INTRODUCTION

Our business is welding and we offer this handbook to both the handyman and industry in general, in an earnest endeavour to assist all those engaged in electric arc welding.

We have not covered all phases of welding, but present briefly, the basic facts of the arc welding process and techniques.

LIST OF CONTENTS

<table>
<thead>
<tr>
<th></th>
<th>Page No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc Welding - The Process</td>
<td>2</td>
</tr>
<tr>
<td>Welding Equipment</td>
<td>4</td>
</tr>
<tr>
<td>The Welding Electrode</td>
<td>5</td>
</tr>
<tr>
<td>The Welding Current</td>
<td>7</td>
</tr>
<tr>
<td>Welding Technique</td>
<td>9</td>
</tr>
<tr>
<td>(A word to beginners)</td>
<td></td>
</tr>
</tbody>
</table>

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ARC WELDING
THE PROCESS

FUSION WELDING is really a melting and casting process in miniature, the various components of the welding process (base metal, weld metal slag, etc) forming the crucible and contents of a tiny electric furnace.

The electric arc, with a temperature of the order of 6,000°C, is a concentrated and efficient source of heat. This heat is utilised in the metal arc welding process by employing a flux-coated electrode to provide filler metal. The electrode and parent metal act as poles of the arc, the core wire of the electrode melting and being transferred across the arc to coalesce with the molten parent metal and form a bond which in most cases, is stronger than the parent metal. The flux covering melts more slowly than the core wire and a cup is formed at the electrode tip which assists in directing the molten droplets to the required spot.

The weld metal itself, as deposited, has a cast structure, its composition is determined by the core wire and coating of the electrode, and by the amount of pick-up of parent metal during welding. For example, a deposit of alloy steel, say, stainless steel on mild steel, no longer has just the properties expected of that alloy, due to dilution with the parent metal. This effect, in many cases, is not important, but, if desired, it may be eliminated by using multi-layer welds.

Welding on materials that have been strengthened by heat-treatment or cold-working generally creates a zone of lower strength along the weld boundary. This may not affect the serviceability of the welded joint, but sometimes it is necessary to restore this strength by further heat-treatment or cold-work.

ADVANTAGES OF WELDING:
Some of the advantages that welding has over riveting and casting methods of assembly are as follows:

1. Welding is usually a cheaper process than riveting for any particular joint, and the joint can often be made much more quickly.

2. It gives a stronger joint and permits the use of less material, thus reducing the weight and cost of the structure.

3. Weld seams are normally pressure tight, and do not need caulking as do riveted joints. Joints are smooth, which is important in many applications. For example, painting is much easier on welded joints, and turbulence in pipes is reduced.
4. Designs not practicable for riveting may be constructed by welding.

5. Plate preparation for welding is generally cheaper than for riveting.

6. Labour necessary can often be cut to less than one-third of that necessary for riveting.

7. Welding is not as noisy as riveting, and permits building and alterations to proceed with the least disturbance to occupants.

8. Welding is more versatile than casting; changes can be made quickly without having to produce a new pattern.

9. Rolled section is often cheaper than cast section, and fabrication by welding of rolled section may be cheaper than casting the same article.

10. No storage of patterns is necessary for welding, as with castings.

11. Articles of consistent and known quality can be produced by welding, whereas castings may have external or hidden internal flaws causing their rejection, or failure in service.
WELDING EQUIPMENT

BESIDES THE welding machines and suitable electrodes, the accessories necessary for a welder are:

1. A substantial work table with a fairly heavy mild steel plate for a top.

2. **Leads.** Two are required — one from the machine to the electrode holder, called the electrode lead, and one from the job or work table back to the machine to complete the circuit, called the work or earth lead. These leads should be heavy enough to carry the required current without overheating. They must be kept in good condition and in close electrical contact with the holder and the work for the best utilisation of current.

3. **Electrode Holders.** These should be heavy enough not to overheat and have well-insulated handles to avoid electric shocks and accidental arcing. Holders are available that are designed for continuous welding at high amperages. These are fully insulated and the jaws are made of metals having high heat conductivity.

4. **Shields.** These are necessary for protecting the eyes and face from glare and ultra-violet radiation from the arc, and spatter from the weld pool. Special tinted glass is used in the shields to absorb ultra-violet rays. A clear piece of replaceable glass is used in front of the coloured glass to protect it from spatter and smoke.

5. **Clothing.** Leather gauntlets and apron should be worn, and clothes should be of material that will deflect spatter and sparks.

6. **Chipping Hammer.** Used for deslagging of welds.

7. **Wire Brush.** Used for removing rust, cleaning slag off welds, etc.

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![THE BASIC ARC-WELDING CIRCUIT](image-url)
THE WELDING ELECTRODE

METAL ARC welding electrodes consist of a core wire surrounded by a flux coating. The flux coating is usually applied to the core wire by an extrusion process.

