

SECTION 4, CHAPTER 3

ELECTRIC ARC WELDING

List of Contents

	<i>Para.</i>		<i>Para.</i>
Introduction	1	ELECTRICAL PRINCIPLES	
Principle	3	D.C. Argon Shielded Tungsten Arc ..	131
Arc Welding Electrodes	6	Removal of Oxides	132
Filler Rods	12	Current Carrying Capacity (Electrodes)	134
Fluxes	13	Arc Voltages	135
Storage	17	A.C. Arc	136
Power	20	Equipment	137
Safety Measures	26	Setting-up Equipment	148
Welding Hazards	29	Preparation for Welding	149
		Edge Preparation	150
METAL-ARC WELDING		Cleaning	154
Introduction	30	Preheating	157
Plant	33	Stresses and Distortion	158
Operation	39	Setting-up the Workpiece	159
Welding Technique	47	Electrodes	160
Preparation for Welding	48	WELDING TECHNIQUE	
Edge Preparation	49	Operation	161
Cleaning	63	Striking the Arc and Maintaining Arc	
Stresses and Distortion	65	Length	162
Setting-up the Workpiece	66	Current	163
Electrodes	69	Butt Welds	164
Current	70	Fillet Welds	169
Striking the Arc	73	Speed	172
Penetration	77	Positional Welding	173
Electrode Angle and Weaving	78	After-treatment of Welds	174
Speed	82	ARGONARC WELDING FAULTS	
Welding Positions	83	General	175
After-Treatment	88	Lack of Penetration	176
		Lack of Fusion	177
ARC WELD FAULTS		Undercut	178
General	92	Edge of Plate Melted Away	179
Unsatisfactory Surface Appearance ..	93	Oxide Inclusions	180
Spatter	96	Porosity	181
Porosity	99	Incorrect Weld Size and Profile	182
Incorrect Weld Size and Profile	102	Poor Surface Appearance	183
Overlap	111	Spatter	184
Undercut	114	SERVICING	
Slag Inclusion	117	Warning	185
Incomplete Penetration	120	Checking for Gas Leaks	186
Lack of Fusion	123	Master Valve	187
Cracks	126	Flow Indicator	188
		Gauges	189
ARGONARC WELDING		Ceramic Shields	190
Introduction	129	Electrodes	191
		Argon Cylinders	192

List of Illustrations

	Fig.		Fig.
Metallic Arc	1	Excessive Reinforcement	21
Arc Welding Plant-Left-Hand Side ..	2	Excessive Convexity	22
Arc Welding Plant-Right-Hand Side ..	3	Uneven Leg Length	23
Welding Controls	4	Reduction in Throat Thickness ..	24
Electrode Holder	5	Restoration of Throat Thickness ..	25
Square-Butt Joints	6	Overlap and Undercut	26
Single-V and Double-V Butt Joints ..	7	Slag Inclusions	27
Single-U and Double-U Butt Joints ..	8	Incomplete Penetration	28
Single-J and Double-J Butt Joints ..	9	Lack of Fusion	29
Single-Bevel and Double-Bevel Butt Joints	10	Crack in Fillet Weld	30
Fillet Welds	11	Pressure Regulator	31
Special Welds	12	Air-Cooled Plant	32
Striking the Arc	13	Master Valve and Flow Indicator ..	33
Weaving	14	Mk. 2a Torch	34
Welding Positions	15	Crater Filler Controls	35
Welding Procedure Effects	16	Edge Preparation for Butt Welds ..	36
Surface Porosity	17	Jig for Thin Sheet	37
Splatter	18	Holding Sheet or Plate for Butt Welding	38
Piping	19	Electrode Taper	39
Lack of Reinforcement	20	Torch and Filler Rod Angles	40
		Motion of Torch and Filler Rod ..	41

Introduction

1. Welding is the process of joining metals by the application of heat and, sometimes, of pressure. The process of heating two pieces of metal where they are required to be joined until the metal becomes molten and flows or fuses together, without hammering or pressure, is termed *fusion welding*. The process may be manual, semi-automatic, or automatic, and the main types of fusion welding are:—

- (a) Arc welding.
- (b) Gas welding (Chap. 5).
- (c) Thermit (fusion) welding.

2. Arc welding is any fusion welding process in which heat for welding is obtained from an electric arc or arcs. There are several types of arc welding, but the information in this chapter is confined to Service requirements.

Principle

3. An arc is a flow of electricity across a gap; this flow of electricity glows and gives off heat. When two pieces of metal at different electrical potentials are brought together, a current will flow from one to the other. Movement of one of the pieces of metal away from the other will, provided the voltage and amperage are sufficient, cause an arc or flame to be formed across the gap between the two pieces of metal. With

alternating current, a potential difference of about 80 volts is required to strike an arc, but once formed, the arc can be maintained under a voltage difference of 20 to 45 volts, depending on the length of arc required.

4. The principle of arc welding can be shown with the aid of a dry battery and two pieces of copper wire. Attach one piece of wire to one of the battery terminals and the second piece to the other terminal. Bring the other ends of the wires together and then slowly separate them. It will be found that an arc has been made with sufficient intensity to heat the wires slightly. Further, the use of a larger source of energy, *e.g.* a 6-volt battery, will produce a larger and hotter arc. The use of still larger sources of energy will show that small globules of metal pass from one metal to the other.

5. The metal being welded is often referred to as the *parent metal* or the *base metal*, and the other piece of metal is known as an *electrode*.

Arc Welding Electrodes

6. An electrode is a metal rod which acts as a conductor of the electric current necessary for the production of the welding heat in electric arc welding; an electric arc is struck between the end of the electrode and the parent metal. The electrodes may be consumable or non-consumable.

7. The composition of the metal rod of a consumable electrode depends upon that of the parent metal; the electrode must deposit metal which, chemically and physically, resembles the parent metal as closely as possible.

8. A consumable electrode is shown in use in Fig. 1. The metal of these electrodes is

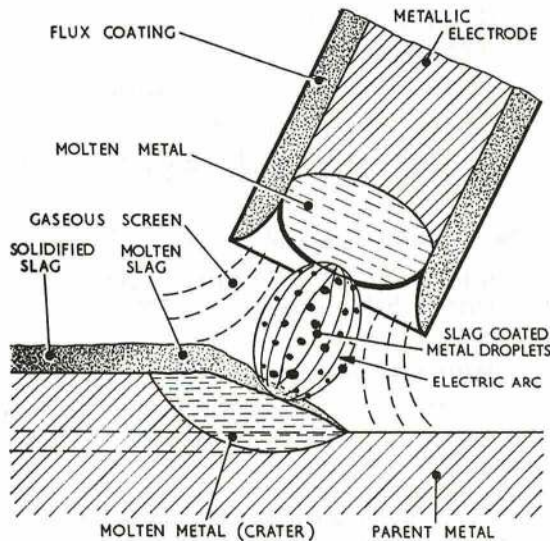


Fig. 1. METALLIC ARC

normally covered with a coating of flux and/or other material; the covering is composed of organic (gas forming) and inorganic (slag forming) elements. The coating generally melts at a slightly higher temperature than the metal core; the greater the heat absorption of the coating, the deeper will be the weld penetration, as more time is available for the parent metal to melt before the electrode metal enters the molten pool. Deep penetration welding is made possible by this fact, because the melting of the electrode metal can be delayed until the parent metal is molten at the required depth.

9. Also, the voltage of the arc is considerably influenced by the electrode coating, *e.g.*, if hydrogen is contained in the coating a considerable increase of the arc voltage is obtained.

10. Non-consumable electrodes produce only the arc, the filler metal being provided from a separate rod. These electrodes are normally uncoated, and flux protection of

the weld is provided by a shield of gas (inert gas welding) or by a separate flux.

11. Modern electrodes cover a wide range of materials and applications, and to ensure a good weld it is essential that the correct type of electrode is used.

Filler Rods

12. A filler or welding rod is filler metal in the form of rod or wire. The rod may be bare or it may be covered with a flux and/or other material to modify the properties of the filler metal.

Fluxes

13. Most metals in their molten condition become oxidized by absorbing oxygen from the atmosphere. To ensure that oxidation is kept to a minimum, that any oxides formed will be dissolved or floated off, and that welding is made as easy and free from difficulties as possible, fluxes are used. Fluxes may be used in powder form, or they may be coated onto electrodes or welding rods.

14. The functions of a flux are:—

- (a) To protect both the parent and the weld metal from atmospheric contamination.
- (b) To form a slag which slows down the rate of cooling of the deposited metal.
- (c) To add alloying or other required constituents into the weld metal.
- (d) To stabilize the arc in electric arc welding, making possible the use of alternating current.

15. When laying down multi-run welds, the slag must be removed from each layer before the next one is started.

16. Many fluxes are corrosive to the metals or alloys with which they are used. Residual flux must, therefore, be removed immediately after a welding operation. Methods of removal generally used include:—

- (a) Chipping.
- (b) Scratch brushing.
- (c) Rinsing or scrubbing in hot water.
- (d) Acid or chemical dips.

Storage

17. Electrodes must be kept in a dry, ventilated store, where they can be maintained

(A.L. 11, June 62)

in an even temperature of approximately 70 deg.F. All electrodes should be returned to store when not in use. Low hydrogen content electrodes should be dried before use.

18. A white film on a coated electrode denotes that it is damp. Not all electrodes can be dried without affecting the properties of their coatings, but where drying is permissible, the necessary details regarding drying temperature and times are given on the electrode carton. If in doubt, reference should be made to the electrode manufacturer. If a coated electrode becomes very damp the coating will disintegrate; *electrodes in this condition must not be used.*

19. Filler rods and fluxes should also be kept in a dry place. If the rods are supplied in packets, it is good practice to keep them in the packets. The lids of tins of flux should be kept tightly secured. Electrodes and filler rods should be stored according to their types.

Power

20. Both direct and alternating current are used for electric arc welding. The essential difference is that *direct current (d.c.)* flows constantly in one direction, whereas *alternating current (a.c.)* reverses its direction of flow a certain number of times per second, which is termed *frequency*. Special welding plant is required for the following reasons:—

- (a) To convert a.c. into d.c. where d.c. welding is desired.
- (b) To reduce the mains voltage to a safer and more suitable range for welding.
- (c) To limit the amount of current used and to provide the high amperage necessary for arc welding.
- (d) To provide suitable arc voltage and welding current relationships at minimum cost.
- (e) To provide suitable arc voltage and welding current relationships for easy starting and maintaining of the arc under broad operating conditions.

21. A.C. mains supply is stepped down by means of a transformer, and d.c. mains supply is reduced by means of a motor driven generator set. Where mains supply is not available, an internal combustion engine is used to drive the generator.

22. As regards the welding operation, for most work there is little to choose between

a.c. and d.c. The local mains supply and the metal to be welded will, to a large extent, determine what equipment is chosen, rather than the welding requirements, except that a.c. gives a smoother arc where high currents are used, and d.c. is necessary for welding some non-ferrous metals.

23. Advantages of a.c. are:—

- (a) First cost of a.c. plant is much lower than d.c. plant.
- (b) Requires very little maintenance.
- (c) No "magnetic arc blow".
- (d) High operating efficiency (85% a.c. to 60% d.c.).

24. Disadvantages of a.c. are:—

- (a) Should not be used for welding with bare or lightly coated electrodes.
- (b) Cannot be used for welding some non-ferrous metals.
- (c) Should not be used in damp confined spaces owing to risk of shock.

25. **Magnetic Arc Blow.** This is associated with d.c. welding plants only, and is the name applied to deflection of the arc away from the point of welding, particularly when welding in corners. When magnetic arc blow occurs, the following ways of counteracting it can be tried:—

- (a) Reverse the direction of welding.
- (b) Move the earth clamp to different parts of the work or bench.
- (c) Change polarity.
- (d) Wind the electrode cable two or three times around the job.

Safety Measures

26. Provided that certain precautions are observed, electric arc welding is no more dangerous than many other industrial occupations. Ventilation, which is very important, will have been taken care of in the design and equipment of the welding shop. Dry floors, and the use of rubber mats or wooden duck-boards, will reduce the risk of shock to a minimum.

27. The electric arc is not only a very brilliant source of visible light, but it also gives off invisible ultra-violet and infra-red rays, which must be kept from direct contact

with the body and especially the eyes. Thus the walls of the welding shop are painted a matt black to minimize reflection, and screens are also necessary to surround the work, particularly if welding is being done outside the welding shop. Passers-by should be warned by means of a notice on the screening: "Arc Welding In Progress", and a similar notice should be displayed on the door of the arc welding bay.

WARNING

Never look at the arc except through the proper protective glass.

28. During electric arc welding operations the following protective clothing and accessories should be used:—

- (a) Helmet, head shield, or hand shield.
- (b) Gloves.
- (c) Apron; the use of an apron is dependent upon the nature of the welding process and the position of the welder relative to the work.
- (d) Rubber knee boots.
- (e) Spraying mask, for use during the welding of metals which give off harmful fumes, e.g. brass or galvanized iron, or when welding in badly ventilated spaces.
- (f) When it is not possible to screen a welding operation, persons working in the vicinity should wear tinted goggles.
- (g) When cleaning a weld by chipping away the slag, safety goggles should always be worn to protect the eyes from small flying pieces.

Welding Hazards

29. If an operator is subjected to electric shock, care must be exercised when giving him attention. First, switch off the current, or disconnect the lead, before removing the operator from the source of danger. If breathing is absent, start artificial respiration and continue it until breathing returns or until the arrival of the Medical Officer. Burns should be covered with a clean, sterile dressing, and the patient placed in the care of the Medical Officer at once. When any other symptoms of illness are felt, the person should immediately report sick.

METAL-ARC WELDING

Introduction

30. Metal-arc welding is a fusion process in which an electric arc is drawn between the tip of an electrode and the surface of the workpiece; the temperature created is over 3,500°C. While the weld area is molten the end of the electrode also melts, and small drops of molten filler metal are projected through the arc to combine with the parent metal (Fig. 1).

31. This process can be used for the welding of most metals, its main application being the welding of all kinds of steels including the heaviest sections; the process is not normally used for very thin gauge materials. In addition, the process may be used for the hard-surfacing of certain metals.

