TM 9-2852

WAR DEPARTMENT TECHNICAL MANUAL

INSTRUCTION GUIDE

WELDING

THEORY AND APPLICATION

WAR DEPARTMENT • 3 JUNE 1943

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(For explanation of symbols, see FM 21-6.)

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PART ONE — Introduction to Welding, Study of Metals, Basic Considerations in Oxyacetylene and Electric Arc Welding

CHAPTER 1

GENERAL

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Purpose	1
Scope	2
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1. PURPOSE.

a. This Technical Manual is published for the information of both the using arms and services and ordnance maintenance personnel. It also contains information which makes the publication of a convenient reference manual.

2. SCOPE.

a. Every ordnance maintenance shop, stationary or mobile, handles maintenance and repair work of varying degrees of complexity. This work usually involves blacksmithing, welding, or cutting, or all three. The theory, equipment, procedure, and technique for such work are described in this manual. This publication is primarily concerned with oxyacetylene and electric arc welding of different metals. Brief descriptions of other welding processes are given, and certain special operations capable of accomplishment by use of the facilities normally available for the welding processes are discussed.

3. REFERENCES.

a. A list of references is given in paragraphs 279 and 280. It includes all Technical Manuals and other publications used in the writing of this manual, as well as a list of publications which are recommended for supplementary reading by the student.

CHAPTER 2

INTRODUCTION TO WELDING

Section I

GENERAL

Paragraph
Definition of welding........ 4
Scope and application of welding........ 5

4. DEFINITION OF WELDING.

a. The joining of metal parts by welding consists of fusing the material together while it is in the plastic or molten state. Heat for melting the metals is most often obtained from a gas flame or an electric arc and additional metal for filling in and reinforcing the weld is melted off from the end of welding rods available for that purpose. In some cases the weld can be made without the use of a welding rod.

b. Definitions of welding terms will be found in paragraph 281.

5. SCOPE AND APPLICATION OF WELDING.

a. Almost all metals can be welded by one or the other of the welding processes mentioned in paragraphs 6 to 10. Metals which have been specially processed, as by heat treating or drop forging, do not ordinarily allow the use of welding in fabrication or making repairs, since the characteristics of the metal are usually adversely affected as a result of the heat applied to the metal during the welding process. Special welding materials and techniques, however, do enable the welder to work on some of these metals. Applications to which welding equipment can be applied in addition to the process of welding are: flame hardening, hard surfacing, flame machining, etc. (pars. 166 to 174). Welding equipment is also used for various brazing and soldering operations.

CHAPTER 2

INTRODUCTION TO WELDING (Cont'd)

Section II

WELDING METHODS

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Forge welding	7
Torch or blowpipe welding methods	8
Electric welding methods	9
Thermit welding	10

6. GENERAL.

a. There are many ways of producing the fusion of metals (fig. 1.). The most important processes are discussed briefly in the following paragraphs. Oxyacetylene welding and electric arc welding will be covered in greater detail in other chapters of this manual.

7. FORGE WELDING.

a. Forge welding is accomplished by heating the ends of metal parts, which are to be welded, in a forge fire. Coal, coke, or charcoal is used as a fuel for the fire. The ends to be joined are heated until the metal is in a plastic state and then the two pieces are united by the application of pressure or by hammering. Forge welding is confined to welding of wrought iron and the lower carbon steels. Alloy steels, as well as most nonferrous metals, cannot be satisfactorily joined by forge welding.

8. TORCH OR BLOWPIPE WELDING METHODS.

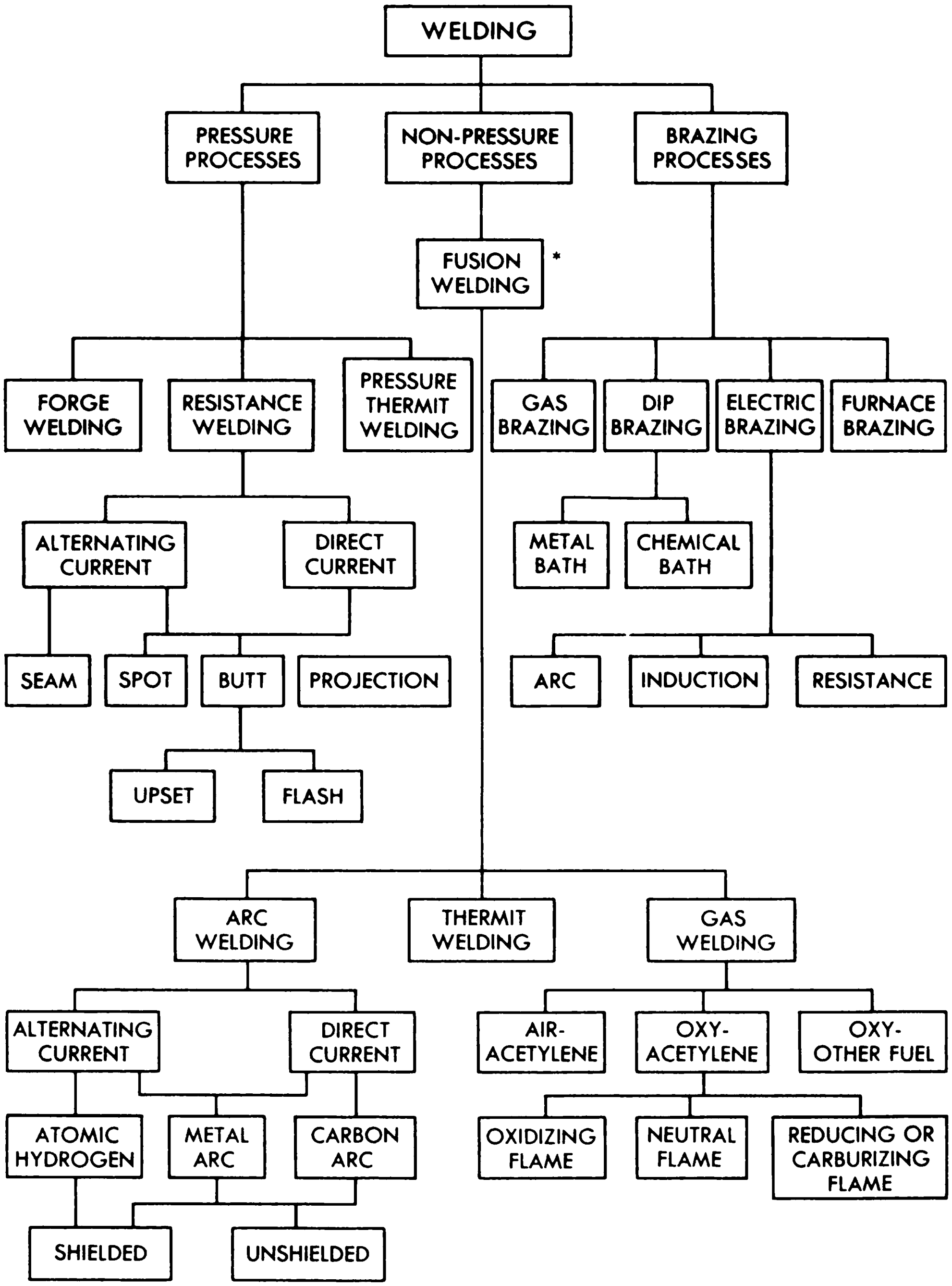
a. Torch or blowpipe welding is accomplished by heating the ends or edges of metal parts to a molten state with a high-temperature flame. This flame is produced with a torch or blowpipe, burning a special gas, such as acetylene or hydrogen, with pure oxygen. The metal, when in a molten state, literally flows together to form a union and the application of mechanical pressure is not required. Blowpipe welding is used extensively in both the manufacturing and repair fields and may be applied to all weldable materials (chs. 5, 6, 7, and 10).

9. ELECTRIC WELDING METHODS.

a. There are several forms of electric welding, in which electrical energy is converted into heat for welding purposes. Electric arc welding, electric resistance welding, and atomic hydrogen arc welding are the methods in general use.

INSTRUCTION GUIDE — WELDING — THEORY AND APPLICATION

MASTER CHART OF WELDING PROCESSES



* THIS TERM (FUSION WELDING) HAS BEEN ESTABLISHED BY LONG USAGE. IT IS RECOGNIZED, HOWEVER, THAT SOME OF THE OTHER WELDING PROCESSES INVOLVE FUSION

RA PD 70952

Figure 1 — Chart of Welding Processes

(1) ELECTRIC ARC WELDING. Electric arc welding is a fusion method of welding in which the heat liberated in the arc stream and at the arc terminals is used to melt or fuse the metal in the weld area. Arc welding is employed for both manufacture and repair and can be satisfactorily used in the joining of all weldable metals. The melting metal flows together to effect a union without the application of pressure in any form. There are three general forms of arc welding; metal arc, carbon arc, and atomic hydrogen processes. Each one of the processes is particularly adapted to certain types of work.

(a) Metal Arc Process. The metal arc process is the most important electric arc process. In this method the metal welding electrode is used as one of the terminals of the arc while the work is made the other. An arc formed between these terminals simultaneously fuses the electrode and the work. The melting metal from the electrode is carried through the arc and deposited in the melting metal of the work to make the weld.

(b) Carbon Arc Process. In the carbon arc method, a carbon or graphite electrode is used as one terminal of the welding arc; the work is used as the other terminal. The work, at the joint, is melted or fused by the arc. If additional metal is required, a metal welding rod is fed into the joint and simultaneously fused with the work to make the weld.

(c) Arc Torch Process. This process employs two carbon or graphite electrodes, between which an arc is formed. This arc flame is used to fuse the work at the joint in the same manner as a torch flame in the oxyacetylene method. Filler metal is added where necessary by means of a welding rod.

(d) Atomic Hydrogen Process. This process employs two tungsten electrodes. An alternating-current arc is maintained between the ends of these electrodes and a stream of hydrogen gas is passed into the arc and around the electrodes. The heat of the arc breaks up the molecules of hydrogen into atoms which recombine outside the arc to form molecular hydrogen again. The intense heat liberated by the atomic hydrogen as it recombines is used to fuse the metal as in torch welding. The hydrogen surrounding the weld area also serves to exclude oxygen and nitrogen and to prevent the bad effects created by the reaction of these gases with the molten metal. The resulting weld metal is therefore more ductile and more easily machined than weld metal produced by other means.

(2) ELECTRIC RESISTANCE WELDING. Resistance welding is a process whereby a low-voltage, high-amperage current is brought to the work through a heavy copper conductor offering very little resistance to its flow. The work placed in the path of the current flow sets up a high resistance to it, and the heat generated by this resistance is sufficient to fuse the parts together at their point of contact. All resistance welding machines are simply alternating-current,

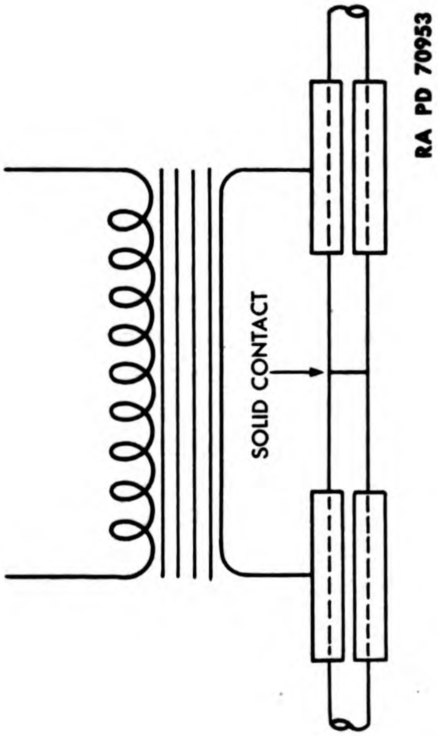


Figure 2a — Elements of Upset-Butt Welding

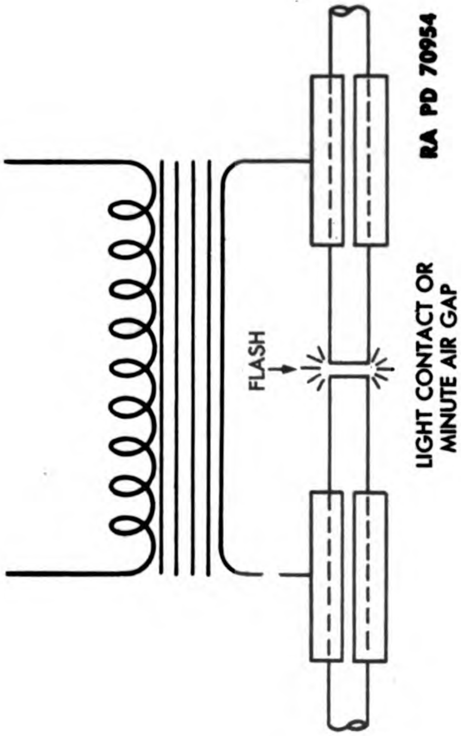


Figure 2b — Relationship of Parts for Flash Welding

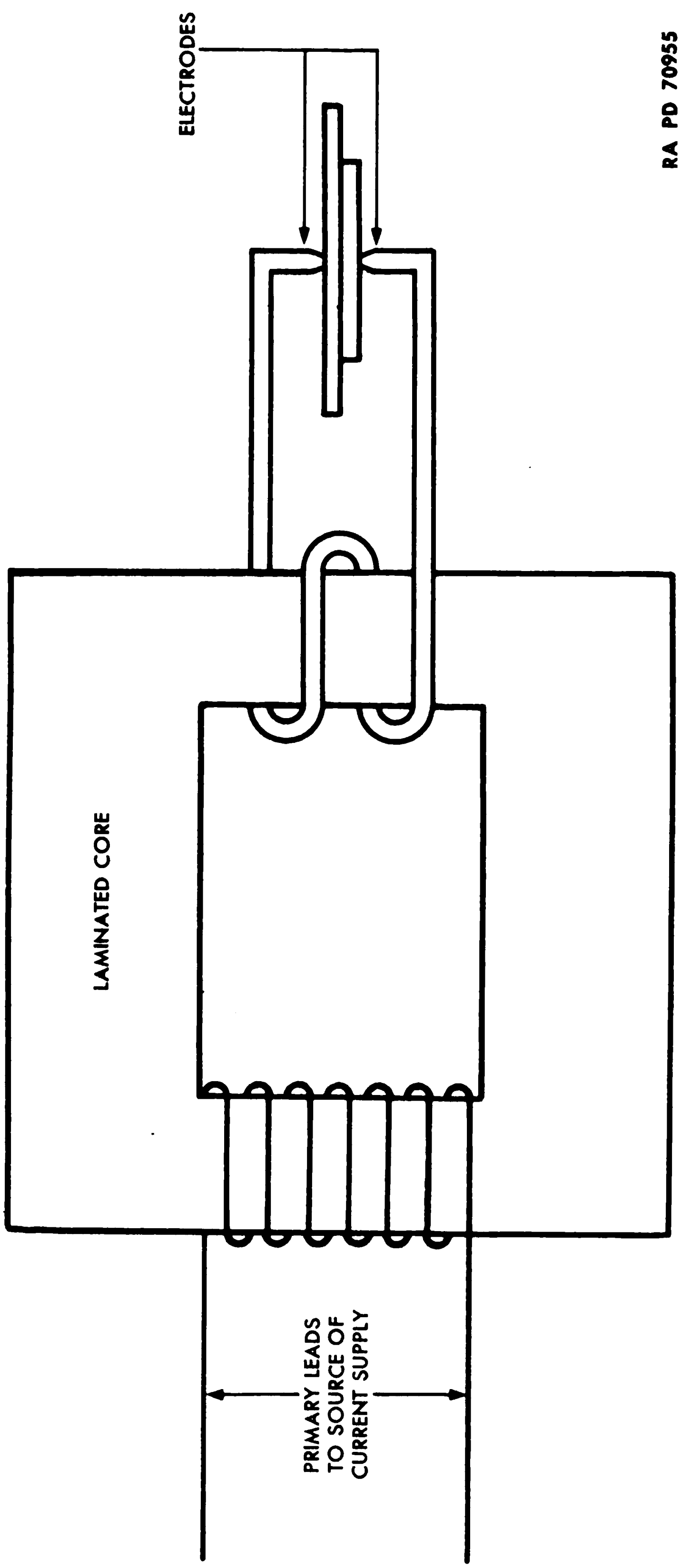


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Figure 3a — Schematic Diagram of a Typical Resistance Spot Welder single-phase transformers, having a secondary coil of one or two turns of very heavy wire. Both the primary and secondary coils of the transformer are wound on a heavy core or frame, and the leads from the high-amperage or secondary side are connected to clamping jaws that are brought together upon the work to be welded (figs. 3a and 3b).

(a) Types of Resistance Welders. Resistance welding is particularly adapted to duplicate or production work and is employed to a considerable extent in the aircraft and automotive industry. Several forms are in common use and may be described as follows:

1. Butt Welding Machine. The butt welding process consists of joining pieces end to end. The welding current flows through the parts to be joined and encounters its highest resistance at their point of contact. The heat generated is sufficient to produce complete fusion of the cross section making a sound weld. The butt welding machine is a simple device composed of a suitable transformer whose high-amperage leads terminate in a pair of jaws. One of these jaws is stationary, while the other is movable by means of a lever. Both

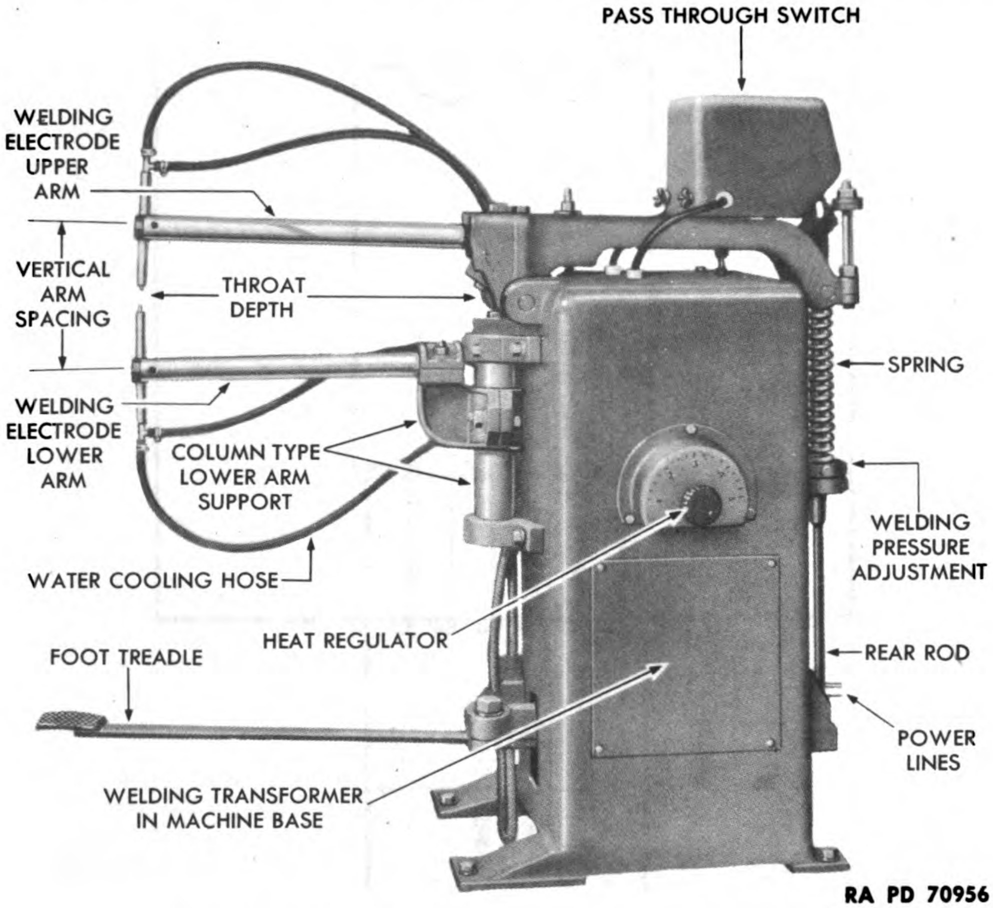

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Figure 3b — Electric Resistance Spot Welder jaws have clamping ends to which the pieces to be welded may be attached. When the work is clamped in place, the circuit is closed, and the lever moved to bring the butt ends of the work together.

2. *Spot Welding Machine.* Spot welding consists of passing the welding current through the plates or sheets to be joined at the "spot" or point of electrode contact. The electrodes are generally made of copper and arranged in a manner whereby considerable force or squeeze may be applied to the metal during the welding process. Spot welding is particularly adaptable to thin sheet metal construction and has many applications in this type of work. Figure 3b shows a typical spot welding machine. The electrode jaws are extended in such a manner as to allow a weld to be made a considerable distance from the edge of the sheet. The copper electrodes terminate in blunt-end die points which concentrate the heat in a small area. A pedal trip or release is generally used to regulate the movement of the jaws, and its action may be manually controlled. A control is also provided for current regulation.

3. *Flash Welding Machine.* In flash welding, the fusing of the parts is accomplished in three steps. The metals to be joined are first subjected to a light pressure between the electrodes, then separated very slightly to allow arcing to occur. The small arc brings the metals to their melting points at the separated edges, and, as a final operation, the parts are forced together by means of heavy pressure. As they meet, the molten metal and oxides are thrown out and a clean fusion results.

NOTE: Butt welding and flash welding can both be performed and are performed with the same machine. The only difference between the two methods is sequence in which the various operations are performed and the timing and power levels or energies used.

4. *Shot Welding Machine.* Shot welding is simply a spot welding process using a high-power level and a very short period of application of the heat or energy. Since the time of contact is much shorter than can be determined by an operator, an automatic timing device is employed. By this process, welds are made that have practically no annealed or critical zone, and the system is therefore particularly adaptable for aluminum alloys and stainless steel. Shot welding machines are very similar to the spot welder illustrated in figure 3, the material difference being in the delicate timing mechanism built into the machine for controlling the operation. This mechanism consists of either a synchronous timer or Thyratron tube. The electrode is generally applied either by compressed air or a hydraulic system, although mechanical means are sometimes used. Many attachments are furnished with this machine, such as a portable "gun" and adapters for large, flat jigs, etc. Current is controllable in graduations of one to two cycles, and the electrode pressure may also be regulated to the desired amount.

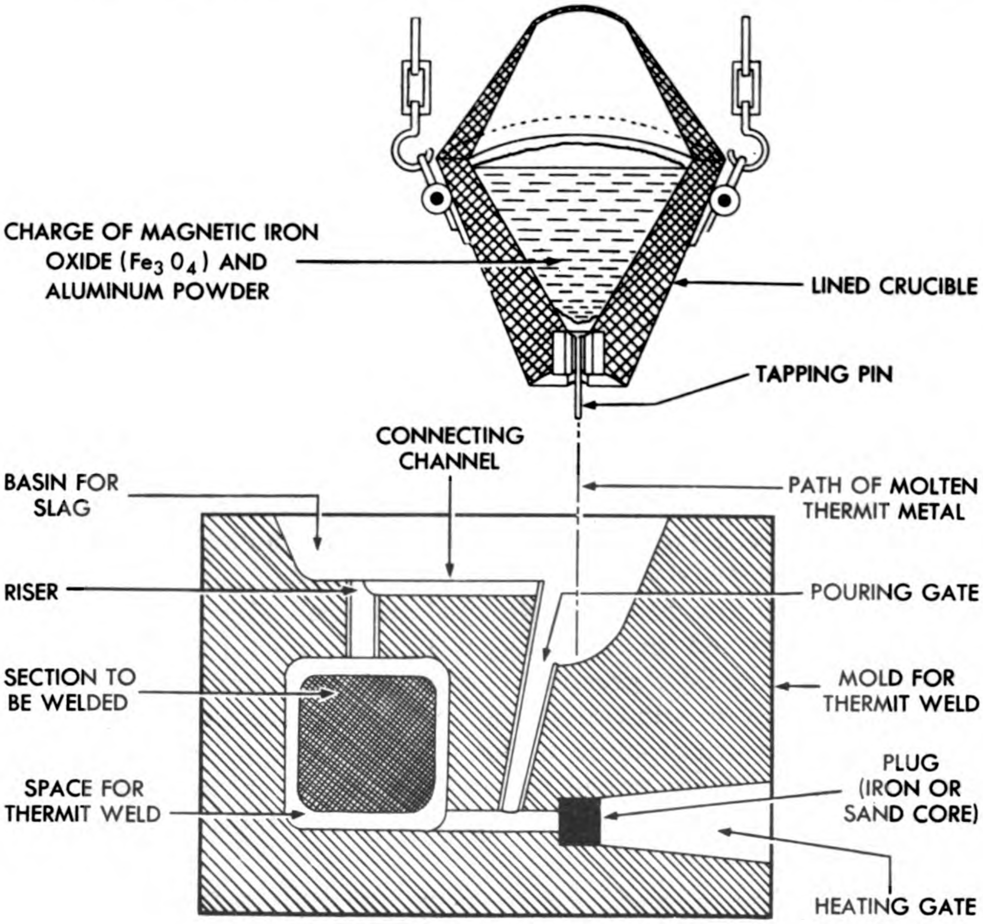

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Figure 4 — Thermit Welding

10. THERMIT WELDING.

a. The thermit welding process (fig. 4) is a casting process which uses superheated liquid steel to make the fusion weld. The very intense heat of the liquid steel, whose temperature is approximately 4,560 F, is used to heat the parts being welded to their welding temperature. The thermit welding process makes use of the rapid rate with which aluminum combines with oxygen, as well as the great amount of heat given off during this chemical reaction. A mixture by weight of approximately ten parts magnetic iron oxide (Fe_3O_4) and three parts of finely divided aluminum is placed in a refractory-lined crucible and ignited by means of a highly inflammable powder composed largely of barium peroxide. This reaction is nonexplosive and requires about 30 seconds for completion. It causes the oxygen to leave the iron oxide and combine with the aluminum. This mixture, when the reaction is complete, will produce seven parts of very hot molten steel by weight, the remainder being an aluminum oxide slag. The free steel thus formed is nearly 1,600 F higher in temperature than ordinary molten steel. It is drawn off from the crucible by tapping and poured into a mold previously prepared around the parts to be welded. The high heat of the steel causes the parts in the mold to become molten while the metal poured into the mold acts as filler metal for the weld. This process is known as the thermit fusion welding process.

b. In some cases, both the steel and aluminum slag are poured into the mold. This process, known as thermit plastic welding or pressure thermit welding, uses the high heat content of the aluminum slag and molten steel, in heating to a plastic state the parts to be joined. The metal parts are then drawn up at the joint by means of clamps to make the weld. The metal poured into the mold is not used as filler metal in this process, and it is removed after the joint is made.

c. The thermit welding process is particularly useful in welding large sections and in the repair of heavy parts such as railroad tracks, connecting rods of locomotives or other large engines, large castings, pipe, and other heavy machine frames. It has its limitations in that the molds required to hold the thermit charge are usually complicated and large. Although the principal application of welding with the thermit process has been on steel structures with the use of iron oxide and aluminum mixtures, other metals or their oxides may be included in the thermit mixture, such as chromium, nickel, manganese, tungsten, titanium, molybdenum, and cobalt. These elements alloy with iron and are used primarily where higher strength, ductility, or hardness are required for special welding applications, and, also, they permit control of both the temperature and the time of the reaction. Cast-iron can be welded with the thermit welding process by means of a special thermit mixture.

d. The precautions to be taken in preparing the joint for thermit welding are very much the same as those required for other methods of fusion welding. The parts or sections to be welded are first cleaned of any slag, dirt, grease, or other foreign matter, and the joints are alined and firmly held in place. Enough of the metal at the joint is removed to permit a free flow of the molten iron to be poured. A wax pattern is then made around the parts at the joint to the size and shape of the intended finished weld. A mold made of refractory sand is built around the wax pattern and joint to hold the molten metal after it is poured. The parts are then preheated to melt out the wax and to dry out the mold. This is usually done by means of gasoline-and-air or kerosene-and-air burners. Care is also taken to vent the mold to permit the escape of gases and to allow a better distribution of the thermit metal at the joint. Preheating by means of these burners permits welding of large sections without setting up shrinkage strains when the weld cools. The thermit metal is poured into the mold through one or more pouring gates, depending upon the size of the section to be welded. Sufficient space is allowed for slag to collect and also for risers to form, in order to obtain a good distribution of hot metal at the joint. After pouring, the mold is allowed to remain in place for several hours in order to anneal the weld. Since the weld metal deposited cools uniformly, it is comparatively free from stresses. Its physical properties resemble those of forged steel. The mold is then removed, the risers and gates are cut away with an oxyacetylene torch, and machining may be used when desirable. The last step applies particularly to welded shafts or similar parts, where the collar of reinforcing metal at the joint would interfere with the finished dimensions required. Rectangular sections as large as 30 inches by 48 inches have been welded by the thermit welding process.

CHAPTER 2

INTRODUCTION TO WELDING (Cont'd)

Section III

CUTTING METHODS

Paragraph
General 11
Flame cutting 12
Electric arc cutting 13

11. GENERAL.

a. In welding practice the term cutting is used to describe the process whereby metal is separated into pieces by the use of welding apparatus. There are two basic cutting processes encountered in cutting practice: oxygen (flame) cutting and electric arc cutting. These processes are further applied as indicated on chart, figure 5.

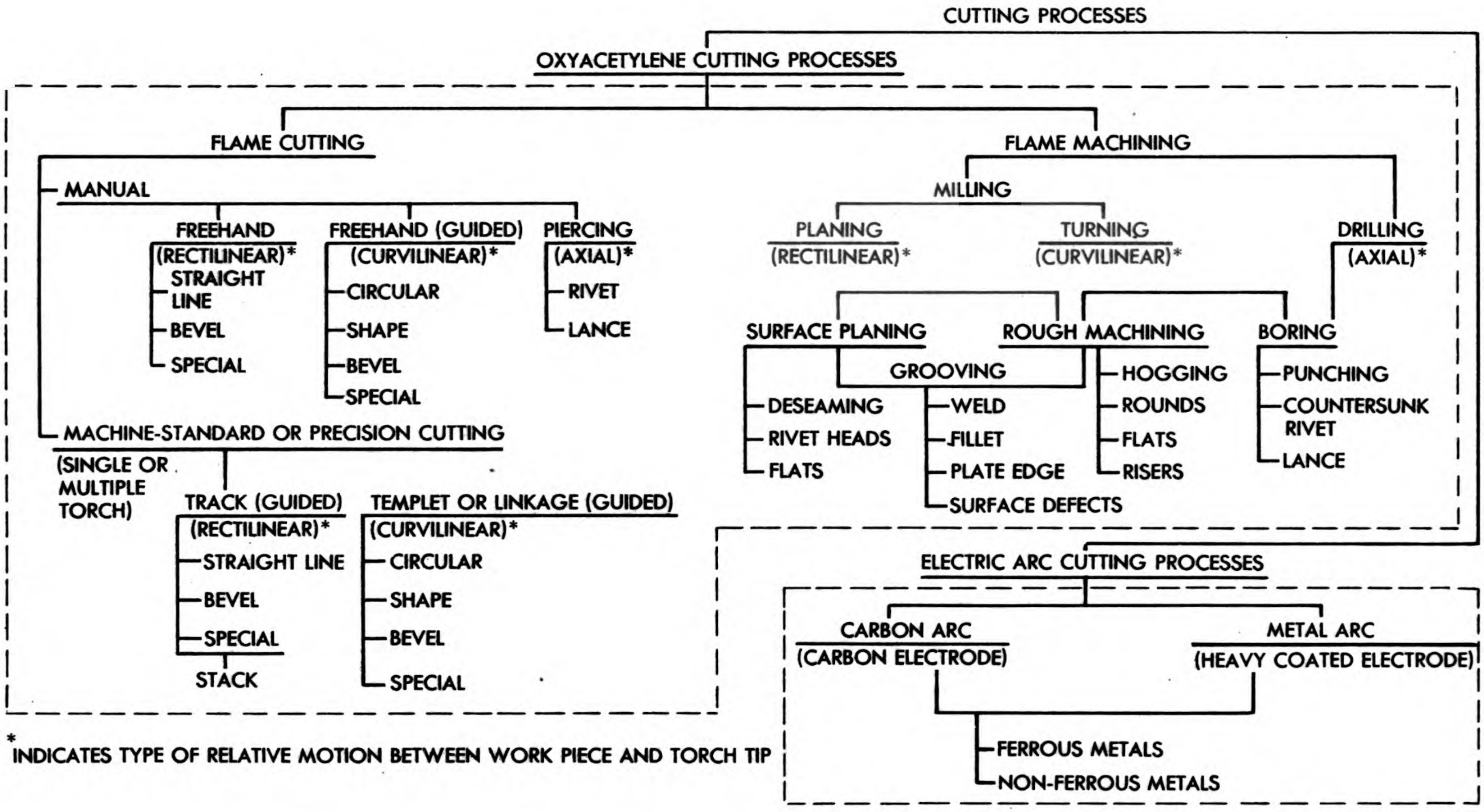
12. FLAME CUTTING.

a. Flame cutting is applied to ferrous metals almost exclusively. It is based on the principle that iron will burn very rapidly in an atmosphere of pure oxygen after the metal is brought up to its kindling temperature which is about 1,600 F. In flame cutting, preheating flames are used for the purpose of heating the metal to its kindling temperature. After this, a quick acting valve is operated which projects a stream of oxygen from the cutting tip onto the heated area to produce the cutting action.

b. Oxygen Lance. The oxygen lance is nothing more than a piece of ¼- or ⅜-inch standard black iron pipe connected to a source of oxygen which is controlled by means of a suitable valve. A separate torch is used to bring the metal to be cut up to the kindling temperature, and then the end of the lance is brought against the heated area, and oxygen at about 40 to 60 pounds per square inch pressure allowed to flow through the pipe. The ferrous metal is burned and in so doing produces sufficient heat to maintain the cutting action without the use of the separate heating source.

13. ELECTRIC ARC CUTTING.

a. Electric arc cutting is a melting process using the heat of the electric arc to melt the metal along the desired line of cut. The quality of the cut is not as good as that produced by the other processes, but the procedure can be applied to almost all metals.



* INDICATES TYPE OF RELATIVE MOTION BETWEEN WORK PIECE AND TORCH TIP

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Figure 5 — Chart of Cutting Processes

CHAPTER 2

INTRODUCTION TO WELDING (Cont'd)

Section IV

SAFETY CONSIDERATIONS

Paragraph
General 14
Protection of the eyes 15
Fire hazards 16
Inflammable or explosive substances 17
Ventilation 18

14. GENERAL.

a. The handling of any type of welding equipment requires that a certain amount of care and precaution be taken to avoid serious accidents and fires. The following general precautions should be strictly observed by all workmen who do welding or cutting by the various processes. Specific safety instructions regarding electric arc and oxyacetylene welding will be found in chapters 5 and 8 respectively.

15. PROTECTION OF THE EYES.

a. Goggles, spectacles, or helmets with colored lenses should always be worn when welding or cutting by any process. This is necessary in order to safeguard the eyes against harmful light rays and to prevent particles of hot metal from coming in contact with the face or the eyes. After welding steel for a short time, the welder will find small particles sticking to the lenses. These particles are iron oxides which would cause injury to the eye if goggles or helmets are not worn. The color of the lenses is an added protection against the intensity of white light or glare, in order to prevent eye strain and at the same time to make it possible to see the metal clearly. The color used is usually some shade of blue or brown.

b. For electric arc welding, the lenses are mounted in a helmet constructed of a strong fiber material that provides protection for the face and head. This protection is necessary, since the ultraviolet rays produced in the arc will cause painful burns to the skin and eyes.

16. FIRE HAZARDS.

a. Welding or cutting should not be undertaken in areas where fire is forbidden, nor should work of this nature be performed near inflammable materials unless proper precautions are taken to prevent ignition.

b. In any form of welding or cutting, hot slag, sparks, and globules of molten metal are formed and sometimes fly appreciable distances. When possible, inflammable materials attached to or near equipment requiring welding, cutting, or brazing should be removed, particularly if there are large quantities of such materials, as a fire, once started, cannot be controlled with the ordinary fire-fighting equipment generally on hand. By the time adequate fire-fighting apparatus has been called in, the fire will have progressed to large dimensions. If it is not practical to remove the parts to be welded or to move the inflammable material to a safe location, a suitable shield of asbestos or other effective heat-resisting material should be used to protect the inflammable material. This procedure should be adopted only where, in the event a fire should get started, damage will not be great. It should never be tried in the vicinity of large stocks of inflammable materials. The results of such unsafe practices may be observed in the case of the former French liner Normandie which was being converted into a naval auxiliary for the U. S. Navy. In this case cutting operations were carried on in the vicinity of large quantities of life preservers which were filled with an inflammable material. Sparks from the cutting torch ignited the material in spite of precautionary shields, and, before the fire was brought under control, three entire decks of the ship were burned. The liner later capsized as a result of the huge quantities of water, used in fighting the fire, which accumulated in her holds and decks.

c. When making repairs with an open flame on equipment such as an airplane, ample precautions must be taken to prevent fire. The equipment being repaired should be placed outside of the hangar or near the door, so that it could be quickly moved to the outside in case of fire. It must also be a safe distance from other aircraft or equipment considered inflammable. If welding is to be done in close proximity to the gas tank, the tank should be removed or drained and filled with water.

17. INFLAMMABLE OR EXPLOSIVE SUBSTANCES.

a. In the heating, welding, or cutting of tanks that contain or have contained inflammable or explosive substances, a number of precautions must be carefully observed to prevent danger of an explosion.

b. Never attempt to weld, cut, braze, solder, or otherwise heat an empty container that previously contained an inflammable or explosive substance, unless all such substances and its latent fumes have been completely removed and the container is well vented.

c. Never attempt to weld, cut, braze, solder, or otherwise heat closed cylinders or jackets unless such units are amply vented.

d. Fuel Tanks. Fuel tanks should be given special consideration since they are frequently encountered in welding operations. Never weld a closed tank, container, or any vessel until every precaution has been taken to vent the confined air sufficiently. This can be done by drilling the vessel or by removing any screwed-in plugs or connections; otherwise, the vessel will act as a bomb. In general the vessel should be prepared as follows before welding operations are started:

(1) Thoroughly steam the vessel until all traces of gas smell are gone.

(2) Use either CARBON TETRACHLORIDE or other noninflammable chlorinated hydrocarbons to clean the tank. Leave some of the chemical compound in the tank during welding. It will fill the tank with fumes and thus prevent an explosive mixture of gasoline vapor from forming in the tank. CARBON TETRACHLORIDE gives off a poisonous vapor when heated to the welding temperature. Therefore, if the operator is subjected to the vapors, he should be provided with a suitable gas mask as a precautionary measure.

(3) Flush the tank with water and fill it to overflowing with water before welding.

18. VENTILATION.

a. The fumes of burning paint are usually laden with particles of lead or zinc, which are poisonous, as are the fumes generated during brazing, welding, and cutting of brass, zinc, and galvanized parts. Under the action of the electric arc, nitrogen and oxygen from the air are converted into poisonous compounds, and, if welding is conducted in a very confined space, these poisonous compounds may become so highly concentrated as to cause death or permanent disability because of the physiological effects if inhaled. Extreme care must therefore be taken to avoid inhaling these gases in any appreciable quantity.

b. During operations in an inadequately ventilated place, the fumes or gases generated in the welding process, or the reduction of the oxygen in the air and the formation of carbon dioxide by the flame, may overcome the operator. For this reason, welding should not be attempted in such places unless adequate forced ventilation is provided or the operator is supplied with a suitable signaling device and an assistant is stationed nearby to render aid when necessary.

c. When it is necessary to weld in a confined space, make certain that there is proper ventilation and that no trace of gasoline, acetylene, or other explosive vapors is present in the area. Wear woolen or other suitable fire-resistant clothing, and have an assistant present to close the cylinder valves and render other aid in case of emergency.

d. It is a good practice, when an operator is welding in the vicinity of inflammable materials or in a confined space, to station the assistant nearby, but outside the danger zone, with express instructions to watch out for fires and to keep the welder under observation in order to detect as soon as possible any signs of the latter's being overcome.

CHAPTER 3

THE METALS: CHARACTERISTICS, HEAT TREATMENT, AND IDENTIFICATION

Section I

IRON: ITS ORIGIN AND PRODUCTION

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Pig iron 22
Difference between cast irons and steels 23

19. GENERAL.

a. Most of the metals used commercially may be welded by one or the other of the methods mentioned in chapter 2. A brief description of these metals is given in this section; ferrous metals, which are most important as far as the welder is concerned, are discussed in greater detail.

b. Iron and its alloys are the materials that the welder will normally have to work upon. These metals will appear in the form of cast iron, carbon steels, tool steels, etc., in nearly all work that must be operated on. The various alloys of iron have as their basis iron ore, which, after undergoing certain processes, becomes pig iron, gray cast iron, white cast iron, malleable iron, wrought iron, Bessemer steel, open hearth steel, basic and acid steels, alloy steels, carbon steels, etc. (chart, fig. 6).

c. Pure elemental iron exists only as a laboratory curiosity. All of the commercial irons mentioned above are mixtures of iron with carbon, manganese, sulphur, phosphorous, and silicon. Other elements are also present, but only in such amounts as will not appreciably effect the characteristics of the metal.

20. IRON ORES.

a. The principal iron ore is hematite (Fe_2O_3), a chemical compound of iron (Fe) and oxgen (O), identical in composition with red iron rust. Hematite is either deep red or black in color and, when pure, contains about 70 percent iron.

b. Another ore is magnetic iron oxide (Fe_3O_4), also called iron scale, magnetite, or when magnetized, lodestone.

21. CONVERSION OF ORE TO IRON.

a. Iron ore is smelted in the blast furnace (fig. 7) to remove the oxygen and to separate the foreign earth matter. Limestone is used as a flux to combine with the earth matter to form a liquid slag.

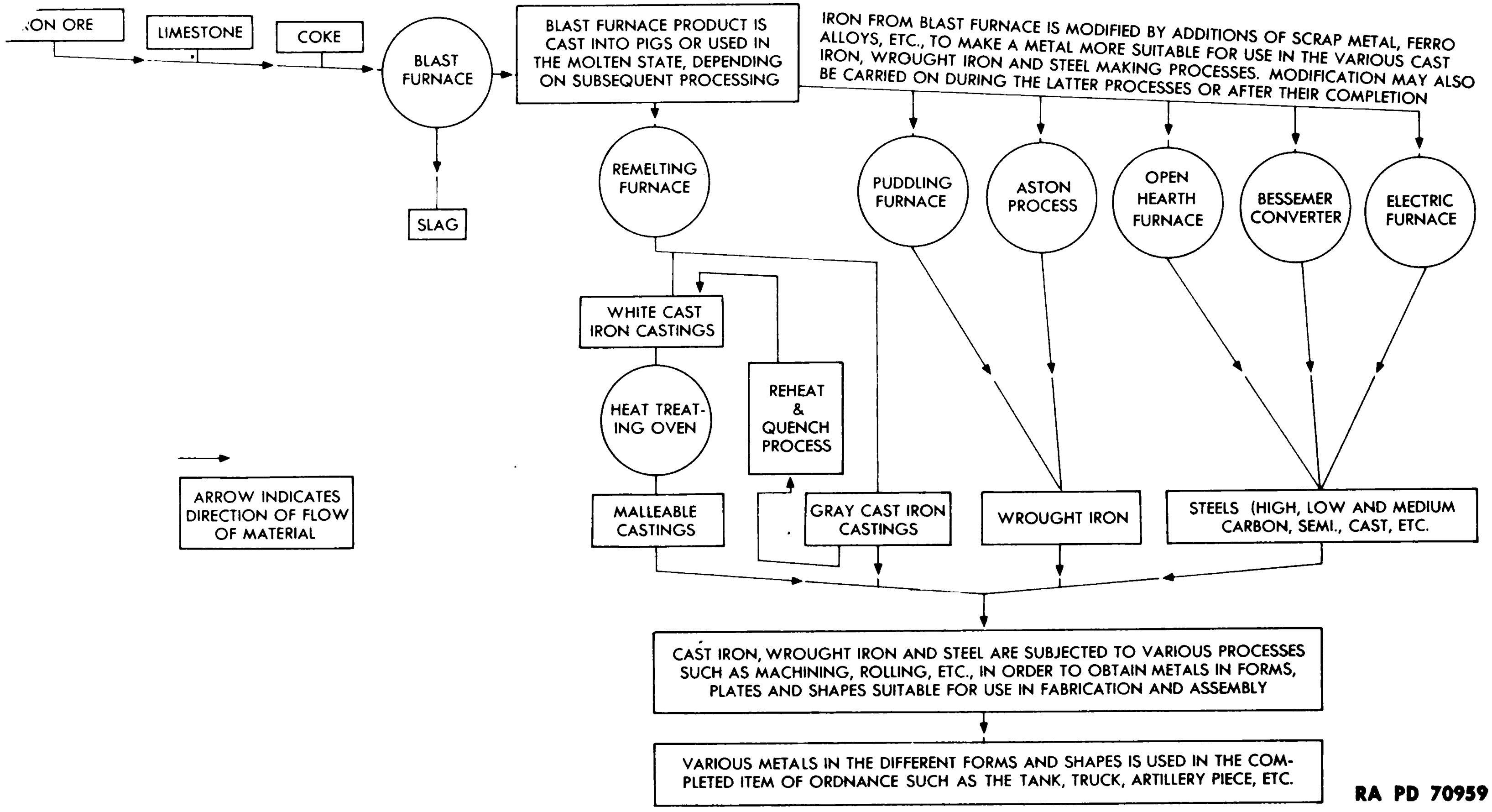

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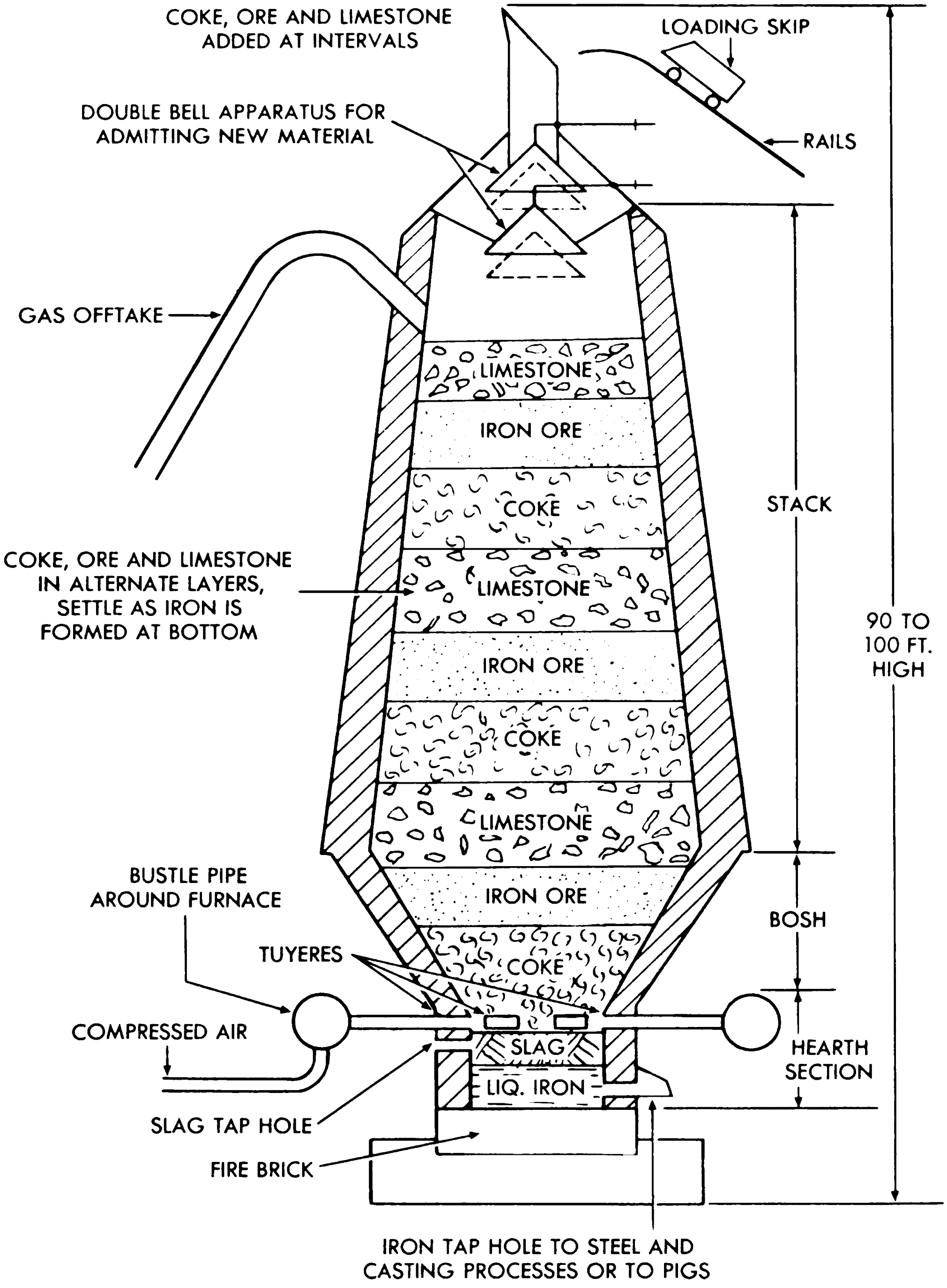
Figure 6 — Flow Chart Showing Conversion of Iron Ore into Cast Iron, Wrought Iron, and Steel



Coke is ignited at bottom and burns under forced draft. As it burns away, ore and limestone are converted to liquid iron and slag. All materials move downward by gravity and stack is kept filled by fresh charges admitted through bells. Slag and iron are tapped off at intervals as they accumulate. 60 tons of metal at each tap or 750 tons a day is average blast furnace output.

RA PD 70960

Figure 7 — The Blast Furnace

The iron ore, limestone, and coke are charged into the top of the furnace. Rapid combustion with a blast of preheated air causes a chemical reaction to take place in the smelter, during which the oxygen is separated from the iron. The iron melts and is drawn off through a taphole in the smelter.

b. The process of reduction is rather complicated chemically, but the net effect is the conversion of the ore into liquid iron in the hearth of the blast furnace. Slag, consisting of the limestone flux and the ash from the coke, together with compounds formed by reaction of the flux with substances present in the ore, floats in a molten state on the iron. The heavier liquid iron settles beneath the lighter liquid slag, and each is drawn off separately.

22. PIG IRON.

a. The liquid metal from the blast furnace is run into molds, holding approximately 100 pounds of iron, to form bars which are termed pig iron.

b. Pig iron is coarsely crystalline and of low strength. It contains some 4 percent carbon and varying percentages of other elements.

c. Pig iron is used in castings by remelting, adding small amounts of other elements, and pouring into a mold. Various types of cast iron are obtained through certain treatments to be discussed later.

d. Pig iron becomes steel in the open-hearth furnace, Bessemer converter, crucible, or electric furnace.

23. DIFFERENCE BETWEEN CAST IRONS AND STEELS.

a. In the following paragraphs it will be noted that the various forms of cast iron, steel, and wrought iron (i.e., white cast iron, gray cast iron, malleable iron, cast steel, high- low- and medium-carbon steels, etc.) consist of chemical compounds and mixtures of iron, carbon, and various other elements present in small quantities. Whether the metal is classified as cast iron or one of the steels depends entirely upon the amount of carbon in it. The following table illustrates the principle:

Item	Percent Total Carbon	Condition in Which Carbon Is Incorporated
Pig iron	4	free and combined
White cast iron	3.5	mostly combined
Gray cast iron	2.5 to 4.0	0.60 to 0.90 free, 2.60 to 2.90 combined
Malleable cast iron	2.0 to 3.5	free and combined
Tool steel	0.80 to 1.70	all combined
High-carbon steel	0.50 to 0.90	all combined
Medium-carbon steel	0.30 to 0.50	all combined
Cast steel	0.15 to 0.60	all combined
ow-carbon steel	up to 0.30	all combined

b. Cast iron differs from steel principally because in cast iron, the excess of carbon (that exceeding the 1.70 percent which will dissolve in iron at 1,150 C) is precipitated throughout the matrix as flakes of graphite, thereby causing most of the remaining carbon also to precipitate. These particles of graphite form the path through which failure occurs and are the reason why cast iron is brittle.

c. By carefully controlling the *silicon content* and *rate of cooling* of cast iron, it is possible to cause any definite amount of the carbon to precipitate as graphite or to remain combined as Fe_3C. Thus we have white, gray, and malleable cast iron, all produced from similar base metal.

CHAPTER 3

THE METALS: CHARACTERISTICS, HEAT TREATMENT, AND IDENTIFICATION (Cont'd)

Section II

CAST IRON: WHITE, GRAY, AND MALLEABLE

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Malleable cast iron 30

24. GENERAL.

a. Anyone at all familiar with machinery realizes that there are several forms of cast iron. In order to handle cast iron jobs successfully, the welder must have a clear understanding of the fundamental factors which determine the physical properties of an iron casting.

b. Cast iron is by no means pure iron; it is a rather complex mixture containing 91 to 94 percent metal iron and varying proportions of other elements, the more important of which are carbon, silicon, manganese, sulphur, and phosphorus.

c. With the possible exception of sulphur, these elements should not be considered as impurities, for each has a definite influence on the properties of the cast iron. By varying the amount of these elements, the foundryman is able to produce a multitude of different irons, each with properties adapting it to certain uses.

25. EFFECT OF OTHER ELEMENTS IN CAST IRON.

a. The effect upon cast iron of the elements other than carbon may be summarized rather briefly.

(1) When present in quantities up to 3 percent, silicon tends to promote the formation of graphitic carbon and is thus important in producing gray iron. Silicon also increases fluidity of the molten metal and lessens casting shrinkage.

(2) Sulphur acts in the opposite manner, increasing shrinkage and preventing separation of graphitic carbon. To an extent, these harmful effects of sulphur may be overcome by the presence of ıfficient manganese.

(3) Considerable phosphorus is used in intricate castings, as it increases fluidity and decreases shrinkage. Since these quantities are attained at the expense of toughness, however, this element is kept low in important castings.

26. MAKING CASTINGS.

a. In making parts of cast iron, the molten iron is poured into a sand mold of the proper shape. A pattern, or duplicate, of the part is made of wood, and then the sand mold is made with the help of the wood pattern. This pattern is removed from the sand after the sand mold has been rammed up, vented, provided with risers, and gated for pouring the molten metal into it. Castings are also made in metal molds and cement molds.

27. STRAINS IN CASTINGS.

a. Defective foundry practice often produces iron castings with internal stresses, due to unbalanced cooling. These stresses may be great enough to cause fractures or cracks long after the casting leaves the foundry. Annealing or preheating will relieve a cooling strain, if not too severe, prior to welding.

28. GRAY CAST IRON.

a. If the molten pig iron is permitted to cool quite slowly, the chemical compound of iron and carbon breaks up to a certain extent, and much of the carbon separates out as tiny flakes of graphite, scattered everywhere through the metal. This graphitic carbon, as it is called to distinguish it from combined carbon, causes the gray appearance of the fracture which characterizes ordinary gray cast iron. Since graphite is an excellent lubricant, and the metal is everywhere shot through with tiny flaky cleavages, it is not difficult to understand, on the one hand, why gray iron is so easy to machine, and, on the other, why it will not withstand a heavy shock.

b. Gray cast iron consists of 90 to 94 percent metallic iron, with varying proportions of carbon, manganese, phosphorus, sulphur, and silicon. Special high-strength grades of this metal contain, in addition to these elements, 0.75 to 1.50 percent nickel and 0.25 to 0.50 percent chromium, or 0.25 to 1.25 percent molybdenum. Commercial gray cast iron has from 2.50 to 4 percent carbon. Of this quantity, about 1 percent of the carbon is combined with the iron, while about 2.75 percent remains in the free, or graphitic, state. In production of gray iron the silicon content is usually increased, since this facilitates the formation of graphitic carbon. The combined carbon, which is a small percentage of the total carbon present in cast iron, is known as cementite. In general, the more free carbon (graphitic carbon) present in cast iron, the lower the combined carbon content and the softer the iron.

c. **Uses.** Certain properties of ordinary gray cast iron make it of great value in the manufacture of a wide variety of metal products. Cast iron, when molten, is very fluid and is slow to solidify, thereby making it possible to produce castings of very intricate design. Cast iron is used for cylinder blocks in automobile engines, brackets, pump bodies, machine frames, pedestals, columns, gears, pulleys, journal boxes, wheels, clutch cases, axle housings, and other applications where weight and stiffness are needed without very great strength or where an intricate shape is desired and must be obtained at low cost per pound. Since graphite is a good lubricant and some of the carbon is present as free graphite, this composition enables cast iron to be easily machined. It will not withstand heavy shock, however, and is nonmalleable at any temperature.

29. WHITE CAST IRON.

a. When gray cast iron is heated to a dull red and cooled very rapidly, all of the carbon present in the gray cast iron is chemically combined with the iron, and white cast iron is formed.

b. In white cast iron carbon is of primary importance. The proportion of carbon in cast iron generally lies between 2½ and 4 percent by weight. In molten cast iron, this amount of carbon is completely dissolved in the iron, probably forming a chemical compound with the iron. If the molten iron is quickly cooled, this chemical compound chills and becomes solid, but remains practically unchanged in its composition. It is customary to refer to the carbon in this compound as combined carbon. Examination of this quickly chilled cast iron will show it to be very hard and brittle, often impossible to machine. It will have a silvery-white fracture; in short, it will be white cast iron.

c. **Uses.** White cast iron is principally used for malleable iron castings and in cases where hardness is necessary or where good wear and abrasion resistance are required.

30. MALLEABLE CAST IRON.

a. **Composition.** By heating white cast iron to between 1,400 F and 1,700 F for about 48 hours in boxes containing hematite ore or iron scale, a portion of the combined carbon is transformed to the free or uncombined state. This combined carbon separates out in a different manner from the carbon in gray cast iron and is called temper carbon. It exists in the form of small, somewhat rounded particles of carbon, which give malleable iron castings the ability to bend before breaking and to withstand shock loads better than gray cast iron. The castings have more of the properties of pure iron: namely, high strength, ductility, toughness, and ability to resist shocks. The product so made is accordingly known as malleable cast iron.

b. Repairs on malleable iron castings may be welded and brazed by the oxyacetylene process. Brazing is the preferred method for repairing malleable iron castings. Metal arc welds on malleable iron can be made by means of a special flux-covered electrode. Small electrodes should be used, with low welding current. The welded part should be annealed after welding.

c. Malleable cast iron is used for castings which must withstand shock and in which gray iron would probably fail because of low ductility. Such equipment as hard-wearing small tools, pipe fittings, and automobile parts (e.g., steering gear brackets, inner brake toggles, shifting forks, clutch release yolks, and clutch pedals) are usually made of malleable cast iron.

CHAPTER 3

THE METALS: CHARACTERISTICS, HEAT TREATMENT, AND IDENTIFICATION (Cont'd)

Section III

WROUGHT IRON

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31. WROUGHT IRON.

a. **Composition.** Wrought iron is made from pig iron in a puddling furnace or by a newly developed process known as the Aston process. The carbon and other elements present in pig iron are eliminated and leave almost pure iron. In the process of manufacture of wrought iron, some slag is mixed with iron to form a fibrous structure, that is, a structure in which long stringers of slag, running lengthwise of the bar, are mixed with long threads of iron.

b. **Uses.** Wrought iron resists corrosion, oxidation, or rusting, because of the slag included in its structure. It is used to manufacture crane hooks, bolts, water pipe, wire, and similar applications. Wrought iron can be welded by oxyacetylene and electric arc processes as well as by forge welding.

CHAPTER 3

THE METALS: CHARACTERISTICS, HEAT TREATMENT, AND IDENTIFICATION (Cont'd)

Section IV

STEEL

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High-carbon steels (SAE 1050 to 1090) 38
Tool steels (SAE 1080 to 10150) 39
Copper bearing steels 40
Cast steel 41
Processes for making steel 42

32. GENERAL.

a. Pure iron and wrought iron are too soft and ductile for many purposes. When iron is alloyed with carbon, however, there is produced a malleable, tough product, which may be tempered, annealed, forged, cast, and altered as desired. Various alloys with carbon go by the general name of steel, although steel may contain other substances as well, for example, magnesium, silicon, phosphorus, chromium, molybdenum, and sulphur. The qualities of steel vary with the amount of these alloying materials, especially carbon.

33. DEFINITION.

a. Steel is any commercial form of iron containing carbon in any amount up to about 1.70 percent as an essential alloying constituent; it is malleable under certain conditions.

34. CLASSIFICATION.

a. For commercial purposes steel is often classified in three grades of hardness: low-carbon (roughly less than 0.30 percent carbon), called mild or soft steel; medium-carbon (roughly 0.30 to 0.50 percent carbon), called medium steel; and high-carbon and tool steels (roughly 0.50 to 1.70 per cent carbon), called hard steel. Steel also contains small quantities of other elements which may have been added to improve certain characteristics or are simply present as impurities.

