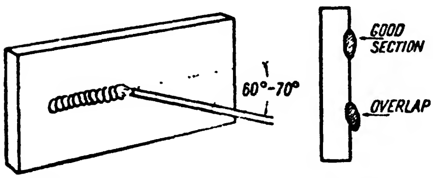


Fig. 242. Horizontal-vertical welding

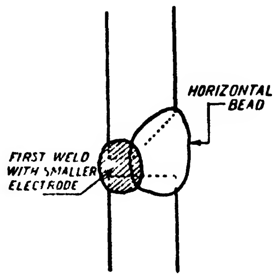


Fig. 243

In butt welds in this class, the joint may be prepared with only one-half a V as shown (Fig. 243), leaving a lower edge as a step on which to weld. A small rod is used to ensure penetration through this type of joint, the first bead being similar to a lap weld. The final bead is then a normal horizontal-vertical one.

In reinforcement of vertical surfaces, the horizontal layer may be first laid along the bottom of the surface and succeeding beads built up above this, using the lower bead in each case as a step. The next layer is then deposited with the beads at right angles to those in the first layer as in padding, this second layer consisting of normal vertical beads. An alternative method is to lay all the beads vertically though this is scarcely so satisfactory.

It may be mentioned here that in welding or building up severely oxidised surfaces, such as found in fireboxes, the metal must be well cleaned and prepared. Even when a bright surface has been exposed it is often found that the weld metal will not fuse correctly into it, indicating a 'burnt' condition of the parent metal. This burnt layer must be completely removed by grinding or chipping, or an unsound weld or reinforcement will result. The welder can soon tell when weld metal is fusing into parent metal correctly.

Overhead Welding

This takes a great deal of practice before the operator is able to deposit an even-bead. Heavily coated rods must not be used, because of the trouble due to the continual dropping of slag. Medium-coated rods of 10 gauge or smaller are generally used, and electrodes recommended for overhead use are most suitable. The most important points about overhead welding are (1) correct control of the current, (2) a very short arc. Correct current control gives a pool that is sufficiently molten to ensure good penetration, but that does not contain enough molten metal to cause it to drip down, while the short arc enables the molten globules to be pulled upwards, against the force of gravity, into the molten pool by surface tension.

For practising overhead welds $\frac{1}{4}$ in. mild steel plate is arranged horizontally, so that the operator can get into a comfortable position underneath it. Good overhead welds are impossible to make unless the welder is in a really comfortable position and free from strain, since the overhead position of the arm is extremely tiring. The body should be out of line with the weld, because of dropping slag or metal, and gauntlet gloves must be worn, and the electrode holder held so that the knuckles are upwards. The arc is struck, and, keeping a very short arc, with the electrode practically at right angles to the plate, the weld is commenced, using only a very small weave (a weave is not really necessary). After practice, in which various current settings should be tried, it will be found that the metal can be placed exactly as required and a neat bead deposited with good fusion. Owing to the weight of cable pulling on the holder, it is often helpful to take a turn of the cable round the arm and thus reduce the drag.

Butt, lap and fillet welds in the overhead position are made in exactly the same manner, the lap and fillet welds being somewhat easier to make, because the vertical leg provides a measure of support for the molten metal. These practice welds *must* be broken open and inspected for penetration and porosity. It is easy to deposit a bead overhead, which is simply 'stuck' on to the surface of the plate. A regular bead is not enough—it *must* have good penetration.

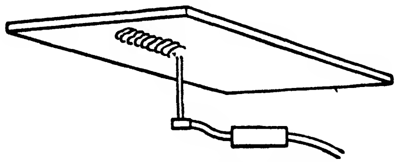


Fig. 244. Overhead welding

Edge Welds

The edges are butted closely together and the electrode held perpendicularly to the seam (Fig. 245). Care must be taken to get correct current control so that a uniform bead will result.

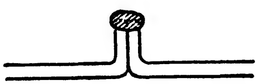


Fig. 245. Edge welding

Sheet Metal Welding (*see also* Carbon Arc Welding)

Both A.C. and D.C. can be used for welding thin gauge sheet metal, but the high-frequency A.C. arc as previously described gives the best results. Sheets from 10 to 22 S.W.G. can be welded, and when using D.C. the electrode should be −ve. The current setting must be low, with a high voltage, while the arc should be short and the welding speed fast. There should be no current surges (a steep volt-ampere curve is required), or this will cause holes to be burnt in the sheet. If the current cannot be reduced low enough by means of the control on the machine, a resistance of 1 to 2 ohms may be connected in series with the electrode cable, and by adjusting this the required current will be obtained.

Welds should first be practised on flat thin gauge sheet, lines of weld being run so as to get the sense of fusion. This exercise must be continued until even beads with fusion through the sheet can be obtained.

Butt Welds

Below $\frac{3}{32}$ in. the sheets are butted with no gap, Fig. 246*a* showing the various methods of preparation. Since distortion occurs during welding, the sheets should be well tacked along the line of weld, or clamped in fixtures to prevent this.

Vertical butt welds are made in a similar manner. Corner welds are prepared as in Fig. 246*b*.

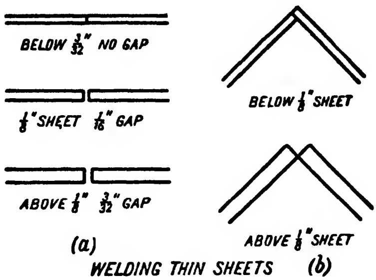


Fig. 246

The following table gives the approximate current settings for various thickness sheets:

Sheet Gauge	Current in Amperes	
	Butt Weld	Corner Weld
14	50–65	65–70
16→$\frac{1}{16}$ in.	25–45	30–50
18	15–35	20–40
20→$\frac{1}{32}$ in.	10–25	15–30

Carbon Arc Welding

The carbon arc (as used in the electric arc furnace) can be used for welding and preheating, and is especially useful for the welding of thin sheets without the use of a filler rod.

In carbon arc welding the holder (see Figs. 205, 206, p. 259) grips the carbon close to the tapered end so as to avoid loss of carbon by vaporisation, and since great heat is evolved, gauntlet gloves should be worn. The approximate currents for various sizes of carbons are given in the table in the appendix and all types of joints can be welded by this method, the method being similar to oxy-acetylene welding, using the carbon arc in place of the flame, the metal being supplied by a filler rod.

The carbon is connected to the negative pole, since this reduces the amount of carbon introduced into the weld. When welding sheet metal the welding should be done quickly and almost daintily to ensure a neat weld. As with metallic arc welding, practice runs should be made on flat sheet so as to obtain the sense of fusion. Runs may be made first of all without a filler rod, fusion being obtained without melting through the plate When this is practicable, a bead can be laid using a filler rod.

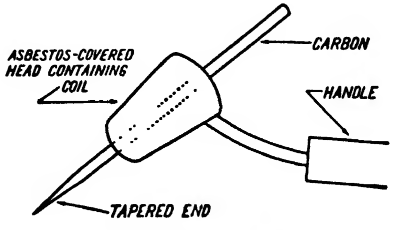


Fig. 247. Position of carbon in holder

Thin sheets are prepared for butt welding by flanging the edges as in Fig. 248. These are then fused together without the use of a filler rod, holding the carbon at right angles to the work. The magnetic field is apt to cause troublesome arc blow when using low currents, and in certain holders for thin gauge work this is prevented by the coil in the head of the holder (Figs. 205 and 247).

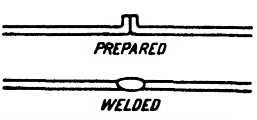


Fig. 248. Sheet welding

Thicker plates are prepared as usual for metallic arc welding, and the weld is performed with the carbon at right angles to the plate, the filler rod being melted into the joint by holding its end in the molten pool (as in oxy-acetylene welding).

Paste-type fluxes (or autogenisers) can be used as in automatic carbon arc welding, and these help to produce welds having better characteristics.

When the carbon arc is used for preheating, it is connected to the −ve pole as before, and the arc moved about over the area to be heated. This heats the whole surface without raising any part to the molten condition.

Cast iron can be welded with the carbon arc. A cast-iron filler rod is used and a flux of the borax type is helpful in producing a sound weld. The welding is done in a similar manner to that explained previously for steel plate, but as usual great care must be taken with the heating and cooling of the casting for fear of cracking.

This method is very like the oxy-acetylene method of welding cast iron, the filler rod being used to float any oxide to the surface. The welds made are fairly machinable, and the deposited metal is stronger than the parent casting.

Cutting with the Carbon Arc. The carbon arc, owing to its high temperature, can be used for cutting steel. A high current is required, and the cut must be started in such a spot that the molten metal can flow away easily. The cut should also be wide enough so that the electrode (of carbon or graphite) can be used well down in it, especially when the metal is thick, so as to melt the lower layers. Cast iron is much more difficult to cut, since the changing of the iron into iron oxide is not easily performed owing to the presence of the graphite.

Arc cutting does not produce anywhere near such a neat cut as the flame cutter, and because of this is only used in special circumstances.

Aluminium and Aluminium Alloys

Aluminium can be arc welded using flux-covered rods. The flux dissolves the layer of oxide (alumina) on the surface of the metal, and also prevents oxidation during welding. The heat of the arc produces rapid melting and, as a result, beginners find a considerable difficulty in managing the arc, since it is so different from the 'steel' arc. With practice, however, and by following the correct procedure, excellent welds can be made.

Preparation. Sheets thinner than ¼ in. can be butted together with no preparation, but with a gap between them for penetration. A backing strip of copper is always advisable in welding aluminium, to prevent collapse, since the metal is so weak at high temperatures. Above ¼ in. thick sheets and castings are prepared with the usual 60° V, as for steel, and the parts should either be tack welded or held in position with clamps or fixtures. The surface must be thoroughly cleaned before attempting to weld (Fig. 249). In many cases the welding can be made easier by sprinkling a little of the powdered flux, used for the oxy-acetylene welding of aluminium, along the line of the weld. This helps in the removal of the oxide. Rods of about ⅛ in. diameter of aluminium-silicon alloy are most suitable for general purposes, and they must be stored in a very dry place to prevent the flux deteriorating.

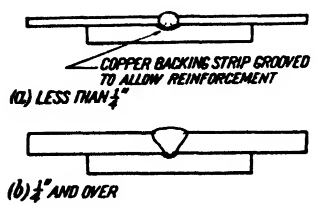


Fig. 249

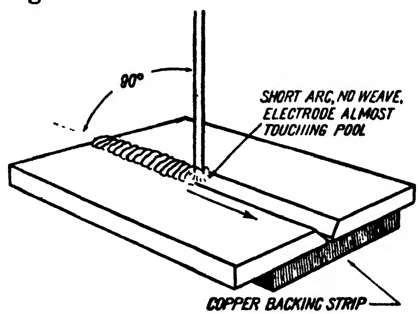


Fig. 250. Aluminium welding

Technique. The rod is connected to the positive pole, and the arc struck by scratching action, as explained for mild steel. It will be found that, as a layer of flux generally forms over the end of the rod, it has to be struck very hard to start the arc. The rod is held at right angles to the work and a *short* arc must be held (Fig. 250), keeping the end pushed down into the molten pool. This short arc, together with the shielding action of the coating of the rod, reduces oxidation to a minimum. A long arc will result in a weak brittle weld. No weaving need be performed, and the rate of welding must be uniform. As the metal warms up the speed of welding must be increased.

The beginner's first attempts at aluminium welding are usually not pretty to look at, consisting of a series of blobs and holes through the plate. As he becomes used to the different characteristics of the arc and regulation of welding speed, however, the welds show great improvement.

Castings are welded in the same way after preparation, but owing to their larger mass, care must be taken to get good fusion right down into the parent metal, since if the arc is held for too short a time on a given portion of the weld the deposited aluminium is merely 'stuck' on the surface as a bead with no fusion. This is a very common fault. Preheating the casting, even to a small degree, helps greatly with the welding.

Lap welds are performed in a similar manner, but with a slight weaving motion to ensure fusion between top and bottom of the joint, especially when the sections are rather thick. The inclination of the rod is shown in Fig. 251*a*.

Fillet welds are performed with no weave and with the rod bisecting the angle between the plates (Fig. 251*b*).

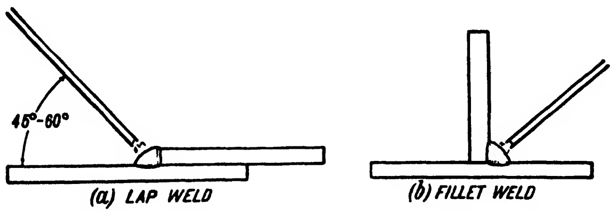


Fig. 251

After Treatment. The flux used is very corrosive and the weld must be thoroughly washed and brushed in hot water after it has cooled out. Immersion in a 5 % solution of nitric acid in water is an even better method of removing the flux, this being followed by brushing and washing in hot water.

Cast-Iron Welding

Cast iron can be welded with the electric arc without the necessity of preheating, and this makes the process extremely useful, since much time and expense is thereby saved.

Preliminary Considerations. Two types of electrode are generally used for cast-iron welding:

(1) Mild steel, or steel base containing alloying elements, such as silicon.

(2) Non-ferrous, such as phosphor-bronze or nickel-copper, e.g. monel.

When steel base weld metal is deposited on cold cast iron, quick cooling results, due to the large mass of cold metal near the weld. This quick cooling results in much of the carbon in an area adjacent to the weld being retained in the combined form (cementite), and thus a hardened zone exists near the weld. In addition, the steel weld metal absorbs carbon and the quick cooling causes this to harden also. As a result welds made with this type of rod have hard zones and cannot always be machined. If, however, the cooling is made as gradual as possible, a good high-speed tool steel will generally cut quite satisfactorily. In many cases, however, machining is not necessary and therefore the previous drawback is no disadvantage. This type of weld has about three times the strength of the parent metal, and steel base rods in particular give good fusion with the cast iron. Rods up to $\frac{1}{8}$ in. diameter are generally used, and a low current ensures the minimum of heat being introduced into the work.

Non-ferrous rods melt at a lower temperature, and thus the hardening effect near the weld is not so great. Also no carbon is absorbed into the weld metal, and thus the weld itself does not harden. The welds are therefore machinable, though as stated above a hardened zone still exists near the weld. Where pre-heating and slow cooling are possible the liability to crack is reduced and the hardening effect much less with both types of rods. Preheating may be done whenever the casting is of complicated shape and liable to fracture easily, though, with care, even a complicated casting may be welded satisfactorily without preheating if the welding is done slowly.

Preparation. Cracks in thin castings should be V'd, or better still U'd, as for example with a bull-nose chisel. Thicker castings should be prepared with a single V below $\frac{3}{8}$ in. thick and a double V above this. Studding (see p. 298) can be thoroughly recommended for thicker sections. The surrounding metal should be well cleaned. The polarity of the electrode depends on the rod being used and the maker's instructions should be followed, though it is generally +ve. With A.C. an open circuit voltage of 90 volts is required and the transformer should be set to give this. Since the heat in the work must be kept to a minimum, a small-gauge electrode, with the lowest current setting that will give sufficient penetration, should be used. A $\frac{1}{8}$ in. rod with 70 to

90 amperes is very suitable for many classes of work. Thick rods with correspondingly heavier currents may be used, but are only advisable in cases where there is no danger of cracking. Full considerations of the effects of expansion and contraction must be given to each particular job.

Technique. The rod is held as for mild steel, and a slight weave can be used as required. Short beads of about 1½ to 2 in. should be run. If longer beads are deposited, cracking will occur unless the casting is of the simplest shape. In the case of a long weld the welding can be done by the skip method, since this will reduce the period of waiting for the section welded to cool. It may be found that with steel base rods, welding fairly thin sections, fine cracks often appear down the centre of the weld on cooling. This can often be prevented, and the weld greatly improved, by peening the weld immediately after depositing a run with quick light blows with a ball-paned hammer. If cracks do appear a further light 'stitching' run will seal them. Remember that the cooler the casting is kept, the less will be the risk of cracking, and the better the result. Therefore take time and let each bead cool before laying another. The weld should be cool enough for the hand to be held on it before proceeding with the next bead. In welding a deep V, lay a deposit on the sides of the V first and follow up by filling in the centre of the V. This reduces risk of cracking. If the weld has been prepared by studding (q.v.), take care that the studs are fused well into the parent metal.

In depositing non-ferrous rods, the welding is performed in the same way, holding a short arc and welding *slowly*. Too fast a welding speed results in porosity. In many cases a nickel copper rod may be deposited first on the cast iron and then a steel base rod used to complete the weld. The nickel-copper rod deposit prevents the absorption of carbon into the weld metal and makes the resulting weld softer. Where a soft deposit is required on the surface of the weld for machining purposes, the weld may be made in the ordinary way with a steel base rod and the final top runs with a non-ferrous rod. The steel base rod often gives a weld which has hard spots in it that can only be ground down, hence this weld can never be completely guaranteed machinable.

Stud Welding or Studding

We have seen that whenever either steel base or non-ferrous rods are used for cast-iron welding, there is a brittle zone near the line of fusion, and since contraction stresses are set up, a weakness exists along this line. This weakened area can be greatly strengthened in thick section castings by studding. Welds made by this method have proved to be exceptionally strong and durable. Studding consists of preparing the casting for welding with the usual single or double V, and then drilling and tapping holes along the V and screwing steel studs into the holes

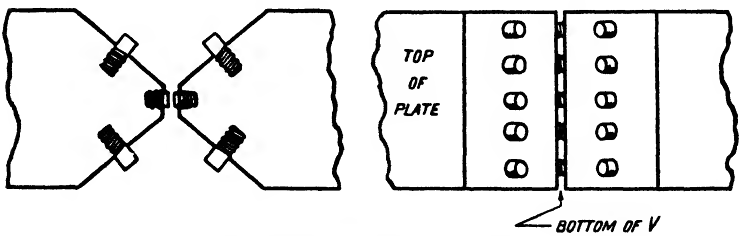


Fig. 252. Method of studding

to a depth slightly deeper than the diameter of the studs. Studs of $\frac{3}{16}$ in. diameter and larger are generally used, depending on the thickness of the casting, and they must project about $\frac{1}{4}$ in. above the surface. The number of studs can be such that their area is about $\frac{1}{6}$th to $\frac{1}{4}$th of the area of the weld, though a lesser number can be used in many cases (Fig. 252). Welding is performed around the area near each stud, using steel or steel-base electrodes, so as to ensure good fusion between the stud and the parent casting. These areas are then welded together with intermittent beads, as before explained, always doing a little at a time and keeping the casting as cool as possible. This method should always be adopted for the repair, by arc welding, of large castings subjected to severe strain.

An alternative method is to weld steel bars across the projecting studs as additional reinforcement. No attempt has been made to describe the welding of any particular job, as no useful purpose would be served by it. Each job presents its own problem. Repair work in cast iron is so varied that experience, together with fundamental technical knowledge, will indicate the best method of welding. The author has performed many successful repairs on large castings using this method of preparation, and steel base rods.

Copper and Bronze Welding

Copper can be welded with the D.C. arc, using coated electrodes of copper or bronze. It can also be carbon arc welded, though this is seldom used.

If the weld must have the same characteristics as the parent metal, as for example for electrical conductivity, coated electrodes

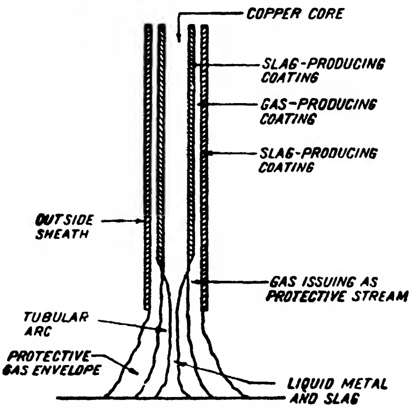


Fig. 253. Lessel process arc for welding copper

of deoxidised copper may be used, but great difficulty is encountered owing to the resulting weld being porous. For this reason at present the oxy-acetylene process is much to be preferred for this type of work. A modern development in copper arc welding is that known as the Lessel process. In this method a specially coated electrode is used, with the electrode +ve, and this gives a long tubular arc. This long arc results in greater energy being dissipated, and owing to the tubular sheath in which the arc is shielded, the heat is concentrated and the arc made steady. Fig. 253 shows a section through this arc. The rate of melting of the rod is controlled by varying the length of the arc and vertical welding can be carried out. The length of arc averages 15 to 25 mm. (⅝ to 1 in.) and the voltage drop across it varies from 40 volts with an 8 mm. arc to 100 volts with a 30 to 35 mm. arc. An arc as long as 50 mm. (2 in.) can be held. This method has applications, as for example in the welding of stays in copper fireboxes where excessive heat over large areas is not desirable, and will undoubtedly be much used in the future.

Bronze Welding

When the weld on copper need not have the same characteristics as the parent metal, covered copper alloy or bronze electrodes will ensure sound welds, and the process is then termed bronze welding. These rods have a lower melting point than copper. Bronze may be laid on copper, brass or bronze and steel with the same ease, and its application to the welding of cast iron has already been considered. It is also useful for the welding of galvanised sheets, as it has a minimum amount of disturbance to the zinc coating. The following description applies also to the use of a copper rod used for copper welding.

Preparation. Plates below ⅛ in. thickness need no preparation, but above this they are prepared as for mild steel with a 60° V and the surfaces thoroughly cleaned. The work must be well supported during welding, since copper especially is very weak when red hot. Asbestos sheet strips can be used as backing strips, this being more essential when using a copper electrode than when using a bronze one. Heavy sections above $\frac{3}{16}$ in. must be preheated, because of the high thermal conductivity of the metal, and this can be done either by the carbon arc (connected to the −ve pole), the oxy-acetylene flame or furnace.

Technique. The rod should be connected to the +ve pole except where otherwise stated. The current value is generally the same or slightly less than that for the same gauge mild-steel electrode, with an arc voltage drop of 20 to 25 volts. The actual values will depend on the particular job. The electrode should be held steeply to the line of weld, and a short arc held keeping the electrode well down into the molten pool. The weld must be made *slowly*, since a quick rate of welding will produce a porous deposit even when bronze rods are used. As welding proceeds and the part heats up, it is usually advisable to reduce the current, or there is a liability to melt through the weld, especially in thinner sections.

After Treatment. Light hammering, while still hot, greatly improves the structure and strength of the weld. The extent to which this should be done depends on the thickness of the metal.

The carbon arc when used to weld copper tends to produce porous welds, and cannot therefore be recommended.

Welding of Copper–Silicon Alloys, such as Everdur

Everdur is an alloy of copper 96 % and silicon 3 % with additions of Al, Fe, Mn, Sn or Zn, and is typical of this range of alloys. Preparation is similar to that for mild steel.

The rod must be of the same composition as the parent metal and can be coated with a flux made of 90 % borax and 10 % sodium fluoride. The rod should be connected to the +ve pole and the welding done with the rod held almost vertically to the line of weld. The weld has properties similar to those of the parent metal.

Inconel, 80 % nickel, 12–14 % chromium, balance mainly iron, is welded in exactly the same way as bronze, using flux-coated inconel rods.

The Building up of Wear– and Abrasion–resisting Surfaces

This type of welding, or surface reinforcement as it may be termed, has reached an important stage in modern production work as well as in the field of repair work. It consists in building up, on a surface of a softer metal, a layer or layers of a metal which will stand wear, abrasion or impact or one that can be used as a cutting surface.

A considerable variety of rods is available under this heading and the final choice will depend entirely upon the nature of the work. We will confine ourselves here to general remarks.

One of the most important types is that containing a high manganese content, and often also nickel and molybdenum, and this type is suitable for building up all types of high (12 to 14 %) manganese steel castings, such as tramway and rail crossings, dredger bucket lips, crusher rolls, steam shovel lips, tractor and caterpillar treads, etc. Certain precautions must be observed in welding manganese castings with these rods.

To prevent any cracking which may develop, the first layers are sometimes deposited on the casting, with rods containing a high nickel and chromium content (as used for stainless steel) and recommended for this purpose. The manganese steel rod is then deposited on this layer and gives the required wear-resisting surface though the cost of this method is high. This type of nickel chrome rod is also used in the repair of fractured castings of this type, as there is once again not the liability of cracking as if a manganese rod was used. Other types of manganese rods may be deposited directly on to the casting and give excellent results at lower cost. The method adopted will depend upon the particular job.

Technique. In depositing manganese steel the surface is cleaned of rust or scale, and the rod connected to the +ve pole if D.C. is used. Use only sufficient current to ensure fusion. Keep a short arc and hold the rod as in welding mild steel. As little heat as possible must be introduced into the casting. The deposit should be laid in wide (½ to 1 in.) short runs about 2 to 3 in. long using a wide weave. The deposited bead should be well hammered after, as this reduces the liability of cracking due to shrinkage. The building up of a deposit is done in the same way as explained in 'padding', still using wide short runs. Each bead is well deslagged and brushed before depositing the next. No quenching is necessary. The deposit work hardens in the same way as an ordinary manganese casting does. Vertical and overhead welding is not recommended with this class of rod.

The technique just explained is typical of that required for this type of work using wear- and abrasion-resisting electrodes. As a rule there is no need to lay such wide runs as with the manganese rods, and no hammering of the weld is necessary after depositing. In the cases where a hard deposit is required, quenching is usual to produce maximum hardness, and these deposits are unmachinable and must be ground to shape.

Some rods give a deposit having a great resistance to impact and are suitable for use connected with parts subjected to impact load or shock, as steel tyres, pile-driver heads, dies, punches, etc.

The hardness of this type of rod varies from 200 to 300 Brinell and depends on the rate of cooling. Other rods air harden to a much greater extent, and these are most suitable for building up deposits on parts which have to stand sliding or rolling abrasion, such as slide-bar guides, friction pins, etc. The hardness again depends on the rate of cooling and may vary from 300 to 500 Brinell.

The choice of electrode therefore depends entirely on the nature of the load to be encountered, and the directions supplied with the rods chosen should be strictly followed.

Another method of depositing an abrasion resisting surface is by the use of granulated tungsten carbide. This is spread evenly on the surface to be faced to a depth of about three times that required. The carbon arc with negative polarity is weaved over the powder to fuse it into the surface, the weave being the full width of the deposit.

This surface has a high resistance to abrasion and corrosion and a Brinell hardness of about 500.

Tipping Tool Steel (*see also* Stelliting)

Cutting tools for lathes, milling machines and high-speed cutting tools of all types can be made by depositing a layer of high-speed steel on to a shank of lower carbon steel. Special electrodes are made for this purpose, and give very good results.

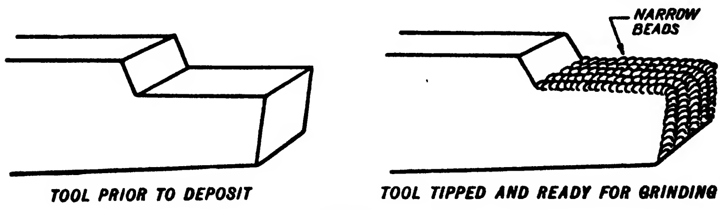


Fig. 254

The surface to be tipped is ground so as to receive the deposit. The electrode is connected to the +ve pole when D.C. is used, and held vertically to the line of weld, a narrow deposit being laid as a general rule. More than one layer is generally advised, since the first layer tends to become alloyed with the parent metal. For this reason the current setting should be as low as possible, giving small penetration. Use a very narrow weave so as to prevent porosity, which is very usual unless great care is taken. Each bead should be allowed to cool out and then be deslagged before depositing the next. The deposited metal when allowed to cool out slowly usually has a Brinell hardness of 500 to 700, depending upon the rod used. The hardness can be increased by heat treatment in the same way as for high-speed tool steel, and the deposit retains its hardness at fairly high temperatures.

These types of rods are very suitable for depositing cutting edges on drills, chisels, shearing blades, dies and tappets, etc. Fig. 254 shows the method of depositing the surface on a lathe tool.

Stelliting

Stellite is an alloy of cobalt, chromium, tungsten and carbon, and when deposited on steel, steel alloy or cast iron gives a surface having excellent wear-resisting qualities and one that will stand up well to corrosive action. It preserves its hardness of surface even when red hot (650° C.), and is thus suitable for use in places where heat is likely to be generated.

It may be deposited very satisfactorily with the arc, though the deposit is not as smooth as one deposited with the oxy-acetylene flame. The arc method of application, however, is specially recommended where it is essential not to introduce undue heat into the part, due to danger of warping or cracking. In many cases, especially where the part has large mass, stelliting by the arc saves time and money compared with the flame. Bare rods of stellite may be used when welding with D.C. and are connected to the +ve pole. If A.C. is employed covered rods must be used, and better results are also obtained with covered rods when using D.C., since the deposit is closer grained and the arc more stable. Covered rods can be obtained or bare rods may be fluxed with a covering of equal parts of calcium carbonate (chalk), silica flour and either borax or sodium carbonate (baking soda), mixed with shellac as a binder.

Preparation. The surface to be stellited must be thoroughly cleaned of all rust and scale and all sharp corners removed. A portable grinder is extremely useful for this purpose. In some cases, where the shape is complicated, preheating to prevent cracking is definitely an advantage.

Technique. In D.C. the rod is connected to the +ve pole and approximate currents are 120 to 140 amperes for $\frac{1}{8}$ in. rod or 200 amperes for $\frac{1}{4}$ in. rod. Higher currents are used with A.C., namely, 150 to 180 amperes for $\frac{1}{8}$ in. rod and 280 amperes for $\frac{1}{4}$ in. rod. A slightly longer arc than usual is held, with the rod nearly perpendicular to the surface, as this helps to spread the stellite more evenly. Care must be taken not to get the penetration too deep, otherwise the stellite will become alloyed with the base metal and a poor deposit will result. Since stellite has no ductility, cooling must be at an even rate throughout to avoid danger of cracking. The surface is finally ground to shape. Lathe centres, valve seats, rock drills and tool tips, cams, bucket lips, dies, punches, shear knives, valve tappet surfaces, thrust washers, stillson teeth, etc. are a few examples of the many applications of hard surfacing by this method.

Welding of Stainless Steel (see p. 74 for description of the classes of stainless steel)

Stainless steel is just as easy to weld as mild steel if the following points are carefully observed. Stainless steel electrodes are also very useful for welding such broken parts as motor-car bumpers, steel tools, etc., and wherever a high strength weld is required.

Preparation. Clean the edges of all rust and scale and either clamp the parts to be welded firmly in position, or tack weld them at very frequent intervals. If the plates are set apart instead of being tacked, it should be remembered that the coefficient of expansion is much greater than for mild steel (50 %) and allowance made for the plates coming in accordingly. Cooling blocks of copper may be used to advantage on sections thinner than 12 gauge, and also backing strips can be used to prevent burning through. Fig. 255 shows the method of preparation of various thickness plate.

Technique. The rod is connected to the +ve pole when D.C. is used (D.C. is easier to weld with than A.C.) and the rod *must* be of the same type as the parent metal, with titanium or columbium as alloying elements. Rods are available for welding the 18/8 class and also for welding the steels of higher chrome nickel content (such as those sometimes called the 25/12 class). In any case the deposited metal must be of the same kind, and in case of doubt the steel or electrode makers should be consulted.

Owing to the high electrical resistance of stainless steel, short electrodes (8 to 9 in.) should be used to prevent overheating. The electrode must be kept cool by welding intermittently if necessary.

A short arc should be held with the electrode at right angles to the line of weld. This is important. No weaving nor puddling should be done. The current should be as recommended for the rods being used, for example, 10 gauge, 70 to 90 amperes; 12 gauge, 40 to 60 amperes; 14 gauge, 25 to 40 amperes.

In multi-run beads the slag should be thoroughly cleaned from one bead before depositing the next.

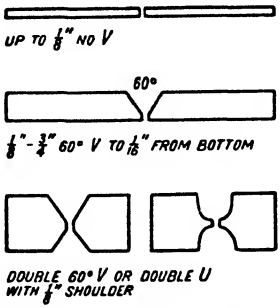


Fig. 255. Preparation for stainless steel

After Treatment. No heat treatment is necessary if decay-proof steels, such as Staybrite FDP, Silver·Fox, 22 and 25, Weldanka, etc., are being welded.