32. Current for the process is normally supplied by a mains fed motor-driven generator, one pole of the generator being connected to the parent metal and the other to an electrode holder. The operator holds the holder in his hand and, after striking the arc, guides the electrode at the correct distance (arc length) along the edges to be welded; it is part of the skill of the welder to keep the arc length as constant as possible.

Plant

33. **General.** The arc welding plant (Fig. 2) is a mobile equipment consisting of a motor-driven generator, a star-delta starter, welding controls, electric cables and an electrode holder. The type of electrode used is dependent on the type of material being welded and the requirements of the job.

34. **Motor-driven Generator.** The driving motor and the generator form a composite assembly which is housed in a common frame. The generator gives an output current which is continuously variable between 20 and 300 amperes, with a striking voltage of 70 and a maximum welding voltage of 30.

35. **Starter.** The hand operated star-delta starter is enclosed in a metal case mounted above the front of the motor. It is controlled by a lever mounted on the left-hand side of the case, and a knob on the front. The mains cable enters the case through a hole in the right-hand side, on which side there is also the attachment for the earth lead (Fig. 3).

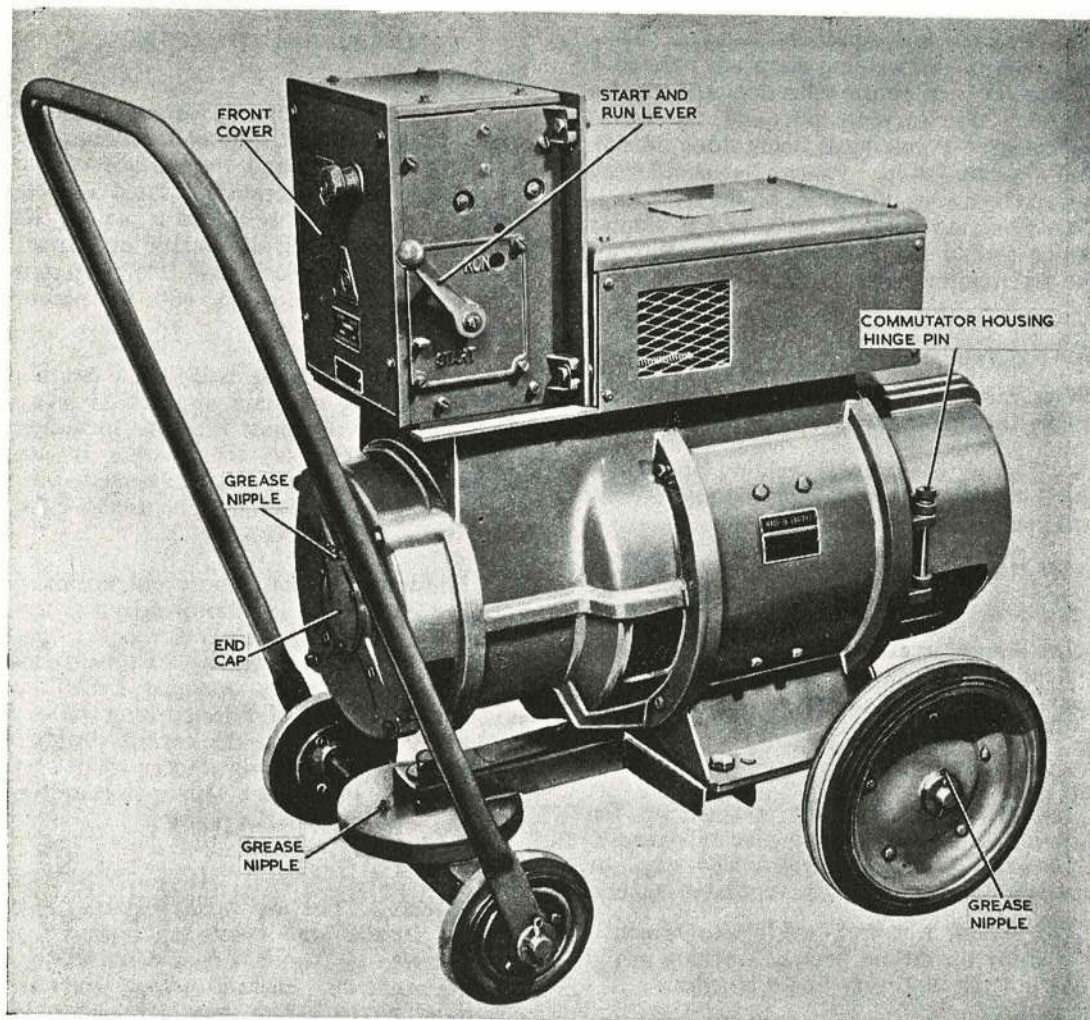


Fig. 2. ARC WELDING PLANT—LEFT-HAND SIDE

36. **Welding Controls.** The welding controls (Fig. 4) are enclosed in a metal case mounted above the generator and are manually operated. They consist of a main current selector switch, a fine regulator and an assembly of resistances. The two output terminals, one positive and the other negative, can also be seen in the illustration. Continuous adjustment of the output current from 20 amperes to a maximum of 300 amperes is provided by the controls.

37. **Cables.** Four electric cables are used:—

- (a) The welding cable, connected at one end to the electrode holder.
- (b) The return cable.

(c) The starter earth.

(d) The mains cable.

38. **Electrode Holder.** The electrode holder (Fig. 5) consists of a pair of crocodile type jaws, held together by a spring and an insulated tubular handle. The welding cable is fed through the handle and clamped to one leg of the jaws.

Operation

39. Before attempting to strike an arc the operator must be wearing the correct protective clothing, and must ensure that the following precautions are complied with:—

- (a) That the voltage used is as low as is consistent with efficient welding.

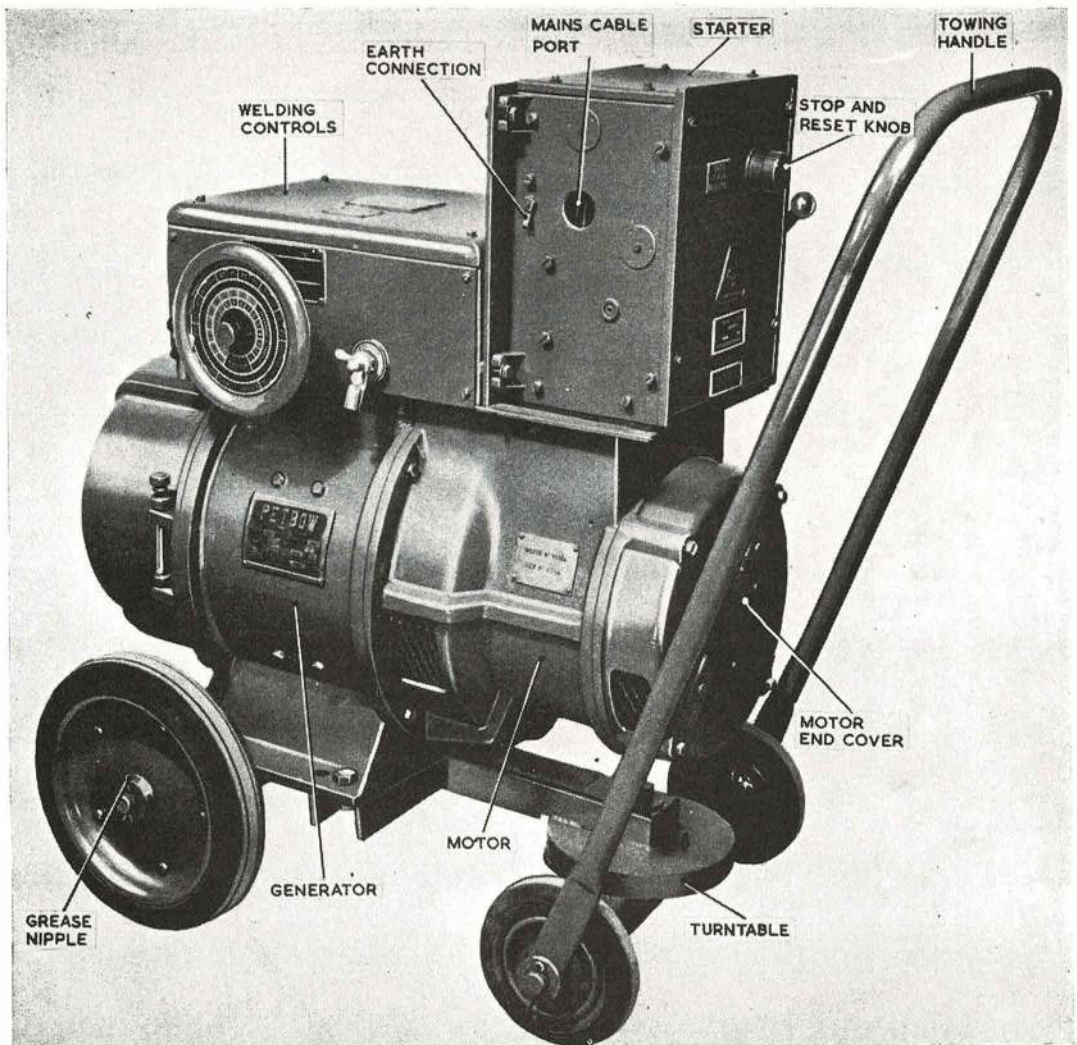


Fig. 3. ARC WELDING PLANT—RIGHT-HAND SIDE

- (b) That the leads are serviceable and correctly attached.
 - (c) Check that the generator is serviceable.
 - (d) That the working area is dry and free from obstructions.
 - (e) That there is provision for the electrode holder when not in use. An insulated hook or a fully insulated holder should be used.
40. Switch on the mains supply and move the starter lever to the start position, holding it there until the motor settles down to full running speed. The lever should then be moved quickly to the run position, and then released.
 41. Move the selector switch handwheel (Fig. 4) until the pointer, yellow for down-hand welding and red for vertical, horizontal-vertical, or overhead welding, coincides with the correct current figures on the appropriate scale. The correct current figure for the job is given on the approved drawing, specific order requirement, or electrode packet.
 42. Strike the arc. If difficulty is experienced in striking the arc, or if the arc splutters, turn the fine control knob anti-clockwise to raise the voltage.
 43. The correct welding procedure is given on the approved drawing, specific order requirement, or on the electrode packet.

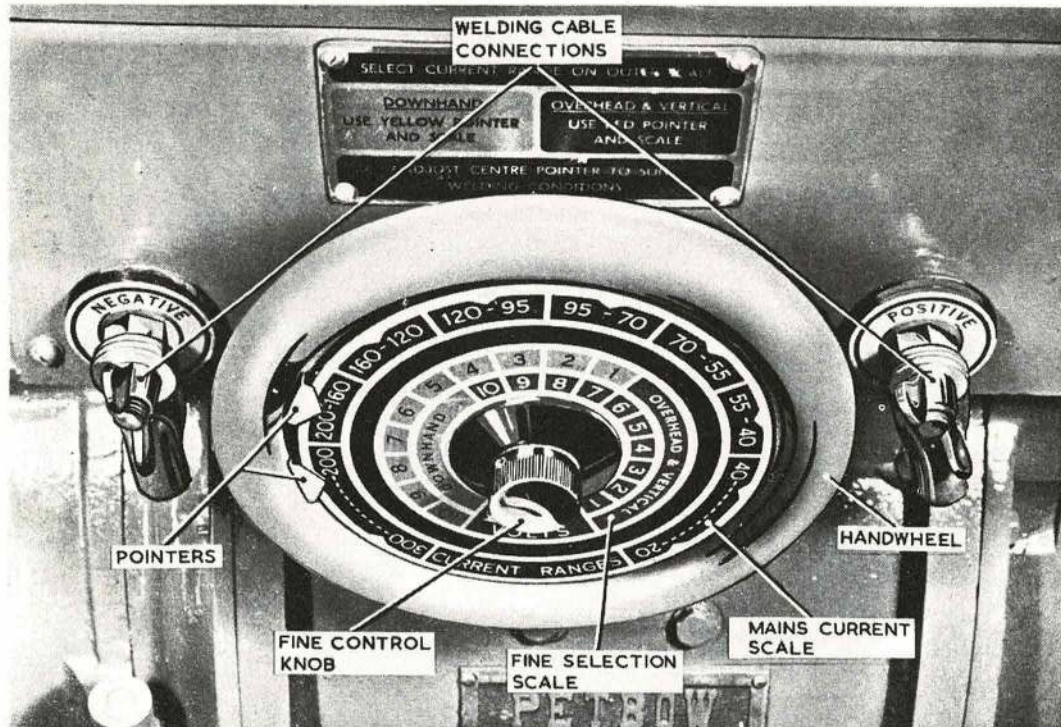


Fig. 4. WELDING CONTROLS

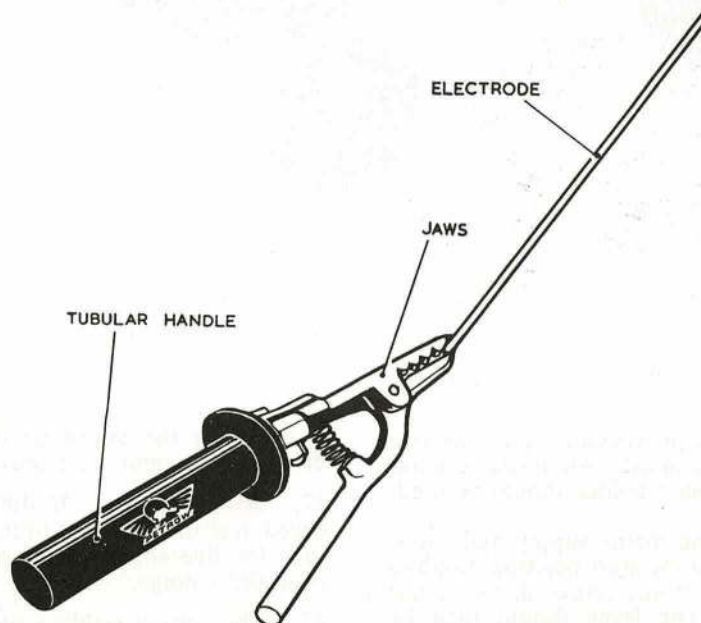


Fig. 5. ELECTRODE HOLDER

44. At the end of the welding operation, stop the plant, place the electrode holder in a safe position, and unclamp the welding return cable from the workpiece. If the plant is not to be used for a further operation, turn off the mains switch and disconnect the mains supply from both the mains supply and the starter. If the plant is required for a further operation, stop the plant, unclamp the welding return cable from the original workpiece and clamp it to the new workpiece.