It is important, for uniform running qualities, for the flux coating to be concentric with the core wire, and the extrusion process allows close control to be kept over this.

The coating on arc welding electrodes serves a number of purposes:

1. To provide a gaseous shield for the weld metal, and preserve it from contamination by the atmosphere whilst in a molten state.
2. To provide a steady arc by having “arc stabilizers” present, which provide a bridge for current to flow across.
3. To remove oxygen from the weld metal with “deoxidizers”.
4. To provide a cleansing action on the work piece and a protective slag cover over the weld metal to prevent the formation of oxides while the metal is solidifying. The slag also helps to produce a bead of the desired contour.
5. To introduce alloys into the weld deposits in special type electrodes, eg the Weldwell hardfacing electrodes, which have mild steel core wire, but contain alloys in the coating.

A wide variety of ingredients are used in the coating of arc welding electrodes. Among them are the minerals limestone, fluorspar, silica, rutile and feldspar for slag and gas shield formation, ferro-manganese and ferro-silicon for deoxidation of the weld metal; ferro-chromium, ferro-molybdenum and nickel powder to introduce alloys for hardening and raising the tensile strength of steel weld metal; potassium and sodium silicates (water glass) to bind the particles together and cause them to adhere to the core wire.
**STORAGE OF ELECTRODES:**

Electrodes not stored in a dry place will absorb moisture from the atmosphere. Dampness in electrodes may have some of the following effects:

1. Fiery arc.
2. Excessive spatter.
3. Porosity in weld metal.
4. Spalling of flux coating.
5. Blistering of electrode tip.
6. High arc voltage.
7. Introduction of hydrogen into the weld metal, with increased danger of hard zone cracking on hardenable steels.
8. Formation of white “fur” on flux coating. In most cases this does not have any deleterious effect.

Mild steel electrodes may be stored in a warm, dry room. Low hydrogen and some special electrodes (eg stainless steel) require to be stored in a proper heated cabinet if the best results are to be achieved. Provided the temperature of the cabinet is 10°C above that of the outside air, and some ventilation is allowed, the electrodes cannot pick up moisture. Mild steel electrodes which have become damp should be redried at 120°C for 15-30 minutes. Low-hydrogen electrodes should always be dried at the temperature recommended for that particular electrode.
THE WELDING CURRENT

BOTH DIRECT and alternating currents may be used for arc welding. AC welding machines have several advantages over DC machines, among them being a lower purchase cost, higher operating efficiency and negligible maintenance. The quality of welds produced using AC is equally as good as when DC is used. However, AC is limited in that it will not satisfactorily run many of the non-ferrous types of electrodes.

The open-circuit voltage of an AC machine is important, because some electrodes need a fairly high voltage to prevent the arc cutting out during welding. The open-circuit voltage depends on the design of the machine.

The question of open-circuit voltage is not so important with DC machines, since there is not the constant reversal of current necessitating continual re-establishment of the arc.

When using AC it does not matter to which terminal the electrodes and the work piece are attached, but when DC is used more heat is produced at the positive pole with most electrode types and the manufacturers’ recommendations for the most suitable polarity should be followed. With the welding of mild steels, although either polarity can be employed, it is usual for the work piece to be made the positive pole. The greater amount of heat generated at the work piece in this way assists the welding operation, especially when the components have a heavy mass. Proper fusion and good penetration are assured in this way. If on the other hand, the electrode is connected to the positive pole, the greater heat generated at the electrode tip results in a faster burn-off rate and the electrode is deposited more quickly. This increase in deposition rate, however, may not amount to more than 5 percent and the advantage gained in this way is offset by the reduction in depth of penetration obtained with the resulting weld deposit. The burn-off rate with AC supply is approximately the same for DC supply with the electrode connected to the negative pole.

Most of the non-ferrous and stainless steel electrodes should be connected to the positive terminal, but this is recommended because of the greater arc stability obtained.
**ARC BLOW:**

This is peculiar to DC. The arc, instead of playing steadily on one spot, is deflected away from the point of welding due to the influence of surrounding magnetic fields created by welding currents flowing in the work. It may often be overcome or minimised by shifting the earth clamp to another part of the work piece.

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**RECOMMENDED CURRENT RANGES FOR STANDARD MILD STEEL TYPES OF ELECTRODES**

<table>
<thead>
<tr>
<th>Size mm</th>
<th>1.6</th>
<th>2.0</th>
<th>2.5</th>
<th>3.15</th>
<th>4.0</th>
<th>5.0</th>
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<tbody>
<tr>
<td>Amperes</td>
<td>20-30</td>
<td>45-70</td>
<td>65-100</td>
<td>100-140</td>
<td>140-190</td>
<td>170-240</td>
<td>230-320</td>
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</tbody>
</table>
FOR THOSE who have not yet done any welding, the simplest way to commence is to run beads on a piece of scrap plate. Use mild steel plate about 12 mm thick and a 4.0 mm electrode. Clean any paint, loose scale or grease off the plate and set it firmly on the work bench so that welding can be carried out in the downhand position. Make sure that the earth clamp is making good electrical contact with the work, either directly or through the work table. For light gauge material, always clamp the earth lead directly to the job, otherwise a poor circuit will probably result.