If non-decay-proof steels are being welded, heat treatment is necessary if the weld will encounter corrosive conditions. The suitable heat treatment is given on p. 75. If no corrosive conditions will be met with in service, no heat treatment need be given.

Suitable chemicals for restoring the silver-like surface on steel that is discoloured and tarnished through welding are given on p. 183.

The Welding of Monel and Nickel

Monel (an alloy containing approximately $\frac{2}{3}$rd nickel and $\frac{1}{3}$rd copper) and nickel are easily and satisfactorily welded by the electric arc, using the same technique as for steel. Special coated rods are available of monel and nickel and are connected to the +ve pole when D.C. is used. Sheets are prepared as for mild steel, under $\frac{1}{8}$ in. being butted with a gap, and above this being prepared with a 60° V (Fig. 256).

Fig. 256

Technique. The electrode chosen should be slightly thicker than the sheet to be welded. The current control is carefully adjusted, using a high arc voltage (especially for thin sheets) to avoid current surges. A short arc, about $\frac{1}{16}$ to $\frac{1}{8}$ in., should be held.

It is advisable to tack the work at intervals of not less than 6 in., particularly on sheets of less than 10 gauge, to prevent distortion. Welding is then performed as for mild steel, with very little weaving, each layer being well cleaned before the next is deposited.

Welds made in monel or nickel have excellent properties, and their resistance to corrosion is as good as that of the parent metal.

Nickel-clad Steel

This consists of a light layer of pure nickel hot rolled on to a heavier layer of steel plate, the result being a permanent bond between the two. In this way the cost of parts made of nickel-clad steel compared with pure nickel is considerably reduced, while the advantages of the nickel as a coating are retained. Joints are easily made by welding and the following points should be observed.

Preparation. The joint is prepared by V'ing from the steel side as far as the nickel cladding. Fig. 257*a* shows various methods of preparation.

Technique. The steel side is welded in the normal way for mild steel. The nickel side is then chipped out with a narrow round-nosed chisel, and the weld is completed on the nickel side using the method just described for nickel, with special nickel electrodes (Fig. 257 *b*). Bevelled butt joints should be closely butted together, and after welding the steel side, all slag which may have passed through the joint should be removed and the nickel chipped until the root of the steel weld is exposed.

In welding the nickel side current should be carefully adjusted to give good fusion, the electrode connected to the +ve pole, and a short arc held ($\frac{1}{16}$ to $\frac{1}{8}$ in.), the nickel being fused into the root of the steel weld.

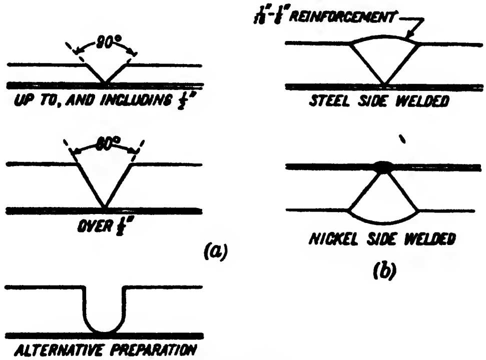


Fig. 257

The Welding of Pipe Lines

The following brief account will indicate to the welder the chief methods used in the welding of pipe lines for gas, oil, water, etc. The lengths of pipes to be welded are placed on rollers, so that they can easily be rotated. The lengths are then lined up and held by clamps and tack welded in four places around the circumference, as many lengths as can be conveniently handled, depending on the nature of the country, being tacked together to make a section. The tack welder is followed by the main squad of welders, and the pipes are rolled on the rollers by assistants using chain wrenches, so that the welding of the joint is entirely done in the downhand position; hence the name *roll welding*.

The technique employed is similar to that described previously for steel, and rods of $\frac{1}{8}$, $\frac{5}{32}$ and $\frac{3}{16}$ in. diameter are used according to the size of pipe. After careful inspection, each welded section is lifted off the rollers by tractor-driven derricks and rested on timber baulks, either over, or near the trench in which it is to be laid. The sections are then *bell hole* welded together. The operator welds right round the pipe, the top portion being done downhand, the sides vertical, and the under side as an overhead weld. Smaller electrodes of $\frac{3}{16}$ and $\frac{5}{32}$ in diameter are used in this type of weld.

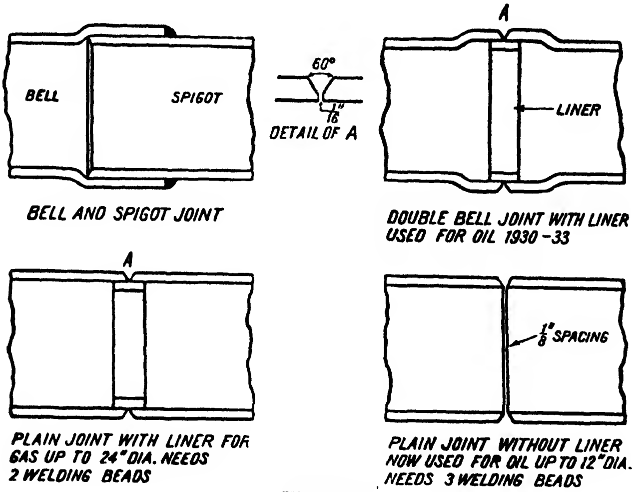


Fig. 258

Through mountainous or swampy country, the *stove-pipe* method is often used. The joints are of the plain end type without a liner and are welded in position as bell-hole welded joints, and thus one length is added to the line at a time, each being first lined up, tacked, and then welded. Two welders often start from the top of the seam and weld downward, thus saving considerable time. This method reduces the man power and equipment necessary to handle the line, and greater skill and care is called for in the actual welding.

For river crossings the pipe thickness is increased by 50 to 100 % and the lengths are roll welded, or bell-hole welded, to the length required for the crossing. Each joint is further reinforced by a sleeve, and large clamps bolted to the line serve as anchor points. The line is then laid in a trench in the river bed.

For water lines from 3 to 5 ft. diameter, bell and spigot joints are often used. On larger diameter pipes the usual joint is the reinforced butt. The pipe is V'd on the inside and welded from the inside. A steel reinforcing band is then slipped over the joint and fillet welded in position.

The types of joint are illustrated in Fig. 258.

WELDING HIGH TENSILE STRUCTURAL STEELS

These steels may contain varying proportions of any of the following: vanadium, manganese, chromium, nickel, cobalt, molybdenum, copper, phosphorus and silicon, in addition to carbon up to 0·7 %.

The following types of rod can be used:

(1) oxidising soft steel (26 tons per sq. in. tensile strength);
(2) mild steel (30 tons per sq. in. tensile strength);
(3) high tensile steel (36 tons per sq. in. tensile strength) containing small amounts of vanadium and molybdenum;
(4) austenitic steel (38 tons per sq. in. tensile strength) either nickel chrome stainless or manganese nickel.

Type (1) is useful for tacking and first runs, but is difficult to manipulate. The weld seldom shows cracks.

Type (2). The titanium oxide partly shielded mild steel electrode is generally satisfactory and the amount of hardening produced depends on the size of the bead laid down. A large gauge rod used with heavy current giving a large bead is recommended for high tensile parent plate.

Type (3). This type of rod is used to give a weld equal in tenacity to the parent high tensile plate. It is more liable to produce cracking than the mild steel rod, thus the latter is generally to be preferred. A large gauge electrode and heavy current is the best method of depositing the bead.

Type (4). Austenitic nickel chrome stainless steel rods are expensive and give welds free from cracks but which have a hard intermediate zone sensitive to fatigue stress. Austenitic manganese nickel rods are less expensive and are satisfactory with some steels, but the nickel chrome are to be preferred.

When welding these steels the following points should be observed:

(*a*) When tacks are used to position the work, as is the general practice, the tack should be well fused into the weld because, due to the rapid cooling and consequent hardening of the area around the tack, cracks may develop.

(*b*) Since the chilling effect is most marked on the first run, careful watch should be kept for any cracks which may develop. Any sealing run applied to the back of the joint should preferably be made either while the joint is still hot, or with a large electrode. The least possible number of runs should be used to fill up the V to minimize distortion.

(*c*) When austenitic rods are used to obtain a weld free from cracks, all the runs should be made with this type of rod and ordinary steel rods not used for subsequent runs. Plates thicker than 15 mm. are preferably preheated to 100–200° C. to avoid cracking. Cold work and interrupted welds should generally be preheated.

(*d*) The electrode or holder should not be struck momentarily or 'flashed' by design or accident on to the plate prior to welding, since the rapid cooling of the small crater produced leads to areas of intense hardness that may result in fatigue cracks developing.

(*e*) Hard spots in the parent plate may be softened by local application of heat as with the blowpipe, but this may reduce the endurance value of the joint.

(Dearden and O'Neill, 'Welding of low alloy structural steel', *Inst. of Welding Trans.*)

Chapter V

THE GAS CUTTING OF IRON AND STEEL

Iron and steel can be cut by the oxy-hydrogen, oxy-coal gas and oxy-acetylene cutting blowpipes with ease, speed and a cleanness of cut.

Principle of Cutting Operation

There are two operations in gas cutting. A heating flame is directed on the metal to be cut and raises it to bright red heat or ignition point. Then a stream of high-pressure oxygen is directed on to the hot metal. The iron is immediately oxidised to magnetic oxide of iron (Fe_3O_4) and, since the melting point of this oxide is well below that of the iron, it is melted immediately and blown away by the oxygen stream.

It will be noted that the metal is cut entirely by chemical action and the iron or steel itself is not melted. Because of the rapid rate at which the oxide is produced, melted and blown away, the conduction of the metal is not sufficiently high to conduct the heat away too rapidly and prevent the edge of the cut from being kept at ignition point.

The heat to keep the cut going once it has started is provided partly by the heating jet, and partly by the heat of the chemical action.

The Cutting Torch or Blowpipe

The cutting blowpipe is quite different in construction from the welding blowpipe. Acetylene and oxygen are mixed and supplied to the heating flame on the injector principle in the same way as in the welding torch; hence either low-pressure or high-pressure gas can be used. In the centre of the nozzle is a hole, through which the stream of oxygen is released when the metal is at ignition point (Fig. 259).

This cutting jet is controlled by a separate valve, usually spring loaded, so that pressure on a lever is sufficient to release the stream of oxygen. Immediately pressure is removed from the lever this oxygen stream is cut off, thus effecting considerable saving. Fig. 260 shows a section of a modern cutting torch.

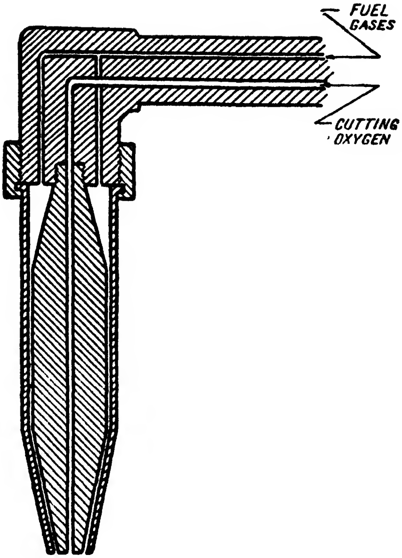


Fig. 259. Section of cutting head of concentric type cutter

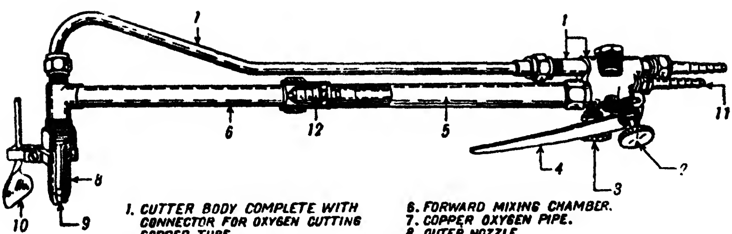


Fig. 260. Titan metal cutting blowpipe

The size of torch varies with the thickness of work it is required to cut and whether it is for light duty or heavy, continuous cutting. Fig. 261 shows a specially designed head for cutting steel sheet up to $\frac{5}{32}$ in. thick.

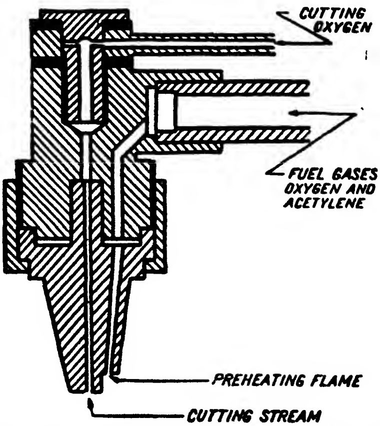


Fig. 261. Cutting head for thin steel sheet

The amount of oxygen consumed will naturally be much greater than that of the coal gas or acetylene. The pressure is also much higher than in welding, and a regulator giving an

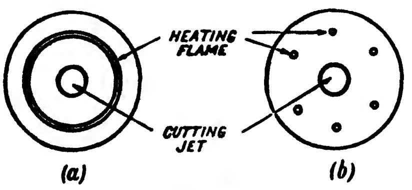


Fig. 262

oxygen pressure on the outlet side of 100 to 400 lb. per sq. in. is necessary for heavy work and the acetylene can be supplied by high-pressure or low-pressure systems with the same equipment. If coal gas is used instead of acetylene, it is supplied from the gas mains through a non-return valve to prevent flame flash back.

The high-pressure acetylene gauge may be the same as for welding. The cutting nozzles will vary in size according to the thickness to be cut, but they are usually of two types. In the first type the heating flame is a concentric jet around the central cutting jet (Fig. 262 *a*), while in the second type the heating jets are separate small jets, as shown in Fig. 262 *b*.

Adjustment of Flame

Oxy-Hydrogen. The correctly adjusted pre-heating flame is a small non-luminous central cone with a pale blue envelope.

Oxy-Coal Gas. This is adjusted until the luminous inner cone assumes a clear, definite shape, that may be up to $\frac{5}{16}$ to $\frac{3}{8}$ in. in length for heavy cuts.

Oxy-Acetylene. This flame is adjusted until there is a circular short blue luminous cone, if the nozzle is of the concentric ring type, or until there is a series of short, blue, luminous

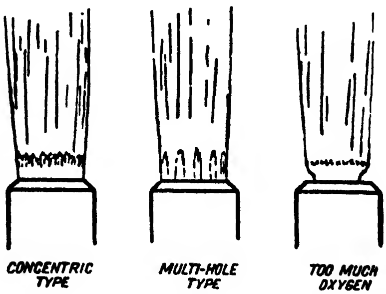


Fig. 263

cones (similar to the neutral welding flame), if it is of the multi-hole type (Fig. 263 *a* and *b*). The effect of too much oxygen is indicated in Fig. 263 *c*.

It may be observed that when the cutting valve is released the flame may show a white feather, denoting excess acetylene. This is due to the slightly decreased pressure of the oxygen to the heating jet when the cutting oxygen is released. The flame should be adjusted in this case so that it is neutral when the cutting oxygen is released.

Care should be taken to see that the cutter nozzle is the correct size for the thickness to be cut and that the oxygen pressure is correct (the nozzle sizes and oxygen pressures vary according to the type of blowpipe used).

The nozzle should be cleaned regularly, since it becomes clogged with metallic particles during use. In the case of the concentric type of burner, the outer ring should be of even width all round, otherwise it will produce an irregular-shaped inner cone, detrimental to good cutting (Fig. 264).

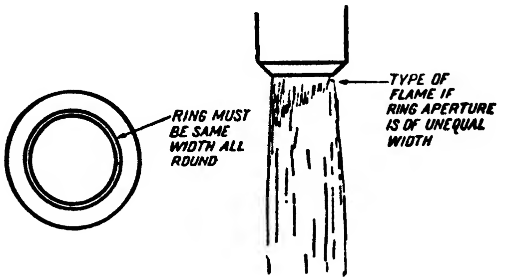


Fig. 264

Technique of Cutting

The surface of the metal to be cut should be free of grease and oil, and the heating flame is held above the edge of the metal to be cut, farthest from the operator, with the nozzle at right angles to the plate. The distance of the nozzle from the plate depends on the thickness of the metal to be cut, varying from $\frac{1}{8}$ to $\frac{3}{16}$ in. for metal up to 2 in. thick, up to $\frac{1}{4}$ in. for metal 2 to 6 in. thick. Since the oxide must be removed quickly to ensure a good, clean cut, it is always preferable to begin on the edge of the metal.

The metal is brought to white heat and then the cutting valve released, and the cut is then proceeded with at a steady rate. If the cutter is moved along too quickly, the edge loses its heat and the cut is halted. In this case, the cutter should be returned to the edge of the cut, the heating flame applied and the cut restarted in the usual manner. Round bars are best nicked with a chisel, as this makes the starting of the cut much easier. Rivet heads can be cut off flush by the use of a special type nozzle while, if galvanised plates are to be cut for any length of time, a respirator is advisable, owing to the poisonous nature of the flames.

To cut a girder, for example, the cut may be commenced at *A* and taken to *B*, Fig. 265. Then commenced at *C* and taken to *B*, that is, the flange is cut first. Then the bottom flange is cut in a similar manner. The cut is then commenced at *B* and taken to *E* along the web, this completing the operation. By cutting the flanges first the strength of the girder is altered but little until the web itself is finally cut.

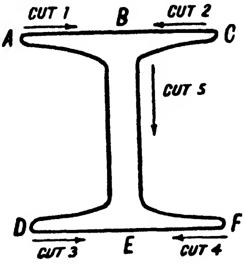


Fig. 265

Rollers and point guides can be affixed to the cutter in order to ensure a steady rate of travel and to enable the operator to execute straight lines or circles, etc. with greater ease (Fig. 266*a*).

The position of the flame and the shape of the cut are illustrated in Fig. 266*b*.

To close down, first shut off the cutting stream, then the coal gas or acetylene and then the oxygen valve. Close the cylinder valves and release the pressure in the tubes by momentarily opening the cutter valves.

To cut holes in plates a slightly higher oxygen pressure may be used. The spot where the hole is required is heated as usual and the cutting valve released gently, at the same time withdrawing the cutter away from the plate. The extra oxygen pressure assists in blowing away the oxide, and withdrawing the nozzle from the plate helps to prevent oxide from being blown on to the nozzle and clogging it. The cutting valve is then closed and the lower surface now exposed is heated again, and this is then blown away, these operations continuing until the hole is blown through. The edges of the hole are easily trimmed up afterwards with the cutter.

When coal gas is used instead of acetylene, the flame temperature is lower; consequently it takes longer to raise the metal to ignition point and to start the cut, and it is not suitable for hand cutting over 4 in. thick nor for cast-iron cutting. Because of this lower temperature, the speed of cutting is also slower. The advantages, however, are in its ease of adjustment and control; it is cheap to instal and operate and, most important of all, since the metal is not raised to such a high temperature as with the oxy-acetylene flame, the rate of cooling of the metal is slower and hence the edges of the cut are not so hard. This is

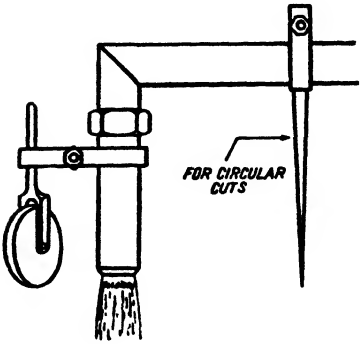


Fig. 266a

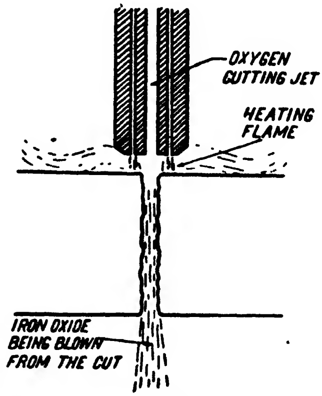


Fig. 266b

especially so in the case of low carbon and alloy steels. For this reason, oxy-coal gas is often used in works where cutting machines are operated (see later).

The oxy-hydrogen flame can also be used (the hydrogen being supplied in cylinders, as the oxygen). It is similar in operation to the oxy-coal gas, but has a higher flame temperature. It is advantageous where cutting has to be done in confined spaces when the ventilation is bad, since the products of combustion are not so harmful as in the case of oxy-acetylene and oxy-coal gas, but is not so convenient, quick and cheap to operate as the oxy-acetylene system.

The Effect of Gas Cutting on Steel

It would be expected that the cut edge would present great hardness, owing to its being raised to a high temperature and then subjected to rapid cooling, due to the rapid rate at which heat is dissipated from the cut edges. Many factors, however, influence the hardness of the edge.

Steels of below 0·3 % carbon can be easily cut, but the cut edges will definitely harden, although the hardness rarely extends more than ⅛ in. inwards and the increase is only 30 to 50 points Brinell.

Steels of 0·3 % carbon and also alloy steels are best pre-heated before cutting, as this reduces the liability to crack.

Nickel, molybdenum, manganese and chrome steels (below 5 %) can be cut in this way. Steels having a high tungsten cobalt or chrome content, however, cannot be cut satisfactorily. Manganese steel, which is machined with difficulty owing to the work hardening, can be cut without any bad effects at all.

The oxy-acetylene flame produces greater hardening effect than the oxy-coal gas flame, as before mentioned, owing to its higher temperature. Excessive cutting speeds also cause increased hardness, since the heat is thereby confined to a narrower zone near the cut and cooling is thus more rapid. Similarly, a thick plate will harden more than a thin one, owing to its more rapid rate of cooling, due to the increased mass of metal being capable of absorbing the heat more quickly. The hardening effect for low carbon steels, however, can be removed either by pre-heating or heat treatment after the cut. The hardening effect in mild steel is very small. On thicknesses of plate over ½ in. it is advisable to grind off the top edge of the cut, as this tends to be very hard and becomes liable to crack on bending.

The structure of the edges of the cut and the nearby areas will naturally depend on the rate of cooling. Should the cutting speed be high and the cooling be very rapid in carbon steels, martensite or troostite may occur, while with a slower rate of cutting and reduced rate of cooling, the structure will be of sorbite. A band of pearlite is usually found, however, very near to the cut edge and, because of this, the hardness zone, containing increased carbon, is naturally very narrow. When the cut edge is welded on directly, without preparation, all this concentration of carbon is removed.

Thus, we may say that, for steels of less than 0·3 % carbon, if the edges of the cut are smooth and free from slag and loose oxide, the weld can be made directly on to the gas-cut edge without preparation.

Oxygen Lance

The oxygen lance is used for cutting out the tap holes of blast furnaces, and making holes in steel castings ingots ready for blasting for scrap purposes.

The spot at which the hole is required is heated to red heat with the welding blowpipe, or any other means, and then the oxygen is directed on to this spot by means of the lance. Fig. 267 shows the lance holder complete with flexible tubing, which owing to the high pressure used should be firmly clipped on to regulator and lance. The oxygen is directed from the holder to the required spot by a small steel pipe (¼ in. gas pipe), which burns away as the hole is cut. The regulating gauge is provided with a safety valve which prevents bursting of the tube in the event of the steel feeding pipe becoming clogged.

The usual precaution regarding cutting should be taken, goggles, gauntlet gloves and leather apron being worn by the operator, and in this way holes can be cut quickly and economically.

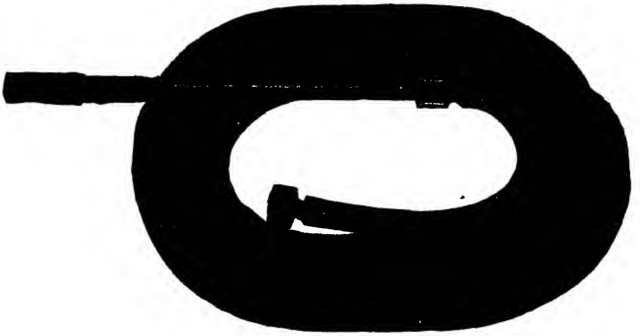


Fig. 267

Cutting Machines

Profiles cut by hand methods are apt to be very irregular and, where accuracy of the cut edge is required, cutting machines are used. The heating flame is similar to that used in the hand cutter and is usually oxy-coal gas or oxy-acetylene (either dissolved or generated), while the thickness of cut depends on the nozzle and gas pressures.

The mechanical devices of the machines vary greatly, depending upon the type of cut for which they are required. In many types a tracing head on the upper table moves over the drawing or template of the shape to be cut. Underneath the table or on the opposite side of the machine (depending on the type) the cutting head describes the same motion, being worked through an intermediate mechanism. The steel being cut is placed on supports below the table.

Simpler machines for easier types of cuts, such as straight lines and circles, bevels, etc., are also made.

Fig. 268 shows a typical type of machine capable of cutting from $\frac{1}{8}$ to 14 in. thick, 10 ft. in a straight line and up to 4 ft. 7 in. diameter circle. The machine incorporates a magnetic tracing roller, which follows round a steel or iron template the exact shape of the cut required, while the cutting head cuts the replica of this shape below the table.

Stack Cutting

Thin plates which are required in quantities can be cut by clamping them tightly in the form of a stack and, due to the accuracy of the modern machines, this gives excellent results and the edges are left smooth and even. Best results are obtained with a stack 3 to 4 in. thick, while G clamps can be used for the simpler types of stack cutting.

Cast-Iron Cutting

Cast-iron cutting is made difficult by the fact that the graphite and silicon present are not easily oxidised. Reasonably clean cuts can now be made, however, using a blowpipe capable of working at high pressures of oxygen and acetylene. Cast iron cannot be cut with hydrogen or coal gas.

Since great heat is evolved in the cutting process, it is advisable to wear protective clothing, face mask and gloves.

The oxygen pressure varies from 110 lb. per sq. in. for $1\frac{1}{2}$ in. thick cast iron to 160 lb. per sq. in. for 14 to 16 in. thick, while the acetylene pressure is increased accordingly.

The flame is adjusted to have a large excess of acetylene, the length of the white plume being from 2 to 4 in. long (e.g. 3 in. long for $1\frac{1}{2}$ to 2 in. thick plate). The speed of cutting is slow, being about 7 ft. per hour for 3 to 5 in. thick metal.

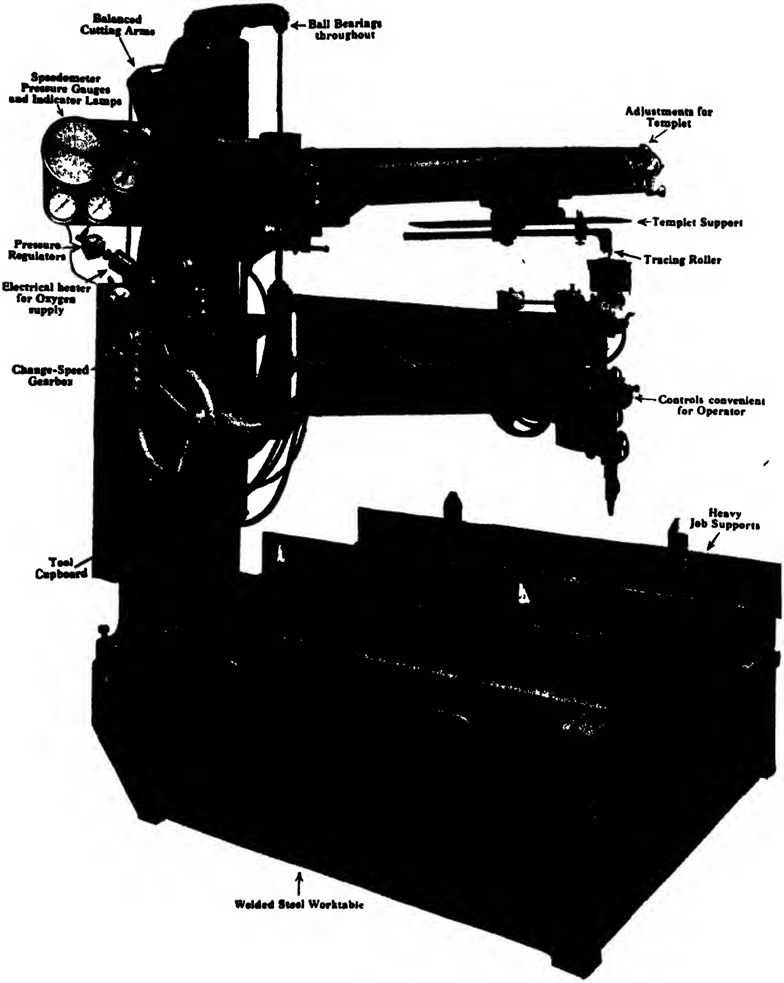

Balanced Cutting Arms
Ball Bearings throughout
Speedometer Pressure Gauges and Indicator Lamps
Adjustments for Templet
Templet Support
Pressure Regulators
Tracing Roller
Electrical heater for Oxygen supply
Change-Speed Gearbox
Controls convenient for Operator
Heavy Job Supports
Tool Cupboard
Welded Steel Worktable

Fig. 268

Technique. The nozzle is held at 45 degrees to the plate with the inner cone $\frac{3}{16}$ to $\frac{1}{4}$ in. from the plate, and the edge where the cut is to be started is heated to red heat over an area about $\frac{1}{2}$ to $\frac{3}{4}$ in. diameter. The oxygen is then released and this area burnt out. The blowpipe is given a zig-zag movement, and the

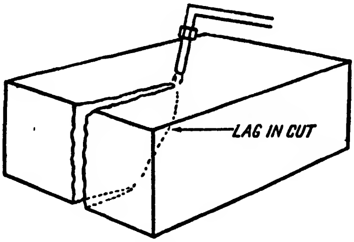


Fig. 269

cut must not be too narrow or the slag and metal removed will clog the cut. About $\frac{1}{2}$ to $\frac{3}{4}$ in. is the normal width. After the cut is commenced the blowpipe may be raised to an angle of 70 to 80°, which will produce a lag in the cut, as shown in Fig. 269.

Owing to the fact that high pressures are used in order to supply sufficient heat for oxidation, large volumes of gas are required, and this is often obtained by connecting several bottles together.

Chapter VI

THE INSPECTION AND TESTING OF WELDS

During the process of welding, faults of various types may creep in. Some, such as those dealing with the quality and hardness of the weld metal, are subjects for the chemist and research worker, while others may be due to lack of skill and knowledge of the welder. These, of course, can be overcome by correct training (both theoretical and practical) of the operator.

In order that factors such as fatigue may not affect the work of a skilled welder, it is evidently necessary to have means of inspection and testing of welds, so as to indicate the quality, strength and properties of the joint being made.

Visual Inspection, both while the weld is in progress and afterwards, will give an excellent idea of the probable strength of the weld, after some experience has been obtained at it.

Inspection during Welding

Electric Arc Welding. The chief items to be observed are:

(1) Rate of burning of rod and progress of weld; (2) Amount of penetration and fusion; (3) The way the welded metal is flowing (no slag inclusions); (4) Sound of the arc, indicating correct current and voltage for the particular work.

Oxy-Acetylene Welding. The chief items are: (1) Correct flame for the work on hand; (2) Correct angle of blowpipe and rod, depending on method used; (3) Depth of fusion and amount of penetration; (4) Rate of progress along the joint.

The above observations are a good indication to anyone with experience what quality of weld is being made, and this method furnishes one of the best ways of observing the progress of welders when undergoing training.

Inspection after Welding

Examination of a weld on completion will indicate many of the following points:

(1) Has correct fusion been obtained between weld metal and parent metal?

(2) Is there an indentation, denoting undercutting along the line where the weld joins the parent metal (line of fusion)?

(3) Has penetration been obtained right through the joint, indicated by the weld metal appearing through the bottom of the V on a single V or U joint?

(4) Has the joint been built up on its upper side (reinforced), or has the weld a concave side on its face, denoting lack of metal and thus weakness?

(5) Does the metal look of close texture or full of pinholes and burnt, denoting incorrect flame?

(6) In arc welding has spatter occurred, indicating too high a current or too high a voltage across arc or too long an arc?

(7) Are the dimensions of the weld correct, tested, for example, by gauges such as shown in Fig. 270?