45. The finished workpiece should be treated as laid down in the approved drawing or specific order requirement; if these are not available, post-welding treatment should follow normal established practice.

46. Heavy articles which have been welded will be very hot on completion, and it is good practice to mark the article clearly with the word "HOT" in chalk.

Welding Technique

47. The ability of the welder to produce a good weld depends on:—

- (a) The correct preparation of the workpiece.
- (b) The use of the correct type of electrode.
- (c) The selection and maintenance of the correct current.
- (d) The maintenance of the correct arc length.
- (e) The correct angle of the electrode during welding.
- (g) The correct after-treatment of the weld.

Preparation for Welding

48. Correct preparation of the parts to be joined is of great importance. In addition to thorough cleaning to ensure that all oil, grease, paint and oxide are removed from the weld surfaces of the parts, preparation for welding may include:—

- (a) Treatment of the edges along which the weld is to be made.
- (b) Preheating or other measures to relieve stresses and avoid distortion.
- (c) Accurate setting up of the parts in relation to one another.

Edge Preparation

49. Except where thin sheet metal is concerned, it is usually necessary to prepare edges of the parts to be joined before com-

mencing welding. The method of edge preparation to be used depends upon the material, its thickness, and the welding technique to be used.

50. **Butt Welds.** The following methods of edge preparation for butt welds may be used:

- (a) Square.
- (b) Single-V.
- (c) Double-V.
- (d) Single-U.
- (e) Double-U.
- (f) Single-J.
- (g) Double-J.
- (h) Single-bevel.
- (j) Double-bevel.

51. **Square-butt.** This type of joint only requires the edges to be true and clean, and may be open or closed. The closed square-butt type of joint (A, B and C in Fig. 6) is used for:—

(a) **Steel.** Without backing bar, up to $\frac{1}{8}$ in. thick, or up to $\frac{5}{8}$ in. thick if a deep penetration electrode is used and the workpiece welded from both sides. If a backing bar is used (C in Fig. 6), steel up to $\frac{5}{16}$ in. thick can be welded; deep penetration electrodes are necessary for plate thicknesses approaching the upper limit.

(b) **Copper and its Alloys.** Up to $\frac{1}{16}$ in. thick.

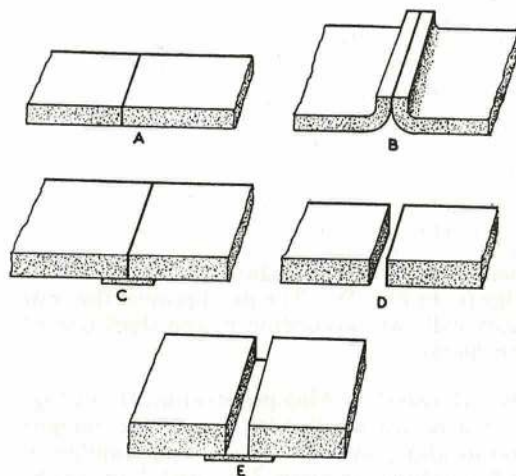


Fig. 6. SQUARE-BUTT JOINTS

(c) **Aluminium and its Alloys.** Up to $\frac{1}{16}$ in. thick with backing bar, and up to $\frac{1}{8}$ in. thick without backing bar, welded both sides.

52. A variation of the closed square-butt joint which may be used with steel up to $\frac{1}{16}$ in. thick, and copper and its alloys up to $\frac{1}{8}$ in. thick, is the flanged type of preparation (B in Fig. 6). Aluminium, magnesium, or alloys of these metals, must not be flanged.

53. The open-square butt joint is used for the following thicknesses of metals:—

(a) **Steel.** Without backing bar (D in Fig. 6), from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. thick, the gap varying from $\frac{1}{16}$ in. to $\frac{1}{8}$ in.; with backing bar (E in Fig. 6), from $\frac{1}{8}$ in. to $\frac{5}{16}$ in., the gap varying from $\frac{1}{16}$ in. to $\frac{3}{8}$ in.

(b) **Copper and its Alloys.** From $\frac{1}{16}$ in. to $\frac{1}{8}$ in., the gap being $\frac{3}{4}$ of the thickness of the parent plates.

(c) **Aluminium and its Alloys.** With backing bar, from $\frac{1}{16}$ in. to $\frac{1}{8}$ in. thick, the gap varying from $\frac{1}{16}$ in. to $\frac{3}{32}$ in.; without backing bar, from $\frac{1}{8}$ in. to $\frac{3}{16}$ in., with a gap of $\frac{1}{16}$ in.

54. For metal of greater thicknesses than those quoted in para. 51 to 53, special preparation of the edges by any of the methods listed in para. 50, sub-para. (b) to (j), is necessary.

55. **Single-V.** This preparation is used for thicknesses of steels from $\frac{3}{16}$ in. to $\frac{3}{8}$ in. thick when a backing bar is used (B in Fig. 7), or from $\frac{3}{16}$ in. to $\frac{1}{2}$ in. thick without a backing bar (A in Fig. 7). It is also used for copper and its alloys from $\frac{1}{8}$ in. to $\frac{3}{4}$ in. thick, and for aluminium and its alloys from $\frac{5}{16}$ in. to $\frac{1}{2}$ in. thick when a backing bar is used, or from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. thick without a backing bar. The lower edge of the bevel for steel and aluminium should have a "flat" or "nose", the purpose of which is to prevent overmelting and undue penetration of the fluid metal. Copper parts should have a "knife" edge (C in Fig. 7). The gap between the root faces will vary according to the thickness of the metal.

56. **Double-V.** This preparation (D in Fig. 7) is used for steels over $\frac{1}{2}$ in. thick, copper and its alloys over $\frac{3}{4}$ in. thick, and aluminium and its alloys between $\frac{3}{8}$ in. and $\frac{1}{2}$ in. thick. The root face is on the centre line of both parts and is formed with a nose. A variation

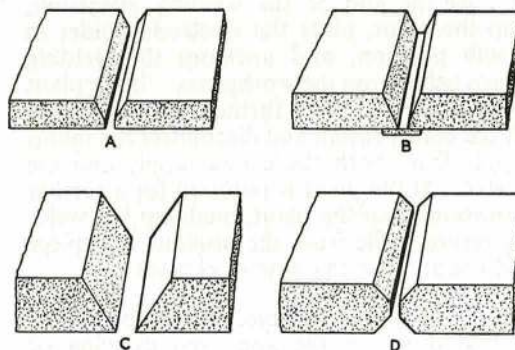


Fig. 7. SINGLE-V AND DOUBLE-V BUTT JOINTS

of this type of preparation is the asymmetric double-V where the root face is not on the centre line of the workpiece. The double-V permits easy welding from both sides.

57. **Single-U.** Single-U (A in Fig. 8) is a variation of the single-V type; it is used where greater ease of electrode manipulation is advantageous. Steel over $\frac{1}{2}$ in. thick, and copper and its alloys over $\frac{3}{4}$ in. thick, may receive this method of edge preparation.

58. **Double-U.** This type of preparation (B in Fig. 8) is a variation of the double-V. It is usually used for steel over one inch thick, and may be used for copper and its alloys over $\frac{3}{4}$ in. thick.

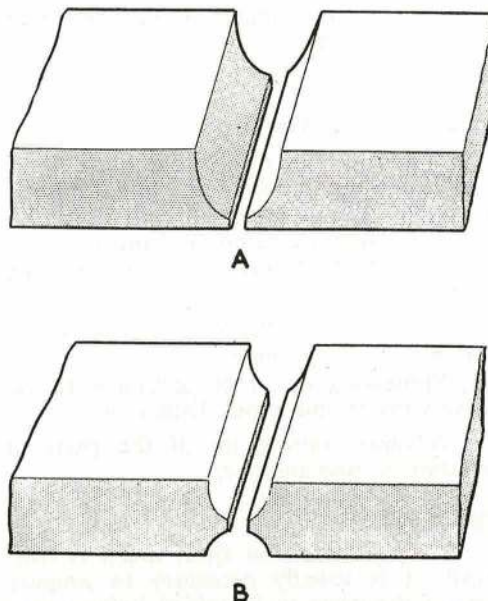


Fig. 8. SINGLE-U AND DOUBLE-U BUTT JOINTS

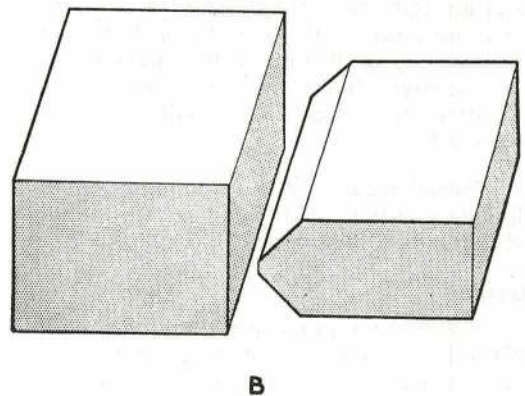
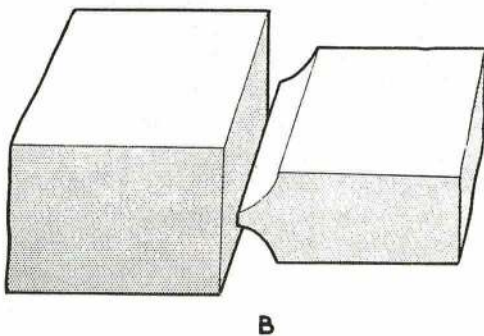
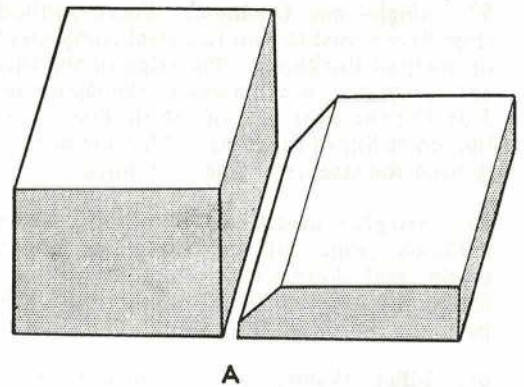
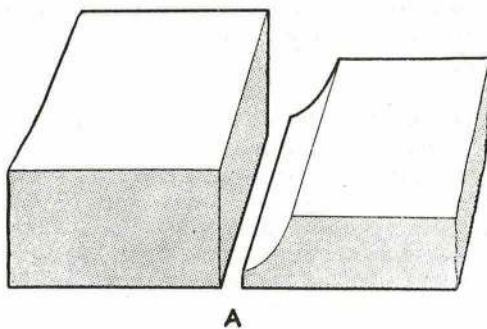


Fig. 9. SINGLE-J AND DOUBLE-J BUTT JOINTS

Fig. 10. SINGLE-BEVEL AND DOUBLE-BEVEL BUTT JOINTS

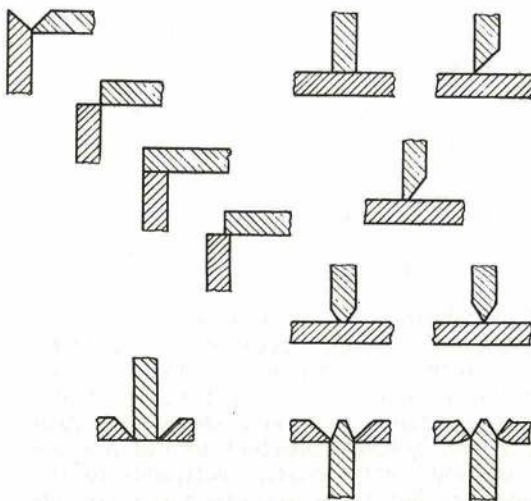


Fig. 11. FILLET WELDS

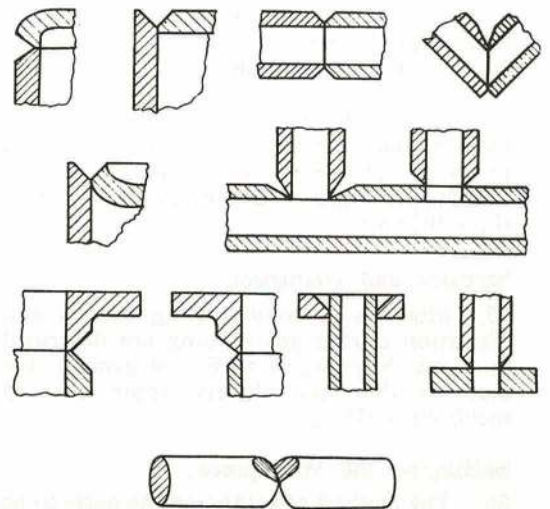


Fig. 12. SPECIAL WELDS

59. Single- and Double-J. These methods (Fig. 9) are used to join two steel components of unequal thickness. The edge of the thinner component is cut away in the shape of a J or J's; the root face of the double-J is on the centre line of the parts. They are normally used for steel over one inch thick.

60. Single- and Double-bevel. These methods (Fig. 10) are variations of the single- and double-J, and are usually used for welding steel assemblies where the thinnest part is over $\frac{3}{16}$ in. thick.

61. Fillet Welds. The normal types of assemblies which are joined by fillet welds are illustrated in Fig. 11. Generally, apart from ensuring that the edges to be welded are clean and true, no special edge preparation is necessary. When welding metals of very heavy gauge it may be advantageous to bevel the edges, but it is not essential; use of the correct electrode will normally ensure a good weld.

62. Special Welds. When welding plates to cylinders, shafts to shafts, and tubes to tubes (Fig. 12), it is advantageous to bevel the edges.

Cleaning

63. Cleaning the parts to be welded should preferably be done by immersing the parts in a degreasing bath; if this is not possible, gasoline or kerosine may be used as alternatives. It is insufficient to clean only the surfaces in the immediate vicinity of the joint, for when the parts become hot any remaining oil or grease may become sufficiently fluid to flow onto the welding surfaces. The parts must be dried after cleaning.