ELECTRODE - TYPE AND SIZE:
The type of electrode will depend on the material to be welded and the position in which welding is to be carried out (ie whether downhand, vertical or overhead). In this case, the general purpose PH28 electrode is the most suitable. We have already chosen a 4.0 mm electrode, but for other jobs the size will depend on the thickness of the material and the type of joint to be welded. For example, on thin material a small size is required, otherwise holes will burn through. The electrode size should allow for adequate root penetration. On vee butt joints, the root run is often made with 4.0 mm or 3.2 mm electrodes and the remaining welding is done with 5.0 mm electrodes.

Generally, the maximum size which may be used on vertical and overhead welding is 5.0 mm, but these more specialised applications can be left for the moment while we concentrate on downhand welding.

AMPERAGE:
Suitable amperages for the various sizes of electrodes are usually printed on the packets. These amperages may be varied to suit conditions — welds on thin plate require low amperages to prevent burn-through, while high welding rates or deep penetration of the weld metal require higher amperages. For 4.0 mm set the machine at about 170 amps.

There are several effects produced by incorrect amperage. If it is too high, spatter becomes excessive, and the weld pool becomes very hot, producing a flattened bead with elongated ripple marks, and the electrode overheats. If the current is too low, it is difficult to maintain the arc and prevent the electrode from sticking, the bead is high and rounded, with poor edge fusion, and penetration is slight. Figures 3, 4 and 5 show the effects of different amperages.
THE WELDER:

Place yourself in a comfortable position before beginning to weld. Get a seat of suitable height and do as much work as possible sitting down. Don’t hold your body tense. A taut attitude of mind and a tense body will soon make you feel tired. Relax and you will find that the job becomes much easier. You can add much to your peace of mind by wearing a leather apron and gauntlets. You won’t be worrying then about sparks setting alight your clothes.

Place the work so that the direction of welding is across, rather than to or from your body. The electrode holder lead should be clear of any obstruction so that you can move your arm freely along as the electrode burns down. If the lead is slung around the back of your neck and over your shoulder, it allows greater freedom of movement and takes a lot of weight off your hand. Be sure the insulation on your cable and electrode holder is not faulty, otherwise you are risking an electric shock.
STRIKING THE ARC:

Practise this on a piece of scrap plate before going on to more exacting work. You may at first experience difficulty due to the tip of the electrode “sticking” to the work piece. It is caused by making too heavy a contact with the work and failing to withdraw the electrode quickly enough. A low amperage will accentuate it. This freezing-on of the tip may be overcome by scratching the electrode along the plate surface in the same way as a match is struck. As soon as the arc is established, withdraw the electrode very slightly (2.0 mm) from the plate and feed it into the weld pool as it melts down. (See Fig. 6)

Another difficulty you may meet is the tendency, after the arc is struck, to withdraw the electrode so far that the arc is broken again. A little practice will soon remedy both of these faults.

ARC LENGTH:

The securing of an arc length necessary to produce a neat weld soon becomes almost automatic. You will find that a long arc produces more heat. A very long arc produces a cracking or spattering noise and the weld metal comes across in large, irregular blobs. The weld bead is flattened and spatter increases. A short arc is essential if a high quality weld is to be obtained, although if it is too short there is the danger of it being blanketed by slag and the electrode tip being frozen in. If this should happen, give the electrode a quick twist back over the weld to detach it. Contact or “touch-weld” electrodes do not stick in this way, and make welding much easier.

RATE OF TRAVEL:

After the arc is struck, your next concern is to maintain it, and this requires moving the electrode tip toward the molten pool at the same rate as it is melting away. At the same time, the electrode has to move along the plate to form a bead. The electrode is directed at the weld pool at about 20° from the vertical. The rate of travel has to be adjusted so that a well-formed bead is produced. If travel is too fast, the bead will be narrow and strung out and may even be broken up into individual globules. If the travel is too slow, the weld metal piles up and the bead is too large.
MAKING WELDED JOINTS:
Having attained some skills in the handling of an electrode, you will be ready to go on to make up welded joints.