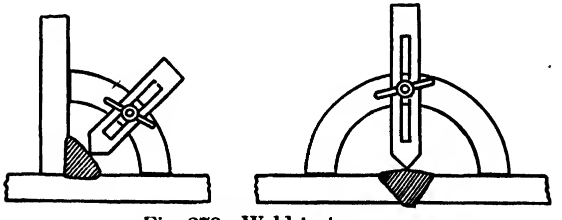


Fig. 270. Weld test gauges

A study of the above will indicate to an experienced welder what faults, if any, exist in the work and then provide a rapid and useful method of ensuring that the right technique of welding is being followed.

Visual inspection, however, has several drawbacks. Take, for example, the double V joint shown in Fig. 271. It will obviously be impossible to observe by visual means whether penetration has occurred at the bottom of the V except at the two ends.

A great variety of methods of testing welds are now available and, for convenience, we can divide them into two classes: (1) Non-Destructive, (2) Destructive.

Destructive tests are usually carried out either on test specimens made specially for the purpose, or may even be made on one specimen taken as representative of several similar ones.

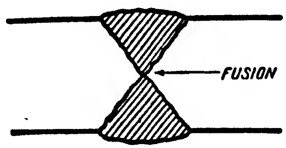


Fig. 271

Destructive tests are of greatest value in detern ning the ultimate strength of a weld and afford a check on the quality of weld metal and skill of the operator. (Visual inspection obviously falls under the heading of Non-Destructive Tests.)

Non-Destructive Tests

(1) Visual inspection.
(2) Magnetic: (*a*) Iron filings in paraffin (magnetic fluid), (*b*) Search coil.
(3) Sound (acoustic) methods: (*a*) Hammer, (*b*) Hammer and stethoscope.
(4) X-ray.
(5) Application of load.

(2) Magnetic Testing

Method (*a*). Iron filings in an extremely finely divided state (colloidal) are suspended (or mixed) in paraffin (this is often termed Magnetic Fluid).

The specimen under test is highly magnetised, usually by magnetising coils, or by being placed in a strong magnetic field, and the fluid is then painted on the weld metal, which must have a machined or polished surface (Fig. 272*b*). If there is any crack in the metal, an alteration in the magnetic field (or flux) occurs at the crack, which is in reality a minute air gap. As a result, the finely divided particles of iron cling to the edges of the crack and show it up as a dark hair (see illustration).

Fig. 272*a*

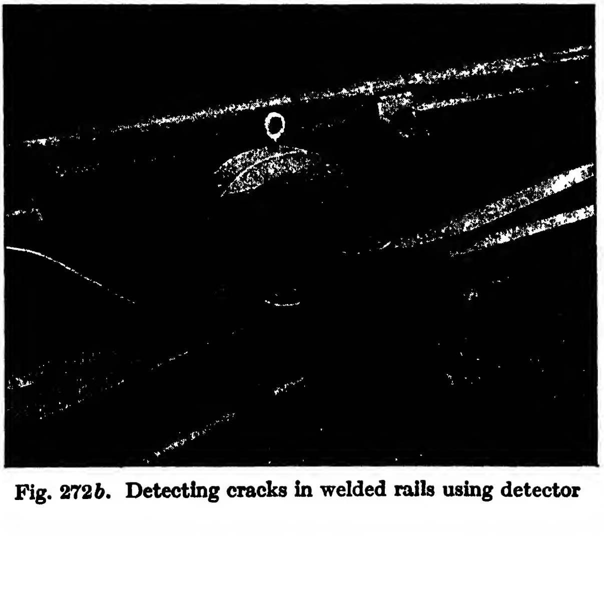


Fig. 272*b*. Detecting cracks in welded rails using detector

For rapid inspection, the fluid can be contained in a circular celluloid container, called a Detector (Fig. 272*b* and *c*), with a thin base. The specimen is magnetised and the container well shaken so as to mix up the iron. Upon placing the detector on the surface of the specimen, any crack will again be shown up as a dark hair. The advantage of the detector is that it can be used continually with no deterioration.

Fig. 272*c*. Portable magnetic crack detector showing up cracks in a welded joint

This fluid method is extensively used at the present time in detecting cracks in every type of metal product from the steel bar to the finished part.

Its drawbacks are that:

(1) It can only be applied to iron and steel, as these are the only magnetic substances.
(2) It only shows up surface cracks.
(3) The specimen must be machined or polished and magnetised.

Method (*b*). The specimen is magnetised as before or by having a heavy current passed through it. Search coils connected to a galvanometer (an instrument which will measure small currents) are then moved over the specimen. If a crack exists in the specimen, the change of magnetic field or flux across it will cause a change in the current in the search coil, and this is indicated by fluctuations of the galvanometer needle. This method has the advantage over Method (*a*) that its surface need not be machined and that defects below the surface are also indicated.

(3) Hammer or Acoustic Method

If metal is struck by a hammer, the note given out will depend on the metal and its size. If, however, there is a crack in the metal, the note is quite different. This is a well-known fact and can easily be verified experimentally. After considerable experience, it is possible to become reasonably proficient in detecting in this way metal which is cracked, by the note it gives out on being struck.

By the use of a stethoscope, different regions of the weld can be explored just as a doctor uses the same instrument to discover weak areas in a patient's chest. In this way, the note given out by any particular part of the weld can be separated from the note given out by the surrounding plate, and this enables the crack to be more easily located. Great experience is necessary, however, to identify the different notes emitted and to understand fully exactly to what each refers.

(4) X-ray Method

X-rays are produced in the following way: A glass tube with two arms and a central bulb is exhausted of air. In one arm is a small electric light filament F which can be heated to white heat. In the other arm is a thick copper stem S ending in a target T made of platinum and inclined at an angle of 45° to the axis of the tube (Fig. 273). A high voltage of between 60,000 and 180,000 volts is placed across the ends of the tube, the end A being positive (called the anode). The fact that the filament is white hot, and emits negatively charged particles, enables the high voltage to send a current through the tube, and the current causes a stream of negatively charged particles, called Kathode Rays, to move from the filament F to the positively charged target T, as shown. On hitting the target, they are reflected as shown and are then termed X-rays.

Owing to their high speed, these rays can penetrate solid substances but, in doing so, a certain proportion of the rays is absorbed. The amount of absorption depends on the thickness of the substance and on its density. The denser and thicker the substance, the less the proportion of rays which get through. Certain substances, such as calcium tungstate and barium platino-cyanide, become fluorescent or luminous when X-rays strike them. If a screen is coated with one of these substances and the rays fall on it, the sensitised screen becomes brightly illuminated. If now an object, such as a piece of steel, is placed in the path of the rays in front of the screen, a shadow of the

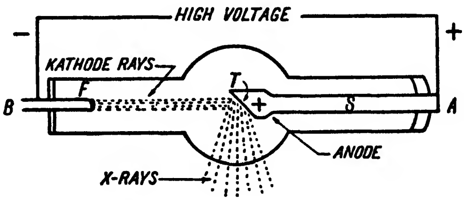


Fig. 273

object will be thrown on the screen, and if the object is of the same thickness and density throughout, the shadow will also be of the same degree of darkness over all its surface. If, however, any holes or cavities exist in the steel, the rays will be less absorbed at these points and the shadow will be more brightly illuminated at these spots.

In the same way, films covered with silver halides are affected by X-rays in the same way that ordinary photographic films are affected by light. Thus if an X-ray film is put in place of the sensitive screen in the above, a 'shadowgraph' of the object will appear when the film is developed. Films are used more than the screen method, because they provide a permanent record of the shadow which can be carefully studied (Fig. 274).

Now, just as in photography an incorrectly exposed film will possess no detail, so with an X-ray photograph no detail of defects in the object can be observed unless correct exposure is given. This is entirely a matter of practice.

In order to make sure that we are getting a correctly exposed negative, so that even the smallest defects will be shown up, it is usual to place a small strip or cutting of the same material

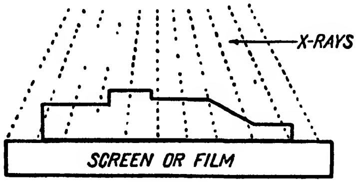


Fig. 274

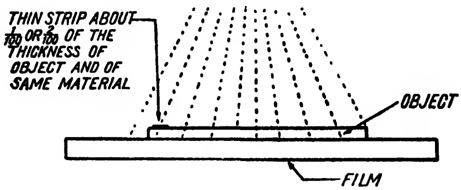


Fig. 275

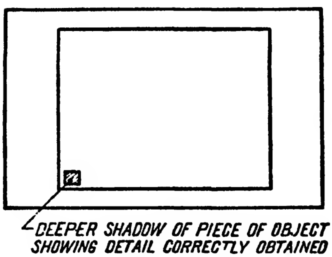


Fig. 276

as the object (steel for example) and about $\frac{1}{100}$ to $\frac{2}{100}$ of its thickness on the upper surface next to the X-ray tube, as shown in Fig. 275.

If this now appears as shown in Fig. 276, as a shadow on the negative, we are sure that any defects or holes of the size $\frac{1}{100}$ to $\frac{2}{100}$ of thickness of the object will be indicated.

Great practice is necessary to interpret the X-ray films of welds correctly and to distinguish between various defects shown up as shadows. Gas holes causing porosity are usually regular in shape, while any included slag is usually very irregular. In this way, we can determine whether penetration to the full depth required has been obtained, whether correct fusion between

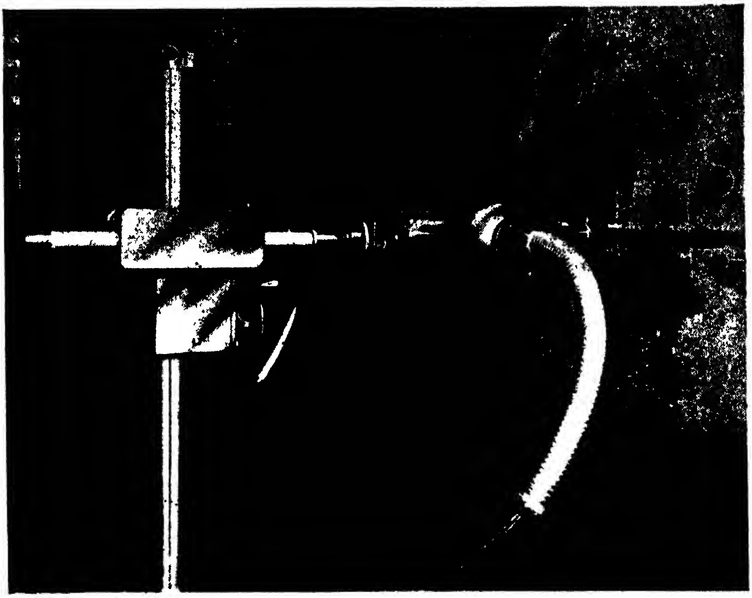


Fig. 277. X-ray equipment photographing welded seams on pressure vessels

parent metal and weld metal or between layer and layer in a multi-layer weld has been obtained, and whether there are regions of entrapped slag, blowholes or other porous defects. In addition, any defects, such as contraction cracks, will also be shown up clearly.

The X-raying of butt welds is comparatively straightforward, but with lap welds and fillet welds special methods have to be adopted, and often more than one photograph taken in different directions. The following series of photographs of electric arc and oxy-acetylene welds indicate some of the defects mentioned above and how they appear in the X-ray photograph.

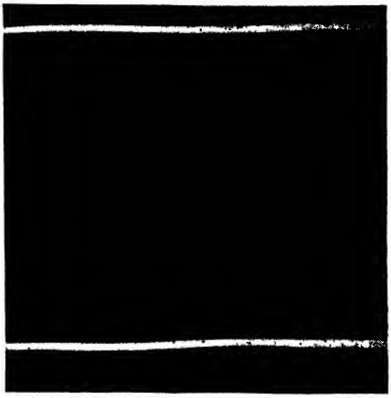


Fig. 278. X-ray photograph of a weld showing gas and slag inclusions

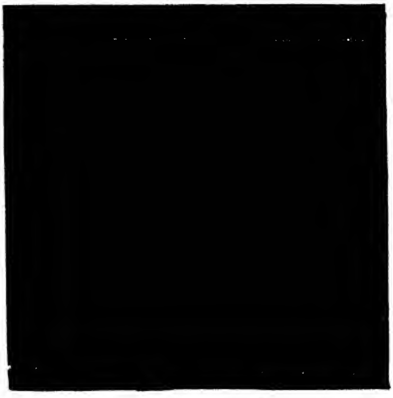


Fig. 279. X-ray photograph of a good sound weld

Finally, the method of X-ray inspection of pressure vessels, such as boilers, may be mentioned. During the welding operation on the boiler, one or more test pieces are made by the welder, i

ii

iii

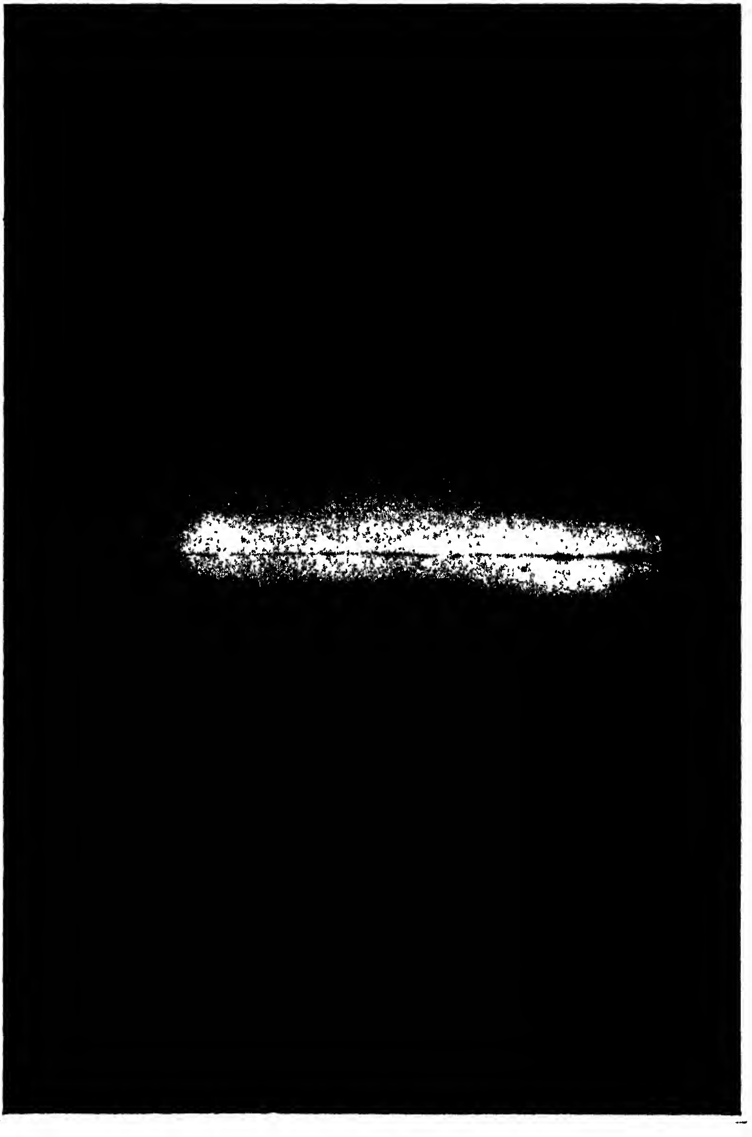


Fig. 280*a*

using the same technique exactly as on the boiler, the test pieces being of the same metal and thickness as the boiler itself. The weld on the boiler is X-rayed along its whole length and the test pieces are also X-rayed. A comparison of the negatives will indicate how closely the structure of the test pieces compare with that of the boiler itself and, if (as is usually the case) this is very close, it can reasonably be supposed that the boiler weld would behave as the test pieces under test. The test pieces are

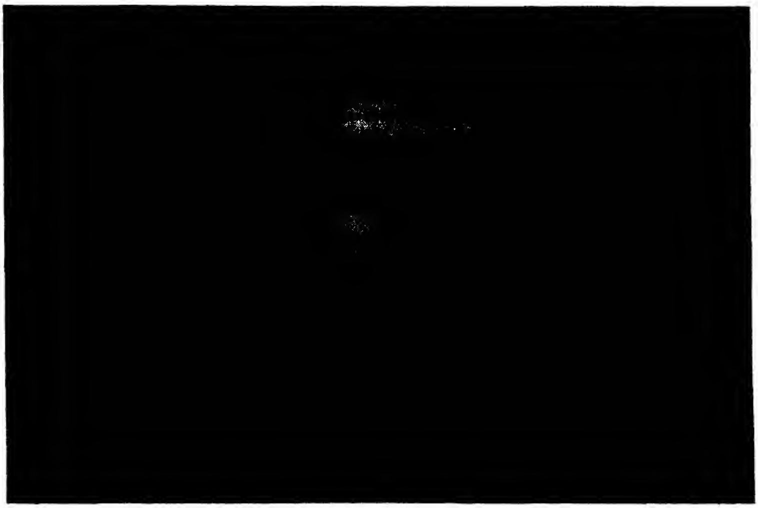


Fig. 280*b*

Fig. 280*a*. X-rays of arc welds in 1″ × $\frac{1}{4}$″ mild steel plate. No preparation—plates set apart. Note the refined, close structure of the deposited metal. (i) Poor penetration and slag inclusion due to too low a current and poor manipulation. Note poor set up—plates diverging. (ii) More current than in (i) giving better penetration. Plates set too close together and thus penetration was insufficient to form an underbead. Better manipulation—no slag inclusions. (iii) Slightly too much current. Penetration good along the seam, but spatter can be seen on left of photograph. Note deep crater formed through bad manipulation when breaking arc.

Fig. 280*b*. X-ray of three butt welds (electric arc) on 1″ × $\frac{1}{4}$″ mild steel plate showing poor penetration, slag inclusion and weakness along lines of fusion (undercutting). (Plates not prepared—set apart.)

then tested by the usual methods and finally tested to destruction. This affords an excellent indication as to the probable behaviour of the boiler weld under test. The American Society of Mechanical Engineers (A.S.M.E.) specify the above test in their Boiler Code, as does Lloyds.

(5) Application of Load

An illustration of this method is furnished by the hydraulic test on boilers. Water is pumped into the welded boiler under test (the safety valve if fitted having been clamped shut) to a pressure usually 1½ to 2 times the working pressure. Should a fault develop in a joint, the hydraulic pressure rapidly falls without danger to persons near, such as there would have been if compressed air or steam had been used.

In the same way, partial compressive or tensile loads may be applied to any welded structure to observe its behaviour. The method adopted will, of course, depend on the nature of the work under test.

Destructive Tests

These may be divided as follows:

(1) Tests capable of being performed in the workshop.
(2) Tests performed in the chemical, metallurgical and strength of materials laboratory.

(1) Workshop Tests

These are usually used to break open the weld in the vice for visual inspection. When operators are first learning to weld, this method is very useful, because as a rule the weld contains many defects and, when broken open, these can quickly be pointed out. Little time is thus lost in finding out the faults and rectifying them. As the welding technique of the beginner however improves, this test becomes of much less value. Obviously much will depend on the actual position of the specimen in the vice, whether held on the joint or just below it. Also on the hammering, whether heavy erratic blows are used or a medium-weight, even hammering is given. In addition, if the weld metal is stronger than the parent metal, fracture may occur in the parent metal and thus the weld itself has hardly been tested. We can make sure that the specimen will break in the weld and afford us opportunity for examination by making two nicks with a hacksaw as shown on each end of the weld, having previously filed or ground the ends square (see Fig. 281).

Another useful method for determining the ductility of the weld is to bend the welded specimen in the vice through 180° with an even bending force. Any cracks appearing on the weld face will indicate lack of ductility. A better method of conducting this test will be described later (see Fig. 282).

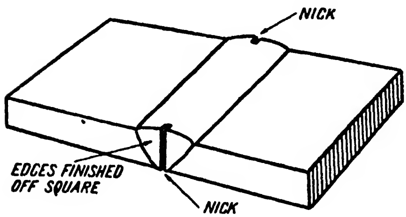


Fig. 281. Specimen for 'nick bend' or 'nick break' test

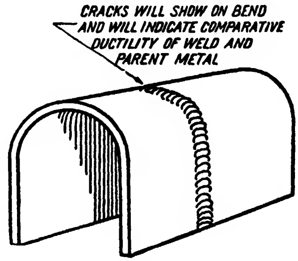


Fig. 282

A useful workshop test, for use in the case in which the welded parts have to be heated up or even forged after welding, consists of actually forging a test specimen after welding. It is always advisable to apply the tests given later also, such as tensile, in order to obtain the ultimate strength of the weld.

Workshop tests are very limited, and their chief advantage is the little time taken to perform them. They are useful during training of welders, but little knowledge of the weld can be gained from them. The visual method, as previously explained, is a valuable addition to the workshop methods given above.

(2) Laboratory Tests

These may be divided as follows: (*a*) Microscopic and macroscopic, (*b*) Chemical, analytical and corrosive, (*c*) Mechanical.

The use of the microscope is very important in determining the actual structure of the weld and parent metal. When a polished section of the weld is observed with the eye, it will look completely homogeneous if no blowholes or entrapped slag are present. On the other hand, if a section is broken open, as in the nick bend test, it may be found that there is a definite crystal-like structure. Since, however, this type of section may have broken at the weakest line, we must take a section across any desired part of the weld in order to have a typical example to examine. Specimens to be microscopically examined are best cut by means of a hacksaw. Any application of heat, as for example with gas cutting, may destroy part of the structure which it is desired to examine. If this specimen was polished by means of abrasives in the usually commercial way, when observed under the microscope it would be found to be covered with a multitude of scratches.

The best method of preparation is to grind carefully the face of the specimen after cutting on a water-cooled slow-running fine grinding wheel of large diameter, care being taken to obtain a flat face. Polishing can then be continued by hand, using finer abrasives, eventually finally polishing by the polishing wheel, using rouge or aluminium oxide as the abrasive.

In order to bring the structure of the section of metal out clearly, the surface must now be 'etched'. This consists of coating it with a chemical, which will eat away and dissolve the metal. Since the section is a definite structure consisting of composite parts, some are more easily dissolved than others, and thus the etching liquid will bring up the pattern of the structure very clearly when observed under the microscope.

The etching liquids employed depend on the metal of the specimen. For iron and steel, a 1 or 2 % solution of nitric acid in alcohol, or picric acid in alcohol, is used. For copper, either ammonium persulphate or ferric chloride acidified with hydrochloric acid. For aluminium and aluminium alloys, either caustic soda or dilute hydrochloric acid and nitric acid.

Most of the microphotographs in this book were prepared by etching with the 2 % nitric acid solution in alcohol. The austenitic structure in Fig. 62 was developed by etching with a dilute aqua regia reagent.

The length of time for which the etching liquid remains on the metal depends on the detail and the magnification required. After etching is complete, the liquid is washed off the surface of the specimen to prevent further action. For example, if steel etched with picric acid is to be examined at 100 diameters, etching could be carried out from 25 to 35 seconds, giving a clear well-cut image. If this, however, was observed under the high-power glass of 1000 diameters, it would be found that the picric acid had eaten deeply into the surface, and the definition and result would be extremely poor. Thus, for high magnification, the etching would only need carrying out from 5 to 10 seconds. Naturally, however, the time will vary entirely with the etching liquid used, the power of magnification and the detail required.

When the section is prepared in this way and the whole crystal structure is visible, the exact metallic condition of the weld can be examined, together with that of the surrounding parent metal. For example, examination of microphotographs of steel at 150 to 200 diameters will indicate the size of the grain, the arrangement of pearlite and ferrite. Increasing magnification to 1000 diameters will indicate the presence of oxides or nitrides, oxides being shown up as fine cracks between the crystals (producing weakness) (Fig. 63), and iron nitrides as needle-like crystals (producing brittleness) (Fig. 64). From this, the metallurgist can tell the suitability of the weld metal, how well the structure compares with that of the parent metal, and its probable strength. This study or test plays an important part in the manufacture of new types of welding rods. Microphotographs of varying magnifications are used in various parts of this book to illustrate the structures referred to.

(*a*) **Macroscopic.** This method consists as before of preparing a cross-section of the weld by polishing and etching. It is then examined either by a low-power microscope magnifying 3 to 20 diameters or even with a magnifying glass. This will show up any cracks, entrapped slag, pin-size blow or gas holes, and will also indicate any coarse structure present (Figs. 283, 284; also Fig. 221).

The etching fluids most suitable for macroscopic examination are:

Steel and Iron. 10 % iodine, 20 % potassium iodide and 70 % distilled water; 10 to 20 % nitric acid in water; 8 % cuprous ammonium chloride in water.

Fig. 283. Fillet weld, one run each side with $\frac{3}{32}''$ (6 gauge) electrode. Note good penetration and profile with no undercut. (Compare with Fig. 110*d*.)

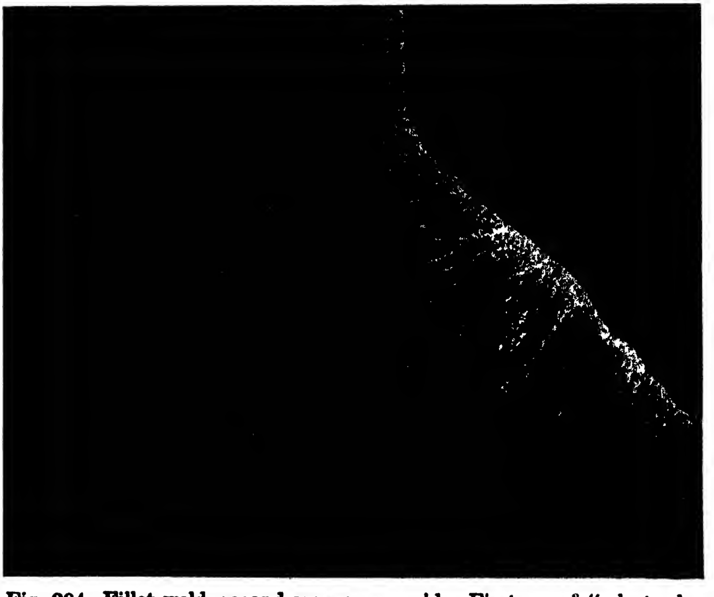


Fig. 284. Fillet weld, second runs on one side. First run $\frac{3}{32}''$ electrode; second run $\frac{5}{16}''$ electrode. (×8.) Note good fusion.

Copper. 25 % solution of nitric acid in water; ammonium hydrate; nitric acid in alcohol.

Brass and Bronze. 25 % solution of nitric acid.

Aluminium and Aluminium Alloys. 10 % solution of hydrochloric acid in water.

The macrographic examination of welds can easily be undertaken in the workshop, using a hand magnifying glass, and the degree of polish required is not so high as for microscopic examination. The microscope, however, will obviously bring out defects and crystal structures which will not be apparent in the macrograph.

(*b*) **Chemical Tests.** Analytical tests are used to determine the chemical composition of the weld metal. From its composition, the physical properties of the metal can be foretold. The addition of manganese increases the toughness of steel, uranium increases its tensile strength, and these are indicated fully in the chapter on metallurgy.

Corrosive tests are used to foretell the behaviour of the weld metal under conditions as would be met with in years of service.

The action of acids and alkalis, present in the atmosphere of large industrial areas (p. 49) and which may have a marked effect on the life of the welded joints, can be observed, the effect in the laboratory being concentrated so as to be equal in a few days to years of normal exposure. From these tests, the most suitable type of weld metal is indicated. The following examples will serve as illustrations:

Along the sea coast, greatest corrosion takes place to those metal parts which are subject to the action both of the salt water and the atmosphere, that is, the areas between high and low tide; for example, pier and landing-stage supports and caissons, and railings and structures exposed to the sea spray. By dipping welded specimens alternately in and out of a concentrated brine solution (Fig. 285), corrosion effects equal to years of exposure are produced.

Suppose it is required to compare the resistance to acid or alkaline corrosion of plates welded together with different types of electrodes. The specimens are polished and marked and then photographed. They are then rotated in a weak acid or alkaline solution, as in Fig. 286. The specimens are photographed at given intervals and the degree of corrosion measured in each case. From the results it is evident which electrode will give the best resistance to this particular type of corrosion.

In the chemical industry, tanks are required for the storing of corrosive chemicals. It is essential that the welded joints should be just as proof against corrosion as the metal of the tank

Fig. 285

itself. Corrosive tests undertaken as above in the laboratory will indicate this, and will enable a correct weld metal to be produced, giving proof against the corrosion.

Evidently, then, these tests are specialised, in that they reproduce as nearly as possible, in the laboratory, conditions to which the weld is subjected.

(*c*) **Mechanical Tests.** These may be classified as follows:

(1) Tensile.
(2) Bending.
(3) Impact: Charpy and Izod.

(4) Hardness: Brinell, Rockwell, Vickers Diamond Pyramid and Schleroscope.
(5) Fatigue: Haig and Wöhler.
(6) Cracking: Reeve.

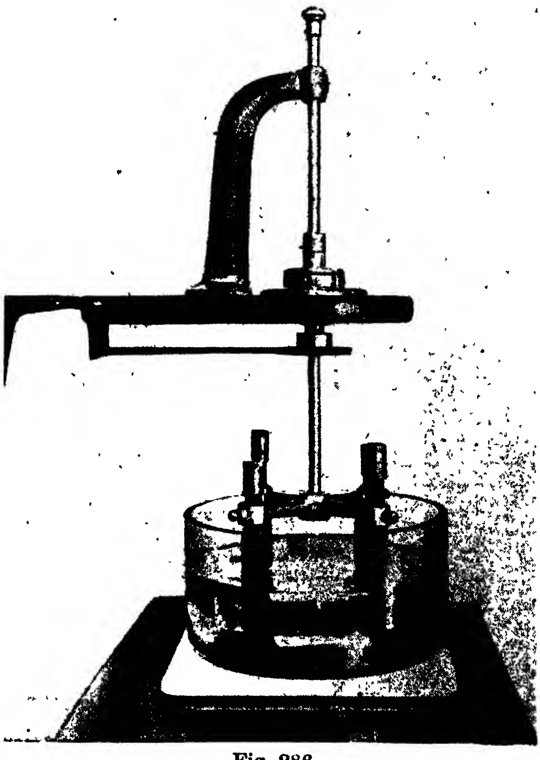


Fig. 286

(1) Tensile Test

As stated previously, a given specimen will resist being pulled out in the direction of its length and up to a point (the yield point) will remain elastic, that is, if the load is removed it will recover its original dimensions. If loaded beyond the yield point or elastic limit the deformation becomes permanent.

Preparation of Specimens

In order to tensile test a welded joint, specimens are cut from a welded seam and one specimen from the plate itself. This latter will give the strength of the parent metal plate. The specimens are machined or filed so as to have all the edges square, and the face can be left with the weld built up or machined flat, depending

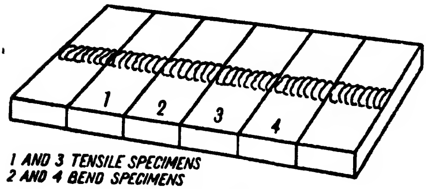


Fig. 287

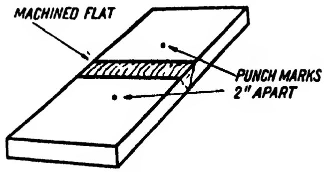


Fig. 288

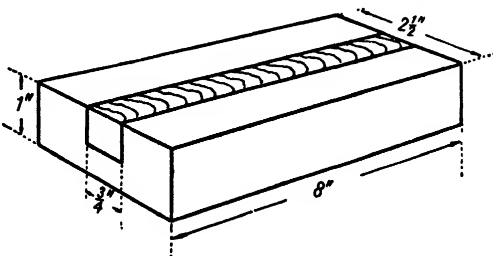


Fig. 289

on the test required. It is usual, in addition, to cut specimens for bend testing from the same plate, and these are usually cut alternately with the tensile specimens, as shown in Fig. 287.

If the elongation is required, it is usual to machine the specimen flat on all faces and to make two punch marks 2 in. apart on each side of the weld, as shown in Fig. 288.