35. OTHER ELEMENTS IN STEEL, AND THEIR EFFECTS.

a. Steels contain five chemical elements in addition to iron. Three of these are added to dissolve and eliminate impurities in the steel, as well as to strengthen and improve the quality of the metal. These elements are carbon, manganese, and silicon. Sulphur and phosphorus are also present in the form of impurities, and, since they produce a harmful effect, they are usually kept below a certain maximum value in order not to destroy the useful properties of the particular steel.

(1) CARBON. Carbon is an element which extensively affects the hardness, wear resistance, and other physical properties of steel. It is added to steel in specific quantities to fulfill the requirements of the particular application for which the steel is intended. Increase in carbon content of steel causes an increase in hardness when the steel is heat-treated.

(2) MANGANESE. Manganese is added in order to remove oxygen and thus to eliminate the formation of ferrous oxide, which would be a harmful impurity. It also combines with sulphur to form manganese sulphide and acts to increase the hardness to a slight extent, to lower the critical or hardening temperature, and to increase considerably the toughness of the steel. Low-carbon steel contains between 0.30 and 1.00 percent of manganese. Tool steels may contain as high as 1.60 percent manganese.

(3) SILICON. Silicon acts as a scavenger to remove gases from the molten steel and thus to make the cast metal sound and free from gas pockets and blowholes. There is present in the finished steel about 0.10 to 0.30 percent silicon, and occasionally as much as 0.40 percent. Silicon is never used as an alloying element alone or simply with carbon. When added in amounts between 0.50 and 2.00 percent along with some deep hardening element like manganese, chromium, or molybdenum, it increases the strength and toughness of the steel.

(4) PHOSPHORUS. Phosphorus is considered an impurity which causes the steel to be brittle by increasing the grain size. In the production of steel, it is generally kept below 0.02 to 0.05 percent maximum. When present in amounts of 0.10 percent or higher, it causes segregation. Phosphorus combines with iron to form iron phosphide and is generally uniformly distributed throughout the steel. Better grades of steel specify a maximum of 0.015 percent for phosphorus content. In machinery steel, phosphorus and sulphur are sometimes deliberately added to make the steel more easily machined. These steels are not heat-treated, and quality is not of primary importance.

(5) SULPHUR. Sulphur, when present in excessive amount (0.10 percent or more), acts in very much the same way as phosphorus to cause the steel to become brittle. This brittleness comes about through the formation of iron sulphide, which melts below the melting point of

steel and thus causes the steel to become nonuniform in structure. During rolling or forging operations, the presence of excessive amounts of sulphur will cause the pieces being worked upon to break when heated to forging or rolling temperatures. Steels which contain less than 0.05 percent sulphur and at least 0.30 percent manganese overcome this difficulty by the formation of manganese sulphide, which is relatively harmless to the essential qualities required in steel.

36. LOW-CARBON OR MILD STEELS (SAE 1030).

a. These steels have a carbon content up to 0.30 percent.

(1) These steels are soft and ductile and can be rolled, punched, sheared, and worked either hot or cold. They may be obtained in the bar, sheet, and tubular form and are used for general machining and forging purposes. They are easily machined and can be readily welded by all methods or case-hardened by means of cyaniding or pack-hardening. They do not harden when cooled suddenly from a high temperature.

(2) These steels are used to make wire, nails, tubes, screws, rivets, plates, and some structural members.

37. MEDIUM-CARBON STEELS (SAE 1030 to 1050).

a. These steels have a carbon content ranging from 0.30 to 0.50 percent.

(1) These steels may be heat-treated after fabrication and are used for general machining and forging of parts which require surface hardness and strength. They are manufactured in bar form and in the cold-rolled or the normalized and annealed condition. During welding, the zone in the vicinity of the weld, which has been heated up to its critical temperature, will become hardened if cooled rapidly. In order to avoid this, the metal must be preheated to a temperature between 300 F and 500 F, depending upon the thickness and carbon content of the steel, and, after welding, stress-relieved at a temperature ranging from 1,100 F to 1,250 F.

(2) These steels are used for general machining or forging purposes, where high strength and surface hardness are required. Crankshafts, axles, wheel flanges, connecting rods, and similar parts are made from this steel.

38. HIGH-CARBON STEELS (SAE 1050 to 1090).

a. These steels contain 0.50 to 0.90 percent carbon. They are used for the manufacture of drills, taps, dies, springs, and other hand and machine tools which are heat-treated after fabrication to develop the hard structure necessary to withstand high shear stress and wear. They are manufactured in bar, sheet, and wire forms, and in the annealed or normalized and annealed condition, so as to be suitable for machining before heat treatment. These steels are more difficult to weld because of the hardening effect of heat on the metal in the vicinity of the welded joint. They must be preheated to at least 500 F and then stress-relieved between 1,100 F and 1,250 F. The hardness obtained by quenching this steel from the critical temperature is greater than that obtained by the medium-carbon steels discussed previously. Springs of this material cannot be satisfactorily repaired, as the weld metal, even though heat-treated to the original spring hardness, will not stand up under repeated loading stresses.

NOTE: Paragraphs 36, 37, and 38 above refer to plain carbon steels without alloy element.

39. TOOL STEELS (SAE 1080 TO 10150).

a. These steels contain 0.80 to 1.50 percent carbon. They are used in the manufacture of chisels, shear blades, cutters, large taps, woodturning tools, smith's tools, razors, and other similar parts where high hardness is required to maintain a sharp cutting edge. They are relatively more difficult to weld and require preheating to about 1,000 F, applied slowly before welding. The welding procedure is similar to that used for high-carbon steels, in that stress-relief heat treatment should follow the welding operation in order to remove stresses caused by the welding heat.

40. COPPER BEARING STEELS.

a. These steels are generally of the low-carbon type and contain from 20 to 30 percent copper. Practically the same welding procedures are applicable as for ordinary steels in the same carbon range.

41. CAST STEEL.

a. Cast steel is simply any one of the above described steels cast into molds in a manner similar to the process applied to cast iron. Plain carbon steel castings contain, as a rule, not more than 0.35 percent carbon and a negligible amount of alloying materials.

42. PROCESSES FOR MAKING STEEL.

a. Steel is made by refining pig iron and removing some of the carbon content from it. The process may start with the molten pig iron as it is discharged from the blast furnace, or the solidified pigs may be remelted at some later time. In general, the carbon and some impurities are removed by any one of a number of processes to be described briefly below, and the carbon content is controlled by adding small amounts of scrap iron containing carbon or by adding pure carbon (chart, fig. 6).

b. **Open-hearth Steel.** The name comes from the type of furnace used in making the steel. The open-hearth furnace is charged with pig on and scrap steel, which is melted by a high-temperature flame, usually gas. The silicon, manganese, and carbon are burned out and slagged off by adding mill scale, iron ore, and limestone periodically. The molten steel is discharged from the furnace through a tap hole into ladles, where additions of various desired elements are made, and thence into ingot molds.

c. **Bessemer Steel.** Bessemer steel is made in a Bessemer converter, which is a tilting vessel, lined with siliceous material, and having a perforated bottom. While the converter is on its side, molten pig iron is poured in. As the converter is righted, a blast of air is blown through the bottom holes and through the molten iron. This burns out the silicon, manganese, and carbon, raising the temperature of the molten metal. Just as the carbon flame dies out, the converter is tilted, and the steel poured into a ladle, where a small, controlled amount of carbon is restored by suitable additions. Spiegeleisen and ferromanganese, commonly used as additions, are irons containing high percentages of carbon and manganese. The steel is then cast into ingot molds for future working into shapes, etc.

d. **Basic and Acid Steel.** Basic steel is made in any one of several furnaces, which must be lined with magnesite or dolomite. Acid steel is made in a furnace lined with ganister, containing a high percentage of silicon. The lining imparts certain characteristics to the steel.

e. **Crucible Steel.** Crucible steel is made from low-carbon steel cut into lengths and packed into crucibles with charcoal to make steel of comparatively high-carbon content. The low-carbon steel absorbs the carbon as it melts, and the product is known as crucible steel, high-carbon steel, or tool steel.

f. **Electric Steels.** Electric steels are steels produced in furnaces in which the heat is furnished by the carbon arc or by induction. Except for its higher purity and freedom from occluded gases, electric steel does not differ basically from other steels.

CHAPTER 3

THE METALS: CHARACTERISTICS, HEAT TREATMENT, AND IDENTIFICATION (Cont'd)

Section V

ALLOY STEELS

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43. GENERAL.

a. Pure iron is too soft for many purposes and does not have the essential characteristics required in certain types of service. When small amounts of other elements are added to it, its characteristics are modified to a considerable extent. Carbon steels are not normally thought of as alloys, though that is what they actually are, alloys of carbon and steel. The term alloy steel is usually applied to combinations of steel with manganese, silicon, chromium, nickel, etc.

b. An alloy is defined as a substance with metallic properties, but composed of two or more metallic elements, or of metallic and nonmetallic elements, which are miscible (capable of being mixed) with each other when molten, and have not separated into layers when solid.

c. The properties of a metal are in general appreciably changed by the addition of another metal, and these changes are often of great industrial importance. The melting point, formation of gas-bubble pockets, hardness, tensile strength, ductility, toughness, elastic limit, thermal expansion, and electrical and magnetic properties are all changed by alloy formation.

d. Alloy steels are used to perform operations for which plain carbon steels are not suited. These extra requirements may be summarized as follows:

(1) To obtain better resistance to wear and greater hardness as required for cutting edges of machine tools.

(2) To develop higher strength and greater toughness.

(3) To make possible hardening without distortion or change in size.

(4) To develop the property of "red hardness"; that is, to enable the steel tool to work at temperatures which are high enough to soften a plain carbon steel tool.

44. METALS ALLOYED WITH STEEL.

a. The principal metals used as alloys in steel are: nickel, manganese, chromium, vanadium, tungsten, and molybdenum. Silicon, when added in quantities larger than that used in plain carbon steels, is combined with manganese, chromium, or molybdenum to obtain certain desired properties. Alloying elements are added to steel in the proper proportions during the process of melting, in the form of suitable alloy scrap or ferroalloys.

b. Many of the alloys are combinations of several alloying elements. Under these conditions, it is difficult to state what causes a change in physical properties under heat treatment. In general, the alloy steel which has the simplest composition which develops a desired physical property is the best from the standpoint of welding, heat treatment, machining, and other methods of fabrication. The effects of some of these alloying elements on steel is discussed in the following paragraphs.

45. MANGANESE STEEL ALLOYS.

a. Manganese is the most important element introduced in steel as a deoxidizer and desulphurizer. It is also used to make manganese steel.

b. Manganese is used in steels to produce sound castings, and to promote easier hot rolling and forging. Both manganese and silicon are termed oxidizing elements because of their ability to fix gases contained in steel. Manganese oxides combine with iron oxides, silica, and other impurities and float them to the surface of the molten metal. When combined with high-carbon steel, manganese promotes hardening of the steel to greater depths. It is added to steel together with silicon to produce strong and tough alloys such as are required for structural plate, rolled sections, and spring steels. The principal use of manganese in steel castings is to increase toughness and to make possible greater wear resistance.

46. SILICON STEEL ALLOYS.

a. Silicon, introduced as ferrosilicon, is second in importance. It is both a scavenger and a residual alloying element.

47. CHROMIUM STEEL ALLOYS.

a. Chromium is probably the most widely used alloying element. It tends to increase corrosion resistance, hardness, and resistance to shock, as well as to impart high strength with little loss in ductility.

b. Chromium, like manganese, causes deeper hardness penetration. It also increases the wear resistance and toughness of steel. It raises the hardening temperature, however, whereas manganese lowers it. Steels containing some carbon, with chromium between 0.50 and 1.50 percent, are used for twist drills, reamers, mandrils, and other tools. When the chromium content is increased to 4 percent, the alloy has suitable red-hardening properties and is used for hot forging dies, gun barrels, ball bearings, etc. Chromium steels, when combined with nickel, produce high-strength and high-yield point steels which are used for parts subjected to shock loads. Stainless steels are alloys of chromium and nickel, a very common one containing 18 percent chromium and 8 percent nickel.

48. NICKEL STEEL ALLOYS.

a. Next in importance as an alloy element is nickel. Alloy steels containing nickel are tough and have good wear-resisting properties. Nickel also increases the strength and slightly increases the ductility of the steel. Alloy steels containing nickel are used for parts which are subjected to wear and high stress. Some of these applications are connecting rods, bolts, studs, keys, pinions, wrist pins, and spline shafts. All highly stressed parts should be heat-treated after fabrication. Nickel lowers the hardening temperatures of steels, raises the yield point, and requires an oil quench rather than a water quench for hardening. Nickel steels have excellent shock and repeated stress resisting properties. These are used to advantage in the design of aircraft structural members and similar parts.

49. VANADIUM STEEL ALLOYS.

a. Vanadium, when added to steel, increases the tensile strength and yield point without affecting the ductility. When combined with chromium, it produces fine-grain steels which are hard and tough. These alloys of chromium and vanadium are used for forging of parts which are subjected to severe wear and high stress, such as ball bearing races, pinions, firing-mechanism parts, wrist pins, hand tools, and the like. These steels must be worked in the annealed condition and require heat treatment after fabrication. Vanadium is used mainly for its alloying qualities, although it is also an excellent deoxidizer and scavenger. It imparts fine grain size and increases elastic limit, yield point and shock resistance, especially in tool steels containing vanadium.

50. TUNGSTEN STEEL ALLOYS.

a. Tungsten and cobalt are alloying elements which give cutting tools their red hardness. A very important alloy of tungsten, known as high-speed tool steel, contains 18 percent tungsten, 4 percent chromium, 1 percent vanadium, and 0.70 percent carbon. This steel is very hard and heat resistant and, when heat-treated, requires an oil hardening quench. As a cutting tool, this steel is capable of cutting even after the edge has been heated to a dull red color, say 900 F to 1,000 F, by the cutting action. Tungsten steel containing 4 percent tungsten and 1.30 percent carbon is difficult to grind on an ordinary emery wheel. After heat treatment, the high heat-resistant properties of tungsten steels combined with chromium and vanadium make this suitable for use in exhaust valves. The high hardness is also used to advantage in tools and dies. Formerly, steels containing 5 percent tungsten were used in the design of high-powered magnets. They are being replaced, however, by chromium and cobalt alloys. These steels are worked in the annealed condition and are heat-treated after fabrication.

51. MOLYBDENUM STEEL ALLOYS.

a. Molybdenum, introduced as ferromolybdenum, is an alloying element which increases elastic limit, hardness, and impact- and fatigue-resistance values. It increases the depth of hardness possible through heat treatment and also increases the wear resistance and red hardness. This last property is applied in the manufacture of high-speed steels to replace some of the tungsten, which is expensive. One good high-speed steel contains between 7 and 10 percent molybdenum, together with chromium, vanadium, and tungsten. Molybdenum (between 0.25 and 1.50 percent when used with silicon, manganese, and chromium) increases the strength and toughness of tool steels. Steels containing 0.50 percent molybdenum and a maximum of 0.30 percent carbon are manufactured in plate, sheet, tubular, and pipe form and are used extensively in aeroplane structural parts, heavy plate sections, steam pipes, valves, and other parts subjected to high pressures and high temperatures. Alloys of molybdenum and chromium develop high strength when heat-treated. All forging and machining operations on this steel are performed while it is in the annealed condition.

52. TITANIUM AND COLUMBIUM STEEL ALLOYS.

a. Titanium, in the form of ferrotitanium, is used chiefly as a deoxidizer and scavenger, but also as an alloying element. It tends to inhibit carbide precipitation at the grain boundaries. Columbium is probably the rarest metal used in steel manufacture. It is used to prevent carbide precipitation.

53. SULPHUR, PHOSPHORUS, ALUMINUM, AND OTHER ELEMENTS IN STEEL ALLOYS.

a. Sulphur and phosphorus are used to some extent to form free cutting and low-alloy high-strength steels (par. 35). Zirconium is a scavenger of oxygen and sulphur and controls the grain size. Aluminum removes gases and other impurities, but is also used as a residual alloy to control grain size. Copper is added to steel to make it more resistant to atmospheric corrosion and to increase its strength and ductility.

CHAPTER 3

THE METALS: CHARACTERISTICS, HEAT TREATMENT, AND IDENTIFICATION (Cont'd)

Section VI

STANDARDIZED WD (SAE) CLASSIFICATION OF STEELS

Paragraph
General 54
Numerical index system 55

54. GENERAL.

a. The numerical index system originally developed by the Society of Automotive Engineers is used for steel specifications, making it possible to use numerals on shop drawings and blueprints to describe in part the quality of material covered by such numbers. For instance, a high-carbon steel is designated as 1070.

55. NUMERICAL INDEX SYSTEM.

a. The first figure of the classification number indicates to which class the steel belongs; thus, the figure 1 in the number 1070 indicates a carbon steel. If the figure were 2 it would indicate a nickel steel, and, if 3, a nickel-chromium steel. In the case of the alloy steels, the second figure generally indicates the approximate percentage of the principal alloying element. *Usually the last two or three figures indicate the average carbon content in points or hundredths of one percent.* Thus the number 2340 indicates a nickel steel of approximately 3 percent nickel (3.25 to 3.75 percent) and 0.40 percent carbon (0.35 to 0.45 percent); and the number 71360 indicates a tungsten steel of about 13 percent tungsten (12 to 15 percent) and 0.60 percent carbon (0.50 to 0.70 percent). The basic numerals for the various qualities of steels specified are as follows:

Carbon steels	1
Nickel steels	2
Nickel-chromium steels	3
Molybdenum steels	4
Chromium steels	5
Chromium-vanadium steels	6
Tungsten steels	7
Manganese-molybdenum and nickel-chromium-molybdenum steels	8
Manganese-silicon steels	9
Manganese-silicon-chromium steels	9
Manganese-silicon-chromium-nickel-molybdenum steels	9

STANDARDIZED WD (SAE) CLASSIFICATION OF STEELS

b. Examples.

(1) STEEL WD 1045.

First figure 1 .... Carbon steel
Second figure 0 .... No alloy
Last two figures 45 .... Carbon range 0.40 to 0.50 percent

(a) It will be seen that the carbon content ranges from five points below to five points above the steel number; that is, the numbers 1040 to 1050 could be substituted for the steel with the number 1045. If the second digit is zero, the steel is a straight carbon steel, and not an alloy steel.

(2) STEEL WD 2340.

First figure 2 .... Nickel steel
Second figure 3 .... 3 percent nickel
Last two figures 40 .... Carbon range 0.35 to 0.45 percent

c. In determining the approximated composition of steel from the WD number it should be noted that the class or basic alloying element is indicated by the first figure; that the percentage of the basic alloying element is indicated by the second figure in certain classes; and the carbon content in hundredths of one percent is indicated by the last two figures.

CHAPTER 3

THE METALS: CHARACTERISTICS, HEAT TREATMENT, AND IDENTIFICATION (Cont'd)

Section VII

NONFERROUS METALS

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Copper	56
Beryllium copper	57
Brass	58
Bronze	59
Nickel	60
Monel	61
White metal	62

56. COPPER.

a. Copper is a red metal available in either the electrolytic or deoxidized forms. It is a very ductile and malleable metal, having high electrical and heat conductivity. It is used as a major element in the manufacture of several hundred commercial alloys. Each one of these alloys has somewhat different welding characteristics. There are certain welding procedures, however, that apply to all.

b. Pure cast copper is soft, tough, and very malleable, while pure copper wire or sheet is much stronger than the cast form, due to the hardening and strengthening produced by the rolling, forging, or drawing operations. Copper is softer than steel and can be hammered out to a thin edge.

c. Some of the soft brasses and bronzes look very similar to copper. They can be easily distinguished by the use of a torch flame adjusted to a neutral mixture. Brasses will give off white fumes of burning zinc, whereas bronzes, although they may not give off white fumes, will usually contain enough volatile metal to leave a ring of whitish or yellowish crust around the edges of the cold, frozen puddle.

d. Commercially pure (electrolytic) copper contains a small amount of oxide and is not suitable for welding, because a weak zone develops in the base metal adjacent to the weld. Deoxidized or oxygen-free copper is entirely satisfactory for fusion welding. It is made by adding a small amount of silicon or manganese, phosphorus or boron, which removes the last trace of oxygen from the copper. The weldability of copper can be tested by heating a piece of it to a bright red, just below the melting point, and then hammering it vigorously on an anvil. If it breaks, it contains oxygen and is unsuitable for fusion welding.

e. Electrolytic and other types of copper that are unsuitable for fusion welding can be joined satisfactorily by bronze welding although deoxidized copper is more suitable for bronze welding.

57. BERYLLIUM COPPER.

a. This metal is an alloy of copper and beryllium and has the highest strength of any copper alloy. It can be heat-treated to give good wear resistance and other properties required for flat and wire springs. Welding ordinarily decreases the strength of the metal in the heat-affected zone. This can be restored, however, by means of heat treatment. When beryllium copper is heated with the oxyacetylene flame, a hard, insoluble oxide is formed on the surface. This oxide is difficult to remove. The most satisfactory method for joining beryllium copper is by means of silver soldering, for which the procedure is the same as that recommended for any of the ferrous and nonferrous metals that can be joined by that process.

58. BRASS.

a. Brass is an alloy of copper and zinc, although certain other metallic elements may be added to improve its physical properties.

b. Naval brass is one of these alloys, consisting of 62 percent copper, 0.50 to 1.50 percent tin, up to 0.10 percent iron, and 0.20 percent lead; the remainder is zinc. It is used for many purposes, especially where high strength, toughness, and resistance to corrosion are important.

c. Ordinary machine brass contains 60 to 68 percent copper and 32 to 40 percent zinc, whereas the high copper brass known as red brass contains 75 to 85 percent copper and 15 to 25 percent zinc. These alloys have a low melting point and low heat conductivity.

d. Other forms of brass are known as spring brass, cartridge brass, common brass, commercial brass, yellow brass, and admiralty brass. These are supplied in sheets, tubes, rods, extruded shapes, and castings. Some of these brasses may also contain lead, tin, manganese, or iron. Lead is added to increase the flowing qualities and machinability of the molten metal, whereas iron, tin, and manganese are added for strength.

59. BRONZE.

a. A bronze is an alloy consisting mainly of copper and tin, and it may or may not contain lead and zinc. Nickel may also be added to these bronzes to give them a white color. Some of the various bronzes available are:

(1) ALUMINUM BRONZE. Aluminum bronze (84 to 93 percent copper, 7 to 10 percent aluminum, and 4 percent iron, with the addition of small amounts of other metals, including nickel, tin, and manganese) is used for bearings and other parts where high strength and corrosion resistance is required.

(2) MANGANESE BRONZE. Manganese bronze (57 to 60 percent copper, 0.50 to 1.50 percent tin, 0.80 to 2 percent iron, 0.50 percent manganese, and 0.25 percent aluminum; the remainder zinc) is used where high strength and corrosion resistance, such as would be required in marine construction, is necessary.

(3) PHOSPHOR BRONZE. Phosphor bronze (89 to 94 percent copper, 3.50 to 9 percent tin, 0.30 percent zinc, 0.50 to 0.10 percent lead, 0.05 to 0.10 percent iron, 0.05 to 0.35 percent phosphorus) is used for bearings, springs, electrical contacts, and similar applications.

b. All the bronzes may be obtained in bar, rod, sheet, strip, and cast form. They may also be extruded into various shapes.

c. Practically all brasses and bronzes may be welded by the oxyacetylene flame, and some can be welded with the carbon arc. In general, the filler rod used for gas welding operations should be of the same composition, approximately, as the alloy being welded.

60. NICKEL.

a. Nickel is a grayish-white metal and is very ductile and malleable. It oxidizes slowly in the presence of moisture or corrosive gases. It is used as an alloy element with chromium in the manufacture of stainless steel. When added to ferrous alloys, it produces high strength and the ability to resist shock loads.

61. MONEL.

a. Monel metal is an alloy of silver-white color, containing approximately 67 percent nickel, 29.80 percent copper, 1.40 percent iron, 1.00 percent manganese, 0.10 percent silicon, and 0.15 percent carbon. In appearance, it resembles untarnished nickel. After use, however, and particularly after contact with chemical solutions, the silver-white color changes to a yellow tinge, and some of the luster is lost. Probably the most important property of monel metal is its resistance to corrosion.

b. The alloy is produced in the form of bar, sheet, tube, and wire, and is used in castings for special purposes.

c. Monel metal is weldable by means of practically all of the welding processes. A flux is required for welding by all fusion methods to protect the hot metal against oxidation. A different technique is required for monel sheet or forged products from that required for welding monel-metal castings.

62. WHITE METAL.

a. The white metal alloys are light in weight and white in color. There are five general classes, according to the basic composition: namely, zinc, aluminum, magnesium, lead, and tin alloys. These alloys are fabricated by either the gravity or pressure (die) casting methods.

NONFERROUS METALS

(1) White metals in the form of die castings made of zinc alloys are by far the most common. These contain approximately 4.10 percent aluminum, 1 to 2.70 percent copper, and 0.03 to 0.04 percent magnesium, the remainder being zinc. In weight these alloys are nearly as heavy as iron.

(2) The zinc alloys are used for such applications as carburetor and fuel pump parts, radiator ornaments, speedometer and small motor frames, gears, certain hardware, and intricate shapes and housings for compact designs.

(3) The magnesium alloys most widely used are known as the Dow metal alloys. These contain approximately 4 to 10 percent aluminum, 0.30 to 1.50 percent manganese, and 91 to 98 percent magnesium. They are the lightest of the white metal alloys and have good mechanical as well as excellent die casting properties. They are used for the manufacture of light portable tools, recording and optical instruments, typewriter and camera parts, motor rotors, and similar parts.

(4) The aluminum alloys used for die castings are very numerous. They have the properties of strength and lightness as well as good resistance to corrosion. Because of these properties, they are used for the same applications as the magnesium alloys.

(5) The tin and lead alloys are used for a large variety of parts where good bearing properties are required and where high strength or light weight is not important.

b. Repairs by welding or soldering can be made on most of the white metal alloys. It is important, however, to identify the type of alloy in question before applying heat to the broken parts. One method commonly used consists of checking the melting point of the white metal alloy by applying a heated bronze rod to the surface of the metal at the fracture. The tin and lead types of alloy will melt at a low temperature and can be welded or soldered by using a suitable lead solder and flux. The zinc and aluminum types of alloy melt at a higher temperature and are satisfactorily welded by using aluminum solder without flux. The magnesium alloys require a special flux and a special welding rod, whose composition is the same as the base metal, to make a satisfactory joint. Many of these alloys are not recommended for welding.

CHAPTER 3

THE METALS: CHARACTERISTICS, HEAT TREATMENT, AND IDENTIFICATION (Cont'd)

Section VIII

HEAT TREATMENT OF METALS

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63. GENERAL.

a. Heat treatment may be defined as an operation, or combination of operations, which involves the heating and cooling of a metal or an alloy in a solid state in order to obtain certain desirable conditions or properties. In general, heat treatment is applied only to ferrous metals and to certain heat-treatable nonferrous metals though annealing has other applications.

b. By controlling the rate of heating, the final temperature, and the rate of cooling, a plain carbon or alloy steel can be hardened or softened as required for a particular operation. Plain carbon steels containing 0.35 percent carbon or higher can be hardened by heating the metal to a cherry red (i.e., to its critical temperature) and by quenching in water. Plain carbon steels containing less than 0.35 percent carbon do not harden appreciably when quenched from a critical temperature.

c. One of the most important factors for a welder to remember is that steel should never be overheated or burned. This occurs when steel is heated to a temperature close to its melting point. When this happens, certain elements in the steel are burned out, and the grain of the steel becomes coarse. A steel which has been ruined in this manner cannot usually be saved or renewed by heat treatment. In general, the lower the carbon content, the higher the temperature to which steels can be heated without being burned.

d. Paragraphs 283 and 285 list data pertaining to heat treatment of metals.

64. ANNEALING.

a. Metals which have been rolled, drawn, hammered, forged (work-hardened), or which have been hardened by heating and quenching, can be made soft and ductile by annealing. This process involves heating to a temperature of about 100 F above the critical temperature range and cooling slowly in a confined space. Annealing also is used to change the structure and toughness of the metal and to remove any gases. Steel, when annealed, can be worked into any shape desired.

65. HARDENING.

a. The ability of carbon steels to harden when heated and rapidly cooled is associated with the physical changes in the atomic structure of iron. When heated, the iron undergoes a transformation in passing through a critical temperature range (about 1,350 F) changing from a form which has a low solubility for carbon to a form which has a high solubility for carbon. Upon cooling, the reverse transformation occurs, but since the changes are progressive and require time for completion, they may be arrested, if the rate of cooling is increased.

b. If the cooling is very rapid, as in water quenching, the transformation takes place at a temperature (400 F to 600 F) very much below the critical temperature range and the carbon is held in a forced and finely divided state with the result that the steel becomes hard and brittle and a great deal stronger than slowly cooled steel. Increasing the carbon content increases the degree of hardening possible for a given cooling rate.

c. Alloy additions alter the rate of transformation on cooling and permit deeper hardening with less severe rates of cooling. This is particularly advantageous in large or complicated sections which would tend to crack or be distorted if made from plain carbon steel and water-quenched. Each alloy or combination of alloys, however, shows individuality in its effect and alloy steels are therefore made up and heat-treated with an eye to the specific properties required in the structures for which they are to be used. Each time a piece of carbon or low alloy steel is heated above its critical temperature a fine grain is developed.

d. If the steel is heated to higher temperatures the grains will become coarser, depending upon the time at temperature and certain inherent characteristics of the steel. Coarse grained steels tend to be more brittle and generally less serviceable than fine grained steels. Therefore, a fine grain is usually desired in alloy structural steels and this is attained by quenching from a temperature not more than 100 F above critical temperature.

66. TEMPERING.

a. When a steel is hardened by quenching, it is too brittle for ordinary purposes; therefore, some of the hardness should be removed by reheating the steel to a lower temperature than the critical temperature and quenching again. This process is also known as tempering or drawing. It is not necessary to quench after reheating providing the correct tempering temperature has not been exceeded.

b. The temperature to which a piece of steel should be heated for tempering depends upon the alloy composition and use to which it is to be put. In general the higher the temperature, the softer the steel (par. 283).

c. When a piece of steel has been hardened and polished by means of an emery cloth or a rubbing stone and reheated to a tempering temperature, colors appear on the surface which vary, as the temperature is increased from approximately 400 F to 640 F, from a light straw to a dark purple.

d. Judging the temperature by the color of the surface is a rough method at best, since the condition of the light in the room and the individual's color sense must be considered. A table of temperature colors for various tempering temperatures is given in paragraph 285.

67. CASE HARDENING.

a. This process consists of causing the surface of a piece of steel to absorb carbon. A thin shell having the properties of tool steel is formed upon the surface of the piece. The case or shell can be hardened by heating and quenching as though it were tool steel. Only the case, which has a high-carbon content, becomes hard, while the core remains soft, tough, and ductile. The case can be varied in depth from a few thousandths of an inch to an eighth of an inch or more, depending upon the process used.

b. Several processes are available for adding carbon to the surface of steel. In the pack hardening process, the parts are packed in charred bone or charred leather in a closed iron container and heated for a considerable time in a forge or furnace. The longer the time, the deeper the case. In the cyanide process, the parts are heated in a bath of molten potassium cyanide. Since cyanide is one of the most dangerous poisons known, this process should never be attempted except under expert supervision. The oxyacetylene flame, adjusted to give a carburizing mixture, can also be used to increase the carbon content in a thin layer on the steel surface.

c. The nitrogen case hardening process, which is known as nitriding, consists in subjecting the machined and generally heat-treated materials to the action of a nitrogenous substance, commonly ammonia gas, under certain conditions and thereby surface hardness is imparted to the material without any further treatment.

CHAPTER 3

THE METALS: CHARACTERISTICS, HEAT TREATMENT, AND IDENTIFICATION (Cont'd)

Section IX

IDENTIFICATION OF METALS

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68. GENERAL.

a. A very important part of the welder's training lies in his ability to identify the various metal products brought to the welding shop. It is up to the welder to identify the metal in order that he may apply the proper welding procedure for the particular metal being welded. For ordnance equipment, drawings should be available, and they must be examined in order to determine the identity of the metal in question and its heat treatment, if any. After some experience, the welder will know that certain parts of machines or equipment are always cast iron, others usually forgings, and so on.

69. TYPES OF TESTS USED IN IDENTIFYING METALS.

a. Simple tests can be performed in the shop to identify metals. Since ability to judge can be developed only through personal experience, the welder should practice these tests with known metals until he becomes familiar with the reactions of each metal under each type of test. These tests are as follows:

(1) APPEARANCE. This includes such general features as color and appearance of machined as well as unmachined surfaces.

(2) FRACTURE. Many metals can be quickly identified by examining the surface of the broken part or by studying the chips produced with a hammer and chisel.

(3) GRINDING WHEEL TESTS. When held lightly against a grinding wheel, the various forms of iron and steel produce sparks which vary in length, shape, and color. The grinding wheel should be a Norton Alundum wheel, type 46-P or its equivalent, rotating so as to give a peripheral speed of 4,000 feet per minute to get good, short, bright sparks. The wheel should be hard enough to wear reasonably long and yet soft enough to retain a free cutting edge. The tests should be performed in well diffused daylight against an ordinary background. In all cases it is advisable to use standard samples of materials whose compositions are known for purposes of comparing their sparks with the test sample.

(4) BEHAVIOR UNDER TORCH. With the oxyacetylene torch itself, the welder can identify the various metals by studying the rate of melting, the appearance of the molten metal and slag, as well as any color changes during heating.

70. GRAY CAST IRON.

a. **Appearance.** Castings present a characteristic appearance. The unmachined surface is very dull gray in color and may be somewhat roughened by the sand mold used in casting the part. Cast-iron castings are rarely machined all over. Unmachined castings may be ground in places to remove rough edges.

b. **Fracture.** Nick a corner all around with a chisel or hacksaw, and hit a sharp blow. The dark gray color of the broken surface is caused by fine black specks of carbon present in the form of graphite. Cast iron breaks short when fractured. Small brittle chips made with a chisel break off as soon as formed.

c. **Grinding Wheel Test.** A small volume of dull red sparks that follow a straight line form close to the wheel. These break up into many fine, repeated spurts, which change to a straw color.

d. **Torch Test.** The puddle of molten metal is quiet, very fluid, and watery. When the torch flame is raised, the depression in the surface of the molten puddle disappears instantly. A heavy, tough film forms on the surface as it melts. The molten puddle takes time to solidify and gives off no sparks.

71. MALLEABLE IRON.

a. **Appearance.** The surface is very much like cast iron but is generally free from sand. It is dull gray and somewhat lighter in color than cast iron.

b. Fracture. The central portion of the broken surface is dark gray, with a bright, steellike band at the edges. The appearance at the fracture may best be described as a picture frame. When of good quality, it is much tougher than cast iron and does not break short when nicked.

c. Grinding Wheel Test. The outer bright layer gives off bright sparks like steel. As the interior is reached, the sparks quickly change to a dull red color near the wheel. These sparks from the interior section are very much like those of cast iron; however, they are somewhat longer and are present in larger volume.

d. Torch Test. The molten metal boils under the torch flame. After the flame has been withdrawn, the surface will be found full of blowholes. The melted parts are very hard and brittle, having, when fractured, the appearance of white cast iron. (They have been changed to white, or chilled iron by the melting and the comparatively rapid cooling.) The outside bright steellike band gives off sparks, but the center does not.

72. CAST STEEL.

a. In general, welding is difficult on steel castings containing over 0.30 percent carbon and 0.20 percent silicon. Alloy steel castings containing nickel or molybdenum or combinations of these metals are readily welded if the carbon content is low. Those containing chromium or vanadium are more difficult to weld satisfactorily. As manganese steel is nearly always used in the form of castings, it is also considered in this paragraph. Its high resistance to abrasion is its most valuable property.

(1) APPEARANCE. The surface is brighter than cast or malleable iron and sometimes contains small, bubblelike depressions.

(2) FRACTURE. The color is bright crystalline. This steel is tough and does not break short. Steel castings are tougher than malleable iron, and chips made with a chisel curl up more. Manganese steel, however, is so tough that it cannot be cut with a chisel, nor can it be machined.

(3) GRINDING WHEEL TEST. The sparks are much brighter than those from cast iron. Manganese steel gives characteristic sparks that explode, throwing off brilliant sparklers at right angles to the original path of the spark.

(4) TORCH TEST. When melted, the steel sparks and solidifies quickly.

73. STEEL FORGINGS.

a. Appearance. The surface is smooth. Where the surface of drop forgings has not been finished, there will be evidence of the fin which results from the metal squeezing out between the two forging dies. This fin is ordinarily removed by the trimming dies, but enough of the sheared surface remains for identification. All forgings are covered with reddish-brown or black scale, unless they have been purposely cleaned.

b. **Fracture.** The color varies from bright crystalline to silky gray. Chips are tough, and when the specimen is nicked it is harder to break than cast steel and has a finer grain. Forgings may be of low- or high-carbon steel or of alloy steel. Tool steel is harder and more brittle than plate steel or other low-carbon material. The fracture is usually whiter and finer-grained. Tool steel can be hardened by heating to a good red and by quenching in water. Low-carbon steel, wrought iron, and steel castings cannot be usefully hardened.

c. **Grinding Wheel Test.** The sparks given off are long white streamers and are typical steel sparks. Sparks from high-carbon steel (machinery and tool steel) are much brighter and whiter than those from low-carbon steel.

d. **Torch Test.** Steel forgings spark when melted, and sparks increase in number and brilliance as the carbon content becomes greater.

74. WROUGHT IRON.

a. **Appearance.** The appearance is the same as that of rolled low-carbon steel.

b. **Fracture.** Wrought iron has a fibrous structure, due to threads of slag. As a result, it can be split in the direction in which the fibres run. The metal is soft and easily cut with a chisel. When bent, it is quite ductile. When nicked and bent, it acts like rolled steel; however, the break is very jagged. Wrought iron cannot be hardened by quenching from bright red heat.

c. **Grinding Wheel Test.** Straw-colored sparks form near the grinding wheel and change to white forked sparklers near the end of the stream.

d. **Torch Test.** Wrought iron melts quietly without sparking. It has a peculiar slag coating with white lines, oily or greasy in appearance.

75. LOW-CARBON STEELS.

a. **Appearance.** The appearance of the steel depends upon the method of preparation rather than upon composition:

(1) CAST. A relatively rough, dark gray surface, except where machined.

(2) ROLLED. Fine surface lines running in one direction.

(3) FORGED. Usually recognizable on account of its shape, hammer marks, or fin.

b. **Fracture.** The color is bright crystalline. It is tough when chipped or nicked.

c. Grinding Wheel Test. The steel gives off sparks in long white streaks brighter than cast iron and shows some tendency to burst into white forked sparklers.

d. Torch Test. The steel gives off sparks when melted, and solidifies quickly, almost instantly

76. HIGH-CARBON STEELS.

a. Appearance. The unfinished surface is dark gray and similar to other steels. These steels are more expensive, and work is usually done on them to produce a smoother surface finish.

b. Fracture. Usually a very fine grained fracture, whiter than low carbon, is produced. Tool steel is harder and more brittle than plate steel or other low-carbon material. High-carbon steel can be hardened by heating to a good red and quenching in water. Low-carbon steel, wrought iron, and steel castings cannot be hardened.

c. Grinding Wheel Test. It gives off a large volume of brilliant white sparklers.

d. Torch Test. The molten metal is brighter than in the case of low-carbon steel, and the melting surface has a cellular appearance. It sparks more freely than mild steel, and the sparks are whiter.

77. ALLOY STEELS.

a. Alloy steels are frequently recognized by the use to which they are subjected. There are a large variety of alloy steels used in the manufacture of ordnance equipment, each of which is best identified by experience. They have greater strength and durability than other steels, and a given strength in a part is secured with less weight of material than when other steels are used. Their economical use depends upon proper heat-treatment, which is destroyed by a welding operation at the region of the weld. Manganese steel is a special alloy steel that is always used in the cast condition and has been discussed under cast steel (par. 72). Nickel, chromium, vanadium, tungsten, molybdenum, and silicon are the most common elements used in alloy steels.

(1) APPEARANCE. They appear the same as other drop-forged steels. Much alloy steel is machined all over.

(2) FRACTURE. Generally, the alloy steels are very close-grained; at times the fracture might be said to have a velvety appearance.

(3) GRINDING WHEEL TESTS. The various alloy steels produce characteristic sparks, both in color and shape. With practice, many varieties of alloy steels can be recognized. Some of the more common alloys used in steel and their effects on the spark stream are as follows:

(a) Manganese. Steels containing this element produce a spark similar to a carbon spark. A moderate increase in manganese increases the volume of the spark stream and the intensity of the bursts. A ste

containing more than normal content of manganese will spark similar to a high-carbon steel with a lower manganese content. For example SAE 1055 spark is similar to that of SAE 1335.

(b) *Nickel.* In the amounts found in SAE steels, nickel can be recognized only when the carbon content is low enough so that the bursts are not too prominent. The nickel spark is a short, sharply defined dash of brilliant light just before the fork. It is rather difficult to differentiate a nickel spark as more rounded bulges appear in some nickel-free steels.

(c) *Chromium.* Steels containing 1 percent to 2 percent chromium have no outstanding features in the spark test. Chromium in large amounts shortens the spark stream length to one-half that of the same steel without chromium without appreciably affecting its brightness. Other elements shorten the stream to the same extent and also make it duller. An 18 percent chromium 8 percent nickel stainless steel produces a spark similar to that of wrought iron only one-half as long. A steel containing 14 percent chromium and no nickel produces an abbreviated version of low-carbon spark. An 18 percent chromium, 2 percent carbon steel (chromium die steel) produces a spark similar to that of a carbon tool steel but one-third as long.

(d) *Molybdenum.* Steels containing this element produce a characteristic spark with a detached arrow head similar to that of wrought iron. It can be seen even in fairly strong carbon bursts. Molybdenum alloy steels contain either nickel or chromium or both.

(e) *Vanadium.* Alloy steels containing vanadium produce sparks with a detached arrow head at the end of the carrier line similar to those arising from molybdenum steels. This test is not a positive one for vanadium steels.

(f) *Tungsten.* This element is simplest to recognize. It imparts a dull red color to the spark stream near the wheel. It also shortens the spark stream and decreases the size of or completely eliminates the carbon burst. A tungsten steel containing about 10 percent tungsten causes short curved orange spear points at the end of the carrier lines. Still lower tungsten content causes small white bursts to appear at the end of the spear point. Carrier lines may be anything from dull red to orange in color depending on other elements present and providing the tungsten content is not too high.

(g) Molybdenum and other elements substituted for some of the tungsten in high-speed steel causes the spark stream to turn orange. Although other metals give off a red spark there is enough difference in their characteristics to distinguish them from the tungsten spark.

(4) TORCH TEST. Action depends upon the nature of the alloy. Steels containing a considerable quantity of chromium produce a greenish-colored slag on the weld when cold.

78. SPECIAL STEELS.

a. Plate for Welded Construction. In the manufacture of built-up welded structures, such as gun carriages, in using nickel steel plate, it has been found by several years of experience, that commercial grades of low-alloy structure steels of not over 0.25 percent carbon, and several containing no nickel at all, are more satisfactory from the welding standpoint than a maximum carbon content of 0.30 percent.

b. Such plate is normally used in the "as rolled" condition. Electric arc welding with a covered electrode may require preheating followed by a proper stress-relief heat treatment, to produce a structure in which the welded joint has properties equal to those of the plate metal.

79. ALUMINUM.

a. Appearance. Aluminum is white in color, very bright when polished, dull when oxidized, and light in weight. Rolled and sheet aluminum material is usually pure metal. Castings are alloys of aluminum with other metals, usually zinc, copper, silicon, and sometimes iron or magnesium. Wrought aluminum alloys may contain chromium, silicon, magnesium, or manganese.

b. Fracture. Castings show a bright crystalline structure. Rolled sections show a smooth and bright structure.

c. Grinding Wheel Test. No sparks are given off.

d. Torch Test. Aluminum does not show red before melting. It holds its shape until almost molten, then collapses suddenly. A heavy film of white oxide forms instantly on the molten surface.

80. COPPER.

a. Appearance. Copper is red in color when polished; it oxidizes to various shades of green.

b. Fracture. It presents a smooth surface, free from crystalline appearance.

c. Grinding Wheel Test. No sparks are given off.

d. Torch Test. On account of good heat-conducting properties, a larger flame is required to produce fusion of copper than would be needed for a steel piece of the same size. Copper melts suddenly and solidifies instantly. Copper alloy, containing small amounts of other metal, melts more easily and solidifies more slowly than pure copper.

81. BRASSES AND BRONZES.

a. Appearance. The color of polished brass and bronze varies with the composition from red, almost like copper, to yellow brass. They oxidize to various shades of green and brown or yellow.

b. Fracture. The surface ranges from smooth to crystalline, depending upon composition and method of preparation, as casting, rolling, or forging.

c. Grinding Wheel Test. No sparks are given off.

d. Torch Test. True brasses contain zinc, which gives off white fumes when the brass is melted. Bronzes contain tin. Even a slight amount of tin makes the alloy flow very freely, like water. Due to a small amount of zinc or tin which is usually present, bronzes may fume slightly, but never as much as brass.

82. ALUMINUM BRONZES.

a. Appearance. When polished, they appear a darker yellow than brass.

b. Fracture. A smooth surface is presented.

c. Grinding Wheel Test. No sparks are given off.

d. Torch Test. Welding is extremely difficult; the surface is quickly covered with a heavy scum which tends to mix with the metal and is difficult to remove.

83. MONEL METAL.

a. Appearance. Monel is light gray in color; when it is machined, this color dulls with age to a darker gray.

b. Fracture. It presents a crystalline surface, with color like nickel.

c. Grinding Wheel Test. Short, orange, wavy streaks, very similar to those given off by nickel, are observed.

d. Torch Test. Monel flows clearly without any sparklers. A heavy black scale forms on cooling.

84. LEAD.

a. Appearance. Lead is white in color when freshly cut, becoming dull gray on exposure to air. It is a very soft and very heavy metal, which bends easily.

b. Fracture. It presents a noncrystalline surface, white in color.

c. Grinding Wheel Test. No sparks are given off.

d. Torch Test. It melts at a very low temperature. The melted metal becomes covered with a thin, dull slag coating.

85. ZINC DIE CASTINGS.

a. Appearance. Die castings are usually alloys of zinc, aluminum, magnesium, lead, and tin. They are light in weight, generally white in color (like aluminum), and frequently of intricate design. A die-cast surface is very much smoother than that of a casting made in sand and is almost as smooth as a machined surface. No tool marks are seen, however. Occasionally, a die casting darkened by use may be confused with malleable iron when judged simply by appearance, but the die-casting is lighter in weight and softer than malleable iron.

b. **Fracture.** Surface is white and somewhat granular in structure.

c. **Grinding Wheel Test.** No sparks are given off.

d. **Torch Test.** Die castings can be recognized by their low melting temperature. The metal boils when heated with the oxyacetylene flame. A die casting, after thorough cleaning, can be welded, with a carburizing flame, tin or aluminum solders being used as filler metal. If necessary, the die-cast part can be used as a pattern to make a new brass casting.

CHAPTER 4

OXYACETYLENE AND ELECTRIC ARC WELDING: GENERAL CONSIDERATIONS

Section I

NOMENCLATURE OF THE WELD

Paragraph
General 86
Sections of a simple weld 87
Multi-pass welds 88

86. GENERAL.

a. In order to define more clearly the various sections of a welded joint, each important part is shown and identified in figure 8. The same terms will apply to both oxyacetylene and electric arc welding and to all the different types of joints that can be made.

87. SECTIONS OF A SIMPLE WELD.

a. The *fusion zone* is that width of the weld metal which has penetrated beyond the original surface of the joint into the base metal.

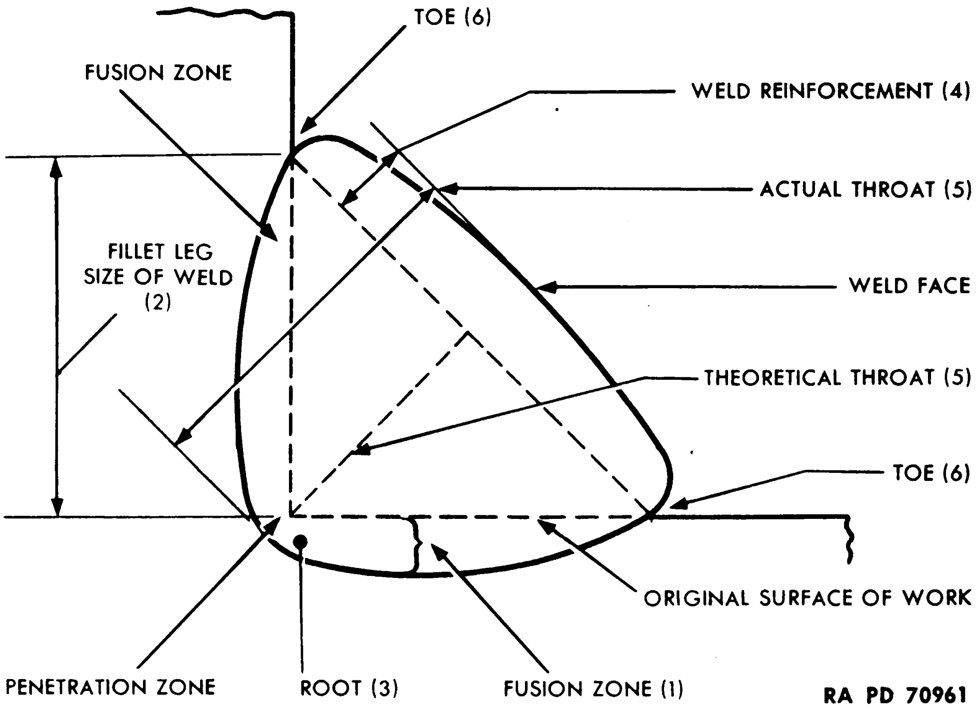

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Figure 8 — Nomenclature of Fillet Welds

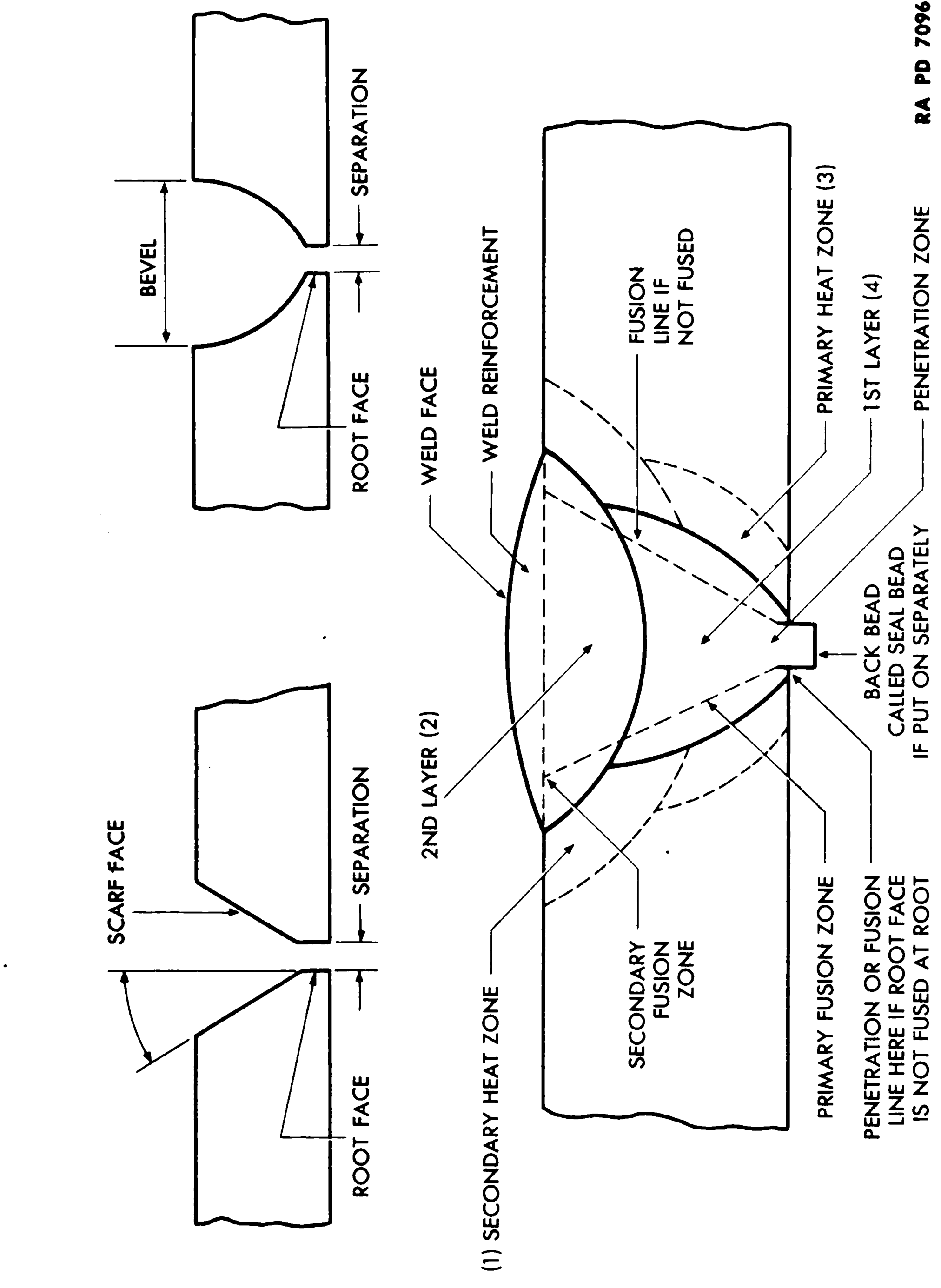

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Figure 9 — Heat-affected Zones in Multi-pass Weld

b. The *size of a concave* fillet is determined by the length of the leg of the largest isosceles triangle which can be inscribed within the cross-section of the fillet.

c. The *root* of the weld is that portion of the weld metal deposited at the bottom of the joint.

d. The weld *reinforcement* is added to insure that the net throat of the weld is not less than that of the plate welded. In fatigue or under vibration the welded joint has a higher strength when ground flush with the plate surface.

e. The *throat* of the weld is the thickness along the center line of the weld measured between the root and the face of the weld.

f. The *toe* of the weld is that portion located at the intersection of the base metal and filler metal on the surface of the weld. It also represents the edge of the fusion zone in the base metal on each side of the weld.

88. MULTI-PASS WELDS.

a. The fusion and heat-affected zones in a butt joint which has been made in more than one pass or layer are shown in figure 9. The secondary heat zone (1) formed by the welding heat given off by the second layer (2) partly overlaps the primary heat zones (3) formed by the first layer of weld metal (4). That portion of the base metal which hardens or changes its properties as the result of the welding heat in the primary heat zone is partly annealed or softened by the welding heat in the secondary heat zone. The weld metal in the first layer is also refined in structure by the welding heat of the second layer. These two heating conditions are important in determining the order or sequence used in depositing weld metal in a particular joint design.

CHAPTER 4

OXYACETYLENE AND ELECTRIC ARC WELDING: GENERAL CONSIDERATIONS (Cont'd)

Section II

TYPES OF WELDED JOINTS

Paragraph
General 89
Butt joint 90
Lap joint 91
T-joint 92
Corner joint 93
Edge joint 94

89. GENERAL.

a. The properties of a welded joint depend largely upon the correct preparation of the metal edges being welded. All mill scale, rust, oxides, and other impurities must be removed from the joint edges or surfaces in order to prevent their inclusion in the weld metal. The welding heat cannot be used to the greatest advantage unless the edges to be welded are so prepared as to permit easy fusion without excessive heating. Care should be taken to keep to a minimum the heat lost due to radiation into the base metal from the weld. The type and position of the joints, when they are properly prepared, will reduce the amount of expansion on heating and contraction on cooling.

b. The preparation of the metal is governed by the form, thickness, kind of metal, available methods for preparing the edges to be joined, and the load which the weld will be required to support. Some of the more important and more common types used for preparing plate edges and joints for welding are shown in figure 10.

c. There are five basic types of joints used to weld the various forms of metal. These are the butt, lap, T-, corner, and edge joints.

90. BUTT JOINT.

a. This type of joint is used to join the ends or edges of two plates or surfaces located approximately in the same plane with each other. Plain square butt joints on light sections are shown in figure 11. Several types of edge preparation used for making butt-welded joints on various thicknesses of metal are shown in figure 12. These can be prepared by flame cutting, shearing, flame grooving, machining, chipping, or grinding. The edge surfaces should in each case be free of oxides, scale, dirt, grease, or other foreign matter.

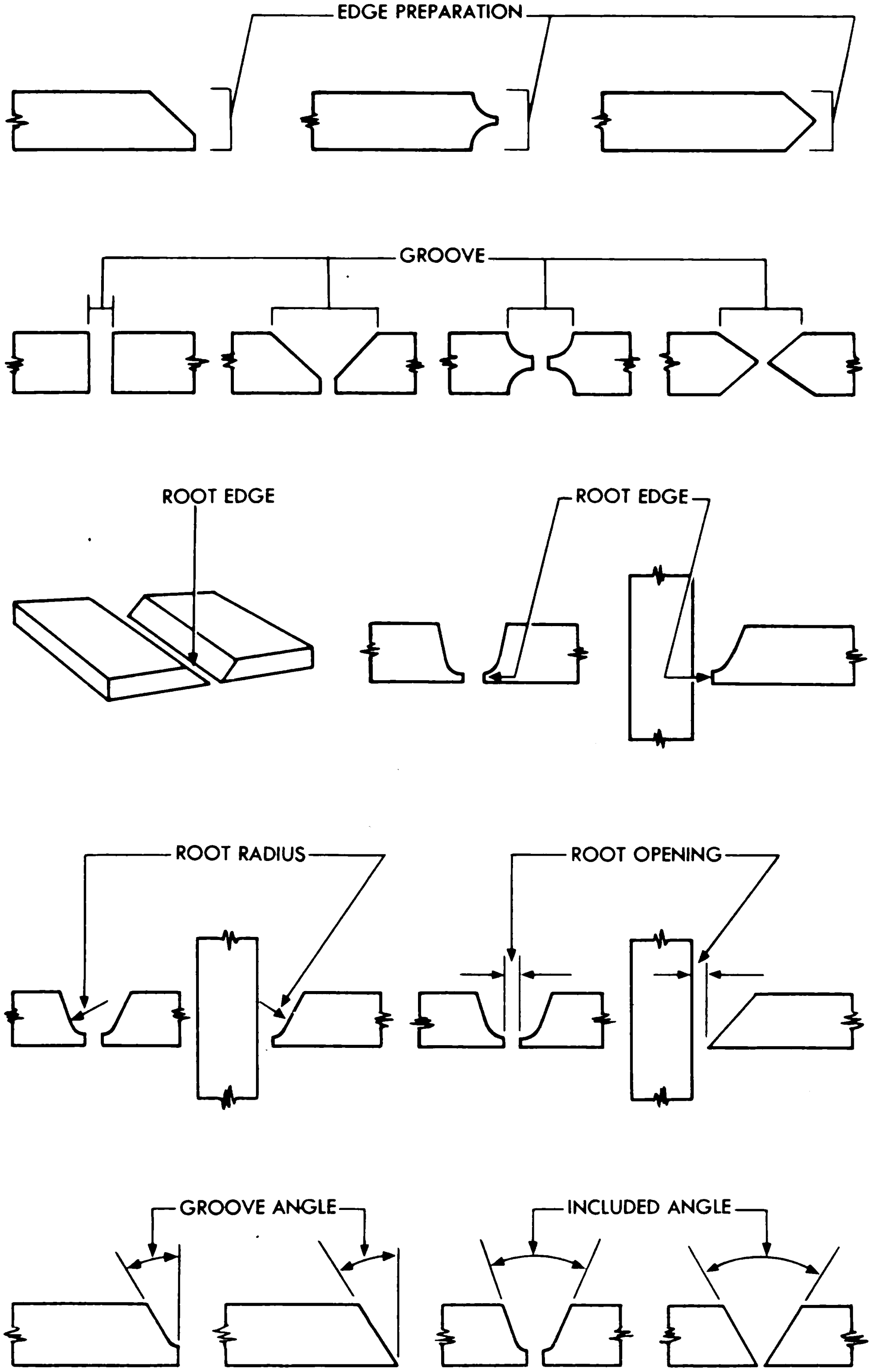

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Figure 10 — Types of Preparation of Plate Edges Before Making a Welded Joint

TYPES OF WELDED JOINTS

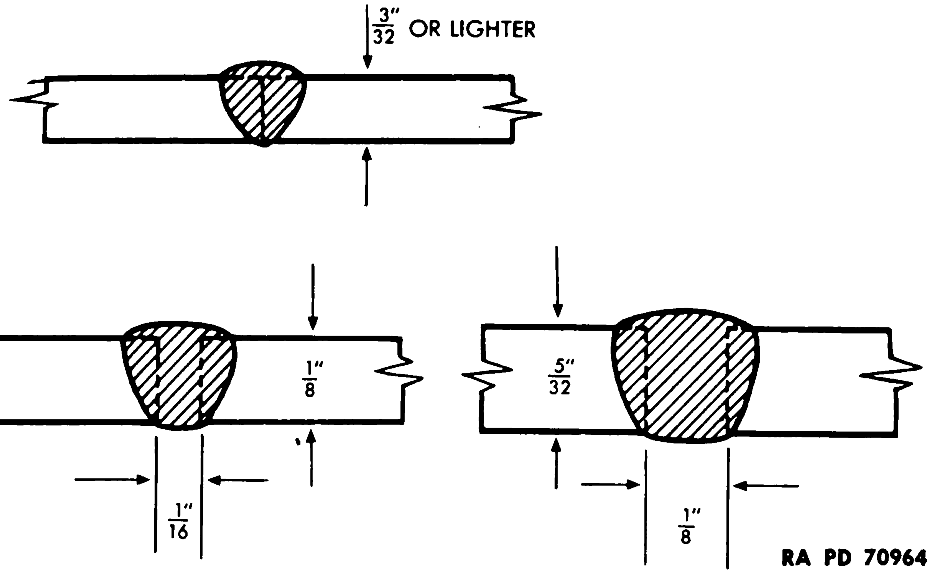

Figure 11 — Butt Joints — Thin Sections

b. The joint shown in A, figure 12, is used for welding sheet metal up to 1/16 inch in thickness by the oxyacetylene or atomic-hydrogen welding process. The plain square butt joint shown in B, figure 12, is used for welding sheet metal up to 1/8 inch thickness by the oxyacetylene and electric arc welding processes. These thin sections should be spaced in jigs to allow for weld shrinkage along the seam. In arc welding, back-up or quench plates made of copper or cast iron are necessary on light sheets to control the warpage or distortion. Welding should be done by the back-step welding method to prevent the thin sections from buckling.

c. Plate thicknesses, 3/8-inch to 1/2-inch, can be satisfactorily welded from one side only by either the oxyacetylene or electric arc welding process, using the single V- or single U-joint types, shown in C and E, respectively, figure 12. Heavier sections should be welded by preparing the edges of the plates from both sides as shown in D and F, figure 12. The U-shaped type of joint is more satisfactory and requires less filler metal than the V-type for welding heavy sections and for welding in deep grooves. The double V-bevel joint requires approximately one-half the amount of filler metal that the single V-bevel joint requires for the same plate thickness. In general, butt joints prepared from both sides permit easier welding, produce less distortion, and insure better weld-metal qualities in heavy sections than joints prepared from one side only.