64. It is good practice to scrape, grind or file the weld surfaces. Care must be taken to remove particles of detached oxide, abrasive material and other foreign matter from the weld area.

Stresses and Distortion

65. Methods of counteracting stresses and distortion during gas welding are described in Chap. 5, para. 54 to 62; in general, the methods described therein apply also to metal-arc welding.

Setting-up the Workpiece

66. The method of arranging the parts to be welded depends largely upon the nature of the work. The welding of small parts should

be done on a welding bench provided with an earth connection.

67. Instructions for setting up a workpiece are normally included on the approved drawing or specific order requirement, otherwise the welder should follow established practice.

68. To facilitate the welding of cylindrical objects and small fittings generally, it is convenient to use a turntable. Jigs are often required for complicated work and these should be specially designed. For very large components it is convenient to use manipulators during the welding process.

Electrodes

69. It is outside the scope of these Notes to deal in detail with electrodes. They have been developed for the welding of most materials, and special types are available for welding the following materials:—

- (a) Medium and high-tensile steel.
- (b) Austenitic corrosion-resisting and heat-resisting steels.
- (c) Aluminium and its alloys.
- (d) Cast iron.
- (e) Tin-bronze.
- (f) Aluminium bronze.
- (g) Nickel and its alloys.

Current

70. The current is properly adjusted before the operator starts to weld. Further fine adjustment may be necessary after the operator has tried out the arc. The correct current which should be used depends mainly upon:—

- (a) The heat capacity of the work.
- (b) The amount of current which the particular electrode can withstand without undue overheating.

71. Polarity. When welding with d.c., polarity is important, because the heat developed at the positive pole is greater than that at the negative pole. In general, therefore, heavily coated electrodes should be used with the holder connected to the positive pole, and lightly coated electrodes to the negative, but there are exceptions to this generalization. In a.c. welding polarity is not important. When welding aluminium

d.c. should be used with positive polarity; a.c. can be used if a high frequency current is superimposed.

72. The effects of current and voltage are:—

(a) **Current Too Low.** Poor penetration, shallow crater, metal heaps up on plate with overlap, and arc has an unsteady spluttering sound.

(b) **Current Too High.** Penetration too deep, deep crater, flat bead, fierce arc with loud crackle, the electrode becomes red hot and there is much spatter.

(c) **Voltage Too Low.** Electrode tends to stick to the workpiece, the arc is difficult to maintain, there is a spluttering sound as the arc fluctuates, and the metal tends to be deposited in blobs without penetration.

(d) **Voltage Too High.** Noisy, hissing, fierce arc which tends to wander; the bead tends to be porous and flat, and spatter occurs.

(e) **Correct Voltage, Current, and Welding Speed.** Steady crackling sound; medium crater, giving good penetration; an easily controlled stable arc, and a smooth even bead.

Striking the Arc

73. There are two methods in common use for striking the arc. In the first method the arc is struck in a deliberate movement similar to the striking of a match (Fig. 13). The electrode should not come to rest, but should be raised slowly off the work drawing the arc to the required length.

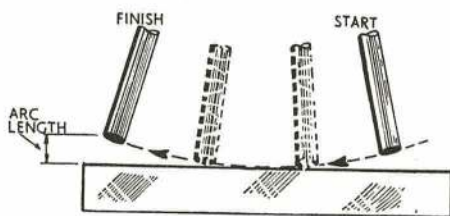


Fig. 13. STRIKING THE ARC

74. In the second method the tip of the electrode is jabbed on to the workpiece and, after the arc is struck, the electrode is lifted until the arc is approximately $\frac{1}{8}$ in. to $\frac{3}{16}$ in. long. If the electrode is not lifted quickly when using this method of striking the arc, there is a possibility that the electrode may

stick or "freeze" to the workpiece. Should this occur, the electrode may be freed by giving it a quick twist. If this fails to free the electrode, the generator should be switched off and the electrode released from the holder; the electrode can then be removed from the workpiece.

75. After the arc has been struck, the operator should maintain the arc at the correct length. The longer the arc, the more heat is lost to the atmosphere and therefore to welding. A very short arc, however, may cause a failure due to a short circuit. In general, it is good practice to keep the arc length approximately equal to the diameter of the electrode core wire; electrodes with large core wires, e.g. $\frac{1}{2}$ in. diameter, should be kept closer than the diameter of the core wire.

76. The welder must watch the arc closely at all times to keep it the correct length, as melting of the electrode will require the holder to be moved downward. The tip of the electrode must also be moved along the workpiece to avoid getting a large pool of molten metal in one place. During a large run the molten pool tends to catch up with the tip of the electrode, which must therefore, at such times, be raised slightly to maintain the arc. Too long an arc makes a fluttering noise and should be avoided. The slag can be distinguished from the molten metal as it appears a brighter red and is more free running.

Penetration

77. The strength of a welded joint depends upon a number of factors, not the least of which is the skill of the welder. There must be complete amalgamation of the electrode deposit and the parent metal, and between the subsequent deposits forming the joint. Such amalgamation is termed "penetration", and is defined as the distance the weld metal fuses into the root of the joint. Good penetration is obtained by the welder ensuring thorough cleanliness of the parts, correct electrode and specified current value, and keeping a short arc length. Lack of penetration is the very negation of welding, and since it may not be possible to detect it in the finished weld it constitutes a hidden menace which can only result in failure when the joint is fully stressed.

Electrode Angle and Weaving

78. When welding downhand the electrode should be held at an angle of 60 to 80 degrees to the surface of the workpiece, and should be moved slowly and evenly across it. The electrode may also be moved in a weaving, *i.e.* side to side, motion, as it progresses along the weld. Weaving assists fusion at the sides of the weld and also enables the metal to be built up or reinforced along any desired line, according to the method of weaving used. The width of the weave can be varied to provide either a narrow or a wide bead. There are three main methods of weaving.

79. The first method (A in Fig. 14) consists of a side-to-side motion, which helps to pile the metal in the weld bead into ripples.

80. The second method of weaving (B in Fig. 14) is a variation of the first method, and is done with a circular side-to-side motion. The weld bead effect is similar to that resulting from the first method. Care should be taken when using this second method with heavily coated electrodes to prevent slag being trapped in the weld metal.

81. A figure-of-eight motion (C in Fig. 14) is used in the third method, which gives increased penetration on the lines of fusion. Care must again be taken to ensure that slag is not trapped in the overlap of the weave on the edges. This method is useful when reinforcing and building up deposits of wear-resisting steels.

Speed

82. The speed of travel of the electrode across the workpiece is very important. Too

fast a speed results in an irregular bead with poor or no penetration. If the speed of travel is too slow too much metal will be deposited, the crater will be too deep and the electrode will tend to become very hot. The molten metal will pile up at the rear of the crater, and give a good indication as to whether the speed of travel is correct; the depth of the crater indicates the degree of penetration being obtained.

Welding Positions

83. A welder must make himself comfortable at his work because a steady hand is essential, and this is possible only if the body is steady. A sitting position is the most comfortable and least fatiguing; alternatively the welding bench will afford convenient support. A right-handed welder should lean his left hip against the bench, holding the welding screen in his left hand. The body should be relaxed, the maximum freedom being afforded the right arm and hand. The electrode holder should be held lightly with just sufficient grip to control the electrode, and in such a position that the welder's line of vision is not obscured. The cable from the regulator to the electrode holder should be hung over the shoulder to take the weight of the cable off the hand, and the electrode should be moved without any movement of the body. The actual posture which the welder will assume will depend upon the welding position, there being four positions in which welding is normally done, *viz.*:

- (a) Downhand.
- (b) Vertical.
- (c) Horizontal-vertical.
- (d) Overhead.

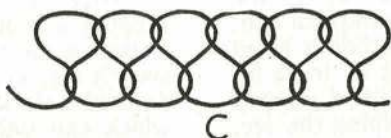
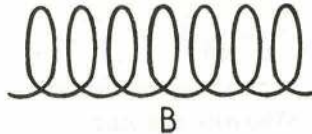


Fig. 14. WEAVING

84. **Downhand.** A weld is said to be deposited in the downhand position (A in Fig. 15) when the bead is laid horizontally on a flat plate, with the operator's hand above the line of the weld. Whenever possible this position should be employed because it is the easiest for the welder.

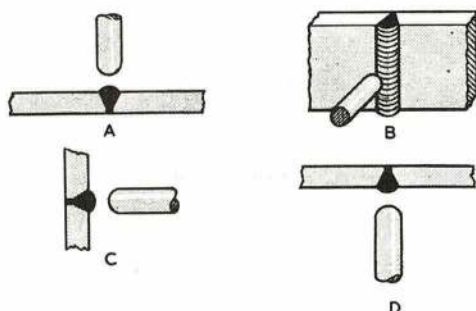


Fig. 15. WELDING POSITIONS

85. **Vertical.** All welds inclined at a greater angle than 45 degrees to the horizontal are usually classed as vertical welds (B in Fig. 15). Welding may be done either upwards or downwards, the former being used for the majority of work; in each case a short arc should be maintained and the electrode held at an angle of 60 to 80 degrees to the surface of the workpiece. Because of the tendency of the molten metal to run down the work, downward welding is usually confined to light runs; also, in downward vertical welding, the slag flows over the molten pool and is liable to hinder penetration. In both methods of vertical welding, accurate control of the molten metal by use of the correct current setting and a short arc are essential. If it is found during downward welding that slag tends to remain behind the electrode, the arc should be lengthened to melt it out and then shortened to continue welding, otherwise, blow-holes may result. Weaving is as used for downhand welding.

86. **Horizontal-Vertical.** This type of weld is one in which the workpiece is in the vertical plane with the run of the weld horizontal across it (C in Fig. 15). In general the factors affecting vertical welding also affect horizontal-vertical welding. The best results may be obtained by depositing the welds in straight runs without weaving. It is important to deposit the first run centrally in the corner to ensure full penetration at the root; care should be taken when laying subsequent runs to ensure that possible slag traps are eliminated.

87. **Overhead.** The overhead position (D in Fig. 15) is the most difficult, and special electrodes are available. The welding procedure is generally similar to that for vertical and horizontal-vertical welding. A fillet weld should be deposited in straight runs; the sequence of the runs can vary, but care must always be taken to avoid possible slag traps. The welding of V-butts is best done by depositing a series of slightly over-lapping parallel beads. Alternatively, a lateral weave movement can be used to produce a bead the full width of the joint.

After-Treatment

88. The after-treatment of the weld consists of cleaning the slag and flux residue from the weld surface, and any necessary weld finish operations. Sometimes heat-treatment is required to relieve stresses and distortion caused by the welding operation.

89. Slag is usually removed by chipping, scraping and wire brushing; it is good practice to finish all slag removal operations by wire brushing the surface. Before starting to remove the slag the operator must cover his eyes with safety goggles. Other means of slag removal which may be used are sand-blasting and air-hammering.

90. The fluxes used in the welding of aluminium, aluminium alloys and magnesium alloys are corrosive. The surfaces of these metals may, therefore, besides having the slag removed, be given anti-corrosive treatment; such treatment, if required, is normally done immediately after completion of welding.

91. **Heat Treatment.** When such treatment is required, detailed instructions are provided on the approved drawing, specific order requirements, or the electrode packet.

ARC WELD FAULTS

General

92. Much could be written and illustrated on the subject of arc weld faults. The following information on a few typical faults which can occur in arc welds in mild and low alloy steels gives only an outline of the causes of the defects, and the methods whereby such flaws may be avoided and corrected.

(A.L. 11, June 62)

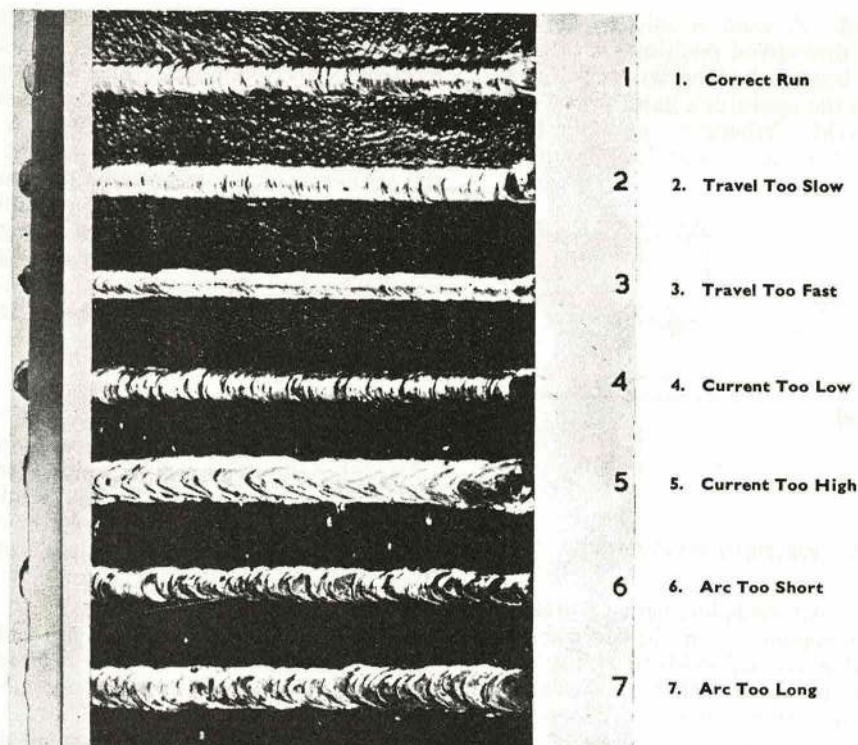


Fig. 16. WELDING PROCEDURE EFFECTS

Unsatisfactory Surface Appearance

93. This embraces a number of faulty conditions of the surface of a weld (Fig. 16) as distinct from weld size and profile. Such faults are non-uniform surface ripples, surface porosity or pock marks (Fig. 17), visible slag inclusions, faulty junctions where welding operations have been recommenced, and craters at the ends of welding runs.