An all-weld specimen, that is, one composed of all-weld metal, can be prepared for test in the following way: A groove about $\frac{3}{4}$ in. wide and $\frac{3}{4}$ in. deep is machined in a piece of steel or formed between two pieces butted together. This is then filled in by welding (see Fig. 289).

Another method is to build up an all-welded pad on a piece of flat plate to the required size, as shown in Fig. 290.

The specimen is then machined as shown, so that the section is circular or rectangular and consists of all-weld metal (Fig. 291).

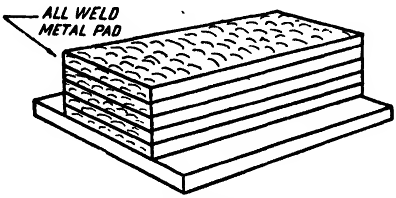


Fig. 290

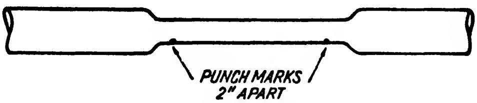


Fig. 291

Description of a Testing Machine

Fig. 292 illustrates a modern self-indicating universal testing machine ranging in capacity from 10 to 100 tons. The machine comprises a pumping unit *D*, straining unit *A*, and load-indicating unit *B*.

Oil is used as a pressure medium, and this is delivered to the cylinders *L* of the straining unit via a control valve *C*. The pressure of oil operating upon the rams *J* force the crosshead *H* upwards, which action is utilised to carry out tensile tests between the crossheads *H* and *K*. Compression, shearing and hardness tests are made between the upper surface of crosshead *H* and the underside of the top crosshead *E*, this latter being in connection by four rods with crosshead *K*. For transverse or bend tests the two dogs *G* on crosshead *H* are used to support the specimen, which is forced against a pressure foot *F* secured to the top crosshead *E*.

The resistance of the specimen determines the pressure within the straining cylinders *L*. which are in communication with a smaller cylinder situated in the load-indicator cabinet. The ram of the small cylinder, which is in direct connection with the weighing mechanism, is reduced in area (by a definite ratio) to that of the rams of the main straining cylinders, so that both weighing and straining are effected through the medium of hydraulic pressure.

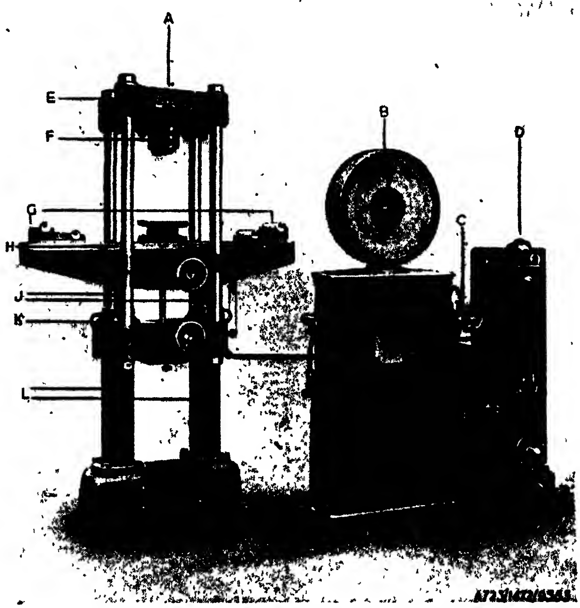


Fig. 292. A modern testing machine

The pressure necessary for applying the load is provided by a motor-driven reciprocating ram-type oil pump, which has three rams and positively seated valves. The pump is direct driven by a constant-speed motor which has a delivery sufficient to give a maximum speed of about 4 in. per minute to the main rams of the testing machine.

The pressure supply to the testing machine is controlled by the valves arranged at the sides of the load-indicator cabinet.

The delivery from the pump is conveyed to a connection on the duplex control valve at the right-hand side of the cabinet, and the supply to the cylinders of the testing machine is regulated by the handwheels according to the fineness of admission required. The small handwheel controls a fine regulating valve

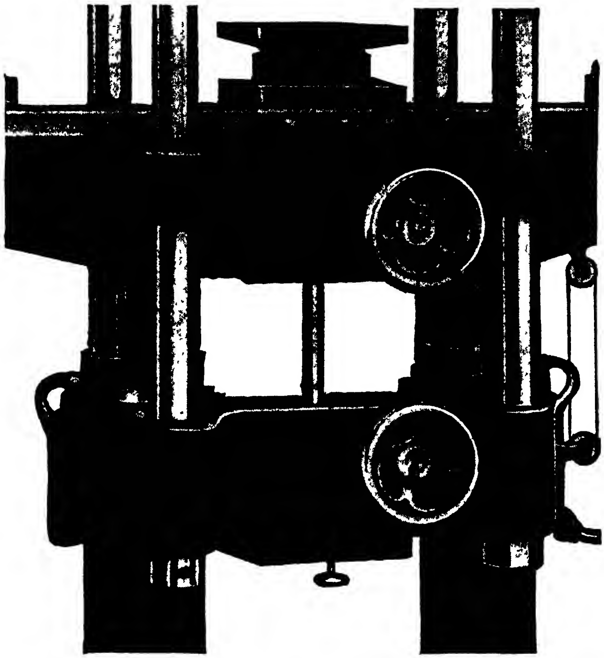


Fig. 293*a*

within the valve main spindle, which is under the control of the large handwheel. It is usual to control a testing operation by means of the small handwheel, the large handwheel being used generally for quickly setting the position of the straining cross-head. Any excess delivery from the pump is bye-passed through the control valve back to the pump suction tank.

To eliminate pulsations from the pressure supply to the testing machine cylinders, a momentum valve is incorporated in the

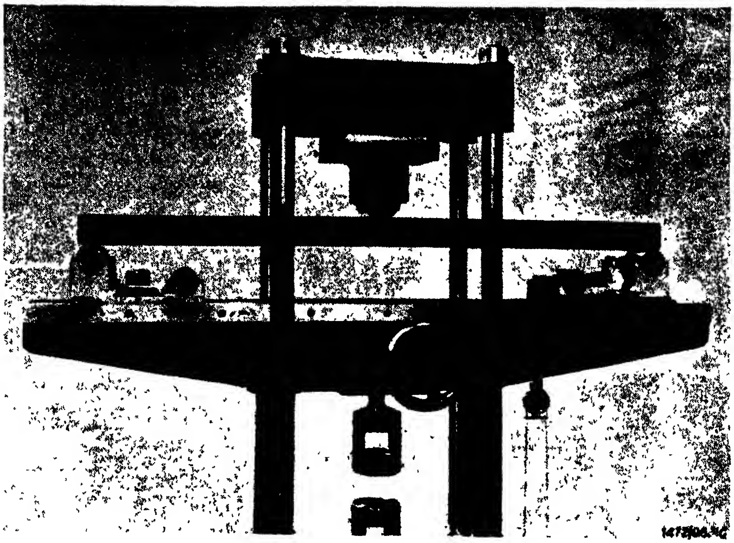


Fig. 293*b*. Bend or transverse test on testing machine

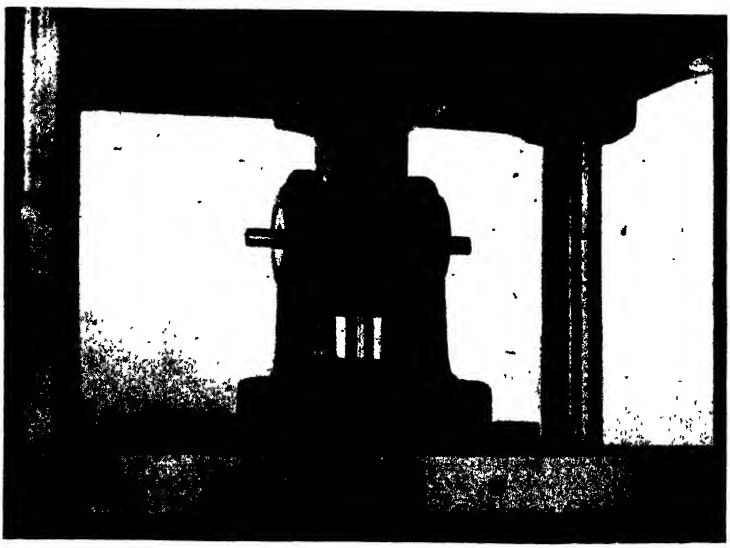


Fig. 293*c*. Testing machine arranged for shearing test

pipe line, and further to obviate pulsations in the pressure transition to the small proportional cylinder, a separate pipe is taken from the main cylinders to the proportional cylinder; any

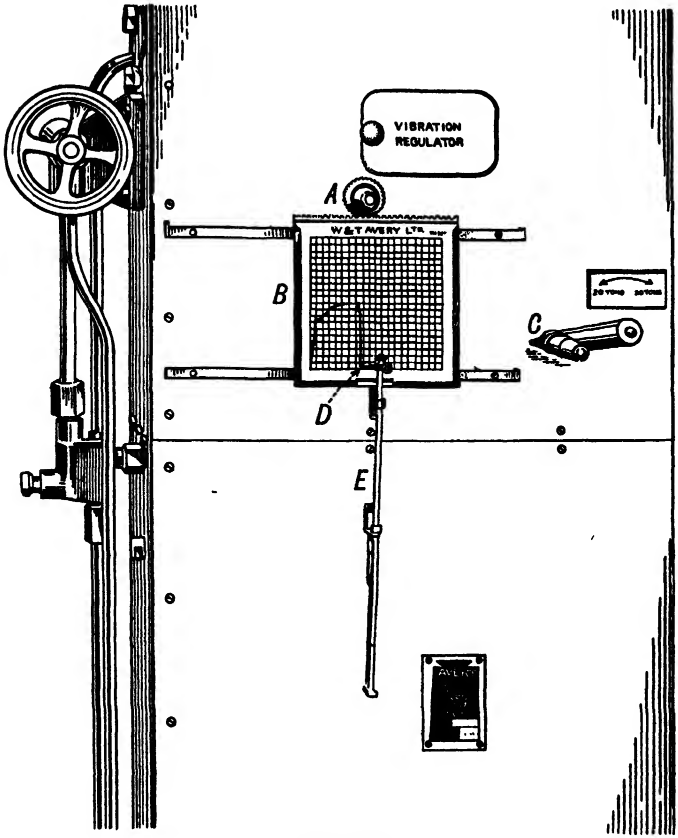


Fig. 293*d*

slight pulsation which may remain in the pressure supply is thus completely damped out when taken from the large cylinder area.

The valve at the left-hand side of the indicator cabinet controls the exhaust from the testing machine cylinders—the maximum speed the main rams attain on the return stroke is approximately 2 ft. per minute from its top position. This valve also serves to control the pressure oil from the main cylinders at the small proportional cylinder in connection with the lever system of the load indicator. The load on the specimen is maintained according to the operation of the handwheel on this valve.

The straining gear comprises two single-acting cylinders, and these are arranged side by side upon a base-plate. The cylinders are connected at the top by a crosshead, which incorporates the bottom tension grip holder; this ensures a unit rigid with the base. Adaptors are provided for tension testing both screw-ended and flat-ended specimens, and with the latter, as the load increases, the tapered jaws grip the specimen more firmly.

Fig. 293*a* illustrates a specimen in position for tension testing. The strain is applied by the upward motion of the beam casing with the rams. Handwheels enable the grips to be raised or lowered, while at the same time they are automatically opened or closed as they slip up and down the holder.

Fig. 293*b* shows a specimen arranged for a bending test and Fig. 293*c* the arrangement for a shearing test on a bar. The machine can be fitted also with an autographic recorder (Fig. 293*d*), by which the load-extension curves are directly obtained.

The graph paper is positioned in guide strips; the curve is produced by the horizontal movement of the plate *B*, which indicates deformation of the specimen, and the vertical movement of the barograph type pen *D* attached to the vertical bar *E*, which indicates the load on the specimen.

To effect the horizontal movement of the plate *B* a rack is provided at its top edge. This rack is in gear with a pinion carried on a spindle *A* passing through the cabinet and having at its opposite end a pulley, which is revolved by a phosphor-bronze cord in connection with the stationary and moving crossheads. The horizontal movement of the plate *B* can be made to be actual or its movement can be increased to three or six times the actual movement of the crosshead. This magnification of movement is effected by means of a small gear box arranged at the end of the spindle *A* at the back of the cabinet. The vertical movement of the pen *D* is effected by means of a spur wheel in gear with a rack on the rod *E*. The spur wheel is secured to the horizontal shaft carried in the cabinet and fitted with two pulleys, one arranged with a cord carrying a weight, the other in connection by a cord with the spring of the momentum valve.

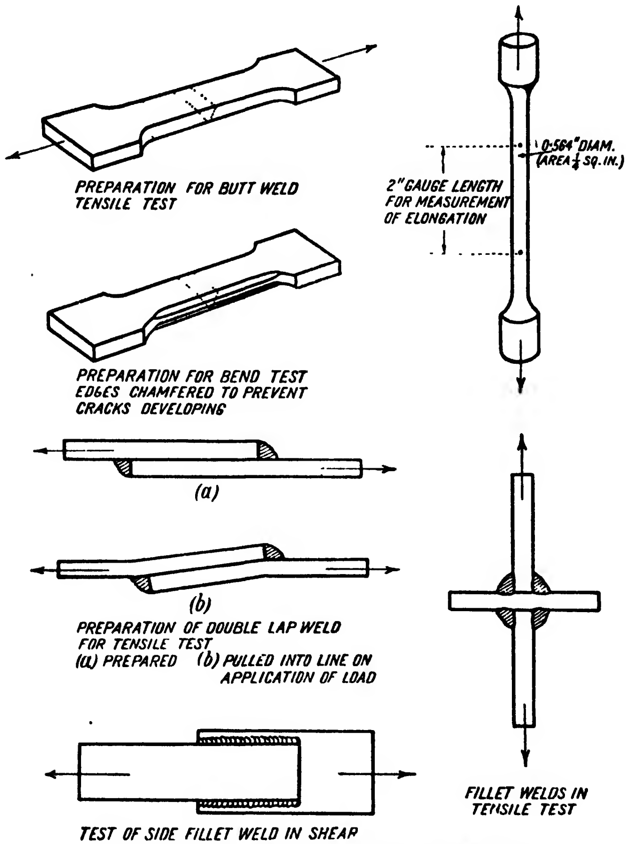


Fig. 294. Preparation of specimens for test

The spring, which is calibrated, controls the movement of the plunger of the momentum valve; the movement of the plunger is pro rata with the pressure within the hydraulic system and therefore proportional to the load on a specimen under test.

As the load on the specimen increases, the rod *E* is moved upwards; when the load decreases, the return motion is effected, by means of the above-mentioned weighted cord. The curve produced can be seen in Fig. 293*d*.

Fig. 294 shows specimens prepared for the various tests.

Details of Tensile Test

Let us suppose that a specimen of mild steel has been prepared and its dimensions are 10 in. long × 2 in. wide × ⅜ in. thick. It is placed between the jaws of the machine and the load is increased

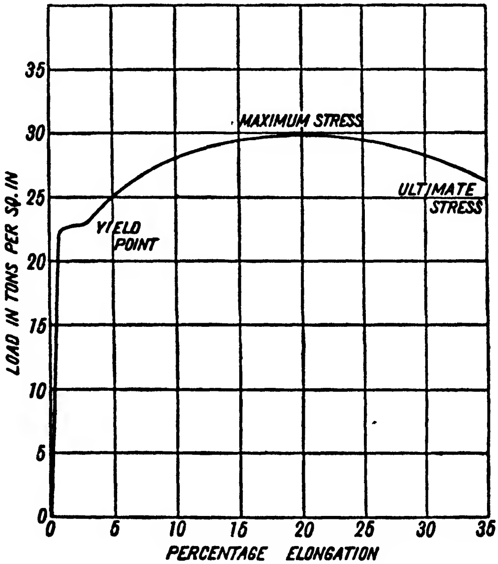


Fig. 295

gradually. The autographic recorder now traces the load-extension curve. As the load increases, at first we notice only a small increase of length, the increase being proportional to the load applied. This continues until a load of about 17 tons is registered, and at this point the increase in length for a given increase of load becomes much greater.

This is the yield point, and since the sectional area is $\frac{3}{8} \times 2$ in., i.e. $\frac{3}{4}$ sq. in., the yield point stress is 22½ tons per sq. in.

Further increase of load produces great increase of length until, at about 22½ tons load, a waist begins to form in the specimen. The maximum or ultimate tensile strength of the specimen is therefore 22½ tons on an area of $\frac{3}{4}$ sq. in., i.e. 30 tons per sq. in. Further increase in load produces great reduction in area at the waist and consequently the specimen breaks at this point. Fig. 295 shows the results of this test, plotted graphically with the load in tons per sq. in., against the percentage elongation as would be given on the graph paper on the recorder. Yield point and maximum stress are clearly indicated. The elasticity can be given as the extension which has occurred on a standard (8 or 2 in.) length up to the yield point, or can be expressed as a percentage.

Tensile Test of a Welded Joint

It will be evident that a tensile test on a welded joint is not quite similar to a test on a homogeneous bar, and the following considerations will make this clear. The steel weld metal may be strong, yet brittle and hard. When tested in the machine, the specimen would most probably break outside the weld, in the parent metal, whereas in service due to its brittleness, failure might easily occur in the weld itself. The result of this test gives the tensile strength of the bar itself and indicates that the weld is sound. It does not indicate any other condition.

If the weld metal is softer than the parent metal, when tested the weld metal itself will yield and fracture will probably occur in the weld. Because of this, the elongation of the specimen will be small, since the parent bar will have only stretched a small amount, and this would lead to the belief that the metal had little elasticity. Quite on the contrary, however, the weld metal may have elongated by a considerable amount, yet because of its small size in comparison to the length of the specimen the actual elongation observed is small. Great care must therefore be taken to study carefully the results and to interpret them correctly, bearing in mind the properties which it is required to test.

A tensile test on an all-weld metal specimen prepared as previously explained indicates the strength and ductility of the metal in its deposited condition and is a valuable test.

A very useful form of test which is used nowadays is that known as the longitudinal test. In this test the welded specimen is placed in the machine so that the load is applied longitudinally along the welded seam (Fig. 296). As the load is applied, if the weld metal is ductile, it will elongate with the parent metal and help to share the load. If, on the other hand, it is brittle, it will not elongate with the parent metal but will crack. Should the parent metal be of good quality and structure, the cracks will be confined to the weld metal mostly and will merely increase in width. If the parent metal is not of such good quality, the cracks will extend into the parent metal and breakage will occur with little elongation of the specimen. This test therefore indicates the quality of the parent metal as well as that of the weld metal.

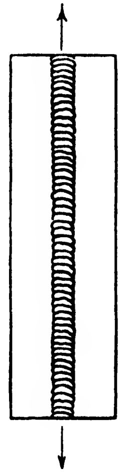


Fig. 296. Longitudinal tensile test of welded specimen

Torsion Test

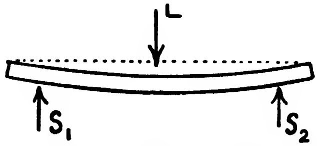
This test is useful to test the uniformity of work turned out by welders. A weld is made between steel plates V'd in the usual manner, and a cylindrical bar is turned out of the deposited metal. This specimen is then gripped firmly at one end, while the other end is rotated in a chuck or other similar device, until breakage occurs. The degree of twist which occurs before breakage will depend upon the type of metal under test.

(2) **The Bend Test** (for ductility of a specimen)

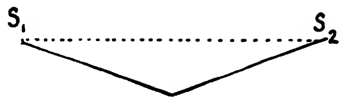
In this test the bar is prepared by chamfering the edges to prevent cracking (if it is of rectangular section), and is then supported on two edges and loaded at the centre (Fig. 297 *a*).

As the load is applied the bar first bends elastically, and in this state if the load is removed it would regain its original shape. On increasing the load a point will be reached when the fibres of the beam at the centre are no longer elastically deformed, i.e. they have reached their yield point, and the bar deforms plastically at the centre (Fig. 297 *c*).

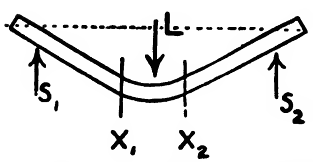
Further increase of load causes yielding to occur farther and farther from the centre, while at the same time the stress at the centre increases until ultimately, when maximum stress is reached, fracture of the bar will occur. If this maximum stress is not reached, fracture of the bar will not occur for any angle of bend. The method of determining the ductility of the bar



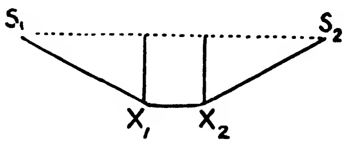
(*a*) Beam deflected elastically



(*b*) Bottom layer stress diagram for elastic deflection, i.e. extension of bottom surface layers



(*c*) Beam deformed or yielded plastically between X_1 and X_2 but has elastic deflection between X_2S_2 and X_1S_1

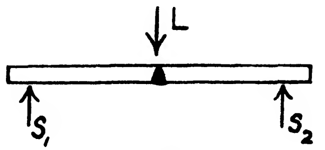


(*d*) Bottom layer stress diagram when yield commences

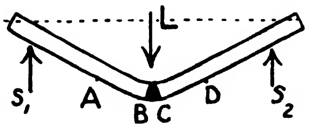
Fig. 297. Uniform bar supported at S_1 and S_2 and loaded at the centre

from the above test is as follows. Lines are scribed on the machined or polished face of the specimen parallel and equidistant to each other across a width of about 6 to 10 in. As the load is applied, the increase in distance between the scribed lines is measured, and this increase is plotted vertically against the actual position of the lines horizontally. When the bar deforms elastically the result is a triangle (Fig. 297*b*), termed the stress diagram, since it represents graphically the stress at these points. The stress diagram is shown for plastic deformation of the bar in Fig. 297*d*.

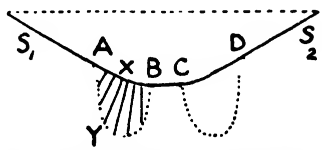
Now consider the test applied to a welded joint and let the weld be placed in position under the applied load. There are now two different metals to be considered, since the weld metal might have quite different properties from those of the parent metal (Fig. 298).



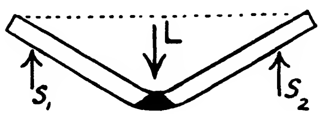
(*a*)



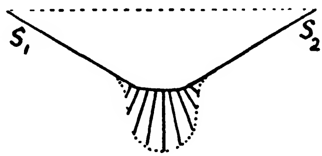
(*b*) Lo.ıd applied. Yield point of weld not reached. Bend taken place in the bar



(*c*) Bottom layer stress diagram. Length of *XY* represents extension at point *X*



(*d*) Load applied. Yield point of *bar* not reached. Bend taken place in the weld



(*e*) Bottom layer stress diagram

Fig. 298. Bar with inserted wedge of weld metal having mechanical properties differing from that of the bar itself, supported at S_1 and S_2 and loaded at the centre

If the load is applied and the yield point of the weld metal is greater than that of the parent bar, plastic yield or bend will occur in the bar, and as the load is increased the bar bends plastically, as in Fig. 298*b*. During this bending, if the yield point of the weld metal is reached, the weld metal will flow or yield somewhat, but in any case most of the bend is taken by the bar. If the yield point of the weld metal is not reached, then all the bend will be taken by the bar.

If, however, the yield point of the weld metal is lower than that of the bar, the weld metal will first bend plastically and will continue to do so, plastic deformation occurring long before the yield point of the bar is reached (Fig. 298 *d*). On such a small area as the weld metal has, therefore, fracture will occur in the weld metal at a small angle of bend. The stress diagrams given in Fig. 298 *c* and *e* indicate where the greatest elongations of the fibres occur in each case.

Since the weld metal is almost always harder or softer than the parent metal the bending will not occur, therefore, equally in the weld and parent metal, and as a result the chief value of this test is to determine whether any flaws exist in the weld. Otherwise its value as a test of ductility of a welded specimen is very limited.

If the weld is placed so that its face is under the central applied load, fracture will occur at the root of the weld if the penetration is imperfect.

(3) Impact Test

These are of two kinds—the Charpy test and the Izod test.

In the **Charpy Test**, the welded bar is held between two supports and a weight on the end of a pendulum strikes the bar under test, bending it. The bar offers resistance to the shock, and some of the energy of the falling weight is taken up in bending the bar and is a measure of the strength of the bar.

The **Izod Test** is in more general use in this country. The specimen is cut 130 mm. long and machined 10 mm. square section, and a notch 2 mm. deep, radius ¼ mm. at its base, and with sides sloping at an angle of 45° to each other, is cut in the bar at the weld.

The bar is then held in a clamp in the machine (Fig. 299). A pendulum carrying a weight at its end is allowed to swing against the specimen and, owing to the weakening effect of the notch, the bar fractures at the notch. The energy possessed by the falling weight is known, since it is measured by the product of the weight and the vertical height through which it has fallen. By means of a small pointer *p* the position to which the pendulum swings after hitting the specimen is indicated (Fig. 300) and, from this, the energy of the pendulum after impact is calculated. Evidently, therefore, since we have the energy before impact

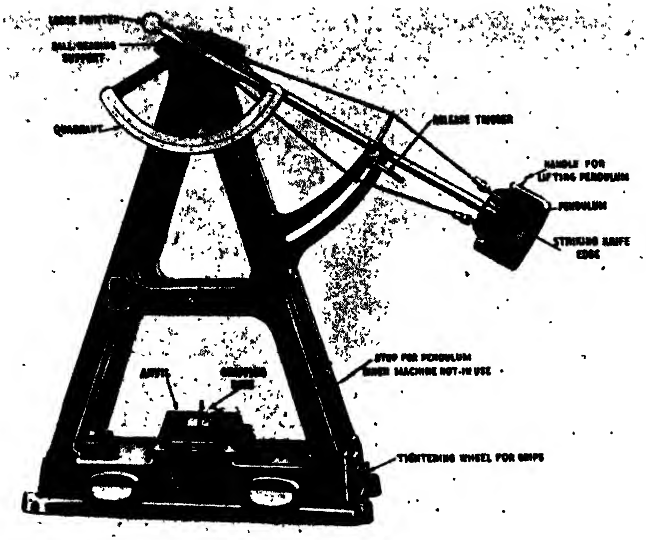


Fig. 299. Izod testing machine

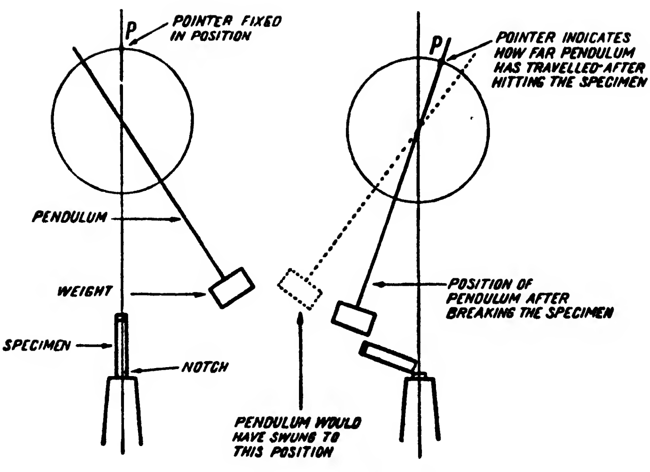


Fig. 300. Izod test

and the energy after impact, the loss in energy is the work done in fracturing the specimen, and indicates the amount of resistance offered by the section to the spreading of a crack through the section. It is, therefore, a measure of the toughness of the welded specimen and can also reveal incorrect composition. For example, too high a percentage of sulphur or phosphorus will cause the material to have a low impact value, and so on. Great care is, however, necessary in machining the notch, as the slightest error in its dimensions greatly affects the strength of the specimen.

The Izod test gives very variable results on different samples of rolled mild steel plate, even when the specimens are taken from the same section of plate. Similarly, on welded specimens, very variable results are often obtained, though it is very difficult to account for these variations.

(4) Hardness Tests

These are useful to indicate the resistance of the metal to wear and abrasion, and give a rough indication of the weldability of alloy steels. If parts, such as tramway crossings, dredger bucket lips, plough shares or steel gear wheels, have been reinforced or built up, it is essential to know the degree of hardness obtained in the deposit. This can be determined by portable hardness testers of the following types.

The chief method of testing are: (*a*) Brinell, (*b*) Rockwell, (*c*) Vickers Diamond Pyramid, (*d*) Schleroscope.

The **Brinell Test** consists in forcing a hardened steel ball, 10 mm. diameter, hydraulically into the surface under test. The area in square millimetres, of the indentation (calculated from the diameter measured by a microscope) made by the ball, is divided into the pressure in kilograms, and the result is the Brinell hardness number or figure. Fig. 301 *a* shows an indentation of 4·2 mm. diameter when measured on the microscope scale.

For example: If the load was 3000 kg., and the area of indentation 10 sq. mm., Brinell number equals 3000 divided by 10, which is 300.

The Brinell figure can be calculated from the following:

$$\text{Brinell figure} = \frac{P}{\frac{\pi D}{2}\left(D - \sqrt{D^2 - d^2}\right)},$$

where P = load in kg., D = diameter of ball in mm., d = diameter of indentation in mm.

The tensile strength in tons per sq. in. of mild steel is approximately 22 % of the Brinell hardness value.

Evidently the ball must be harder than the metal under test or the ball itself will deform and as a result it is used only up to a figure of about 500.

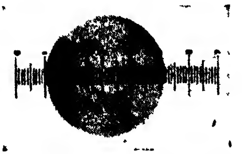


Fig. 301 *a*. Indentation made by Brinell ball in hard surface and measured by microscope scale

Fig. 301 *b* shows a testing machine arranged for a Brinell test, with ball in position.

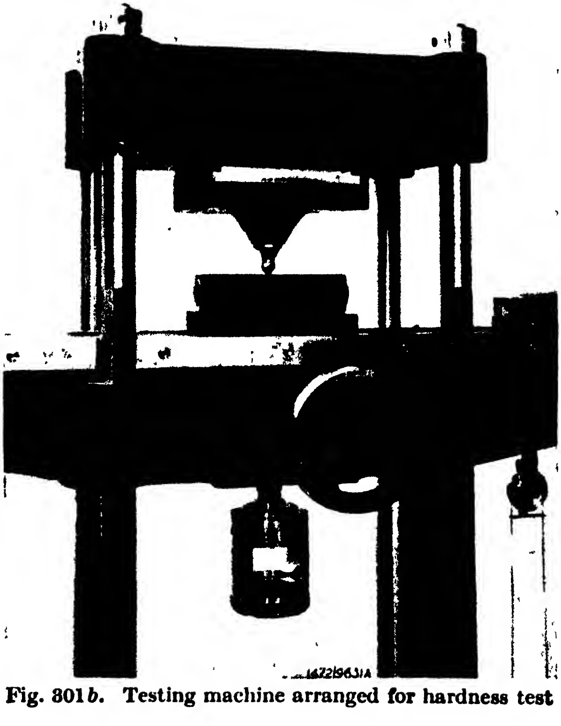


Fig. 301 *b*. Testing machine arranged for hardness test

The **Rockwell Test** is somewhat similar. A hardened steel ball $\frac{1}{16}$ in. diameter is used on steels lower than 200 Brinell. Above this, a diamond-shaped cone with an angle of 120° is used. The ball or cone is first pressed into the surface under test with a light load. Then a heavy load is applied and the additional penetration caused by the increase in load is automatically measured on a dial and indicates the Rockwell hardness number. This method is largely used in routine hardness tests on articles.

The **Vickers Diamond Pyramid Test** is similar, but a diamond-shaped pyramid with a square base is used to indent the surface. This shape does not deform like the Brinell ball on hard surfaces and gives a square indentation. It is very much used for testing hard polished surfaces.

The **Scleroscope Test** consists of allowing a hard steel cylinder, called the hammer, having a pointed end to fall from a certain height on to the surface under test. The height to which it will rebound will depend upon the hardness of the surface, and the rebound figure is taken as the hardness figure. The fall is about 10 in., giving with a hard steel surface a rebound height of about 6 in., this being 90 to 100 on the Scleroscope scale.