91. LAP JOINT.

a. This type of joint is used to join two overlapping plates, so that the edge of each plate is welded to the surface of the other. Figure

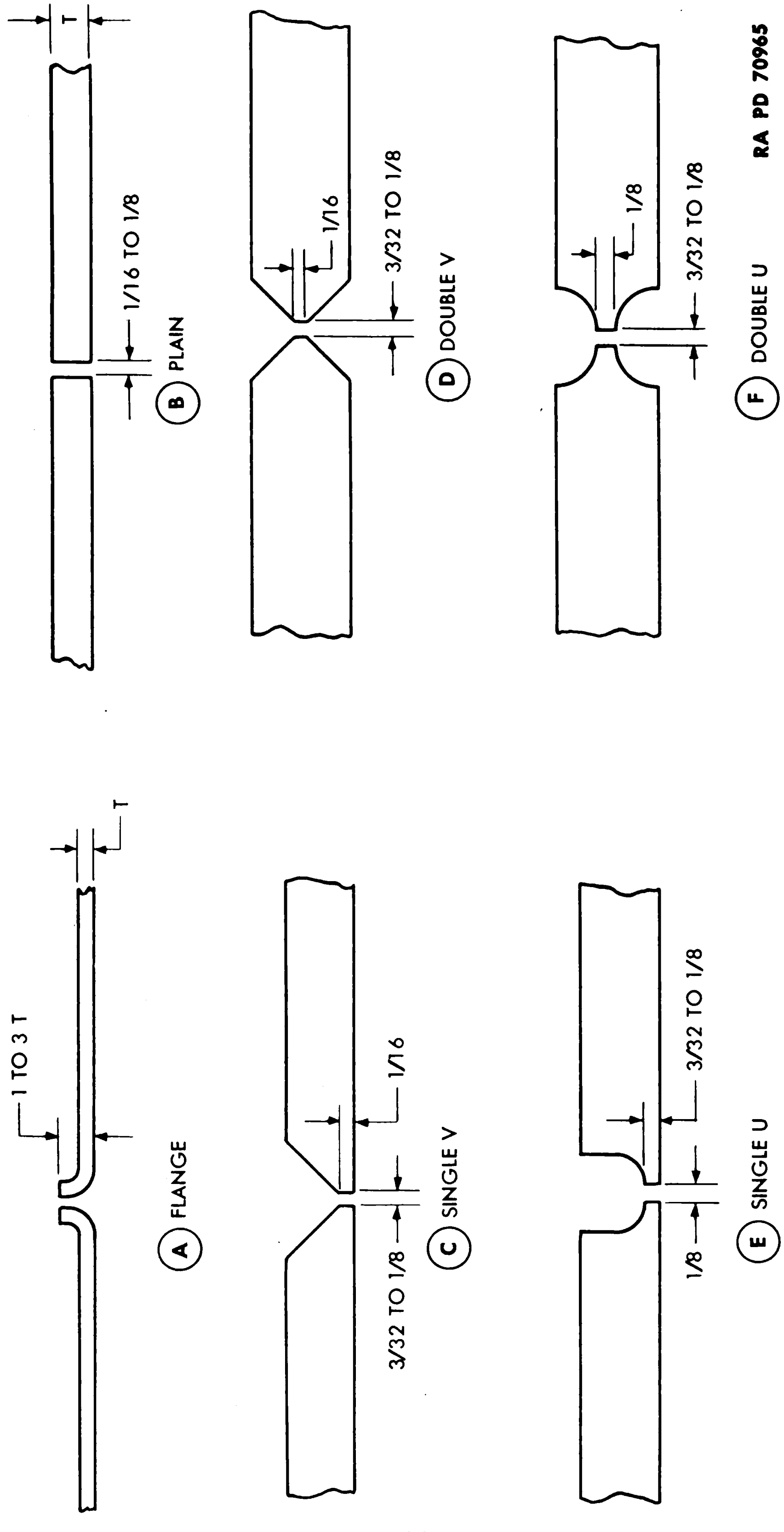

Figure 12 — Types of Preparation of Metal for Welding Butt Joints

TYPES OF WELDED JOINTS

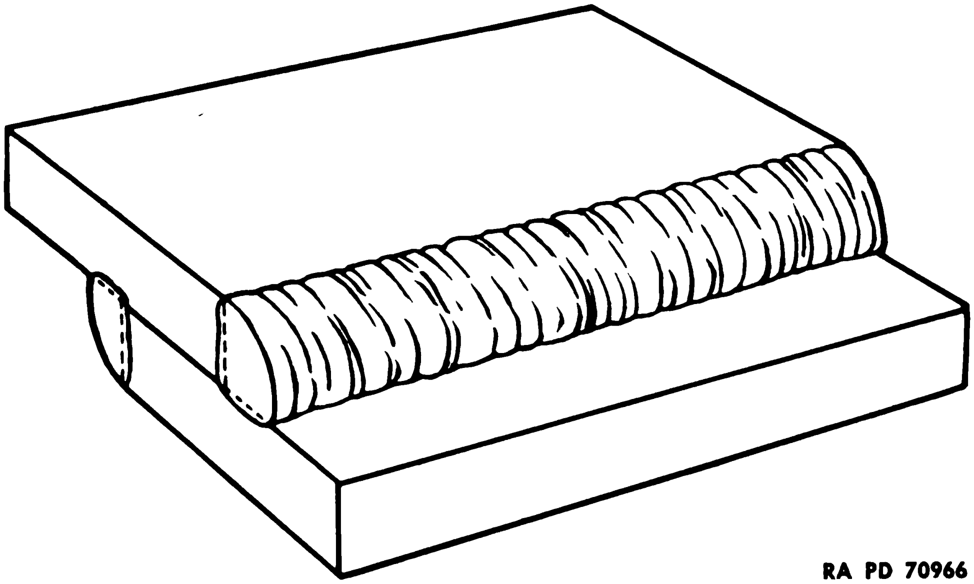

Figure 13 — Lap Joint — Single-pass Fillet Welds

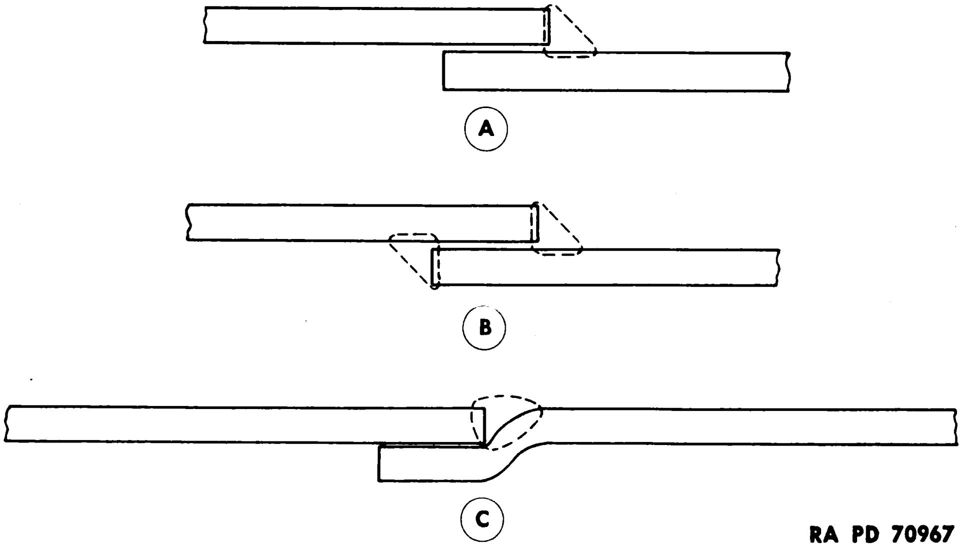

Figure 14 — Types of Preparation of Metal Sheet for Lap Joints

13 shows this type of joint. Where the design of the joint does not permit welding from both sides, these joints can be made by welding from one side only. When so welded, the joint does not develop its full strength, but it is stronger than a butt weld for some applications. Tubing or frames that overlap or telescope together are cases in which the lap joint is preferable to the butt joint.

b. The included angles of bevel for arc welding range between 60 degrees and 75 degrees, whereas included angles ranging between 75 degrees and 90 degrees are required for oxyacetylene welding. Where arc welding must be done from one side on heavy sections from 1½ inches to 2 inches in thickness, a single V-bevel with an included angle of 40 degrees to 45 degrees should be used. The spacing between plates or sections increases with increasing thickness of metal being welded.

c. Other edge preparations for lap joints are shown in figure 14. That in A, figure 14, is known as a single lap joint and is used where welding must be done from one side. B, figure 14, shows a double lap joint which will develop the full strength of the sheet or plate being welded. C, figure 14, shows an offset or "joggled" lap joint, used where two overlapping plates must be joined and the welded plates must be kept in the same plane. This lap joint is stronger than the single lap type, but it is more difficult to prepare.

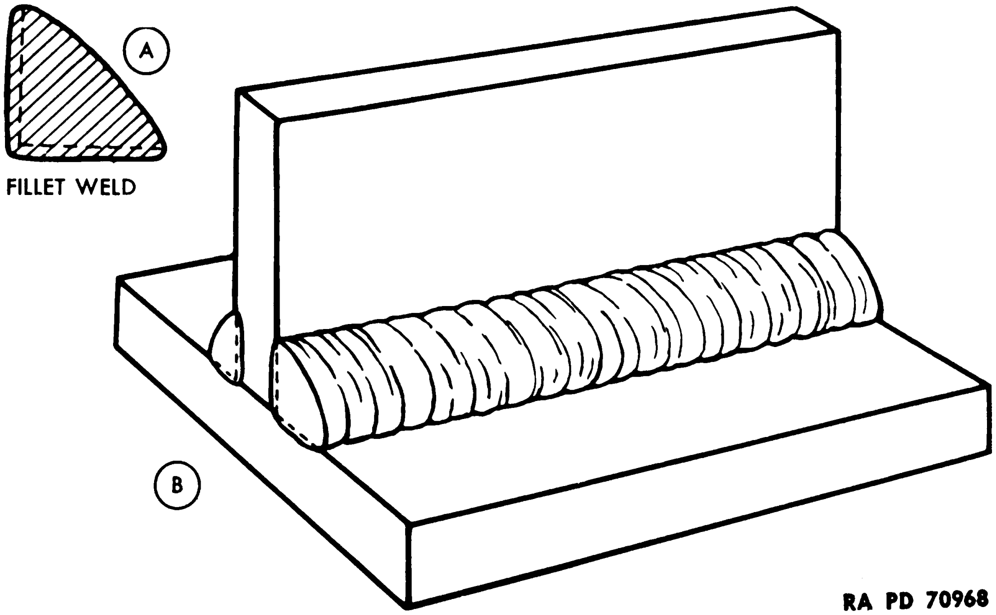

Figure 15 – T-joint – Single-pass Fillet Weld

92. T-JOINT.

a. T-joints are used to weld two plates or sections whose surfaces are located at approximately 90 degrees to each other at the joint. Figure 15 shows a typical plain T-joint welded from both sides. Other edge preparations used for making T-joints are shown in figure 16. The included angle of bevel used for these joints is approximately equal to one-half the included angle used for butt joints. A, figure 16, shows the plain T-joint, which requires no special preparation

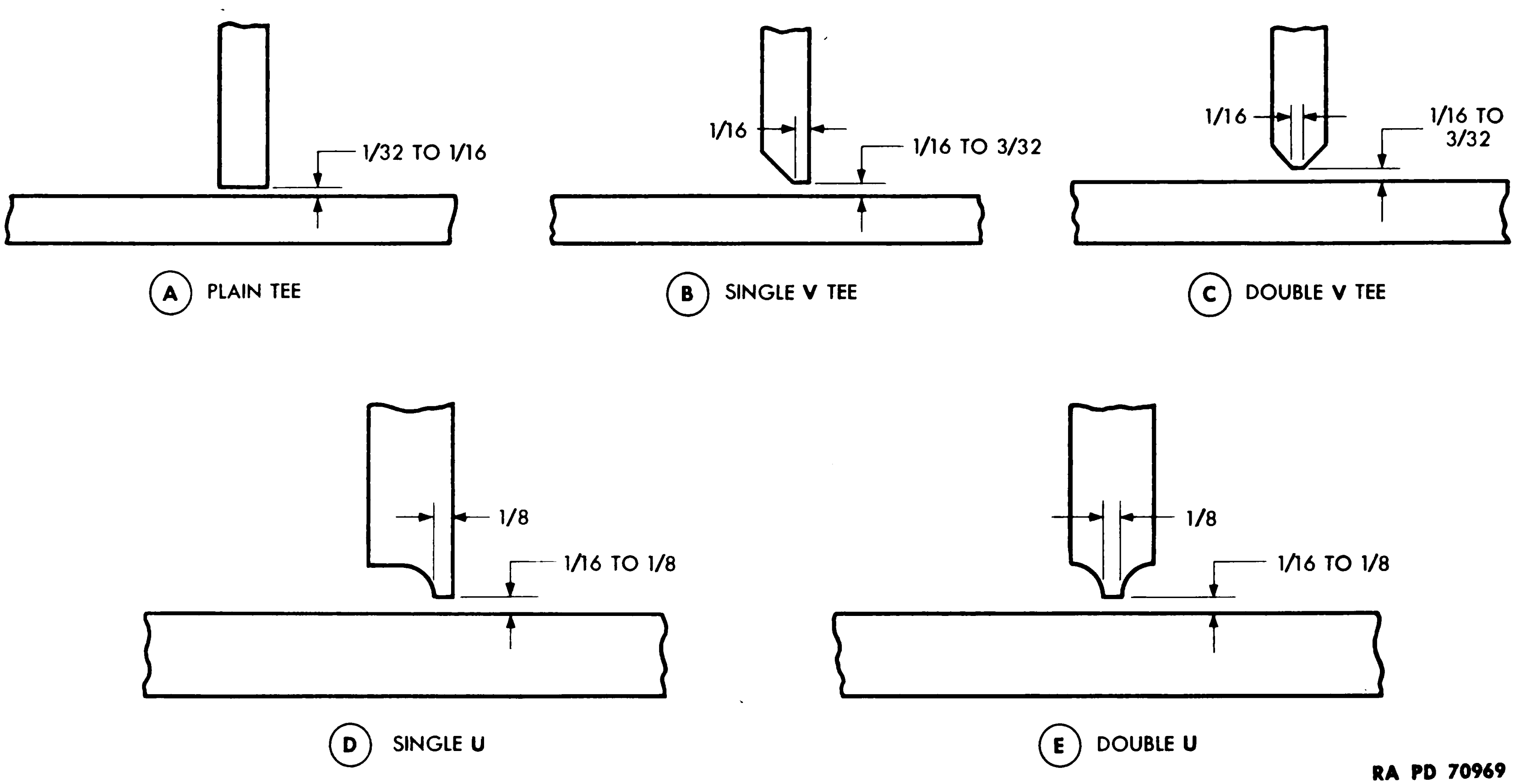

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Figure 16 — Preparation of Metals for Welding T-joints

other than cleaning the end of the vertical plate and the surface of the horizontal plate. The plate edge and surface should fit evenly at the joint in order to insure uniform penetration and fusion.

b. The single V type of joint, shown in B, figure 16, is used for plates and sections up to ½-inch in thickness. In heavy plates where the joint can be welded from both sides, the double bevel T-joint shown in C, figure 16, is used. Care should be taken to obtain complete weld-metal penetration into the root of the V from both sides. The single U-joint, as shown in D, figure 16, is used for welding plate and sections 1-inch thick and heavier where welding must be done from one side. The double U-joint (E, fig. 16) is used for welding very heavy plates or sections from both sides. Care should be taken to obtain full penetration into the root of the weld from each side. As in butt welding, less filler metal is required for making the single U T-joint than for the single V T-joint, and the same is true for the double joints.

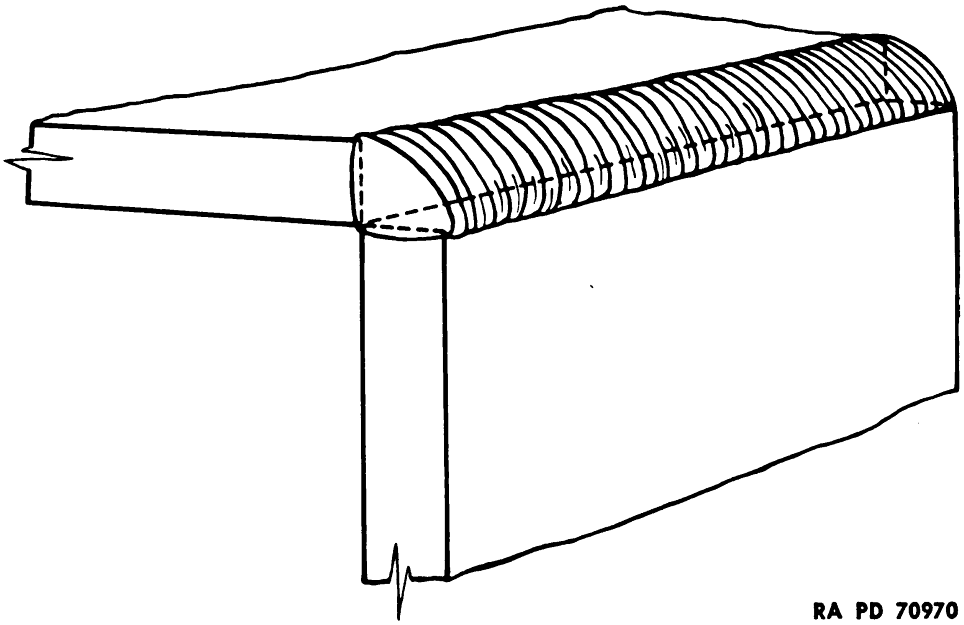

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Figure 17 — Corner Edge Joint

93. CORNER JOINT.

a. This type of joint is used to join the edges of two plates whose surfaces are at an angle of approximately 90 degrees to each other. It is shown in figure 17 and is used in the construction of box frames, tanks, boxes, and similar articles. Welding can be done from one or both sides, depending upon the position and type of corner joint used.

b. Figure 18 shows some of the more common joint designs used for making corner joints.

TYPES OF WELDED JOINTS

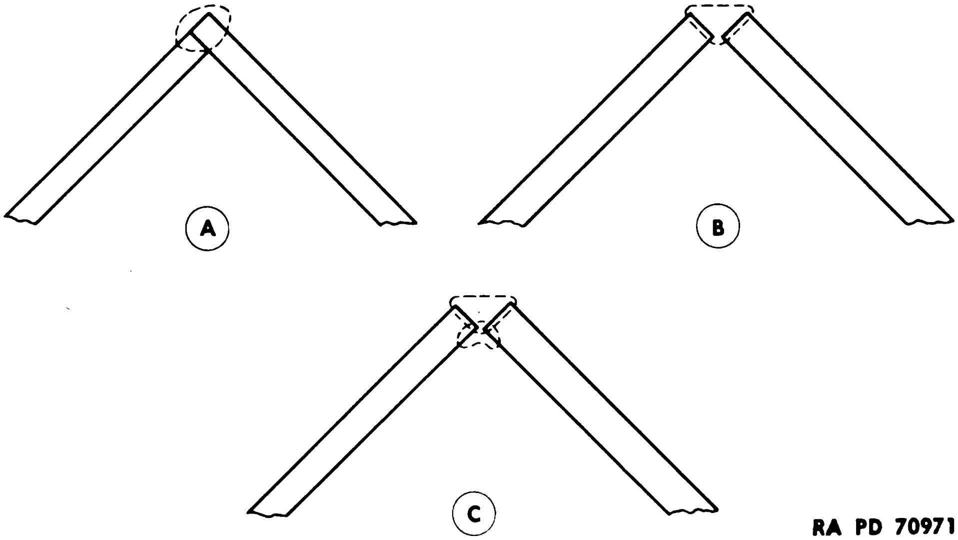


Figure 18 — Types of Corner Joint for Sheet and Plate

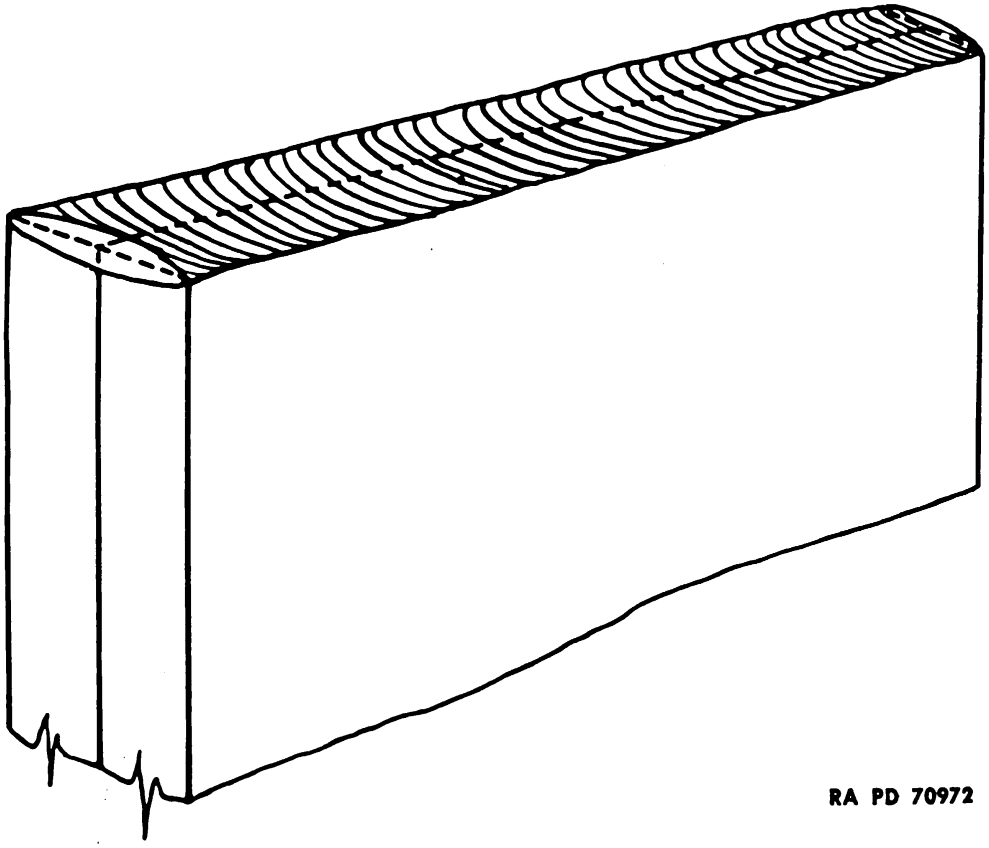


Figure 19 — Edge Joints

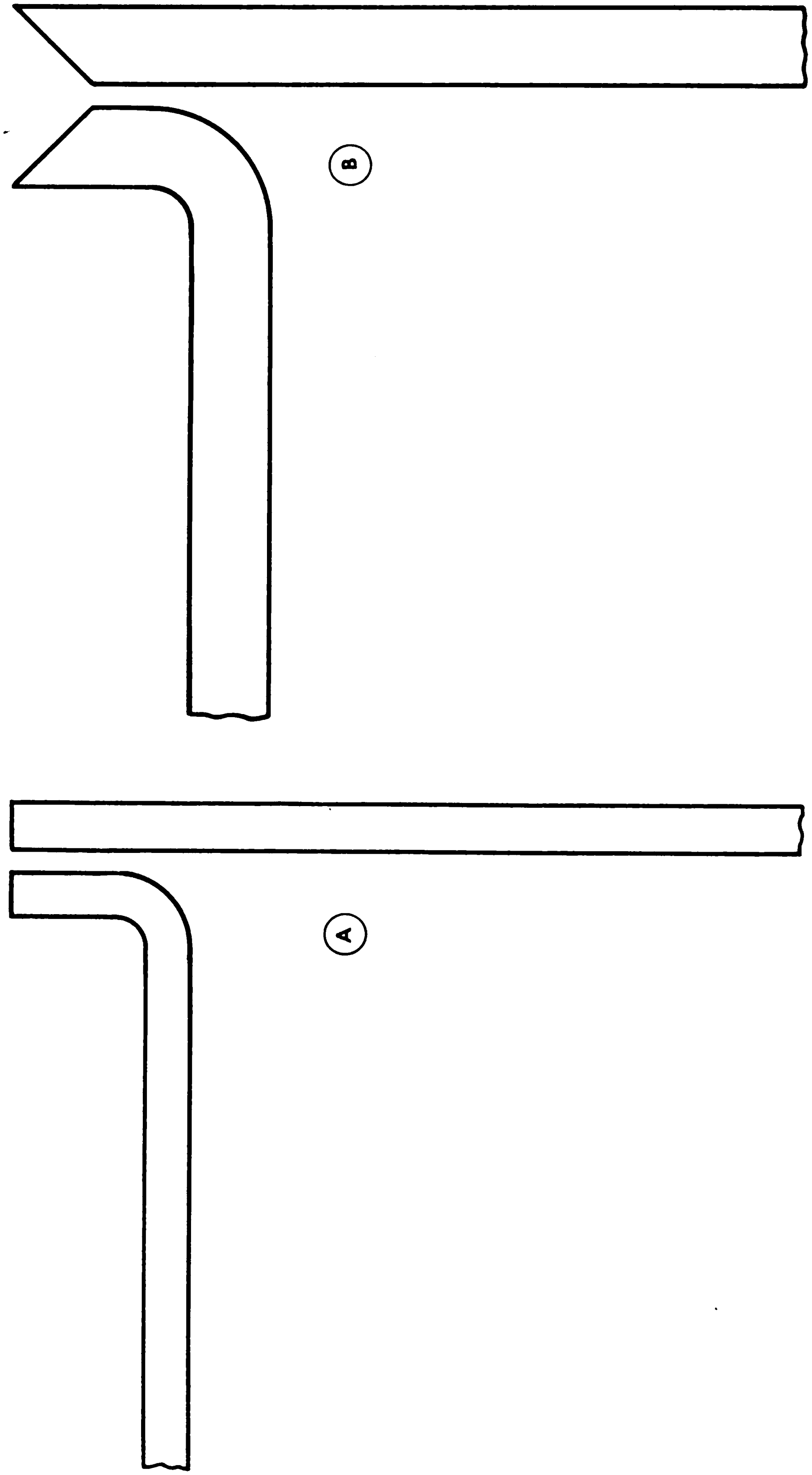


Figure 20 — Types of Edge Joint for Sheet and Plate

(1) A, figure 18, is a closed-type corner joint used on lighter sheets and plates where the strength required at the joint is not too high. To make the joint, the overlapping edge is melted down with an oxy-acetylene flame, little or no filler metal being added. In arc welding, only a very light bead is required to make the joint. In welding heavy sections, the lapped plate is V-bevelled or U-grooved to permit penetration to the root of the joint.

(2) B, figure 18, shows an open-type corner joint, used on heavier sheet and plate. The two edges of the plate are melted down, and sufficient filler metal is added to build up the corner from one side.

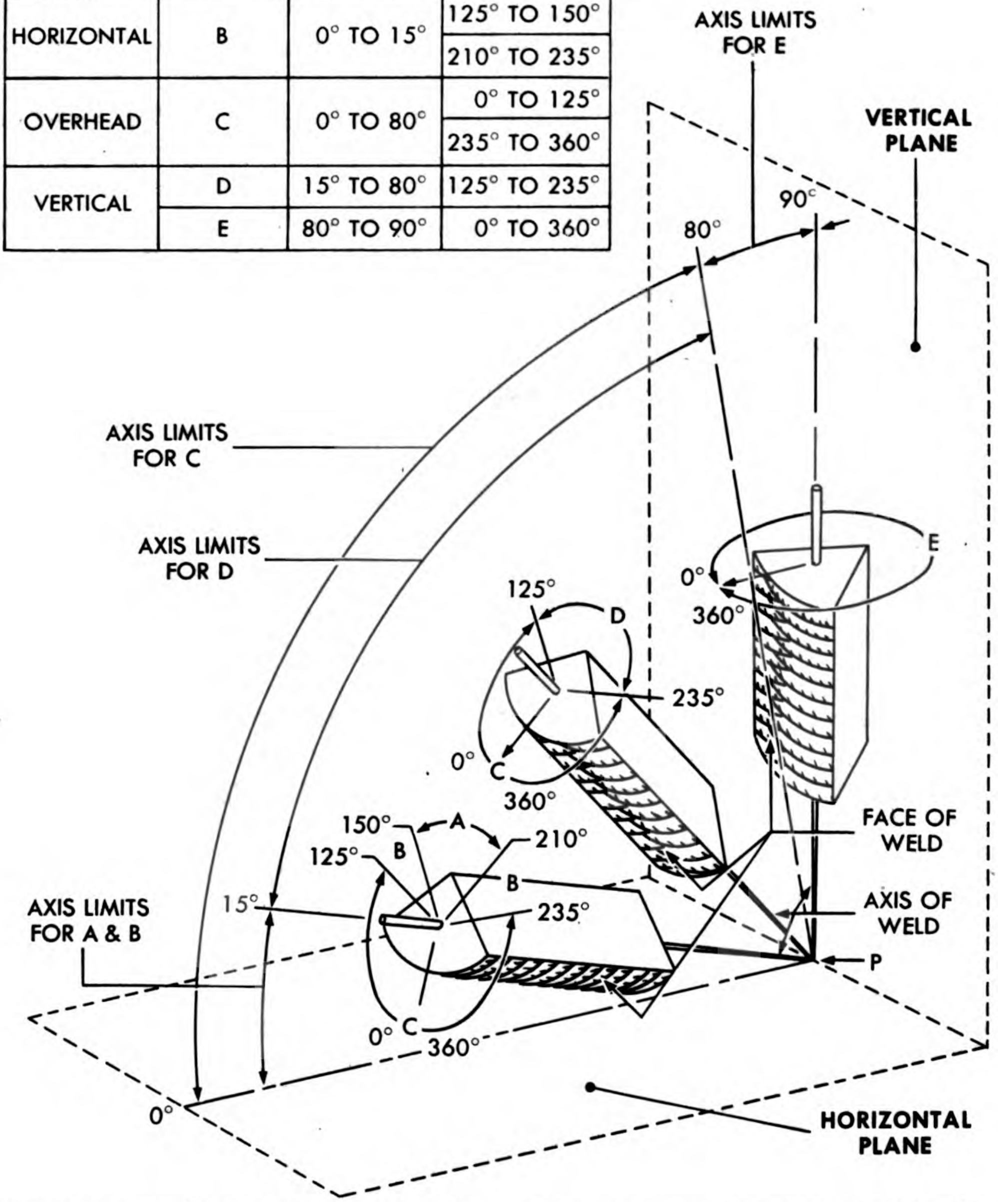
(3) Heavy plate is welded from both sides, as shown in the open corner joint (C, fig. 18). The joint is first welded from the outside, then reinforced from the back side by means of a seal bead.

94. EDGE JOINT.

a. Two parallel plates are joined together, as shown in figure 19, by means of a weld on an edge joint. This joint is not very strong and is used principally to join the edges of sheet metal and to weld reinforcing plates on flanges of I-beams or edges of angles. Sufficient filler metal is added to fuse or melt each edge completely and to reinforce the joint.

b. Two common types of edge joint are shown in figure 20. Thin sheets are welded by using the joint type shown in A, figure 20, no special preparation being necessary except to clean the edges and tack-weld them in position for welding. The joint shown in B, figure 20, is used for welding heavy plates and requires that the edges be bevelled in order to secure good depth of penetration and fusion of the sidewalls.

TABULATION OF POSITIONS OF FILLET WELDS			
POSITION	DIAGRAM REFERENCE	INCLINATION OF AXIS	ROTATION OF FACE
FLAT	A	0° TO 15°	150° TO 210°
HORIZONTAL	B	0° TO 15°	125° TO 150°
			210° TO 235°
OVERHEAD	C	0° TO 80°	0° TO 125°
			235° TO 360°
VERTICAL	D	15° TO 80°	125° TO 235°
	E	80° TO 90°	0° TO 360°



The horizontal reference plane is taken to lie always below the weld under consideration.

Inclination of axis is measured from the horizontal reference plane toward the vertical.

Angle of rotation of face is measured from a line perpendicular to the axis of the weld and lying in a vertical plane containing this axis. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. The angle of rotation of the face of weld is measured in a clockwise direction from this reference position (0°) when looking at point P.

RA PD 70974

Figure 21 — Welding Positions According to Position of Weld Metal, Fillet Welds

CHAPTER 4

OXYACETYLENE AND ELECTRIC ARC WELDING: GENERAL CONSIDERATIONS (Cont'd)

Section III

POSITIONS OF WELDS

Paragraph
General 95
Positions 96

95. GENERAL.

a. All welding can be classified according to the position of the plate or welded joint on the plates or sections being welded. There are four general positions in which welds are required to be made. These are designated as flat, vertical, horizontal, and overhead positions. To make a butt weld in pipe which is fixed in the horizontal plane, the welder must use the flat, vertical, and overhead welding positions.

96. POSITIONS.

a. The four general welding positions are illustrated in figure 21.

(1) FLAT POSITION OF WELDING. A position of welding in which filler metal is deposited from the upper side of the joint and the face of the weld is approximately horizontal. The limits of this position are defined in figures 21 and 22.

(2) HORIZONTAL POSITION OF WELDING.

(a) Fillet Weld. A position of welding in which the weld is deposited on the upper side of an approximately horizontal surface and against an approximately vertical surface. The limits of this position are defined in figure 21.

(b) Groove Weld. A position of welding in which the axis of the weld lies in an approximately horizontal plane and the face of the weld lies in an approximately vertical plane. The limits of this position are defined in figure 22.

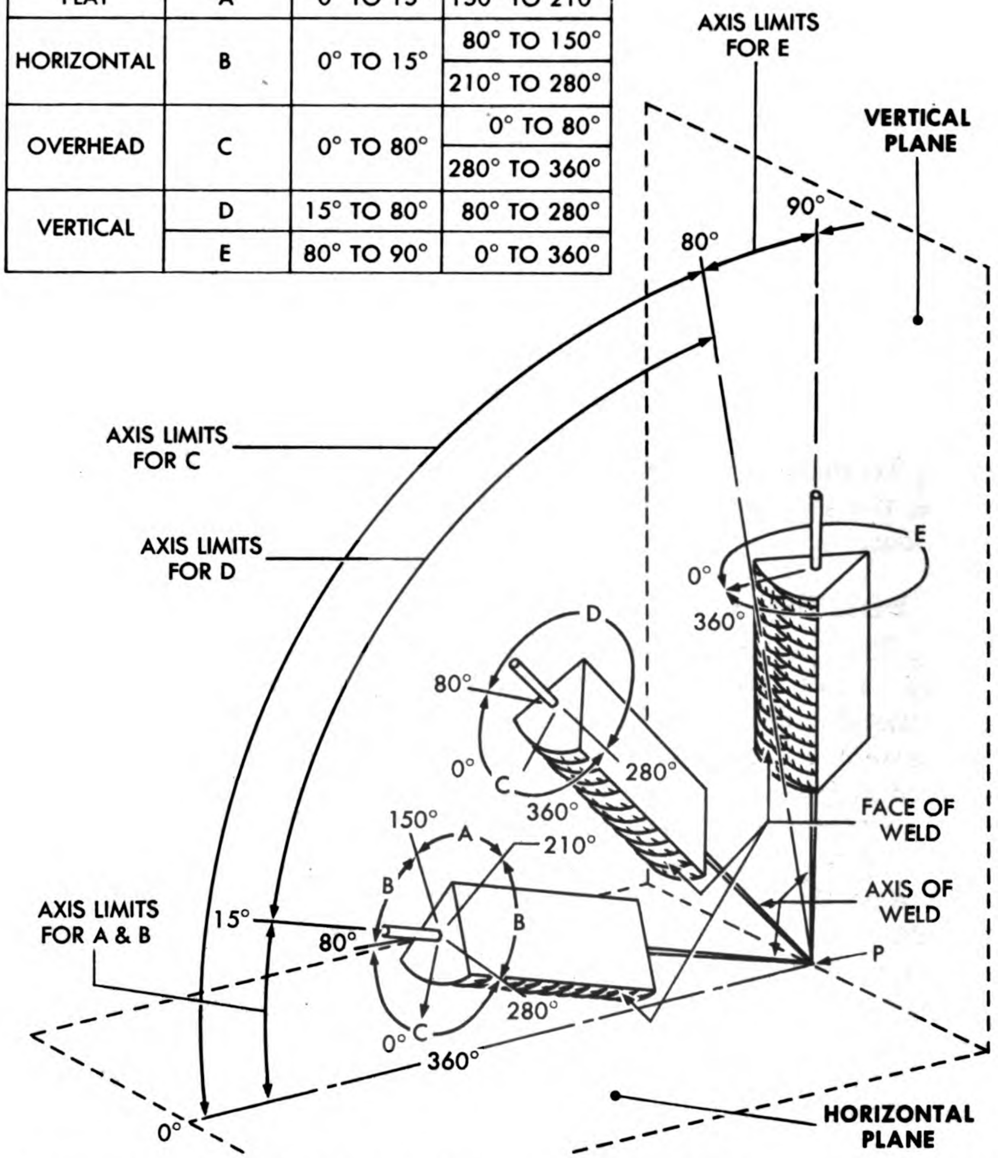
(3) VERTICAL POSITION OF WELDING. A position of welding in which the axis of the weld is approximately vertical. The limits of this position are defined in figures 21 and 22.

(4) OVERHEAD POSITION OF WELDING. A position of welding in which filler metal is deposited from the under side of the joint and the face of the weld is approximately horizontal. The limits of this position are defined in figures 21 and 22.

b. A somewhat more detailed analysis of welding positions is shown in figures 21 and 22. This diagram classifies the welded joints according to the position of the weld metal deposited.

TABULATION OF POSITIONS OF GROOVE WELDS

POSITION	DIAGRAM REFERENCE	INCLINATION OF AXIS	ROTATION OF FACE
FLAT	A	0° TO 15°	150° TO 210°
HORIZONTAL	B	0° TO 15°	80° TO 150°
			210° TO 280°
OVERHEAD	C	0° TO 80°	0° TO 80°
			280° TO 360°
VERTICAL	D	15° TO 80°	80° TO 280°
	E	80° TO 90°	0° TO 360°



For groove welds in pipe the following definitions shall apply:

Horizontal fixed position: When the axis of the pipe does not deviate by more than 30° from the horizontal plane and the pipe is not rotated during welding.

Horizontal rolled position: When the axis of the pipe does not deviate by more than 30° from the horizontal plane, the pipe is rotated during welding, and the weld metal is deposited within an arc not to exceed 15° on either side of a vertical plane passing through the axis of the pipe.

Vertical position: When the axis of the pipe does not deviate by more than 10° from the vertical position (the pipe may or may not be rotated during welding).

RA PD 70975

Figure 22 — Welding Positions According to Position of Weld Metal Groove Welds

CHAPTER 4

OXYACETYLENE AND ELECTRIC ARC WELDING: GENERAL CONSIDERATIONS (Cont'd)

Section IV

EXPANSION AND CONTRACTION IN WELDING OPERATIONS

Paragraph
General 97
Controlling contraction and expansion in sheet metal 98
Controlling contraction and expansion in castings 99

97. GENERAL.

a. The heat developed at the welding joint by either the oxyacetylene flame, the electric arc, or any other welding process will cause the metal to expand. Upon cooling, the metal contracts or shrinks. Results of weld-metal shrinkage are shown in figure 23. It is necessary, therefore, to keep the welding heat as uniform as possible in order to obtain even expansion and contraction. If the expansion of the parts being welded is restrained, buckling or warping may occur as a result of the expansion stresses developed. In contraction also, if there is any restraint on the welded parts, the weld metal or plate may be distorted or cracked as a result of contraction stresses. The welding procedure, then, should be so outlined that these stresses will be kept at a minimum, in order to retain the desired shape and strength of the finished piece.

98. CONTROLLING CONTRACTION AND EXPANSION IN SHEET METAL.

a. The back-step method may be used to offset contraction (fig. 24). In welding long seams, the contraction of the metal deposited at the joint will cause the two edges being welded to draw together and actually overlap. To allow for this, the plates should be spaced according to the type of metal and the thickness being welded (fig. 25). The average spacing allowances per foot of seam are as follows:

Metal	Inches Per Foot
Steel	¼ in. to ⅜ in.
Brass and bronze	3/16 in.
Aluminum	⅕ in.
Monel	⅜ in.
Copper	3/16 in.
Lead	5/16 in.

NOTE: This procedure is recommended when welding plate in thicknesses above ⅛ inch.

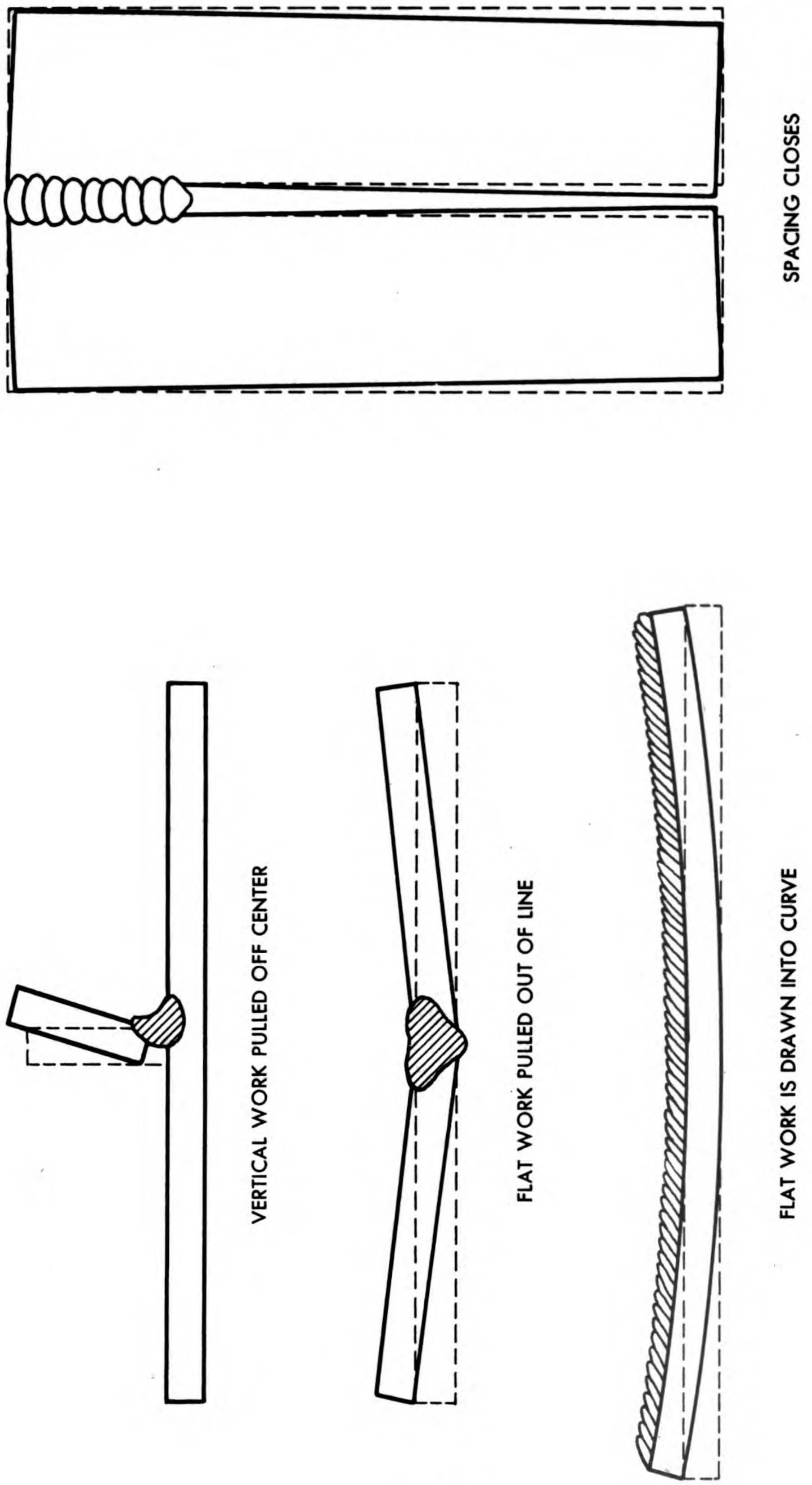


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Figure 23 — Results of Weld-metal Shrinkage

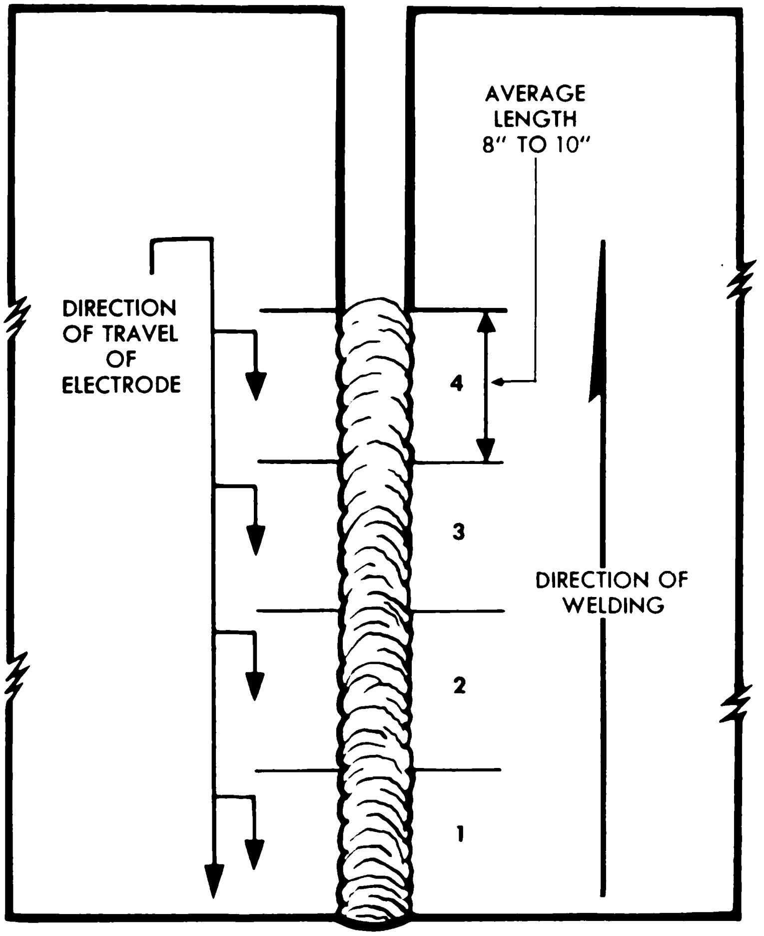

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Figure 24 — Back-step Welding Method for Counteracting Contraction

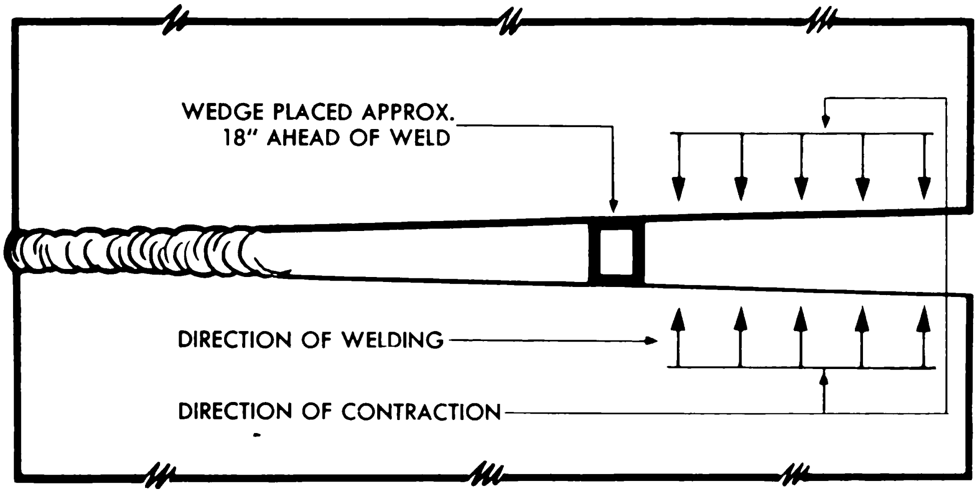

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Figure 25 — Wedge Type of Spacing for Counteracting Contraction

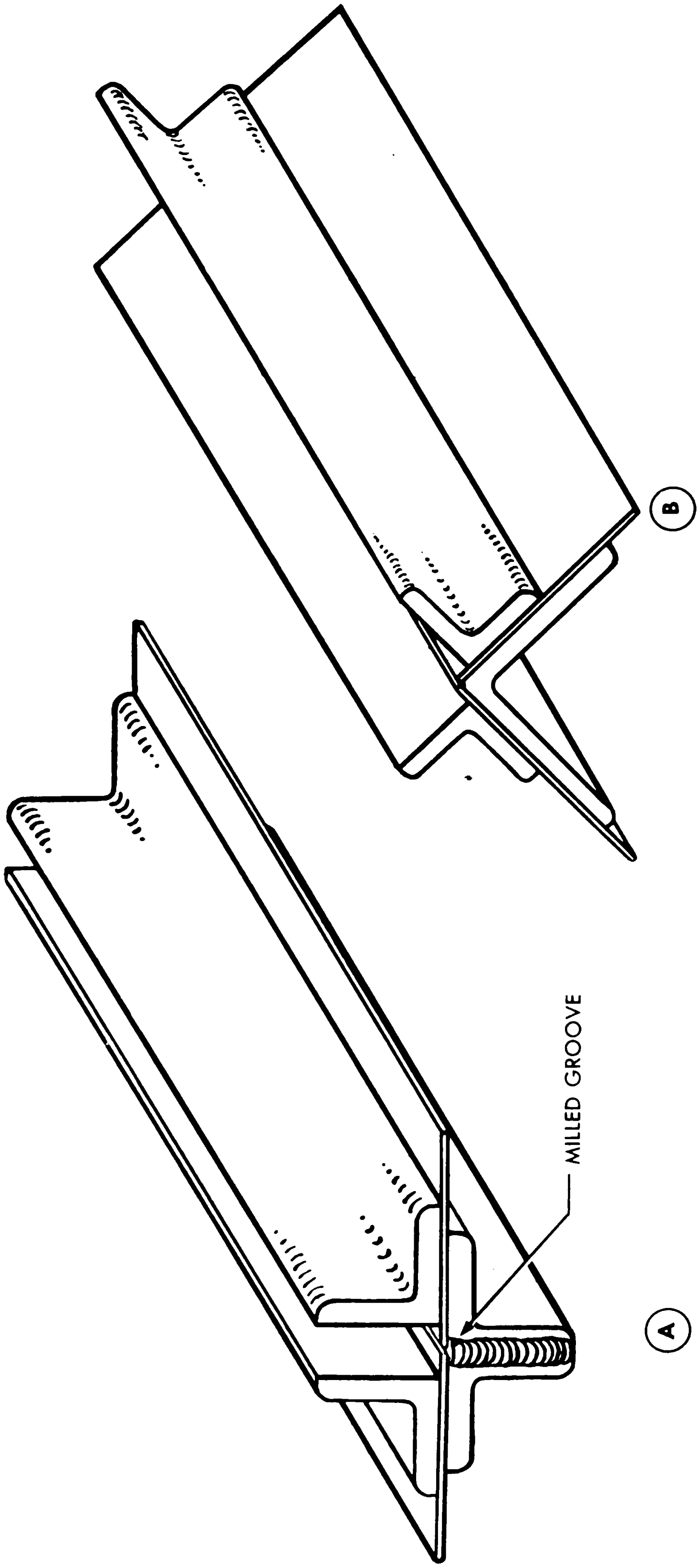

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Figure 26 — Quench Plates for Welding Sheet Metal

EXPANSION AND CONTRACTION IN WELDING OPERATIONS

b. Sheet metal under $^1/_{16}$ inch in thickness may be welded by flanging the edges and tacking at intervals along the seam before welding. In this manner, the weld can be produced without the addition of filler metal.

c. Another method of preventing buckling and warping of sheet metal during welding is the use of quench plates near the zone of welding to remove the heat of welding at the joint and thus to prevent its distorting the sheet. This can be accomplished by means of heavy pieces of metal clamped parallel to the seam being welded and allowing sufficient space to make the welded joint. These bars will act to absorb the heat of welding and will therefore eliminate stresses or distortion due to expansion or contraction (fig. 26).

d. Jigs and fixtures may be used to hold the pieces in place. These are usually designed for heavy sections in the vicinity of the welded seam, so that the plate is held in place by means of the clamps as well as cooled by means of the heavy bars (fig. 27).

e. The heat of welding may also be removed by use of wet asbestos along either side of the seam being welded.

f. In welding pipe, spacing as in figure 25 is not practical, and proper alinement of the two pieces of pipe can best be had by tack-

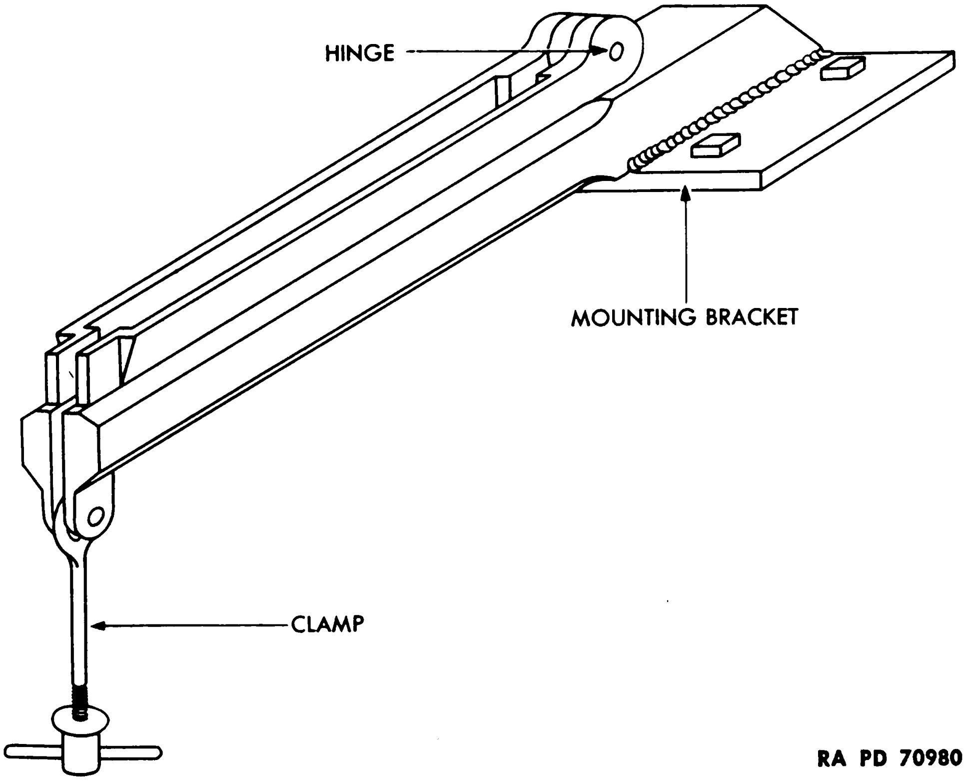
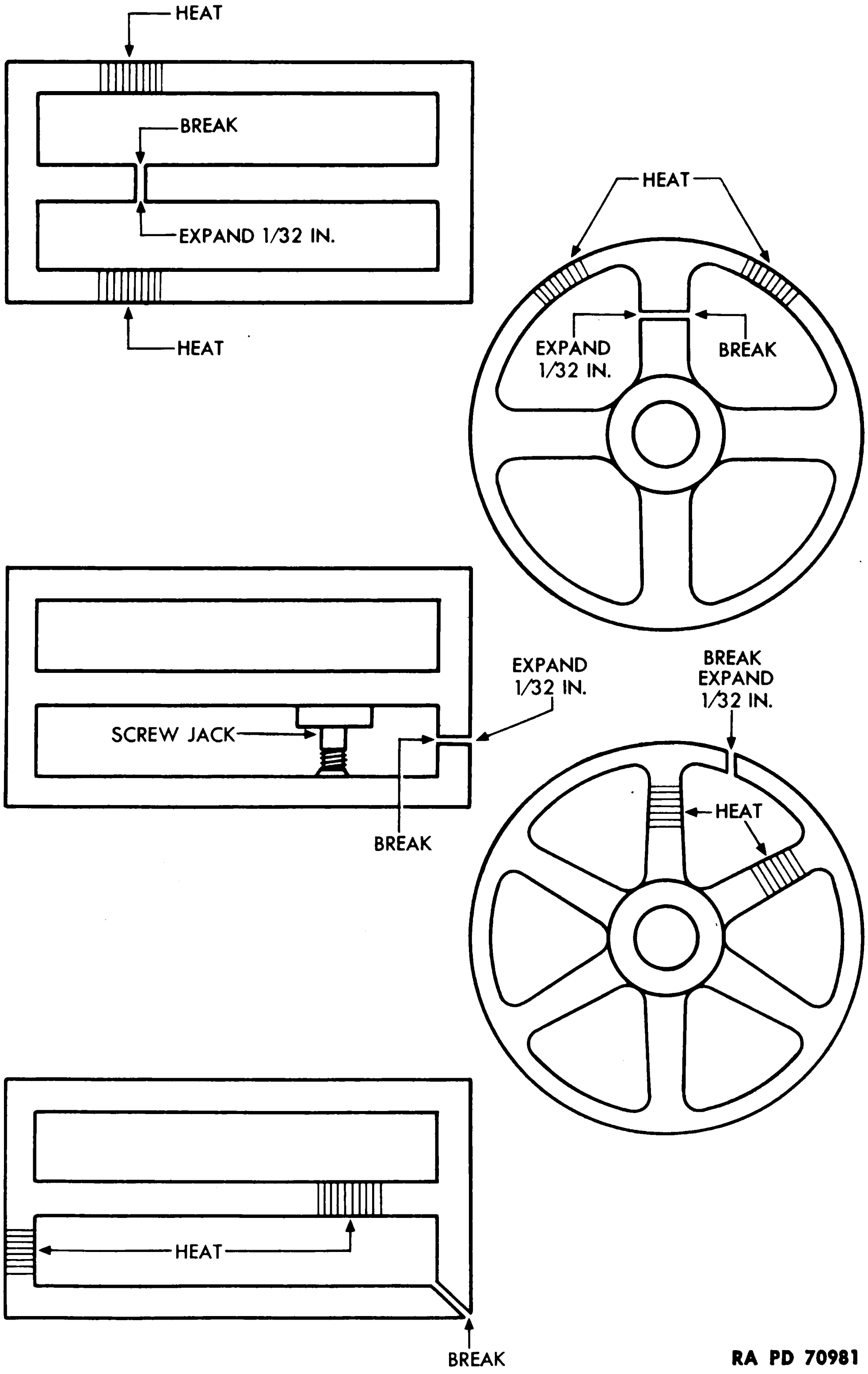


Figure 27 — Welding Jig for Sheet-metal Butt Joints



RA PD 70981

Figure 28 — Spot Preheating of Castings for Controlling Expansion

welding to hold the pieces in place for welding. The pipes should be separated by a gap of 1/8 inch to 1/4 inch, depending upon the size of the pipe being welded.