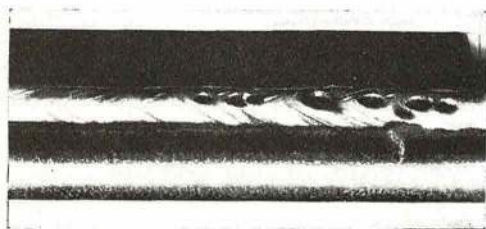


Fig. 17. SURFACE POROSITY

94. **Causes.** The formation of rough or irregular weld surfaces is due, in the main, to the use of incorrect welding techniques, although in certain circumstances the welding characteristics of the electrode may affect the surface appearance of the weld. When the

appearance of a weld is under consideration, attention should be paid to the welding position in which the joint was made.

95. **Corrective Action.** Surface roughness, surface porosity, or visible slag inclusions can be rectified by removal of the faulty weld metal and re-welding. Care should be taken to remove all slag and scale before re-welding operations are commenced.

Spatter

96. "Spatter" is the term used to describe a condition in which, during welding operations, small globular deposits of weld metal from the electrode become scattered over the surface of the weld and the adjacent parent metal (Fig. 18); in most instances the small deposits adhere strongly.

97. **Causes.** Spatter is mainly associated with the use of too high a density of electric current, although in some instances the welding characteristics of the electrode, or dampness of the electrode covering, may give rise to this condition. Frequent interruptions of the arc during welding operations may also

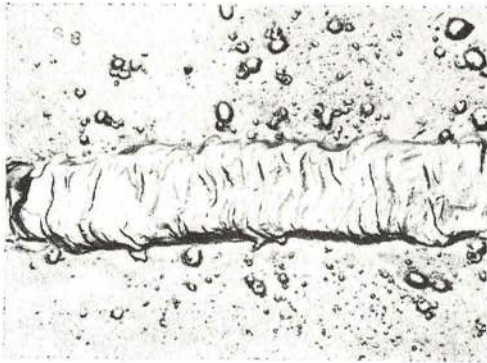


Fig. 18. SPATTER

tend to cause spatter and such interruptions should, therefore, be avoided as much as possible.

98. Corrective Action. Remove the spatter deposits by chipping and wire-brushing them from the surface of the weld and the parent metal.

Porosity

99. The term porosity refers to the presence of cavities in the weld metal as a result of gas being trapped. In general, porosity takes the form of small spherical cavities which are either scattered throughout the weld or clustered in local regions. In some instances, elongated or tubular cavities known as piping or worm holes (Fig. 19), or large, round,

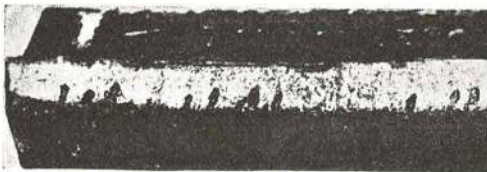


Fig. 19. PIPING

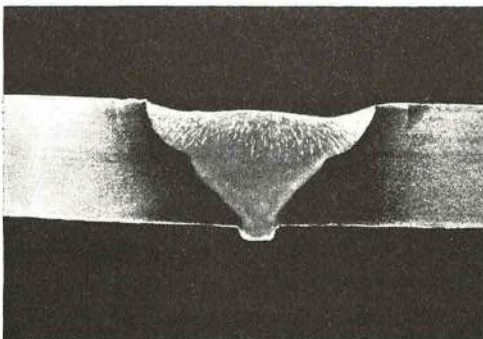


Fig. 20. LACK OF REINFORCEMENT

isolated gas cavities called blow holes, may be present in a weld; such cavities may be partially filled with slag.

100. Causes. The gas which, if trapped, causes porosity, is formed by chemical reaction during the welding process. A number of factors may contribute to the occurrence of porosity: the composition of the parent metal and electrode core wire; a damp electrode; incorrect density of electric current; and bad preparation of the fusion faces of the joint.

101. Corrective Action. Welds which contain excessive porosity should be rectified by the removal of the defective portions of the weld seam, and should then be re-welded. The areas which surround the groove formed by the removal of the defective metal should be thoroughly cleaned of slag and scale, and the groove should be large enough to allow adequate manipulation of the electrode, thus permitting full penetration of the weld metal.

Incorrect Weld Size and Profile

102. These defects are departures from the shape and size of a weld, which is otherwise correctly formed, from those specified. Incorrect weld size refers to undersize fillet welds, or fillet welds of variable size, as measured by the minimum leg length; incorrect profile in butt welds refers to lack of reinforcement (Fig. 20), excessive reinforcement (Fig. 21), or irregularity of the deposit of weld metal.

103. Causes. Welds of incorrect size or profile are generally the result of faulty welding technique. Excessive convexity or concavity of a weld face may, in certain circumstances, be due to the welding characteristics

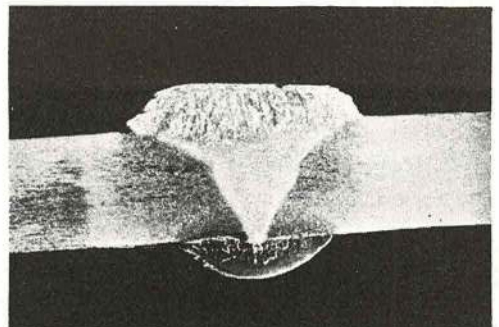


Fig. 21. EXCESSIVE REINFORCEMENT
(A.L. 11, June 62)

of the electrode, but are more generally caused by an incorrect density of electric current, convexity (Fig. 22) being associated with low and concavity with high current density. The welding position is also a contributory factor in these instances.

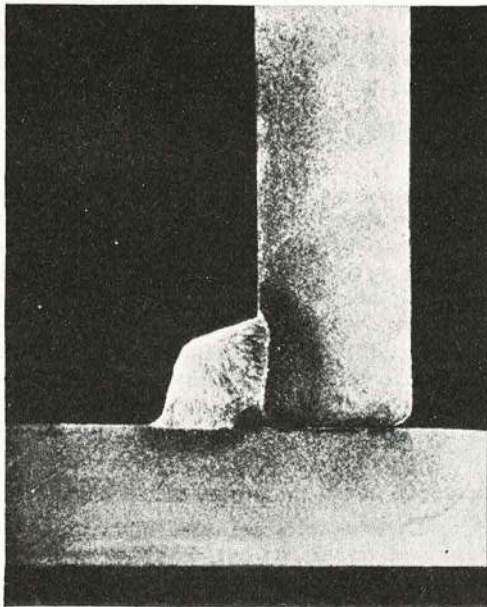


Fig. 22. EXCESSIVE CONVEXITY

104. Fillet welds having unequal leg lengths (Fig. 23) are usually the result of faulty manipulation of the electrode, or of incorrect positioning of the workpiece when welding in the downhand or tilted position. Normally it is difficult to deposit large single-run fillet welds having consistent leg lengths in the horizontal-vertical position, as such welds tend to sag at the base.

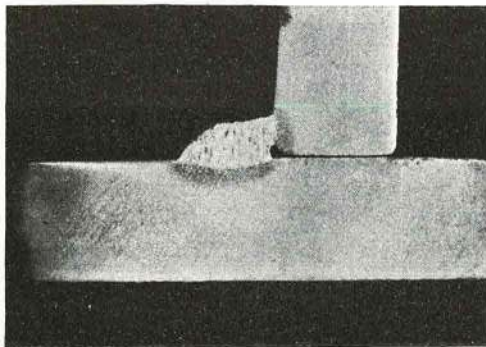


Fig. 23. UNEVEN LEG LENGTH

105. Fillet welds of more than $\frac{5}{16}$ in. in size should be made by deposits of weld metal by more than one welding run, unless they can be made in the downhand position. Undersized fillet welds will be produced if, as the result of bad assembly of the parts of a joint prior to welding, the effective leg length is reduced by excessive root gaps.

106. Excessive or lack of reinforcement in butt welds result from incorrect welding procedure and should not arise if the preparation of the parts of a joint, the size of the electrode, the density of the electric current, the number of welding runs made, and the speed or length of welding run per electrode, are correctly specified and followed.

107. **Corrective Action.** Excessive concavity and unequal leg lengths in fillet welds can be rectified by depositing more weld metal, but to correct the effects of excessive convexity it will be necessary to chip away the excess weld metal. Excessive reinforcement in butt welds may be rectified by the removal of the excess weld metal; lack of reinforcement can be corrected by depositing further weld metal. When any of these faults are to be remedied, the joint and surrounding parent metal should be thoroughly de-slugged and de-scaled, before any re-welding operations are commenced.

108. A particular instance of incorrect weld size and profile is when a fillet weld is deposited in a lap or strap joint, the exposed corner of one of the parent plates being melted away along the length of the weld, resulting in a reduction in thickness of the plate edge and throat thickness (Fig. 24).

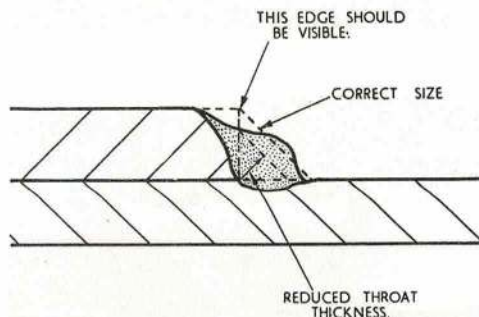


Fig. 24. REDUCTION IN THROAT THICKNESS

109. **Causes.** This defect may be caused by incorrect manipulation of the electrode, insufficient lap, or by the use of an electrode

which is too large in relation to the thickness of the parent plate. When a fillet weld is to be applied to the square edge of a plate, it should be arranged, where practicable, that the size of the weld fillet will be at least $\frac{1}{16}$ in. less than the edge thickness of the plate to avoid melting off the exposed corner.

110. Corrective Action. Rectification is by deposition of additional runs of weld metal to restore the throat thickness of the weld to the correct size (Fig. 25).

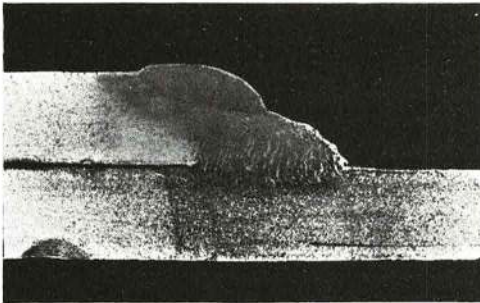


Fig. 25. RESTORATION OF THROAT THICKNESS

Overlap

111. Overlap is an excess of weld metal extending beyond the limits of fusion of the surface of the parent plate (Fig. 26). This condition may exist only at isolated points, or occur continuously along the length of the welded joint. Overlap is more often associated with fillet welds and causes an apparent increase in their size.

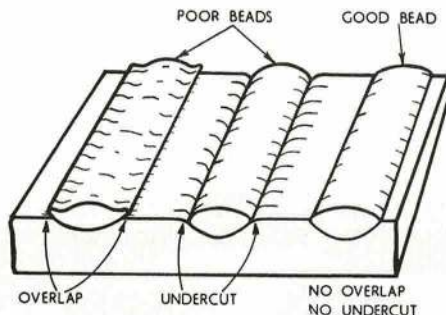


Fig. 26. OVERLAP AND UNDERCUT

112. Causes. This fault arises, frequently, from use of the wrong electrode angle which allows the molten weld metal to flow away from the fusion zone, as does the use of too

large an electrode in relation to the position of the work being welded. The correct density of the electric current and the correct arc length assist in the prevention of overlap; too high a current density may cause overlap due to the increased melting rate of the last portion of the electrode. The welding speed should be that which gives adequate fusion at the toes of the weld; too low a welding speed may result in the molten weld metal flowing beyond the fusion zone.

113. Corrective Action. Overlap can generally be remedied by the removal of the excess weld metal, but care should be taken that a smooth surface remains without any traces of deep grinding marks in either the parent or weld metals.

Undercut

114. Undercut is a local reduction in the section of the parent metal which occurs adjacent to the deposit of weld metal (Fig. 26); the fault generally appears as a groove or channel, and may be either continuous or not. The condition may occur either on the surface of the parent metal at the toes of the weld, or in the fusion faces of multi-run welds.

115. Causes. Undercutting is most commonly associated with the use of too high a density of electric current, but is also frequently the result of incorrect techniques such as too rapid a welding speed, excessive side manipulation, or an incorrect electrode angle. It may also be due to the inherent welding characteristics of the electrode, and can also be caused by heavy mill-scale on the parent metal or the use of a damp electrode.

116. Corrective Action. This defect may be rectified by adding further weld metal where required. Deep undercutting should be chipped away before further welding, particularly if the undercut contains slag, as inclusions are likely to prevent complete fusion with the underlying metal. The additional weld metal which is deposited to remedy an undercut should conform as nearly as possible to the general shape of the desired weld.

Slag Inclusion

117. Slag inclusion refers to any non-metallic matter which may be included in the weld. The usual source of such inclusion is from slag formed by the electrode coverings.

(A.L. 11, June 62)

The inclusions shown in Fig. 27 are due to the incomplete removal of slag between welding runs.

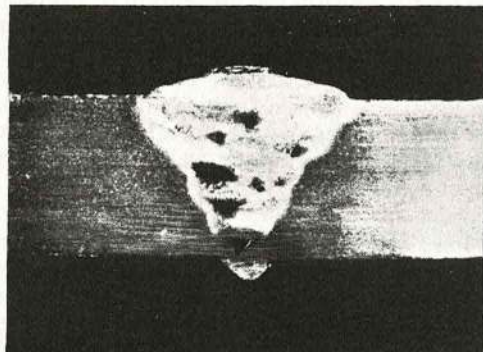


Fig. 27. SLAG INCLUSIONS

118. Causes. Slag that is forced into the weld metal by the arc during welding is usually finely dispersed throughout the weld; that trapped in cavities formed by undercutting or uneven earlier runs is likely to appear as an elongated line of slag, which may or may not be continuous. In multi-run welds, inclusions frequently occur as a result of imperfect slag removal between welding runs and, for this reason, the shape and surface condition of the preceding welding runs are of importance. Poor preparation, *i.e.* cleanliness and fusion faces not reasonably smooth, will also cause slag pockets or voids. Slag inclusions are often associated with lack of penetration and full consideration should, therefore, be given to those factors which are liable to cause poor penetration, *e.g.*, the use of too large an electrode, an inadequate welding groove angle, oversize root faces, incorrect angle of the electrode, and an incorrect density of electric current.