(5) Fatigue Test

If a specimen is subjected to a continuously alternating set of push and pull forces operating for long periods, the specimen may fail due to fatigue of the molecules, and the magnitude of the force under which it may fail will be much less than its maximum tensile or compressive strength. The forces applied rise to a maximum tension, decrease to zero, rise to a maximum compression and decrease again to zero. This is termed a cycle of operations and may be written 0-Maximum Tension-0-Maximum Compression-0 and so on. Fatigue tests are based on this phenomena exhibited by metals.

In the **Haigh Tests**, a soft-iron core or armature vibrates between the poles of an electro-magnet carrying alternating current, and is connected to the specimen under test. As alternating current is passed through the coil, the armature vibrates at the frequency of the supply (usually 50 per second) between the poles, and the welded specimen is thus subjected to alternating push-pull forces at this frequency. The alternating current, and therefore the force on the armature, rising as above: 0-Maximum in one direction-0-Maximum in opposite direction-0; this being, as before, one cycle of operations.

The drawback to this test is that at 3000 reversals per minute an endurance test of 10,000,000 reversals would take about 56 hours and a complete endurance test will take many days.

The latest type of electromagnetic fatigue tester gives approximately 17,000 reversals per second, and thus the required tests can be performed in a fraction of the time and the machine automatically shuts off when failure occurs.

The pick up which causes the vibration is controlled from an oscillator and non-magnetic metals can also be tested.

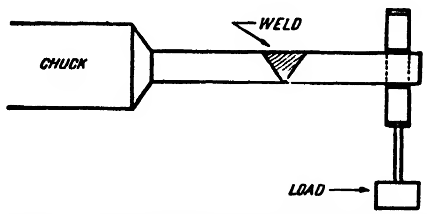


Fig. 302. Illustrating principle of Wöhler test

In the **Wöhler Test**, the specimen is gripped at one end in a device like a chuck and the load is applied at the other end by fixing it to a bearing, as shown in Fig. 302. When the chuck rotates at speed, the specimen is continuously under an alternating tension and compression, tension when the face of the weld is uppermost, as shown, and compression when it is below. If the load applied is great, difficulty is experienced by it pulling the specimen out of balance. These out-of-balance forces then increase the forces on the specimen, and we are unable to tell the load under which the weld failed. This can be overcome, however, by a slight modification of the machine having a bearing at each side of the joint under test and the load applied between the bearings, but the test remains the same. In conducting a fatigue test, a certain load is placed on the specimen, and this produces a certain stress. Suppose the stress produced is 20,000 lb. per sq. in.; this stress varies from zero to 20,000 lb.

tensile stress, then back to zero and to 20,000 lb. compressive stress and back to zero. This is a complete cycle.

Fatigue tests are extremely useful for observing the resistance to fatigue of welded shafts, cranks and other rotating parts, which are subjected to varying alternating loads. They also provide a method of comparing the resistance to fatigue of solid drop forged and welded fabricated components.

(6) Reeve Test

This is used in the study of the hardening and cracking of welds and is of especial value in ascertaining the weldability of low alloy structural steels and high tensile steels, which as before mentioned are prone to harden and develop cracks on cooling.

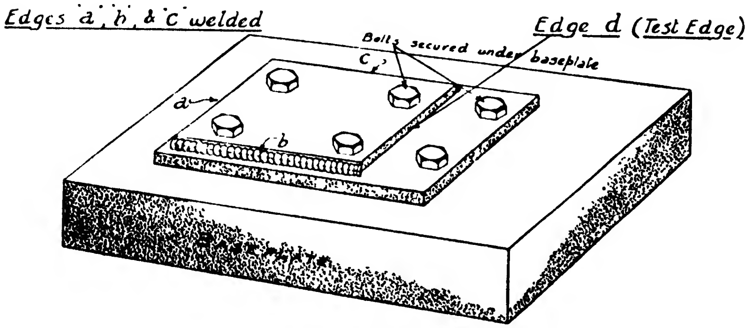


Fig. 303. Reeve test

A 6″ square plate of the metal to be welded is placed on another larger plate of the same metal and the two are firmly secured to a heavy bed plate, 2″ or more in thickness, by means of bolts as shown in Fig. 303.

Edges *a*, *b* and *c* are then lap welded with any selected electrode, thus firmly welding the two plates together, and they are then allowed to cool off. Edge *d* is the one on which the test run is to be deposited using the electrode under test, and evidently since the two plates are completely restrained in movement, any tendency to crack on cooling will show in the weld on the edge *d*.

After cooling, the bolts are removed and the weld examined by previously described methods for cracks. Sections can then be sawn off from the plate and hardness of the weld tested at various points and sections etched and examined microscopically.

It can be seen from this outline of available tests for welds that the particular test chosen will depend entirely upon the type of welded joint and the conditions under which it is to operate. These conditions will govern the tests which must be applied to indicate the way in which the weld will behave under actual service conditions.

Chapter VII

ADDITIONAL PROCESSES OF WELDING

Automatic Metallic Arc Welding

Automatic metallic arc-welding machines are used for all classes of tank and boiler welding, in fact in any application where long seams have to be welded.

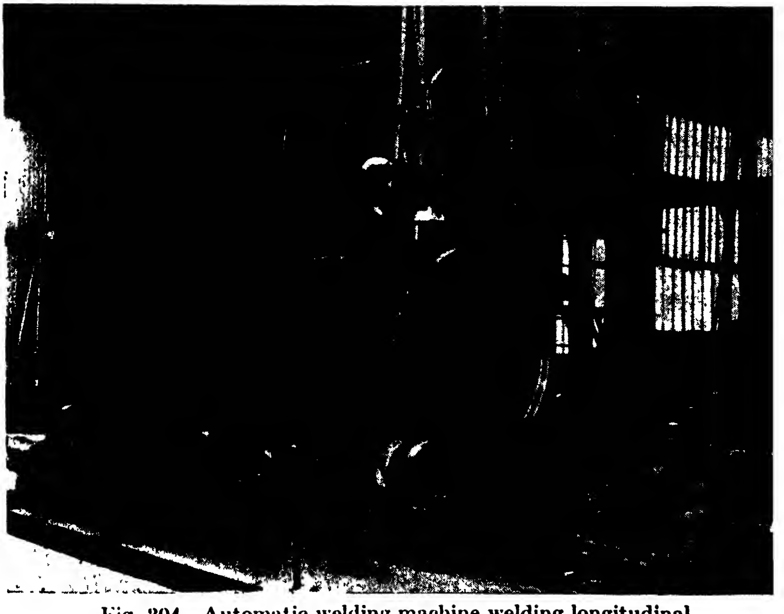


Fig. 304. Automatic welding machine welding longitudinal seam on pressure vessel

The welding head is usually fitted with a drum on which the bare wire or covered electrode is wound in a continuous length. The electrode is fed from this drum to the holder by a motor-driven mechanism, and the rate of feed is completely automatic and such that if the arc gets too long, the voltage across it increases, and this increases the rate of feed (the speed of the motor feeding the electrode being controlled by the arc voltage),

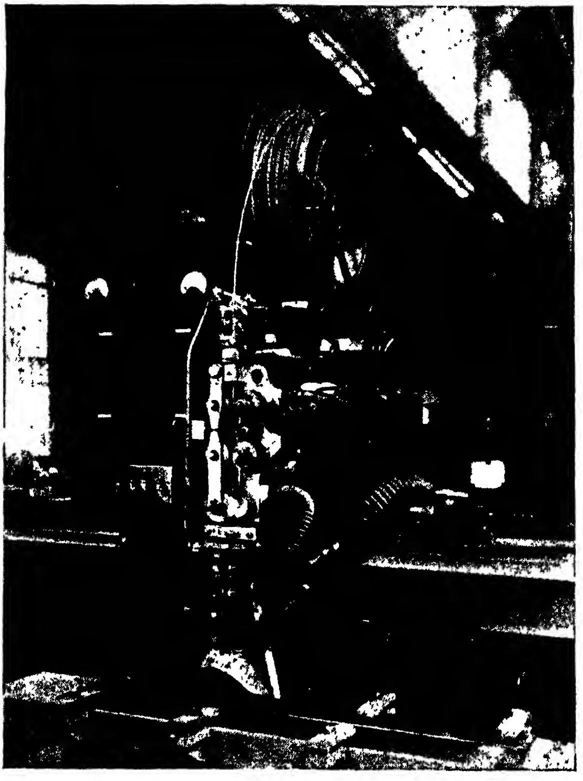


Fig. 305. Automatic arc welding equipment showing control panel and method of feeding electrode continuously

thus shortening the arc length. Conversely, if the arc length gets too short, the voltage across it is lowered and the rate of feed is slowed down, thus lengthening the arc. By controlling the rate of feed in this way the arc length can be kept very constant.

The rate of travel of the arc along the seam can be varied according to the thickness of the plate being welded, and limit switches stop the machine at the end of the seam.

The current is usually supplied by a transformer, as in manual arc welding.

The illustration, Fig. 304, shows a universal type of machine for welding cylinders up to 30 ft. in length, and 11 ft. 6 in. diameter, and the rollers on which the work is rotated can clearly be seen.

Fig. 305 shows the automatic travelling head of the machine, for use with covered electrodes, and any type of jig or table for holding the work can be accommodated below the head. Machines of the type illustrated have a welding speed of from 3½ to 38 in. per minute. The machine is shown set up for performing a butt weld on the plates, which are securely clamped in position on the table.

Atomic Hydrogen Arc Welding

In this method, an alternating current arc is maintained between two tungsten electrodes. Hydrogen is fed into this arc, and the energy of the arc, together with the action of the tungsten electrodes, splits up or dissociates the molecules of hydrogen into atoms. The atoms recombine when they reach the slightly cooler regions outside the arc and the heat liberated by this recombination results in temperatures of up to 4000° C. being attained.

Hydrogen, as previously mentioned, is a strong reducing agent, especially in its atomic state, and as a result the weld metal is protected by a strongly reducing gas and no oxidation or other atmospheric absorption can take place, and in addition the electrodes are prevented from burning away rapidly by oxidation, since no oxygen can possibly be present near the arc. Any oxygen present in the surrounding regions combines with the hydrogen, forming water, which is immediately converted into steam, while the remaining hydrogen burns beyond the region of recombination into molecules, in the usual way.

Equipment. Atomic hydrogen sets are designed in various sizes, such as 7½ to 35 amperes, 15 to 75 amperes, and a transformer supplies the current for the arc. The arc is struck at

300 volts, falling to 70 to 90 volts when operating (since a much higher voltage is required to maintain an arc in hydrogen than in air). The current is, as usual, adjusted according to the thickness of the work. The blowpipe or torch is fitted with a cable supplying current to the electrodes and with a metallic hose which supplies the hydrogen gas to the arc. The hydrogen supply may either be from cylinders containing the gas in compressed form, through a reducing valve, or it may be from an equipment by which ammonia gas (NH_3) is cracked or broken down into hydrogen and nitrogen, the hydrogen being fed to the arc.

The set is fitted with a start and stop button, connected to the control cabinet by a flexible cable. With this the welder can control the gas and electrical supply from where he is welding.

Welding Process. The start button is pressed and the tungsten electrodes are drawn apart from each other by a lever on the torch striking the arc. The gas supply is then adjusted, and the bottom of the elliptical or fan-shaped arc is brought on

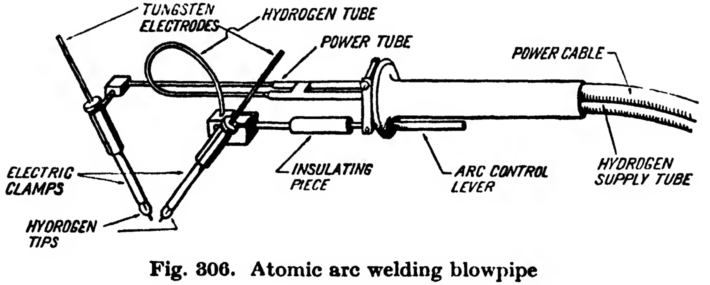
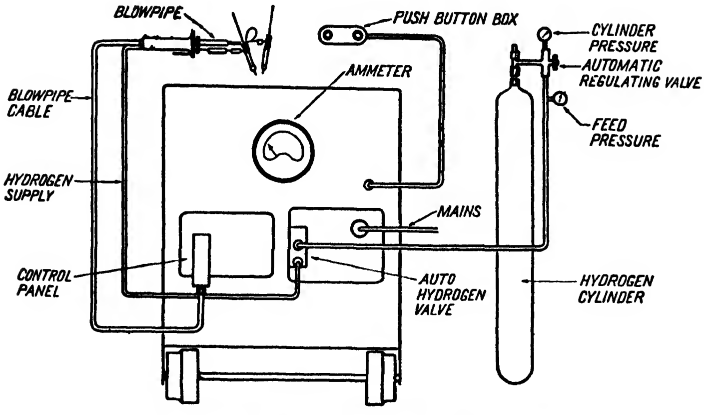


Fig. 306. Atomic arc welding blowpipe

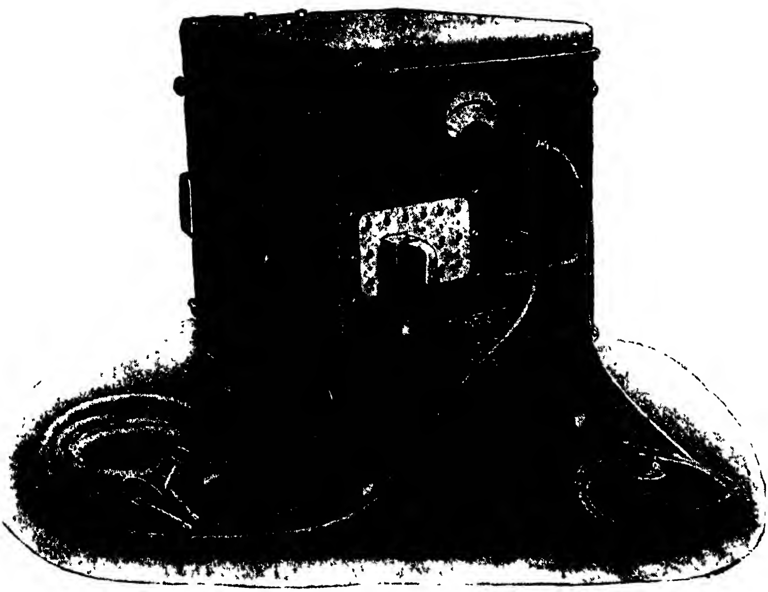
to the metal to be fused. Filler rod may be used as in oxy-acetylene welding, or the arc may be used simply to fuse two surfaces together.

The arc is extinguished by drawing the electrodes well apart or by pressing the stop button, which cuts off the current and shuts off the gas.

Automatic atomic arc-welding machines are available in which the electrodes are fed automatically through a water-cooled nozzle, through which the gas is also fed. These machines are



(a)



(b)

Fig. 307. Atomic hydrogen welding equipment

mounted on frames, so that their rate of travel along the seam to be welded is automatic and at a constant rate, and they are especially useful for welding long seams, such as those in transformer cooling radiators, the resulting weld being absolutely watertight.

The atomic hydrogen-welding process gives excellent welds entirely free from inclusions of any kind, and is applicable chiefly to steel plate, although non-ferrous metals may also be welded, taking the same precautions as for oxy-acetylene welding.

The two electrodes burn away evenly and the consumption is very slow (e.g. with $\frac{1}{8}$ in. electrodes at 50 amperes the rate is $1\frac{1}{2}$ in. per hour); this is an important point, since they are expensive.

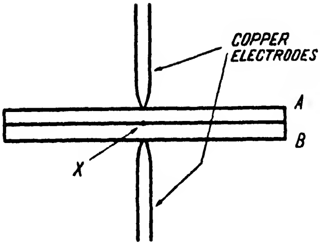
Tungsten may be absorbed into the weld, strengthening it and making up for any deficiency that may occur. In addition, a certain amount of hydrogen may be absorbed.

Fig. 306 shows a typical blowpipe, while Fig. 307 shows the general lay out of the equipment, the current being adjusted on the 'control panel', while the hydrogen supply pressure is adjusted at the reducing valve on the cylinder.

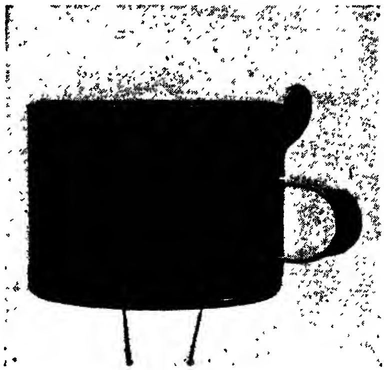
Resistance Welding

In this method of welding use is made of the heating effect which occurs when a current flows through a resistance. Suppose two plates *A* and *B* are to be welded together at *X* (Fig. 308*a*). Two copper-alloy electrodes are pressed against the plates at this point, and the contact between the plates is evidently best at this point. The electrical resistance, however, is still fairly high, and when a heavy current is passed between the electrodes this high resistance (it is high in comparison to the resistance of the rest of the circuit) causes heat to be evolved. By suitably choosing the correct current sufficient heat can be evolved to make the metal plastic, and under the pressure exerted by the electrodes the plates are welded together at the spot *X*. Since the electrical resistance causes the heating effect, the lower this resistance is (it will vary with the metal being welded) the greater will the current have to be to generate sufficient heat for welding to take place.

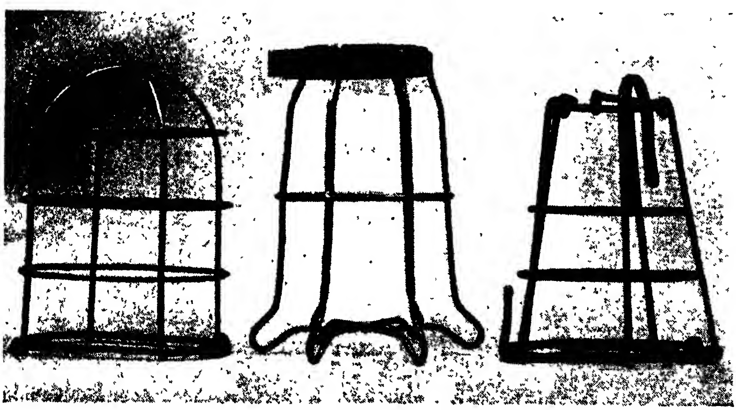
This is termed spot welding, and other methods of resistance welding are variations of this.



(*a*) Spot welding



(*b*) Hospital mug—handle spot welded at each point of contact



(c) Lamp shades built up by spot welding

Fig. 808

The thermal conductivity of the metal also affects the operation, since it determines the rate at which the heat will be conducted away from the weld.

The amount of heat evolved at the spot depends upon (1) the metal being welded, (2) the pressure between the plates, (3) the current and time for which it is flowing, and (4) the area of contact of the spot. All kinds of metals can be welded by the resistance method—steel, bronze, aluminium and its alloys, zinc, brass, monel, etc. Even thin sections of copper can be welded by using sufficiently heavy currents.

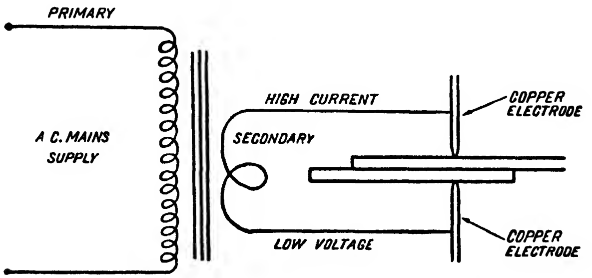
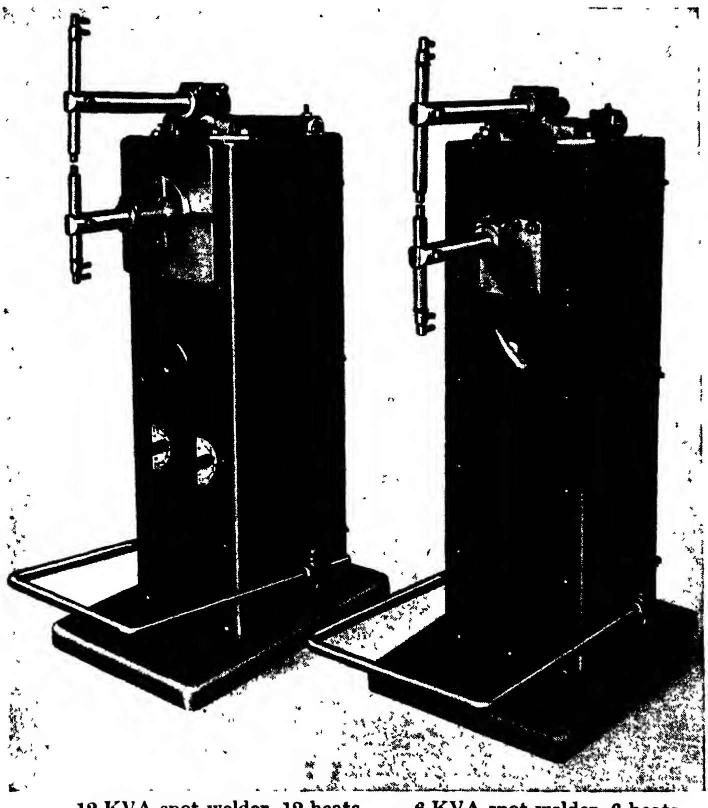


Fig. 309. High resistance exists between the electrodes. The rest of the circuit has a low resistance

Alternating current is supplied to the electrodes from a transformer, as shown in Fig. 309, the primary being fed from the main supply, while the secondary need only have a pressure of 1 to 10 volts, just sufficient to cause the heavy current to flow across the resistance of the plates. The current may be up to 50,000 amperes or more, depending upon the kind of metal being welded and its thickness, and the size of spot welders manufactured varies for 2 to 250 kilovolt-amperes capacity.

It is evident that a spot weld is similar to a rivet, yet without the weakening effect of the rivet on the plate. Plates from the thinnest gauges up to ½ in. thick can be spot welded in this way. Fig. 308*b* and *c* show typical applications of spot welding.

The general type of machine is shown in Fig. 310. The foot pedal causes the electrodes to be pressed on to the surfaces to be welded, and can be operated simply by foot pressure only or motor or compressed air. This pressure is adjustable, and heat tappings enable the current to be varied and thus control the heat given out. When the pressure is applied, further movement



12 KVA spot welder, 12 heats 6 KVA spot welder, 6 heats

Fig. 310

of the pedal makes a contact that switches the current on to the primary circuit of the transformer. The current is left on for sufficient time to raise the metal to welding heat and the weld is made. When the pedal is released the current is first switched off and the pressure on the electrodes released. Current must flow only when the pressure is applied to the plates, otherwise burning and pitting of the electrodes will occur, and it will be noted that the making and breaking of the circuit is done on the primary side of the transformer, so that there is no sparkwear due to this on the welding circuit itself.

The parts to be welded must be reasonably free from surface irregularities that would prevent the surfaces being brought into close contact except by excessive pressure, since this would place undue strain on the machine. In large machines the electrodes are water cooled, and since greatest wear takes place on the machine at the electrodes, they are made readily interchangeable, and various types and shapes of electrodes are available for various classes of work.

Portable type machines, such as the plier and gun type, are extremely popular because of their utility and handiness, and they operate on exactly the same principle. These machines have transportable jaws and the transformer can either be fixed, or mounted on wheels, as required. Connection is made by heavy cable from the transformer to the jaws.

In the case of long seams which have to be welded, and where it is not convenient to use roller electrodes (as in seam welding), continuous spot welding is used. The upper electrode in this case can be either manually or automatically operated. If the latter, it is usually motor driven, rising and falling automatically when the operator presses the foot pedal. The work is fed into the machine each time the jaws open. Modern automatic machines controlled by thyratrons and ignitrons (see later) can time the welding operation to $\frac{1}{100}$ second and thus danger of overheating and waste of power through delay in switching off is avoided, and the speed of welding is increased.

Seam Welding

If the two electrodes in the spot-welding machine are replaced by copper-alloy rollers, and these are arranged to press and roll on any plates pushed between them, a continuous line or seam is welded, this being termed continuous seam welding. The machines are similar in type and operation to the spot-welding machines. The one roller is usually driven by an electric motor,

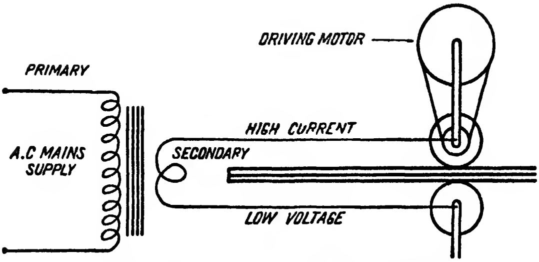


Fig. 311*a*. Lay out of seam welder

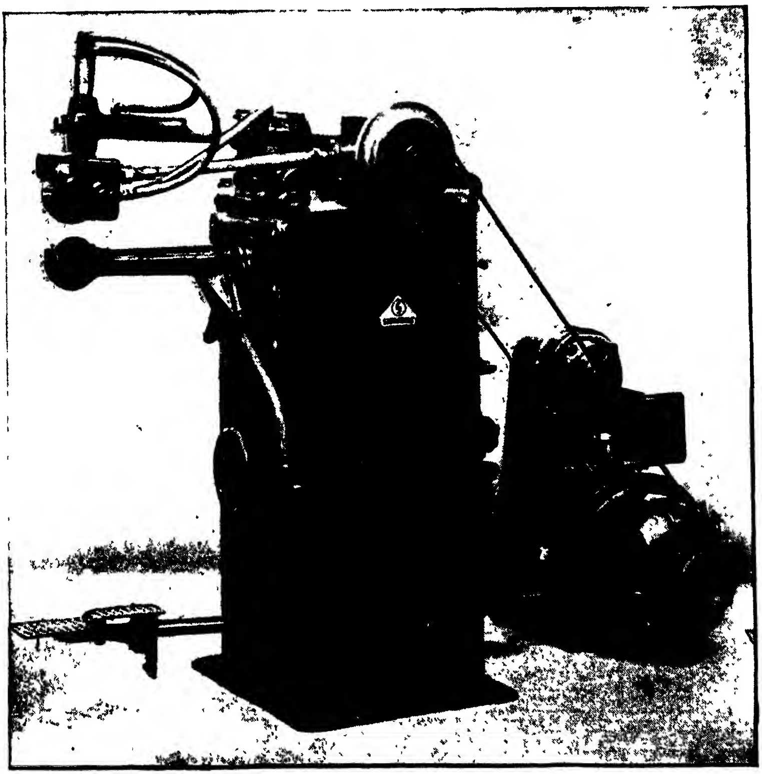


Fig. 311*b*. Modern seam-welding machine

and pressure is applied to the rollers by a foot pedal as before. The welded seam may be continuously or intermittently welded (intermittent seam welding), and the intermittent welds are made by switching the current on and off while the rollers are driven continuously along the seam. Fig. 311 *a* shows the simple lay out of a seam welder, while Fig. 311 *b* is a typical modern machine.

Thyratron and Ignitron controlled Automatic Spot and Seam Welders

It is evident that as the continuous seam weld progresses the heat required for the weld becomes less, since the line of weld heats up. As a result, if the current setting is correct for the thickest sections of the seam, the thinnest sections may be burnt through.

When intermittent seam welding is used, the welds can be made sufficiently close together for them to overlap, yet each weld has time to cool slightly before the next one is made. Thus the heat in the welded seam is kept uniform and there is no danger of burning through. This intermittent seam weld is now really a series of overlapping spot welds, and sufficient voltage is applied so that the current flowing will give sufficient heating effect to ensure a sound weld.

The interruptions of the current in the circuit can be mechanically, magnetically, or thyratron or ignitron controlled. Either mechanical or magnetic methods of interruption are used very satisfactorily on lower-powered machines, the maximum number of interruptions per minute with the mechanical method being about 150 (i.e. 150 welds per minute). When higher-powered machines are required to operate at high speed, the thyratron or ignitron control is generally used.

The ratio of the 'welding time' to the total time which the apparatus is in use is known as the 'duty cycle', and when the mechanical method of operation is used this may vary considerably. With the thyratron control it is accurately controlled.

The thyratron is a method of control using the thyratron or hot cathode mercury vapour tube (or valve). This control can give up to a maximum of 1500 interruptions per minute on a 50~ supply by means of the synchronous timer and, once a given welding condition has been secured, each weld is made under exactly the same conditions and with the same duration, and therefore the welded seam exhibits the same characteristics throughout its length. Fig. 312*a* shows an elementary circuit diagram of thyratron control. The thyratron tubes or power tubes in the diagram can be made either conducting or non-conducting, as required, by means of the control tubes and a synchronous timer.

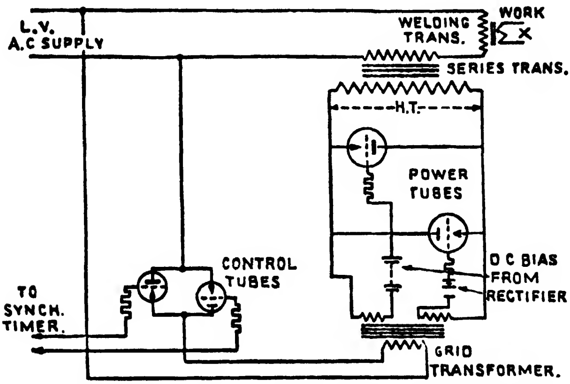


Fig. 312*a*. Circuit diagram of thyratron control of welder

A series transformer, in circuit with the welding transformer, provides the high voltage for the tubes by its secondary winding. When the power tubes are made conducting, the secondary of the series transformer is short circuited, and the full voltage is applied to the primary of the welding transformer, and the weld is made. When the power tubes do not conduct, the primary of the series transformer acts as a choke, and as a result the line voltage is choked and a low voltage applied at the primary of the welding transformer. This voltage is not sufficient to make a weld and therefore this is one of the 'off' periods.

Mild steel can be easily intermittent or stitch welded with no fear of burning. Chrome and cadmium plated steel can also be welded through the plating. Duralumin and other aluminium alloys used in the aircraft industry can be welded in thicknesses of from 0·032 to 0·101 in. Accurate heat control is essential and heavy currents (up to 40,000 amperes), for very short periods, are required to prevent burning. Duralumin, for example, has a very small range of temperature in which it is plastic, and as a result the weld cannot be made merely by applying pressure when it is in the plastic state, as in the case of mild steel. Instead, the temperature must be raised until the metal is actually molten, and this gives an indication of the accuracy of current timing required, since a hole would be burnt in the metal sheet if the metal was molten for the smallest fraction of a second too long.

The control enables a very wide range of welding conditions to be obtained, such as one cycle on, one cycle off; one cycle on, five cycles off; three cycles on, six cycles off, etc., exactly as required.

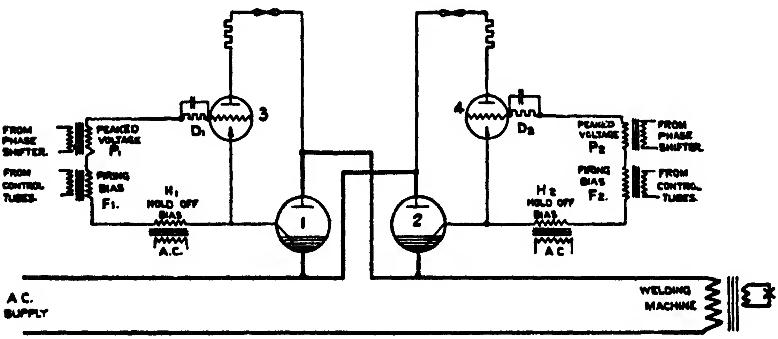


Fig. 312*b*. Ignitron control.