99. CONTROLLING CONTRACTION AND EXPANSION IN CASTINGS.

a. Contraction and expansion in castings are provided for by preheating. Before fusion welding, small gray-iron castings are preheated by means of a torch to a very dull red heat visible in a darkened room. After welding, a reheating and controlled slow cooling, or annealing, will relieve all internal stresses and assure a proper gray-iron grain structure. For larger castings, temporary charcoal-fired furnaces are often built of fire brick and covered with asbestos sheet. Very often only local preheating of the part adjacent to the weld is necessary. Gasoline or kerosene torches, temporary furnaces, and, sometimes, the welding torch may be used for this purpose.

b. Before welding a crack that extends from the edge of a casting, it is always advisable to drill a small hole about 1/2 to 1 inch beyond the visible end of the crack. Should the crack start to run when the heat is applied, it will then run only as far as the drilled hole.

c. The foregoing procedures apply to gray iron castings. The same methods are applicable to steel castings or castings to be bronze-welded, except that in these cases less preheat is necessary.

d. Some special methods of expanding certain castings before welding, when it is inconvenient to preheat them all over, are shown in figure 28.

CHAPTER 4

OXYACETYLENE AND ELECTRIC ARC WELDING: GENERAL CONSIDERATIONS (Cont'd)

Section V

STRESSES IN WELDING OPERATIONS

Paragraph
General 100
Stress-relieving 101
Methods of relieving stresses 102

100. GENERAL.

a. When metal is added in the form of weld metal to the base metal being welded, it is essentially cast metal. Upon cooling, the metal shrinks, and, because it is firmly welded to the base metal, it exerts a drawing action on it. This drawing action produces stresses in the weld which may cause warping or buckling of the parts being welded. These stresses are known as shrinkage stresses or residual stresses.

101. STRESS-RELIEVING.

a. The process which removes the residual stresses or decreases their intensity is known as stress-relieving. In particular, where the parts being welded are firmly fixed to prevent any movement, or where the parts are not uniformly heated during welding, stresses will be developed by the shrinking of the weld metal at the joint. It is necessary, therefore, in order to keep the stresses in the finished weld low and to prevent cracking, that the parts being welded be free to move and that the heating be applied uniformly. These precautions are particularly important in welding aluminum, cast iron, high-carbon steel, and other brittle or "hot-short" metals (those with low strength at temperatures below the melting point). Ductile materials such as bronze, brass, copper, and mild steel yield or stretch while still in the plastic or soft condition and are therefore less likely to crack; however, they may still retain undesirable stresses which tend to weaken the finished weld.

102. METHODS OF RELIEVING STRESSES.

a. Steel welds may be stress-relieved by heating from 1,100 F to 1,250 F, whereas special alloy steels may require heating up to 1,600 F. The temperature must be held for a sufficient length of time for the stresses to be relieved, and it will vary for different thicknesses of the parts so treated. In stress-relieving mild steel, a good rule to follow is to heat the completed weld 1 hour per inch of thickness at the stress-relieving temperature. On this basis, steels ¼ inch in thickness should be heated for 15 minutes at the stress-relieving temperature.

b. Another method of stress-relieving is peening of the finished weld with an air hammer, if possible. By this method the weld metal is caused to flow, thus relieving some of the stresses; however, excessive peening may cause brittleness or hardening of the finished weld and actually cause cracking. Peening, wherever necessary, should be done by means of other than hand tools.

c. Use of Preheating.

(1) In some applications of welding, it is desirable to preheat the parts to be welded. Preheating slows down the rate of cooling at the temperature range of the preheat used, sufficiently, if proper preheat for the steel composition is used, to prevent the formation of hard martensite which causes cracking troubles. Stresses are formed but to a lesser degree than when preheat is not used. The proper use of preheating greatly facilitates the application of welding in many cases, and avoids cracking troubles in the heat-affected zone particularly on the first passes of weld metal.

(2) The following table may be used as a guide for preheating temperatures before welding. The wide variation in preheating temperatures for alloy steels is governed by the carbon content as well as the alloy content of the steel.

PREHEATING TEMPERATURES

Metal	Recommended Preheating
Low-carbon steels (up to 0.30 percent carbon)	200 F to 300 F
Medium-carbon steels (0.30 percent to 0.50 percent carbon)	300 F to 500 F
High-carbon steels (0.50 percent to 0.90 percent carbon)	500 F to 800 F
Carbon molybdenum steels with carbon 0.10 to 0.30 percent	300 F to 600 F
Carbon molybdenum steels with carbon 0.30 to 0.35 percent	500 F to 800 F
Manganese steels, manganese up to 1.75 percent	300 F to 800 F
Manganese steels, manganese up to 15 percent	Usually not required
Nickel steels, nickel up to 3.50 percent	200 F to 700 F
Nickel chromium steels	200 F to 1,100 F
Chromium steels	300 F to 500 F
Stainless steels	Usually not required

PREHEATING TEMPERATURES (Cont'd)

Metal	Recommended Preheating
Cast iron	700 F to 800 F
Aluminum	500 F to 800 F
Copper	500 F to 800 F
Nickel	200 F to 300 F
Monel	200 F to 300 F
Brass and bronze	300 F to 500 F

(3) Preheating before welding, in addition to reducing or eliminating shrinkage stresses, also prevents cracking, distortion or warping, and hard zones in the welded joint. The need for preheating is increased in the case of steels and some other metals as follows:

(a) The lower the temperature of the atmosphere or of the piece being welded.

(b) The smaller the diameter of the welding rod.

(c) The greater the speed of welding.

(d) The more complicated the shape and design of the parts being welded.

(e) The larger the mass or the greater the difference between the mass of the parts being welded.

(f) For steels:

1. The higher the carbon, manganese, or alloy content of the steel.

2. The greater the capacity of the steel to harden when cooled in the air from the welding temperature.

(4) Preheating temperatures for specific ferrous and nonferrous metals are given in paragraphs 288 and 289 under process charts for oxyacetylene and electric arc welding.

PART TWO — Oxyacetylene Welding

CHAPTER 5

OXYACETYLENE WELDING: EQUIPMENT, PROCEDURE, AND TECHNIQUE

Section I

GENERAL

	Paragraph
Oxyacetylene welding, definition	103
General requirements of a weld	104
General welding procedure	105

103. OXYACETYLENE WELDING, DEFINITION.

a. Oxyacetylene welding is a nonpressure welding process in which the heat is obtained from an oxyacetylene flame formed by the combustion or burning of oxygen and acetylene. The two gases are mixed in correct proportions in a properly designed torch, which can be controlled by the operator to give any desired flame adjustment. By "nonpressure process" is meant one in which no pressure is required to make a fusion weld.

104. GENERAL REQUIREMENTS OF A WELD.

a. A good weld cannot be made unless every precaution is taken to insure the use of a proper tip size, welding rod, flame adjustment, and rod and torch manipulation. In some welding operations, such additional considerations as preheating, slow cooling, heat treatment after welding, and other special procedures are necessary. In some cases, when welding certain metals, a flux is required to remove oxides and slag from the molten metal and to protect the puddle from contact with the air. Other considerations have been covered in chapter 4.

b. A properly welded joint should be uniform in appearance and in the amount of weld metal deposited. Fusion of the sidewalls is important, and it should be complete for good joint efficiency.

c. Paragraphs 291 and 292 show common defects in welds and indicate procedure for correcting same.

105. GENERAL WELDING PROCEDURE.

a. In general, the edges to be welded in oxyacetylene welding are first properly prepared. Consideration must be given to correct spacing and alinement of the parts, so that the finished weld will have the desired appearance and shape. The edges of the plate at the joint must be melted down uniformly by means of a proper torch movement.

b. In welding light sheet metal, no filler metal or rod is used. The edges of the sheet at the joint are flanged, and, when melted, they flow together to form one solid piece with some reinforcement at the joint. In welding heavier sheets and plates, filler metals are required, and the edges of the plates being welded are usually bevelled to permit penetration to the base of the joint. Both the filler metal and the base metal, after being melted, solidify to form one continuous piece.

CHAPTER 5

OXYACETYLENE WELDING: EQUIPMENT, PROCEDURE, AND TECHNIQUE (Cont'd)

Section II

SAFETY PRECAUTIONS

Paragraph
General precautions 106
Acetylene cylinders 107
Oxygen cylinders 108
Hose 109

106. GENERAL PRECAUTIONS (pars. 14 to 18).

a. Use no oil, grease, or any other lubricant on welding or cutting apparatus. Never allow oil or grease to come in contact with oxygen under pressure.

b. Do not experiment with or change torches or regulators in any way. Never modify oxygen regulators or use them with acetylene cylinders.

c. Always use the proper tip or nozzle, and operate it at the proper pressure for the particular work involved. This information should be taken from tables or work sheets supplied with the equipment.

d. Do not permit unauthorized persons or bystanders to use oxyacetylene welding or cutting equipment.

e. Do not hang a torch with its hose on regulators or cylinder valves. Make certain that the torch is not burning when not in use, and that the valves are closed tightly.

f. Do not use matches for lighting torches; a serious hand burn may result. Use friction lighters, stationary pilot flames, or some other suitable source of ignition.

g. Do not light torches from hot metal in a confined space. An explosive mixture of acetylene and oxygen in a confined space may cause damage or personal injury when ignited. Do not allow such a mixture to accumulate.

h. Always wear goggles when working with a lighted torch. Use only goggles designed specifically for welding use.

i. Do not weld or cut material without first making certain that hot sparks or hot metal will not fall on the legs or feet of the operator, on the hose and cylinders, or on any inflammable material.

j. No welding or cutting operations should be performed in wooden buildings with wooden floors unless the floors are protected from sparks and hot metal by means of asbestos paper or sand. Have a fire extinguisher on hand.

k. Keep a clear space between the cylinders and the work so that the cylinder valves can be reached easily and quickly if necessary.

l. Use cylinders in the order received to avoid rental charge. Store full and empty cylinders separately, and mark the latter "MT." No compressed gas cylinders owned by commercial companies should be painted the regulation Army olive-drab while in the hands of troops.

m. Never use cylinders for rollers or supports or for any other purpose than that for which they are intended.

107. ACETYLENE CYLINDERS.

a. Refer to acetylene by its full name, "acetylene," and not by the word "gas." Acetylene is very different from city or furnace gas.

b. Acetylene cylinders should be stored in an upright position. Do not lay them on their sides. Acetylene cylinders should be handled carefully to avoid damage to the valves or fuse plugs, which will cause leakage. Do not drop the acetylene cylinders or handle them roughly.

c. Acetylene cylinders should be stored in a well-protected, well-ventilated, and dry place, at a distance from highly combustible material such as oil or paint. Do not store the cylinders near stoves, radiators, or furnaces. The heat will increase the pressure, and it may melt or blow out the safety plug in the acetylene cylinder. Outlet valves which have become clogged with ice should be thawed with warm water. Do not use scalding water or an open flame.

d. Never use acetylene from cylinders without reducing the pressure through a suitable pressure-reducing regulator. Never use acetylene at pressures in excess of 15 pounds per square inch.

e. Always open the acetylene cylinder valve slowly to avoid strain on the regulator gage recording the cylinder pressure. Be sure the regulator tension screw is released before opening the cylinder valve. Do not open acetylene cylinder valves more than one and one-half turns of the spindle. One half-turn of the spindle is sufficient. Always use the special T-wrench provided for the acetylene cylinder valve. Leave this special wrench in position on the stem of the acetylene valve while the cylinder is in use, so that the acetylene can be quickly turned off in an emergency.

f. Acetylene is a highly combustible fuel gas. Care should be taken to keep sparks, flames, and heat away from acetylene cylinders.

g. Never open an acetylene cylinder valve near sparks, flame, or other welding or cutting work.

h. Always turn the acetylene cylinder so that the valve outlet will point away from the oxygen cylinder.

i. Never interchange acetylene regulators, hose, or other apparatus with similar equipment intended for oxygen.

j. Never test for acetylene leaks with an open flame. Test all joints for leaks with soapy water. Should a leak occur in an acetylene cylinder around the valve stem, close the valve and tighten the packing nut. Cylinders leaking around the fuse plugs should be taken out to the open air, away from all fires and sparks, and the contents of the cylinder should be wasted by slightly opening the valve.

k. Never attempt to transfer acetylene from one cylinder to another, or to refill an acetylene cylinder, or to mix any other gas or gases in an acetylene cylinder.

l. When returning empty cylinders, see that the valves are closed tight to prevent escape of residual acetylene or acetone solvent. Screw on the valve protecting caps.

m. If an acetylene cylinder should catch fire, it can usually be extinguished with a wet blanket. If this fails, spray a stream of water on it to keep it cool. A burlap bag wet with calcium chloride should be kept handy for such an emergency.

n. Before attaching the pressure regulators, open each cylinder valve for an instant to blow dirt out of nozzles. Wipe off the connection seat with a clean cloth. Do not stand in front of valves when opening them.

108. OXYGEN CYLINDERS.

a. Always refer to oxygen by its full name, "oxygen," and not by the word "air."

b. Keep oxygen away from oil, grease, and other inflammable materials. Do not handle oxygen cylinders, valves, regulators, hose, or apparatus with oily hands or oily gloves. Do not cause a jet of oxygen to strike an oily surface or greasy clothes, or to enter a fuel-oil storage tank. CAUTION: Oil or grease in the presence of oxygen under pressure will ignite violently.

c. Do not store oxygen and acetylene cylinders together. They should be grouped separately and, if possible, with a fire-resisting wall between the two groups of cylinders.

d. When oxygen cylinders are in use or being moved, take care to see that the cylinders are not knocked over or struck by heavy objects. Do not drop oxygen cylinders or handle them roughly.

e. All oxygen cylinders with leaky valves or safety plugs should be set aside and marked for the attention of the supplier. Do not tamper with or attempt to repair oxygen cylinder valves. Do not use a hammer or wrench to open cylinder valves. In all such instances, notify the officer in charge or mark the cylinders as defective for attention of the supplier.

f. Do not substitute oxygen for compressed air in pneumatic tools; do not use it to blow out pipe lines or to "dust" clothing or work.

g. Open the oxygen cylinder valve slowly to prevent damage to the regulator high-pressure-gage mechanism. Be sure the regulator tension screw is released before opening the cylinder valve. When not in use, the oxygen cylinder valves should be closed, and the protecting caps should be screwed on tight to prevent damage to the valves.

h. When the oxygen cylinder is in use, open the valve to the full limit to prevent leakage around the valve stem.

i. Always use regulators on oxygen cylinders to decrease the cylinder pressure to a low working pressure; otherwise the high pressure will burst the hose.

j. Do not use on oxygen cylinders any regulators, hose, or apparatus which have been designed for or used with other gases.

109. HOSE.

a. Do not allow the hose to come in contact with oil or grease. These will penetrate and deteriorate the rubber and constitute a hazard with oxygen.

b. Always protect hose from being trampled upon or run over. Avoid tangles and kinks. Do not leave the hose where anybody can trip over it and pull a connection off, or, worse still, knock over the cylinders and equipment attached to it.

c. Protect the hose from flying sparks, hot slag, hot objects, and open flame.

d. Never force hose connections that do not fit. Do not use white lead, oil, grease, or other pipe-fitting compounds for making joints on hose, torch, or regulator connections.

e. Examine all hose periodically for leaks by immersing the hose in water while under pressure. Do not use matches for checking leaks in acetylene hose. Leaks in hose should be repaired by cutting the hose and inserting a splice. Do not use tape to repair defective hose.

f. Be certain that the hose is securely attached to the torches and regulators before using.

g. Do not use new or stored hose lengths without first blowing them out to eliminate talc or accumulated foreign matter which might otherwise enter and clog up the torch ports.

CHAPTER 5

OXYACETYLENE WELDING: EQUIPMENT, PROCEDURE, AND TECHNIQUE (Cont'd)

Section III

WELDING APPARATUS

Paragraph
General 110
Stationary and portable equipment 111
Acetylene and its production 112
Acetylene cylinders 113
Oxygen and its production 114
Oxygen cylinders 115
Oxygen and acetylene regulators 116
Oxyacetylene welding torch 117
Welding tips and mixers 118
Hose 119

110. GENERAL.

a. The equipment used for oxyacetylene welding consists of a cylinder of oxygen, a cylinder of acetylene, two regulators, two lengths of hose with fittings, a welding torch with a cutting attachment or a separate cutting torch. It may be either portable or stationary, depending upon the class of work being done. A portable outfit is shown in figure 29. In addition, suitable goggles are required for eye protection, a spark lighter to light the torch, gloves to protect the hands, and an apparatus wrench for the various connections on cylinders, regulators, and torches.

111. STATIONARY AND PORTABLE EQUIPMENT.

a. A stationary welding outfit is similar to the portable outfit except for the source of oxygen and acetylene. The oxygen is obtained from a number of cylinders manifolded or connected together and equipped with a master regulator to control the pressure and the flow. The oxygen is thereby supplied to a pipe line which distributes gas to a number of stations. A typical stationary type of oxygen cylinder manifold is shown in figure 30. Both the oxygen and the acetylene is obtained at the station through a station outlet similar to that shown in figure 31. In the stationary type of welding

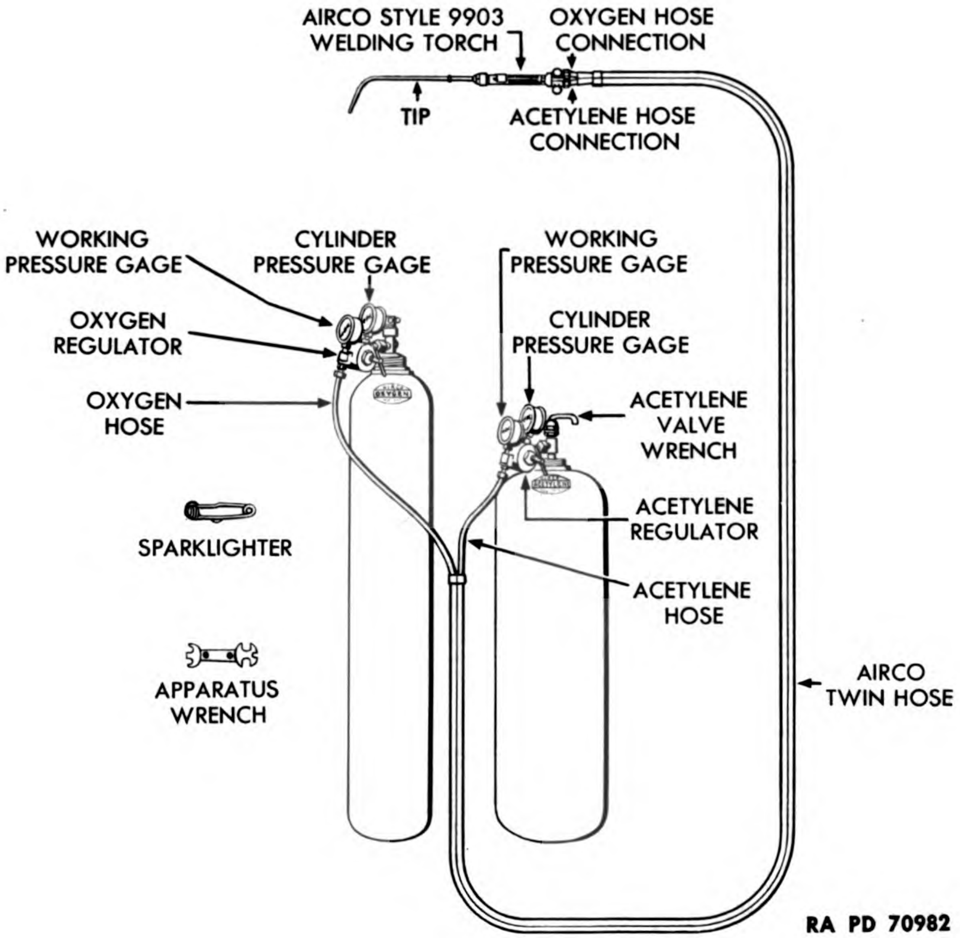


Figure 29 — Oxyacetylene Welding and Cutting Outfit

outfit, the acetylene is either obtained from an acetylene manifold connected to a number of acetylene cylinders or is generated in a suitable acetylene generator. A typical acetylene cylinder manifold, used to supply acetylene to a pipe line for distribution to welding stations, is shown in figure 32. The manifold is equipped with special safety devices to protect it from flashbacks occurring in the torch which might be carried back to the cylinders. A suitable regulator is also required to control the flow of acetylene from the manifold to the pipe line.

b. In stationary installations where an acetylene manifold is not used, the acetylene is obtained from an acetylene generator similar in design to that shown in figure 33. The generators are set to deliver clean, cool acetylene under a pressure not exceeding 15 pounds per square inch.

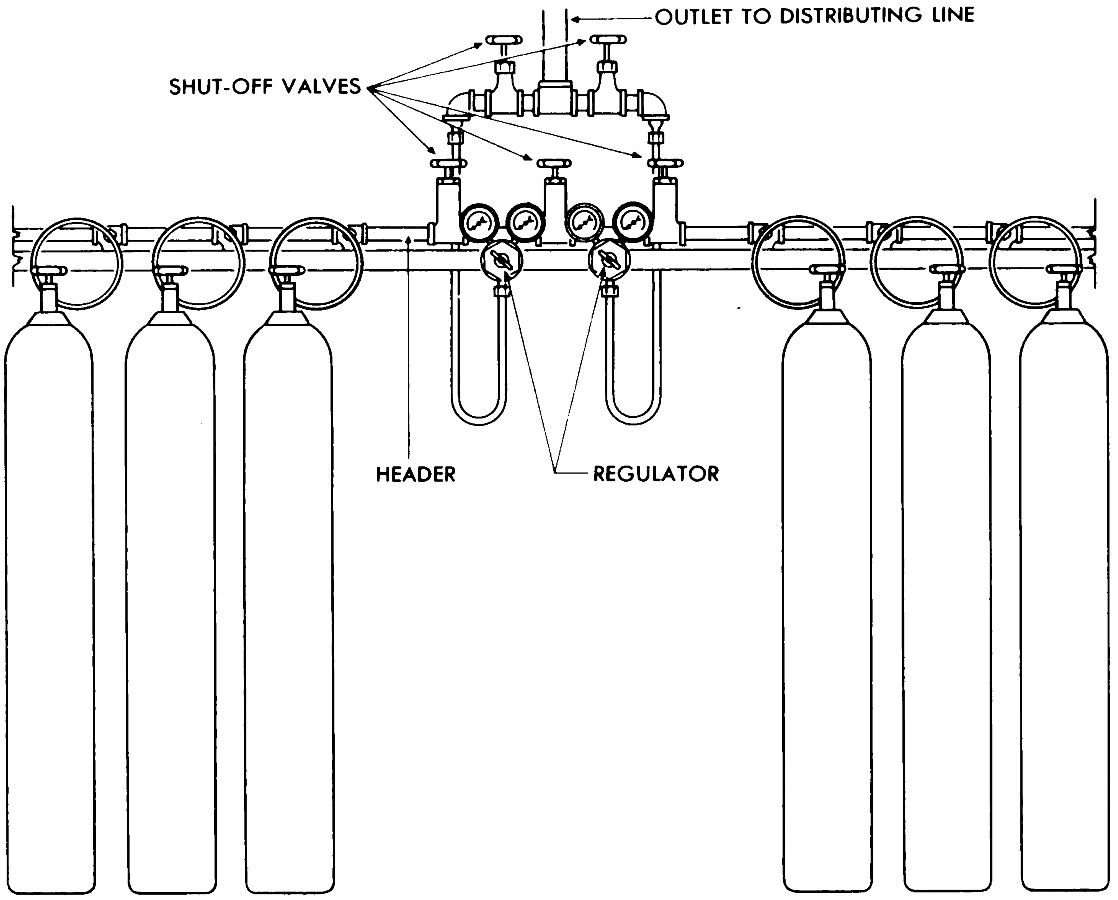


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Figure 30 — Stationary-type Oxygen Cylinder Manifold

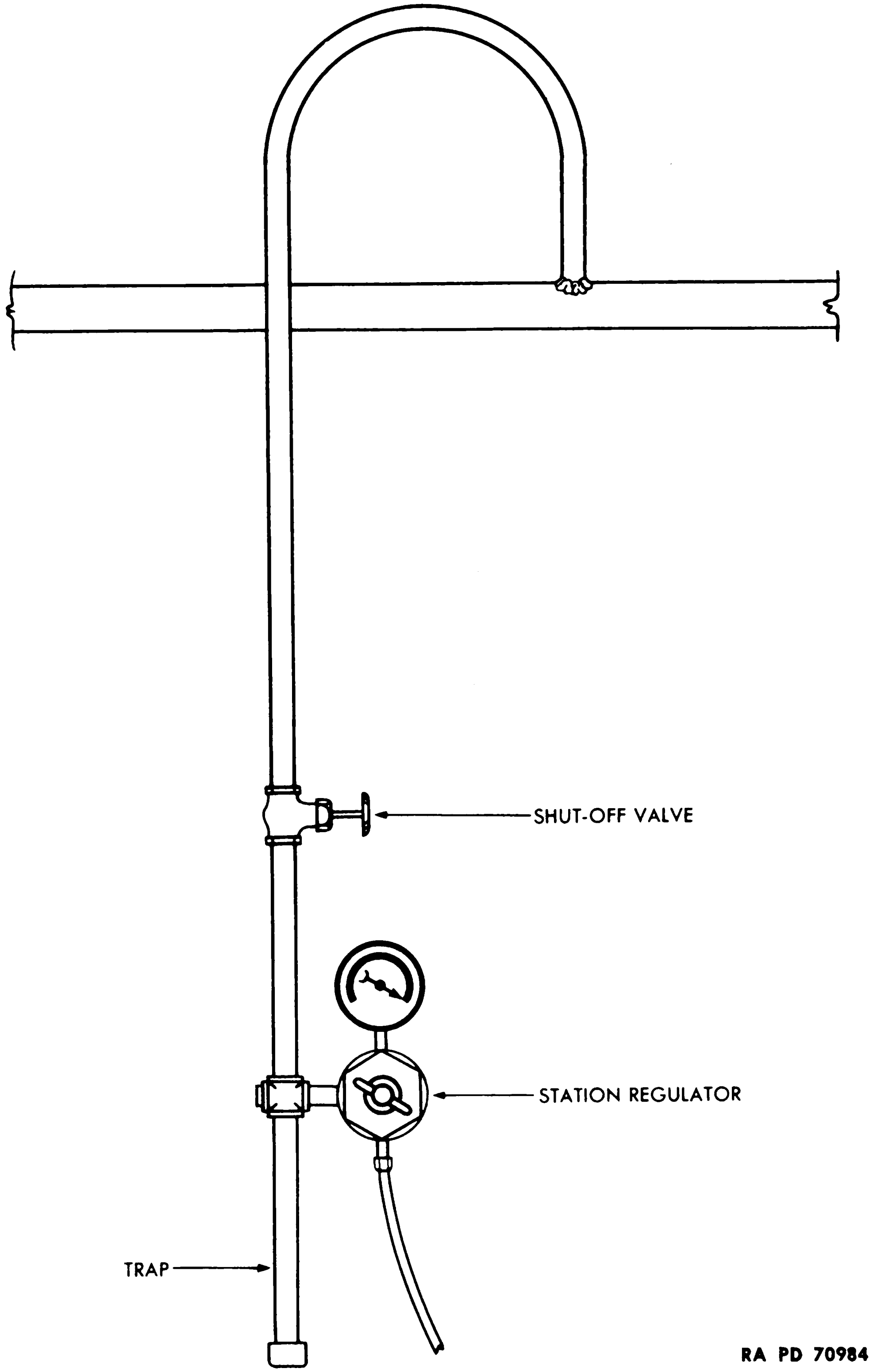


Figure 31 — Station Outlet for Overhead Acetylene Distributing Line

112. ACETYLENE AND ITS PRODUCTION.

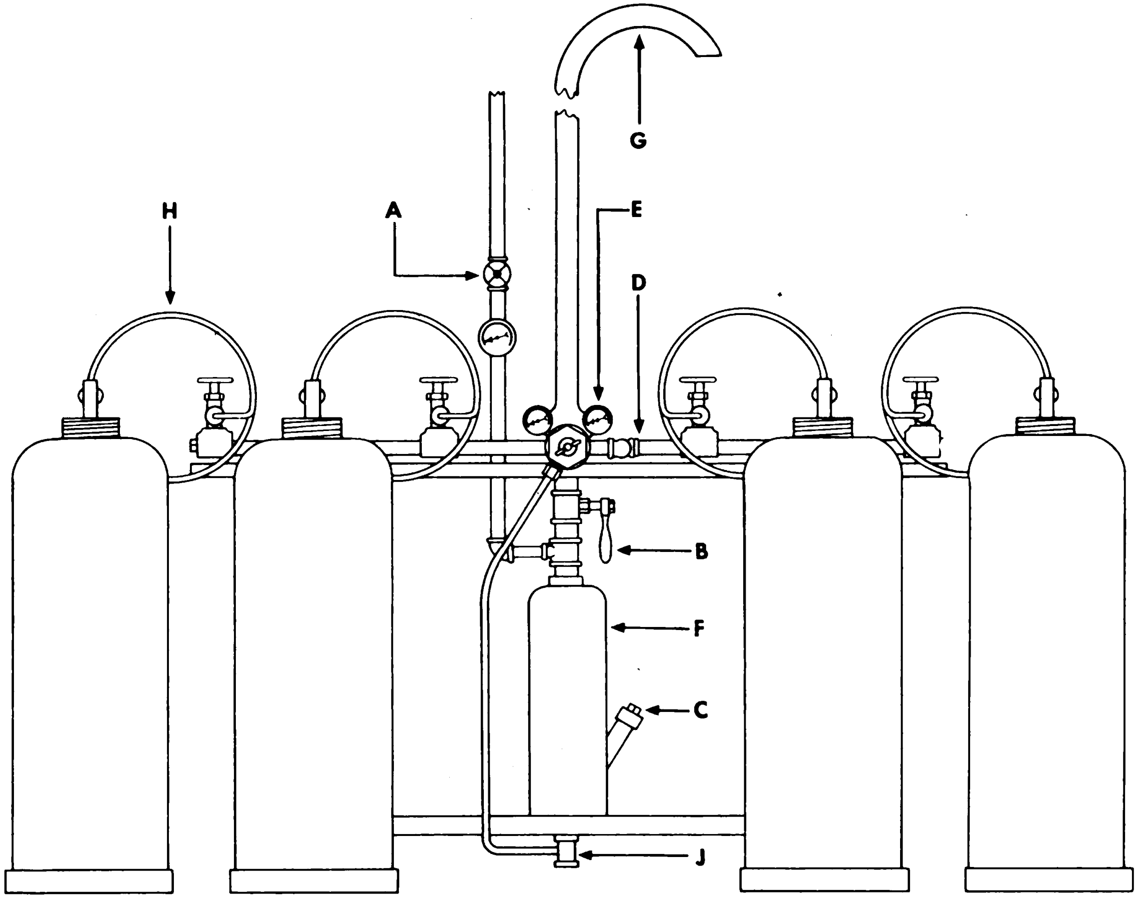
a. Acetylene is a fuel gas composed of carbon and hydrogen. Its chemical formula is C_2H_2. When burned with oxygen, acetylene produces an oxyacetylene flame with a temperature, for an oxidizing flame mixture, of approximately 6,300 F. A neutral flame produces a temperature of approximately 5,850 F, while a carburizing flame produces a temperature of approximately 5,700 F. These temperatures are developed at the tip of the inner cone of the flame. Combustion constants of other fuel gases are compared with those of acetylene in paragraph 284. Acetylene is without color but has a distinctive odor that can be easily detected.

b. Mixtures of acetylene and air containing from 2 to 80 percent acetylene by volume will explode when ignited. With the proper precautions and suitable welding apparatus, however, acetylene can be safely burned with oxygen for heating, welding, and cutting purposes.

c. Acetylene is generated by the action between calcium carbide, a gray, stonelike substance, and water, leaving a hydrated (or slaked) lime as a sludge. The reaction of the carbide and the water produces acetylene gas, leaving the sludge of lime at the bottom of the generator. Since considerable heat is given off in this reaction, special precautions are taken to prevent excessive pressures in the generator which might cause fire or explosions. The calcium carbide is added to water through a hopper mechanism, and the rate of feed of carbide is regulated so as to maintain a given working pressure automatically, usually about 15 pounds per square inch. A pressure regulator is required at the generator to control the pressure of the gas entering the pipe-line. This unit is built in as part of the generator. Acetylene generators are known as single-rated or double-rated, depending upon their capacity to produce acetylene. A single-rated 300-pound generator is filled with 300 pounds of calcium carbide and 300 gallons of water. This generator has a capacity of delivering acetylene at rates up to 300 cubic feet per hour. Since calcium carbide generates 4.5 cubic feet of acetylene per pound, this generator can operate at full load for a period of 4.5 hours. A double-rated 300-pound generator when filled with 300 pounds of calcium carbide and 300 gallons of water will deliver 600 cubic feet of acetylene per hour for 2¼ hours when operating under full load. The double-rated generator is similar to the single-rated generator except that finer sized calcium carbide is used through a special hopper.

113. ACETYLENE CYLINDERS.

a. Acetylene can be compressed into steel cylinders under a pressure of 250 pounds per square inch, or it may be directly piped from the generators to the stations where it will be used. Acetylene cylinders used to supply gas for welding purposes are constructed



A—LINE VALVE
B—RELEASE VALVE
C—FILLER PLUG
D—HEADER PIPE
E—REGULATOR
F—FLASH ARRESTOR CHAMBER
G—ESCAPE PIPE
H—CYLINDER CONNECTION PIPE
J—CHECK VALVE AND DRAIN PLUG

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Figure 32 — Stationary-type Acetylene Cylinder Manifold

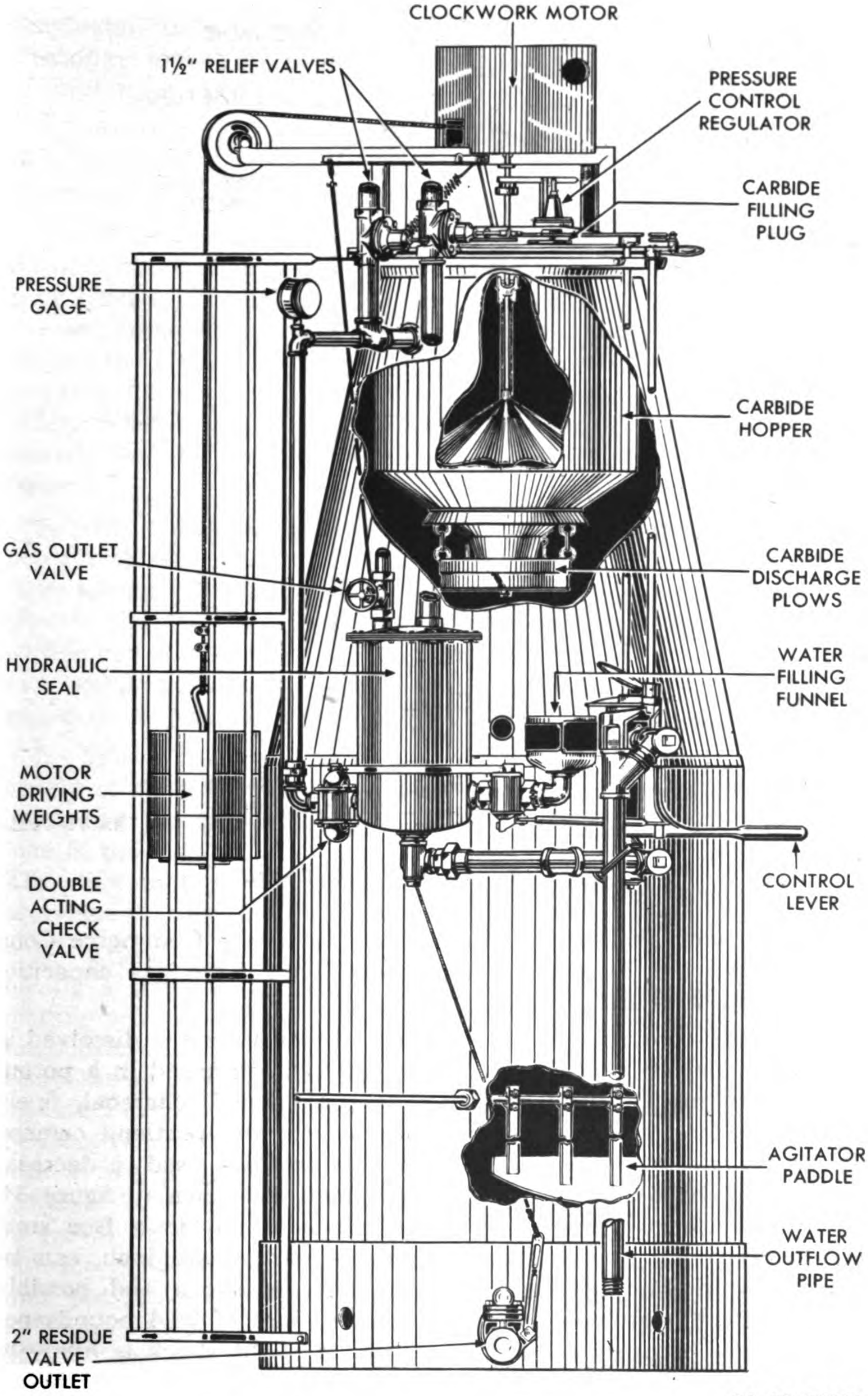


Figure 33 — 300-pound-capacity Acetylene Generator

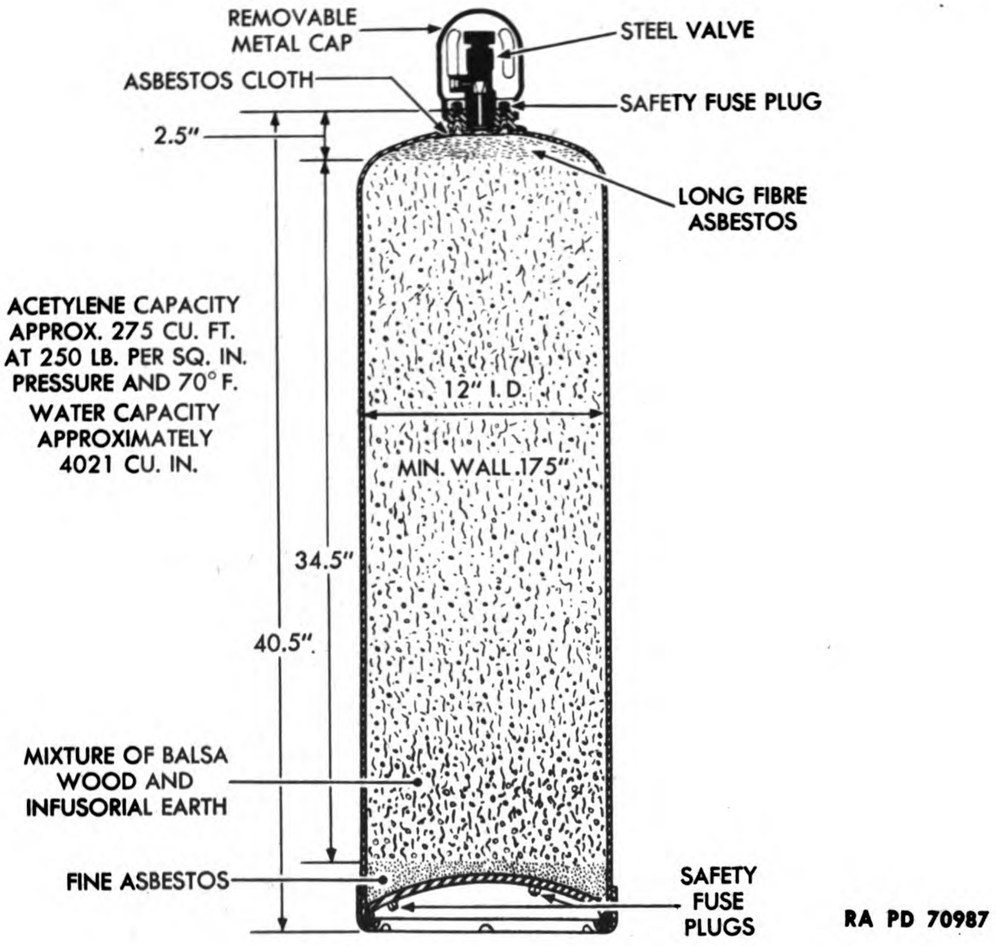


Figure 34 — Acetylene Cylinder

to comply with the specifications of the Interstate Commerce Commission and the Bureau of Explosives. They have gas capacities of 110, 250, 275, and 300 cubic feet.

b. When compressed into cylinders, the acetylene is dissolved in acetone, which is a liquid, and this solution is absorbed in a porous filler consisting of such materials as balsa wood, charcoal, finely shredded asbestos, infusorial earth, corn pith, and portland cement. These cylinder filler materials are porous and are used to decrease the size of the open spaces in the cylinder, as shown in figure 34. This is necessary because acetylene, when stored in a free state under pressures greater than 15 pounds per square inch, can be made to dissociate or break down by heat or shock and possibly explode. Pure acetylene, when under a pressure of 29.4 pounds per square inch, becomes self-explosive, and a slight shock is likely to cause it to explode even in the absence of oxygen or air. When dissolved in acetone, however, it can be compressed into cylinders at pressures up to 250 pounds per square inch, at which pressure a cylinder contains approximately 275 cubic feet of acetylene. The charging capacity of acetylene cylinders, as set forth by the Bureau of Explosives, is 250 pounds per square inch at a temperature of 70 F.

c. Acetone is a colorless liquid produced in the dry distillation of wood; under a pressure of 250 pounds per square inch, it dissolves about 420 volumes of acetylene.

d. When acetylene is used from a cylinder, it should not be drawn off at a continuous rate in volumes greater than 50 cubic feet per hour from a 275-cubic-foot standard cylinder. This precaution is to prevent acetone from being drawn off with the gas and thereby impairing the quality of the weld. No attempt should be made to refill empty cylinders or to transfer the contents of one cylinder into another. When volumes greater than 50 cubic feet per hour are required, the acetylene cylinders should be manifolded as shown in figure 32.

e. The acetylene cylinders have a porosity of from 75 to 80 percent of the total bulk of the porous filler. The filler acts as a large sponge to absorb the liquid acetone, which in turn dissolves or absorbs the acetylene. About 40 percent of the porous filler is filled with acetone. This allows room for expansion of the acetone, which increases in volume as it dissolves acetylene, while acetylene, being a gas, decreases in volume.

f. When filling the cylinders, the manufacturer determines the weight of acetylene dissolved in the acetone by using the factor 14.5 cubic feet per pound at 70 F. To determine the amount of acetylene in the cylinder, the cylinder is weighed before and after filling. The difference in weight multiplied by 14.5 gives the volume of acetylene in cubic feet.

g. The acetylene cylinders are designed with steel safety plugs having a small hole through the center which is filled with a low-melting-point metal alloy. The metal alloy in these plugs melts at a temperature of 212 to 220 F. The plugs are located in the base of the acetylene cylinder and in the cylinder valve located at the top of the cylinder. In case the cylinder is overheated, this alloy will melt and be forced out, thus permitting the gas to escape through small openings in the plugs before a dangerous pressure is built up in the cylinder. The holes in the plugs are small enough to cause the gas to escape at a speed which will prevent a flame from burning back into the cylinder if the escaping gas should become ignited. If these were not provided, the pressure in the cylinder would reach a point sufficiently high to form a bulge in, or to burst, the cylinders, should they become exposed to an excessively high temperature.

h. The acetylene cylinder valves are designed so that a squared end on the valve stems can be fitted by a cylinder wrench and opened or closed when the acetylene cylinder is in use. The outlet of the valve is threaded for connection to an acetylene pressure regulator by means of a union nut. The regulator inlet connection gland fits against the face of the threaded cylinder connection, and the inlet connection nut draws the two surfaces together. Whenever the threads on the valve connection are damaged so as to prevent assembling to a regulator, the cylinder should not be used, but should be marked or set aside for return to the manufacturer. A protective cap screws onto the valve to prevent damage during shipment or storage. All cylinders should be checked for leakage at the valves and safety plugs, since acetylene accumulated in the storage room or a confined space is a fire and explosive hazard.

114. OXYGEN AND ITS PRODUCTION.

a. Oxygen is a colorless, tasteless, and odorless gas, slightly heavier than air. It is noninflammable (that is, it will not burn of itself), but it will support combustion with other elements, and this combustion or burning will give off considerable heat and light. In the free state, it is one of the most common elements. The atmosphere is made up of approximately 21 parts oxygen and 78 parts nitrogen, the remainder being rare gases. Rusting of ferrous metals, the discoloration on copper, and corrosion of aluminum are all due to the action of atmospheric oxygen on these metals. This action is known as oxidation.

b. The principal use of oxygen in the oxyacteylene welding process is for cutting ferrous metals and for burning acetylene and other fuel gases in the oxyacetylene welding torch.

c. Oxygen is obtained commercially either by the liquid-air process or by the electrolytic process.

d. The liquid-air process furnishes the larger part of the oxygen used for welding purposes. In this process, the atmosphere or air is compressed and cooled to a point where the gases become liquid. As the temperature of the liquid air is raised, the nitrogen, in a gaseous form, is given off first, since the boiling point of liquid nitrogen is -321 F. The oxygen is given off when a temperature of -297 F is reached. These gases, having been thus separated, are then further purified and are compressed into cylinders for use.

e. In the electrolytic process, oxygen is obtained by separating water into hydrogen and oxygen by passing a direct electric current through water, to which an acid or alkali has been added, in an electric cell. The electric current breaks the water down into its chemical elements of hydrogen and oxygen. The oxygen collects at the positive terminal, while the hydrogen collects at the negative terminal, and each gas, having passed off through suitable pipes, is pressed in containers.

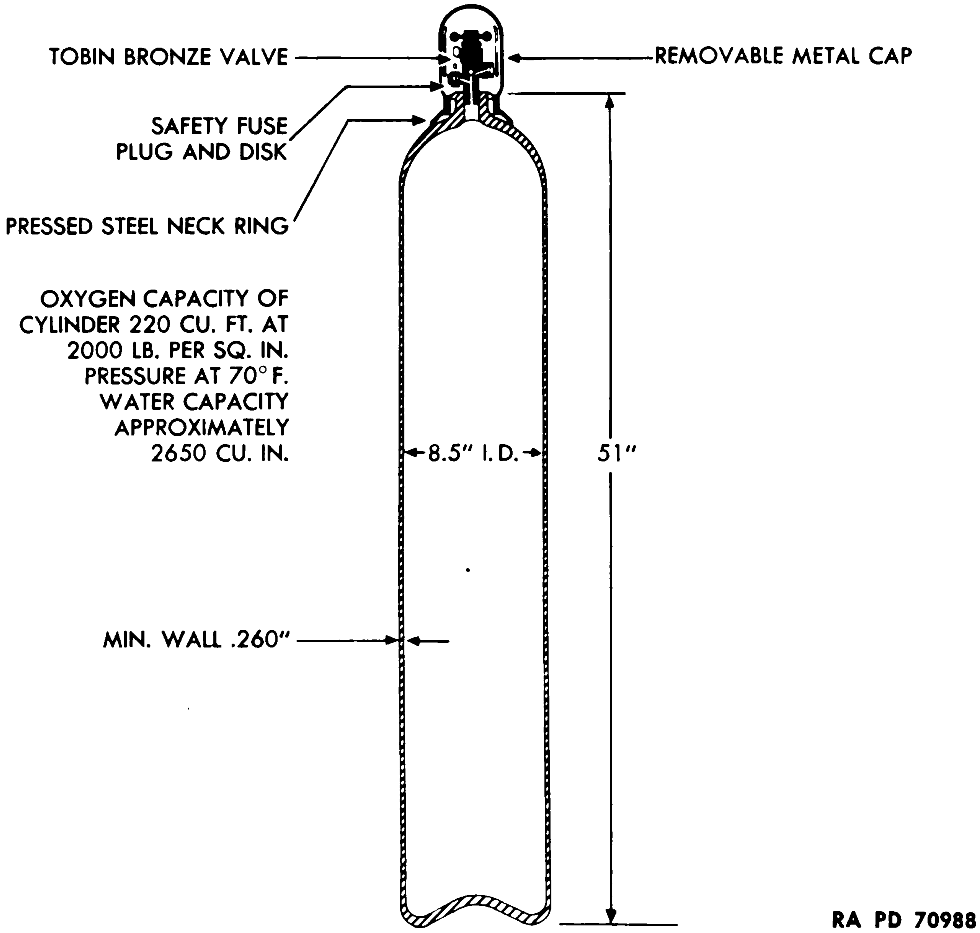


Figure 35 — 220-cubic-foot Oxygen Cylinder

115. OXYGEN CYLINDERS.

a. When supplied for use in oxyacetylene welding and cutting applications, oxygen is contained in seamless steel cylinders which have a capacity of 220 cubic feet of oxygen at a pressure of 2,000 pounds per square inch and at a temperature of 70 F. A typical oxygen cylinder is shown in figure 35.

116. OXYGEN AND ACETYLENE REGULATORS.

a. The gases compressed in oxygen and acetylene cylinders are at pressures too high for oxyacetylene welding. Regulators are necessary, therefore, to reduce these high pressures and to control the flow of gases from the cylinders. The design of these regulators varies according to the use for which they are intended. Most regulators today are either of the single-stage or two-stage type. Single-stage regulators reduce the pressure of the gases to working pressures in one step, or stage, while the two-stage regulators perform the same work in two steps, or stages. Less readjustment is generally necessary when the cylinders are being used with the two-stage regulators.

b. Single-stage Oxygen Regulators.

(1) Figure 36 shows the design of a typical single-stage regulator. The regulator mechanism consists of a nozzle through which the high-pressure gases pass, a valve seat to close off the nozzle, a diaphragm, and balancing springs. These are all enclosed in a suitable housing. Pressure gages are provided to indicate the pressure in the cylinder or pipe line (inlet), as well as the working pressure (outlet). The inlet pressure gage, used to record cylinder pressures, is a high-pressure gage, while the outlet pressure gage, used to record working pressures, is a low-pressure gage.

(2) The oxygen enters the regulator through the high-pressure inlet connection and passes through a glass wool filter, which removes dust and dirt. The seat closing off the nozzle is not raised

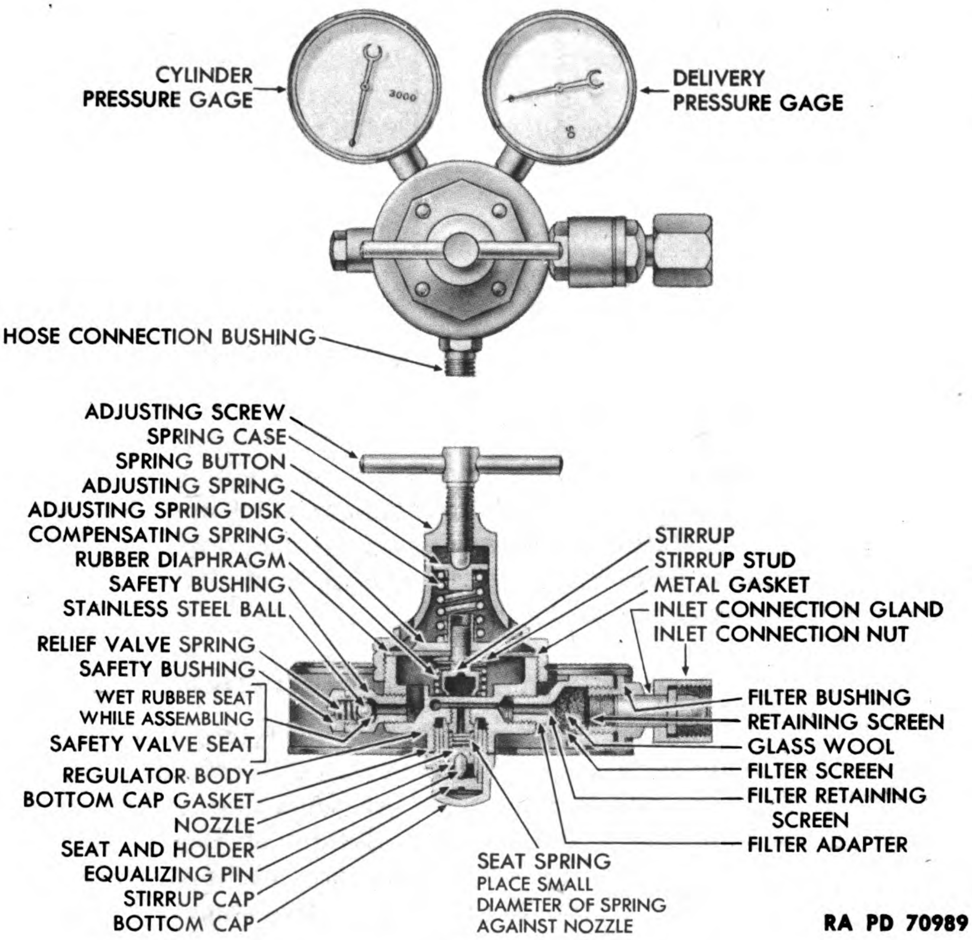


Figure 36 — Single-stage Regulator

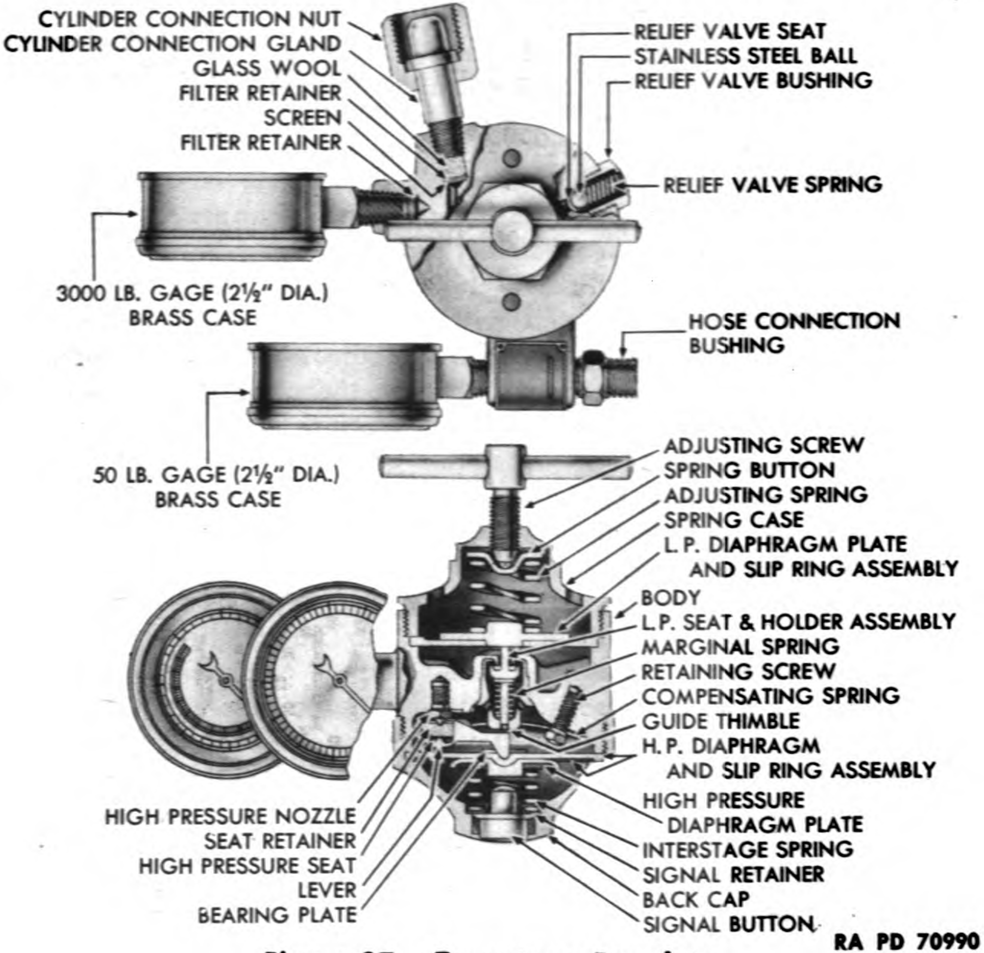
until the adjusting screw is turned in. Turning in the adjusting screw applies pressure to the adjusting spring, which bears down on a diaphragm. This, in turn, presses downward on the stirrup and overcomes the pressure of the compensating spring. With the stirrup forced downward, the passage through the nozzle is opened, thus allowing oxygen to flow into the low-pressure chamber of the regulator. The oxygen passes from here through the regulator outlet and hose to the torch. The orifices or holes in the torch mixer and tip are comparatively small. Even with the torch needle valve wide open, therefore, a certain set pressure in the low-pressure chamber of the regulator will be required, so that the oxygen will continue to be forced through the torch. This pressure is indicated on the working-pressure gage of the regulator and it will vary, depending upon the position of the regulator adjusting screw. Turning the adjusting screw to the right increases the working pressure; turning it to the left decreases the working pressure.

(3) The high-pressure gages on oxygen regulators are graduated in pounds per square inch from 0 to 3,000, although oxygen cylinder pressures do not exceed 2,000 pounds per square inch. The high-pressure gages are also graduated in cubic feet from 0 to 220 for the range of pressures from 0 to 2,000 pounds per square inch. This permits the direct reading of cylinder pressures and of the oxygen content of the cylinders in cubic feet at these particular pressures. The gages are graduated to read correctly at a temperature of 70 F. The working-pressure gages for welding regulators are usually graduated in pounds per square inch from 0 to 50, from 0 to 200, or from 0 to 400. In regulators designed for heavy-duty cutting, the working-pressure gage is graduated in pounds per square inch from 0 to 300, or from 0 to 400.

c. **Two-stage Oxygen Regulator.** The operation of the two-stage regulator is similar in principle to that of the single-stage regulator, the principal difference being that the total pressure drop takes place in two stages or steps, instead of one. In the high-pressure stage, the pressure is reduced from cylinder pressure to an intermediate pressure. In the low-pressure stage, the pressure is reduced from an intermediate pressure to a working pressure. A typical two-stage regulator is shown in figure 37.

d. **Acetylene Regulators.** Acetylene regulators are of the same general design as oxygen regulators, although they are not made to withstand such high pressures. The high-pressure gage is graduated to 400 pounds per square inch, while the working-pressure gage is usually graduated to 30 pounds per square inch. Acetylene should not be used at pressures in excess of 15 pounds per square inch.

e. Regulators used at stations to which gases are piped from the oxygen manifold, acetylene manifold, or acetylene generators have



RA PD 70990

Figure 37 — Two-stage Regulator

only one gage, which is used to regulate the pressure of gases flowing through the hose to the torch. These gages are designed for low pressures, since the line pressures set at the manifolds are approximately 15 pounds per square inch for acetylene, and 200 pounds per square inch for oxygen.

117. OXYACETYLENE WELDING TORCH.

a. The oxyacetylene welding torch is used to mix oxygen and acetylene gases in definite proportions and to control the volume of these gases burned at the welding tip. The torches are designed to have two needle valves, one for adjusting the flow of acetylene and one for adjusting the flow of oxygen. In addition, they consist of a handle, two tubes, one each for the oxygen and the acetylene, a mixing head, and a tip. The tubes are assembled and silver-soldered to the head and the rear end forgings, which, in turn, are fitted into the handle so as to give stability and strength. The welding tips are made from drawn copper and are available in different sizes to handle a wide range of plate thicknesses.

b. There are two general types of welding torches: namely, the low-pressure or injector type, and the medium-pressure type.

(1) In the low-pressure type, the acetylene pressure is less than 1 pound per square inch. A jet of high-pressure oxygen is necessary to produce a suction effect which draws in the required amount of acetylene. This is accomplished by designing the mixer in the torch to operate on the injector principle. The welding tips may or may not have separate injectors designed integrally with each tip. Injector or low-pressure types of torch are shown in figure 38.

(2) In the medium-pressure torches, the acetylene is operated at pressures from 1 to 15 pounds per square inch. These torches are designed to operate at equal pressures for oxygen and acetylene. Hence, they are known as equal-pressure or balanced-pressure torches. The medium-pressure torch has certain advantages over the low-pressure torch in that the type of flame desired can be more readily adjusted, and, since equal pressures are used for each gas, the torch is less susceptible to flashbacks. A typical equal-pressure welding torch is shown in figure 39.