119. Corrective Action. To rectify welds which contain slag inclusions, the defective portions should be removed and the joint re-welded. The areas around the groove formed by the removal of the defective metal should be properly cleaned of slag and scale, and care should be taken that the groove is large enough to allow adequate movement of the electrode and thus permit full penetration of the weld metal.

Incomplete Penetration

120. Incomplete penetration is when the weld metal fails to reach the root of the joint or fails to fuse completely with the root faces of the parent metals of plates or tubes. As a

result of incomplete penetration, voids and/or slag inclusions may exist at the root zone of the weld (Fig. 28).

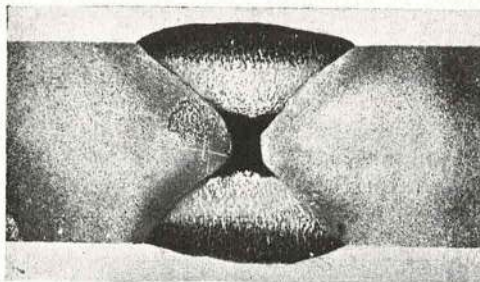


Fig. 28. INCOMPLETE PENETRATION

121. Causes. Ineffective penetration may be caused by use of the wrong size of electrode, wrong density of electric current and, in butt welds, by unsuitable joint preparation preventing correct manipulation of the electrode. To obtain complete penetration in double vee butt welds, it may be necessary to chip out or flame gouge the back of the first run of weld metal, before the root or sealing run of weld metal is deposited on the opposite side of the joint.

122. Corrective Action. Lack of penetration can only be rectified by complete removal of the defective portions, and re-welding these regions. The areas around the groove formed by the removal of the defective metal should be properly cleaned of slag and scale, and care should be taken that the groove or recess is large enough to allow adequate manipulation of the electrode and thus permit full penetration of the weld metal.

Lack of Fusion

123. Lack of fusion is a condition in which boundaries of unfused metal exist either between the parent metal and the weld metal of a joint (Fig. 29), or between adjacent layers

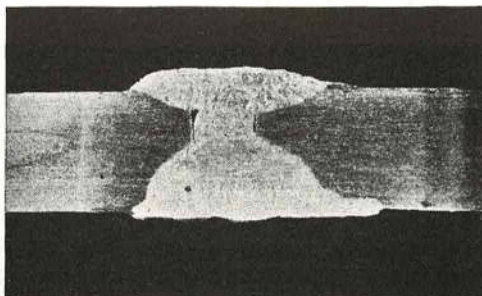


Fig. 29. LACK OF FUSION

of weld metal; it should not be confused with lack of penetration (para. 120).

124. Causes. Imperfect fusion results mainly from the presence of foreign matter, i.e., slag, oxides, etc., which prevent the underlying metal from reaching fusion temperature; the fault can generally be avoided provided that the surfaces of the joint are kept clean. Care should be taken to de-slag between successive runs, and it may be found necessary to chip or grind if the surfaces are rough. The fault may also arise if the density of the electric current is not correct.

125. Corrective Action. Rectification is the same as for lack of penetration (para. 122).

Cracks

126. Cracks may occur either in the weld (Fig. 30) or in the parent metal, and when the metals are hot or cold. Weld metal cracks are usually associated with slag inclusions, and parent metal cracks normally occur within the heat affected zone of the material.

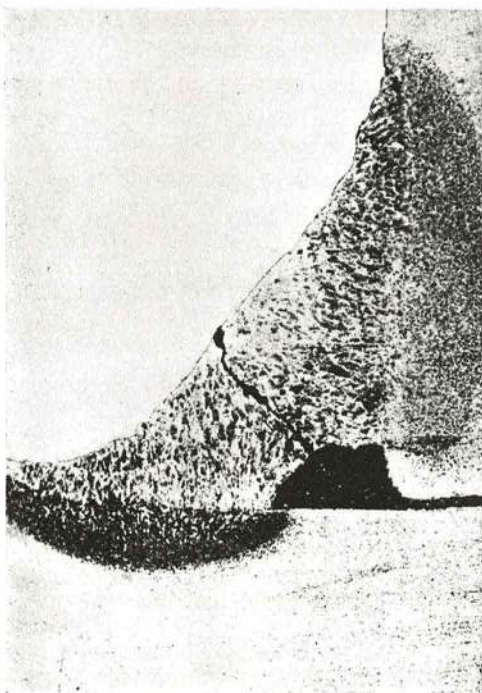


Fig. 30. CRACK IN FILLET WELD

127. Causes. Weld metal cracks are caused by high localized stresses in the joint, which arise from the shrinkage of the weld metal and the resistance to movement of the parts

of the joint during welding operations. It is necessary, therefore, to give careful consideration to the joint conditions and the degree of restraint which opposes movement of the parts of the joint caused by weld shrinkage; the order in which the parts of the joint are assembled should be such as to allow shrinkage to occur as freely as possible. Rapid cooling of the weld metal by draughts or low temperature conditions will increase the tendency for cracks to occur, as will badly fitted or incorrectly prepared joints.

128. Corrective Action. Weld or parent metal containing cracks can only be rectified by complete removal and then re-welding the defective portions; the metal removed should preferably extend well beyond the visible ends of the cracks. The surrounding surfaces should be cleaned of slag and scale, and a modified welding technique may be required to avoid a recurrence of the fault.

ARGONARC WELDING

Introduction

129. Argonarc welding is a shielded-arc fusion process in which the arc, electrode and welding area are protected from atmospheric contamination by a shielding medium, the chemically inert gas argon; fluxes are unnecessary. The heat for welding is supplied by an electric arc formed between the tip of the tungsten electrode and the parent metal. The current required to produce the arc may be either a.c. or d.c., depending on the material to be welded and its thickness. The arc provides heat only, filler metal being added, as required, from a filler rod in a similar manner to oxy-acetylene welding. As a general rule a.c. is used for welding aluminium alloys, aluminium bronze, magnesium, brass and thin stainless steels, and d.c. is used for nickel chromium alloys, thick stainless steels, copper and high quality steels.

130. The process involves:—

- (a) Preparation of the parts to be welded.
- (b) Making the weld.
- (c) After-treatment of the weld.

ELECTRICAL PRINCIPLES

D.C. Argon Shielded Tungsten Arc

131. When using d.c. the electrode may be positive or negative, depending on the material to be welded; the heat distribution is two-thirds to the positive end of the arc and one-third to the negative end (A.L. 11, June 62)

third to the negative. When the electrode is positive it will tend to overheat, and maybe melt, while the workpiece will remain comparatively cool, resulting in an unsatisfactory weld, this method of connection is not recommended. It is, however, under positive polarity conditions that the refractory surface oxide films are removed from aluminium and magnesium. This is an essential feature of the Argonarc process because it eliminates the need for oxide-removing chemical fluxes. Aluminium and magnesium alloys are welded on a.c. plant using superimposed high frequency currents for arc ignition and stabilization.

Removal of Oxides

132. Two theories have been advanced to explain the removal of surface oxides during positive polarity welding:—

- (a) Electrical emission from the metal in the weld area.
- (b) Positive ions of the shielding gas are drawn to the negative pole by the electrical field and so bombard the plate surface, thus removing or dispersing the oxide film.

133. If the torch is made negative and the workpiece positive no scavenging action will take place, because the flow of electrons and positive ions is now reversed, the heat balance is also reversed, and the electrode remains comparatively cool while the bulk of the heat is developed at the workpiece. This is the most efficient method of connection, and although it is unsuitable for welding aluminium and magnesium alloys, negative polarity is used widely when welding stainless and heat resistant steels, mild steels, chrome-nickel and nickel-copper alloys, copper, lead, titanium, molybdenum, zirconium and silver, where there is no problem of removing refractory surface oxides.

Current Carrying Capacity (Electrodes)

134. The negative polarity d.c. arc will carry four to eight times as much current as the positive polarity arc, and twice as much as the a.c. arc, without overheating. The addition of thorium, zirconia or alumina has the following effects:—

- (a) Increased arc current carrying capacity.
- (b) Reduced operating temperatures.
- (c) Easier arc striking (an important feature when welding with very low currents).

Arc Voltages

135. Arc voltages vary with polarity. For equal arc lengths (between $\frac{1}{8}$ in. and $\frac{3}{16}$ in.) negative polarity arc voltage is between 11 and 13 volts, and positive polarity is between 18 and 20 volts. This difference in arc volts may be as high as 25% of the average arc volts, there being also a corresponding increase in arc current during negative polarity arc and a decrease during positive polarity arc.

A.C. Arc

136. In the a.c. arc, volt/ampere reversals occur 100 times per second in a 50 cycle frequency supply. During the negative half-cycles there is an excess of current over that of the positive half-cycles which is the d.c. component, and this condition is known as inherent rectification which is a characteristic of all a.c. arcs in which electrodes of dissimilar materials are used.

Equipment

137. **General.** The equipment required for Argonarc welding comprises:—

- (a) An argon cylinder and pressure regulator.
- (b) A master valve.
- (c) An argon flow indicator.
- (d) A welding torch.
- (e) Electrodes.
- (f) An electric welding set.
- (g) Filler rods.
- (h) Coupling hose.
- (j) Goggles and protective clothing, including gloves.
- (k) Other ancillary equipment similar to that used for oxy-acetylene welding.

138. **Argon Gas.** The argon gas is supplied in steel cylinders of 35 cu. ft. and 100 cu. ft. capacity, in which it is stored initially at a pressure of 1,800 lb. per sq. in. Argon cylinders are painted peacock blue with the word ARGON in white paint on a black panel. Each cylinder is fitted with an ON-OFF type of outlet valve, having a right-hand thread which indicates a non-combustible gas. Standard size keys are provided for operating the outlet valve and they should always be used. Because the argon gas in the cylinders is at a much higher pressure than that required for welding, a pressure regulator

is fitted to the outlet valve of each cylinder when in use. A cylinder must not be emptied below a pressure of 30 lb. per sq. in.

139. Pressure Regulator (Fig. 31). The regulator is connected to the gas cylinder by a nipple which seats into the outlet of the cylinder valve, and is secured in position by a wing or union nut. Its purpose is to ensure an even flow of gas at the correct pressure for welding, *i.e.* 30 lb. per sq. in. A regulator is pre-set to operate at this pressure, and no attempt should be made to alter it.

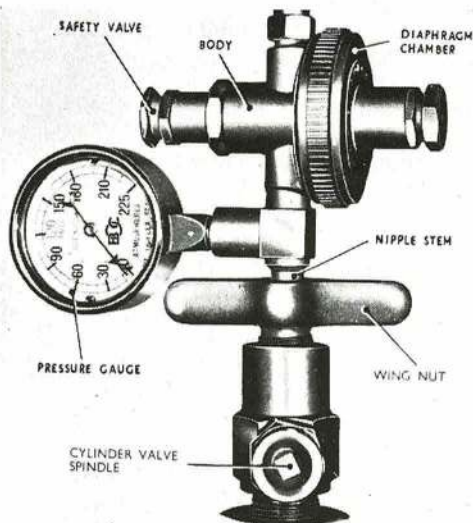


Fig. 31. PRESSURE REGULATOR

140. Electrodes. Electrodes used with the Argonarc welding process are of tungsten (melting point 3,550 deg.C.) and are virtually non-consumable, *i.e.*, they produce only the arc; electrodes are designated according to their diameters. Small percentages of thorium and zirconia may be added to improve emissivity, which is shown by superior striking qualities, good stability at low welding currents and almost total absence of arc wander.

141. Filler Rods. Thin sheet steel and certain other metals may be welded without the addition of filling material, but in most welding operations—and in all instances where the edges of the parts to be joined have been prepared by bevelling or veeing—fresh metal must be added while the operation is in progress to fill in or build up the joint. This added metal is known as the

weld metal, and is obtained from the end of a length of wire or rod which is melted into the small pool of molten metal formed directly under the arc. Filler rods have been developed for the Argonarc welding of most materials.

142. Argonarc Welding Plants. Two types are supplied for Service use, a water-cooled plant and an air-cooled plant (Fig. 32). The gas cylinder and pressure regulator are common to both types; the following components are applicable only to the air-cooled plant.

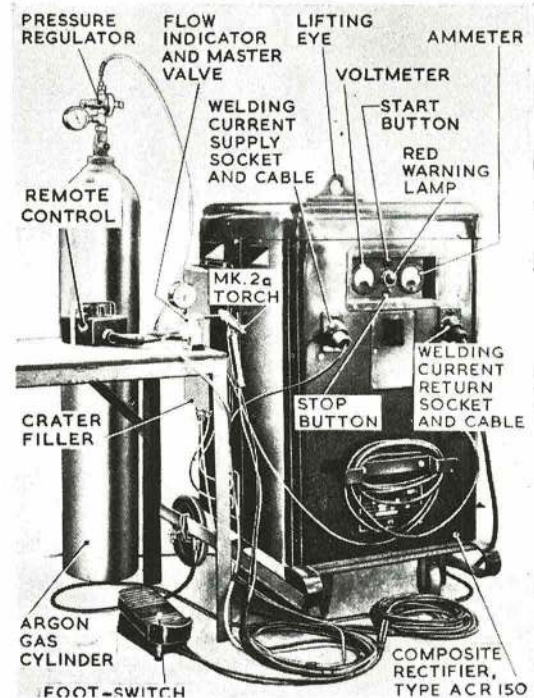


Fig. 32. AIR-COOLED PLANT

143. Master Valve and Flow Indicator (Fig. 33). These components are used as a combined unit to control the flow of argon to the torch. When not in use, the torch is hung on the hooked end of the master valve lever and its weight, through the medium of the lever, plunger, spring loaded diaphragm valve and seat, shuts off the supply of gas to the flow indicator. Removal of the torch from the lever allows gas to flow through the master valve and into the flow indicator. The flow indicator is a needle type valve which provides a fine adjustment for the argon flow.