Ignitron Control

Glass ignitrons are used in the same way as thyratrons. The ignitron has a mercury pool as the anode and ignition is effected by passing a momentary current through the igniter element the tip of which is immersed in the mercury pool. Two glass ignitrons are used and are air cooled to increase the rating, being able in this way to handle up to 780 kilovolt-amperes at 440 volts, the two ignitrons directly controlling the primary current to the welding transformer. In a spot welder the weld operates often for a few cycles only, thus the duty cycle for spot welders is often from 10 % to 20 % and hence the equipment is operating well within its capacity.

With seam welding the duty cycle may rise to 60 % or 80 %. In this case, with such high powers, glass thyratrons and ignitrons have too low a rating to be satisfactory and the steel ignitron is used. The steel ignitron consists of a sealed evacuated steel cylinder at the bottom of which is a cathode lug sealed into the end of the cylinder.

The anode is held on an insulating glass seal at the top of the tube and the igniter is supported from a glass insert at the bottom, mercury being added up to the correct level. The tube is water-cooled by being surrounded by a water-jacket, and thereby its rating is greatly increased and the size correspondingly reduced.

It has previously been stated that in the thyratron control, the tubes pass current for a given number of cycles on, followed by a given number off, and the control varies the number on and off as required. Many operations with metals such as stainless steel demand such accurate heat control that, although the machines may have many heat tappings, the exact setting cannot be obtained and evidently it is not commercially possible to provide an infinite number of heat taps. The solution, therefore, must be to vary the welding time in periods of *less* than one cycle.

In the previously described thyratron and ignitron control the tubes operate over a whole cycle, one tube firing one half cycle in turn after the other has stopped passing current.

By delaying the firing of each tube a given number of degrees after the other has ceased to pass current, the average value of current is lessened.

Further delay of the firing point still further reduces the average current value and so on.

The tubes are fired by a peaked voltage from a transformer supplied from a phase shifting bridge. The peaked voltage can be phase shifted over about 100°, the amount depending on the power factor of the welding machine. This has the effect of a rotary rheostat having an infinite number of steps and thus an infinite number of heat settings are available and very fine adjustments of heat can be made without altering the number of cycles on. By this means the number of heat taps can be reduced and it is possible even to do without them, half cycle welds being easily arranged.

The power circuit diagram is shown in Fig. 312*b*. 1 and 2 are the steel ignitrons connected in reverse parallel and then in series with the power supply and the primary of the welding transformer.

Each ignitron has its igniter energised by a thyratron connected as shown, these being known as the firing tubes, 3 and 4.

The firing tube grid circuit voltage is made up of four voltages in series.

(1) An A.C. hold-off bias, H1 and H2.
(2) A D.C. hold-off bias, D1 and D2.
(3) An A.C. firing bias, F1 and F2.
(4) A peaked voltage, P1 and P2.

H1 and H2, in conjunction with D1 and D2, keep the firing tubes non-conducting, since P1 and P2 are insufficient to overcome the hold-off bias voltages.

When the control tubes energise the firing transformer, the firing bias F1 and F2 appears, tending partially to overcome the hold-off bias, and so enables the peaked voltage to cause the tubes to conduct.

The firing tubes may be fired at a point in the voltage wave giving maximum or minimum heat as required.

When the firing tubes become conducting, the current through the igniters causes the ignitrons to fire and these immediately short circuit the firing tubes which are therefore extinguished. The ignitrons then pass current to the welding transformer primary. Thus the number of cycles is set by the control tube and the mean value of the current passed in each half cycle is set by the heat control phase shifter. This, therefore, decides the firing point of the firing tubes and thus of the ignitrons.

Difficulty was experienced in the welding of stainless steel by the resistance method, because during the welding process the steel is raised to a temperature at which carbide precipitation occurs at the grain boundaries (p. 75) and, as a result, if the non-decay proof steels were to be welded on account of their having a higher degree of surface polish for decorative work than the decay proof types, their corrosion-resisting properties were greatly reduced. A recent development, known as 'shot welding' and used first in the U.S.A. for the welding of the 18/8 stainless steel trains, enables the spot weld to be carried out without affecting the austenitic and corrosion-resisting qualities of the steel.

The copper-alloy electrodes are pressed pneumatically against the work, and current is passed, sufficient to cause about 80 %

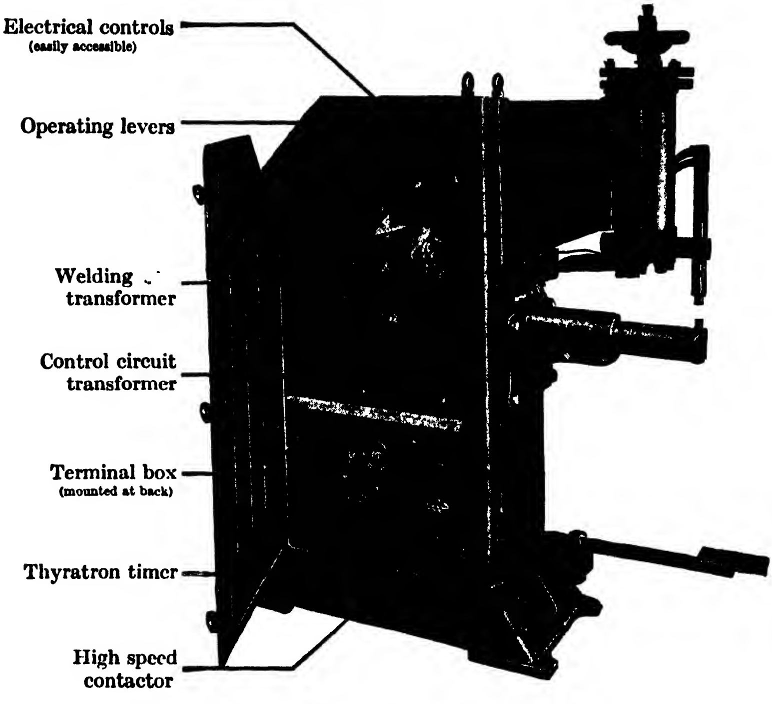


Fig. 313. 20 KVA spot welder with side door open to show interior

fusion. The time of passage of the current is very short and accurately controlled by the hot cathode tube, as just described. The short application of heat, together with the cooling action of the electrodes, causes the weld to cool so quickly that no carbide precipitation occurs, the austenitic structure of the steel is unaffected and the steel remains corrosion proof.

The thyratron or ignitron can also be applied to control the ordinary spot welder, so as to give accurate control of the period during which the current flows. The foot pedal is pressed, the electrodes are pressed on to the work, the thyratron is brought into circuit and switches the current on for

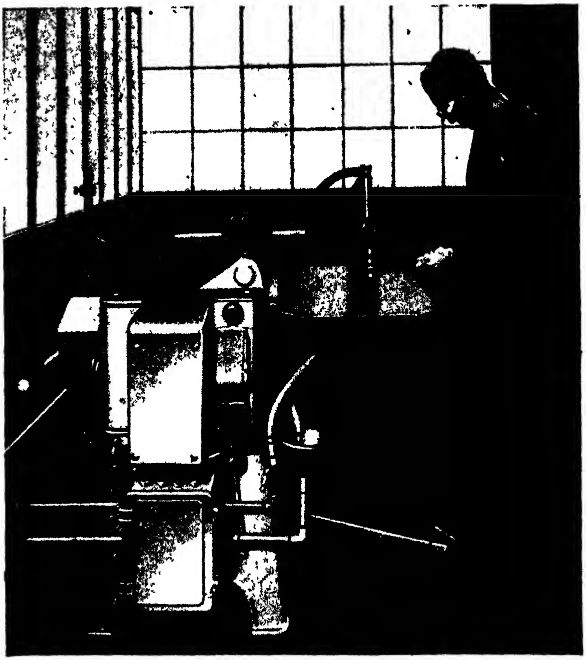


Fig. 314. Spot welding machine equipped with thyratron contactor timing equipment

a given period as desired. The weld is made, therefore, with the welding current flowing for a period independent of the time for which the operator depresses the foot pedal. This type of machine is especially useful for the welding of aluminium alloys and stainless steel, because of the reasons previously explained.

Upset Butt Welding

This method is similar to spot welding except that the parts to be butt welded now take the place of the electrodes. The two ends are prepared so that they butt together with good contact. They are then placed in the jaws of the machine, which presses them close together end to end. When a given pressure has been reached, the heavy current is switched on, and the current flowing through the contact resistance between the ends brings them to welding heat. Extra pressure is now applied and the ends are pushed into each other, the white hot metal welding together and an enlargement of section taking place. The section may be machined to size after the operation if necessary.

Flash Butt Welding

The ends to be welded by this method are unprepared and are held in the jaws of the machine. The ends are brought together and the current switched on. The ends are then drawn apart by

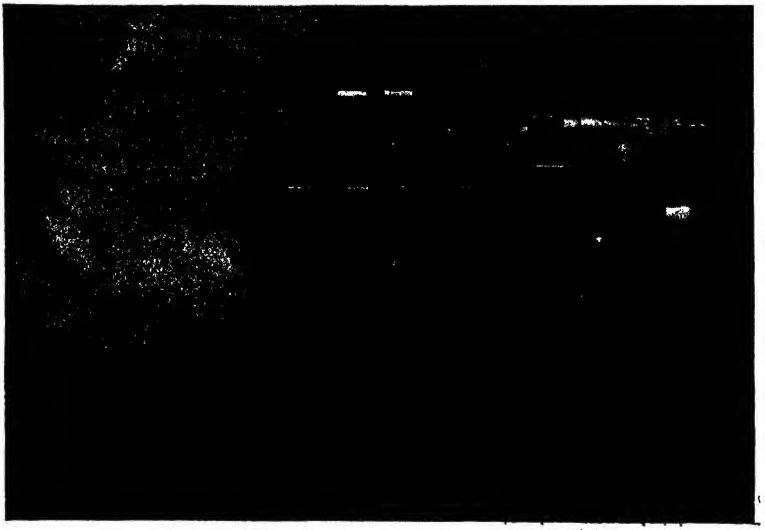


Fig. 315a. Automatic butt welder arranged for horizontal welding

the machine and an arc drawn between the ends. The ends are again brought together and again arced, and in this way any irregularities are burnt off. When the ends are uniform, they

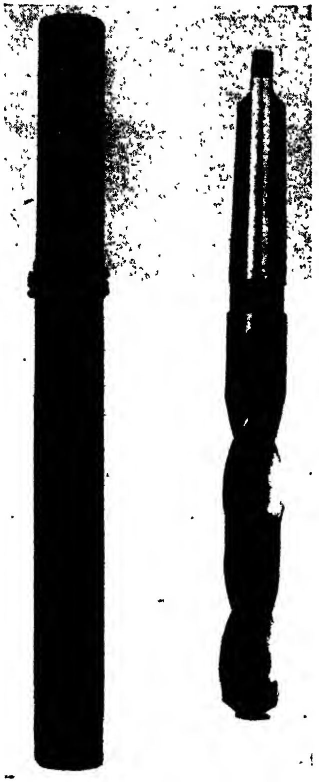


Fig. 315*b*. Butt welding in tool manufacture. A twist drill showing welded blank and finished product

Fig. 315*c*. A flash butt weld on steel piping

are brought together, the current interrupted, and the ends remain firmly welded together. Any impurities are forced out at the joint, and leave a raised portion which can be removed by chipping or grinding.

Butt welding is especially suited to the welding of rails and steel tyres, hoops, etc. Rails are now being welded together for main-line railways by this method, to form continuous lengths of thousands of yards, the butt welders used in this case being of very large capacity and capable of exerting a pressure between the ends of the rails of 15 to 25 tons per sq. in., depending on the section of the rail being welded.

Thermit Welding

Thermit is the name given to a mixture of finely divided iron oxide and powdered aluminium. If this mixture is placed in a fireclay crucible and ignited by means of a special powder giving off great heat, the action, once started, continues throughout the mass of the mixture. The aluminium is a strong reducing agent, and combines with the oxygen from the iron oxide, the iron oxide being reduced to iron (see p. 37).

The intense heat that results, because of the chemical action, not only melts the iron, but raises it to a temperature of about 3000° C. The aluminium oxide floats to the top of the molten metal as a slag. The crucible is then tapped and the superheated metal run around the parts to be welded, which are contained in a mould. The high temperature of the iron results in excellent fusion taking place with the parts to be welded. Additions may be added to the mixture in the form of good steel scrap, or a small percentage of manganese or other alloying elements, thereby producing a good quality thermit steel. The thermit mixture may consist of about 5 parts of aluminium to 8 parts of iron oxide, and the weight of thermit used will depend on the size of the parts to be welded. The ignition powder usually consists of powdered magnesium or a mixture of aluminium and barium peroxide.

Preparation. The ends which are to be welded are thoroughly cleaned of scale and rust and prepared so that there is a gap between them so that the molten metal can penetrate well into the joint. Wax is then moulded into this gap, and also moulded into a collar round the fracture. This is important, as it gives the necessary reinforcement to the weld section (Fig. 316). The moulding box is now placed around the joint and a mould of fire clay and sand made, a riser, pouring gate and pre-heating gate being included, as in Fig. 317. The ends to be welded are now heated through the pre-heating gate by means of a flame and the wax is first melted from between the ends of the joint. The heating is continued until the ends to be welded are at a red heat. This prevents the thermit steel being chilled, as it would be if it came into contact with cold metal. The pre-heating gate

Fig. 316

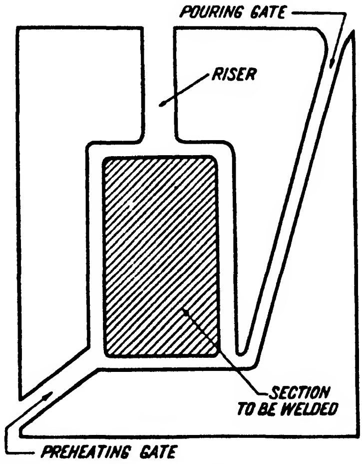


Fig. 317. Mould for thermit welding

is now sealed off with sand and the thermit process started by igniting the powder. The thermit reaction takes up to about 1 minute, depending upon the size of the charge and the additions that have been made in the form of steel scrap, etc. When the action is completed the steel is poured from the crucible through the pouring gate, and it flows around the red hot ends to be welded, excellent fusion resulting. The riser allows extra metal to be drawn by the welded section when contraction occurs on cooling, that is, it acts as a reservoir.

The weld should be left in the mould as long as possible (up to 12 hours), since this anneals the steel and improves the weld.

Thermit steel is pure and contains few inclusions. It has a tensile strength of about 30 tons per sq. in. The process is especially useful in welding together parts of large section, such as locomotive frames, ships' stern posts and rudders, etc. It is also being used in place of flash butt welding for the welding together of rail sections into long lengths.

Chapter VIII

ENGINEERING DRAWING

During periods of training, and certainly in the course of his work, the welder will find that an elementary knowledge of technical drawing is of great help, both from the point of view of his being able to read and understand the conventional blue print or working drawing, and being able to make sketches of parts to scale. To enable the welder to have some knowledge of the subject it will be well to consider the way in which drawings are made, the standard methods used, and then to proceed to the consideration of a few special examples of drawings of welded construction with brief descriptions.

The principal method usually adopted in the making of machine drawings is known as orthographic projection.

Suppose the part under construction is shown in Fig. 318*a*. This 'picture' is known as an isometric view. It is of small use to the engineer, since it is difficult to include on it all the details and dimensions required, especially those on the back part of the picture, which is hidden.

Imagine that around the object a box is constructed (*o* being the corner farthest from the observer) having the sides *ox*, *oy*, *oz* all at right angles to each other. The plane or surface of the box bounded by *ox* and *oy* is the *vertical* plane, indicated by V.P.; that bounded by *oy*, *oz* is the side vertical plane, S.V.P., and that bounded by *ox* and *oz*, the horizontal plane, H.P., these three planes being the three sides of the box farthest from the observer. Lines are projected, as shown, on to these planes from the object under consideration, and the view projected on the vertical plane is the side elevation, and is the view obtained when looking at the object in the direction of the arrow *A*. The end elevation is the view obtained by projection on to the side vertical plane, while the plan is the view obtained by projection on to the horizontal plane. The arrow *B* shows the direction in which the object is viewed for the side elevation and *C* the direction for the plan.

Now imagine the sides V.P., S.V.P. and H.P. opened out on their axes *ox*, *oy* and *oz*. The three projections will then be disposed in position, as shown in Fig. 318*b*, i.e. the end elevation is to the *right* of the elevation and the plan is *below* the elevation.

On these three projections, which are those used by the engineer, almost all the details required during manufacture can be included, and hence they are of the greatest importance.

This method of projection is known as First Angle Projection, and is that usually adopted in British Engineering circles, the projection lines being clearly indicated in Fig. 318*a*.

A second method, called Third Angle Projection, is extensively used in the U.S.A., and can be understood by reference to Fig. 319*a*.

From this it will be seen that the corner of the box *o* is chosen to be that nearest the observer, and the three planes are those sides of the box also nearest to the observer, the part under consideration being seen through these planes of projection. The elevation is again that view formed by projection on to the vertical plane *ox*, *oy*, the end elevation that formed by projection on the side vertical plane *oy*, *oz* and the plan formed by projection in the horizontal plane *ox*, *oz*. Owing, however, to the change in the axes when they are unfolded the projections are disposed differently, the plan now being *above* the elevation and the side elevation being to the *left* of the elevation (Fig. 319*b*). (N.B. The object is viewed in the same direction as previously, as indicated by the arrows.)

By noting the above difference between the two methods the welder can immediately tell which method has been used.

Sometimes a combination of these two methods may be encountered but need not be considered here.

Scales

Engineering or working drawings are usually drawn to a definite scale. Small parts may be drawn full size (stated scale full size) and its choice is limited usually by the size of drawing paper used. Larger parts may be drawn half or quarter full size (stated scale half size, or scale quarter size), but the measurements or dimensions given on the drawing will represent the *true*

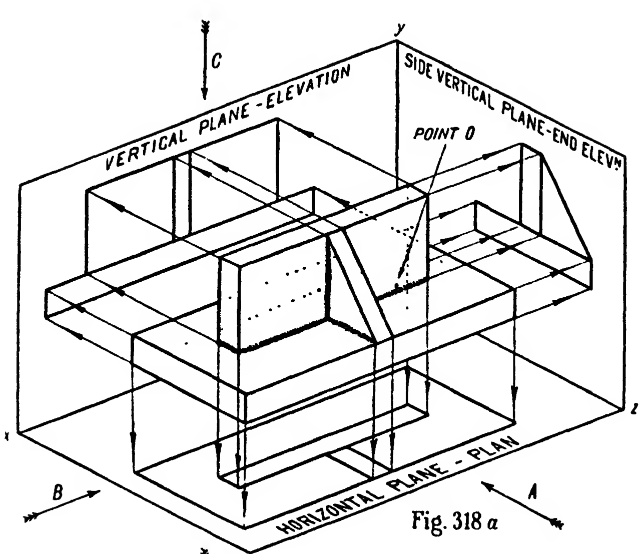


Fig. 318 *a*

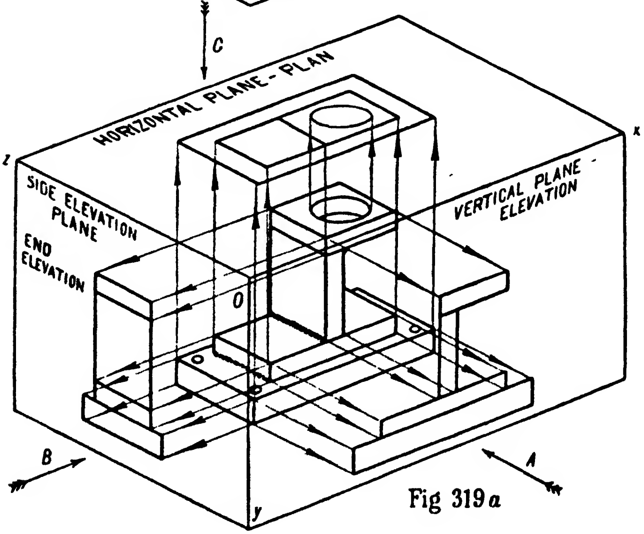


Fig 319 *a*

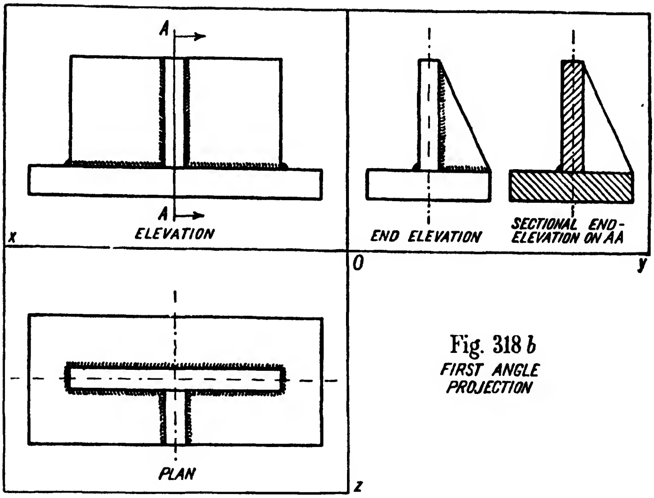


Fig. 318 b
FIRST ANGLE PROJECTION

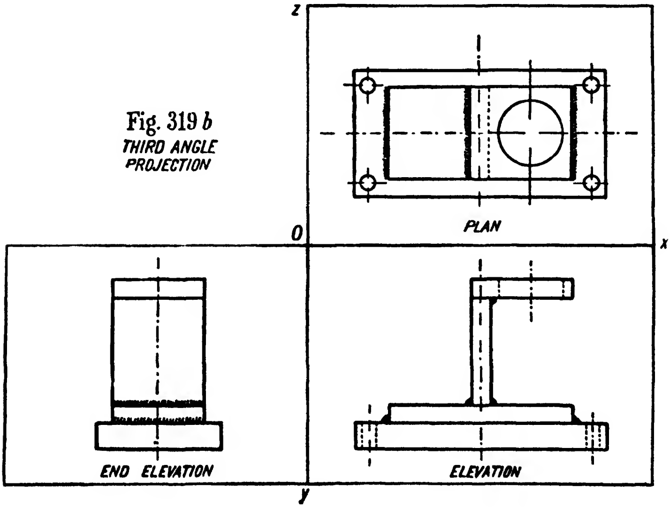


Fig. 319 b
THIRD ANGLE PROJECTION

size of the parts. Larger parts still may be drawn with a given number of inches to represent a foot, for example, 1 in. = 1 ft., 2 in. = 1 ft., 3 in. = 1 ft.

Tracings of these drawings are then made, and these are used as negatives in the production of blue, brown or white prints. In the process of making the print (which is chemical) a change of size occurs and therefore lines on the blue print may not be to the scale of their correct length. For this reason measurements should not be made by means of a ruler or other measuring instrument from the print—the dimension printed on the print gives the correct lengths and distances and should be followed. A good working drawing is always fully dimensioned, and if a dimension does not appear on one view it will always be found on one or other of the remaining views. In a case where the actual measurement on a drawing is evidently not equal to the dimensioned size after allowing for the scale of the drawing the dimension will be underlined thus: 6 in., and this means that the true size which the part must be is 6 in. irrespective of its apparent size on the drawing. The engineer or welder should accustom himself to the addition and subtraction of dimensions to give him those not indicated, e.g. a tube inner radius 3 in., outer radius 4 in. evidently has a wall thickness of 1 in. Hidden parts are usually denoted by dotted lines, as in Fig. 319*b*.

Sections

A section may be considered as the view on an imaginary plane which cuts through the object under consideration at any given point, and these are used to give further detailed information about the part. When the section plane, as it is termed, coincides with part of the true surface of the object it is no longer a true section. Various methods of cross-hatching sections may be used to represent different materials, as indicated in Fig. 320, but in modern drawings it is more usual to indicate the materials by means of a schedule in the bottom right-hand corner of the drawing (see Fig. 324) rather than to use a plain hatching, owing to the great variety of metals in use at the present time.

Another case in which cross-hatching is omitted is that of a rib. This is illustrated in the sectional end elevation, Fig. 318*b*, the rib being left plain. Fig. 321 indicates a simple bearing with an oil hole drilled in it. Sections on *AA* and *BB* are, as indicated by the arrows, to the left of the part, while those in *CC* and *DD* are to the right. *A*, *B* and *D* are true sections and are therefore cross-hatched, but at *CC* it will be noticed that the section plane coincides with the surface of the flange and this portion is therefore not cross-hatched. Evidently any number of section

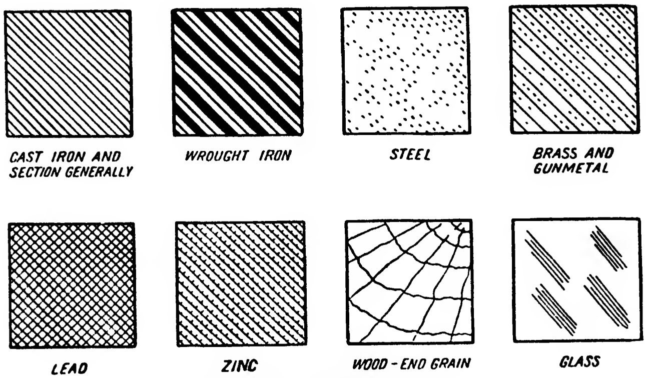


Fig. 320. Cross-hatching

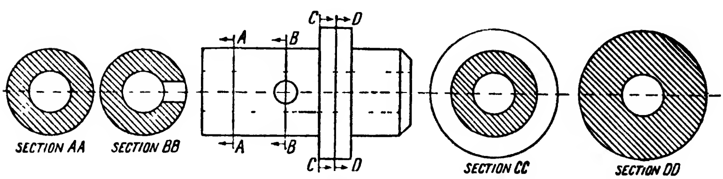


Fig. 321

planes may be chosen, but usually each is chosen so as to give some additional information essential to the manufacture of the part.

In an elevation and section welds are usually blacked out thus: _▼‾‾, while in a plan they are indicated by a series of parallel lines thus: ////////////, or by × × × × as in Fig. 326.

Elevations and plans of butt, lap and fillet welds are shown in Fig. 322. Fig. 323 shows the method of drawing the lap-welded plates of which the isometric view is also given.

We may now consider as an example of fabricated work the frame of an electric motor or dynamo shown in Fig. 324. The casing is of steel rolled to circular shape and the joint welded

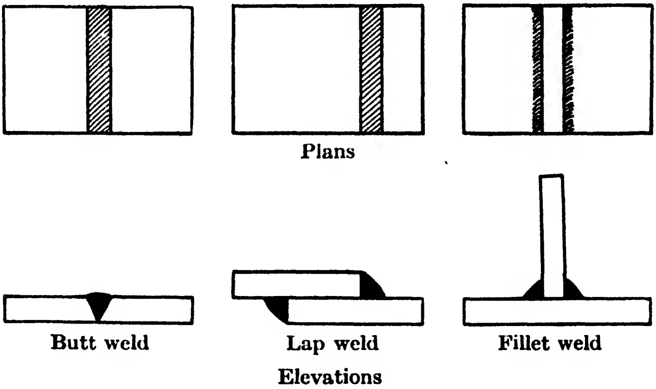


Fig. 322

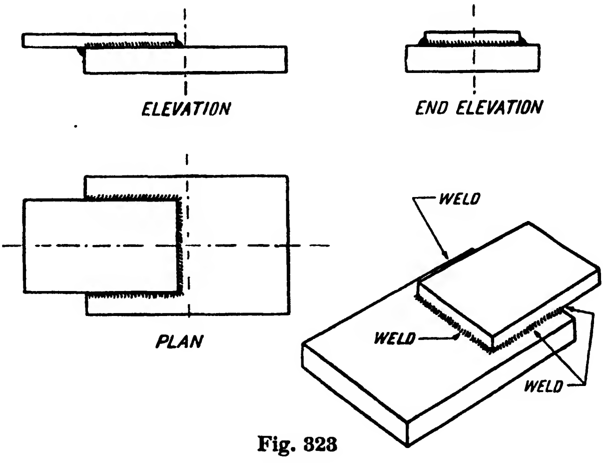
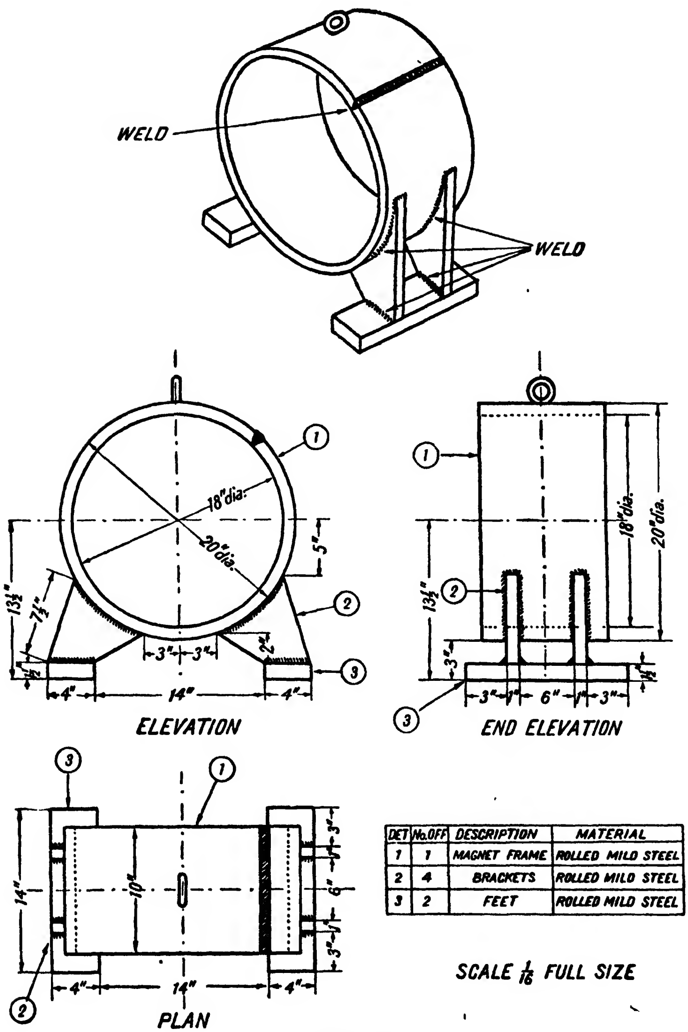


Fig. 323

(along the line) as shown. The feet and lifting lug are then welded on. The elevation, end elevation and plan studied in conjunction with the isometric view makes all required details quite clear.



DET	No. OFF	DESCRIPTION	MATERIAL
1	1	MAGNET FRAME	ROLLED MILD STEEL
2	4	BRACKETS	ROLLED MILD STEEL
3	2	FEET	ROLLED MILD STEEL

SCALE $\frac{1}{16}$ FULL SIZE

Fig. 824

Figs. 325 (opposite), 326 and 327 (in pocket at back) illustrate typical working drawings in use at the present time and should be carefully studied. Parts to be machined are indicated either by the letter *m* or the symbol .

The following points will be found to be very helpful when making sketches of parts for fabrication or welding:

(1) Draw a centre line for each part and build up each part of the drawing from these centre lines.
(2) Always make them on orthographic projection (elevation, side elevation and plan), because they are simpler, clearer and easier to dimension.
(3) Make the sketch as large as possible and include all detail in its correct proportion, i.e. diagram of holes, radii of fillets, etc.
(4) Dimension the sketch fully, as a missing dimension may hold up production, and run dimensions from line to line, all holes having centre lines.
(5) Use a hard pencil and good paper to ensure clarity.