118. WELDING TIPS AND MIXERS.

a. Some makes of torches are provided with an individual mixing head or mixer for each size of tip, while other makes have only one mixer for several tip sizes. Welding tips are furnished in various styles or types, some having a one-piece hard-copper tip, others having a two-piece tip which includes an extension tube to make connection between the tip and mixing head. When used with an extension tube, the removable tips are made either of hard copper or of a copper alloy such as brass or bronze. The tip sizes are designated by numbers, and each manufacturer has his own arrangement for classifying them. The tip sizes differ in the diameter of the orifice in order to obtain, in each case, the correct volume of heat for the work to be done.

b. The mixers used in the low-pressure or injector type of torch are designed so that the central orifice will cause the oxygen to issue at a very high velocity. The orifices which control the flow of acetylene are located so that the acetylene will be drawn in by and mixed with the oxygen. The mixed gases contain the proper amount of oxygen and acetylene to produce a suitable welding flame at the welding tip. The proportion of these two gases and the working pressures for each gas are controlled by the size of the orifices designed in the mixer.

c. The mixers used in the medium-pressure or balanced-pressure type of torch are designed so that the orifices pass equal amounts of oxygen and acetylene at equal pressures. These gases are mixed in a small expansion chamber and are burned at the welding tip.

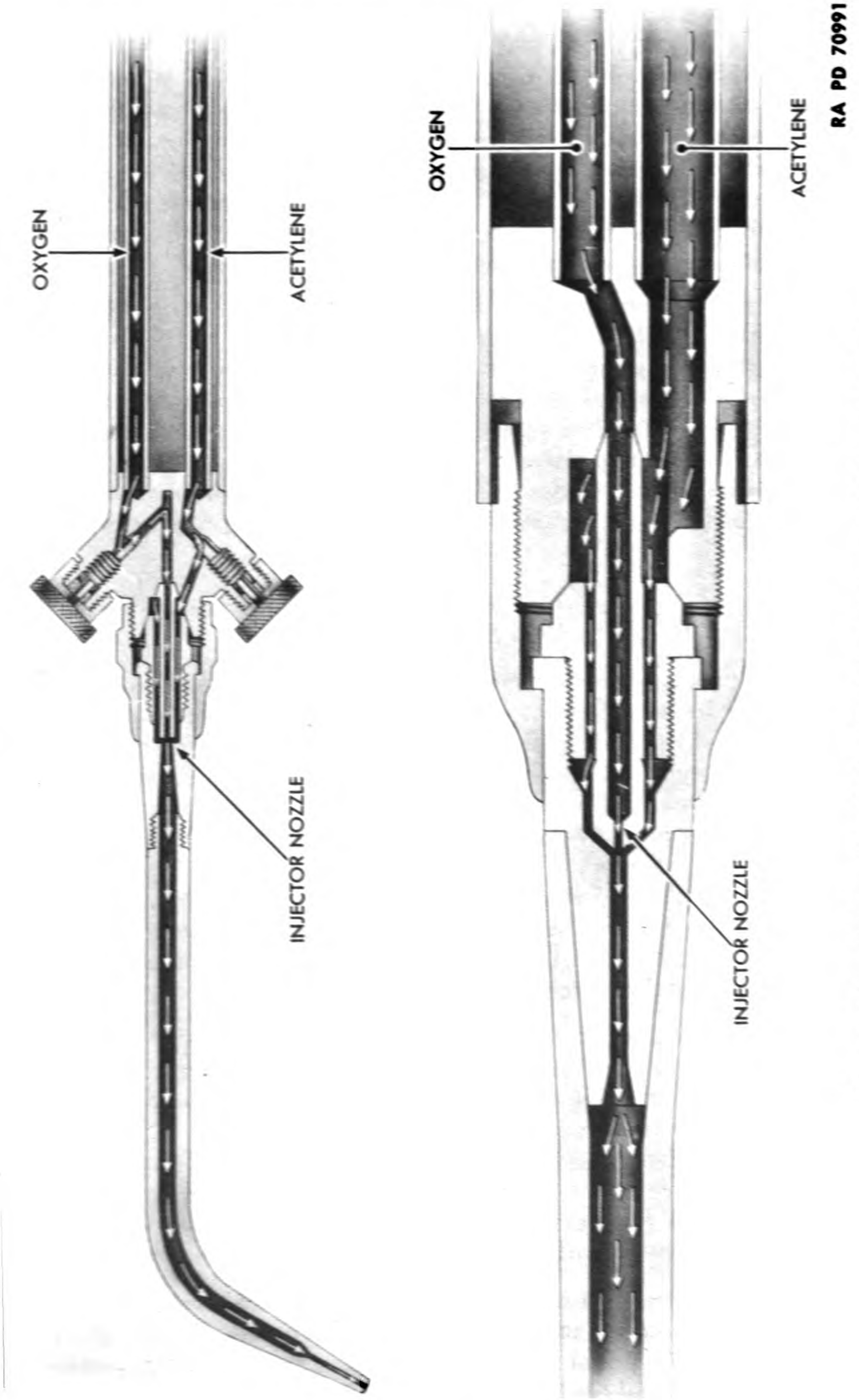


Figure 38 — Mixing Heads for the Injector-type Welding Torches

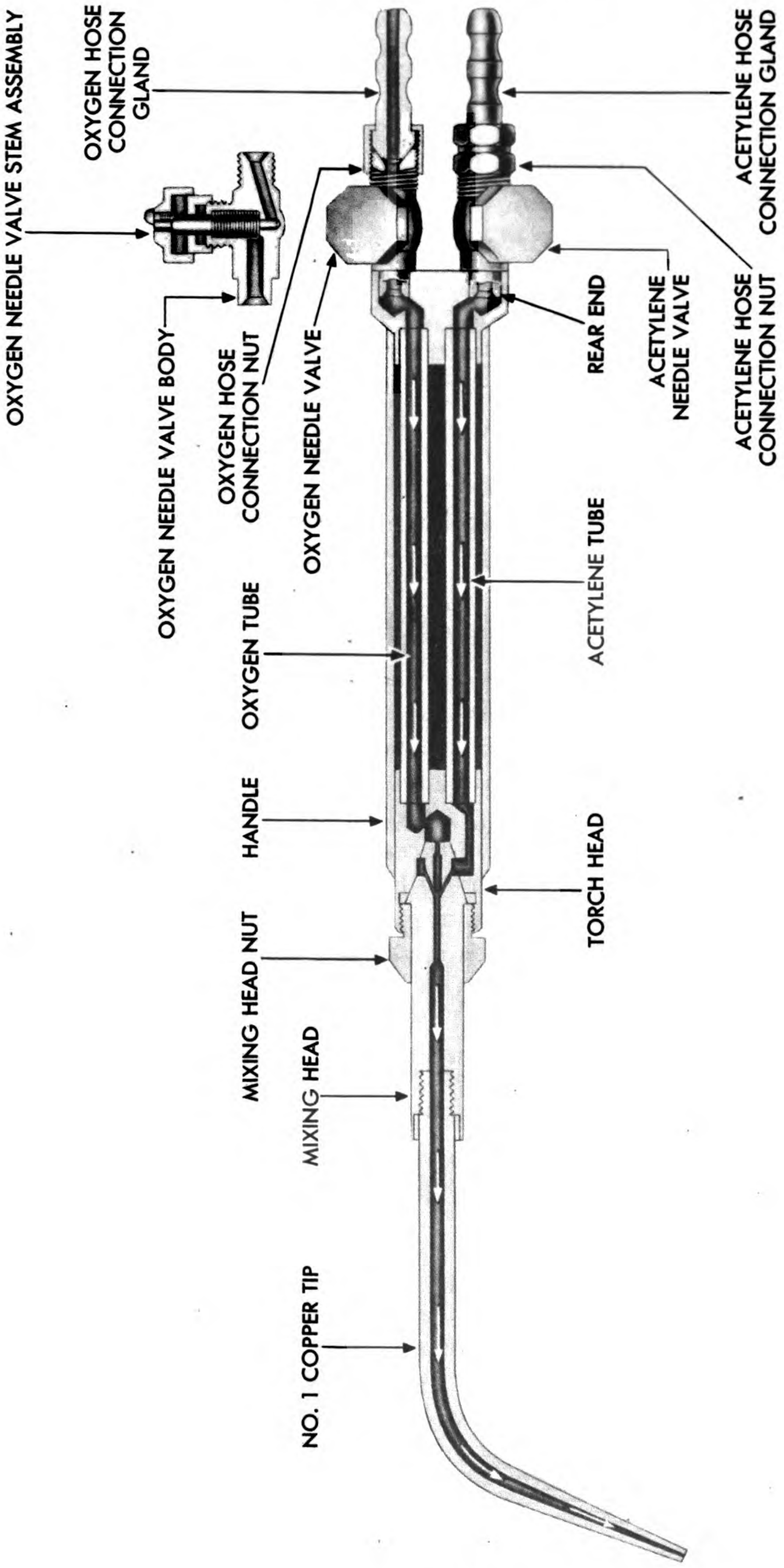


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Figure 39 — Equal Pressure Type General Purpose Welding Torch

119. HOSE.

a. The hose used to make connection between the torch and the regulators is specially manufactured for this purpose. It is strong, nonporous, and sufficiently flexible and light to yield readily to torch movements. It is built to withstand high internal pressures, and the rubber used in its manufacture is chemically treated to remove sulphur in order to avoid any possibility of spontaneous combustion.

b. Welding hose is available in various sizes, depending upon the class of work for which it is intended. The size of the hose is designated by the inside diameter and the number of plies of fabric which it contains. Single hose is furnished in sizes from 1/8-inch to 1/2-inch inside diameter and is available in lengths ranging from 12 1/2 feet to 25 feet. The hose used for light torches is 1/8 inch to 3/16 inch in diameter and has one or two plies of fabric. For heavy-duty welding and cutting operations, 1/4-inch to 1/2-inch hose, having three to five plies of fabric, is used.

c. The acetylene and oxygen hoses are the same in grade but different in color. The oxygen hose is green, while the acetylene hose is red.

d. The hoses are equipped with connections and swivel nuts at each end so that they may be attached to their respective regulator outlet and torch inlet connections. Connect the oxygen regulator to the oxygen cylinder and the acetylene regulator to the acetylene cylinder and screw the nuts up tight, using the wrench made specially for the purpose. All oxygen cylinder valve threads are right-hand. Acetylene cylinder valve threads, however, are either right-hand or left-hand, depending upon the cylinder manufacturer. To prevent a dangerous interchange of welding hose, the threads on all acetylene hose connections, regulator outlets, and acetylene torch inlets are left-hand. Acetylene connection nuts attached to welding hose are grooved to further simplify their identification. Welding and cutting hose is available as a single hose for each gas, or it may be obtained in the "twinned" type of hose, that is, with the oxygen and acetylene hoses molded or bonded together along their length by a thin strip of rubber. This design prevents the hose from kinking or becoming entangled while welding.

CHAPTER 5

OXYACETYLENE WELDING: EQUIPMENT, PROCEDURE, AND TECHNIQUE (Cont'd)

Section IV

FAULTY OPERATION OF WELDING APPARATUS

Paragraph
Regulator troubles and remedies 120
Torch troubles and remedies 121

120. REGULATOR TROUBLES AND REMEDIES.

a. Leakage.

(1) The principal trouble experienced with regulators is leakage of gas between the regulator seat and nozzle. It can be detected by a gradual increase in pressure on the working-pressure gage when the adjusting screw is fully released or is in position after adjustment. This defect is known as "creeping regulator" and results from worn or cracked seats or from some foreign matter lodged between the seat and the nozzle. Regulators with leaks across the seats should be repaired immediately in order to avoid damage to other parts of the regulator or apparatus. This is particularly dangerous in the case of acetylene regulators, since acetylene at a very high pressure in the hose becomes an explosive hazard.

(2) To correct this trouble, the seat should be removed and replaced if found defective. If the trouble is due to a fouled seat, the seat and nozzle should be thoroughly cleaned, and any dust or dirt in the valve chamber should be blown out before reassembly. The procedure for removing valve seats and nozzles from regulators will vary with the make or design.

b. Other regulator troubles are broken or buckled gage tubes, and distorted or buckled diaphragms. These defects are usually caused by a backfire at the torch, by leaks across the regulator seats, or by failure to release the regulator adjusting screw fully before opening the cylinder valves. Defective bourdon tubes in the gages are indicated by improper action and by gas escaping from the gage case. Gages with defective tubes should be removed and replaced by new ones, since satisfactory repair cannot be made without special equipment. Buckled or distorted diaphragms will not respond properly to adjustment and should be replaced with new ones. Rubber diaphragms can easily be replaced by removing the spring case by means of a vise or a wrench. Metal diaphragms are sometimes soldered to the valve case. To replace these diaphragms is a factory or special repair shop job and should not be attempted by anyone unfamiliar with the work.

121. TORCH TROUBLES AND REMEDIES.

a. The principal causes for improper operation of welding torches are leaking valves, leaks in the mixing-head seat, scored or out-of-round welding-tip orifices, clogged tubes and tips, and damaged inlet connection threads. These defects, unless corrected immediately, may be the source of gas leaks resulting in severe burns to the operator, or they may cause damage to the welding apparatus by flashbacks or backfires.

b. Leaking valves are indicated when the gases continue to flow after the valves are closed. This condition is due to worn or bent valve stems, damaged seats, or a combination of both. Loose packings will cause leaks around the valve handle and may be corrected by tightening the packing nut. Bent or worn valve stems should be replaced, and damaged seats should be refaced, in order to correct the trouble.

c. Leaks in the mixing-head seat will cause oxygen and acetylene leaks between the inlet orifices which lead to the mixing-head. This condition leads to improper mixing of the gases, which, in turn, results in flashbacks; that is, the gases will ignite and burn back of the mixing-head in the torch tubes. This trouble is indicated by the popping out of the flame and by the emission of sparks from the tip, accompanied by a squealing noise. A flashback causes the torch head and handle tubes to become suddenly very hot. To correct this defect, the seat in the torch head should be reamed out, and the mixing-head seat should be trued. These repairs should be made by the manufacturer, since special reamers are required for truing these seats.

d. Scored or out-of-round tip orifices will cause the flame shape to be irregular even after the tip has been thoroughly cleaned. Tips found defective in this manner cannot be repaired and must be replaced.

e. Torches with clogged tubes and tips cause greater working pressures for the gases than are normally required to produce the welding flame for a given size of tip. The flame produced will be distorted in shape. This condition is due to carbon deposits caused by backfires and flashbacks or to the presence of foreign matter which has entered the torch through the hoses. To correct the trouble, the torch should be disconnected, and each component part, such as the tip, mixing-head, valves, and hose, should be cleaned and blown out with oxygen at 20- to 30-pound pressure. The tip and mixing-head should first be thoroughly cleaned with a soft copper or brass wire or with proper sized cleaning drills and then blown out with oxygen. The cleaning drills should be approximately one drill size smaller than the tip orifice so that they will not enlarge the orifice during cleaning.

f. Damaged inlet connection threads will cause leaks to occur and can be detected by closing the cylinder valves and keeping the torch needle valves closed. Leaks at the inlet connection threads will cause the regulator pressures to drop. Some difficulty will also be experienced in tightening up the hose connection nuts to the torch inlet connection threads. Unless corrected, this condition may cause fires, due to the ignition of the leaking gas by sparks, as well as serious burns to the welding operator. To correct this defect, the threads should be recut with the proper thread dies, and the hose connections should be thoroughly cleaned.

CHAPTER 5

OXYACETYLENE WELDING: EQUIPMENT, PROCEDURE, AND TECHNIQUE (Cont'd)

Section V

OPERATION OF WELDING APPARATUS

Paragraph
Setting up apparatus and preparing for welding 122
Shutting down welding apparatus 123
Working pressures for apparatus 124

122. SETTING UP APPARATUS AND PREPARING FOR WELDING.

a. It is important, when setting up welding and cutting apparatus, that all operations be performed systematically in a definite order so as to avoid mistakes. The following instructions will assure practical safety to the operator and the apparatus, and should be followed in the order given.

(1) SETTING UP. Place the oxygen and acetylene cylinders on a level floor and tie them firmly to a workbench, a post, a wall, or to each other so as to prevent their being accidentally knocked or pulled over. Remove the valve protecting caps.

(2) "CRACKING" THE CYLINDER VALVES. To "crack" the cylinder valves, open each valve slightly for an instant to blow out any dirt and foreign matter which may have accumulated during shipment or storage. Close the valves, and wipe off the connection seats with a clean cloth. CAUTION: Do not stand in front of valves when opening them.

(3) ATTACHING THE PRESSURE REGULATORS. Connect the acetylene regulator to the acetylene cylinder and the oxygen regulator to the oxygen cylinder. Use either a regulator wrench or a close-fitting wrench, and tighten the connecting nuts sufficiently to prevent leakage.

(4) CONNECTING THE HOSE TO THE REGULATORS. First connect the red hose to the acetylene regulator and then the green hose to the oxygen regulator. Screw the connecting nuts up tightly to insure leakproof seating. Note the left-hand thread on the acetylene hose connections.

(5) OPENING THE CYLINDER VALVES. Release the regulator screws to avoid abuse or damage to the regulators and gages, and open the cylinder valves slowly. Read the high-pressure gage to check the pressure of the contents in each cylinder.

(6) BLOWING OUT THE HOSE. By turning in the regulator screw, open each regulator so as to blow out the hose, and then release the

regulator screw. This procedure is to be followed for the oxygen hose. If it becomes necessary to blow out the acetylene hose, the work should be done in a well-ventilated place, free from sparks, flame, or other sources of ignition.

(7) CONNECTING THE HOSE TO THE TORCH. Connect the red acetylene hose to the torch needle valve, stamped "AC," and the green oxygen hose to the oxygen needle valve, stamped "OX." Test all hose connections for leaks at the regulators and torch valves by turning in both regulator screws with the torch needle valves closed. Release the regulator screws after testing, and drain both lines by opening the torch needle valves.

(8) ADJUSTING THE TIP. Slip the tip nut over mixing head, screw tip into mixing head, and assemble in the torch body. Tighten by hand, and adjust the tip to the proper angle. Secure this adjustment by tightening with the tip-nut wrench.

(9) ADJUSTING THE WORKING PRESSURES. To adjust the acetylene working pressure, open the acetylene torch needle valve and, by turning the regulator screw to the right, adjust acetylene regulator to required working pressure for the particular tip size, shown in paragraph 124. Close the needle valve. Adjust oxygen working pressure in the same manner.

(10) LIGHTING AND ADJUSTING THE WELDING TIP. Open the acetylene needle valve on the torch, and light the acetylene with a spark lighter. Adjust the acetylene valve until the flame just leaves the tip face. Open and adjust the oxygen valve to obtain the proper neutral flame. Note that the pure acetylene flame which just leaves the tip face is drawn back to the tip face when the oxygen is turned on.

123. SHUTTING DOWN WELDING APPARATUS.

a. To shut off the gases, first close the acetylene valve, then the oxygen valve on the torch. Close the acetylene and oxygen cylinder valves to shut off the gas supply.

b. To drain the regulators and hoses, open the torch acetylene valve until gas ceases to flow, then close the valve. Next, open the torch oxygen valve to drain the oxygen regulator and hose. When gas ceases to flow, close this valve. This operation, when performed properly, will cause both high- and low-pressure gages on the oxygen and acetylene regulators to read "0."

c. To release the tension on both regulator screws, turn the screws to the left until they rotate freely.

d. Coil the hose and suspend on a suitable holder to avoid accidents by tipping the cylinders to which they are attached. Avoid kinking the hose.

124. WORKING PRESSURES FOR APPARATUS.

a. The approximate working pressures for oxygen and acetylene to be used with various sized tips in the low-pressure or injector type of torch are given below:

Tip Size No.	Acetylene Pressure lb per sq in.	Oxygen Pressure lb per sq in.
0	1	9
1	1	9
2	1	10
3	1	10
4	1	11
5	1	12
6	1	14
7	1	16
8	1	19
10	1	21
12	1	25
15	1	30

b. The approximate working pressures for oxygen and acetylene to be used with various sized tips in the medium-pressure or balanced-pressure type of torch are given below:

Tip Size No.	Acetylene Pressure lb per sq in.	Oxygen Pressure lb per sq in.
00	1	1
0	1	1
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6

CHAPTER 5

OXYACETYLENE WELDING: EQUIPMENT, PROCEDURE, AND TECHNIQUE (Cont'd)

Section VI

WELDING PROCEDURE

Paragraph
Flame adjustment 125
Types of flame 126
Technique of torch and rod manipulation 127
Forehand, puddle, or ripple welding 128
Backhand welding 129
Multi-layer welding 130
Flat position welding 131
Vertical position welding 132
Overhead position welding 133

125. FLAME ADJUSTMENT.

a. To light the welding tip, first open only the acetylene valve. The flame is obtained by striking the spark-lighter in front of the tip, the hand being kept well to one side. The torch should be held so as to direct the flame away from the operator, gas cylinders, hose, or other inflammable material. The pure acetylene flame is long and bushy and has a yellowish color. Since the oxygen valve is closed at this point, the acetylene is burned by the oxygen in the air. This is not sufficient to burn the acetylene completely; therefore, the flame is smoky, producing a soot of fine unburned carbon. The pure acetylene flame is unsuitable for welding.

b. Before opening the oxygen valve, the acetylene valve should be opened slowly until the pure acetylene flame leaves the end of the tip and the base of the flame is approximately 1/16 inch to 1/8 inch away from the tip face. At this adjustment, the velocity of the gas issuing from the tip is greater than the burning velocity of the acetylene back to the tip face. The welding flame, when so adjusted, is stable and free from flashbacks and backfires.

c. When the oxygen valve is opened, the acetylene flame is shortened, and the mixed gases burn in contact with the tip face. The flame changes to a bluish-white color and forms a bright inner cone surrounded by an outer flame envelope or sheath flame. The inner cone develops the high temperature required for welding, while the outer envelope contains varying amounts of incandescent carbon soot, depending upon the proportion of oxygen to acetylene.

d. The theoretical mixture of oxygen and acetylene for complete combustion consists of 2½ volumes of oxygen to one volume of acetylene. Mixtures of oxygen and acetylene cannot burn completely to form a single cone. The temperature produced is so high (up to 6,300 F) as to decompose the products of complete combustion, carbon dioxide and water vapor, into their elements. Thus the acetylene, burning in the inner cone of the flame with the oxygen supplied through the torch, forms carbon monoxide and hydrogen, both combustible gases. These gases, as they cool from the high temperature of the inner cone flame, burn completely with the oxygen supplied from the surrounding air to form the lower-temperature sheath flame. The carbon monoxide burns to form carbon dioxide, and the hydrogen burns to form water vapor. Actually, to burn one volume of acetylene, the torch supplies one volume of oxygen, while the surrounding air supplies 1½ volumes of oxygen to burn the acetylene completely. Since the inner cone of the flame contains only carbon monoxide and hydrogen, which are reducing in character (able to combine with oxygen and remove it), oxidation of the metal does not occur.

126. TYPES OF FLAME.

a. There are three flame types commonly used for welding. These are the neutral, reducing or carburizing, and oxidizing flames, as shown in figure 40.

(1) NEUTRAL FLAME. The welding flame should always be adjusted to neutral before either the oxidizing or carburizing flame mixture is set. There are two clearly defined zones in a neutral flame. The inner portion consists of a luminous cone, which is bluish-white in color. Surrounding this is a large flame envelope or sheath, which is faintly luminous and has a light bluish tint. The neutral or balanced flame is produced when the mixed gases consist of approximately one volume of oxygen and one volume of acetylene supplied from the torch. This type of flame is obtained by gradually opening the oxygen valve to shorten the acetylene flame, until a clearly defined inner luminous cone is visible. For a strictly neutral flame, no whitish streamers should be present at the end of this cone. The actual ratio of the volume of oxygen to acetylene supplied by the torch to produce a neutral flame is $\frac{1.04 \text{ to } 1.14}{1}$. This flame adjustment is used for most welding and for the preheating flames during cutting operations. When welding steel with this flame, the molten metal puddle is quiet and clear, and the metal flows easily without boiling, foaming, or sparking. In some cases, it is desirable to leave a slight acetylene streamer or "feather" ($\frac{1}{16}$ in. to $\frac{1}{8}$ in. long) at the end of the inner cone to insure that the flame is not oxidizing. In a neutral flame, the temperature at the tip of the inner cone is

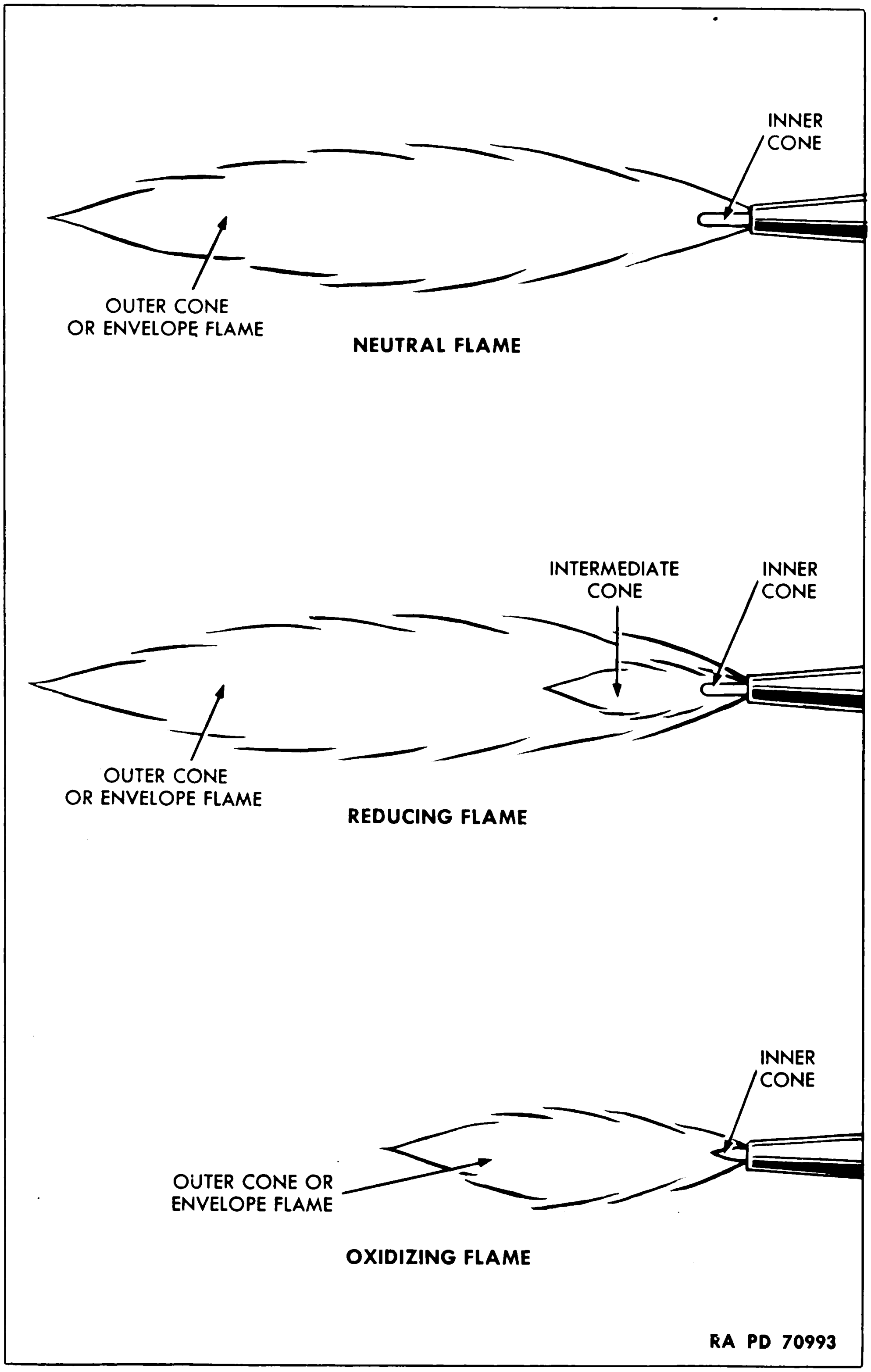


Figure 40 — Oxyacetylene Flames

approximately 5,850 F, while at the extreme end of the outer envelope or sheath flame, the temperature drops to approximately 2,300 F. This permits some temperature control in making a weld, since the position of the flame with respect to the molten puddle may be changed.

(2) REDUCING OR CARBURIZING FLAME.

(a) The reducing or carburizing flame is produced when slightly less than one volume of oxygen is mixed with one volume of acetylene, or more specifically, when these gases are mixed at the ratio of $\frac{0.85 \text{ to } 0.95}{1}$. This adjustment is obtained by first adjusting the welding flame to neutral and then further opening the acetylene valve slightly so as to produce a white streamer or "feather" of acetylene at the end of the inner cone. The length of this excess streamer can be taken as a measure of the degree of carburization obtained with the flame. For most welding operations, the length of this excess feather should be equal to approximately twice the length of the inner cone. The reducing or carburizing flame can always be recognized by the presence of three distinct flame zones. These are the clearly defined bluish-white inner cone, a white intermediate cone indicating the amount of excess acetylene, and the light-blue outer flame envelope. This type of flame burns with a coarse rushing sound and has a temperature of approximately 5,700 F at the tip of the inner cone.

(b) When a strongly carburizing flame is used for welding steel, the metal boils and is not clear. The boiling action is caused by the heat given off by the steel in absorbing carbon from the flame. When cold, the weld will have the properties of high-carbon steel, being brittle and subject to cracking. A slight feather of acetylene is sometimes used for welding steel by the backhand welding process.

(c) A carburizing or slight excess acetylene flame is advantageous for welding high-carbon steel, for hard-facing operations, and for welding such nonferrous alloys as nickel and monel. It is also used for silver-soldering operations. In the latter operation only the intermediate and outer flame cones are used in order to impart a low-temperature soaking heat to the parts being joined by silver soldering.

(3) OXIDIZING FLAME.

(a) The oxidizing type of welding flame is more difficult to adjust than the neutral or carburizing types. It is produced when slightly more than one volume of oxygen is mixed with one volume of acetylene. The ratio of the volume of oxygen to the volume of acetylene supplied by the torch is $\frac{1.15 \text{ to } 1.7}{1}$. To adjust for this type of flame, the torch should first be adjusted to give a neutral flame. The flow of oxygen is then increased by opening the oxygen valve further, until the inner cone is shortened by about one-tenth of its original length.

In addition to being shorter than the inner cone of a neutral flame, it is also more pointed and somewhat purplish in color. An oxidizing flame can also be recognized by its distinct hissing sound. The temperature of this flame is approximately 6,300 F.

(b) A slightly oxidizing flame is used in bronze welding of steel and cast iron. A stronger oxidizing flame is used for fusion welding of brass and bronze.

(c) When applied to steel, an oxidizing flame causes the molten metal to foam and give off sparks. This indicates that the excess oxygen from the flame is combining with the steel and burning it. An oxidizing flame should not be used for welding steel, since the deposited metal will be porous, oxidized, and brittle. This flame is ruinous to most metals and should be avoided except as noted in substep *(b)*, above.

(d) In most cases, the exact amount of excess oxygen used in this type of flame adjustment must be determined by noting the action of the flame on the molten metal.

127. TECHNIQUE OF TORCH AND ROD MANIPULATION.

a. There are several different methods of oxyacetylene welding which produce good results. Right-handed welders usually hold the torch in the right hand and the welding rod in the left, while left-

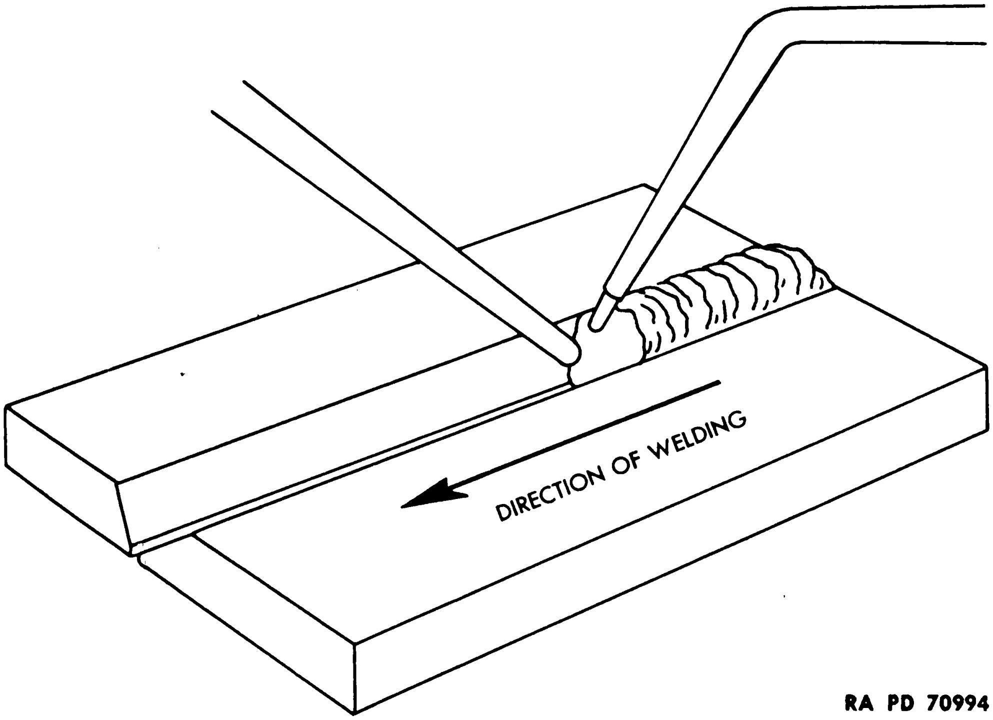


Figure 41 — Forehand, Puddle, or Ripple Welding

handed welders usually hold the torch in the left hand and the welding rod in the right. Some prefer to weld from left to right, and others prefer to weld from right to left. The most satisfactory method to employ depends largely upon the type of joint, its position, and the necessity for controlling the heat on the parts being welded.

128. FOREHAND, PUDDLE, OR RIPPLE WELDING.

a. This is the older method of welding. It is illustrated in figure 41. The welding rod precedes the tip in the direction in which the weld is being made. The flame is pointed in the direction of welding, and the tip is held at an angle of approximately 60 degrees to the plates being welded. This position of the welding flame permits uniform preheating of the plate edges immediately ahead of the molten puddle. By moving the tip and welding rod in opposite semicircular paths, the heat can be carefully balanced to melt the end of the welding rod and the side walls of the plates into a uniformly distributed molten puddle. The motion of the flame past the end of the rod melts off a short length and adds it to the molten puddle. The heat deflected backwards from the rod keeps the metal molten. The semicircular motion of the torch and rod distribute the heat and molten metal evenly to both edges being welded, as well as to the deposited metal bead.

b. This method of welding is satisfactory for welding sheets and light plates in all welding positions. Some disadvantages are experienced in welding heavier plates by this method, as a wide V, 90-degree included angle of bevel is necessary. This edge preparation is required in order to melt down the plate edges satisfactorily and to obtain good penetration and fusion of the weld metal to the base metal. A large molten puddle, which is difficult to control, must be carried, and a wide movement of the torch and welding rod as well as good depth of fusion, are required to obtain a good joint.

129. BACKHAND WELDING.

a. This is the newer method of welding. It is illustrated in figure 42. The welding tip precedes the rod in the direction of welding, and the flame is pointed back at the molten puddle and the completed weld. The end of the rod is placed between the welding flame and the molten puddle, and the welding tip should make an angle of approximately 60 degrees with the plates being welded. These positions of the welding rod and tip flame require less motion than that used in forehand welding. A straight welding rod may be used, in which case the rod should be rotated so that the end will roll from side to side in the puddle and melt off evenly. Also, the welding rod may be bent, and both the rod and tip moved toward and away from each other, so as to describe a rapid bellows action. In welding operations in which a large weld deposit is being made,

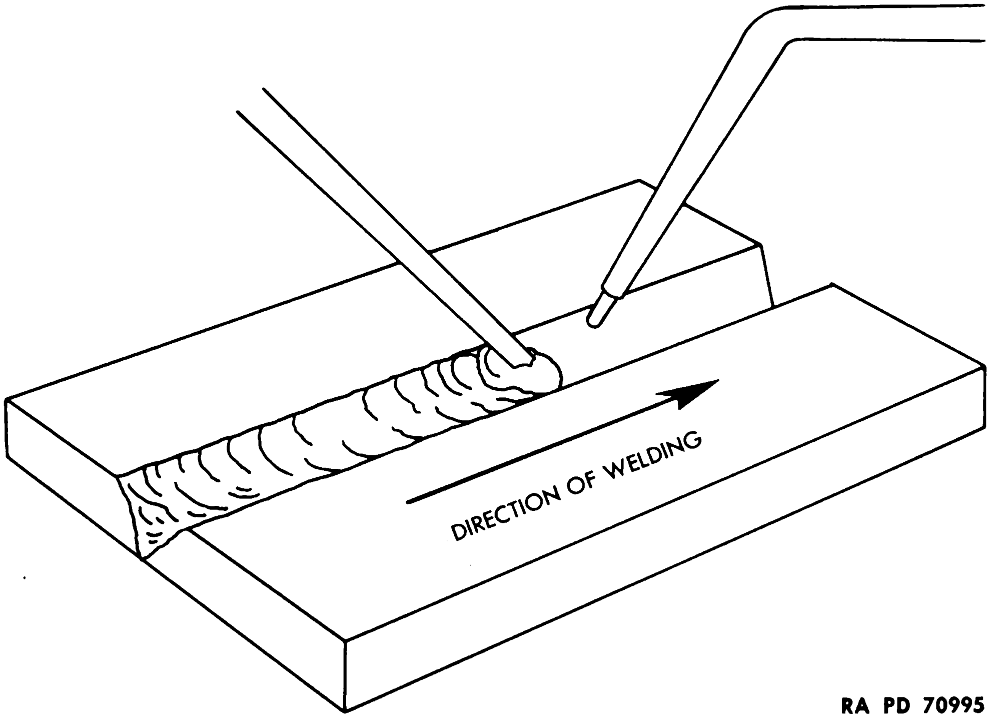


Figure 42 — Backhand Welding

the end of the rod is moved so as to describe full circles in the molten puddle. The torch is moved to and fro across the weld while advancing slowly and uniformly in the direction of welding.

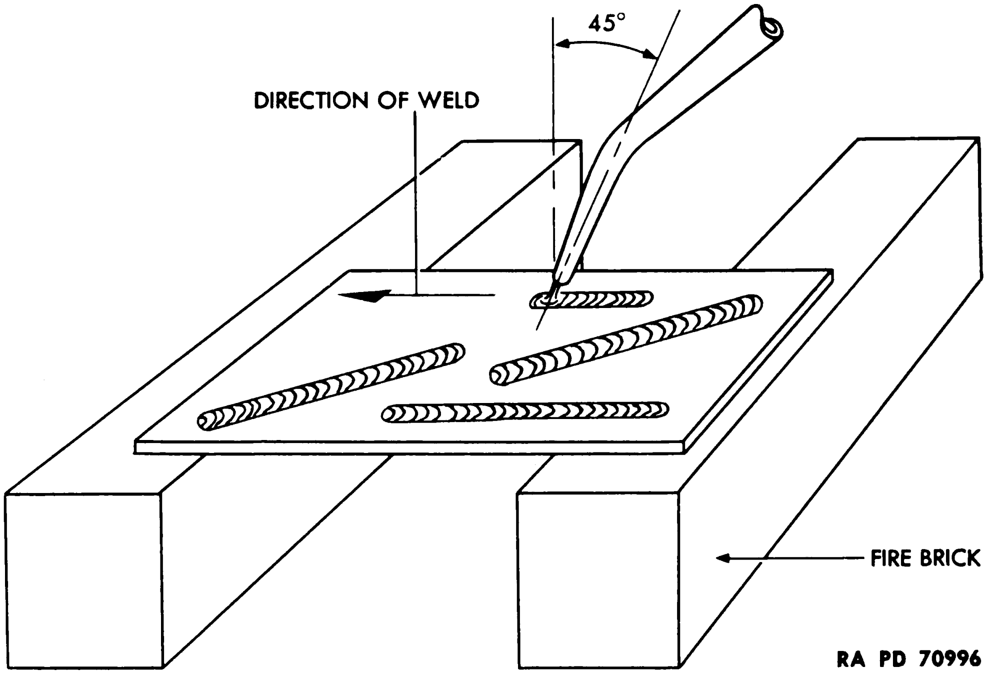
b. Backhand welding is used principally for welding heavy sections and permits the use of narrower V's at the joint. A 60-degree included angle of bevel is sufficient for good joint efficiency. In general, less puddling of the molten metal and less welding rod are used in welding by this method as compared with forehand welding.

130. MULTI-LAYER WELDING.

a. This procedure consists of welding or depositing metal in more than one layer. It is used in welding thick plates and pipes in order to avoid carrying too large a puddle of molten metal, which is difficult to control. In addition, the sidewalls of the V are apt to be melted excessively in single-layer welding in an effort to insure proper penetration, and thereby the weld is widened considerably.

b. By using the multi-layer method of welding, the welder can concentrate on getting good penetration at the root of the V in the first pass or layer. On succeeding layers, he can devote himself entirely to getting good fusion with the sides of the V and the preceding layer. The final layer is then easily controlled to obtain a good smooth surface.

c. This method of welding permits the metal deposited in a given layer to be partly or wholly refined and therefore improved in ductility, by the succeeding layers. The lower layer of weld metal, after cooling to a black heat, is reheated by the upper layer through the critical temperature range and then cooled (in effect it is heat-treated). The depth of metal affected by this action is dependent upon the penetration of the welding heat. In some classes of work, when this added quality is desired in the top layer of the welded joint, an excess layer of weld metal is deposited on the finished weld and then machined off. The purpose of this bead is simply to supply welding heat to refine the weld metal in the final layer at the surface of the joint.



RA PD 70996

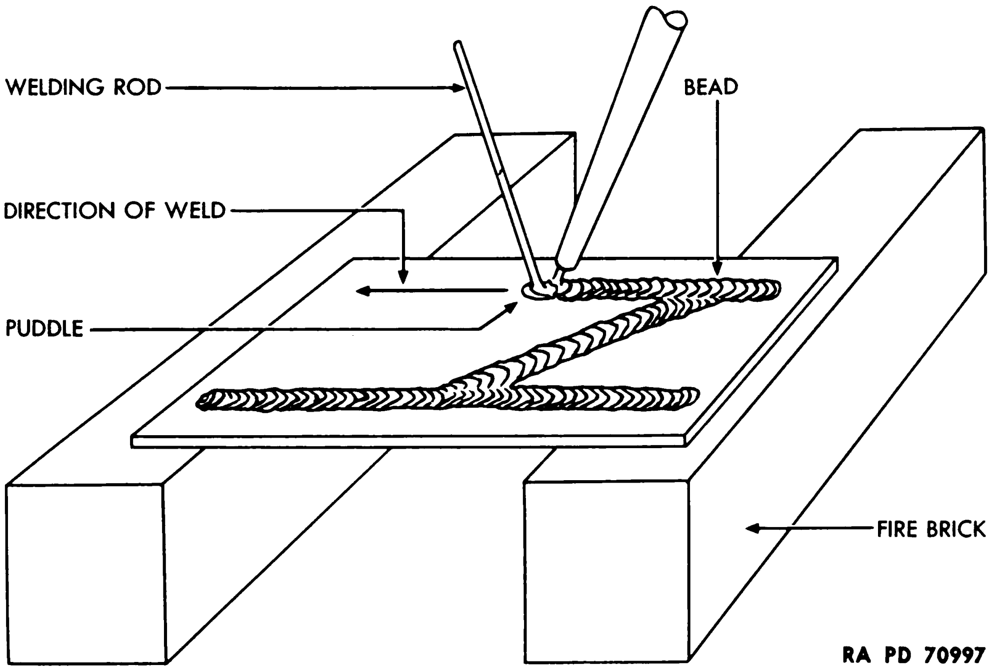
Figure 43 — Bead Welds Without Welding Rod

131. FLAT POSITION WELDING.

a. Bead Welds.

(1) The oxyacetylene welding torch should be adjusted to give the proper type of flame for the particular metal being welded. To obtain the proper welding heat for a given plate thickness, the correct tip size and both oxygen and acetylene regulator pressures should be used. In order to make satisfactory bead welds on the surface of plate, the flame motion, tip angle, and position of the welding flame above the molten puddle should be carefully maintained.

(2) Narrow bead welds are made by raising and lowering the



RA PD 70997

Figure 44 — Bead Welds with Welding Rod

welding flame in a slight circular motion while progressing in the forward direction. The tip should form an angle of approximately 45 degrees with the plate surface, the flame being pointed in the direction of welding at all times. To increase the depth of fusion, either the tip angle should be increased or the welding speed decreased. The size of the molten puddle should not be too large, as this will cause the flame to burn through the plate. A properly made bead weld without the addition of filler rod will be slightly depressed below the upper surface of the plate, while a ridge should be formed on the bottom side of the plate to indicate complete penetration.

(3) Bead welts made on the surface of plate without the addition of filler metal are shown in figure 43. The speed with which the flame is carried along the surface should be regulated so that good fusion or melting is obtained without burning through the plate.

(4) Figure 44 shows a bead welding operation with the use of a welding rod on the surface of the plate. The surface of the steel should be heated to bring a small portion up to the melting temperature. At this point, the welding rod is inserted into the puddle, and both the base plate and rod are melted together. In making this weld, the torch should be moved slightly from side to side to obtain good fusion. By varying the speed of welding and the amount of metal deposited from the welding rod, the size of the welding bead can be controlled to any desired limits.

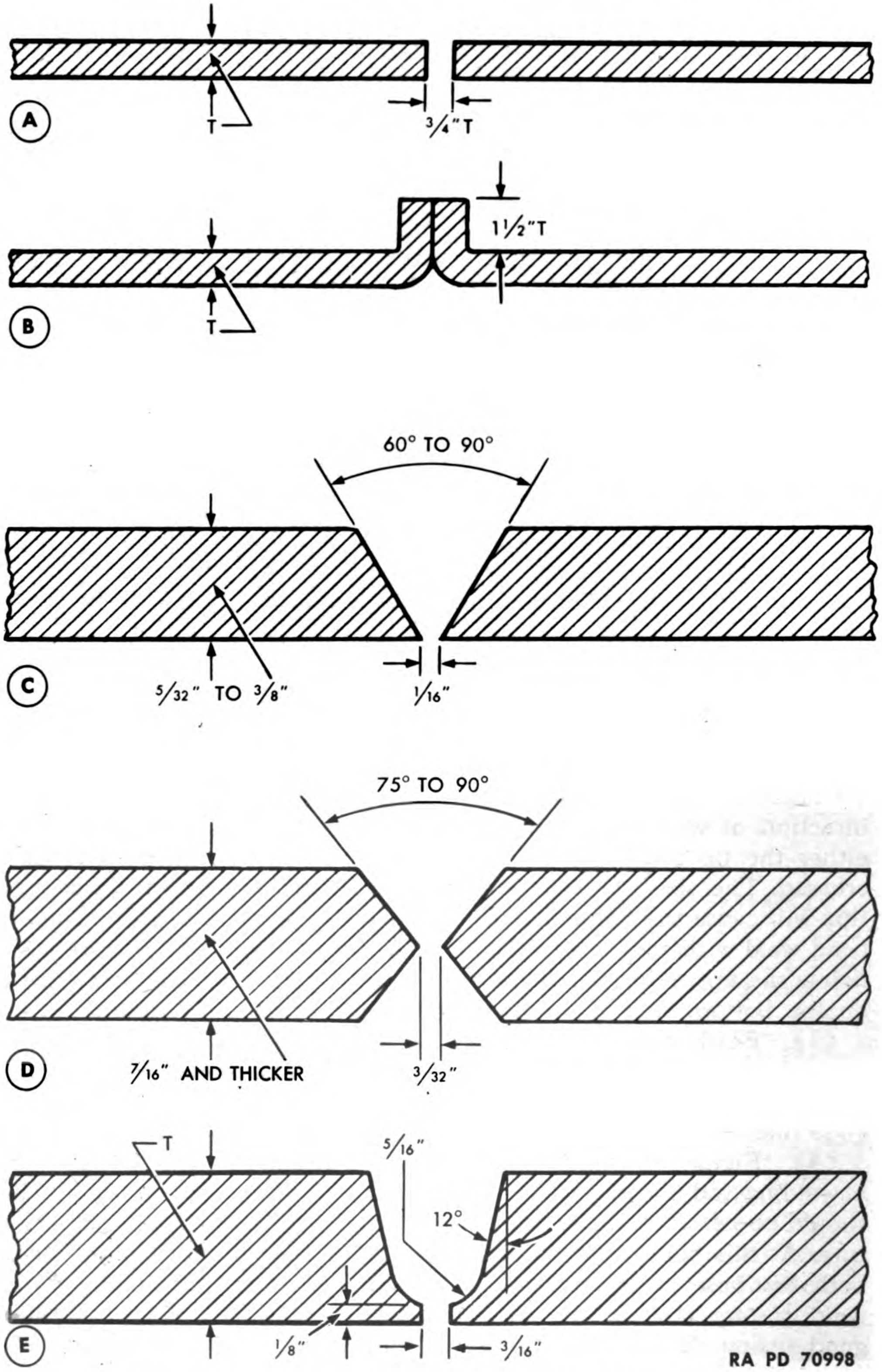


Figure 45 — Preparation for Various Types of Welds

b. Butt Joints.

(1) Several types of joints are used to make butt welds in the flat position. Some of these are similar in design to those used for electric arc welding (par. 90). Some of the more common joint types used for oxyacetylene welding are shown in figure 45. For sheets up to ⅛ inch in thickness, the joints shown in A and B, figure 45, are used. For heavier plates, the joints are prepared as shown in C, D, and E, figure 45.

(2) Tack welds should be used to keep the heavier plates alined for welding. The lighter sheets and plates should be spaced to allow for weld metal contraction and thus to prevent warpage.

(3) The following should be used as a guide for selecting the proper number of passes in welding steel plates:

Plate Thickness	Number of Passes
⅛ to ¼ in.	1
⅜ to ⅝ in.	2
⅝ to ⅞ in.	3
⅞ to 1⅛ in.	4

(4) Figure 46 shows the position of the welding rod and welding tip relative to the plates being welded in making a butt point. The welding tip should be held at an angle of approximately 45 degrees to the base plate. The motion of the flame should be controlled so as to

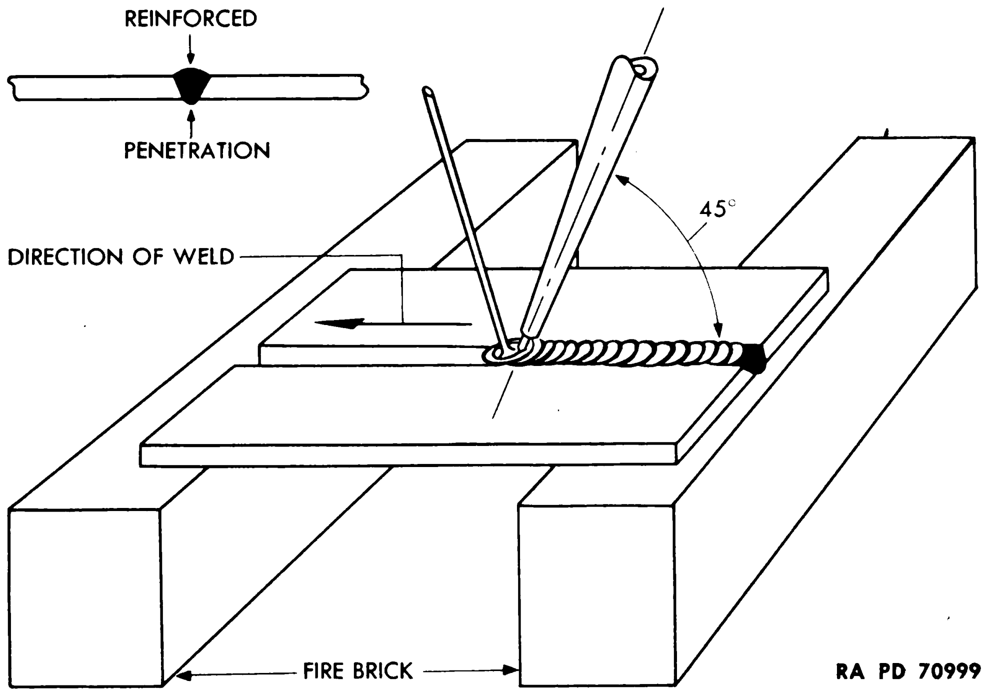


Figure 46 — Position of Rod and Torch in Making a Butt Joint in the Flat Position

melt or break down the sidewalls of the plates at the joint, as well as to melt enough of the welding rod to produce a puddle of the desired size. By oscillating the welding tip and welding rod, a molten puddle of a given size can be carried along the joint at a speed which will insure both complete penetration and sufficient filler metal to provide some reinforcement at the weld. Care should be taken not to overheat the molten puddle; this will result in burnt metal, porosity, and low strength in the completed weld.

132. VERTICAL POSITION WELDING.

a. Bead Welds.

(1) In welding on a vertical surface, the molten metal will have a tendency to run down and pile up, due to the force of gravity. A weld that is not carefully made will result in a joint which has excessive reinforcement and some undercutting on the surface of the plates. To control the flow of molten metal, the flame should be held below the welding rod, pointing upwards at an angle of 45 degrees to the plate. The flow of gases from the tip will support the molten metal and distribute it evenly along the joint. The welding rod should be bent at an angle of 90 degrees a short distance from the end to facilitate adding the filler metal to the joint.

(2) In welding on vertical plate in the horizontal plane, the tip should be held at an angle of 45 degrees to the plate in the horizontal plane and should be inclined slightly in the vertical plane to direct the flame upward. The position of the welding rod relative to the tip is the same as that used when welding up on vertical plate. The slight inclination given to the tip keeps the molten metal from sagging or falling, at the same time as complete penetration and good fusion is obtained at the joint. Both the tip and the welding rod should be oscillated or moved to deposit the metal in a uniform bead along the joint. The welding rod should be held slightly above the center line of the joint and the welding flame should sweep the molten metal across the joint to distribute it evenly.

b. Butt Joints. Butt joints welded in the vertical position should be prepared for welding in a manner similar to that used for butt joints in the flat position. Figure 47 a shows the position of the welding tip and welding rod for making a butt joint on vertical plates. The sidewalls of the joint are melted and sufficient filler metal is added by melting the welding rod. To distribute the molten metal and prevent it from sagging, the tip should be inclined at an angle of 45 degees so as to direct the flame upward.

133. OVERHEAD POSITION WELDING.

a. Bead Welds. Overhead welding with the oxyacetylene welding process presents many of the same difficulties that are experienced in

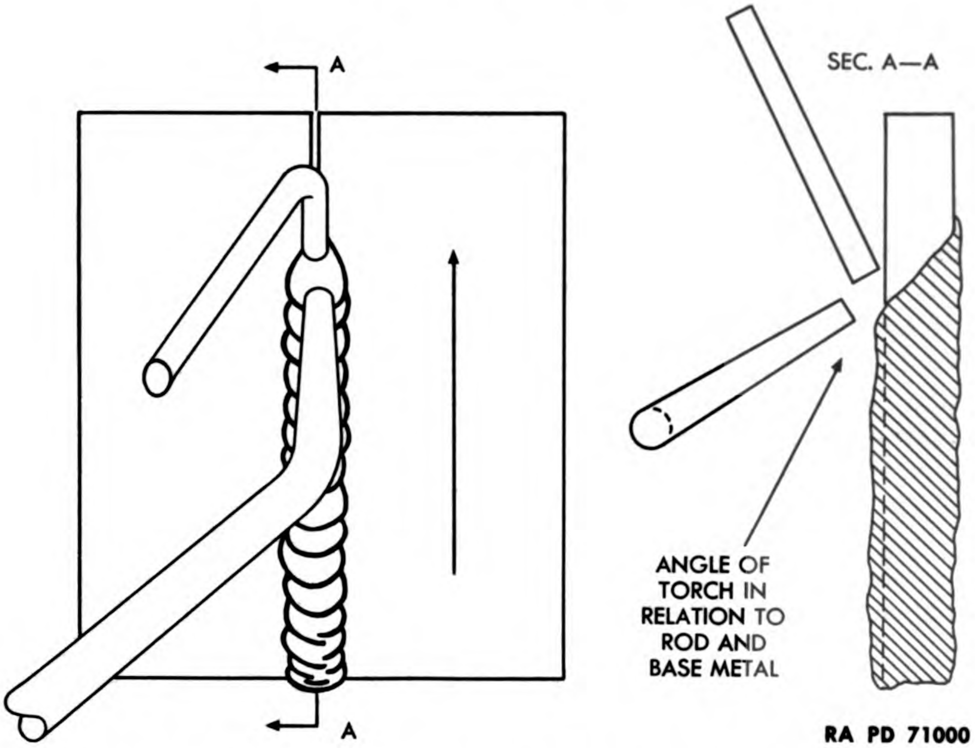


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Figure 47a — Welding a Butt Joint in the Vertical Position

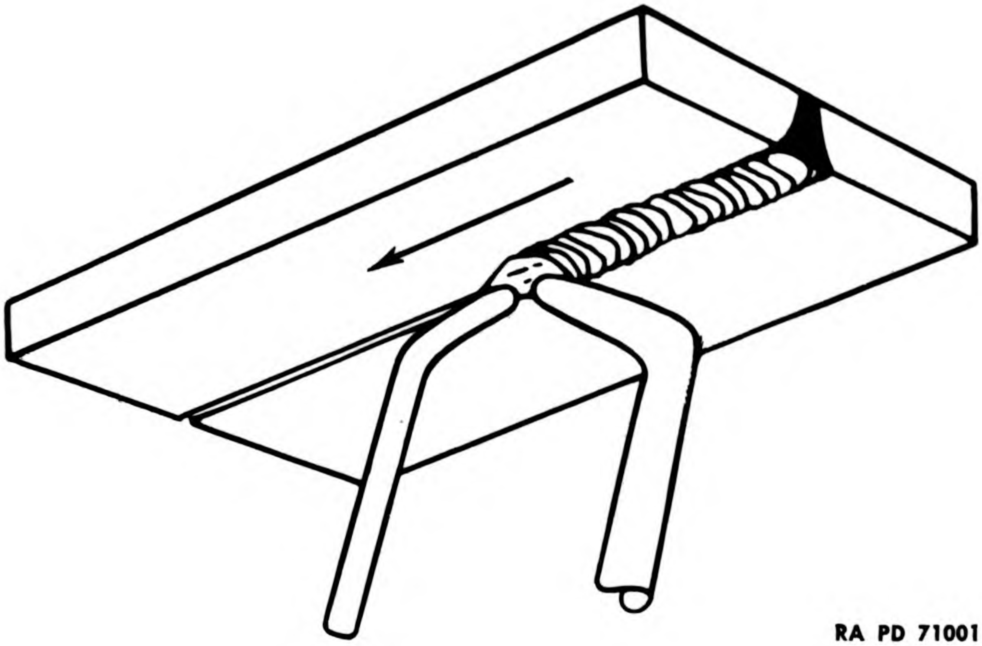

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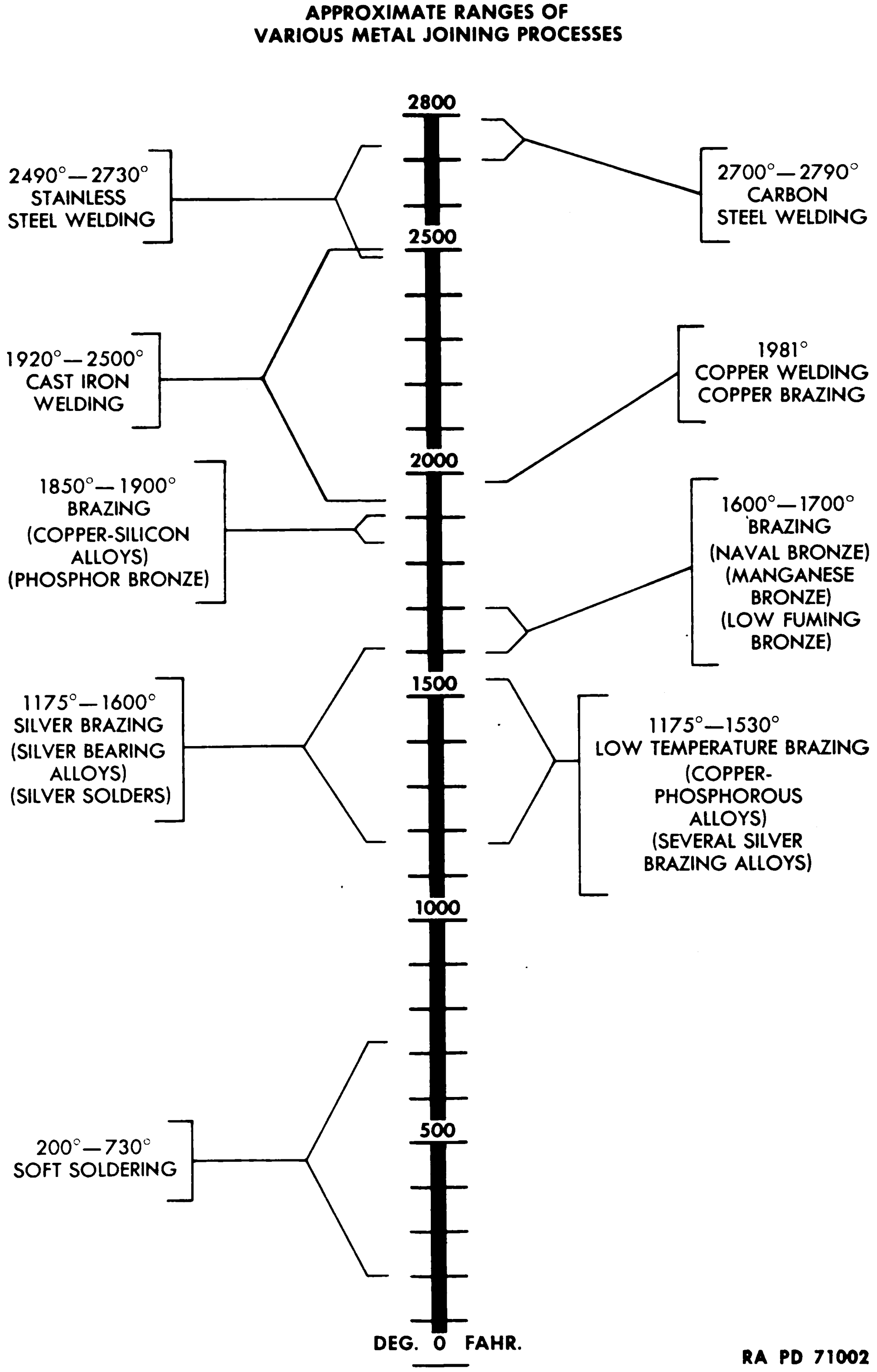
Figure 47b — Welding a Butt Joint in the Overhead Position



RA PD 71002

Figure 48a — Approximate Ranges of Various Metal-Joining Processes electric arc welding. The molten metal deposited tends to drop down or sag on the plate, causing the bead to have a high crown. To overcome this difficulty, the molten puddle should be kept small, and enough filler metal should be added to obtain good fusion with some reinforcement at the bead. If the molten puddle becomes too large, the flame should be removed from the welding puddle for an instant so as to allow the weld metal to freeze before welding is resumed. In welding on light sheets, the heat should be applied equally to the base metal and filler rod, in order to control the size of the puddle.

b. **Butt Joints.** The position of the welding rod and welding tip for butt joints in the overhead position is shown in figure 48. The flame should be directed so as to melt down both edges of the joint, and sufficient filler metal should be added to maintain the puddle at the desired size and to give sufficient reinforcement. The position of the welding flame should be controlled so as to support the molten metal and distribute it along the joint. Care should be taken not to use too large a welding rod, which would interfere with the welding since only a small puddle of molten metal is used. Care should also be taken to control the heat evenly, so as not to burn through the plates being welded. This is especially important when welding can only be done from one side.