BUTT WELDS:
Set up two plates with their edges parallel, as shown in Fig. 7, allowing a 1.6 mm gap between them and tack weld at both ends. This is to prevent contraction stresses from the cooling weld metal pulling the plates out of alignment. Plates thicker than 6.0 mm should have their mating edges bevelled to form a 70-90° included angle. This allows full penetration of the weld metal to the root. Using a 4.0 mm electrode at 170 amps, deposit a run of weld metal on the bottom of the joint. Do not weave the electrode, but maintain a steady rate of travel along the joint sufficient to produce a well-formed bead. At first you may notice a tendency for undercut to form, but keeping the arc length short, the angle of the electrode at about 20° from vertical, and the rate of travel not too fast, will help to eliminate this. The electrode needs to be moved along fast enough to prevent the slag pool from getting ahead of the arc. To complete the joint in thin plate, turn the job over, clean the slag out of the back and deposit a similar weld.

Heavy plate will require several runs to complete the joint. After completing the first run, chip the slag out and clean the weld with a wire brush. It is important to do this to prevent slag being trapped by the second run. Subsequent runs are then deposited using either a weave technique or single beads laid down in the sequence shown in Fig. 57. The width of weave should not be more than three times the core wire diameter. When the joint is completely filled, the back is either machined, ground or gouged out to remove slag which may be trapped in the root, and to prepare a suitable joint for depositing the backing run. If a backing bar is used, it is not usually necessary to remove this, since it serves a similar purpose to the backing run in securing proper fusion at the root of the weld.

Fig. 7
FILLET WELDS:

These are welds of approximately triangular cross-section made by depositing metal in the corner of two faces meeting at right angles (Fig. 18).

A piece of angle iron is a suitable specimen with which to begin, or two lengths of strip steel may be tacked together at right angles. Position the angle iron so that the two legs are at 45° to the bench and run in a weld bead using a similar technique as for butt welds, using a 4.0 mm electrode at 170 amps. When you are familiar with this, position another piece of angle iron with one leg horizontal and the other vertical. This is known as a horizontal-vertical (HV) fillet. Strike the arc and immediately bring the electrode to a position perpendicular to the line of the fillet and about 45° from the vertical. Some electrodes require to be sloped about 20° away from the perpendicular position to prevent slag from running ahead of the weld. (See Fig. 8.) Do not attempt to build up much larger than 6.0 mm leg length with a 4.0 mm electrode, otherwise the weld metal tends to sag towards the base, and undercut forms on the vertical leg. Multi-runs can be made as shown in Fig. 9. Weaving in HV fillet welds is undesirable.

VERTICAL WELDS:

Vertical up.
Tack weld a 1 metre length of angle iron to your work bench in an upright position. Use a 4.0 mm electrode and set the current at 140 amps. Make yourself comfortable on a seat in front of the job and strike the arc in the corner of the fillet. The electrode needs to be about 10° from the horizontal to enable a good bead to be deposited. (See Fig. 10.) Use a short arc, and do not attempt to weave on the first run. When the first run has been completed deslag the weld deposit and begin the second run at the bottom. This time a slight weaving motion is necessary to cover the first run and obtain a good fusion at the edges. At the completion of each side motion, pause for a moment to allow weld metal to build up at the edges, otherwise undercut will form and too much metal will accumulate in the centre of the weld. Fig. 11 illustrates multi-run technique and Fig. 12 and 13 show the effects of pausing at the edge of weave and of too rapidly weaving.
VERTICAL FILLET WELDS

SINGLE RUN

Electrodes at right angles, or $10^\circ$ from perpendicular

MULTI RUN

Weaving motion for second and subsequent runs

Pause at edge of weave

Fig. 10

Fig. 11
To execute this method, it is advisable to use electrodes which are designed to have a very quick freezing slag. Generally higher amperages are used with fast travel speeds. The easiest type to use when learning is the contact PH C18. The electrode is pointed slightly upward at approximately 80° and when the arc is struck, the tip is pressed onto the work and welding commences and advances as the electrode is drawn slowly down the work.

OVERHEAD WELDS:
Apart from the rather awkward position necessary overhead welding is not much more difficult than downhand welding. Set up a specimen for overhead welding by first tacking a length of angle iron at right angles to another piece of angle iron or a length of waste pipe. Then tack this to the work bench or hold in a vice so that the specimen is positioned in the overhead position as shown in the sketch. The electrode is held at 45° to the horizontal and tilted 10° in the line of travel (Fig. 14 shows this). The tip of the electrode may be touched lightly on the metal, which helps to give a steady run.

A weave technique is not advisable for overhead fillet welds. Use a 4.0 mm electrode at 160 amps, and deposit the first run by simply drawing the electrode along at a steady rate. You will notice that the weld deposit is rather convex, due to the effect of gravity before the metal freezes. Second and third runs are deposited in the order shown in Fig. 15.
OVERHEAD FILLET WELD

Fig. 14

BUILD UP SEQUENCE

Fig. 15