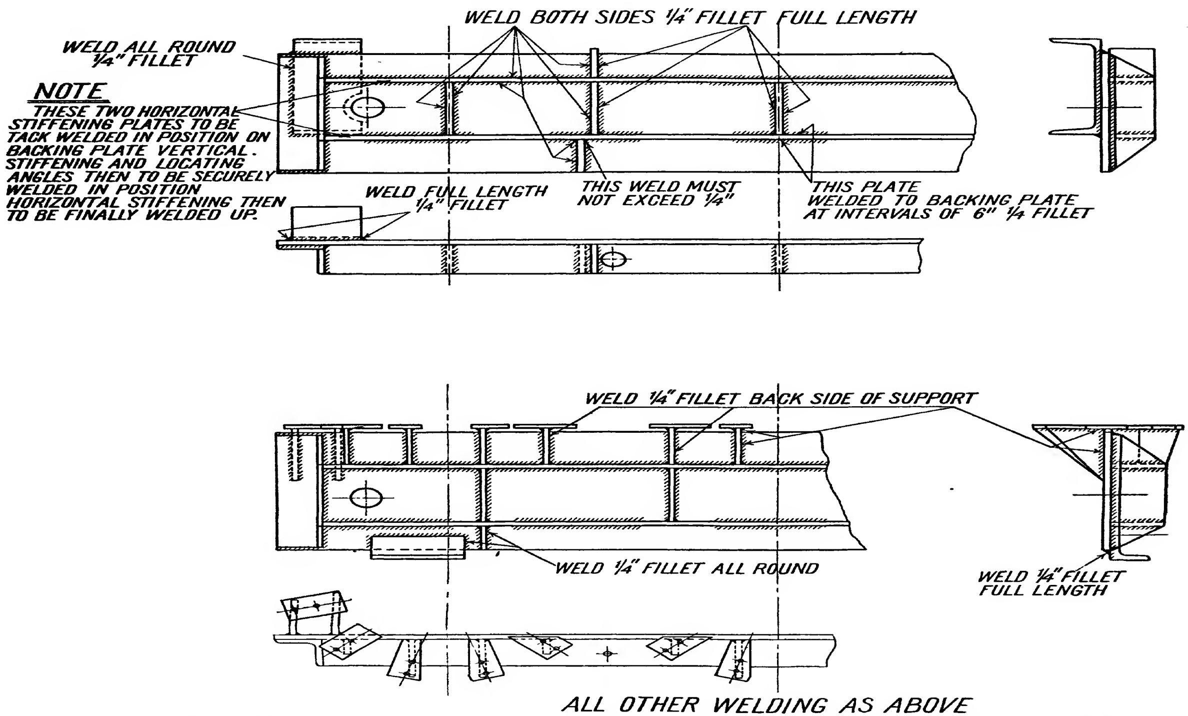


Fig. 325. The drawing shows fabricated frames for top and bottom yokes of a large three phase transformer. This has three limbs over which the three coils fit, and the drawing shows the centre lines of the first and second cores, the third core being repeated symmetrically to the right and not shown.

The coils which surround the transformer core rest on the radiating plates shown in the lower view. The frames are from mild steel plate $\frac{1}{2}-\frac{5}{8}$ in. thick and stiffened by webs so that the laminated cores can be clamped on uniformly at a pressure of about 100 lb. per sq. in. Care must be taken when welding to see that the webs are tack welded in position in a correct sequence. This is chosen as a result of practical experience to bring distortion to a minimum and in general is similar to the method used in tightening down the cylinder head bolts of a six cylinder engine, that is working alternately. (Scale 1 : 12.)

Figure 325

(To face p. 396)

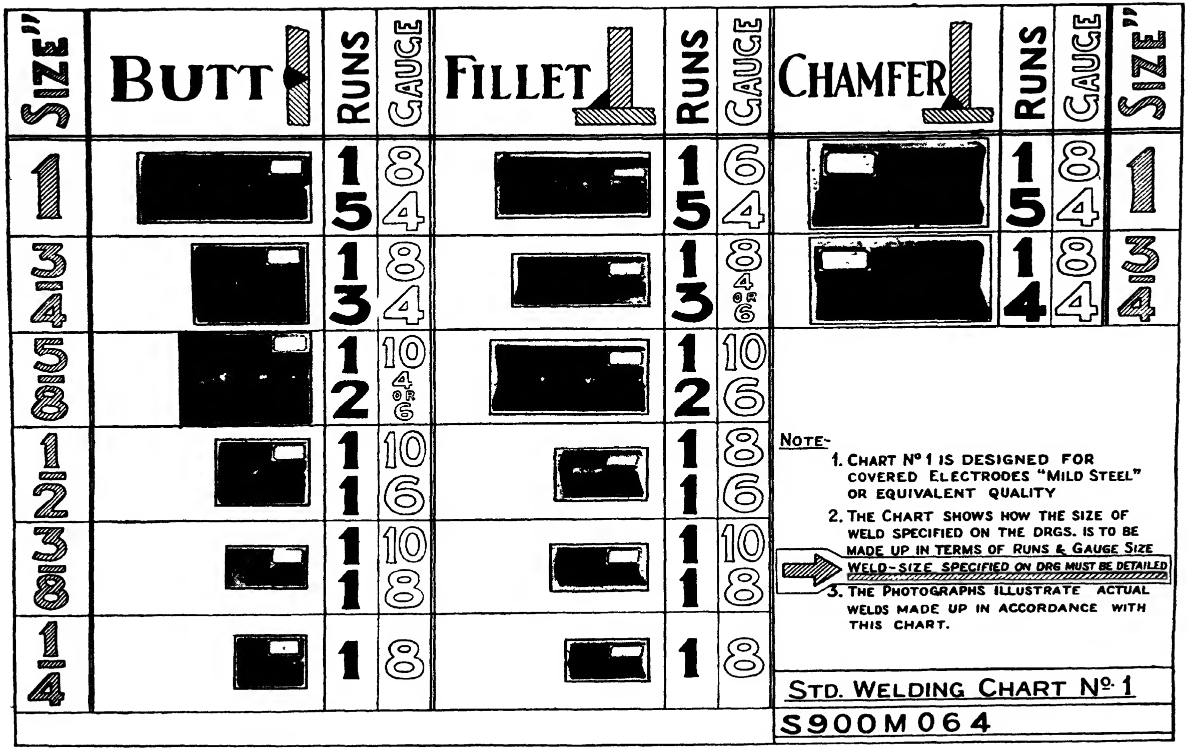

SIZE"
BUTT
RUNS
GAUGE
FILLET
RUNS
GAUGE
CHAMFER
RUNS
GAUGE
SIZE"
1 | 1 5 | 8 4 | 1 5 | 6 4 | 1 5 | 8 4 | 1
3/4 | 1 3 | 8 4 | 1 3 | 8 4 OR 6 | 1 4 | 8 4 | 3/4
5/8 | 1 2 | 10 4 OR 6 | 1 2 | 10 6
1/2 | 1 1 | 10 6 | 1 1 | 8 6
3/8 | 1 1 | 10 8 | 1 1 | 10 8
1/4 | 1 | 8 | 1 | 8
NOTE-
1. CHART Nº 1 IS DESIGNED FOR COVERED ELECTRODES "MILD STEEL" OR EQUIVALENT QUALITY
2. THE CHART SHOWS HOW THE SIZE OF WELD SPECIFIED ON THE DRGS. IS TO BE MADE UP IN TERMS OF RUNS & GAUGE SIZE
WELD-SIZE SPECIFIED ON DRG MUST BE DETAILED
3. THE PHOTOGRAPHS ILLUSTRATE ACTUAL WELDS MADE UP IN ACCORDANCE WITH THIS CHART.
STD. WELDING CHART Nº 1
S900M064

Fig. 328

Chapter IX

THE SHORTER PROCESS OF SURFACE HARDENING FERROUS METALS

Although it is many years since the blow pipe was first used for surface hardening steel and cast iron the initial attempts were very unreliable and unscientific. The blowpipe was held in the hand and the flame moved over the surface to be hardened until its critical temperature was reached. It was then quenched by spraying water from a jet on to the surface or by dropping it into a water bath. This method was used for the flanks of gear teeth and for any small areas, but the variation in hardness caused by the hand operation set up localised stresses which were liable to cause failure under load, and the results depended largely on the skill of the operator. In the Shorter process these drawbacks are eliminated by using machine operated burners and coolers and by better control of the oxygen and fuel gas and precision setting the instability of hand operation has been eliminated.

One of the earliest difficulties experienced was backfiring of the burner and each time this occurred a soft spot was caused in the hardened surface. This instability was due to varying the position of the burner to the surface and to the proximity of the quenching water; by bringing the water under the direct control of the burner, and stabilising the gases and regulating the operation on a full precision basis the work of surface hardening has been completely stabilised, in the Shorter Process.

The Shorter machines are now constructed for mass production work and automatic operation and may be divided into the following classes:

(1) Machines in which the job is stationary and the burner moves over the surface to be treated closely followed by a quenching jet or jets (Fig. 329).

(2) Machines in which burner and quench are stationary and the job moves past (Fig. 330).

(3) Machines in which burner and quench move in one direction, e.g. longitudinally or vertically and the work moves in another direction, e.g. rotates (Fig. 331).

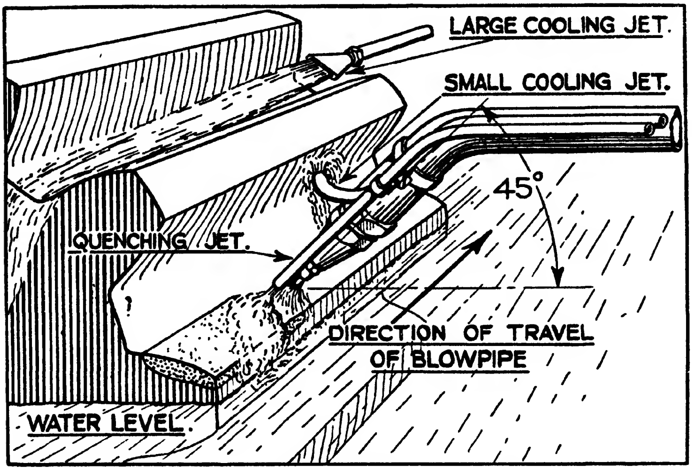


Fig. 329

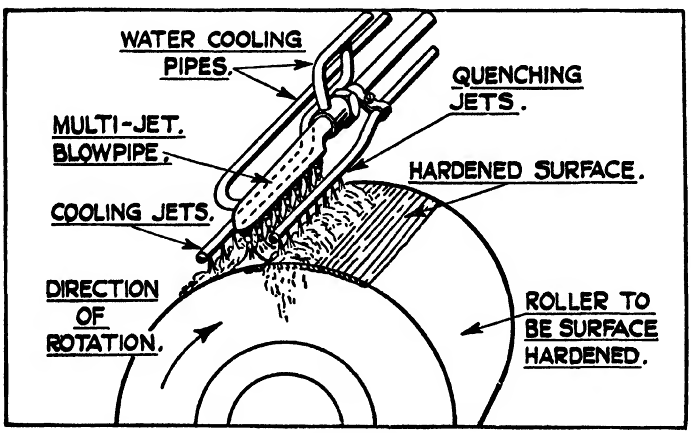


Fig. 330

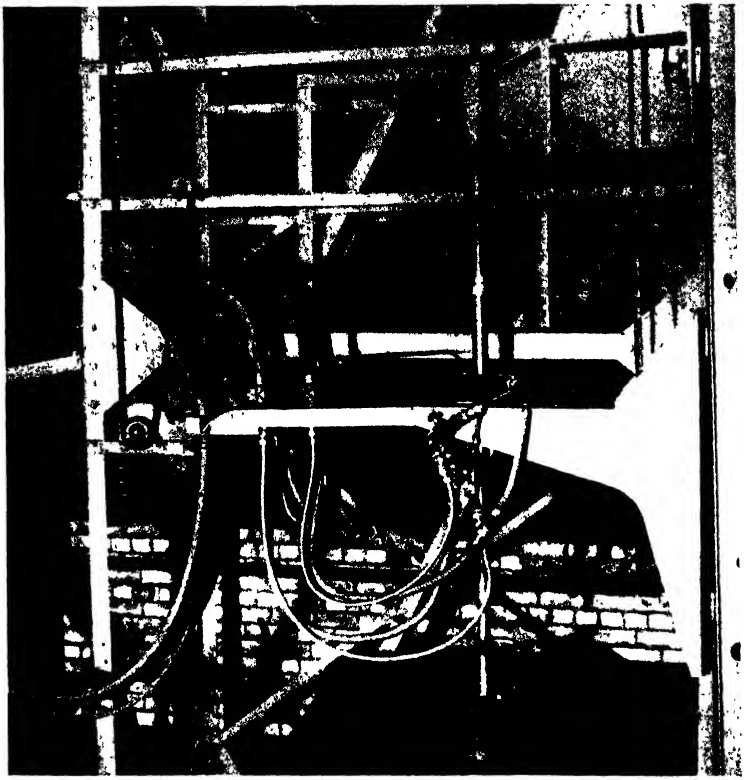


Fig. 331. Roller Hardening Machine (Shorter Type R2). The rollers to be hardened are placed vertically between the centres shown on the right of the photograph. The platform holding the flame jets and quenching gear can be raised by the motor-driven cantilever bracket, and moves vertically upwards. Rollers from 1½ to 16 in. diameter can be hardened on this machine.

(4) Machines in which the burner is first applied to a rapidly rotating workpiece and then the burner is removed and a quench is brought into action (Fig. 332).

Classes (1), (2), and (3) are similar in that heating and quenching are progressive, the heating rate being governed by the size of the heating burner and the rate of travel, and the intensity of quenching by the distance of the quench from the burner and the flow, or by the type of coolant employed, e.g. water, oil or air.

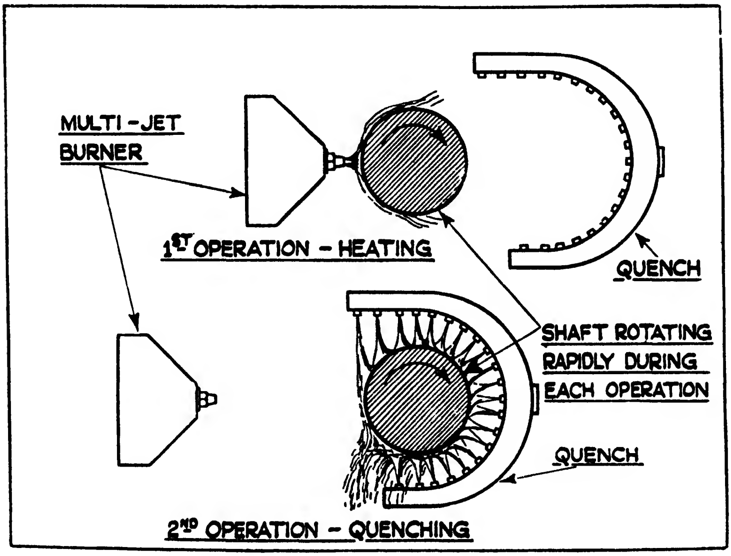


Fig. 332

Class (4) is a consecutive method, there being two separate operations, the heating up and the quench, the intensity of the latter depending upon the interval between the removal of the burner and the application of the quench. This method which is used for crankshaft hardening is known as the Shorter-Double-Duro.

The many applications of the process have resulted in a variety of machines being developed for particular work, but the four classes mentioned cover the principal of all the machines. Complicated castings requiring localised heat treatment can be dealt with since the mass of the casting is not heated. The burner is applied to a small area and then passes over the area under treatment being followed closely by the quenching unit. The mass of metal raised to the critical temperature at a given instant is therefore small compared with the total mass.

Structural change before hardening

When processes such as case hardening or nitralloying are applied to steels a chemical change occurs in the composition of the steel. Generally speaking steels between 0·09 % and 0·2 % carbon content must undergo chemical change before any surface hardness can be developed. In other hardening processes there is no change in the chemical composition, but there is a change in the physical condition, and steels of over 0·35 % carbon can be hardened by physical change. The Shorter process is applied to the latter group. When steels of this carbon content or over are heated to their critical temperature a solution of carbon in iron is formed sufficient to form a martensitic structure or case to a definite depth when quenched. With carbon steels 0·30 % carbon is the minimum for this condition. With alloy steels the carbon precipitation is delayed and a higher degree of hardness is obtained than on a plain carbon steel of similar carbon content. The change to the martensitic structure is not sharply defined, there being a gradual change from the martensitic case to the pearlitic core.

The depth of hardness is standardised at 0·1 to 0·125 in. The minimum depth is about 0·0625 in. and the maximum depth will depend upon the mass and quality of the material being hardened (Fig. 333).

Suitable materials for hardening

Where surface hardening only is required most carbon steels above 0·35 % carbon are suitable, and in general above this, the higher the carbon content the harder the surface. No advantage in hardness degree is obtained by using steels of above 0·6 % carbon, though in point of wear resistance some advantage may be found. Forged steel and cast iron can both be hardened, but in the case of cast iron it is desirable to have the combined carbon content about 0·5 %. Alloy steels of medium carbon content harden well and the inclusion of a small quantity of molybdenum in carbon steels improves its physical properties. The process should hardly be applied to steels which are treated to above 60–65 tons tensile for core.

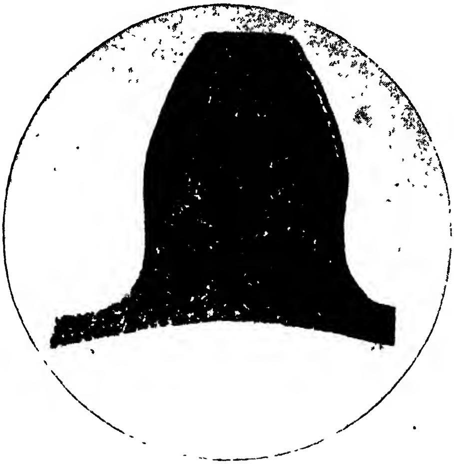


Fig. 333. Shorter hardened gear tooth

Treatment before hardening

The material should be given the correct heat treatment (normalising, annealing, or hardening and fully tempering) to relieve internal stresses. The process enables the steel to be treated so as to give the maximum toughness to the core with maximum hardness in the case.

Applications

Flanks of gear teeth (spur, helical, spiral bevel, worm wheels), gear rings, brake drums, tyres and axles, cams (of automatic machines, petrol and diesel engines, etc.), shafts, crankshaft journals are treated with excellent results (Figs. 334 and 335).

In some of the latest machines, as for example one designed for hardening the ends of engine tappet screws, the operation is completely automatic once the parts are fed into the hopper. Upon the operator depressing a lever a cam operated switch opens a duplex gas valve by means of a solenoid and a pilot jet

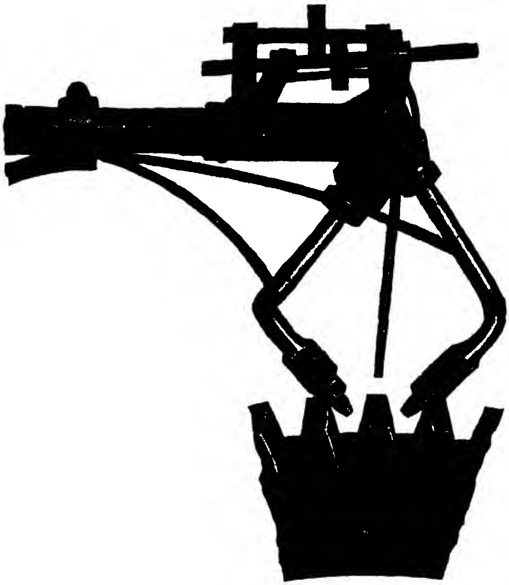


Fig. 334

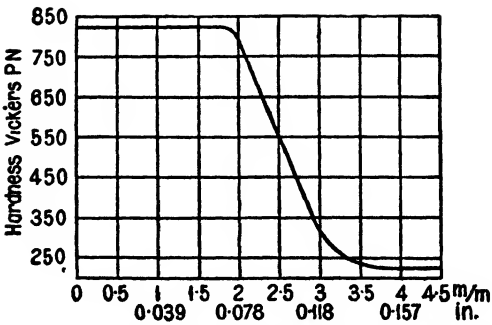


Fig. 335. Depth of hardness curve on carbon steel

lights the burner. At this instant a clock with a pointer attached registers the heating time. The pointer is set to give the exact time required to bring the surface to the critical temperature, and when the pointer has reached zero this condition has been reached and the burner is extinguished. The water quench is applied automatically and controlled in a similar manner to the burner by a clock.

Another recent development is in machine tool production. The beds of large machine tools are fabricated from mild steel plate. Carbon steel slides are welded on in position and are then hardened by the Process.

Hardness

Testing the hardness of the surface by the Brinell ball and heavy pressure may cause the hardened surface to be crushed into the softer core and the result will be misleading. The best method of testing is to use the Vickers Pyramid Hardness tester or the Firth Hardometer with a light load of 30 kg. The diamond-shaped indentations are measured with the microscope and the hardness number read off from a chart, this being the Vickers Pyramid Number (V.P.N.). The Scleroscope or the Autopunch are also frequently used. Fig. 335 shows the depth of hardness on carbon steel hardened by the Process.

Appendix

COSTING. TABLES. QUESTIONS ON WELDING SCIENCE, OXY-ACETYLENE WELDING AND ELECTRIC ARC WELDING

COSTING

Modern costing is a complicated process and entirely outside the scope of this book. The following notes are only intended to give the welder an outline of the methods by which costs are estimated and the factors influencing them.

Costing of production and repair work must be done on a scientific basis to ensure fair prices being charged to customers and to enable competition to be met, while paying fair wages, cost of materials, overhead charges, and allowing a fair margin of profit.

The operations involved in welding production or repair work may be divided into (1) Preparation, (2) Welding, (3) Finishing.

Preparation includes any or all of the following: dismantling, cleaning, machining, setting up in jigs or fixtures, preheating.

Welding simply includes the actual welding operation and the deslagging or descaling while welding.

Finishing includes heat treatment, stress relieving, cleaning, machining to final dimensions, erection, painting and packing.

In production work the question of preparation is very important, since for equal strength it is important to prepare the work in the most economical way. For example, a V or U butt joint may be used for a given piece of work, both being equally suitable. The U costs more to machine than the V, but takes less weld metal and can be welded more quickly; hence which joint shall be chosen? The cost of each type of weld is arrived at in the case of arc welding from the following data:

(1) Cost of preparation and setting up.
(2) Number of beads required.
(3) Current used (giving the cost of the energy used).
(4) Speed of welding in feet per minute, allowing for change of electrodes and fatigue of operator.
(5) Number of pounds of rod used per foot of weld.

The cost of these five items is added up and the total cost per foot of weld calculated for the particular joint and thickness being welded. Whichever type is the more economical can then be employed, and it is also evident that the type of electrode used will greatly affect the cost of the weld. In production work figures are available to the costing department which give the overall cost per foot run of all types and sizes of joints, and this enables estimates and costs of given jobs to be quickly worked out.

Job cards are often used, particularly in repair work, so that complete figures are available for costing. Under the three main headings given previously the job card is filled in by the workman or men concerned and indicates (1) time taken on any particular operation, (2) materials used (electrodes, filler rods, flux, etc. and cleaning materials), (3) current settings or blowpipe tips used.

Each workman fills up the card and initials it, and his time on these corresponds with that on his time sheet.

The cost card is made out from the job card. The workmen's time is charged at the correct rate of pay and this gives the cost of the labour for the job. The cost of (1) electrodes or filler rods and flux, (2) electrical power or oxygen and acetylene, (3) incidentals is calculated from the items entered on the card, and this, together with the labour charge, gives the total cost to the works of the job, say £x.

To this must be added a definite percentage (which will vary with the amount of machinery installed) for overhead charges (office staff, wear and tear of plant and depreciation, etc.). This is, say, £y, giving a total cost now of £$(x+y)$. A certain percentage of this is now added as clear profit (say £z) and the cost of the job to the customer is now £$x+y+z$. Any packing, carriage and freightage charges are then added to this unless previously arranged.

JOB CARD

JOB NO. .... DATE........................

INSTRUCTIONS

WORKMAN'S NAME	TIME IN HOURS
{Size of welding tip {Time burning {Cutter size {Time burning Mild steel rod Cast-iron rod Brazing rod Aluminium rod Copper rod and type Bronze rod and type Cleaning materials Pre-heating materials Cast-iron flux Aluminium flux Brazing flux Copper flux Extras Additional materials and sundries	

Date completed.............................. ....

Remarks

TYPICAL JOB CARD FOR OXY-ACETYLENE WELDING SHOP

COST CARD

DATE . . JOB NO.. ....

CUSTOMER'S NAME .... ADDRESS . ...

TYPE OF JOB . . . .

DATE COMPLETED . . ..

				TOTAL £ s. d.
Time Acetylene Oxygen Mild steel rod Cast-iron rod Brazing rod Aluminium rod Copper rod Bronze rod Cleaning materials Pre-heating materials Additional expenses		Cast-iron flux Aluminium flux Brazing flux Copper flux Extras		
			Total	

	£ s. d.
Total as above	
Overhead charges	
Total	
Profit	
Total	
Packing	
Freightage or postage	
Total	

TYPICAL COST CARD FOR OXY-ACETYLENE SHOP

Monel, approximately 2/3 nickel and 1/3 copper, is strong and tough, resistant to impact, fatigue, abrasion and corrosion, is easily fabricated and welded by oxy-acetylene process, metallic or carbon arc, and spot or seam process. In the annealed condition it has a tensile strength of 30 tons per sq. in. and hard drawn 60 tons per sq. in. It has a density of 8·82.

No heat treatment after welding is necessary and welded joints have high strength. It can be brazed, silver soldered or soft soldered almost as easily as brass or copper.

It is not corroded by water, petrol, oil, ethylglycol, salt water, etc., and is used for taps, sinks, petrol tanks, aircraft floats, inserted valve seats of cylinder heads, petrol pump parts, radiators and chemical vats and pipes of all types.

'*K*' *Monel*, a variety of Monel containing aluminium, is non-magnetic, and is welded in a similar manner to Monel. It is used for stressed parts near compasses such as aircraft strut wires, anchorages, and chains for actuating controls.

Inconel, 80% nickel, 13% chromium, remainder iron, has the resistance to corrosion of the nickel-chrome alloys.

Strength in annealed condition 35 tons per sq. in.; in hard drawn form 88 tons per sq. in. Density 8·55.

Resistance to corrosion is superior to that of nickel under oxidising and sulphurous conditions. Is durable at temperature of 1000° C. and retains its strength well at elevated temperatures.

It can be soft soldered, silver soldered, brazed, welded by oxy-acetylene or metallic arc processes and does not suffer from weld decay, so that heat treatment after welding is not necessary. It is non-magnetic and is used among other things for exhaust collector rings, manifolds, silencers, heaters of all types and for apparatus which must be corrosion and oxidation resistant at elevated temperatures.

EARTHING

If a person touches a 'live' or electrified metal conductor, a current will flow from this conductor, through the body to earth, since the conductor is at higher electrical pressure (or potential) than the earth. The shock that will be felt will depend upon how much current passes through the body and this in turn depends upon (1) the voltage of the conductor, (2) the resistance of the human body, (3) the contact resistance between body and earth.

The resistance of the human body varies considerably and may range from 8000 to 100,000 ohms, while the contact resistance between body and earth also has a wide range. Resistance to earth is high if a person is standing on a dry wooden floor and thus a low current would pass through the body if a live conductor is touched, while if a person is standing on a wet concrete floor and touches a live conductor with wet hands the resistance to earth is greatly lowered, a larger current would pass through the body and consequently a greater shock would be felt. It may be stated here that care should be taken to avoid shock when welding in damp situations especially with A.C. The operator can wear gloves and thus avoid touching the welding terminals with bare hands and he can stand on dry boards.

Most electrical apparatus, such as motors, switch gear, cables, etc., is mounted in, or surrounded by, a metal casing, and if this should come into contact, through any cause whatever, with the live conductors inside, it will then become electrified and a source of danger to anyone touching it.

To prevent this danger, *all* metal parts of electrical apparatus *must* be 'earthed', that is, must be connected with the general mass of the earth so that at all times there will be an immediate and safe discharge of energy. Good connection to earth is essential. If the connection is poor, its resistance is high and a current may follow an easier alternative path to earth through the human body if the live metal part is touched.

For earthing of electrical installations in houses, the lead pipes of the cold water system are very satisfactory since they are sufficient to carry to earth currents likely to be met with in this type of load.

Connection from the 'earthing system', as it is termed, to earth is made in various ways. Earth plates of cast iron or copper, 3 to 4 ft. square and buried 4 to 5 ft. deep, are in general use in this country. They are surrounded by coke and the area round copiously watered. Tubes, pipes, rods and strips of copper driven deep into the ground are used both in this country and in the U.S.A. and the area round them is frequently covered with common salt and again copiously watered.

It is evident that the 'earthing system' must be continuous throughout its length and must connect up and make good contact with every piece of metal likely to come into contact with live conductors. In factories and workshops the cables are carried in steel conduit and this forms the earthing system, the conduit making good contact with all the apparatus which it connects. Any metal part which may become live discharges to earth, through the continuous steel tubing system. To ensure that connection to earth is well made, extra wires of copper with terminal lugs attached are connected from the conduit to the metal parts of apparatus such as motors and switch gear, and ensures a good 'bond' in case of poor connection developing between the conduit and the metal casing of the apparatus. In the case of portable apparatus such as welding transformers, regulators, welding dynamos (motor driven), drills, hand lamps, etc., an extra earthing wire is run (sometimes included in the flexible tough rubber supply cable) and makes good connection from the metal parts of the portable apparatus to the main earthing system.

When steel wire or steel tape armoured cable is used, the wire or tape is utilised as the earthing system. In all cases extra wires are run whenever necessary to ensure good continuity with earth, and the whole continuous system is then well connected to the earth plate by copper cables.

In A.C. welding from a transformer it is usual to earth one of the welding supply terminals in addition to the metal parts of the transformer and regulator tanks. This protects the welder in event of a breakdown in the transformer causing the main supply pressure to come into contact with the welding supply.