CHAPTER 6

OXYACETYLENE WELDING, BRAZING AND SOLDERING OF METALS

Section I

GENERAL

Paragraph
Welding sheet metal 134
Welding steel plate 135

134. WELDING SHEET METAL.

a. For welding purposes, the term sheet metal is restricted to thicknesses up to and including 1/8 inch (No. 11 gage).

b. Welds in sheet metal up to 1/16 inch in thickness can be made satisfactorily by flanging the edges of the joint (B, fig. 45). The edges are prepared by turning up a very thin lip or flange along the line of the joint. The height of this flange should be equal to the thickness of the sheet being welded. The edges should be alined so that the flanges stand up, and the joint should be tack-welded every 5 or 6 inches. Heavy angles or bars should be clamped on each side of the joint to prevent distortion or buckling (fig. 26). No filler metal is required for making this joint. The raised edges are quickly melted by the heat of the welding flame so as to produce an even weld bead which is nearly flush with the original sheet metal surface. By controlling the speed of welding and the motion of the flame, good fusion to the under side of the sheets can be obtained without burning through.

c. A plain square butt joint can also be made on sheet metal up to 1/16 inch (No. 16 gage) in thickness by using a copper-coated low-carbon filler rod 1/16 inch in diameter. The method of lining up the joint and tacking the edges is the same as that used for welding flanged edge joints.

d. Where it is necessary to make a weld in inside edges or corners, there is danger of burning through the sheet metal unless special care is taken to control the heat. Such welds can be made satisfactorily on sheet metal 1/16 inch (No. 16 gage) or less in thickness by using the following procedure:

(1) Heat the end of a low-carbon welding rod 1/8 inch in diameter until approximately 1/2 inch of the end of the rod is molten.

(2) Hold the rod so that the molten globule or drop of metal is above the joint to be welded.

(3) By sweeping the flame across the molten end of the rod, the molten metal is removed and deposited on the seam to be welded.

(4) The quantity of molten metal is relatively large as compared with the lighter-gage sheet, and its heat, therefore, is sufficient to preheat the sheet metal. By quickly passing the flame back and forth, the filler metal is distributed along the joint, and the additional heat supplied by the flame is sufficient to obtain complete fusion. This method of welding can be used satisfactorily for making difficult repairs on automobile bodies and sheet metal containers and for similar applications.

e. For sheet metal 1/16 inch to 1/8 inch in thickness, a plain square butt joint should be prepared at the edges to be welded. A space of approximately 1/8 inch should be maintained between the edges to be welded, and a copper-coated low-carbon filler rod 1/8 inch in diameter should be used. All sheet metal welding on plain square butt joints with a filler rod should be done by the forehand method of welding.

135. WELDING STEEL PLATE.

a. Plates should be spaced 1/8 inch to 5/16 inch apart, depending on the thickness, to permit entry of the flame and welding rod to the base of the joint in order to obtain good penetration. Proper allowance should also be made for expansion and contraction as the plates are being welded, in order to eliminate warping of the plates or cracking in the weld. Figure 45 shows edge preparation for different thicknesses of metals.

b. The edges of steel plates more than 1/8 inch in thickness should be bevelled in order to obtain full penetration and good fusion at the joint. A 90-degree included angle of bevel is used for plates up to 1/2 inch in thickness, and the plates are usually welded by the forehand method of welding (par. 128).

c. Plates 1/2 inch to 3/4 inch in thickness are bevelled to give a 60- to 70-degree included angle or a U-shaped joint, and they are usually welded by the backhand method of welding. In all cases, a 1/16- to 1/8-inch unbevelled land or shoulder is provided at the base of the joint to cushion the first bead or layer of weld metal.

d. The edges of plates 3/4 inch or thicker are usually prepared by using the double-bevel or double U-type of joint when welding can be done from both sides of the plate. When all welding must be done from one side only, a single-bevel or single U-shaped joint is used for all plate thicknesses.

INSTRUCTION GUIDE — WELDING — THEORY AND APPLICATION

CHAPTER 6

OXYACETYLENE WELDING, BRAZING AND SOLDERING OF METALS (Cont'd)

Section II

WELDING AND BRAZING FERROUS METALS

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General 136
Steel 137
Low-carbon steel 138
Medium-carbon steel 139
High-carbon steels 140
Tool steels 141
Chrome-molybdenum alloy steels 142
Chrome-nickel corrosion-resistant steels 143
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Brazing gray cast iron 146
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136. GENERAL.

a. The application of the process of welding to steel exceeds by many times its application to all of the other metals taken together. The term "steel" may be applied to many ferrous mixtures which differ greatly in both chemical and physical properties. In general, steels may be divided into the plain carbon and the alloy groups, although there are many grades in each of these classifications (ch. 3). Most steels may be successfully welded provided the proper procedure is employed; the steels which are generally used for parts fabricated by welding, however, are those which contain not more than 0.30 percent carbon. All steels have a definite amount of carbon which is added during the manufacturing process to give the metal certain properties. Heat increases the combining power of steel for carbon and care must be used during all welding processes to avoid carbon pick-up in the molten steel.

137. STEEL.

a. Steel, when heated with an oxyacetylene flame, does not become fluid until its temperature is raised to between 2,450 F and 2,750 F, depending on its composition, and it goes through a soft or mushy range between the solid state and the liquid state. This is an important consideration when welding in the horizontal, vertical, or overhead position, as it enables the welding operator to control the weld. In order to produce a good fusion weld, the pieces to be welded should be brought to a molten temperature, the welding rod should be placed in the molten puddle, and then the rod and base metal should be melted together so that both are solidified to form a solid joint. Care should be taken to avoid heating a large portion of the joint, since some of the weld metal will merely adhere to the sides of the welded joint and not be fused with it. The flame should be so directed against the sides and bottom of the welded joint that complete penetration to the lower V is obtained. Welding rod should be added in sufficient quantities to fill the joint without leaving any undercut or overlap. It is important not to overheat the metal, since this would burn the weld metal and reduce the strength of the finished joint.

b. The reactions of oxygen, carbon, and nitrogen are harmful to final weld-metal properties, as they increase the danger of oxide and slag inclusions, blowholes, and porosity, and, in general, act to produce defective weld metal.

(1) Oxygen is destructive to steel, as it combines with the metal to form iron oxides. An oxidizing flame causes steel to foam and give off sparks. The oxides formed are distributed throughout the molten metal and cause the weld to become brittle and porous. Since steel oxidizes in the air very rapidly when brought to a red or molten temperature, care should be taken to insure that all the oxides thus formed are removed by proper manipulation of the rod and torch flame. Oxides that form on the finished weld can be removed by wire brushing after cooling.

(2) A carburizing flame adds carbon to the molten steel and causes boiling of the metal. Steel welds made with strongly carburizing flames are hard and brittle.

(3) Nitrogen from the atmosphere will combine with melting steel to form nitrides of iron, which, when included in the metal to any great extent, will lower its strength and ductility.

(4) By controlling the rate of melting of the base metal and the welding rod, the size of the molten puddle, the speed of welding, and the flame adjustment, the inclusion of impurities from these sources may be held to a minimum.

c. Special Precautions. The following points should be observed when welding steels with the oxyacetylene flame. Many of these precautions apply to all oxyacetylene welding operations, since skill in controlling the motion of the flame, rod, and molten puddle are required in order to develop any sound weld.

(1) A well-balanced neutral flame is satisfactory for welding most steels. In order to insure that the flame is not oxidizing, the

oxyacetylene flame is sometimes adjusted to neutral with a slight feather of acetylene. A very slight excess of acetylene may be used for welding alloys of a high-carbon, chromium, or nickel content.

(2) The tip size and volume of flame used should be sufficient to reduce the metal fully to the molten state and to permit complete penetration to the bottom surface of the joint being welded. No excess molten metal should be permitted to form in drip beads from the bottom of the joint.

(3) The flame should bring the edges of the weld to the fusion point ahead of the puddle as it is advanced along the seam. Excessive pressure of the gases should be avoided, as this gives a harsh flame which makes it difficult to control the melting metal and often results in cold shuts or laps.

(4) The pool of molten metal should progress evenly down the seam as the weld is being made.

(5) The tip of the inner flame cone should be held slightly above the work and should not be permitted to come in contact with the welding rod, molten puddle, or base metal. The flame should be manipulated so that the molten metal is protected from the atmosphere by the envelope or outer flame.

(6) The hot end of the welding rod should be melted by the flame by placing it in the puddle under the protection of the enveloping flame. The rod should not be melted and held above the puddle and allowed to drip into it.

138. LOW-CARBON STEEL.

a. In general, no unusual difficulties are experienced in welding low-carbon steels, and the procedure noted above for welding steel plates applies in this case.

b. When properly made, welds in these steels will equal or exceed the base metal in strength.

c. The welding rods should be copper-coated low-carbon rods, and they should be used for various plate thicknesses as follows:

Plate Thickness	Rod Diameter
1/16 to 1/8 in.	1/16 in.
1/8 to 3/8 in.	1/8 in.
3/8 to 1/2 in.	3/16 in.
1/2 in. and heavier	1/4 in.

NOTE: For heavy welding, rods from 5/16 inch to 3/8 inch in diameter are available. By properly controlling the puddle and the rate of melting of the rod, however, heavy welds can be made with the 3/16-inch or 1/4-inch rods.

d. The joints may be prepared by flame cutting or machining, and the type of joint preparation used will be determined by the plate thickness and the position of welding.

e. No preheating, except that used to remove the chill from the plates, is required.

f. The flame should be adjusted to neutral. Either the forehand or backhand welding methods may be used depending upon the thickness of the plates being welded.

g. Care should be taken not to overheat the molten metal, since this will cause the metal to boil and spark excessively; the resultant grain structure of the weld metal and adjacent base metal will be large, strength will be lowered, and the welds will be badly scaled.

h. Low-carbon steels do not harden in the fusion zone as a result of the heat effects of welding.

139. MEDIUM-CARBON STEEL.

a. The steels in this group are usually heat-treated to develop hardness and strength in the finished part. When welded in the heat-treated condition, these steels should be preheated to from 300 F to 500 F before welding, depending upon the carbon content (0.30 percent to 0.50 percent) and the thickness of the steel. The temperature can be checked by applying 50-50 solder (melting point 450 F) to the plate at the joint and noting when the solder begins to melt.

b. Either a low-carbon or high-strength rod can be used for welding medium-carbon steels.

c. The flame should be adjusted to give a slightly carburizing mixture, and the puddle of metal kept as small as practicable to make a sound joint. Welding with a carburizing flame causes the metal to heat up more quickly, since heat is given off when steel absorbs carbon. This action permits welding at higher speeds.

d. Care should be taken to cool the parts slowly after welding to prevent cracking in the weld. The entire welded part should be stress-relieved by uniformly heating to between 1,100 F and 1,250 F for 1 hour per inch of thickness and by cooling slowly. Slow cooling is accomplished by covering the parts with asbestos or sand.

e. Small parts should be annealed or softened before welding by heating to above the critical temperature (red heat) and by slow cooling. The parts should be preheated at the joint and welded with a filler rod that produces heat-treatable welds, and the whole piece should be heat-treated after welding to restore its original properties.

f. Medium-carbon steels can be satisfactorily joined by bronze welding by the use of a preheat of from 200 F to 400 F, a good bronze welding rod, and a brazing flux. Steels in this group, however, are more satisfactorily welded by the metal arc process with mild-steel shielded-arc electrodes.

140. HIGH-CARBON STEELS.

a. These steels are more difficult to weld because of the high carbon content and the heat treatment given them to develop special properties. The heat of welding changes these properties in the vicinity of the welded joint. Heat treatment after welding is necessary, therefore, to restore the original properties in welded parts. These steels should be preheated to from 500 F to 800 F before welding (a pine stick will char at these temperatures).

b. Since these steels melt at a lower temperature than the low- and medium-carbon steels, care should be taken not to overheat the weld or base metal and thus to cause excessive sparking. Welding should be completed as quickly as possible, and the amount of sparking of the molten metal can be used as a check on the welding heat.

c. The flame should be adjusted to carburizing, since this type of flame helps to produce sound welds.

d. Either a medium- or high-carbon welding rod should be used to make the weld. After welding, the entire piece should be stress-relieved at 1,200 F to 1,450 F by using the procedure noted for medium-carbon steels. If the parts can be easily softened or annealed before welding, a high-carbon welding rod should be used to make the joint. The entire piece should be heat-treated to restore the original properties of the base metal.

e. Tools such as chisels, drills, and hammers should be welded by this method. Springs cannot be satisfactorily welded, since the cast metal of the weld will not stand up under the bending and twisting stresses even though the weld has been heat-treated to the original degree of hardness.

f. In some cases, minor repairs can be made to these steels by silver soldering or bronze welding. These processes do not require temperatures as high as those used for welding, with the result that the properties of the base metal are not seriously affected or changed by the welding heat. The hardness and strength of these joints, however, are not as high as those of the original base metal, and these processes should be used only in special cases (pars. 150 and 161).

141. TOOL STEELS.

a. These steels are rarely welded, because of the difficulty in controlling the properties of the metal. The high carbon content and the heat treatment given to these steels causes them to be very sensitive to welding heat unless uniformly high preheating temperatures (up to 1,000 F) are used.

b. In general, the same precautions should be taken as those outlined for welding high-carbon steels. Welding should be done as quickly as possible, care being taken not to overheat the molten metal. After welding, the steels should be heat-treated to restore the original properties.

c. The welding flame should be adjusted to carburizing to prevent burning out the carbon in the weld metal.

d. Drill rods should be used as filler rods, as their high-carbon content compares closely with that of the tool steels.

e. A flux suitable for welding cast iron should be used in small quantities to protect the molten puddle of high-carbon steel and to remove any oxides in the weld metal.

142. CHROME-MOLYBDENUM ALLOY STEELS.

a. Chrome-molybdenum alloy steel is extensively used for parts fabricated by welding. It is obtainable in the bar, sheet, and seamless tube forms. The sheet and tube forms are employed in aircraft construction for welded assemblies, such as steel tube fuselages, engine mounts, and landing gears. These forms are also used in the construction of fittings and brackets to support auxiliary parts.

b. This steel may be welded satisfactorily by all methods and processes. The oxyacetylene flame is generally preferred for welding thin-walled tubing and light-gage sheet, particularly where the metal cannot be backed up on the side opposite that from which the weld is to be made. For material greater than 0.093 inch in thickness, the arc is preferred, as the heat zone will be much narrower, and, as a result, heat stresses will be lower and metal will be heat-affected. This is an advantage, especially when the part is too large to be heat-treated to relieve stresses produced by the welding.

c. The welding technique with the oxyacetylene flame is about the same as that required for the plain carbon steels. The surrounding area, however, should be preheated to between 300 F and 800 F, depending upon the thickness, before starting the weld. This is necessary because a sudden application of the flame without some preliminary heating sometimes results in the formation of cracks in the heated area. The flame should be directed on the metal at such an angle that preheating takes place ahead of the weld.

d. A copper-coated low-carbon welding rod is used for general welding of this metal with the oxyacetylene flame. Chrome-molybdenum or high-strength rod may be used for joints requiring high strength. The strength of parts welded with these rods can be increased by heat treatment after welding.

e. A soft (neutral to slightly carburizing) flame must always be used since an oxidizing flame burns the steel and weakens it. A weld made with an oxidizing flame may crack on cooling if contraction is restrained. A highly carburizing flame makes the metal brittle and will also cause cracking on cooling. The volume of flame should be just large enough to melt the base metal and to obtain good fusion.

f. The weld should be protected from the air as much as possible while hot, to avoid scaling and rapid cooling. When available, a jet of hydrogen directed on the metal from the side opposite to the weld will reduce scaling caused by oxidation and will add to the strength of the finished part by eliminating air hardening around the weld.

g. Overheating will result in severe stresses being set up and will cause excessive grain growth. This condition produces low strength in the welds and in the area adjacent to the base metal.

h. When jigs or fixtures are used, they should be designed to allow a maximum amount of movement of the parts in order to prevent distortion or cracking from contraction as the metal cools.

143. CHROME-NICKEL CORROSION-RESISTANT STEELS.

a. Chrome-nickel corrosion-resistant steels, commonly referred to as stainless steels, contain chromium with varying amounts of carbon, manganese, molybdenum, titanium, and columbium. Stainless steels are known as the 18-8, 25-20, 25-12, 19-9, etc. types. The first figure indicates the chromium content in percent, and the second figure the nickel content. More recent developments have stressed the design of so called modified 18-8 stainless steels, wherein small percentages of manganese and molybdenum are added to develop good physical properties in the joint without subsequent heat treatment.

b. These metals are weldable by all processes, and welds made under proper conditions, with either the electric arc or the oxyacetylene flame, will develop a strength equal to that of the base metal in the annealed condition.

c. Due to the heat required for welding, the corrosion-resistant properties will be reduced somewhat in the weld metal and in the heat-affected zone of the adjacent base metal. This is caused by an increase of carbides in an area which is exposed to temperatures between 800 F and 1,400 F. These carbides accumulate at the grain boundaries in the weld metal and also in the base metal in two parallel zones ¼ inch on each side of the weld bead. When either columbium or titanium is added to the base metal or welding rod, the carbides do not form at the grain boundaries, and the welded joint retains its corrosion-resistant properties. If, after welding, the metal can be heated uniformly to a temperature of 1,850 F to 2,100 F and cooled quickly, these carbides will be put back into solution, and the corrosion-resistant property will be restored. An air quench is considered sufficiently rapid for thicknesses up to 0.0625 inch, while heavier sheets and plates will require a water quench to accomplish the desired effect.

d. These steels have a melting point of 2,400 F to 2,600 F. The coefficient of expansion is about 50 percent greater than that of the carbon steels, and the thermal conductivity is from one-third to one-half less than that of carbon steels. Extra care should be taken to provide for expansion and contraction in welding these steels.

e. Corrosion-resistant steel oxidizes readily if heated with a flame containing an excess of oxygen. As oxides formed in this manner tend to prevent good fusion between the weld metal and base metal, careful attention must be given to the adjustment of the welding flame. strictly neutral setting is preferable but is difficult to maintain with the average equipment, and the flame may change from the neutral to the oxidizing side without being noticed. A very slight excess of acetylene should be used in most cases for welding stainless steels. The feather or brushlike second cone, indicating an excess of acetylene, should not extend more than 1/16 inch beyond the tip of the inner cone. If the flame contains more acetylene than is required, the hot metal will take up the free carbon so as to produce a brittle weld. Any increase in carbon content will also reduce the corrosion resistance of the metal. Atomic hydrogen is also recommended for flame welding stainless steels because no carbon is present in the flame.

f. Corrosion-resistant steel should be well protected from the air during welding, to prevent the oxygen and nitrogen of the atmosphere from combining with the hot metal. Welding in an atmosphere of hydrogen, or the direction of a hydrogen flame on the side of the seam opposite to that from which the weld is being made, provides the best kind of shield. If this method is not available, the metal must be protected with a suitable flux.

g. Flux used for oxyacetylene welding is obtainable in the powder form and is mixed in clean, cold water to form a creamlike paste. A film of the flux should be brushed on both sides of the joint and should also be applied to the rod. This flux, when allowed to dry, protects the metal that cannot be covered with the flame.

h. In welding with the oxyacetylene flame, the end of the rod should be kept within the limits of the flame envelope and added to the weld by allowing to melt and flow into the molten puddle. Stirring or puddling the hot metal with the rod is not necessary and should be avoided.

i. Either of the following methods is satisfactory for butt welding of sheets and plates:

(1) Set the work up with the edges separated a distance equal to the metal thickness, and tack-weld at regular intervals of 2 inches.

(2) Separate the edges so that the spacing is equal to the metal thickness at the starting point, but gradually tapers out at the rate of 3/8 inch per foot of seam length (fig. 25).

j. The welding tip should be in good condition in order to give a flame that does not fork or spread. The tip may be one size smaller than is regularly used for a similar thickness of ordinary carbon steel. In welding sheet metal, the sections should be held in a jig whenever possible in order to keep the edges in alinement. Chill bars applied along the edges of the weld reduce the conduction of heat into the sheet. When a jig is used, the clamps should allow some movement, so as to prevent cracking. After a weld has been started in this metal, it should be continued without interruption until the joint is completed. If for any reason the weld is stopped midway in a joint, it must not be restarted without first preheating the met to a red heat for several inches. After the weld is completed, the joint should be wire-brushed to remove all scale, slag, and remaining flux.

144. HIGH-TENSILE LOW-ALLOY STEELS.

a. This group includes several types of steel which have been developed for use where high strengths are required. These steels should be welded with rods which either have the same composition as the base metal or produce the same properties in the weld that exist in the base metal. Where resistance to corrosion is desired, rods having the same composition as the base metal produce the best results. Heat treatment after welding is required in order to develop good properties in the welded joint. More information as to preheating and welding procedure for the more important high-tensile low-alloy steels is covered in paragraph 288.

145. GRAY CAST IRON.

a. General. In order to weld gray cast iron by the oxyacetylene welding process, it is necessary to consider the structure of cast iron. Cast iron should be heated to a dull red heat before welding in order to equalize expansion and contraction stresses, which might be sufficient to distort or crack the brittle metal. If this preheating is not uniform, the finished weld will be warped, and cracks may appear on the surface or in the base metal. Preheating also helps to soften or anneal the casting, since the preheated metal, when allowed to cool slowly, will cause the carbon in the weld metal to separate as graphite. This permits the finished weld to be machined, and the finished piece will have a minimum of cooling stresses and internal strains. If the casting is not slowly cooled after welding, the weld metal and the base metal in the vicinity of the weld will be quickly cooled and thus be transformed into white cast iron. This form of cast iron is very brittle and difficult to machine and may crack when the part is assembled and in use.

b. Preparation for Welding. The parts to be welded should be cleaned by grinding, wire brushing, sand blasting, or the cold chisel. By this means any scale, cutting slag, grease, or dirt will be completely removed and the formation of a good welded joint will be facilitated. The edges to be welded should be bevelled to form a 90-degree V. Cracks in castings should be chipped out by means of a hammer and cold chisel, and the V should extend to within approximately 1/8 inch from the bottom of the crack. The land or blunt bevel at the base of the edges to be welded will help to prevent metal from burning through during welding. In the event castings are cracked, a hole should be drilled at either extreme of the crack to prevent it from spreading during welding. The base metal should be cleaned approximately 1 inch beyond the edge of the crack.

c. **Preheating.** In fusion welding of castings, the entire casting should be preheated to a dull red before welding is begun. This may be done by means of an oxyacetylene flame, a preheating furnace made of fire brick heated by charcoal, oil or air burners, gasoline and kerosene torches, or a preheating torch.

d. **Welding Rod.** The cast-iron welding rod should have properties which will produce a finished weld whose strength will be equal to or better than the original piece. Silicon is important in weld metal, and the welding rod should contain enough of this element to insure good properties in the weld.

e. **Flux.** Flux must be used in welding cast iron in order to remove the slag of silicon dioxide mixed with iron oxide formed on the molten cast-iron puddle. This flux also acts to clean the weld metal, remove porosity and slag inclusions, and leave a sound weld. A carbon block may be placed on the back side of the V in order to support the weld metal when molten and to insure a sound weld at the base of the V.

f. **Method of Welding.**

(1) The torch should be adjusted to give a neutral flame; a welding tip one size larger than that used for steel of the same thickness should be used. The flame should be pointed towards the finished weld (backhand welding), and the tip of the inner cone of the flame should be approximately 1/8 inch to 1/4 inch away from the molten puddle. A slight weaving motion should be used to melt down the sides and to penetrate to the bottom of the V.

(2) In general, the same precautions should be taken as in welding steel. The end of the welding rod should be heated, dipped into the flux, placed into the molten puddle of weld metal, and melted gradually. The rod should not be held above the weld and melted drop by drop into the puddle. Care should be taken that the sides of the plate are completely melted and that the weld metal does not come in contact with cold base metal. The rod may be used to puddle out any slag, dirt, or blowholes that may occur during welding.

(3) Care should be taken not to overheat the metal and thus cause the puddle to run away or to burn through. The rod should be dipped into flux often enough to insure fluidity of the weld metal, and the weld should be built up slightly above the level of the base metal to provide some reinforcement.

(4) Allowances should be made for expansion during heating and contraction while cooling, and the parts to be welded should be lined up in such a manner that the welded pieces will assume the desired shape.

(5) Cast-iron welding should be carried on as fast as possible, and, when the weld has been completed, the entire piece should b

reheated to remove any strains or stresses that may have been introduced into the piece by the welding operation. The reheated piece should be covered with asbestos, placed away from drafts, and thus allowed to cool slowly.

g. Localized Preheating of Large Castings. When a section of a large casting to be welded is so located that the weld can be made without upsetting the entire casting, then local preheating may be used. This should not be attempted, however, unless the work is checked by a competent welder. In welding large castings, sections of which vary in thickness, it is necessary to control the preheating so as not to overheat and warp the lighter sections.

h. Sealing Porous Cast-Iron Welds.

(1) Welds in cast-iron castings such as cylinder blocks require that the joints be watertight, that is, free from pores, minute cracks, or other defects which will cause leakage. In order to insure that the welded joint is tight against leaks from these sources, a sealing coat made of powdered sulphur and fine graphite powder is applied to the completed weld.

(2) This material is prepared by melting four to five parts of sulphur and adding one part of graphite. Heating is continued, and the graphite thoroughly mixed with the sulphur. If the mixture should ignite, the flame can be extinguished by smothering with asbestos paper. The material is then cast into long bars by pouring the mixture into the V of an angle-iron section lined with paper. The cast bar is removed when cold and the paper scraped off before applying to the weld.

(3) Welds made on cast-iron castings should be coated with this sealing material while the weld is still hot. The end of the cast bar is rubbed into the hot weld so as to cause a small portion of the bar to melt off and deposit itself on the weld in a thin film. The film will penetrate into any small pores or cracks that may exist and will seal them effectively when the weld and seal film cool. All surface scale, slag, and other foreign material should be chipped off or wire-brushed from the weld before application of the sealing-bar material. This procedure for sealing welds can be used equally well on welds made by either the oxyacetylene or electric arc process. When little or no preheating is used, as in arc welding of cast iron, each small section of the welded joint should be treated after chipping while the metal is hot. The bar can also be applied to cold welds by careful heating of the weld with the oxyacetylene torch.

146. BRAZING GRAY CAST IRON.

a. Gray cast-iron can be successfully brazed with very little or no preheating. Broken castings that would otherwise need to be dismantled and preheated can be bronze-welded in place. Parts adjacent to the broken sections being welded should be protected by covering with asbestos or sand to avoid uneven expansion and cracking. Intricate castings, containing thin sections adjacent to heavy ones, always give difficulty in preheating; much of this can be avoided by bronze welding. Under field conditions, bronze welding of gray iron castings is preferred to fusion welding with cast-iron filler rod.

b. Large Castings.

(1) The operations involved in preparing large castings for brazing are very much like those outlined for welding with cast iron. If a weld is to be made in a thin section of the casting, it may not be necessary to bevel the edges. The edges, however, should be cleaned of foreign matter. The hot bronze will run into a thin crack if the metal is warm enough not to chill the liquid bronze. When possible, the joint should be brazed from both sides to insure uniform strength throughout the joint thickness. The strength of the bond between the bronze and iron surfaces will develop the full strength of the original cast-iron section. In heavier sections, the edges should be bevelled to form a 60- to 90-degree V.

(2) Large castings should be preheated before brazing, as this permits easier control of the molten metal and will produce less stress in the finished piece. The extent of preheating depends upon the design of the casting and the break. Occasionally it may be necessary to preheat the entire casting, but local preheating will usually be sufficient. The temperature for local preheating in brazing is considerably lower than in cast-iron welding; a heat only slightly above a black heat is required. It may be necessary to use a lower temperature when preheating the entire casting in order to prevent distortion.

(3) In general, the welding technique is the same as for smaller castings. Where two adjacent sections differ in thickness, the heat of the flame should be kept more on the heavier sections so as not to overheat the thinner part.

147. BRAZING MALLEABLE IRON CASTINGS.

a. Malleable iron castings cannot be welded according to the methods outlined for gray cast-iron. This is because the heat necessary to melt the edges of a break would completely destroy the properties of malleable iron. Because of the special and long continued heat treatment required to develop malleability, it would be impossible to restore completely these properties by brief and simple annealing. Consequently, malleable iron pieces are usually brazed together. Where heat treatment after welding can be done, welding with cast-iron filler rod and remalleabilizing does an excellent job.

INSTRUCTION GUIDE — WELDING — THEORY AND APPLICATION

CHAPTER 6

OXYACETYLENE WELDING, BRAZING AND SOLDERING OF METALS (Cont'd)

Section III

WELDING AND BRAZING NONFERROUS METALS AND SOLDERING OF METALS

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148. COPPER WELDING.

a. In general, the same procedure should be followed for welding copper as for steel.

b. Preparation for Welding.

(1) The welding rod used to weld copper should have approximately the same composition as the base metal. Rods similar to Airco No. 23 Deoxidized Copper or Oxweld No. 19 Cupro-Rods may be used with satisfactory results.

(2) Copper has a high thermal conductivity, and consequently the heat required is approximately twice that used for steel of a similar thickness. For this reason, the tip should be one or two sizes larger than the one recommended for steel.

(3) A slightly oxidizing flame should be used. This flame adjustment is necessary because copper has the property of absorbing carbon-monoxide gases liberated from a carburizing flame and this results in an extremely porous weld.

(4) No flux is required to make the weld.

(5) It is advisable to back up the seam on the under side with carbon, asbestos, or thin sheet metal, in order to prevent uneven penetration. These materials should be undercut or channeled to permit complete fusion to the base of the joint. The metal on each side of the weld should also be covered with asbestos to prevent radiation

of heat into the atmosphere and thus to allow the molten metal in the weld to solidify slowly.

c. Welding Technique.

(1) In welding copper, the plates should be alined and heated along the seam for about 3 inches to bring the metal up to a full red heat. The weld should be started at some point away from the edge and welded back to the nearest edge, filler metal being added. Then, after returning to the starting point, the weld should be restarted and made in the opposite direction as far as the other end. During this welding operation, the torch should be held at approximately a 60-degree angle to the base plate.

(2) The welding speed should be uniform, and the end of the filler rod should be kept in the molten puddle. All during the welding operation, the molten metal should be protected by the outer flame envelope.

(3) If the metal ceases to flow freely during the operation, the filler rod should be raised and the base metal should be heated to a red heat for 2 to 3 inches along the seam. The weld should again be started and should be continued until the seam weld is completed.

(4) When possible, preheating should be done with a separate heating unit or torch. This makes the welding operation much easier, and the weld is less porous than one made by preheating and welding with one flame.

(5) In welding thin sheets, the forehand welding method is more satisfactory, while the backhand welding method is preferred for thicknesses of ¼ inch or more. For sheets up to ⅛ inch in thickness, a plain butt joint with squared edges is preferred. For thicknesses greater than ⅛ inch, the edges should be bevelled at an angle of 60 degrees to 90 degrees, in order to obtain penetration without spreading the fusion zone over a wide area.

149. COPPER BRAZING.

a. For many applications, copper can be brazed to produce a joint with satisfactory properties. Under these conditions, the same precautions should be taken as in brazing steel, a bronze rod with good flowing qualities and suitable brazing flux being used. This method of making the joint is desirable where a color match is not important.

b. Copper may be joined by means of silver soldering, a carburizing flame, a good grade of silver solder, and suitable silver soldering flux being used. Where a high degree of ductility is not required, phoscopper may be used to make the joint. This welding process requires the use of a slightly carburizing flame and no flux.

150. BRONZE WELDING OR BRAZING.

a. General.

(1) Brazing is the term applied to a group of joining processes in which the filler metal is a nonferrous metal or alloy whose melting

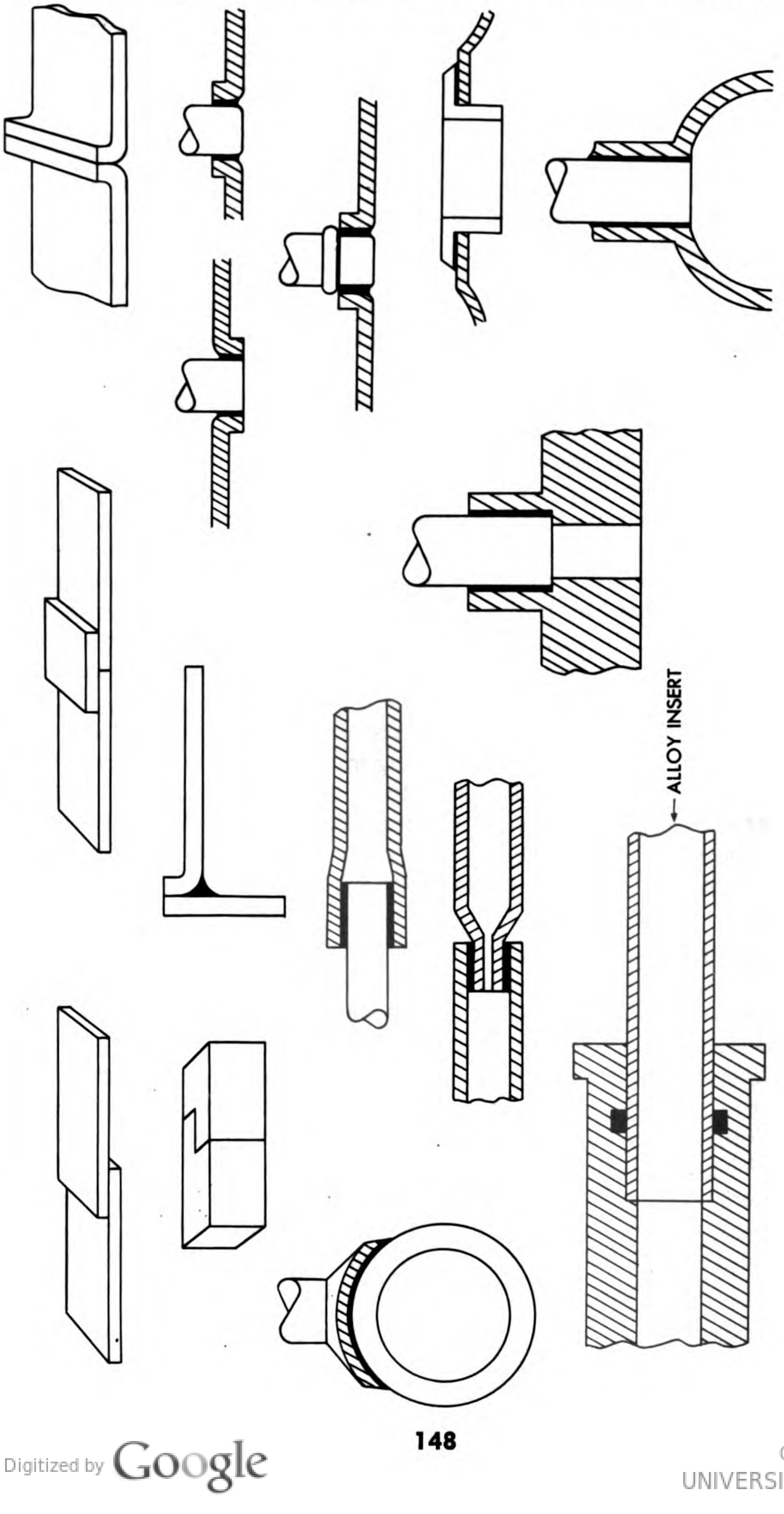


Figure 48b — Typical Joint Designs for Low Temperature Brazing point is higher than 1,000 F but is lower than that of the metals or alloys to be joined. Bronze welding is a brazing process in which the filler metal is a bronze rod. Bronze welding is a convenient method of joining dissimilar metals, such as malleable iron or copper, to iron or steel. Under field conditions, it is usually better to bronze-weld gray iron castings than to weld them with cast-iron filler rod. Metals whose properties are either destroyed or impaired by fusion welding, such as malleable iron and high-carbon or tool steels, are satisfactorily repaired by bronze welding.

(2) Repairs on high-carbon and tool steels should be made by bronze welding only in cases of emergency, and where the lower strength and hardness of the bronze are acceptable.

(3) Copper, nickel, and many of their alloys, whether in the form of castings or plates and shapes, can often be bronze-welded to give results equal or superior to fusion welding. This is especially true if a color match between the base and filler metals is either unimportant or unnecessary.

(4) Bronze welding is not a true fusion welding process, since the base metals joined are not heated to their melting temperature. It consists of joining metals having a higher melting point than the bronze filler rod, such as cast iron, malleable iron, wrought iron, steel, copper, nickel, and high-melting-point brasses and bronzes. Some of these brasses and bronzes, however, melt at a temperature so near to that of the bronze welding rod that fusion welding, rather than bronze welding, must be used.

(5) In brazing with an oxyacetylene torch, the base-metal parts are heated only to a red heat, while the bronze filler rod is actually melted. The joints produced with a suitable bronze welding rod and a good brazing flux will have high strength and toughness, comparable to that of a true fusion weld. The strength of joints made by bronze welding is dependent upon the quality of the bond between the filler metal and the base metal. It is also important that the bronze filler metal deposited in the joint be free from blowholes, slag inclusions, and other defects, in order to have good physical properties.

(6) There are three distinct forces that act to develop the bond strength between the bronze and the base metal. These are as follows:

(a) Tinning. In the same manner that water will spread over a clean glass plate, a clean metal surface will receive a thin film of molten metal of low surface tension (liquid metal must "wet" the base metal). The bond is produced by the action of molecular forces at the interface of the bronze and base metal.

(b) Interalloying. In a narrow zone at the interface of the bronze base metal the constituents of bronze, namely, copper, zinc, tin, and

others, diffuse into the base metal and a corresponding diffusion of the base-metal constituents into the bronze takes place. This diffusion is accompanied by an alloying of the bronze and base metals to effect a chemical bond.

(c) *Intergranular Penetration.* The action of the bronze on the base-metal surface opens up the crystal grain structure of the base-metal surface and allows the bronze to penetrate the base metal along the grain boundaries. This causes a physical bond between the bronze and base metals. It is the action of these forces and not surface fusion that acts to produce the great strength of the bond between the base metal and the bronze.

(7) Bronze welding should never be used where the part is subjected to service conditions where the temperature is higher than 650 F because of the decreased strength of bronze at high temperatures. Even at temperatures of 500 F, the strength decreases rapidly.

b. Material and Equipment Required.

(1) Besides a welding torch with proper tip size, a good welding rod and flux are very important to the success of any bronze-welding operation.

(2) The composition of the welding rod is just as important a factor in bronze welding as in welding steel. Airco No. 27 or Oxweld No. 25M bronze welding rods are representative of brands which have been used and found satisfactory. Bronze welds made with these rods have high tensile strength and ductility. The hardness and strength in shear of welds made with these rods are also greater. These properties result chiefly from the carefully balanced content of certain deoxidizing or reducing agents, the purpose of which is to reduce the loss of zinc in the rod during welding and to prevent in the molten bronze, the formation of gases and oxides which would otherwise result in unsound and porous weld metal. The loss of zinc by fuming during the welding operation is thus practically eliminated, waste of welding rod is prevented, and the comfort of the welder is greatly increased.

(3) Two properties are required of a suitable flux for use with bronze welding rod. Airco Marvel and Oxweld Brazo types of flux are representative of brands which have been used and found satisfactory. At bronze-welding temperatures, a proper flux will unite with any oxides remaining on the base metal and will thus permit good "tinning" of the base metal to occur. By coating the weld puddle, the molten flux will dissolve the oxides of copper, zinc, and tin that form in slight amounts, and will float them to the surface. These might otherwise become entrapped in the weld metal, thus lowering its quality.

c. Preparation for Welding.

(1) Much of the success in a bronze welded joint of good quality can be traced to good preparation of the joint or surface to

be welded. Butt joints over 1/8 inch in thickness should be of the V-type, if penetration and joint efficiency are to be obtained. The edges to be joined or the surfaces to be built up should be thoroughly cleaned of oxides by grinding or brushing. Surface dirt and grease should be washed with a grease solvent such as CARBON TETRACHLORIDE or gasoline. The parts to be bronze welded should be bevelled to give an included angle of 90 degrees. Otherwise, it will be found difficult to secure proper bonding at the bottom of the joint. The surface, for a distance of approximately 1 inch each side of the groove, should be thoroughly cleaned of all grease, dirt, and scale. In welding galvanized iron, however, the galvanized coating need not be removed. A flux paste applied for a distance of 2 inches each side of the joint will prevent the galvanized coating from burning or peeling off.

(2) Parts to be joined should be alined correctly and tack-welded or clamped in the proper position. It is important to use a flame that is slightly oxidizing so as to permit better bonding between the bronze and base metal as well as to suppress zinc fumes. The proper oxidizing flame is obtained by adjusting to neutral and then closing the acetylene valve slowly until the inner cone has been reduced in length by about one-tenth. The flame should be checked periodically for this adjustment. In some cases, the proper oxidizing flame adjustment is obtained after the bronze welding operation is started by noting the point at which fuming ceases.

(3) TINNING.

(a) "Tinning" is the operation of coating the base metal with bronze a short distance in advance of the molten puddle. Clean base-metal surfaces and good fluxing action are necessary to obtain thorough tinning without any cold shuts of metal at the bond. Care should also be taken not to overheat either the base metal or the bronze, as this would cause oxide inclusions and blowholes in the weld metal.

(b) Tinning will take place only when the base metal is at the right temperature. If the metal is not hot enough, the bronze will not run; if too hot, the molten bronze will boil and fume excessively and will form droplets on the edges of the base metal. Proper tinning will be similar in appearance to water spreading over a clean, moist surface, whereas improper tinning has the appearance of water on a greasy surface.

(4) A liberal amount of flux should be used, especially where the rate of welding is rapid. This can be done by heating several inches of the end of the bronze rod and dipping or rolling it in a container of flux. Where bronze welding progresses more slowly, as in the case of heavy castings, it is sufficient to dip only the hot end of the rod in the can of flux and to add to the puddle as required.

d. Welding.

(1) To begin welding, a small area should be heated to a temperature just hot enough so that metal from the bronze rod, sufficiently fluxed, will spread out evenly to produce the tinning coating a little ahead of the main deposit. The inner cone of the slightly oxidizing flame should be kept from ⅛ inch to ¼ inch away from the surface of the metal. Usually the flame is pointed ahead of the completed weld at an angle of about 45 degrees, with the puddle under and slightly behind the flame. This angle may vary, depending on the position of welding (whether overhead or vertical) and on the thickness of the weld being made. As in the case of fusion welding, the motion given the rod and torch will depend on the size of the puddle being carried, the nature of the joint or surface welded, and the speed of welding.

(2) When bronze welding heavy sections, it is frequently necessary to deposit the bronze in layers. To obtain a good joint weld under these conditions, the base metal should be thoroughly tinned in depositing the first layer and good fusion should be obtained between layers.

(3) After a weld has once solidified, never reheat it without adding more filler rod. Otherwise, deposited bronze becomes porous and of low strength. Bronze welds should be made in one pass or layer whenever possible.

(4) It is important that bronze welds, especially on castings, be protected from drafts to permit slow cooling. This can be done by covering the finished piece with a sheet of asbestos paper or burying it in a box of lime, asbestos powder, or fine sand. No stress should be placed on a bronze-welded joint until it has completely cooled, because bronze has relatively low strength at temperatures above 500 F. The finished weld should be cleaned with a wire brush to remove any excess flux which may remain on the surface.

151. FUSION WELDING OF BRASS AND BRONZE.

a. General.

(1) Fusion welding of brass and bronze differs from bronze welding in that both the welding rod and base metal are melted in order to make a satisfactory joint.

(2) The process of welding brasses and bronzes with brass or bronze welding rods is a fusion welding process. This process requires the melting down of the edges of the base metal; however, in brazing of steel, cast iron, and other ferrous metals, the base metal is not melted down and the strength of the joint is dependent upon a physical and chemical bond between the bronze or brass filler metal and the steel base metal.

(3) The principal elements contained in brass alloys are copper and zinc, the zinc content ranging from 15 percent to 40 percent. Intermediate alloys frequently contain 1 percent or more of tin,

manganese, iron, or lead. A bronze may be of almost any copper-base alloy; however, this term is usually reserved for alloys containing relatively high percentages of tin and lead, with or without small amounts of zinc. In addition, there are a number of miscellaneous alloys, such as those containing various amounts of nickel, which gives these alloys a white color.

b. **Welding Rods.** For welds of high strength and soundness, the welding rods recommended for bronze welding should also be used for fusion welding of brass and bronze. Bronze rods will give excellent results in the fusion welding of these metals. In some cases, the welding rod will not produce an exact match in color with the base plate being welded, since there are a considerable number of brasses and bronzes.

c. **Fluxes.** A good grade of flux is important. Airco Marvel or Oxweld Brazo types of flux are representative brands which have been used and found satisfactory. Flux should be added continuously in liberal amounts; this may be done by keeping about 1 foot of the rod coated with flux, according to the method described in the previous section.

d. **Flame Adjustment for Welding Brasses.** In welding brass, if the base metal is brought almost to the melting point by means of the neutral flame, it will be noticed that zinc fumes start to come off and that the surface of the metal is rather bright. If the flow of acetylene is then gradually reduced, or the flow of oxygen increased gradually, it will be seen that at a certain point of excess oxygen flame adjustment the fuming practically ceases and a distinct coating is formed on the surface of the brass. The flame adjustment for this is quite strongly oxidizing. Avoid increasing the oxygen in the flame beyond this point, as the coating or film would then become so very thick and refractory as to interfere with welding. By using the oxidizing flame adjustment which just begins to produce a film, the boiling and fuming of the base metal will be practically eliminated; this is the point at which the best weld, free from porosity and of good tensile strength, is produced.

e. **Flame Adjustment for Welding Bronzes.**

(1) In fusion welding of bronzes which contain relatively high amounts of tin, lead, or both, these elements start boiling out before the base metal is even at a red heat.

(2) Any lead present in brass or bronze does not form an alloy but is distributed in small droplets throughout the base metal. Since lead melts at 621 F, it forms sweatlike drops on the surface of the still solid brass or bronze being welded.

(3) By using a strongly oxidizing flame, however, for both preheating and welding, the boiling out of tin and lead is eliminated. After the base metal has melted and there is a noticeable film on

the surface of the molten puddle, the amount of excess oxygen in the flame should be varied over a fairly wide range; it will be found that for one particular flame adjustment the film or coating tends to disappear, and a bright surface is maintained on the metal. This is the correct flame adjustment necessary for good welding of the high tin and high lead copper alloys. Only a few preliminary trials are necessary to determine this adjustment. Welds made with this flame adjustment will be free from porosity or oxide inclusions.

(4) With alloys containing relatively large amounts of lead, say over 5 percent, some difficulty may be encountered, due to the excessive formation of lead oxide but this may be largely eliminated by the use of an abundant quantity of flux on the welding rod.

f. Edge Preparation. For brass or bronze plate and pipe with wall thicknesses up to one-eighth inch, the weld can be made without any edge bevelling. For plate thicknesses greater than one-eighth inch, the edges should be bevelled by means of grinding, filing, or machining to give an included angle of 90 degrees, leaving a 1/16-inch unbevelled shoulder at the inside wall.

g. Welding Technique.

(1) The welding operation is carried on in much the same manner as the bronze welding of cast iron and steel, except that attention to tinning is unnecessary because the base metal, in this case, is actually melted.

(2) In general, the same precautions as to tip size, oxygen and acetylene pressures, and torch motion should be taken as required for brazing steel.

(3) The plate should be heated to melting temperature and the rod should be kept in the molten puddle during the progress of welding. Care should be taken to break down the sidewalls of the brass or bronze plates and to add sufficient flux, by means of dipping the hot rod into the flux container, to insure a clean, smooth, quiet puddle of molten metal. The oxidizing flame mixture should be maintained, as a carburizing flame would cause the puddle of the molten metal to boil and thus form blowholes or gas-pockets in the finished weld. In many cases, the amount of excess oxygen used in an oxidizing flame will have to be adjusted for the particular alloy being welded, however, a slight oxidizing flame is satisfactory for most brass and bronze fusion welding.

(4) In some cases, flux should be placed on the joint ahead of the welding puddle so that it will not be necessary to force the weld.

(5) The molten puddle of weld metal should not be excessively large, since this condition will cause the metal to become oxidized by contact with the oxygen of the air.

(6) The metal or the rod should not be overheated, as this may cause excessive zinc fuming.

(7) Operators who have been exposed to heavy concentrations of zinc fumes will feel an irritation in the nose and throat caused by the zinc fumes attacking the membranes. Drinking milk is one of the quickest and most effective remedies to overcome the effects of long exposure to zinc fumes.

h. There are a few complex casting alloys which may require special care, particularly in welding in restrained areas. In many cases, these alloys have very little resistance to hot work and to stress at high temperatures. Unless proper precautions are taken to preheat the parts before welding, cracking in the base metal or weld metal will occur. The stresses in these alloys caused by welding may be relieved by using the preheating temperatures outlined in paragraph 288. By slow cooling after welding, sound welds will be produced with no cracks in the base metal.

152. SILVER SOLDERING OF BRASSES AND BRONZES.

a. All brasses and bronzes may be satisfactorily silver-soldered by means of a low-melting-point alloy such as Easy-Flo or Castolin and a suitable silver soldering flux such as the Handy and Harmon flux. These alloys permit joining steels and nonferrous metals at low temperatures, which is advantageous for emergency repairs in the field. Several small brass parts can be machined and assembled to fit closely without any special joint preparation such as bevelling. It is important that the parts be cleaned to remove all oxides, grease, dirt, or other impurities. The flux should be made into a paste by adding water and painted into the joints before assembling. The melting temperature of the silver solder (1,175 F) is below the melting temperature of the brass or bronze (1,625 F to 1,675 F). It is necessary to heat the base metal only to the melting point of the silver solder to make the joint. Because of this difference in temperature, silver soldering is more properly called low-temperature brazing.

b. The heat should be applied uniformly to the section, with the torch adjusted to give a highly carburizing flame. The flame should be played on the heavier sections of the assembly to avoid overheating and melting of the lighter parts. By this procedure, a soaking heat is obtained which is more uniformly distributed throughout the piece. The flame should be held so that only the outer envelope is in contact with the pieces being heated. The melting point of the flux (1,125 F) should be used as an indication of the heat applied to the parts. When this temperature is reached, the silver solder wire, coated with flux paste, should be applied at the joint. The base plates will melt the silver solder into the joint. No reinforcement is necessary, as the joint is held by means of the thin film of silver solder which penetrates into it. The flame should be removed slowly to permit uniform cooling.

153. BRONZE SURFACING.

a. General.

(1) In some brazing operations, it is desired to build up sections of surfaces which have been worn down by sliding friction or other types of wear. This type of repair does not involve the joining of two metal parts by brazing, but merely the addition of bronze metal to the surface of a piece to restore it to its original size and shape. After bronze surfacing, the piece is machined down to the desired finished dimensions. Such metals as cast iron, carbon and alloy steels, wrought iron, malleable iron, monel metal, nickel, and copper-base alloys are satisfactorily built up by this process.

(2) Bronze surfacing is used for building up wearing surfaces that are lubricated, as well as nonlubricated surfaces where low heat conditions prevail. Pistons, sliding valves, seal rings, and other similar wearing parts are operated under lubricated conditions. These parts should be carefully machined when rebuilt to provide the proper clearances between the mating wearing surfaces. In some cases, several reapplications of bronze to steel surfaces are necessary especially when the wearing parts operate under heavy repeated loads. The number of such reapplications of bronze to steel is limited, in that the bronze will penetrate between the grains of the steel to such an extent as to cause cracking. This limitation does not apply to cast iron or to steel parts operating under low stresses.

(3) The worn surfaces of rocker arm rollers, lever bearings, gear teeth, shafts, spindles, yokes, pins, and clevises are satisfactorily repaired by this method. Small bushings can be renewed by filling up the hole in the cast iron or steel part with bronze and then drilling out to size.

b. Technique of Bronze Surfacing.

(1) The welding conditions outlined for bronze welding apply to all bronze surfacing operations. The same precautions as to uniform preheating and slow cooling should be taken. The welding flame should be adjusted to be slightly oxidizing. A suitable brazing flux should be used to obtain good tinning of the molten bronze to the base metal and to reduce oxidation and porosity in the deposit.

(2) The bronze rod selected should fulfill the requirements of hardness or ductility needed for the particular application. The metal should be applied in a continuous layer until the surface is completely rebuilt. Usually a layer of bronze varying in thickness from 1/16 inch to ¼ inch is sufficient. The bronze-surfaced piece shoud be allowed to cool slowly to room temperature and should then be machined to the desired dimensions.

c. Preparation. The surfaces to be rebuilt must be ground down or machined to remove any scale, dirt, or other foreign matter. The nze is then applied to the surface, and sufficient excess metal added to allow for machining to a finished dimension. Cast-iron surfaces should be chipped or ground, where possible, to clean them, as machining will smear the surface with the graphite particles present in cast-iron and will thereby increase the difficulty in obtaining a good bond to the bronze. Cast-iron surfaces that have been machined should be treated before bronze surfacing by passing an oxidizing flame over the surface to burn off the surface graphite or carbon. Hollow piston heads or castings should be vented by removing the core plugs or by drilling a hole into the cavities. This precaution is necessary in order to prevent trapped gases from being expanded by the welding heat and thus bursting the casting.

154. ALUMINUM WELDING.

a. General.

(1) Aluminum or its alloys can be satisfactorily fusion-welded with the oxyacetylene or oxyhydrogen torch. After some training and experience, the welding of aluminum parts of all thicknesses becomes a simple and rapid process.

(2) The apparatus for welding aluminum is the same for other oxyacetylene welding. Because of the high heat conductivity of aluminum (more than four times as fast as steel), a welding tip one size larger than that required for steel should be used.

(3) The forehand method of welding and a neutral flame adjustment for the oxyacetylene torch are recommended.

b. Preparation and Welding.

(1) USE OF FLUX.

(a) As a natural characteristic, all aluminum is coated with a thin film of aluminum oxide which does not melt at welding temperature. To produce a sound weld in aluminum, it is necessary to remove this oxide film from the welding zone either by mechanical means or by chemical means using a flux.

(b) Good fluxes are prepared by a number of reputable manufacturers. Airco Napolitan or Matchless Fluxes, Oxweld Aluminum, Smith's Aluminum-Flux, and Aluminum Company of America's No. 22 Welding Flux are representative of brands which have been used with satisfactory results.

(c) A satisfactory way to use the flux is to mix it with water to form a thin paste (about two parts of flux to one part of water). A day's supply of the flux paste should be made up each morning. If any is left overnight, it should be broken up and thoroughly stirred the next morning, as it has a tendency to crystallize in a lump when standing. Since aluminum flux absorbs some moisture from the air, the container for the dry flux should be kept tightly closed to prevent spoiling.

(d) The flux paste should be applied to the seam by means of a

brush. If a welding wire or rod is used, it should also be coated with the flux paste just prior to welding. The coating of flux on the rod is melted by the heat of the torch. It runs down on the work and flows along the seam ahead of the torch flame. The flux melts below the welding temperature and acts to break up the oxides and float them to the top of the molten metal. The flux also forms a protective coating on the surface of the molten puddle, thus preventing oxidization and permitting slow cooling. By a slower rate of cooling, the gases and impurities in the molten metal are given time to float to the surface, leaving clean weld metal.

(2) WELDING ROD.

(a) It is important that the proper welding rod be used to insure a sound weld with the required strength for the particular welded part.

(b) The common aluminum alloys "2S" (commercially pure aluminum) and "3S" (97 percent aluminum, 1.20 percent manganese, and the rest impurities) should ordinarily be welded with "2S" wire. (Airco No. 25, Oxweld No. 14, and Alcoa No. 1 are representative brands which have been used and proven satisfactory.) The common alloy "52S" (2.50 percent magnesium, 0.25 percent chromium, the balance aluminum and impurities), the heat-treatable alloys "51S" (1.00 percent silicon, 0.60 percent magnesium, the balance aluminum and impurities), and "53S" (0.70 percent silicon, 1.25 percent magnesium, 0.25 percent chromium, the balance aluminum and impurities) should ordinarily be welded with a rod consisting of 5 percent silicon and 95 percent aluminum. (Airco No. 26, Oxweld No. 23, and Alcoa No. 2 are representative brands which have been used with satisfactory results.)

(c) Where the parts are held tightly in jigs, the Airco No. 26 type or its equivalent should be used, regardless of the composition of the alloy. This is particularly important for the strong alloys, as they are more "hot-short" (i.e., have lower strength at high temperatures) than pure aluminum. This type of rod fuses readily with all the aluminum alloys, has a good corrosion resistance and high strength, and is not "hot-short." It is satisfactory to use in welding any of the regular aluminum alloys and contracts but slightly when the molten metal cools. The lower melting point and wider plastic range of this alloy rod enables the molten filler metal to cool slowly and fill in the voids formed during cooling. It also withstands strains caused by the welding heat, as it has fair ductility and strength at temperatures just under the melting point.

(d) A rod diameter should be chosen that will approximate the thickness of the metal to be welded. Ordinarily a rod of ⅛-inch diameter is suitable for welding any thickness of metal up to ⅛ inch, and a rod of 5⁄32-inch diameter for the heavier gages.