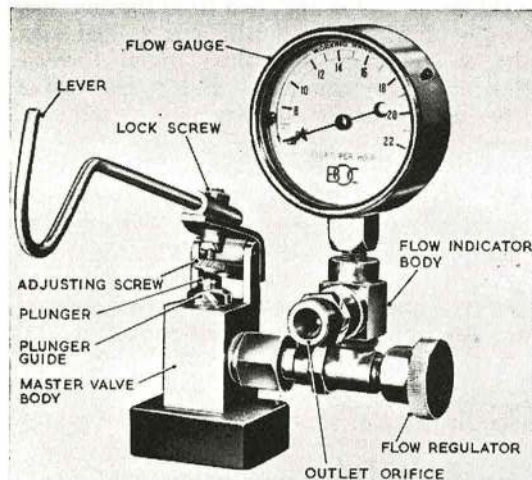


Fig. 33. MASTER VALVE AND FLOW INDICATOR

The gauge is calibrated to show the consumption of argon in cubic feet per hour, and the flow may be altered as required by operation of the flow regulator.

144. Mk.2a Torch (Fig. 34). This torch is a lightweight fully insulated air-cooled hand instrument. Its capacity is 75 amps. d.c. for continuous welding and up to 100 amps.

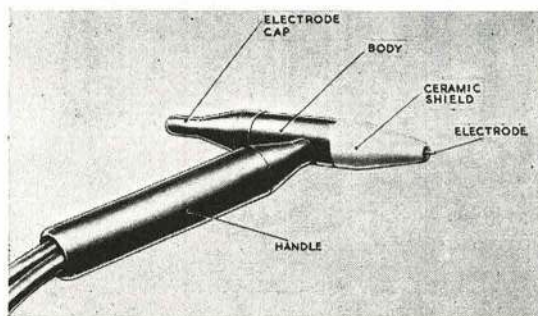


Fig. 34. MK.2A TORCH

for intermittent work. When welding intermittently the working cycle should be five minutes ON and ten minutes OFF. The torch is designed to hold four sizes of electrodes: $\frac{3}{64}$ in.; $\frac{1}{16}$ in.; $\frac{3}{32}$ in. or $\frac{1}{8}$ in. Two sizes of electrode holding collets are supplied with each torch, one for the two smaller diameter electrodes and the other for the two larger diameter electrodes. An electrode cap is screwed into one end of the head sleeve, and a ceramic gas shield fits on to the other end.

145. Composite Rectifier, Type A.C.R. 150.

This composite rectifier (Fig. 32) consists of a 3-phase transformer and a selenium type rectifier enclosed in a steel case. The rectifier is designed to operate on a power input of 360 to 440 volts, 3-phase, 50 cycles. A terminal board with various tapings from 360 to 440 volts is fitted on the left-hand side of the rectifier. The set provides an output of from 10 to 150 amperes d.c. for welding; the open circuit voltage is 70 volts. Two push buttons, one for START and the other for STOP, are fitted on the front of the case. The set also embodies a high frequency spark starter to assist in striking the arc; this should be switched off once the arc is established. The spark starter is operated by a two-way foot switch or by a two-way manual press button switch, each of which is connected to tapings on the right-hand side of the rectifier.

146. Remote Control Box. A calibrated remote control box is connected to the rectifier and gives stepless control of the welding current between 10 and 150 amperes. When not in use the control box is stowed on a bracket on the front panel of the rectifier casing.

147. Crater Filler. A crater filler device is bolted to the right-hand side of the composite rectifier case. The device embodies a relay system which, when the foot switch or press button switch is operated at the end of a welding run, reduces the welding current in four steps during a set time which is adjustable between $1\frac{1}{2}$ and $3\frac{1}{2}$ seconds. This progressive reduction of the welding current obviates craters and ensures a smooth finish to the end of the weld run. The unit is controlled by three externally mounted switches: a time cycle switch; a variable resistance switch; and an IN-OUT control switch (Fig. 35).

Setting-Up the Equipment

148. If the components are not already connected, proceed as follows:—

(a) Stand the argon cylinder in a vertical position convenient to the welder. Remove the protective cap and examine the valve seating for dirt, moisture, etc. Open the valve slowly and blow off a small quantity of gas; close the valve. Fit a pressure regulator to the valve.

(b) Connect the regulator to the master valve by means of the gas tube supplied,

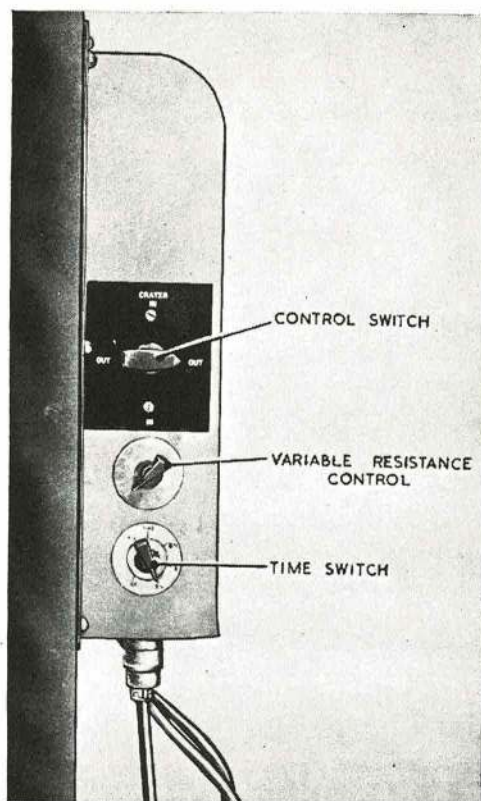


Fig. 35. CRATER FILLER CONTROLS

which should be kept suspended and as short as possible. Attach the flow indicator to the master valve. Secure the master valve convenient to the operator.

(c) Connect the torch argon supply tube to the outlet of the flow indicator. Open the cylinder valve slowly, check the pressure on the regulator gauge and, if necessary, adjust the flow of argon by means of the flow regulator. Depress the lever of the master valve to ensure that it stops the flow of gas to the torch; release the lever and close the cylinder valve.

(d) Select an electrode and collet of suitable size for the work to be done and fit them into the torch head. Fit a ceramic shield to the torch, and adjust the electrode to protrude beyond the shield as required; approximate positions are $\frac{1}{8}$ in. for corner welds, $\frac{3}{16}$ in. for butt welds and $\frac{1}{4}$ in. for fillet welds. Tighten the collet holder by screwing down the electrode cap, but do not use excessive force.

(e) Connect the torch welding current supply cable to the negative output terminal

of the composite rectifier. Connect the foot switch by inserting the plug into the socket of the rectifier (red spot uppermost), and the other plug into the crater filler. Connect the welding return cable to the positive output terminal of the composite rectifier.

(f) Ensure that protective clothing (head mask and gloves) is ready at the work bench.

(g) Prepare and set up the workpiece.

(h) Attach the earth clamp of the welding current return cable to the work bench or direct to the job.

Preparation for Welding

149. In addition to thorough cleaning to ensure that all oil, grease, paint and oxide are removed from the weld surfaces of the parts, preparation for welding may include:—

(a) Treatment of the edges along which the weld is to be made.

(b) Preheating or other measures to relieve stresses and avoid distortion.

(c) Accurate setting up of the parts in relation to one another.

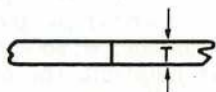
Edge Preparation

150. Except where very thin sheet metal is concerned, it is usually necessary to prepare the edges of the parts to be joined before commencing welding. The method depends upon the material, its thickness, and the welding technique to be used.

151. **Butt Welds.** This type forms a large proportion of the welds made with the Argon-arc process. Permissible gap tolerances are much closer than normally allowed in gas welding. Fusion between the two abutting edges depends to a great extent on the surface tension of the molten metal and, since flux is not used with this process, surface tension will be higher than in other welding processes. Fig. 36 illustrates the types of edge preparation used for butt welds with the Argonarc process; the range of thicknesses and tolerances given are for guidance only and will vary slightly according to the type of material to be welded and the nature of the workpiece.

152. Flanged edge joints are normally used on material of thicknesses less than approx. 0.038 in., but instances may arise where such

(A.L. 11, June 62)



(A) SQUARE-EDGE CLOSED-BUTT

(A) 'T' should not exceed $\frac{1}{8}$ in. for manual welding.



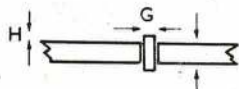
(B) FLANGED-EDGE CLOSED-BUTT

(B) Used on material up to $\frac{1}{16}$ in. thick.



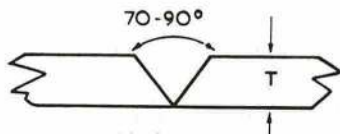
(C) SQUARE-EDGE OPEN-BUTT

(C) This form of preparation is only used when filler wire is to be added. Gap should not normally exceed $\frac{1}{16}$ in. and then only when plate is to be welded from both sides. 'T' should not exceed $\frac{1}{8}$ in.



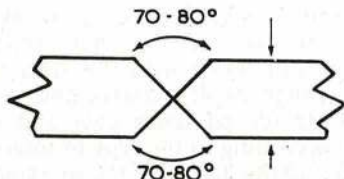
(D) OPEN-BUTT, INSERTED STRIP

(D) This method of preparation avoids the use of separate wire and is suitably mainly for machine welding applications. Thickness should not normally exceed $\frac{1}{16}$ in. and the thickness of the filler strip should not exceed approx. 12 S.W.G. The edges of the plate must butt closely to the filler strip throughout the whole length of the weld seam. 'H' should not exceed $\frac{1}{8}$ in. for the whole range of metal thicknesses involved.



(E) SINGLE-BEVEL CLOSED-BUTT

(E) Single-pass welds on materials up to $\frac{1}{8}$ in. thick are possible with this type of preparation. Multi-pass welds are recommended where 'T' exceeds $\frac{1}{16}$ in.



(F) DOUBLE-BEVEL CLOSED-BUTT

(F) This preparation is recommended where 'T' is in excess of $\frac{1}{8}$ in., assuming both sides of the joint are accessible.

Fig. 36. EDGE PREPARATION FOR BUTT WELDS

a joint might not be suitable, and a closed-butt weld may be specified. It may be necessary, therefore, to use closed-butt welds down to thicknesses below 0.010 in. The main limiting factors, however, in the making of any successful butt weld, are the accuracy of fit-up and the use of specially designed and constructed jigs and fixtures.

153. Fillet Welds. The edge preparation of parts to be fillet welded by the Argonarc process is the same as for metal-arc welding (para. 61).

Cleaning

154. Cleaning of parts to be welded should preferably be done in a degreasing bath; if this is not possible, gasoline, kerosine, trichlorethylene, carbon tetrachloride, acetone, and other similar solvents may be used as degreasing agents. All traces of the solvents must be removed before starting to weld. It is insufficient to clean only the surfaces in the immediate vicinity of the joint, for when the parts become hot any remaining oil or grease may become sufficiently fluid to flow onto the welding surfaces. The parts must be dried after cleaning.

155. It is good practice to scrape, grind, or file the weld surfaces, care being taken to remove all particles of detached oxide, abrasive material, and other foreign matter from the weld area.

156. Aluminium and Magnesium Alloys. The removal of the tenacious surface oxides on these metals is best done by wire scratch brushing, which must be done vigorously to be effective. The use of a high-speed rotary wire brush is good practice. Pickling solutions, and mild solutions of caustic soda for aluminium alloy parts which are small enough to be dipped, may also be used, but all traces of the solutions must be removed to prevent risk of corrosion; pickling must always be followed by vigorous washing. Any filler rods which are to be used should be included in the cleaning process.

Preheating

157. As a general rule preheating is carried out in the same manner as for oxy-acetylene welding, except for one main difference. When preheating for Argonarc welding, the flames must be extinguished when the required temperature is attained and only re-lit during non-welding periods; otherwise the argon shroud may be affected. To prevent damage to the earth cable insulation, clamp a strip of metal to the workpiece so that it extends to the outside of the furnace wall, where the cable can then be attached.

Stresses and Distortion

158. Methods of counteracting stresses and distortion during gas welding are described in Chap. 5, para. 54 to 62; in general, the methods described therein apply also to

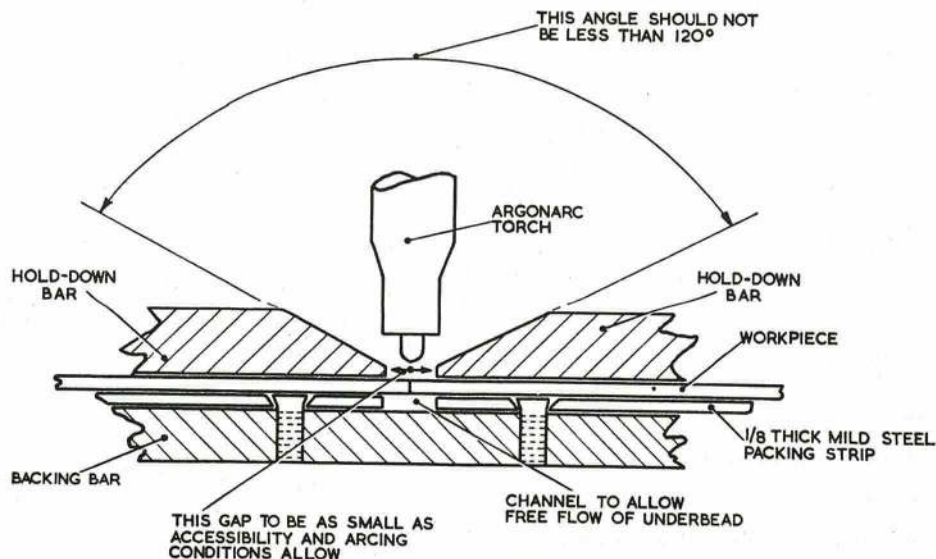


Fig. 37. JIG FOR THIN SHEET

Argonarc welding. In practice, restraint against distortion may be applied by clamps, jigs or fixtures, or by adequately tack-welding the component parts together.

Setting-Up the Workpiece

159. The information given in para. 66 to 68 for metal-arc welding applies equally to the Argonarc process. Two examples of simple jigs for holding workpieces during Argonarc welding are illustrated at Figs. 37 and 38.