TABLES

Homogeneous Copper Alloys

Type	Commercial Alloys	Composition
Copper tin	Wrought phosphor bronzes	Sn 3·5–5 % Sn 4·5–7 % Sn 7·5–9 % } Balance copper
Copper zinc brasses	Gilding metals Brazing brass Cartridge brass Baris brass	Cu 80–95 % Cu 78–82 % Cu 70 % Cu 63 % } Balance zinc
Copper aluminium	Aluminium bronze	Al 4–7 %. Balance copper
Copper silicon	Wrought silicon bronzes: Duronze Everdur Herculoy Olympic bronze P.M.G. metal	Cu 96 %, Si 3 % plus small additions of Al, Fe, Mn, Sn or Zn
Copper nickel	Cupro nickels denoted by nickel content, e.g. 20 % cupro nickel	Ni 15 % Ni 20 % Ni 25 % Ni 30 % } Balance copper
Copper nickel zinc	Nickel silvers denoted by nickel content, e.g. 20 % nickel silver	Cu 60–65 % Ni 10 % Ni 12 % Ni 15 % Ni 18 % Ni 20 % } Balance zinc or: Cu 55–60 % Ni 25 % No 30 % } Balance zinc

Duplex Copper Alloys

Type	Commercial Alloy	Composition
Copper tin	Cast phosphor bronze	Cu 89 %, Sn 10 % min., P 0·5 % min. Cu 85 %, Sn 15 %, P 0·1 %
Copper tin zinc	Admiralty gunmetal	Cu 88 %, Sn 10 %, Zn 2 %
Copper zinc brasses	Munz metal or yellow brass. Manganese bronze or brass	Cu 60 %, Zn 40 % Cu 58 %, Hardeners 4 %, Zn 38 % Cu 70 %, Hardeners 11 %, Zn 19 %
Copper aluminium	Aluminium bronze Aluminium nickel iron bronze	Cu 90 %, Al 9·5 % Cu 80 %, Al 10 %, Ni 5 %, Fe 5 %
Copper nickel zinc	Nickel brass or bronze	Cu 45 %, Ni 10 %, Zn 45 %

Approximate Values of Tensile Strength of Rolled Steels with Varying Carbon Content

% Carbon	Tensile Strength in tons per sq. in.	% Carbon	Tensile Strength in tons per sq. in.
0·12	25	0·29	37½
0·13	26	0·30	37½
0·14	27	0·31	37½
0·15	28	0·32	38
0·16	29	0·33	38
0·17	30	0·34	38½
0·18	31	0·35	38½
0·19	32	0·36	39
0·20	33	0·37	39
0·21	33½	0·38	39
0·22	34	0·39	39½
0·23	34½	0·40	39½
0·24	35¼	0·41	40
0·25	36	0·42	40
0·26	37	0·43	40½
0·27	37	0·44	40½
0·28	37	0·45	41

Wrought Magnesium Alloys. Elektron

Type	Used for	Composition	Specific Gravity	Ultimate Strength tons per sq. in.
		Not more than		
AZM	Stressed parts and stiffeners and struts	Aluminium 11 % Zinc 1·5 % Manganese 1 % Impurities 1·5 % Remainder magnesium	1·82	18–22
AM503	Cowlings, fairings, linings, fuel and oil tanks, rudders. Welded easily	Manganese 2·5 % Aluminium 0·2 % Zinc 0·2 % Copper 0·2 % Silicon 0·4 % Impurities 0·5 % Remainder magnesium	1·82	12–17
A4	Sheets and strips	Aluminium 9·0 % Zinc 1·5 % Manganese 1·0 % Copper 0·3 % Silicon 0·4 % Remainder magnesium		

Metal or Alloy	Composition
Cast iron: White	97 % Fe, 3 % C
Grey	97 % Fe, 3 % C, 2 % Si
Ferro-manganese	40–80 % Mn, 5–8 % C. Remainder iron
Ferro-chrome	60–68 % Cr, 2–5 % C. Remainder iron
Invar	64 % Fe, 36 % Ni
Inconel	80 % Ni, 12–14 % Cr. Remainder iron
Magnalium	90 % Al, 10 % Mg
Monel	68 % Ni, 29 % Cu, 1·2 % Fe. Remainder manganese, silicon, carbon and sulphur

Elements: their Symbols, Atomic Weights and Melting Points

Element	Symbol	Atomic Weight	Melting Point, ° C.
Aluminium	Al	26·97	658·7
Antimony	Sb	121·77	630
Argon	A	39·94	−188
Arsenic	As	74·96	850
Barium	Ba	137·36	850
Beryllium	Be	9·02	1280
Bismuth	Bi	209·00	271
Boron	B	10·82	2200–2500
Bromine	Br	79·91	−7·3
Cadmium	Cd	112·41	320·9
Caesium	Cs	132·81	26
Calcium	Ca	40·07	810·0
Carbon	C	12·00	3600
Cerium	Ce	140·13	635
Chlorine	Cl	35·45	−101·5
Chromium	Cr	52·01	1615
Cobalt	Co	58·94	1480
Columbium	Cb	93·1	1700
Copper	Cu	63·57	1083
Erbium	Er	167·64	—
Fluorine	F	19·0	−223
Gadinolium	Gd	157·26	—
Gallium	Ga	69·72	30·1
Germanium	Ge	72·60	958
Gold	Au	197·2	1063
Helium	He	4·00	−272
Hydrogen	H	1·0078	−259
Indium	In	114·8	155
Iodine	I	126·932	113·5
Iridium	Ir	193·1	2350
Iron	Fe	55·84	1530
Krypton	Kr	83·7	−169
Lanthanum	La	138·90	810
Lead	Pb	207·22	327·4
Lithium	Li	6·94	186
Magnesium	Mg	24·32	651
Manganese	Mn	54·93	1230
Mercury	Hg	200·61	−38·87
Molybdenum	Mo	96	2620

ELEMENTS: THEIR SYMBOLS, ATOMIC WEIGHTS AND MELTING POINTS (*contd*)

ELEMENT	SYMBOL	ATOMIC WEIGHT	MELTING POINT, ° C.
Neodymium	Nd	144·27	840
Neon	Ne	20·18	−253
Nickel	Ni	58·69	1452
Nitrogen	N	14·008	−210
Osmium	Os	190·8	2700
Oxygen	O	16·000	−218
Palladium	Pd	106·7	1549
Phosphorus	P	31·02	44
Platinum	Pt	195·23	1755
Potassium	K	39·1	62·3
Praseodymium	Pr	140·92	940
Radium	Ra	225·97	700
Rhodium	Rh	102·91	1950
Rubidium	Rb	85·44	38
Ruthenium	Ru	101·7	2450
Samarium	Sm	150·43	1300–1400
Scandium	Sc	45·10	1200
Selenium	Se	79·2	217–220
Silicon	Si	28·06	1420
Silver	Ag	107·88	960·5
Sodium	Na	22·997	97·5
Strontium	Sr	87·63	800
Sulphur	S	32·06	112·8
Tantalum	Ta	181·5	2900
Tellurium	Te	127·5	452
Terbium	Tb	159·2	—
Thallium	Tl	204·39	302
Thorium	Th	232·12	1700
Tin	Sn	118·70	231·9
Titanium	Ti	47·9	1800
Tungsten (Wolfram)	W	184·0	3400
Uranium	U	238·14	1850
Vanadium	V	50·96	1720
Xenon	Xe	131·3	−140
Ytterbium	Yb	173·6	—
Yttrium	Y	88·92	1490
Zinc	Zn	65·38	419·4
Zirconium	Zr	91·22	1700

Gauge Table. Imperial Standard

No.	Size in Inches	Size in Millimetres
0	0·324	8·229
1	0·300	7·620
2	0·276	7·010
3	0·252	6·401
4	0·232	5·893
5	0·212	5·385
6	0·192	4·877
7	0·176	4·470
8	0·160	4·064
9	0·144	3·658
10	0·128 approx. $\frac{1}{8}$ in.	3·251
11	0·116	2·946
12	0·104	2·642
13	0·092	2·337
14	0·080	2·032
15	0·072	1·829
16	0·064 approx. $\frac{1}{16}$ in.	1·626
17	0·056	1·422
18	0·048	1·219
19	0·040	1·016
20	0·036	0·914
21	0·032 approx. $\frac{1}{32}$ in.	0·813
22	0·028	0·711
23	0·024	0·610
24	0·022	0·559
25	0·020	0·508
26	0·018	0·457
27	0·0164	0·4166
28	0·0148	0·3759
29	0·0136	0·3454
30	0·0124	0·315

Conversion Tables

To Convert	To	Multiply by
Atmospheres	Pounds per sq. in.	14·7
British Thermal Units	Calories	0·252
Calories	British Thermal Units	3·97
Cubic centimetres	Cubic inches	0·061
Cubic inches	Cubic centimetres	16·39
Feet	Metres	0·305
Feet per sec.	Miles per hr.	0·682
Gallons	Litres	4·546
Imperial gallons	U.S. gallons	1·205
Inches	Metres	0·254
Kilogrammes	Pounds	2·205
Kilogrammes per sq. cm.	Pounds per sq. in.	14·22
Kilometres	Miles	0·621
Pounds	Kilogrammes	0·454
Pounds per sq. in.	Atmospheres	0·068
Pounds per sq. in.	Kilogrammes per sq. cm.	0·0703
Litres	Cubic inches	61·0
Litres	Gallons	0·220
Miles	Kilometres	1·609
Miles per hr.	Metres per sec.	0·447
U.S. gallons	Imperial gallons	0·830

Carbon Arc Welding

Carbon size	Maximum current
$\frac{5}{32}''$	50
$\frac{3}{16}''$	100
$\frac{1}{4}''$	200
$\frac{5}{16}''$	350

Table giving some of the Chief Types of Oxy-acetylene Welding Rods available for Welding Carbon and Alloy Steels

(See pp. 183–187 for technique)

Rod	Description and use
Low carbon steel	A general purpose rod for mild steel. Easily filed and machined. Deposit can be case hardened
High-tensile steel	Gives a machinable deposit of greater tensile strength than the previous rod. Can be used instead of the above wherever greater strength is required
High carbon steel	Gives a deposit which is machinable as deposited, but which can be heat treated to give a hard abrasion-resisting surface. When used for welding broken parts, these should be of high carbon steel, and heat treatment given after welding
High nickel steel (3½–4%)	Produces a machinable deposit with good wear-resisting properties. Suitable for building up teeth in gear and chain wheels, splines and keyways in shafts, etc.
Wear-resisting steel (12–14% manganese)	Gives a dense tough unmachinable deposit which must be ground or forged into shape, and can be heat treated. Useful for building up worn sliding surfaces, cam profiles, teeth on excavators, tracks, etc.
Stellite	For hard surfacing and wear and abrasion-resisting surfaces (see p. 186)
Chrome-molybdenum steel (creep resisting)	High-tensile alloy steel deposit for pressure vessels and high-pressure steam pipes, etc. Rod should match the analysis of the parent metal
Chrome-vanadium steel	A high-tensile alloy rod for very highly stressed parts
Tool steel	Suitable for making cutting tools by tipping the ends of mild or low carbon steel shanks
Stainless steel	Decay proof. Rod should match the analysis of the parent metal (pp. 182–183)

Table giving some of the Chief Types of Arc Welding Electrodes available for Welding Alloy Steels

Electrode	Description and uses
Alloy mild steel	Has a higher tensile strength than mild steel and better hot forging properties. For building up and reinforcing shafts, keyways, welding rails to girders, etc.
Austenitic steel	Tensile strength 40–45 tons per sq. in. For alloy high-tensile steels where preheating cannot be used to prevent cracks forming in the hardened zone of the parent plate near the weld
Mild steel	Suitable for high-tensile structural steels from 37–44 tons per sq. in. (in addition to the usual mild steel applications). Since rapid cooling of the weld metal causes the junction of weld and parent plate to crack on contraction, the maximum amount of weld metal should be laid down especially on the first run, with a large gauge electrode (see pp. 310–311)
High-tensile steel	For high-tensile steels, low carbon nickel steels, structural silicon steels, and all low-alloy steels under 0·3% carbon. Weld has a strength up to 44 tons per sq. in. On high carbon alloy steels, preheating to 250° C. must be carried out to avoid cracks in the hardened zone of the parent plate
Carbon steel	For building up worn carbon steel parts such as steel rails, cross-overs, gears, etc. Electrodes are available giving deposits of Brinell hardness of 220–250 and 320–450
Manganese steel, 12–14% manganese	Gives a 12–14% manganese steel deposit which work hardens similar to the parent manganese casting. Used for building up worn parts of crushing machinery, dredger bucket lips, rail crossings, caterpillar tracks, etc.
Austenitic manganese	An austenitic manganese-nickel-molybdenum electrode for welding up cracks and fractures in manganese castings, and suitable for use as a layer between the 12–14% manganese electrode and the parent casting, since no brittle zone is thereby formed at the junction (see pp. 301–302)
High-speed steel	Used for depositing a high-speed steel cutting edge on tools. The weld metal can be heat treated similar to high-speed steel, and the deposit also laid on a mild steel shank (see p. 303)

Table giving some of the Chief Types of Arc Welding Electrodes available for Welding Alloy Steels (*continued*)

Electrode	Description and uses
Wear resisting	Electrodes giving a hard dense tough surface on carbon steel (Brinell hardness 500), and suitable for cutting and shear blades, impellers, rolls, crusher jaws, etc.
Shock and abrasion resisting	Type 1. Gives an air-hardening deposit of great hardness and toughness on non-austenitic steels. Deposit will stand shock and abrasion Type 2. Can be used where abrasion is severe but little shock encountered, to build up straight carbon steel, low alloy steel, or high manganese steel surfaces with good results
Stellite	Is supplied in various grades (p. 185), and can be used for tipping tool steel, and building up wear and abrasion resisting surfaces (see pp. 304–305)
High nickel chrome	Gives a high nickel chrome deposit suitable for welds on high carbon and alloy steel. Welds have a high corrosion resistance, tensile strength and ductility; are free from porosity and are almost non-magnetic. Tensile strength 43–47 tons per sq. in. Suitable for welding non-magnetic inserts into electrical equipment, for corrosion-resisting welds in chemical plant, and for high-pressure joint faces free from porosity defects after machining
Stainless iron and stainless steels	A range of electrodes is available suitable for welding any type from low carbon stainless iron (carbon 0·1%, chrome 14%) to the austenitic steels containing titanium, columbium, tungsten or molybdenum, in addition to nickel, chromium, and carbon. When the analysis of the parent metal is known a suitable electrode can be chosen (pp. 305–306)

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PRACTICAL TESTS

The welder should have carried out, during his course of instruction at a Technical Institute, tests 1, 2 and 3 and at least three of the other tests by the electric arc process for the examination in arc welding, and tests 1, 2 and 3 below and at least three of the other tests by the oxy-acetylene process for the examination in oxy-acetylene welding. A candidate entering for both oxy-acetylene and electric arc welding must have carried out successfully tests 1, 2 and 3 and at least six other tests from the remaining tests 4 to 12, three by each process.

1. The welding on the flat from one side of an open single V butt joint with full chamfer in two prepared mild steel plates, approximately square, from 4 to 6 in. long, ¼ in. thick. (See British Standards Institution Specification No. 499–1933, p. 23, Fig. 93.)

2. The welding in a vertical position of two prepared mild steel plates, approximately square, from 4 to 6 in. long, ¼ in. thick, at right angles to each other to form a close or open joint. (See B.S.I. Specification No. 499–1933, p. 53, Figs. 93, 95.)

3. The welding from one side of either a close square or a close single-bevel T in mild steel plate, from 4 to 6 in. long, ¼ in. thick. (See B.S.I. Specification No. 499–1933, p. 47, Fig. 71, and p. 49, Fig. 75.)

The welds 1, 2 and 3, after visual inspection, to be bent from both sides and broken, the character of the weld to be carefully examined and passed only if entirely satisfactory.

4. The butt welding of two short lengths of 2 in. steam pipe, each bevelled at one end, to be in true alignment after welding. It is desirable that a hydraulic test should be applied to the welded pipe.

5. The cutting of a suitable hole in the middle of a short length of a 2 in. steam pipe, and the welding of a short ¾ in. steam pipe branch into it at right angles.

6. The welding of a flange to one end of a 2 in. diameter steam pipe, the end of the pipe to be flush with the face of the flange, and a fillet weld to be made to connect the back of the flange with the pipe.

7. The butt weld of two 6 in. lengths of mild steel plate, 22 gauge.

8. The welding together, without the use of a filter rod, of two 6 in. lengths of mild steel sheet, 22 gauge, the edges of which are turned up at right angles about $\frac{1}{16}$ in. and the turned edges to be welded.

9. The welding of two pieces of cast-iron plate not less than $\frac{1}{4}$ in. thick by a close single V butt joint not less than 4 in. long. (See B.S.I. Specification No. 499–1933, p. 41, Fig. 59.)

10. The welding on the flat of two prepared 8 gauge copper or aluminium plates 6 in. long.

11. The welding together of the ends of two bars of mild steel, each $\frac{1}{2}$ in. in diameter and about 4 in. long, by a butt double V joint of approximately the same diameter as the bars.

12. The making of an overhead fillet-welded lap joint in $\frac{1}{4}$ in. mild steel plates, approximately 6 in. square with an overlap of 2 in.

The finished test pieces 4 to 12 to be visually inspected, including the inside of the pipes, and to be carefully examined for correct penetration, blowholes, and slag inclusions.

QUESTIONS ON WELDING SCIENCE

1. Give some reasons for concluding that air is a mixture of gases. Explain the nature of combustion.

2. What are the chief physical properties of the compounds of oxygen with each of the following elements: carbon, hydrogen, iron and aluminium?

3. How is the 'Centigrade' scale of temperature established? Describe one method of measuring a temperature above 500° C.

4. Explain carefully how you would determine the melting point of a substance which melts between 150° C. and 300° C.

5. What do you understand by the terms 'crystalline' and 'amorphous'? Illustrate your answer by reference to any materials you have used in welding practice.

6. In what units are 'stress' and 'strain' reported in a tensile test? What constant for the material may be obtained from these values and up to what point in the test is this constant true?

7. Draw a sketch in perspective, also a plan and end elevation, of the set-up of each of the following joints in $\frac{3}{8}$ in. mild steel plates:

(*a*) A double vee butt joint.
(*b*) An inside corner weld.

8. A plain carbon mild steel may have the following analysis: iron 99·10 %, carbon 0·20 %, manganese 0·50 %, silicon 0·10 %, phosphorus 0·05 %.

(*a*) Indicate, briefly, in what form each element is present in the steel.
(*b*) How are the properties of iron affected by these elements?

9. The micro-section of a 0·30 % carbon steel in the normalised condition shows that two constituents are present. Name and describe these constituents. Specify, giving your reasons, a heat-treatment process which will modify the structure so as to render the steel as hard as possible.

10. Describe the preparation of (i) a macro- and (ii) a micro-section of a mild steel weld, showing clearly, with the aid of sketches, what information is obtained from each.

11. How may evidence that oxidation has taken place during welding appear in the finished weld? State the probable effects of such oxidation on the mechanical properties of the weld.

12. (*a*) Describe a fatigue test, and indicate how a value for the fatigue limit of a material is obtained.

(*b*) Give your opinion, with reasons, on the suitability of the fatigue test as a guide to the welding engineer.

13. What are the chief characteristics of the nickel-chromium alloy steels? Refer to the possibilities of welding as applied to them.

14. Give the approximate compositions of two different types of brasses and indicate their chief mechanical properties.

15. Describe briefly any three of the following systems of welding: (*a*) metallic arc, (*b*) automatic arc, (*c*) carbon arc, (*d*) resistance, (*e*) atomic hydrogen, (*f*) thermit, (*g*) gas. Indicate a typical application of each of the three you choose.

16. (*a*) Name and describe the products which are formed when air is passed over red-hot copper.

(*b*) What do you understand by the term 'oxidation'? Why is oxygen used in conjunction with welding gases?

17. Define the term 'coefficient of linear expansion'. Why is an understanding of the phenomenon of expansion of assistance to the practical welder?

18. (*a*) What is the 'thermal conductivity' of a substance? How would you compare the thermal conductivities of two metals?

(*b*) Draw a cooling curve of a metal or alloy and explain how the shape of the curve is affected by the latent heat. Indicate how this curve may be used for the determination of the melting point.

19. (*a*) A certain weld metal gives the following mechanical test results:

Maximum stress ...	28 tons per sq. in.
Elongation	20 % on 4 in.

Describe how these figures have been obtained, and indicate what properties of the material they represent.

(*b*) Explain carefully why brittleness in structural welds is to be avoided. What tests may be carried out on weld metal in order to ensure that it is free from this defect?

20. Sketch, approximately to scale, a plan and end elevation of each of three types of welded joints, in $\frac{3}{4}$ in. boiler plate. Give the necessary dimensions on each view.

21. What is the effect of 'cold work' on mild steel? Explain how a condition of 'cold work' may be set up due to a welding operation.

22. (*a*) What are the main purposes of the coating on a metallic arc electrode?

(*b*) Explain when, and for what purposes, fluxes are used in gas welding.

23. What are the conditions which decide whether a cast iron will be 'white' or 'grey'? How are these conditions controlled in welding practice?

24. Discuss, from the point of view of the structure of the weld and the surrounding metal, the problems of welding a steel containing 1 % carbon and 12 % manganese.

25. Distinguish carefully between overheated and 'burnt' steel, particularly with a view to its being put into service.

26. A plain carbon steel containing 0·3 % carbon is hardened when it is quenched in water from above its critical temperature. What is this critical temperature? What changes of structure occur during the quenching operation?

27. (*a*) Discuss the effect of the presence of oxygen and arsenic on the weldability of copper.

(*b*) Discuss the heat treatment of an alloy containing approximately 89% copper and 11% aluminium.

QUESTIONS ON OXY-ACETYLENE WELDING

1. What are the chief difficulties encountered in the welding of aluminium and its alloys? How are these difficulties overcome?

2. In a steel tube plate of a boiler, cracks have developed at the points marked 1, 2, 3 and 4 on the diagram. Describe in detail your procedure for repairing the tube plate, in order to make this serviceable for new tubes of the same size.

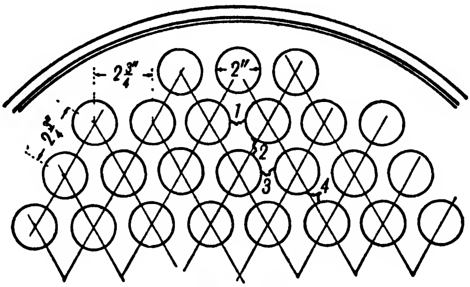


PLATE ⅝" THICK
TUBE PLATE MUST REMAIN VERTICAL DURING WELDING
BOTH SIDES CAN BE GOT AT

3. What is a flux and what is its purpose? Give reasons why a flux is, or is not, used in the welding of the following metals: (*a*) cast iron, (*b*) nickel, (*c*) mild steel, (*d*) copper, (*e*) brass, (*f*) stainless steel.

4. A tube 8 ft. long by 4 ft. outside diameter is to be fabricated from three ⅜ in. mild steel plates rolled to a 2 ft. radius, necessitating three longitudinal welds. It is most important that when completed it should be circular throughout its length. Describe in detail how you would prepare the work and carry out the welding.

5. What is understood by, and what are the advantages of, vertical upward welding in the making of butt-welded seams? How is the operation performed on $\frac{3}{16}$ in. plate and $\frac{3}{4}$ in. plate?

6. (*a*) Why is it important to get complete penetration in making a butt weld?

(*b*) How can a small bead on the underside of this type of weld best be obtained?

(*c*) Is it satisfactory to compensate for lack of penetration by reinforcement on the weld face?

Give reasons for your answers.

7. Describe, with the aid of sketches, the purpose and functioning of a hydraulic safety valve (back-pressure valve) on a low-pressure acetylene installation. What is the comparable safety device when high pressure acetylene or dissolved acetylene is used?

8. In the repair of iron castings:

(*a*) What is meant by 'preheating' and why is it employed?

(*b*) How would you execute the work and cool a preheated casting? Give reasons.

9. When steel is cut with the blowpipe:

(*a*) What gases can be used in the process and what are their merits and demerits?

(*b*) What causes the severance of the metal?

10. If you were in charge of a welding shop, describe in detail how you would have the welding carried out on a longitudinal seam in a copper tube 4 ft. diameter by 5 ft. long by $\frac{3}{8}$ in. thick.

11. (*a*) What are the chief impurities in acetylene?

(*b*) How can these impurities be removed?

(*c*) If not removed, what are their effects on a mild steel weld?

12. Describe in detail how you would make a fillet weld on mild steel plate $\frac{5}{16}$ in. thick. Give reasons for the method you employ.

13. (*a*) How would you weld 20 S.W.G. sheet aluminium?

(*b*) What are the chief difficulties experienced in welding stainless steel?

(*c*) What are the most common defects found in a copper weld when it is tested?

14. Describe a simple workshop method of testing whether a butt-welded joint in mild steel is ductile.

Give details of such a test that a good weld should withstand when made in (*a*) 16 S.W.G. plate, and (*b*) in $\frac{3}{8}$ in. plate.

15. How would you weld:

(*a*) A broken malleable cast-iron lorry brake lever?

(*b*) A cast-iron hydraulic ram cylinder weighing 15 cwt., cracked in the stuffing box longitudinally for 6 in. where the metal is 2 in. thick, as shown in Fig. 1?

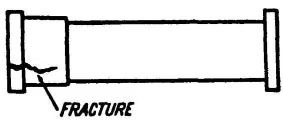


Fig. 1

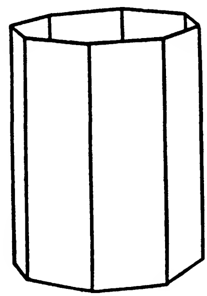


Fig. 2

16. An open-top welded tank, 10 ft. diameter by 12 ft. deep, of $\frac{1}{4}$ in. mild steel plate, is to be built as shown in Fig. 2. Describe the welding procedure you would employ.

17. Describe and make a sectional sketch of what you consider to be a good generator for producing acetylene for welding.

18. Why is a flux unnecessary in welding mild steel but essential in welding aluminium and its alloys?

What tests would you carry out on the weld to distinguish a good aluminium flux from a bad aluminium flux?

19. A 15 in. diameter mild steel tube has to be welded to the end of an existing tube fixed in position in a trench; the tube wall is $\frac{5}{16}$ in. thick in each case. How would you execute this work? You may assume that your oxygen and acetylene supply is satisfactory.

20. (*a*) Discuss the properties of the oxy-acetylene flame which make it more suitable than either oxy-hydrogen or oxy-coal gas for welding ferrous metals.

(*b*) Describe briefly the difference between the welding and the cutting blowpipe.

21. (*a*) What is meant by hard-facing?

(*b*) How is it done?

(*c*) Give two typical examples of its application and state the advantages of its use in each case.

22. Describe briefly the dangers attendant upon the use of acetylene gas for welding and the precautions which are advised in the Home Office Memorandum 1704 on Oxy-Acetylene Welding.

23. Explain and illustrate by sketches the terms given below, and state the uses for which each is suited:

(*a*) A 'rightward' weld.

(*b*) An upward vertical weld, single-operator technique.

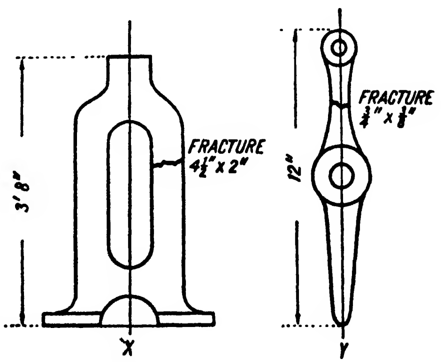
(*c*) An upward vertical weld, two-operator technique.

24. Describe the process known as 'bronze welding' when applied to the joining of ferrous metals. State the classes of work for which it is advantageous and give reasons.

25. The fractures indicated in the grey iron castings *X* and *Y* are to be repaired. In order to make a sound weld in each case, state:

(*a*) The fundamental difference in the methods which can be employed in the two cases.

(*b*) The size of filling rod that you would use in each case.



(*c*) The chief difference in composition between the casting and the filling rod.

QUESTIONS ON ELECTRIC ARC WELDING

1. (*a*) Describe the relative merits of alternating current and direct current supplies for arc welding.

(*b*) Show by means of a sketch the connections between a supply of 440 volts A.C. and two welding points.

(*c*) Which type of plant would you use for welding where electric current supply is not available?

2. To what is distortion of welded work due?

Describe how this can be reduced to a minimum by methods of welding in the case of:

(*a*) Butt weld between two pieces of steel plate each 12 ft. square and $\frac{1}{4}$ in. thick.

(*b*) Reinforcing a worn shaft.

(*c*) A double vee butt joint between two pieces of steel bar each 2 in. thick, 4 in. wide and 4 ft. long.

3. What is meant by:

(*a*) Arc p.d. (potential difference)?

(*b*) Penetration: (i) in a fillet weld, (ii) in a butt weld?

(*c*) Preheating?

(*d*) Undercut?

4. (*a*) Why are flux coverings used on electrodes?

(*b*) Compare the mechanical properties of welds made with bare wire and those made with flux-covered electrodes.

5. With the aid of sketches, describe how you would weld, in the case of mild steel:

(*a*) A double vee butt joint in 1 in. thick plate.

(*b*) A corner butt joint in $\frac{3}{8}$ in. thick plate.

(*c*) A pipe flange joint.

(*d*) A joggled lap weld in $\frac{1}{8}$ in. thick plate.

6. (*a*) Describe workshop and laboratory tests that you would apply to prove whether the weld metal in a butt joint in a $\frac{1}{2}$ in. thick plate was ductile or not.

(*b*) Specify the tensile strength and elongation for an all-weld metal for connecting mild steel plates of a pressure vessel.

7. (*a*) Mention three different kinds of alloy steels and explain the methods of welding them, stating the types of electrodes to be used.

(*b*) What is meant by 'weld decay' in stainless steel and how is it prevented?

8. (*a*) Indicate a fusion method used for cutting steel plate prior to arc welding, and the precautions to be taken with regard to welding the cut edge of the plate.

(*b*) Describe briefly the atomic hydrogen method of arc welding.

9. Given a 400 volts A.C. supply:

(*a*) Which type of welding set would you instal?

(*b*) Give a list of the accessories that would be required and explain the use of each.

(*c*) Give a diagram showing the connections of the welding circuit.

10. Explain what is meant by the following terms, and illustrate your remarks by sketches:

(*a*) Arc crater.

(*b*) Weld penetration.

(*c*) Leg length of a fillet weld.

(*d*) Double vee butt weld.

(*e*) Step-back method of welding.

(*f*) Undercut.

11. If two $\frac{3}{8}$ in. thick plates, each 18 by 18 in. and with a central butt weld, were submitted to you for examination and you were advised that the welds were made by different types of electrodes, which methods of examination would you use and which tests employ to indicate the relative merits of the two welds? Give reasons.

12. What is meant by:

(*a*) Preheating?

(*b*) Stress relieving?

(*c*) Normalising?

Indicate, with reasons, which of these treatments you would use in connection with:

(i) Welding a high-pressure boiler drum.

(ii) Welding a thin-walled cast-iron structure.

(iii) Welding a construction made from high carbon chrome steel.

13. Describe briefly the safety methods advised in the Home Office Memorandum on Electric Arc Welding.

14. Describe in detail, with sketches, the method you would adopt in making:

(*a*) A butt weld in mild steel plate $1\frac{1}{2}$ in. thick.

(*b*) A full section vertical corner butt weld in mild steel $\frac{3}{8}$ in. thick.

Give the sizes of electrodes, number of runs and the current used for each.

15. Give the composition of the following types of metal and describe the method of butt welding joints in each case, stating the types and sizes of electrodes to be used:

(*a*) Austenitic stainless steel plate $\frac{1}{8}$ in. thick.

(*b*) Malleable iron casting $\frac{1}{2}$ in. thick.

(*c*) Boiler plate $\frac{3}{8}$ in. thick.

(*d*) Monel metal $\frac{1}{4}$ in. thick.

16. (*a*) Describe the relative merits of making joints by riveting and electric arc welding.

(*b*) Describe the relative merits of electric arc welding with the use of (i) bare wire, (ii) covered electrodes.

17. A works requires to instal equipment to supply electric power to six adjacent welding bays. Electric power at 400 volts A.C. single phase is available. Describe, with the aid of sketches, the equipment required to provide the bays with suitable current conditions for welding with different sizes of electrodes. Make a sketch of a cable connection.

18. You are required to construct a flat circular steel partition 10 ft. in diameter by joining together steel plates each 3 ft. wide by 5 ft. deep by $\frac{1}{4}$ in. thick. Show, by means of a sketch, the order in which you would weld the joints to prevent distortion, and the types of joints to be used.

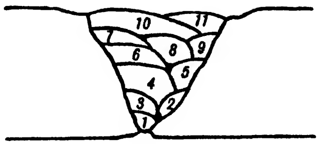
How would you obtain the final shape for the partition or bulkhead?

19. What are the advantages of using flux-covered electrodes as compared with the use of bare wire, with regard to:

(*a*) Welding with A.C. and D.C.?

(*b*) Mechanical properties and resistance to corrosion of the weld metal?

20. A section through a butt weld, in 1 in. thick plate, is as shown in the sketch:



State any defects in the weld and describe how they may have been caused.

Also describe any better technique to obtain an improved weld.

21. Describe a suitable method of repairing by welding each of the following:

(*a*) A transverse fracture in a cast-iron pipe 6 in. in diameter and ½ in. thick.

(*b*) A cracked spoke in a locomotive driving wheel (cast steel).

(*c*) A worn bearing on a lorry axle.

22. What recommendations are given in the Home Office Memorandum on Electric Arc Welding with regard to:

(*a*) Design of electrode holders?

(*b*) Installation of alternating current welding equipment?

(*c*) The welding supply to be used outdoors when the welder is operating on staging?

23. (*a*) Describe the test or tests you would employ to estimate the ductility of the weld metal from a given type of electrode.

(*b*) Describe briefly any methods put forward for the non-destructive testing of welds, and indicate whether any of these are of any practical value.

24. Give the composition of the most suitable deposited weld metal in each of the following cases, and describe the method of welding:

(*a*) 12–14% manganese steel }
(*b*) 0·4% carbon steel } Butt joints and reinforcing worn parts.

(*c*) Malleable iron }
(*d*) Austenitic stainless steel } Butt joints.

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