(3) PLATE EDGE PREPARATION. The edges of 16-gage and lighter sheet should be flanged, and the upturned edges should be painted with

WELDING AND BRAZING NONFERROUS METALS AND SOLDERING OF METALS

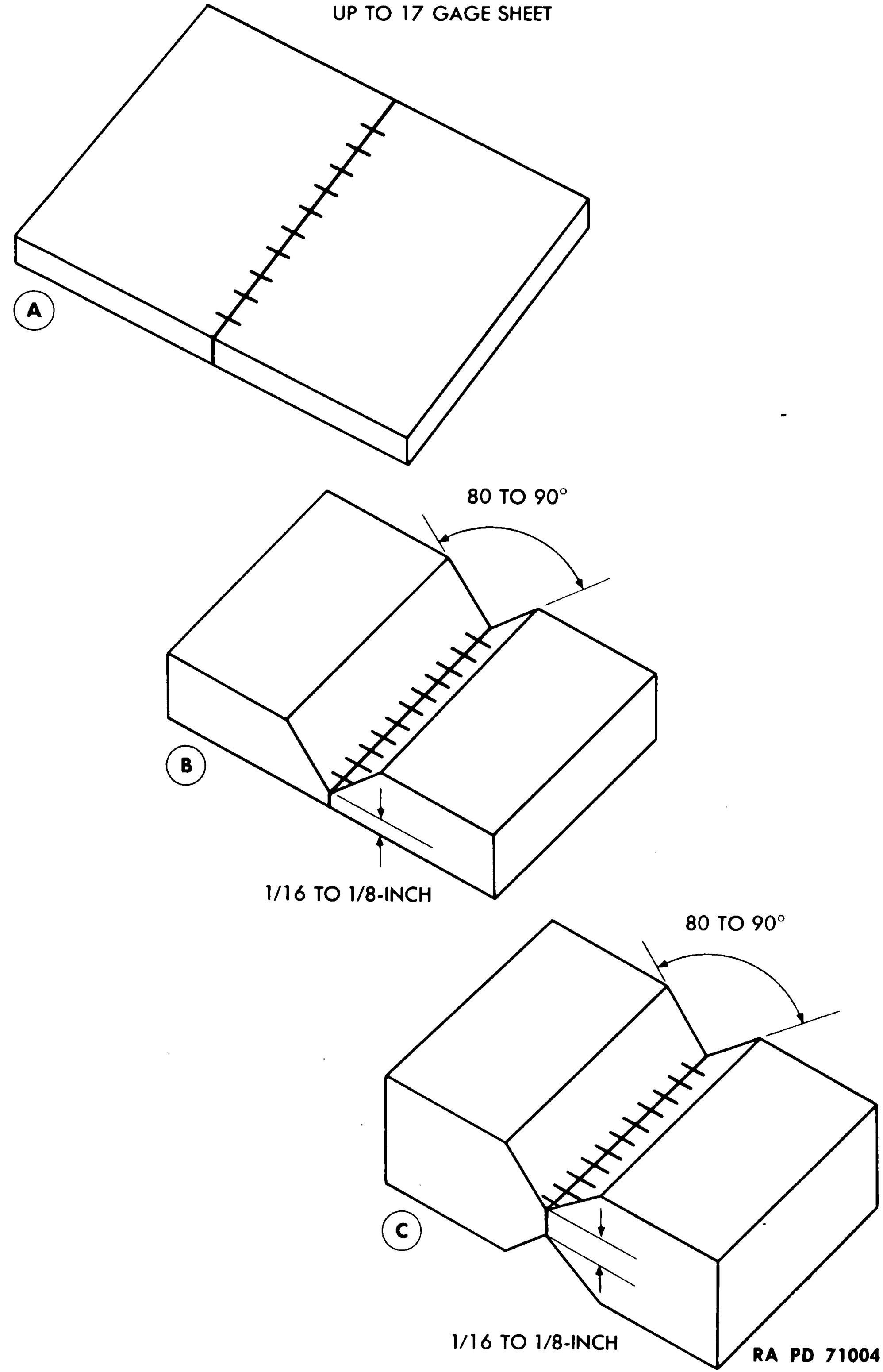


Figure 49 — Square Butt Joint, Single V- and Double V-joints for Aluminum, Showing Method of Notching

flux before welding. These plates may also be welded with the square butt joint. Plate thicknesses of 1/16 inch to 1/8 inch are welded with the notched square butt joint shown in A, figure 49. The notches are best made 1/16 inch deep and 3/16 inch apart with a sharp cold chisel. They enable the flux to work down to the bottom of the sheet, thus helping the welder to obtain full penetration in welding. There is less chance of melting holes through the sheet and of distorting the work. For heavier plate, notched single V- and double V-joints are used, as shown in B and C, figure 49.

(4) PREHEATING.

(a) Aluminum sheet 3/8 inch or more in thickness, as well as the larger aluminum castings, should be preheated to between 500 F and 700 F in order to avoid stresses, buckling, or even cracking due to the localized welding heat. If the base metal for some distance on either side of the seam is maintained at a temperature slightly below its melting point, then, when the torch is applied, the additional expansion at any one point will be small and unlikely to cause distortion.

(b) The preheating temperature should not exceed the upper limit of approximately 700 F. If the temperature goes much above this, there is danger that some of the ingredients of the alloy will melt and thus produce "burned" material. High temperatures may also cause large castings to collapse in the preheating furnace. There are three methods which may be used for determining the proper preheating temperatures:

1. At the proper temperature for welding, a pine stick rubbed on a casting will leave a char mark on it.

2. Chalk marks, made with carpenter's blue chalk, will turn white at the proper temperature for welding.

3. When struck, cold aluminum gives a metallic sound, which becomes duller as the temperature is raised. At the temperature required for welding, there is no longer a metallic ring.

c. Welding Technique.

(1) With the torch adjusted to a neutral flame, hold the tip at an angle of about 30 degrees to the work so as to avoid blowing holes through the heated metal. The end of the inner cone of the flame should be about 1/8 inch away from the work, and the flame should be directed so that it heats both edges of the joint evenly and also the end of the welding rod. The edges should begin to melt before the welding rod is added. It is necessary to direct a considerable portion of the heat on the rod itself since the molten puddle will not melt the rod as in steel welding. Since fusion takes place rapidly, it is necessary to weld quickly along the seam to make a weld of good quality.

(2) As soon as the weld is completed and the work has had time to cool, it should be thoroughly washed to remove all traces of flux. If aluminum flux is left on the weld, it will corrode the metal; it should be

finished. Cleaning by means of hot water and a brush may not be thorough enough to remove flux from the smaller crevices. In such cases after washing with hot water, the weld should be cleaned with a cold 10 percent solution of sulphuric acid for 30 minutes. The acid solution should afterwards be washed off with clean hot water.

d. Welding Aluminum Castings.

(1) In general, the welding of aluminum alloy castings requires a technique similar to that used on aluminum sheet and wrought sections. Many castings depend upon heat treatment for their strength and welding tends to destroy the properties developed by this initial heat treatment. Unless satisfactory facilities for heat treatment after welding are available, the welding of such heat-treated castings is not recommended.

(2) When a broken aluminum casting is to be welded, it should first be cleaned carefully with a wire brush and gasoline to remove every trace of oil, grease, and dirt. Cracks in very heavy cross sections should be V-bevelled before welding, whereas welds in lighter sections can be made by using a torch and puddling iron without this preparation. Pieces that have broken away should be held in correct position by light iron or copper bars and appropriate clamps and should be tack-welded in place. The clamps should be so attached that the casting will not be put under stress during heating.

(3) If the casting is a large one, or one with intricate sections, it should be preheated slowly and uniformly in a suitable furnace prior to welding. If the casting is small, or if the weld is near the edge and in a thin-walled section, the casting may be preheated in the region of the weld by means of a torch flame. Cast aluminum should be heated slowly to avoid cracking in the section of the casting nearest the flame. Specific preheating temperatures for the more common aluminum alloys are given in paragraph 288.

(4) After preheating and tack-welding, the actual welding of the piece should begin at the middle of the break, and welding should be done towards the ends. When the weld is finished, the excess molten metal should be scraped off with a puddling iron, and the casting allowed to cool slowly.

(5) Holes in castings are welded in much the same manner as are cracked and broken castings. It is necessary to melt or cut away the sides of the hole in order to remove all pockets and to permit proper movement of the torch.

(6) For welding ordinary castings either an aluminum alloy rod containing 5 percent silicon or an aluminum-copper-silicon welding rod is generally used. In the case of heat-treated alloy castings, however, it is best to use a welding rod of the same alloy as the casting or strips cut from the base metal.

(7) A flux should be used in welding aluminum castings. Puddling alone will merely break up the oxide film and allow it to become included in the weld, while fluxing will cause the oxide particles to rise to the surface with the flux and a clean, sound weld will result. It is important that the added metal be completely melted and the molten metal thoroughly worked with the end of the welding rod or with a puddling iron.

(8) In welding aluminum castings it is often necessary that the joints be watertight. In order to insure that the welds are sealed so as to be free from minute cracks or pores, a sealing coat made of powdered sulphur and fine aluminum powder is used. This material is prepared by melting four to five parts of sulphur and adding one part of aluminum powder when the sulphur is heated to a plastic state. Heating should be continued, and the aluminum powder thoroughly mixed with the sulphur. The mixture is then poured into the V of an angle iron section lined with paper to form long cast bars. The cast bar is removed when cold and the paper scraped off before applying to the weld. Welds made in aluminum castings should be coated with this sealing material while the welds are still hot. The end of the cast bar is rubbed onto the hot weld, causing a small portion of the bar to melt off and deposit itself on the weld in a thin film. The film will penetrate into any small pores or cracks that may exist and will seal them effectively when the weld and seal film cool. Care should be taken to remove all scale flux and other foreign material from the weld before applying the sealing bar material. This procedure for sealing welds can be used equally well on welds made by either the oxy-acetylene or electric arc process.

155. HEAT-TREATED ALUMINUM ALLOYS.

a. Heating the strong alloys tends to destroy the effects of previous heat treatment. The hardness and strength of the metal near the fusion zone is decreased somewhat by the welding heat. The change in the temper of the metal resulting from the heating also decreases its corrosion resistance. These properties can be partially recovered by a second heat treatment, or when possible, welding operations should be performed before heat treatment.

b. Welds made on "51S" or "53S" alloy parts clamped in jigs should be allowed to expand and contract freely, as these alloys are more sensitive than are the common alloys to cracking next to the weld bead upon cooling. Steps must be taken to prevent the contraction from placing stress on the weld. The parts may be tack-welded while they are in the jig, and the jig clamps loosened before completion of the seam weld. The clamps should be placed far enough away from the weld to prevent stresses and cracking on cooling.

c. Aluminum alloys "53S" or "51S" should be welded in one pass and in the flat position if possible. Reheating the metal to lay down a second bead is undesirable, particularly on containers that are to be watertight or gastight. Welding in one pass is generally faster and more economical than welding in two or more passes.

d. The "53S" or "51S" alloys may be finished flush with the plate surface by light grinding or buffing. They should not be chipped with a chisel or hammered, as the weld metal work-hardens more readily than the common alloys and may fail by cracking.

156. NICKEL AND MONEL METAL WELDING.

a. **Preliminary Procedure.** In welding these metals, it is important that the correct welding rod, welding procedure, and set-up be used.

(1) The same precautions should be taken for supporting the work, cleaning the joint, bevelling, and preventing warpage as are required for welding aluminum castings.

(2) The parts to be welded should be held firmly in place by means of jigs or clamps to prevent distortion.

(3) In welding pure nickel, a slightly carburizing flame should be used in order that the nickel may not be oxidized. In welding monel metal, a carburizing flame prevents the formation of cuprous oxide, which causes brittleness. The flame should be adjusted so that a feather of acetylene approximately ⅛ inch long is visible at the end of the luminous cone. The tip of the oxyacetylene cone should just touch the surface.

(4) Welding should be controlled so that the molten puddle will be quiet, and the welding rod should be kept within the flame to prevent oxidation.

(5) The welding tip selected for a particular monel metal welding operation should be one or two sizes larger than that required for steel of the same thickness.

(6) Welding, once started, should be continued along the seam without removing the torch from the work. The weld should be made correctly the first time, as monel is "hot-short." This is important in order to prevent the surface of the metal from becoming excessively oxidized and also because attempts to reweld and smooth up sections may result in cracking. Heavy sections should be bevelled out and preheated to a dull red heat.

(7) A special flux or a brazing flux should be used in welding monel metal in order to obtain a good joint and to prevent discoloration. The special flux for monel may be used either as a thin paste, by mixing it with alcohol or dissolving it slowly in boiling water, or as a dry powder, by dipping the hot welding rod into the flux. No flux is used for nickel. In some special applications, a special silicon-monel gas-welding rod is used for welding nickel. The joint to be welded should be thoroughly cleaned and the flux should be applied to both

sides of the joint, as well as to the welding rod, by means of a small brush.

(8) Welding rods or strips cut from sheet of the same composition as the base metal should be used. This is important in order to make the corrosion resistance of the weld equal to that of the base metal.

b. Welding Technique.

(1) The flame should be applied to the bottom of the bevelled joint and no welding rod should be added until after a small molten pool of metal has been formed. Both the welding rod and base metal should be melted together at the same time, and the welding rod should be kept in the pool throughout the welding operation. The secondary envelope of the flame thus prevents the oxygen of the air from attacking the molten metal. The pool should be quiet and should not be puddled or boiled, as this takes the life out of the metal. If surface oxides or slag form on the surface of the molten metal, the rod should be melted into the weld beneath this surface film. Welding should be rapid so as to avoid overheating or burning the metal.

(2) Sufficient reinforcement should be added to the weld to allow any surface oxides that might form to be removed by grinding without undercutting the finished weld. Monel metal castings may contain sand or oxides. These should be removed during the welding operation by floating them out to the surface or by using the welding rod to work them out.

(3) After the welding operation has been completed, the entire monel metal casting should be reheated to a uniform temperature and then allowed to cool slowly in a temporary firebrick furnace by covering with sheet asbestos.

(4) Sheet monel metal joints are best welded by flanging the edges of the joint clamping them lightly in a jig, and covering them with the flux paste. The edges should be tack-welded every 5 inches along the entire seam. In this particular case, a welding rod is not required. Upon completion of the joint any unwelded portions or irregularities at the bottom side of the joint can be filled with soft solder, silver solder, or brazing rod, depending upon the corrosion-resisting properties required. During this finishing operation, care should be taken to preheat the welded joint and to cool it slowly in order to prevent cracking.

(5) Heavier sheet, 1/16 inch or greater in thickness, should be bevelled to a 90-degree included angle, and, when laid out for welding, the sheets should be separated 3/8 inch per foot along the seam to allow for contraction.

c. Nickel and monel can be silver-soldered satisfactorily. Any of the joint types recommended for silver soldering may be used, depending on the requirements of the particular application. Monel metal can also be successfully welded by means of the metallic arc welding process. This is especially true when welding cold-worked monel metal.

157. LEAD WELDING.

a. In order to understand the fusion welding of lead, or lead burning, as it is sometimes called, it is necessary to think of the operation in terms of welding of other metals. For example, it is similar to welding aluminum or steel; however, the melting point of lead is considerably lower and consequently, the size of the tip and welding flame must be proportionately smaller in order to control the heat and dimensions of the weld.

b. **Flame Adjustment.** The proper flame adjustment for welding lead is a slightly carburizing flame. Lead welding is a delicate operation and requires skill in order to make an efficient joint. The flame should be held almost perpendicular to the surface, with the inner cone touching the surface of the metal. Care should be taken not to overheat the metal and thus cause the flame to burn through.

c. **Welding Technique.**

(1) The flame should be directed against the metal and should be quickly removed when melting occurs in order to allow the metal to solidify and retain itself in the weld.

(2) Light sheet lead can be welded by flanging the edges and requires no filler rod; however, butt seams using sheet lead can be made with the use of a proper rod. This filler rod can be obtained by cutting strips from the sheet lead or by melting lead and then molding it into the V of an angle iron, thus forming a rod of the proper size. In placing the flame on the edges of the metal to be melted, the rod should be held in close contact with these edges so that both will melt at the same time.

(3) Joints made of lead are not strong, as the lead itself has low physical properties. Alloys of lead containing antimony, however, possess greater strength and hardness and can be used where strength is a requirement. It is necessary, in either case, to clean the edges and surface of the lead of any impurities by means of special tools or scrapers. These impurities are principally oxides, gray in color, and other compounds which form when lead is exposed to the atmosphere.

(4) Where the weld cannot be made on sheet lead from both sides, a butt joint should be used and the weld made from one side. It is desirable, however, to use lap joints in such operations as the manufacture of tank linings. The lead parts to be welded can be easily fitted into shape because of the softness of the metal, and, when desired, holes can be burned through in order to make T-connections.

(5) Before welding lead sheet that has been exposed to an acid atmosphere or is used to convey chemicals, it is necessary to clean the

surface completely and to neutralize the acid with a solution of ammonia or sodium bicarbonate. This will permit the formation of a good joint.

158. SOLDERING.

a. Soft Soldering. The application of lead to a metal or alloy with higher melting point, such as copper, brass, steel, galvanized sheet, nickel, monel, tin, and zinc is known as soft soldering or lead soldering. In many respects, this operation is similar to brazing, in that the base metal is not melted but is merely tinned at the surface by the lead filler rod. The strength of the bond between the lead and the base metal depends upon both a chemical and a physical bond; that is, there is a very fine layer of base metal lead alloy, and some of the lead also penetrates into the pores of the base metal thus forming a physical bond. Joints made in this manner are soft and ductile and can be easily shaped to fit a given contour. The strength of the joint is governed by the strength of the lead itself.

b. Soft Solders.

(1) Several types of lead solders are prepared for this purpose and are classified as soft solders. These solders melt at temperatures ranging from 300 F to 700 F, and, in general, become alloyed to some degree with metals with which they unite. They are composed principally of lead and tin in varying proportions. In general, the higher the lead content, the higher the melting point of the solder. Therefore, the application of high-lead solder is suitable for joints to be used at higher temperatures, say up to 400 F.

(2) The low-lead, high-tin solders melt at correspondingly lower temperatures and are suitable for welding low-melting-point, fusable alloys. A very common solder used for general purpose welding contains 50 percent tin and 50 percent lead and is known as a 50-50 solder.

(3) A special solder containing 95 percent cadmium and 5 percent silver is also used for joints on metals subjected to elevated temperatures.

c. Soldering Action and Fluxing.

(1) JOINT PREPARATION. The parts to be soldered must be clean and sometimes pickled with caustic or acid solutions, filed, scraped, sandblasted, or prepared in a similar manner. Good joints require that the base metal be tinned before the joint is made, that is, the parts to be soldered must be thoroughly coated with solder individually before they are assembled for final soldering.

(2) FLUX. All soldering operations require a flux in order to develop full strength at the joints. Rosin or stearic acid will help to keep the parts clean and free from oxide during the soldering operation. This prevents oxides from forming on the plate until the soldering

temperature is reached. Where the parts to be soldered are tarnished, some scavenging flux like zinc chloride or zinc ammonium chloride may be used to paint the tarnished surface and thus permit good tinning. A 5 percent hydrochloric acid solution cut with zinc is a good general purpose flux for soldering.

d. Methods and Applications.

(1) Soft solder joints may be made by several methods, namely, by using gas flames or soldering irons, by wiping, by sweating the joint, and by dipping in solder baths. Dipping is particularly applicable to the repair of radiator cores. Soldering irons constructed of solid copper vary in shape and may be heated in gas flames or furnaces. These irons may also be electrically heated by means of an internal-resistance unit and are very convenient to use.

(2) Electrical connections and sheet metal are easily soldered with soldering irons. When the parts to be soldered are large and massive, it may be necessary to preheat with a blowtorch or gas torch in order to solder the small parts on their surface areas (for example, soldering copper lugs to electrical wires or sleeve joints on copper tubing). Wiping of solder joints is usually used on lead cable coverings or for lead pipes and sheeting. This method permits working in confined spaces where tools cannot be used conveniently. Sweated joints are generally made where a great number of metal parts are to be soldered. A mixture of finely divided solder and paste is applied to the joints, and the whole unit is heated at one time to complete the soldering operation. Solder is also used to make joints airtight or watertight. In such cases, the strength of the joint itself depends upon riveting, crimping, or bolting, whereas the soldering serves the purpose of sealing the joint. Leaks in radiator cores or at connections are easily repaired by thorough cleaning with acid and soft soldering. Galvanized iron or zinc is best soldered by means of lead-tin solder containing no antimony.

159. SOLDERING ALUMINUM.

a. Aluminum may be soldered with a low-melting-point alloy in much the same manner as soft solders are applied (par. 158 **a**). The base metal must be heated and wire-brushed to break up and remove surface oxides which form on the aluminum sheet when the metal is exposed to the air.

b. Before the joint is made, it is necessary to tin the cleaned surface with the aluminum soldering rod. Tinning is accomplished by heating the base metal, wire brushing, applying the rod to the heated plate or sheet, and allowing the heat of the base metal to melt the rod along the joint. Sufficient metal is then added to the tinned surface to fill the joint completely. The melted solder is wire-brushed so as to work it into the pores of the heated base metal.

c. One rod that has been successfully used for this application is known as the Aladdin Rod. This operation does not require the use of flux, the joint made has satisfactory physical properties and can be used for repairing either aluminum or white metal parts. In building up sections to restore their original shape, it is sometimes desirable to tin surface of aluminum with the aluminum solder and to follow this with an application of 50-50 body solder. The plastic metal is easily spread with a bronze paddle made from a bronze welding rod of ⅛-inch diameter. Any quantity of the filler metal can then be applied to the tinned base metal to give the desired joint dimensions.

160. WELDING WHITE METAL.

a. The application of the Aladdin Rod to white metal is a fusion welding process, in that both the white metal and the filler rod are heated to their melting temperatures and are allowed to cool to form a solid joint. The edges of the white metal casting should be bevelled and thoroughly cleaned by filing or wire brushing.

b. The oxyacetylene flame should be adjusted to give a carburizing flame without smoking up the joint. This, in most cases, is a flame with an acetylene feather of approximately 1 inch in length. The cleaned edges to be welded are heated and wire-brushed to break up the surface oxides. The casting should be heated sufficiently to flow the rod without the aid of flame. The rod should be flowed into the joint and tinned by wire brushing parallel to the surface. A side flame should be maintained to hold the metal at this heat. The welding rod and the base metal should be heated to the welding temperature. When this temperature is reached, the welding rod should be applied and thoroughly fused to the walls of the V. This operation should be continued until the V is filled with some weld metal reinforcement. To obtain good penetration, the rod should be so manipulated as to break the surface oxides.

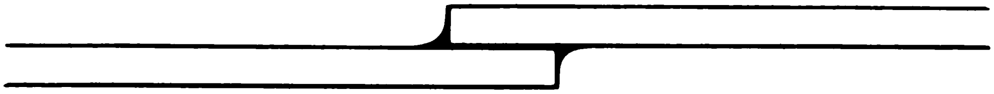
161. SILVER SOLDERING OF METALS.

a. General.

(1) Silver soldering, like brazing, is not a true fusion process, as the base metals or parts being joined are not heated to their melting temperature. The process of silver soldering is really low-temperature brazing, since the melting points of the silver solders (1,175 F to 1,600 F) are lower than those of brazing rods. The strength of the joint made with this process is dependent upon a thin film of silver solder which is well bonded or sweated to the surface of the base metals.

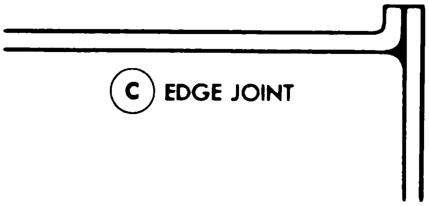
(2) Silver solders are used for joining parts made of various metals, the principal ones being copper, nickel, monel metal, stainless steel, brass and bronze.

(3) Silver solders are alloys of silver, copper, zinc, phosphorus,

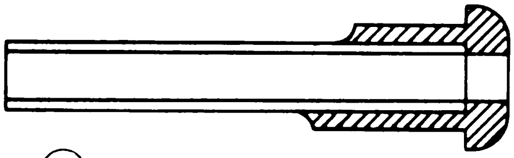


Ⓐ LAP JOINT

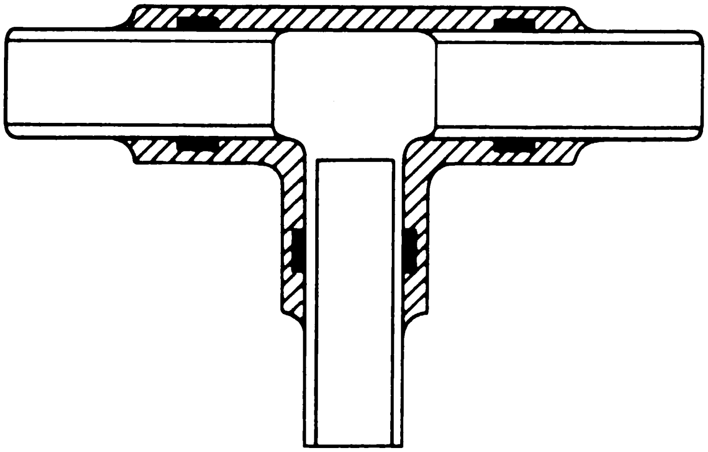
Ⓑ FLANGED BUTT JOINT



Ⓒ EDGE JOINT



Ⓓ FLANGED TUBE CONNECTION



Ⓔ TEE TYPE TUBE ASSEMBLY

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Figure 50 — Joints Made by Silver Soldering

and cadmium. The percentage of these various metals determine the color of the alloy, its strength, and its melting point.

b. Procedure.

(1) In silver soldering various parts, the welder must select a silver solder which will have a melting point lower than that of the metal to be joined so as to avoid heating the parts to a temperature too close to their melting point.

(2) Silver soldering can be performed with an oxyacetylene or an air acetylene flame. The oxyacetylene flame should be adjusted to carburizing, and the heating should be done with the secondary flame only. The inner cone of the flame is too hot for this operation and will burn both the base and filler metals.

(3) In silver soldering joints, it is essential that the parts to be joined be free from dirt, grease, scale, oxides, or other foreign matter. Cleaning can be done mechanically with a wire brush, emery cloth, or other means, or chemically with an acid solution. The parts to be joined should fit together very closely, as only a thin film of the freely flowing silver solder is necessary to make the joint. A fillet built up around the joint causes an unnecessary waste of silver solder, as the fillet does not materially strengthen the joint. Figure 50 shows the recommended types of joints to be used for silver soldering.

(4) The use of a proper flux is important. Its melting point should be lower than the melting point of the silver solder, so that it will clean the base metal and flux the molten metal during the silver soldering operation. The Handy & Harmon type of silver solder and silver soldering flux paste are the most satisfactory for this operation. A mixture of twelve parts borax and one part boric acid may be used as a flux for high-melting-point solders, in case a prepared flux is not available.

c. Silver Soldering Technique.

(1) The flux paste should be applied by means of a brush to both parts being silver-soldered, as well as to the silver soldering rod or strip.

(2) In preheating the parts, if one is heavier than the other, the heavier part should receive the most heat. Where the heat conductivities of metal being joined differ to a considerable extent, it is necessary to preheat the surrounding parts of the metal having a high heat conductivity to a greater extent that those of the metal of low conductivity. The metals should be heated until the flux starts to melt along the line of the joint. At this point silver solder is added, and heating is continued just long enough to flow the metal completely between the parts being joined.

(3) The finished silver-soldered joint should be smooth and uniform, without pinholes or other imperfections. If pinholes occur, it is an indication that dirt or grit was present on the part before the job was started or that poor fluxing and insufficient or excessive heat were used.

CHAPTER 7

CUTTING AND OTHER USES OF THE OXYACETYLENE FLAME

Section I

CUTTING BY THE OXYACETYLENE PROCESS

	Paragraph
General	162
The cutting torch and other cutting apparatus	163
Operation of cutting equipment	164
Cutting steel and cast iron	165

162. GENERAL.

a. The principle of cutting with the oxyacetylene cutting torch is based on the fact that steel will burn very rapidly in an atmosphere of pure oxygen after it is brought up to the kindling temperature range which is between 1,400 F and 1,600 F. The reaction of oxygen with steel forms iron oxide (Fe_3O_4) and gives off considerable heat. The melting point of the oxide, however, is somewhat below the melting point of steel. The heat generated by the burning iron is sufficient to melt the iron oxide and some free iron, which runs off as molten slag, exposing more iron to the oxygen jet. The jet can thus be moved along to produce a clean cut in the steel plate. From another point of view, it may be said that burning or oxidizing iron is extremely rapid-rusting, the rust formed being molten. The principle of the cutting process is shown in figure 51.

b. In actual cutting the iron or steel removed from the kerf is not entirely oxidized by the oxygen, but due to the eroding effect of the cutting oxygen jet about 30 to 40 percent of the metal is washed out of the cut as metallic iron.

c. Theoretically, the heat formed by the burning iron would be sufficient to heat adjacent iron red hot, so that the cut, once started, could be continued indefinitely with oxygen only as is done with the oxygen lance. Practically, the smoothness of this operation is interrupted by excessive radiation at the surface and by pieces of dirt, paint, or scale on the metal. This makes it necessary to keep the preheating flames of the cutting torch burning throughout the cutting operation.

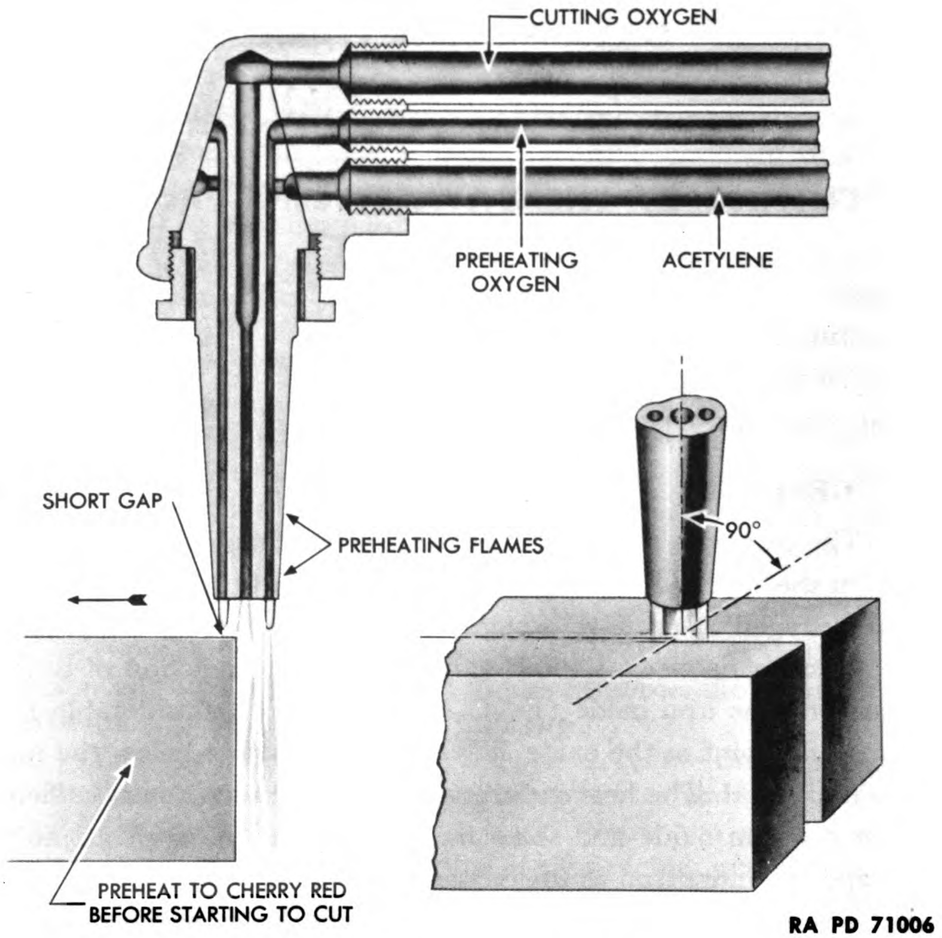

Figure 51 – Starting a Cut and Cutting with a Cutting Torch

163. THE CUTTING TORCH AND OTHER CUTTING APPARATUS.

a. The cutting torch, although it resembles the welding torch in some respects, is used to separate or cut pieces rather than to join them (fig. 52). It has an additional tube for high-pressure oxygen, and the cutting tip or nozzle is made with a number of holes. Through the center hole passes a jet of pure oxygen under pressure, which can be directed against the steel to be cut. Mixed oxygen and acetylene pass through the holes surrounding the center hole for the preheating flames. The heat for starting and maintaining the combustion is supplied by these preheating flames surrounding the cutting jet. The cutting oxygen is controlled by a trigger-operated valve. The cutting torch is furnished with interchangeable tips for cutting steel of thicknesses ¼ inch or less to 12 inches or more. For best results, the cutting tips should be kept clean of slag at all times.

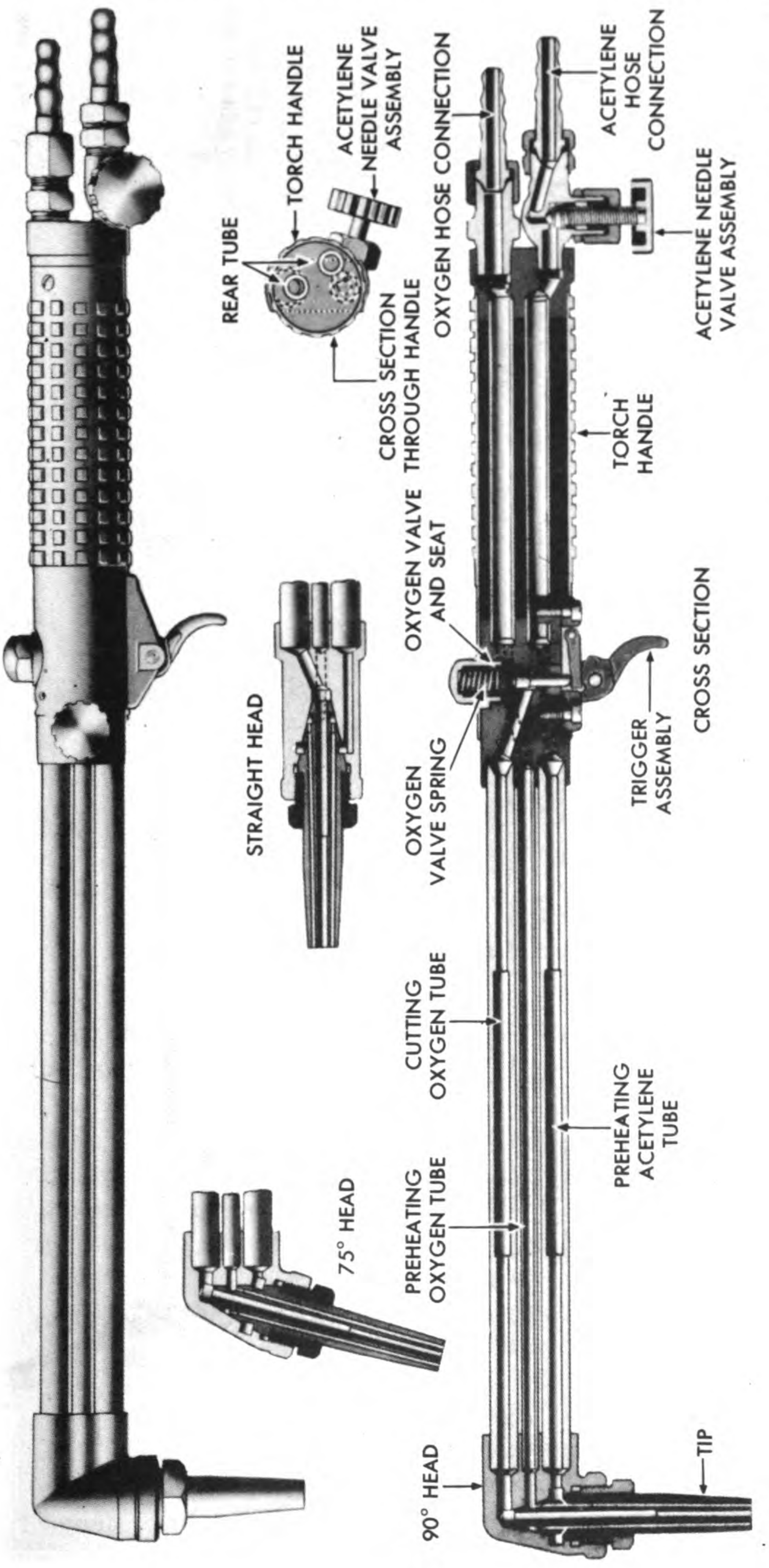

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Figure 52 — The Cutting Torch

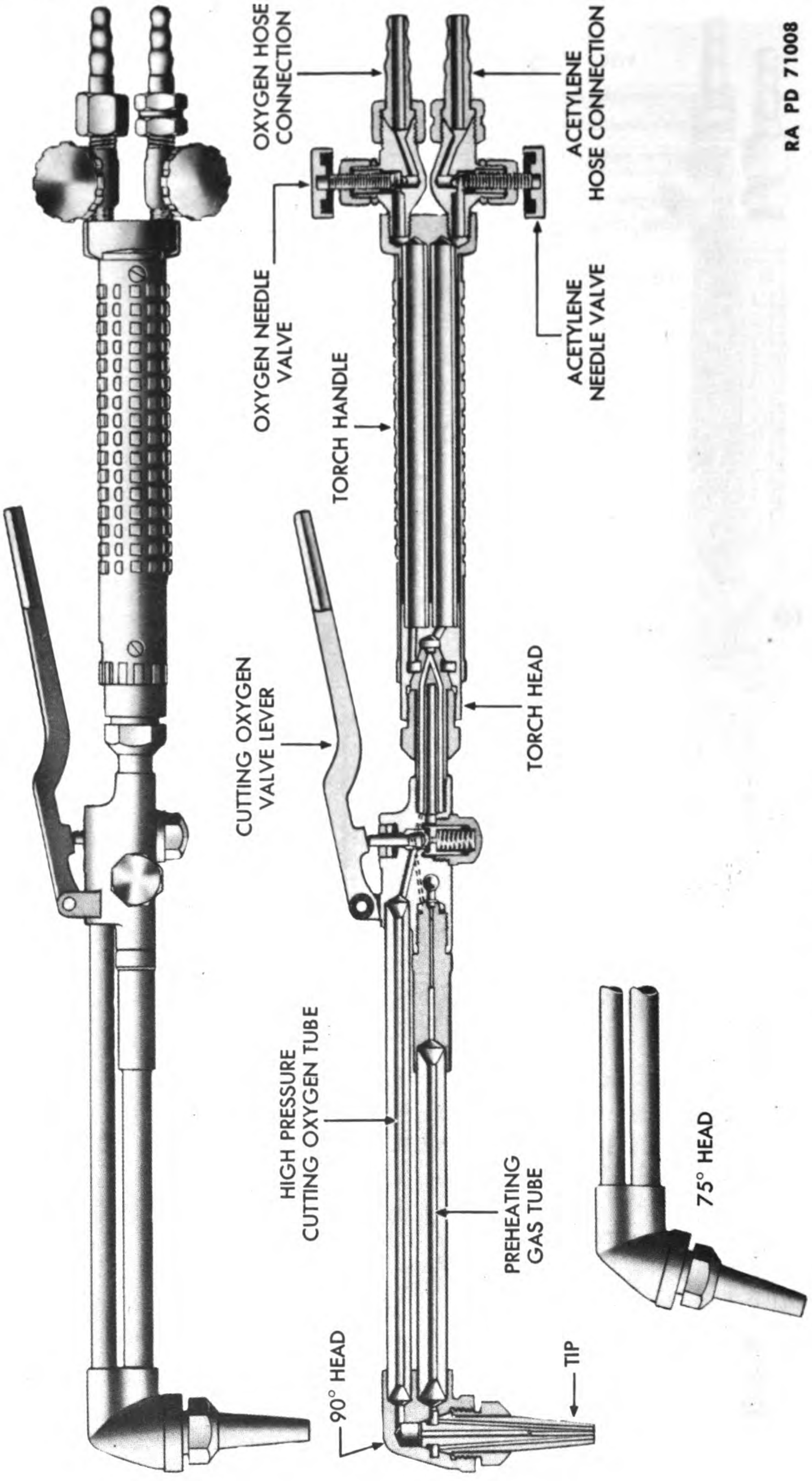

Figure 53 — Cutting Attachment for a Welding Torch

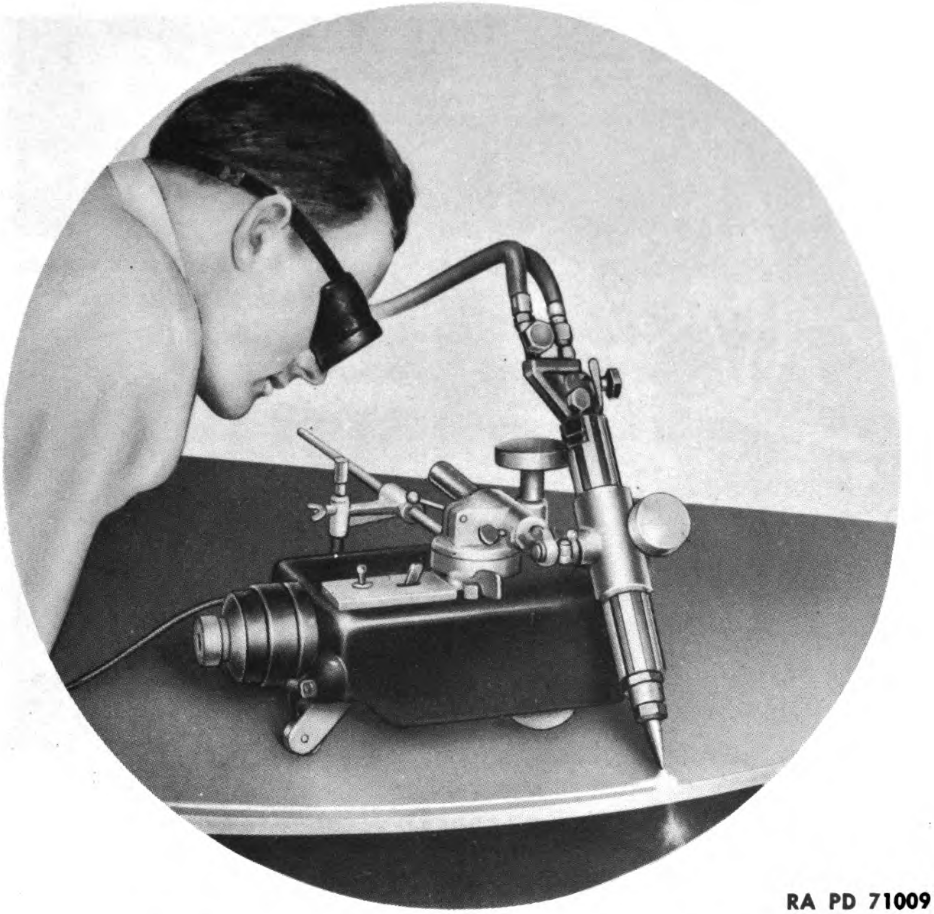

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Figure 54 — Making a Bevel Cut on a Circular Path with Special Cutting Machine

b. Figure 53 shows a cutting attachment fitted to a welding torch in place of the welding head. It serves practically the same purpose as a cutting torch.

c. Torches have been designed with an attachment to feed a welding rod or starting rod in front of the cutting tip. The heat developed when the cutting oxygen reacts with the bur or starting rod preheats the plate or heavy section sufficiently to start the cut.

d. In order to make uniformly clean cuts or bevels on steel plate, motor-driven cutting machines have been designed to support the cutting torch and guide it along the line of cut. Straight-line cutting or bevelling is accomplished by guiding the machine along a straight line on steel tracks. Arcs and circles may be cut by guiding the machine with a radius rod pivoted about a center point. A typical motor-driven cutting machine is shown in figure 54. Special cutting apparatus, designed to make several cuts of various shapes, are shown in figure 55.

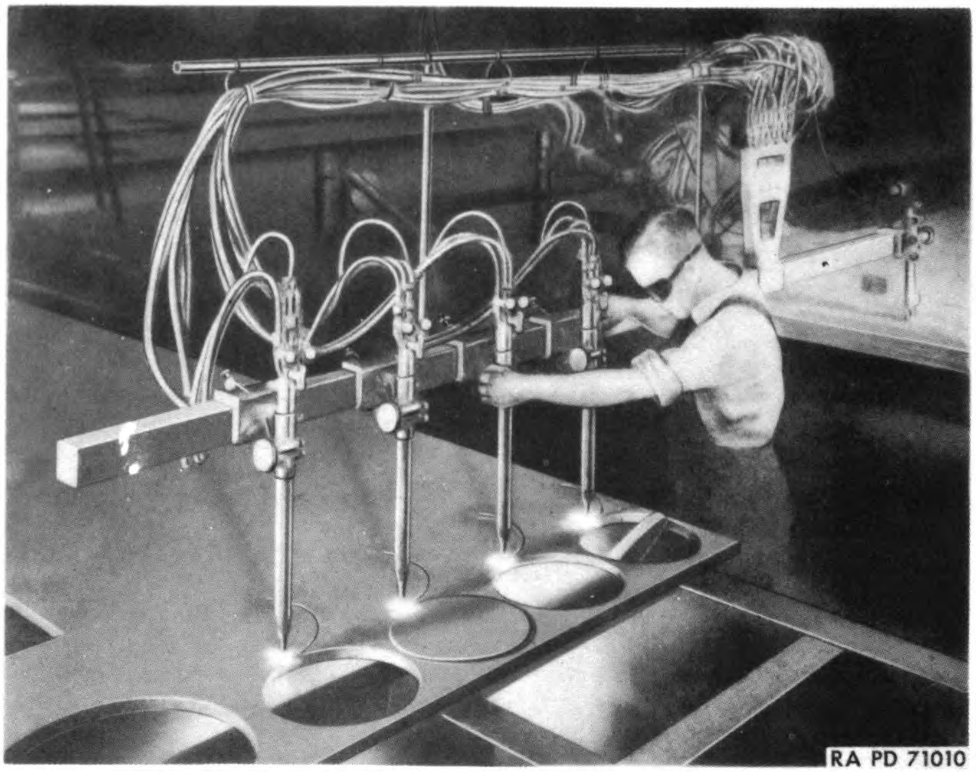


Figure 55—Machine for Making Four Oxyacetylene Cuts Simultaneously

164. OPERATION OF CUTTING EQUIPMENT.

a. Attach the proper cutting tip for the thickness of the metal to be cut to the cutting torch and adjust the oxygen and acetylene pressures according to the manufacturer's instructions. The preheating flames are first adjusted to neutral. To start cutting, hold the torch perpendicular to the work with the inner cones of the preheating flame about one sixteenth inch above the end of the line to be cut. Hold the torch stationary in this position until this spot has been raised to bright red heat; then open the cutting oxygen valve slowly but steadily over the line to be cut. If the cut has started properly, a shower of sparks will fall from the opposite side of the work, indicating that the cut is penetrating all the way through. The movement should be just fast enough for the cut to continue to penetrate the work completely. If cutting has been done properly, the result will be a clean, narrow cut, comparable to one made by sawing. When cutting billets, round bars, or heavy sections, time and gas are saved if a small bur is raised with a chisel where the cut is to start. This small raised portion will heat quickly, and cutting will start immediately. A steel welding rod can also be used to start a cut on heavy sections and, when so used, it is called a starting rod.

b. There is wide variety of cutting tips available in different styles and sizes designed to suit every conceivable type of work. The thickness of the material to be cut generally governs the selection of the tip size having the correct size of the cutting orifice diameter; however, best results are obtained when the cutting oxygen pressure, cutting speed, tip size, and preheating intensity are controlled to give narrow, parallel-sided kerfs. Cuts that are improperly made will produce ragged and irregular edges with adhering slag at the bottom of the plates. The tip sizes and oxygen and acetylene pressures usually used for cutting plates of various thicknesses are listed below.

CUTTING TABLE

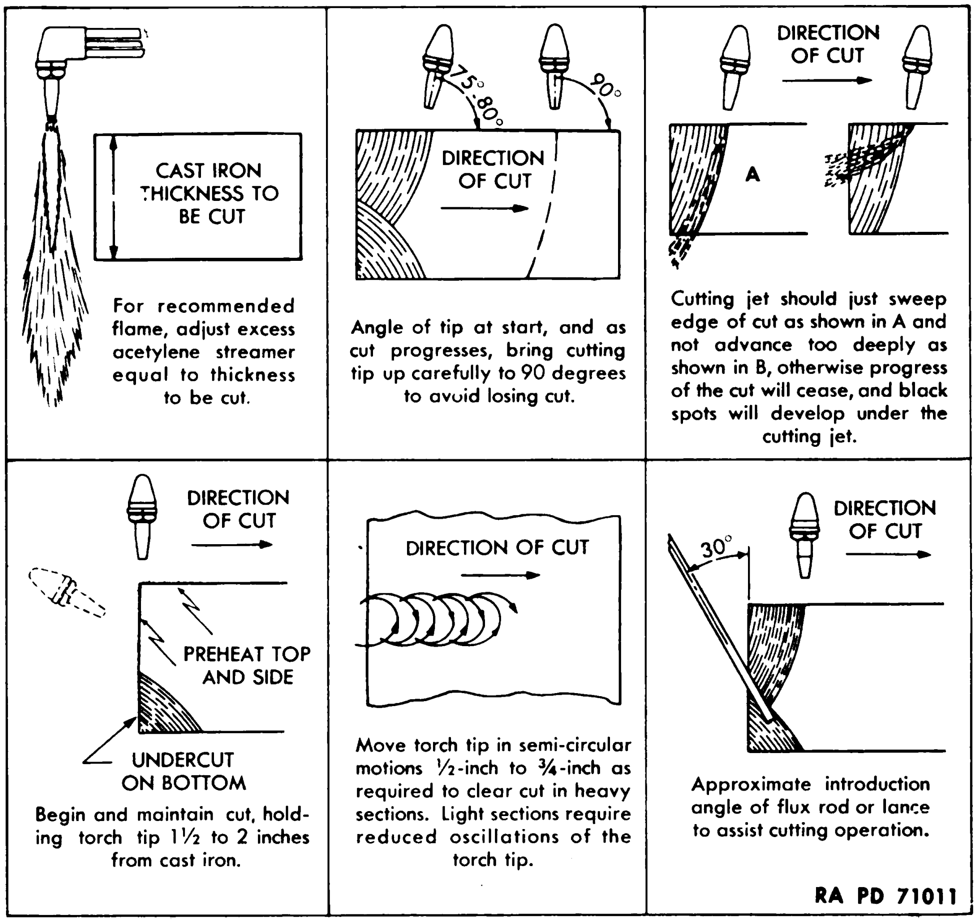
Plate Thickness	Tip Size No.	Acetylene Pressure lb per sq in.	Oxygen Pressure lb per sq in.
¼ in.	0	3	25 to 30
⅜ to ½ in.	1	3	30 to 40
¾ to 1 in.	2	3	40 to 50
1½ in.	3	3	45 to 50
2 in.	4	3	50 to 55
3 to 4 in.	5	4	50 to 65
5 to 6 in.	6	5	55 to 60
8 to 10 in.	7	6	60 to 70
12 in.	8	6	70 to 80

c. The theoretical oxygen requirement for cutting is 4.6 cubic feet of oxygen per pound of iron removed from the slot. This reaction generates 1,865 Btu per pound of iron removed. Actually since some of the metal removed is unoxidized, as little as 3.5 cubic feet of oxygen is consumed per pound of iron removed.

165. CUTTING STEEL AND CAST IRON.

a. Plain carbon steels whose carbon content does not exceed 0.35 percent can be cut without special precautions other than those required for cuts of good quality; however, for higher carbon and alloy steels care should be taken to prevent the formation of a hard layer at the edges of the plates. This is especially true when so-called air-hardening steels are cut, since a thin layer of metal at the cut edge is heated to its critical temperature and rapidly quenched by the adjacent plate and surrounding atmosphere. The hard edges thus formed are difficult to machine when further machining is required, and the lower ductility of this hard layer may cause cracking under load. In order to avoid this, the plate edges are preheated in advance of the cut; this prevents formation of the hard layer, by lowering the temperature gradient, and, therefore, the rate of quench. Preheating temperatures of from 500 F to 600 F should be used in cutting steels in this class.

b. Stainless steels are designed to resist oxidation and therefore have considerable resistance to oxyacetylene cutting. These steels can be cut by laying a steel welding rod or steel plate along the line of cut. The heat developed by the reaction of oxygen with the steel rod or plate is sufficient to melt a slot in the stainless steel. Stainless steel cutting is a melting process rather than an oxidation process.



For recommended flame, adjust excess acetylene streamer equal to thickness to be cut.

Angle of tip at start, and as cut progresses, bring cutting tip up carefully to 90 degrees to avoid losing cut.

Cutting jet should just sweep edge of cut as shown in A and not advance too deeply as shown in B, otherwise progress of the cut will cease, and black spots will develop under the cutting jet.

Begin and maintain cut, holding torch tip 1½ to 2 inches from cast iron.

Move torch tip in semi-circular motions ½-inch to ¾-inch as required to clear cut in heavy sections. Light sections require reduced oscillations of the torch tip.

Approximate introduction angle of flux rod or lance to assist cutting operation.

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Figure 56 — Procedure for Oxyacetylene Cutting of Cast Iron

c. Cast iron melts at a lower temperature than its oxide, and, when cast iron melts, the oxide mixes with it. It is much more difficult, therefore, to cut cast iron than steel. Cast iron must be preheated to a much higher temperature, and requires an oxygen pressure from 25 to 100 percent greater than steel of the same thickness. The preheating flames should be adjusted to carburizing so that the length of the feather of acetylene will be equal to the thickness of the cast iron being cut. It can be cut by using a weaving motion, as illustrated in figure 56.

CHAPTER 7

CUTTING AND OTHER USES OF THE OXYACETYLENE FLAME (Cont'd)

Section II

OTHER USES OF THE OXYACETYLENE FLAME

Paragraph
Flame hardening 166
Flame softening 167
Flame straightening 168
Flame strengthening 169
Flame descaling 170
Flame machining 171
Flame gouging or flame planing 172
Rivet cutting 173
Flame dehydrating 174

166. FLAME HARDENING.

a. The oxyacetylene flame can be used to harden the surface of heavier sections or the entire thickness of lighter sections to produce better wearing qualities. This process consists of heating steels whose carbon content is 0.40 percent or higher up to their critical temperature and quenching in water. Steels containing 0.70 percent carbon or higher can be handled in the same manner, except that compressed air, or compressed air and water mixtures in the form of a spray, are used so as to quench the heated parts less rapidly, thus preventing surface checking.

b. Flame hardening uses the oxyacetylene flame merely as a heating source, and no carbon is added to the surface. In this operation hardening only is being performed. The depth of hardness is no greater than the heat penetration in a steel capable of hardening. In this respect, flame hardening differs from case hardening, which requires the addition of carbon to the surface before the steel is heated to its critical temperature and quenched in water. In case hardening, the depth of hardness is no greater than the depth or thickness of the high-carbon layer on the steel; however, the oxyacetylene flame can be adjusted to a high carburizing flame, so as to introduce carbon into the surface of steels whose carbon content is below 0.40 percent. By quenching the piece after heating to its critical temperature, a thin layer of hard surface is formed on top of a base of soft low-carbon steel. This particular application of flame hardening is similar to case hardening. Both carburizing and hardening are performed simultaneously on a steel of such low-carbon content that it would not harden otherwise.

c. The flame hardening process is a useful tool of the maintenance welder, since, in steels capable of hardening, those areas which are subjected to the greatest wear can be selectively hardened, while the remainder of the piece retains its original qualities.

167. FLAME SOFTENING.

a. Certain steels, on being cooled rapidly in air from a red hot condition, become hard and brittle. These steels are known as air-hardening steels. Where it is necessary to machine a flame-cut or arc-welded surface of these steels further, the hardness should be decreased to permit easier removal of metal. The oxyacetylene flame adjusted to neutral and used as a heating flame is a convenient means of heating the hardened surface to softening temperatures, particularly when only small areas of large objects are to be treated. On slow cooling from these softening temperatures, the original softness of the metal is restored. Flame softening can be done by hand or by mounting a heating torch with special heating tips on a standard cutting machine and moving it slowly across the area to be softened. This process is frequently used after cutting silicon structural steels and other low alloy steels of medium carbon content.

168. FLAME STRAIGHTENING.

a. It is often desirable to straighten steel which has expanded due to uneven heat and has thereby been distorted from its original shape. This is especially true if the steel is prevented from expanding by adjacent cold metal, as occurs when a spot is heated on a heavy plate. The hot metal at the center of the heated zone expands in all directions and "upsets" itself by pressing against the colder plate. The metal adjacent to the colder plate is plastic, and therefore, during the upsetting action, a slight ridge may be formed along the outside edges of the heated spot. On cooling, the metal contracts, tending to shorten the surface dimensions of the heated portion of the plate. Since some of the metal has been upset permanently, the plate cannot return to its original dimensions and therefore becomes dished or forms a concave surface.

b. Since it is known that heat affects metal in this manner, this principle can be used to remove warped sections, buckles, and other irregularities from plate, shafts, damaged structural members, and other parts. These irregularities will often be caused by improper allowances for expansion and contraction in welding or by improper alinement of the parts to be welded. Raised portions of a sheet or plate can be locally heated to upset the metal by expansion; peening or quenching follow. On cooling, the metal will draw down the raised sections, due to contraction of an area whose dimensions have been decreased. By repeating this process and by carefully applying heat to the proper sections, surface irregularities can be easily removed. Shafts with slight variations in straightness caused by mechanical damage or warping due to heat treatment can be straightened by local selective heating and quenching.

169. FLAME STRENGTHENING.

a. The oxyacetylene flame, by the principle of flame hardening, can be used in certain special cases to strengthen a piece which has been affected by the heat of a welding flame. Where a piece is machined with sharp corners or fillets, or where there are severe changes in section, flame strengthening can be used to remove the stress concentration at these sharp corners. The part of the section which is to be hardened or strengthened is heated up to the hardening temperature with the oxyacetylene flame and quenched with water, a water-air mixture, or air, depending upon the composition of the steel being treated. In this manner, a thin, hard layer of metal is formed in a smooth contour at the base of the sharp fillets. This hardened section helps to carry the load placed on the members away from the notches and thus reduces the danger that the part will break.

170. FLAME DESCALING.

a. Before the surface of heavy steel sections can be removed by machining, it is often desirable to remove any scale, rust, and other surface irregularities that may be present. This can be accomplished by passing the high-temperature oxyacetylene flame, or a group of oxyacetylene flames, over the scale, thus causing it to expand rapidly and flake off. This process is also applied to sections which are badly scaled and which are to be flame-cut. Under these conditions, the flame is passsed along the line of the intended cut to clean the surface of scale.

171. FLAME MACHINING.

a. In many cases, it is desirable to remove surface defects such as cracks, seams, pits, or defective sections of welds from the steel. This can be accomplished by flame machining, an operation in which a cutting torch operating at low oxygen pressures is held at an angle to the steel surface and moved slowly either by hand or by a machine over the defective section. The surface is grooved by this operation and can be rewelded to restore the desired surface dimensions. Defects in welds or in the steel plate show up in the reaction zone in the form of bright spots or lines. The slag produced by the cutting is washed up and out of the groove by the oxyacetylene flame. It can then be removed from the surface by wire brushing or light grinding. In this manner, sections that have already been welded and cracked can easily be repaired. For many flame-machining operations, the standard cutting tips can be used satisfactorily; however, special tips are commercially available which can be used to make deep, narrow grooves, sufficiently wide at the top to permit rewelding either by the oxyacetylene or the electric arc method.

172. FLAME GOUGING OR FLAME PLANING.

a. One of the applications of the oxyacetylene torch consists in the removal of wide and relatively shallow surface cuts from steel sections which are to be further rolled or machined. Cutting tips designed with special cutting orifices are used, and the operation is performed in much the same manner as flame machining. The speed with which a surface can be processed by this method may be as high as 15 feet per minute. The cutting operator can control the width and depth of the portion of the surface removed by controlling the oxygen pressure, the tip angle with relation to the plate, and the speed with which the cutting progresses.

173. RIVET CUTTING.

a. When it is desired to remove rivets from plates that are to be disassembled, the standard cutting torch can be used with satisfactory results. The rivet head is heated by the preheating flames of the cutting tip, and, when brought up to its critical temperature, it is washed off by means of the cutting oxygen. The cutting tip can then be held in a vertical position, and the shank of the rivet can be cut through as in any cutting operation. This frees the remaining portion of the rivet enough to permit it either to drop out or be punched out with a light hammer blow.

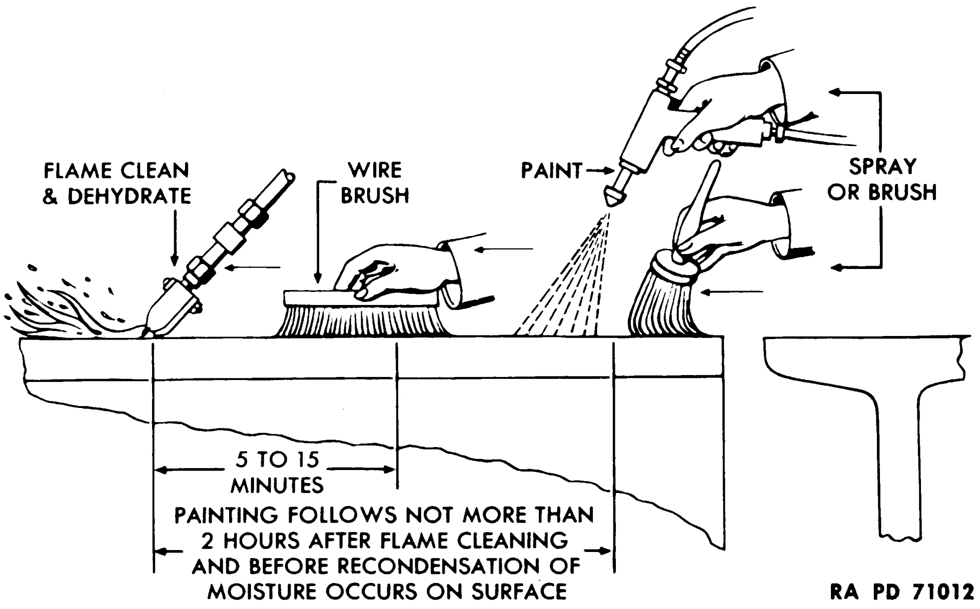

Figure 57 — Operations and Time Intervals in Flame Cleaning and Dehydrating

OTHER USES OF THE OXYACETYLENE FLAME

174. FLAME DEHYDRATING.

a. In certain cases, it may be desirable to paint sections that have become heavily rusted or badly scaled. In order to obtain a good bond between the steel surface and the paint film, the steel must be clean and dry. Steel surfaces are easily cleaned by passing an oxyacetylene flame over the surface by means of either a welding tip or special tips with a row of heating flames designed for this purpose. The intense localized heat of the oxyacetylene flame causes the surface scale to flake off, while the more adherent scale is loosened when the moisture it contains is changed rapidly into steam. The rust and scale can then be easily removed by means of wire brushing, and the surface should be painted while the plate is still warm to the hand. This operation is shown in figure 57.