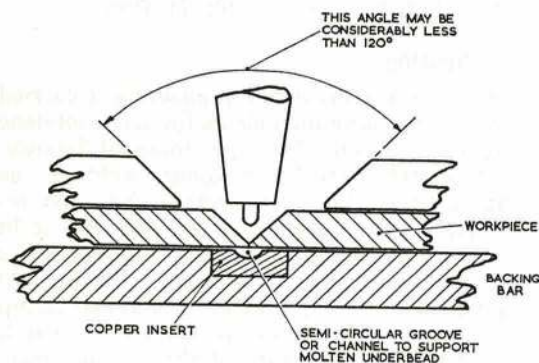


Fig. 38. HOLDING SHEET OR PLATE FOR BUTT WELDING

Electrodes

160. To obtain the best results from an electrode it is essential that it should be free from contamination and be ground to the correct shape. If an electrode becomes contaminated due to contact with the workpiece or by cooling out of the argon stream, it must be reground. A fine grinding wheel must be used, preferably one which is reserved for this purpose only. For general use an electrode should be ground to a taper equal to half the diameter of the electrode, but when currents of less than 20 amperes are to be used then the taper should be increased to two or three times the diameter of the electrode (Fig. 39).

WELDING TECHNIQUE

Operation

161. Having ensured that all is ready:—

- Switch on the mains supply.
- Depress the START (black) button of the composite rectifier; the red warning lamp should light.

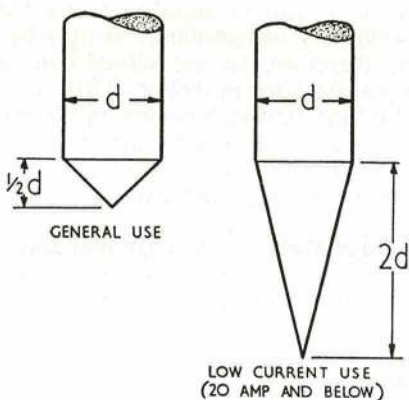


Fig. 39. ELECTRODE TAPER

- Ensure that the foot switch is in the OFF position by checking that the voltmeter is at zero.
- Set the desired current on the welding current control.
- Put the torch approximately in the welding position, and pull down the head mask.
- Depress the toe of the foot switch to make the composite rectifier contactor, then depress the heel of the switch to operate the spark starter. Initiate the arc (para. 163) and proceed to weld.
- On completion of the welding operation, depress the toe of the switch to extinguish the arc.
- Allow the electrode to cool to at least black heat in the argon stream, then hang the torch on the hook of the master valve lever.
- If no further welding is to be done, press the STOP (red) button of the composite rectifier to switch off; the red warning lamp will go out.
- Switch off the mains supply and close the argon gas cylinder.

Striking the Arc and Maintaining Arc Length

162. After the spark starter has been brought into operation, the torch should be moved slowly towards the workpiece, the electrode being at right-angles to the surface. When the tip of the electrode is approximately $\frac{1}{2}$ in. from the surface, a steady continuous stream of sparks should pass between it and the workpiece. The tip of the electrode should then be brought to between

$\frac{1}{4}$ in. to $\frac{1}{8}$ in. of the surface, depending on the type of material and the current. As soon as the arc is stable the starting device should be switched off.

Current

163. The selection of the current which should be used depends mainly on:—

- (a) The heat capacity of the work.
- (b) The amount of current which the particular electrode can withstand without undue overheating.

Butt Welds

164. The normal angles of the torch and filler rod are approximately 80 deg. to 90 deg. and 10 deg. to 20 deg. respectively from the surface of a horizontal plate (Fig. 40).

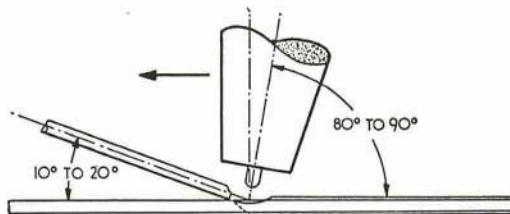


Fig. 40. TORCH AND FILLER ROD ANGLES

165. The filler rod should be fed into the leading edge of the molten pool (not into the arc core), and should be added with a slightly transverse scraping motion, with the tip of the filler rod actually making contact with the weld metal. This ensures that the rod

is at the same electrical potential as the work-piece during transfer of metal to the weld, and avoids any tendency to "spatter". The heated end of the filler rod must be kept in the argon gas shroud in order to prevent its oxidation.

166. Butt welds in thin gauge materials should always be done with a progressive forward motion without weaving. However, when welding medium and heavy section plate a different technique is required.

167. As the filler rod diameter increases with increasing thickness of workpiece, there is a tendency for the end of the rod to foul the tungsten electrode. Contamination of the hot electrode by particles of molten metal will cause "spluttering" of the arc, and particles of tungsten may become embedded in the weld. Such loss of tungsten will cause the arc to become erratic and unstable, and will necessitate replacement of the electrode before further welding is attempted. The arc length should then be increased slightly to accommodate the larger filler rod, but this procedure is limited because there is a maximum arc length beyond which good welding becomes impossible. The upper limit of arc length is usually about $\frac{1}{4}$ in. for aluminium, which does not allow the free access of a $\frac{1}{4}$ in. diameter filler rod.

168. For heavier sections, therefore, a forward and backward swinging motion of the torch should be used. The weld area should first be melted under the arc, the torch then being drawn backwards for about $\frac{1}{4}$ in. to $\frac{1}{2}$ in. along the line of the weld and the filler rod

- MOTION OF TORCH
1. WITHDRAW FILLER WIRE AND MELT UNFUSED PLATE
 2. WITHDRAW TORCH AND INSERT FILLER WIRE. CONTINUE OPERATIONS 1 & 2 UNTIL WELD IS COMPLETED.

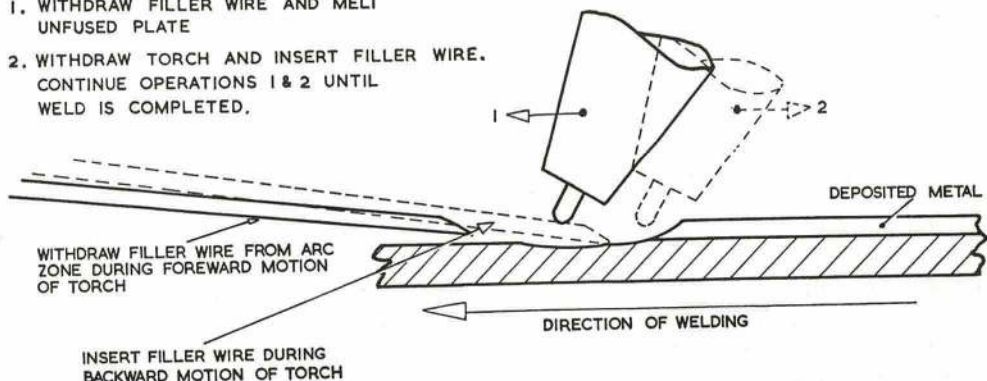


Fig. 41. MOTION OF TORCH AND FILLER ROD

inserted in the molten pool (Fig. 41). The torch should then be moved forward and the filler rod withdrawn simultaneously from the pool. A rhythmical motion of both torch and filler rod backwards and forwards in a progressive motion will melt the filler rod and workpiece, without the rod entering the core of the arc, and a good weld will result. This method is recommended when welding material over $\frac{1}{4}$ in. thick.

Fillet Welds

169. During a fillet welding operation the angle of the electrode should be 90 deg. to the line of weld and should bisect the joint angle. This prevents, as far as possible, fouling of the ceramic shield on the surface of the workpiece, and provides the best and most economical shrouding of the molten metal.

170. The filler rod should be fed into the molten pool at a very acute angle using the same technique as for butt welding. The backward and forward swinging motion should be used on sections thicker than $\frac{3}{8}$ in. so as to obtain full root penetration. Where permissible and practicable the joint should be tilted to assist the welder to obtain equal leg-length and avoid undercut of the vertical member.

171. When welding in awkward corners it is permissible to extend the electrode tip slightly beyond the $\frac{1}{4}$ in. from the ceramic shield, provided that at the same time the argon flow is increased slightly.

Speed

172. The speed of travel of the electrode across the workpiece is very important. Too high a speed will result in an irregular bead with little or no penetration. If the speed of travel is too low, too much metal will be deposited, the crater will be too deep, and the electrode will tend to overheat. Molten metal piling up at the rear of the crater will indicate whether the speed is correct; the depth of the crater indicates the depth of penetration being obtained.

Positional Welding

173. Positional welding should be avoided because it reduces welding speeds without reducing heat input, which may induce distortion unnecessarily. When it is not possible to avoid positional welding it is

advisable to use the downward vertical method on thin sheet and outside corner welds at normal welding speeds. Upwards vertical welding should be used on sections thicker than $\frac{5}{32}$ in.; at such times, some side-to-side or weaving motion may be necessary to avoid excessive droplet formation, the filler rod being inserted in fairly rapid and short bursts, thus depositing a very small amount of rod with each movement.

After-treatment of Welds

174. After-treatment usually consists of cleaning the weld surface and heat treatment where necessary. The best way to clean the surface is by wire-brushing, and whilst employed on such work the operator must always wear safety goggles. When heat treatment is required it is normally detailed on the approved drawing or specific order requirements.

ARGONARC WELDING FAULTS

General

175. The effects of various faults are similar in appearance to those shown in arc weld faults (para. 92). The following information outlines the causes of the defects and how they may be remedied. In all cases where it is necessary to remove defective metal it is essential that the surrounding areas are properly cleaned of slag and scale, and that the groove formed by removal of the defective metal is large enough to allow adequate manipulation of the electrode.

Lack of Penetration

176. This defect may be caused by incorrect preparation, wrong size of electrode, insufficient density of current, insufficient preheating of thick materials, or by the use of backing-bars or jigs. It can only be remedied by removing the defective metal and, after correct preparation, re-welding.

Lack of Fusion

177. Lack of fusion results mainly from insufficient cleaning, *i.e.*, the presence of foreign matter such as slag or oxides which prevent the metal from reaching fusion temperature. The fault may also arise if the welding speed is excessive or when the current density is too low. The only remedy is to remove the defective parts and re-weld.

Undercut

178. Undercutting may occur where heavy fillet welds are made in the standing position or, if the weld is being made on steel, where the plates are scaled or dirty. Fillet welds should, whenever possible, be done in the downhand position, tilting the workpiece as required. This defect may be remedied by additional weld metal, but if the undercutting is deep, it will be necessary to chip away some of the weld deposit and parent metal to ensure there are no slag inclusions before additional weld metal is deposited.

Edge of Plate Melted Away

179. This fault may occur in lap welds when welding without filler rod. To avoid this defect it is usual to place end tabs at the start and finish of a weld, so that the arc passes smoothly from the weld on to a piece of waste plate. This defect can be rectified by the deposition of additional runs of weld metal to restore the correct throat thickness.

Oxide Inclusions

180. Oxide inclusions may be due to: insufficient Argon gas around the weld area; too long an arc length; the contamination of Argon gas by water vapour; insufficient cleaning of the parent metal; and to the electrode protruding beyond the Argon shield. Rectification is by removal of defective portions and re-welding.

Porosity

181. This defect is usually caused by entrapped gas; it is rectified by removal of defective portions and re-welding. A number of factors may contribute to this condition:—

- (a) The composition of the parent metal and filler rod.
- (b) Insufficient Argon gas.
- (c) Contamination of the gas by water.
- (d) Incorrect density of current.
- (e) Poor preparation of the fusion faces of the joint.
- (f) Incorrect welding speed.
- (g) Excessive protrusion of the electrode beyond the Argon shield.

Incorrect Weld Size and Profile

182. These defects may be either undersize or oversize as measured by leg length in fillet welds or reinforcement on butt welds. When

the weld is undersize it may be corrected by depositing additional weld metal, and when oversize the excess may have to be chipped away.

Poor Surface Appearance

183. This may be seen as non-uniform surface ripples, surface porosity or pock marks, visible slag inclusions, faulty junctions where welding has been interrupted, or a crater at the end of a welding run. It can be rectified by removal of the faulty metal and re-welding, attention being paid to welding technique and position.

Spatter

184. This defect does not usually occur with Argonarc welds, except when using a tungsten electrode that is contaminated by particles of the weld metal. At such times a black or grey deposit is formed around the weld zone, possibly with particles of tungsten and other inclusions in the weld, or in the surface around the weld area. It can be remedied by chipping and wire-brushing the spatter deposits from the surface of the weld and parent metal and, if necessary, re-welding.

SERVICING

Warning

185. *Before doing any servicing, ensure that the electricity mains supply switch is in the OFF position to prevent any possibility of an electric shock.*

Checking for Gas Leaks

186. To inspect the connections for gas leakage, paint them with a soapy water solution and then turn on the gas at the cylinder. Any leaks will be indicated by the presence of bubbles; if these are observed, tighten the connections using the special spanner supplied with the torch outfit. The various tubes should be checked for leaks and/or chafing, and for signs of contact with heated metal. When it is found necessary to replace any tubing it should be bound with copper wire to the respective nipple.

Master Valve

187. If depression of the master valve lever fails to stop the flow of argon gas, close the cylinder valve and proceed as follows:—

- (a) Rotate the lever adjusting screw anti-clockwise and then hang the torch on the

(A.L. 11, June 62)

lever. Allow gas to flow from the cylinder and check that no gas enters the flow indicator.

(b) Should the movement of the adjusting screw fail to correct the fault, remove the hinge pin lock screw and withdraw the hinge pin and lever. Unscrew the plunger guide complete with plunger from the body and remove the diaphragm; check for serviceability and renew if necessary. Assemble in reverse order to dismantling.

Flow Indicator

188. Periodically, or if it is thought that gas consumption is excessive, remove the flow indicator from its union on the master valve and remove the outlet union from the flow indicator. Blow out any dust particles that may have accumulated, and refit and test the indicator. If it still appears to be faulty, return the item to the Equipment Section and fit a new indicator.

Gauges

189. At the specified times the pressure regulator gauge and the flow indicator gauge

should be returned for checking and calibration.

Ceramic Shields

190. If cracks have developed around the outlet orifice of a white shield, remove the shield from the torch and grind the end gently to form a new surface. This may only be done once because with further grinding the shield would lose its ability to guide the gas properly, and disturbance of the argon flow would result. Pink shields cannot be so ground because of their extreme hardness.

Electrodes

191. If contamination has occurred, remove the electrode and grind away the contaminated portion, using a fine grinding wheel reserved for this purpose.

Argon Cylinders

192. To preserve the purity of the gas, a cylinder should be removed for charging when the contents gauge registers 30 lb. per sq. in.



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