INSTRUCTION GUIDE — WELDING — THEORY AND APPLICATION

PART THREE — Electric Arc Welding, Hard-Surfacing of Metals by the Welding Arc and Oxyacetylene Processes, Forge Welding

CHAPTER 8

ELECTRIC ARC WELDING: EQUIPMENT, PROCEDURE, AND TECHNIQUE

Section I

GENERAL

	Paragraph
General	175
Metal arc welding	176
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Atomic-hydrogen welding	178

175. GENERAL.

a. Arc welding is one of the three major welding processes which do not require pressure to complete the weld. Oxyacetylene welding and thermit welding are the other two nonpressure fusion welding processes.

b. Arc welding consists of a local progressive melting and flowing together of adjacent plate edges by means of temperatures ranging from 5,000 F to 10,000 F, developed in the electric arc between a suitable electrode and the base metal or between two electrodes.

c. In metal arc welding, the arc is maintained between a metal electrode and the base metal. In carbon arc welding, the arc is formed between two carbon electrodes or between a carbon electrode and a base metal. In atomic-hydrogen welding, the arc is formed and maintained between two tungsten electrodes. The filler metal is furnished by the melting electrode in metal arc welding. The arc and the rate of electrode feed may be maintained by either manual or automatic control. In atomic-hydrogen and carbon arc welding, the filler metal in either wire or rod form may or may not be manually or automatically fed into the arc and melted together with base metal. Thus, in carbon arc and atomic-hydrogen welding, weld metal may consist entirely of base metal, whereas in metal arc welding it will be either filler metal with no base metal or a mixture of base metal and filler metal, depending upon the location of the weld metal in relation to the base metal.

176. METAL ARC WELDING.

a. The metal arc welding process is a nonpressure fusion welding process which develops its welding heat in an arc produced between a metal electrode or wire and the work to be welded. Under the intense heat developed by the arc, a small part of the base metal or work to be welded is brought to the melting point instantaneously. At the same time, the end of the metal electrode is also melted, and tiny globules or drops of molten metal pass through the arc to the base metal. The force of the arc carries the molten metal globules directly into the puddle formed on the base metal, and thus filler metal is added to the part being welded. By moving the metal electrode along the joint and down to the work, a controlled amount of filler metal can be deposited on the base metal to form a weld bead. This motion should be controlled so that a proper arc length is maintained at all times during the welding operation. The speed of welding should be controlled so as to give good penetration of the weld metal into the base metal. The deposited metal can be used to build up the surface of plates by means of a series of welding beads, or it can be used to fill the groove formed between two plates, thus making a welded joint.

b. The edges to be welded should be cleaned of all dirt, slag, and other foreign matter before the weld is made. Cracks in plates should be chipped out so as to permit the weld metal to penetrate to the bottom of the plate, in order to obtain complete fusion. The surface of each weld bead deposited should be chipped and wire-brushed to remove all oxides and slag before additional beads are deposited in the joint. This preparation will prevent these impurities from being trapped in the weld metal deposited and will allow good fusion throughout the joint.

c. In making a welded joint on plates whose edges have been bevelled, the first bead should be deposited without any movement of the electrode from side to side; this is known as a "string" bead. This type of bead gives good penetration and fusion to the sidewalls and bottom of the base metal in the narrow V. Upper layers of weld metal are added by moving the electrode from side to side to fill in the wider opening of the joint and to obtain good fusion to the sidewalls of the joint as well as to the filler metal already deposited. This type of bead is known as a "weave" bead. The width of weave beads should be limited to three or four times the diameter of the electrode being used. In all cases, the joint and weld metal deposited should be thoroughly cleaned before additional metal is added.

d. There are several operating variables or conditions which must be controlled in order to obtain a uniform and sound weld. These are: welding current, voltage, speed, arc length, position of electrode, weaving motion, and polarity. Good welds cannot be produced unless all of these conditions are maintained and carefully controlled by the welder.

e. See paragraph 292 for short cuts to improve weld quality in arc welding.

177. CARBON ARC WELDING.

a. Carbon arc welding is a nonpressure fusion welding process which develops its welding heat in an arc formed between two carbon electrodes or between a carbon electrode and the base metal. In the latter case, the work is connected to the ground cable, as in metal arc welding, to complete the welding circuit to the machine. Filler metal may or may not be required, depending upon the design of the joint and the thickness of the plate being welded.

b. Carbon arc welding is similar to oxyacetylene welding, except that, due to the higher temperatures developed (6,870 F to 9,570 F for carbon arc welding, as compared with 5,700 F to 6,300 F for oxyacetylene welding), the electrode must be manipulated more rapidly than the torch. The carbon electrode holder may be operated manually, or the process may be entirely automatic.

c. In carbon arc welding, the welding machine is set for straight polarity (electrode negative), and a weaving motion may or may not be required during welding. If used with reverse polarity, the carbon electrode will give off a black sooty smoke because of the excessive heat developed at the electrode and the arc will be difficult to control.

d. Manual carbon arc welding with a filler rod is illustrated in figure 58.

(1) Care should be taken to see that the carbon electrode is tapered to a point by grinding to allow easier control of the arc.

(2) Carbon electrodes for manual carbon arc welding and cutting are available in 12-inch lengths, from $\frac{5}{32}$-inch to 1-inch in diameter. These carbons are made of pure graphite or baked carbon. The graphite type is more satisfactory for use with high current.

(3) The carbon electrode should be gripped about 2 inches from the point and held at approximately 90 degrees to the work. The carbon arc is more flexible and less sensitive than the metal arc. Its length can be varied more widely without putting out the arc and without sticking the electrode to the work. During the welding operation, the carbon electrode is consumed very slowly, by oxidation and vaporization only.

e. In automatic carbon arc welding, the arc is struck, the electrode is rotated to keep it pointed, and it is fed by automatic control. In some cases, the arc is shielded by a gas given off from a treated fibrous string or cord which is fed into and burned by the carbon arc. The purpose of this gas shielding is to prevent the oxygen and nitrogen of the air from reacting with the molten metal and thus lowering its quality.

f. The carbon arc welding process is used for welding aluminum, aluminum alloys, copper, copper alloys, nickel, and monel. It can also

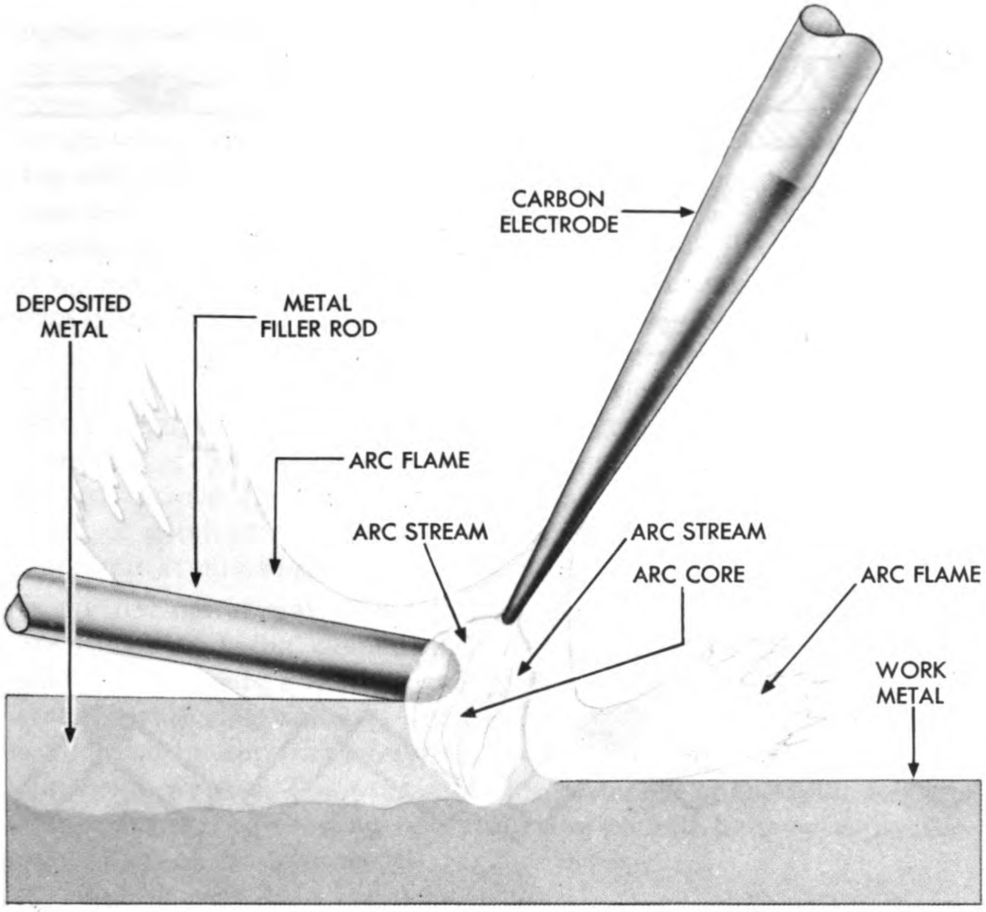

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Figure 58a — Diagram of Carbon Welding Arc

be used to weld together some dissimilar metals such as monel and steel or nickel and steel. In both of the above applications, a flux-coated monel electrode is used, as neither a steel nor a nickel electrode produces satisfactory results.

g. In welding thin metal sheets, the joints are prepared and welded as shown in figure 58 b. Heavier sections are welded with a filler metal of practically the same composition as the base metal.

178. ATOMIC-HYDROGEN WELDING.

a. Atomic-hydrogen arc welding is a nonpressure fusion welding process. In electric arc welding, the heat for welding is derived from electrical energy supplied by the welding current. The heat energy thus obtained is applied directly to the work by an arc. In atomic-hydrogen arc welding, an electric arc formed between two tungsten electrodes is used as a source of energy; however, the method by which the energy is transferred to the work is quite different.

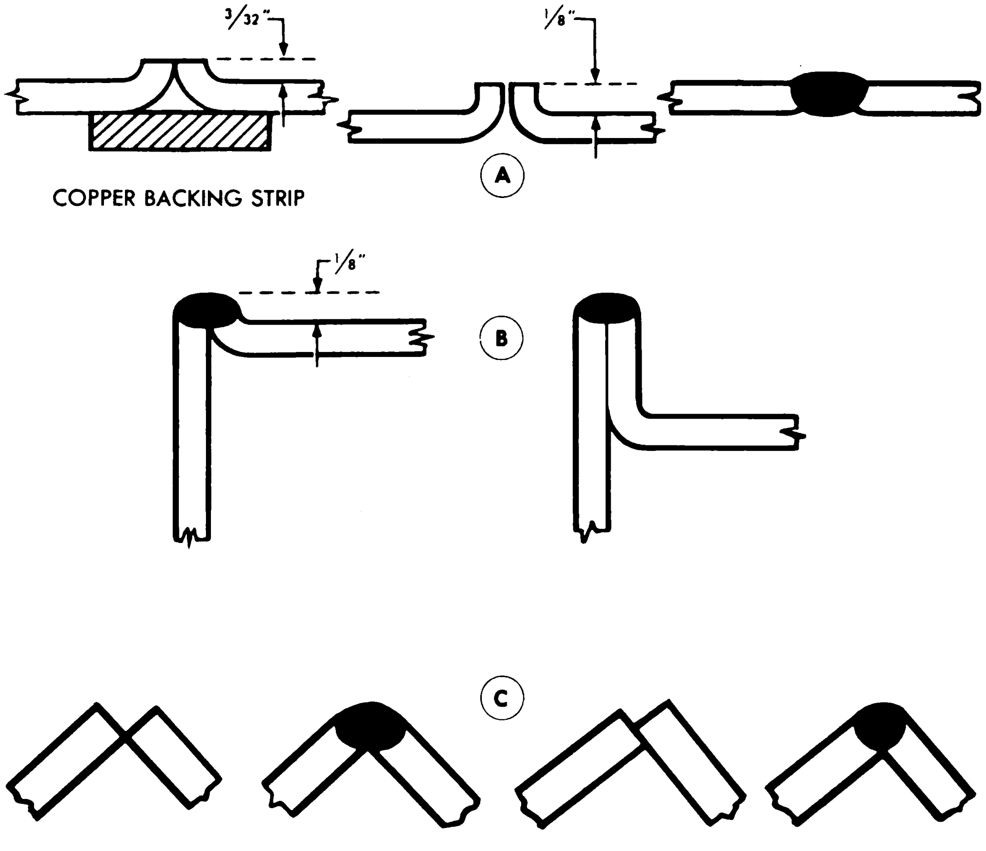

Figure 58b — Joint Preparation for Carbon Arc Welding

b. In the free state, hydrogen gas exists in the form of molecules which are composed of two smaller units known as atoms. When the arc is struck, a temperature of approximately 7,250 F is developed in the stream of hydrogen and this temperature is sufficient to break down the molecular hydrogen to atomic-hydrogen. The atoms of hydrogen thus formed recombine at the surface of the metal being welded to form molecules of hydrogen, and the heat energy previously absorbed is released. Since heat is absorbed by the hydrogen at the arc between the two electrodes, the arc temperature is decreased to approximately 6,340 F thus keeping the electrodes below their melting point. The hydrogen also acts, by combining with the oxygen in the air and thus shielding the welding zone, to keep both the electrodes and the molten weld metal from being oxidized rapidly.

c. Alternating current is used for atomic-hydrogen welding, as this enables both electrodes to be consumed equally. Direct current causes more heat to be developed at one electrode than at the other, thus causing them to be consumed unequally.

GENERAL

d. The principal items of equipment consist of a transformer, a suitable power-control unit, an electrode holder, and a cylinder of hydrogen gas, the flow of which is controlled by a regulator. The arc is struck between two tungsten electrodes held in hollow holders through which the hydrogen gas flows. These holders are attached to tubes which are current conductors as well as gas conductors. The arc forms between the electrodes and ignites the stream of hydrogen. By changing the separation between electrodes the arc can be varied in size between ⅛ inch and over 1 inch. The current can be adjusted by means of a handwheel to any desired value, while the flow of hydrogen gas is controlled automatically by the regulator attached to the hydrogen tank. The arc can be stopped by increasing the gap between the welding electrodes until the arc breaks. The tungsten electrodes used in this process are available in several sizes so as to permit the welding of plate in various thicknesses. The electrodes used should be large enough to conduct the current required without being consumed or evaporated at an excessive rate.

e. Filler metal may or may not be required, depending upon the plate thickness being welded and the type of joint preparation. In welding alloy steels, about 40 to 50 percent of the carbon in the filler metal is lost during welding. This requires that the carbon content of the filler rod be approximately one-third higher than that of the base metal being welded. The other alloying elements in the filler rod are not lost during the welding operation and should be practically the same as that of the base metal.

f. Atomic-hydrogen arc welding is used for welding thin sheets and light sections made of chrome steel, nickel steel, molybdenum steel, and stainless steel. It is also used to weld thin sheet metals as well as to weld or build up sections in nonferrous metals such as aluminum, monel, copper, brass, and bronze. Some brasses and bronzes require a flux when welded by this process.

CHAPTER 8

ELECTRIC ARC WELDING: EQUIPMENT, PROCEDURE, AND TECHNIQUE (Cont'd)

Section II

SAFETY PRECAUTIONS

	Paragraph
General precautions	179
Precautions in operating welding equipment	180
Personal protection	181

179. GENERAL PRECAUTIONS.

a. *Wear safety goggles when* chipping, peening, removing slag, or grinding metal surfaces or welds. Never strike an arc without having the eyes protected with welding goggles or helmets.

b. Do not weld in wooden buildings with wooden floors unless the floors are protected from hot metal by means of asbestos paper or sand.

c. *Remove all inflammable material,* such as wood, waste, oil, and gasoline, *from the vicinity of welding.*

d. *Keep a fire extinguisher conveniently located at all times.*

e. Arc welding with gasoline-driven machines should be performed in well-ventilated places to avoid carbon-monoxide poisoning from the exhaust gases.

f. *Do not weld in places where dust or combustible particles are suspended in the air.* Either move the work to a safe place or make special provisions for proper ventilation, for shielding the work, and for fire protection.

g. *Never strike an arc or weld on sealed containers,* clutch or gear housings, or enclosed structures without checking the nature of their contents. Sealed containers should be vented and thoroughly cleaned. Care should be taken to remove all traces of fuel gases, grease, oil, or other lubricants before welding. These are a fire hazard and may cause an explosion when confined. Remove all assembled parts from structures to avoid warpage, damage to heat-treated parts, or melting of any low-melting-point alloys that may be present.

h. *Do not strike an arc on compressed-gas cylinders.* A serious explosion or fire may result.

i. All welding on brass, bronze, galvanized iron, painted surfaces, or alloys containing lead, zinc, or tin should be done in well-ventilated places. These elements are volatilized by the heat of the arc and may cause nausea or serious irritation to the nose, throat, or eyes of the operator. Relief from prolonged exposure to these fumes may be obtained by drinking milk.

j. Do not leave hot rejected electrode studs, steel scrap, or tools on the floor or in the booth. These interfere with good progress in welding and may cause accidents or fires.

180. PRECAUTIONS IN OPERATING WELDING EQUIPMENT.

a. Welding Machines.

(1) All checking of circuits on electric welding machines must be performed on dead circuits. The high-power feed voltage of the machine may cause severe injury or even death under certain circumstances. All serious welding trouble should be investigated by a trained electrician.

(2) Do not operate the polarity switch while the machine is working under the load of a welding current. Arcing at the switch causes severe burning of the contact surfaces of the switch and may also burn the person throwing the switch. The polarity switch should be operated while the machine is idling.

(3) Do not operate the rotary switch for current settings while the machine is operating under the load of a welding current. Severe burning of the switch contact surfaces will result. Operate the rotary switch while the machine is idling.

(4) A motor-generator type of arc welding machine should not be operated without a power ground on the machine. Stray current may cause a severe shock to the operator if he should contact the machine and a good ground.

b. Electric Circuits.

(1) Place the electrode holder, when not in use, on an insulated hook or on any insulating material. A dead short circuit between the electrode holder and the welding ground will result in overload and damage to fuses.

(2) Perform all welding operations within the rated capacity of the welding cables. Excessive heating due to overload will overheat the insulation and damage the cable leads.

(3) Inspect the cables at the joints periodically for looseness, defects due to wear, or other damage. Defective or loose cables are a fire hazard and operate inefficiently.

(4) Defective electrode holders should be replaced, and loose cable connections to the holder should be tightened, to avoid burning the operator and to permit control of the welding operations.

(5) Welding generators should be so located that dust, water, or other foreign matter cannot enter the electrical windings or bearings.

181. PERSONAL PROTECTION.

a. Helmet and Shield.

(1) A helmet or hand shield should be used to protect the operator's eyes, face, and neck from the direct rays of the arc. Do not weld with cracked or defective helmets or shields, as stray radiations from the arc may cause serious burns.

(2) Be sure that the colored glass plates are not cracked and are of the proper shade for arc welding. Always use a protecting cover glass over the colored glass plates to avoid damage from the spatter. These cover glasses should be replaced when excessively damaged or spotted by molten spatter.

(3) *Never look at an electric arc with the naked eye.* Not only is the intense visible light too strong, but the invisible radiations, ultraviolet and infrared, will cause very painful burns, and also serious eye trouble.

b. Gloves.

(1) Leather gauntlet gloves and sleeves should be worn to protect the hands and arms from the heat of welding, molten or hot metal spatter, and injurious rays of the arc. The leather should be of good quality, and the gloves should be heavy enough not to burn through easily.

(2) Do not allow oil or grease to come in contact with or soil the leather gloves, as they can easily be ignited or charred by molten metal or hot spatter.

c. Clothing.

(1) It is recommended that woolen clothing be worn instead of cotton, as the former is less easily burned or damaged by weld metal spatter.

(2) Aprons or jackets made of asbestos cloth or leather should be worn to prevent fires in clothing or flesh burns during welding with large electrodes or in vertical or overhead positions.

(3) The operator's trousers should be without cuffs and should be long enough to prevent hot globules of metal from falling into his shoes.

d. Screens.

(1) When welding is done near other people, screens should be used to protect their eyes from the arc. Portable screens should be placed to keep drafts of air from interfering with the stability of the arc.

(2) Arc welding operations give off an intense light; snap-on lightproof screens should therefore be used to cover the windows of the welding truck to avoid detection when welding at night.

CHAPTER 8

ELECTRIC ARC WELDING: EQUIPMENT, PROCEDURE, AND TECHNIQUE (Cont'd)

Section III

ELECTRIC ARC WELDING APPARATUS

Paragraph
General 182
Types of machines 183
Other equipment 184
Accessories 185

182. GENERAL.

a. The following welding equipment is necessary: an electric arc welding machine driven either by an electric motor or a gasoline engine, two cables, an electrode holder, metal and carbon electrodes, a face shield or helmet, protective gloves, and other protective clothing.

183. TYPES OF MACHINES.

a. Arc welding machines may be classed by their use of direct or alternating current. The common types of each class are discussed in the following paragraphs, along with general information on their proper maintenance.

(1) DIRECT-CURRENT MACHINES. A direct-current welder consists of a heavy-duty direct-current generator driven by a suitable type of motive power. The voltage of such a generator will usually range from 15 to 45 volts across the arc, although any setting is subjected to constant variation due to changes in the arc conditions. Current output will vary from 20 to 800 amperes, depending on the type of unit, as a fairly wide range is necessary to accommodate the various classes of work. In most direct-current welders, the generator is of a variable-voltage type and is so arranged that the voltage automatically adjusts itself to the demands of the arc; however, this voltage may be manually set to the correct range by means of a rheostat mounted on the control panel. Amperage of the welding current is also manually adjustable and is usually set to the proper range by means of a selector switch or series of plug receptacles. In either case, the desired amperage is obtained by tapping into the field coils of the generator at different points to increase or decrease its strength. When both voltage and amperage of the welder are adjustable by means of the controls described above, the machine is referred to as a dual-control type. The arc welding machine located on

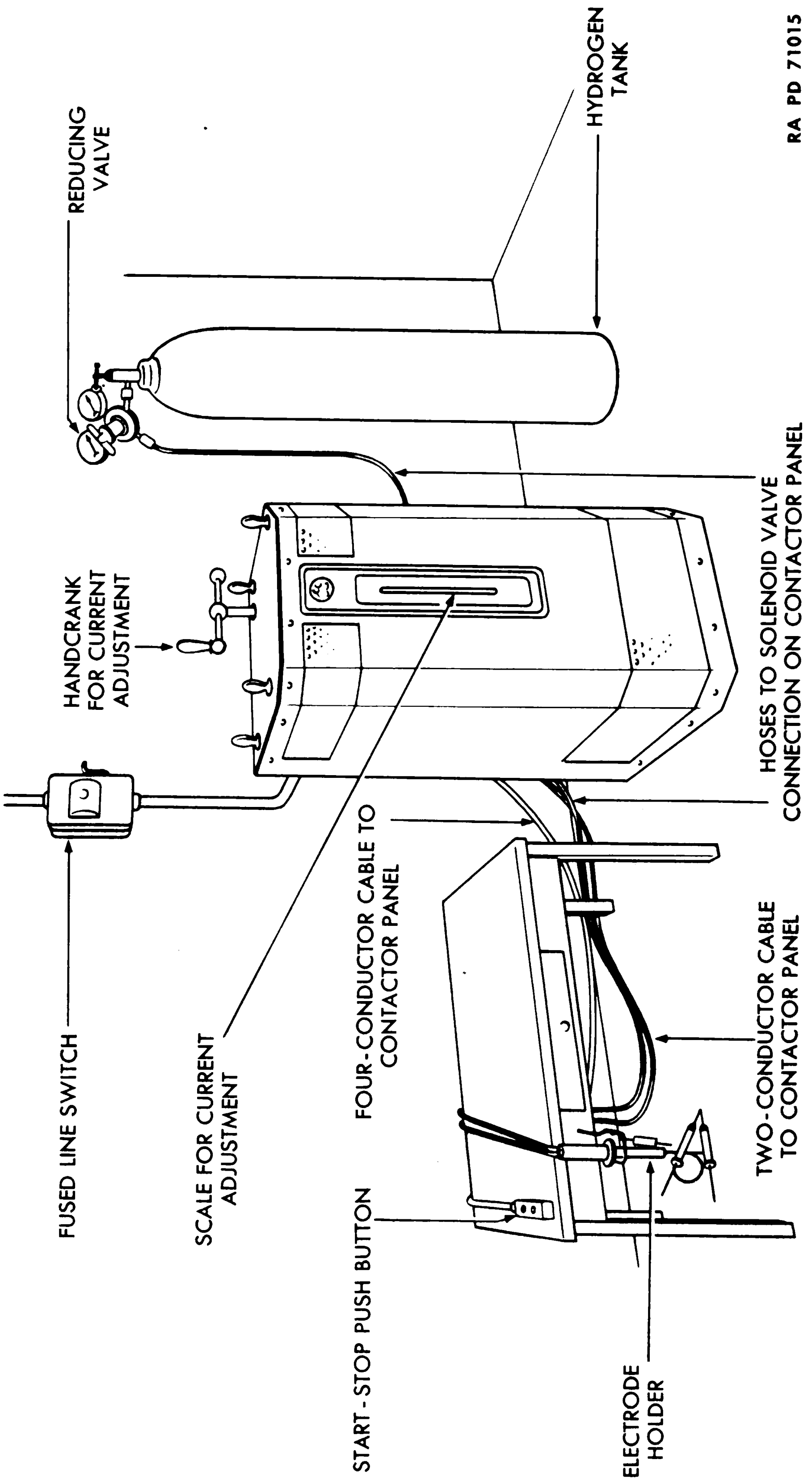

Figure 59a — Equipment for Manual Welding

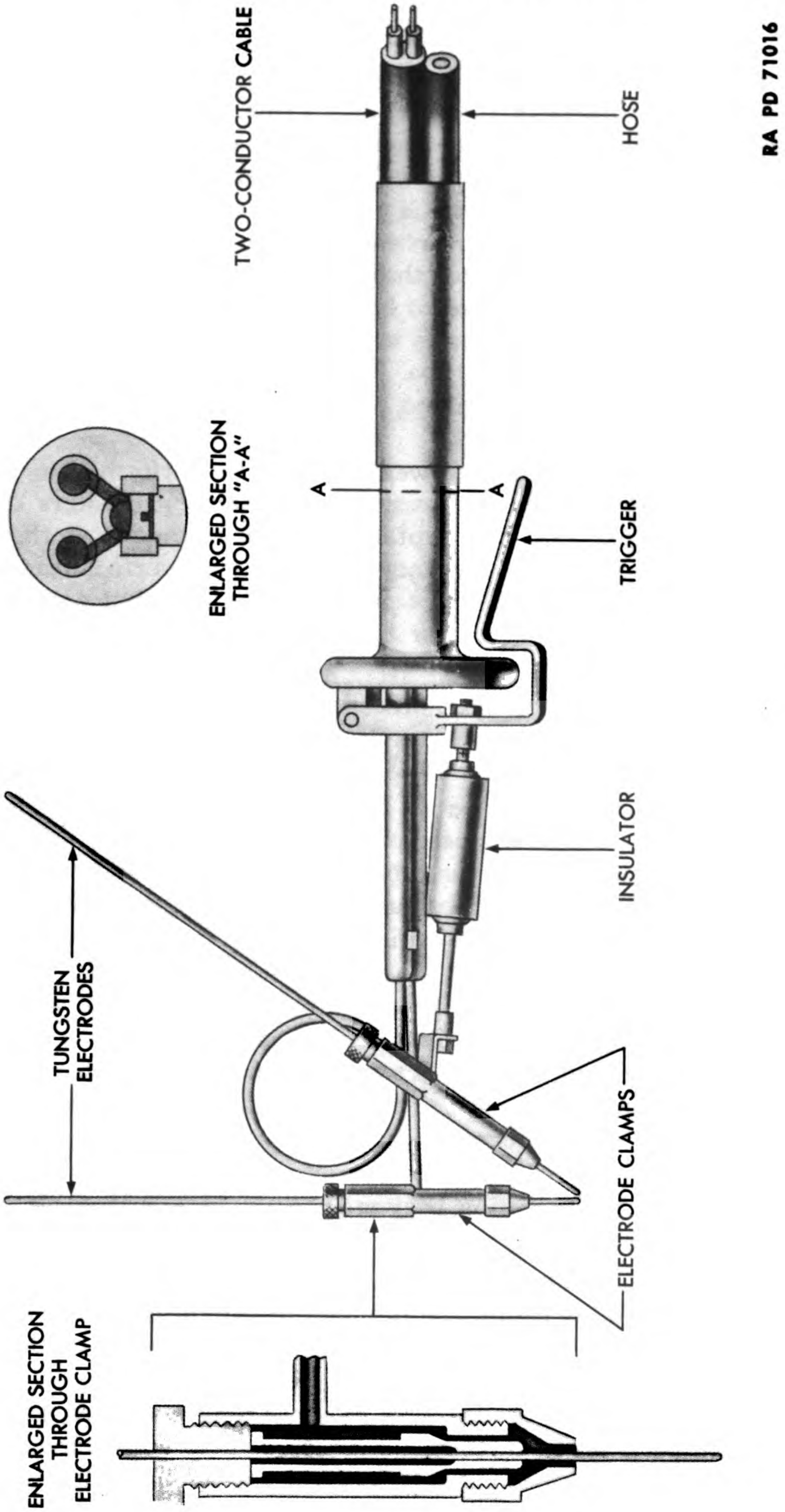

Figure 59b — Electrode Holder

the Ordnance Department welding truck is a dual-control type of machine. Another system employed to a certain extent in the manufacture of welding machines makes use of adjustable generator brushes for the control of the current. In this case, only one control is provided, and both the amperage and voltage are varied proportionately by the movement of the brush assembly.

(a) When a power supply is available, welding generators are generally driven by means of an electric motor. The motor may be arranged to drive the generator through a flexible coupling, although many units have the armatures of both the generator and motor on a common shaft. Figure 60 shows a typical motor-generator welding machine of the dual-control type. In this figure, the ground plate is attached to the work to be welded, and the metal or carbon electrode clamped in the electrode holder.

(b) In many instances, arc welding must be performed in places where a power supply is not available. Portable generators driven by gasoline are particularly adaptable in such instances, as they are available in compact units that may easily be transported from place to place. The engine used for this purpose must be fitted with a suitable governor to compensate for the varying loads imposed by the welder.

(2) ALTERNATING-CURRENT MACHINES. Alternating-current welding machines may be divided into two general classes, the transformer type and the motor-generator type.

(a) The transformer type of alternating-current welder derives its welding current from a closed-core transformer. The primary coil of this transformer is hooked directly to the power line, and the secondary coil is tapped at intervals for varying the welding-current strength. A machine of this type is shown in figure 61, and the secondary taps may be seen on its front panel.

(b) The motor-generator type of alternating-current welder is shown in figure 62a. The welding current is supplied by a high-frequency generator equipped with a two-position switch which allows the output to be changed from a high to a low value. An auxiliary control is also provided for fine current adjustment.

(c) Alternating-current welders require the use of heavily coated electrodes; with this exception, they are practically as adaptable as the direct-current machines.

(3) MAINTENANCE. Due to the amount of dust and grit that is present in all welding shops, the problem of proper maintenance is a very important one. The following instructions will apply to most arc welding machines:

(a) Forced draft is used to cool most welding machines, and, due to this fact, particles of dirt are carried through the machine. Under average conditions, the unit should be given a cleaning with clean, dry

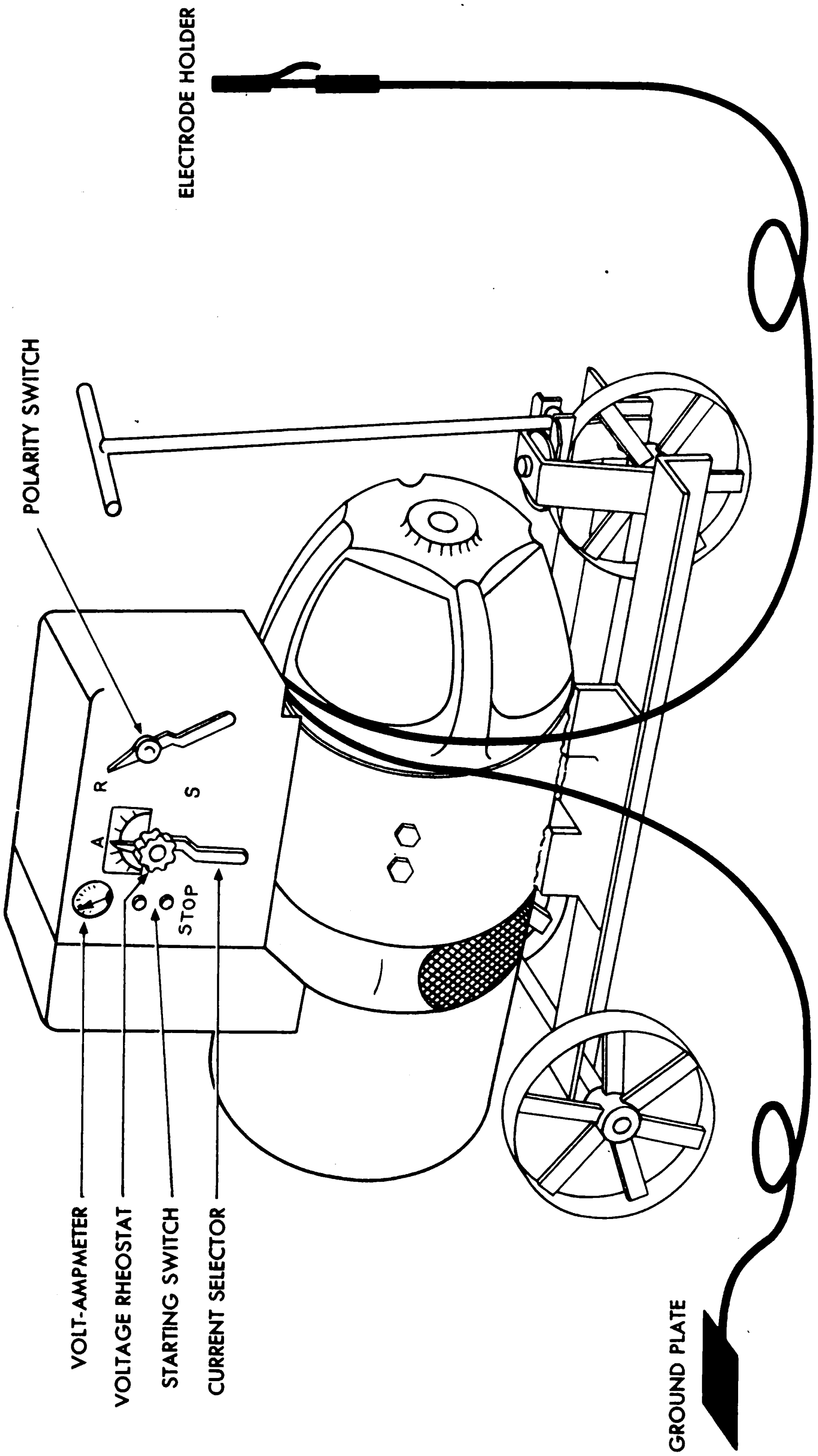

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Figure 60 — Direct-current, Motor Generator Arc Welding Machine

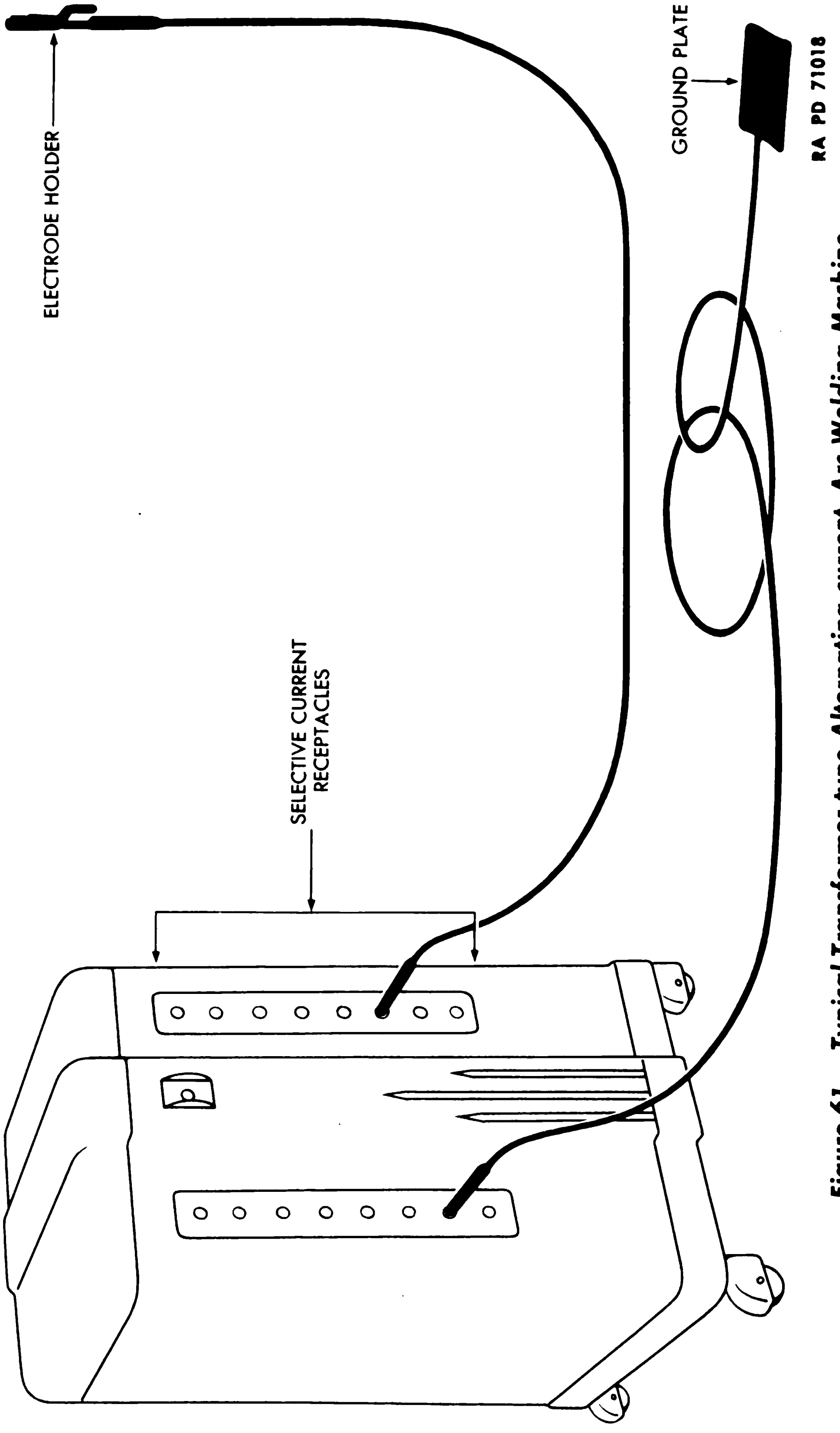

Figure 61 — Typical Transformer-type Alternating-current Arc-Welding Machine

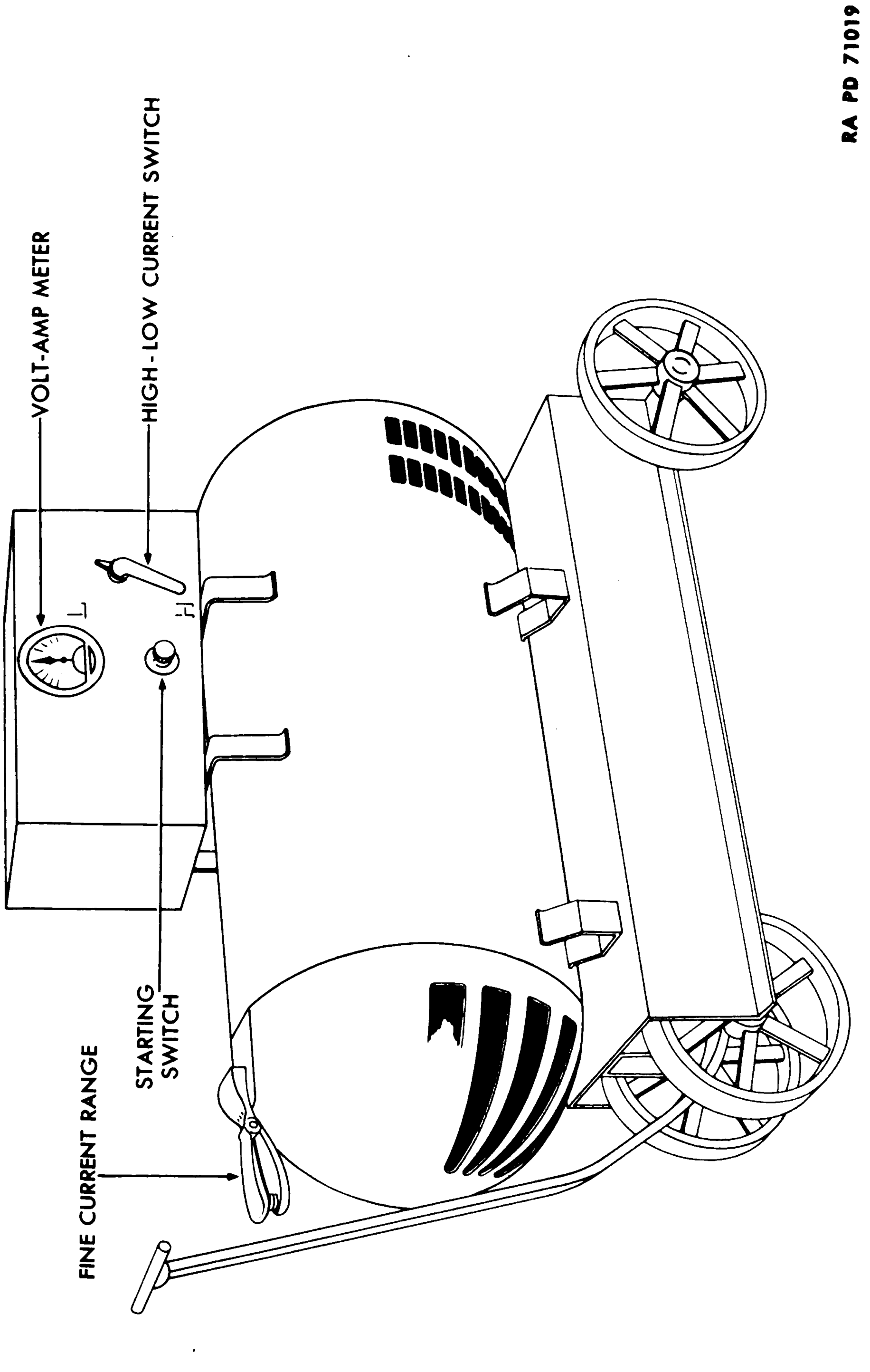

Figure 62a — Alternating-current, Motor Generator Arc-Welding Machine compressed air at least once each month. This may readily be done by removing the dust covers and shields. Should the machine appear greasy at the time of cleaning, it should be dismantled and thoroughly washed with a mixture of CARBON TETRACHLORIDE and SOLVENT, dry-cleaning. During the regular monthly cleaning, an inspection should be made of the condition of the switch points, brushes, commutator, and bearings.

(b) The machine should be given a thorough greasing at 4- to 6-month intervals. This may follow the cleaning operation and should include all bearings in the unit. Too much grease is almost as harmful as not enough, since a surplus will be thrown onto the commutator, resulting in serious troubles. To grease properly a bearing of the type used in welding machines, the drain plug should be removed on the lower side of the bearing boss and the machine started. Grease may then be injected into the fitting until it begins to emerge from the drain plug hole. After allowing the machine to run for several minutes to force out any pressure on the grease, it may be shut off and the plug replaced. Only an approved grease should be used for this purpose.

(c) The brushes and commutators of both the motor and generator are subject to considerable wear. Brushes that have worn enough to reduce their spring tension appreciably must be replaced to maintain proper efficiency of the machine. Although new brushes are formed to

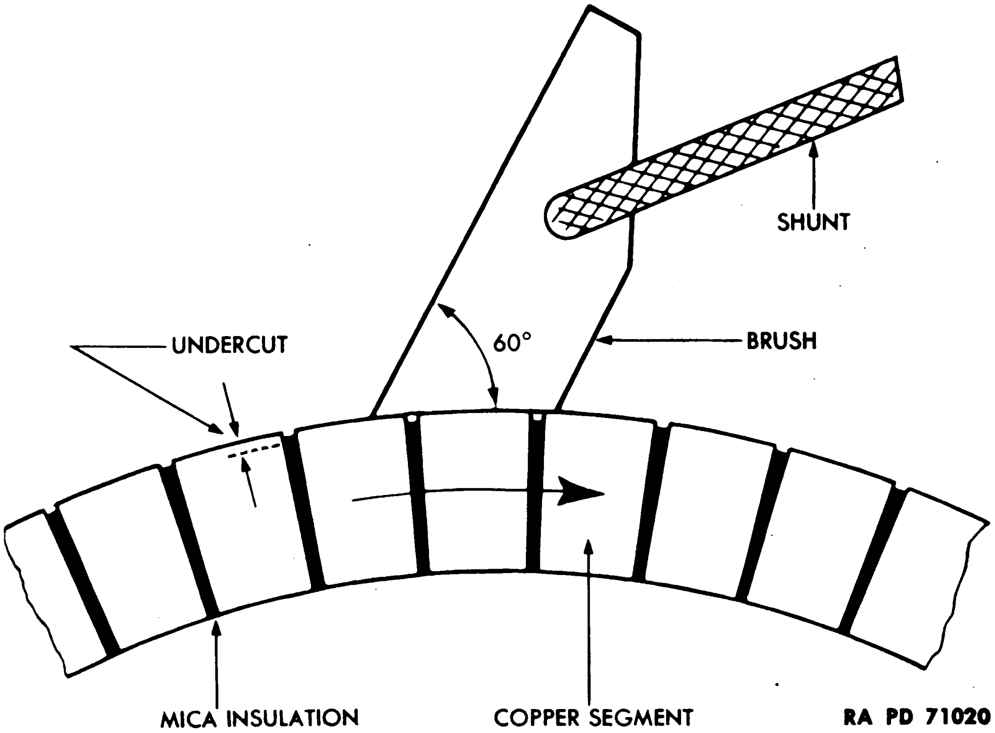

Figure 62b — Shaping New Brushes on Commutator

fit the commutator, they must often be sanded in to give the proper amount of contact. This may be done by wrapping a strip of PAPER, flint, Class B, No. 00, around the commutator with the rough side out and turning the armature by hand until the brushes have been worked down to a perfect fit. Brush springs that have become weakened from overheating should also be replaced to assure positive brush contact. Each time brushes are replaced, the commutator should be checked for cleanliness and wear. If a deposit of graphite from the brushes is found, it may be removed by holding a piece of PAPER, flint, class B, No. 00, against the commutator while the armature is in motion. Ridges or pockets on the surface of the commutator will require the removal of the armature so that it may be trued up on a lathe. The commutator should then be polished with flintpaper by wrapping the paper around the commutator and holding the ends while the armature is turning. Start with No. 00 and work to No. 00000000 paper or until the armature reaches a brown bronze color. Do not use emery paper or CLOTH, abrasive, aluminum oxide, for this purpose. Only a light cut should be taken, and the mica separators between the bars of the commutator must be undercut from 1/64 inch to 1/32 inch after the truing operation. Although a special cutter should be used for this purpose, a hacksaw blade will serve in an emergency. All electrical switch contacts should be sanded clean if pitted. Parts that have been badly burned should be replaced. At least once each year, the windings of generator and motor should be inspected and, if found dry or cracked, given a coat of shellac.

184. OTHER EQUIPMENT.

a. Cables. The welding cables used should have sufficient current-carrying capacity and should be insulated with a heavy rubber cover as shown in figure 63. One end of one cable is attached to the work table, the other end to the ground lug on the welding machine. The

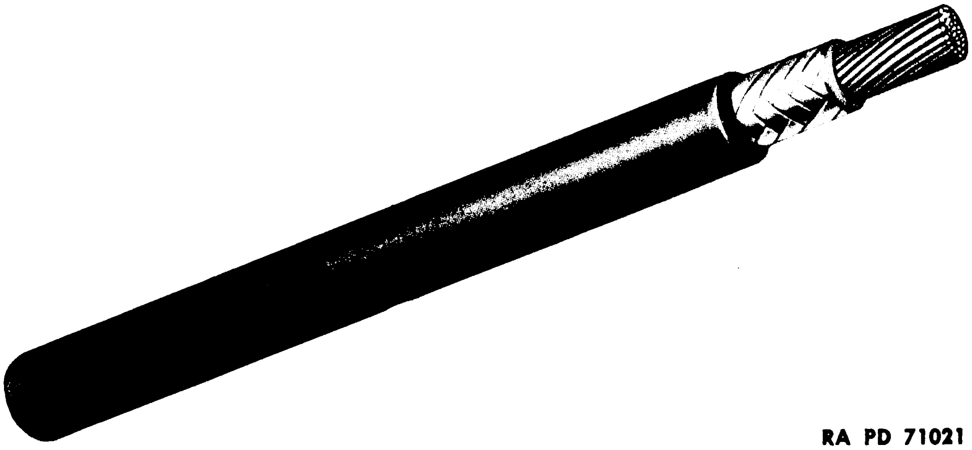

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Figure 63 — Welding Cable

other cable is attached to the electrode holder and is more flexible than the cable attached to the work, being composed of more and finer copper strands. This cable is also attached to the machine on a separate lug. For straight polarity, the electrode holder with electrode is connected to the negative terminal of a direct-current welding machine, while the cable attached to the work is connected to the positive terminal of the machine. In welding with reversed polarity, these cables are interchanged at the machine to make the electrode holder the positive terminal and the work the negative terminal. On some machines a polarity switch can be thrown to make this change without actually interchanging the welding cables at the terminals of the machine.

b. **Electrode Holder.** An electrode holder is an insulated clamping device for holding the electrode for welding. By means of a lever held in place by a spring, the electrode jaws can be opened to receive the bare end of an electrode and held at any angle desired for welding. The insulation on the electrode holder is necessary in order to protect the welder, since the welding current is carried from the electrode lead through the electrode holder to the electrode. The electrode holder jaws should give a good electrical contact as well as enable the welder to change electrodes when necessary. Figure 64 shows three types of electrode holders used in arc welding. The holder should be light in weight and balanced so as to make welding easy without tiring the welder's hand. The holder should have sufficient current-carrying capacity for the size of welding machine and cable used, so as not to overheat during welding. When not in use, the electrode holder should be placed on an insulated hook away from the work to avoid shorting or accidentally grounding the holder.

c. **Electrodes.** Metal electrodes used for arc welding are available in sizes ranging from $\frac{1}{16}$ inch to larger than $\frac{3}{8}$ inch in diameter, in lengths of 8, 11½, 14, 18, and 24 inches. They are available in bare, light or wash-coated, and heavy-coated or shielded-arc types. Bare and light or wash-coated electrodes are not used very extensively, and the most important metal arc welds are made with heavy-coated electrodes because of the greater strength and ductility of the weld metal as compared with that obtained with bare electrodes. A more detailed discussion of electrodes is given in chapter 8, section IV. Carbon electrodes for hand welding and cutting are available in diameters ranging from $\frac{5}{32}$ inch to 1 inch, all being 12 inches in length. They are made of pure graphite or baked carbon and are used for carbon arc welding with bare or flux-coated filler rods.

d. **Helmets, Hand or Face Shields.** In order to protect the eyes and face of a welder from the dangerous ultraviolet and infrared rays of the arc, the welder should wear a helmet and a hand or face shield. The ultraviolet rays can burn the skin with the same effect as severe

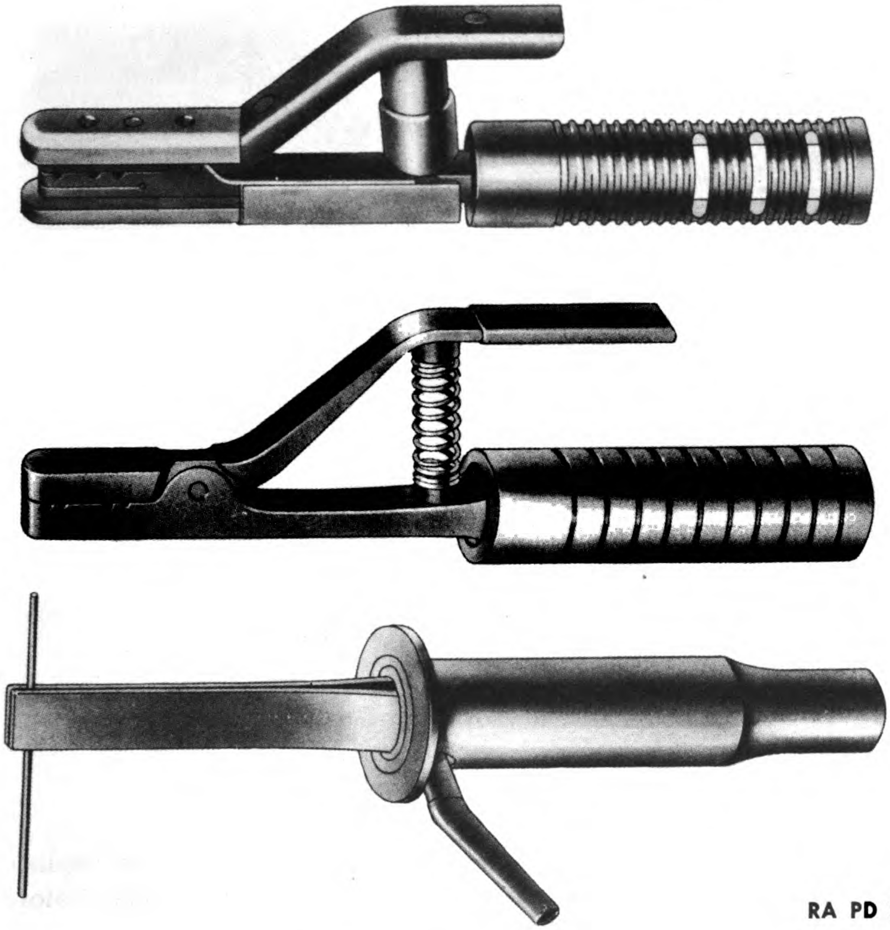

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Figure 64 — Electrode Holders

sunburn, while the infrared rays can cause temporary painful injury to the eyes. A, figure 65, shows a helmet which can be worn on the head of the welder and raised out of the way on a hinged strap when not in use. B, figure 65, shows a hand or face shield which is held in one hand and placed in front of the face by the welder while welding with the other hand. These helmets and shields should be well fitted to the face and should be leakproof against the rays given off by the arc. They are made of vulcanized or pressed fibre insulating material and are flat black in color so as to minimize reflection. These helmets and hand shields are provided with windows measuring 2 x 4⅛ inches or 2 x 4½ inches, into which clear and colored glass plates are fitted tightly. The clear glass is known as a cover glass and is placed on the outside to protect the more expensive colored glass from the spatter of the electrode, which otherwise would cause pitting. The colored glass is designed to absorb most of the harmful effects of the infrared and ultraviolet rays given off by the arc, as

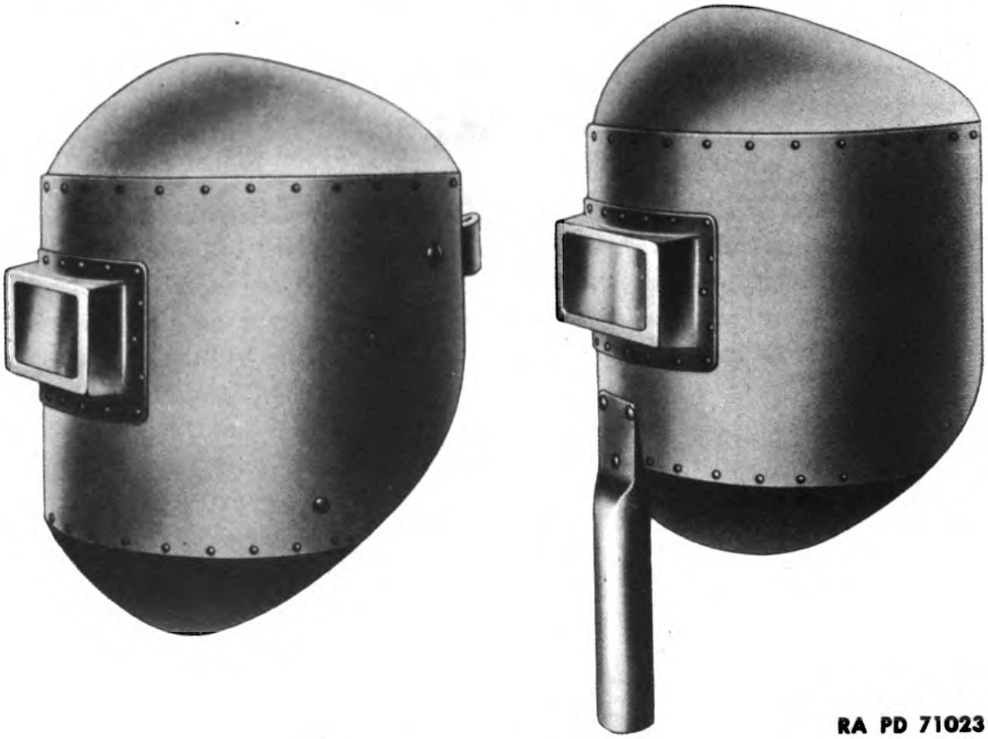

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Figure 65 — Helmets

well as some of the visible rays. The cover glass should be replaced from time to time, as it becomes badly pitted in use. The colored glass allows sufficient light to pass to enable the welder to observe the arc clearly.

e. **Protective Gloves.** Protective gloves should be worn by the

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Figure 66 — Gloves

RA PD 71025

Figure 67 — Apron

welder to keep his hands protected from the rays of the arc, molten metal spatter, sparks, and hot metal. These gloves should be made of flexible leather and should be of the gauntlet type. The leather should be heavy enough so that it will not shrivel up, burn through, or wear out quickly. These gloves also provide protection when handling the work (fig. 66).

f. Protective Clothing. In order to provide protection against spatter of molten metal, the welder should wear a leather apron and leather capes or sleeves. This is especially important in welding in the vertical and overhead positions. Figure 67 shows a leather apron suitable for electric arc welding. The welder should wear high-cuff shoes and should turn the cuffs of his pants down at the bottom to prevent molten metal from being caught in them.

185. ACCESSORIES.

a. Chipping Hammer and Wire Brush. In order to remove scale, slag, and oxides, a chipping hammer is required to loosen the slag

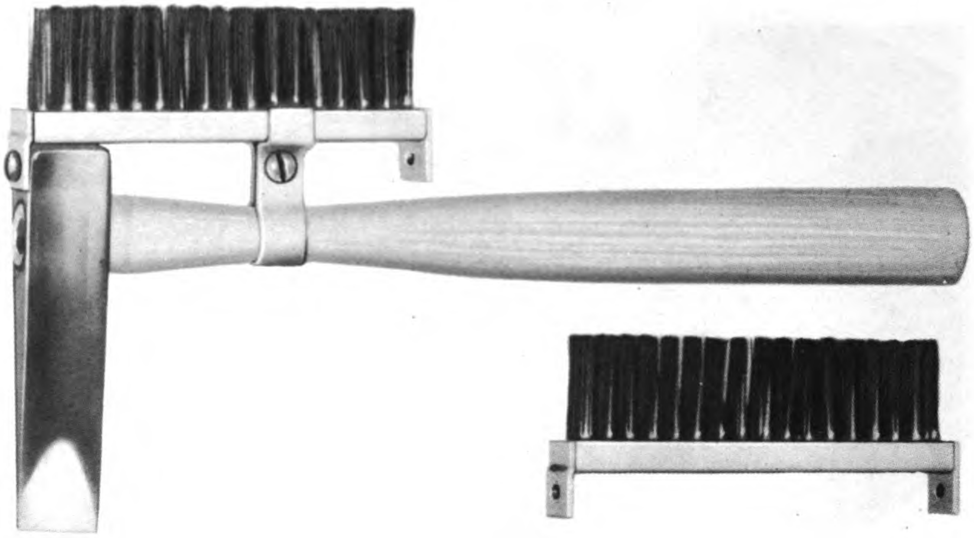

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Figure 68 — Chipping Hammer and Wire Brush

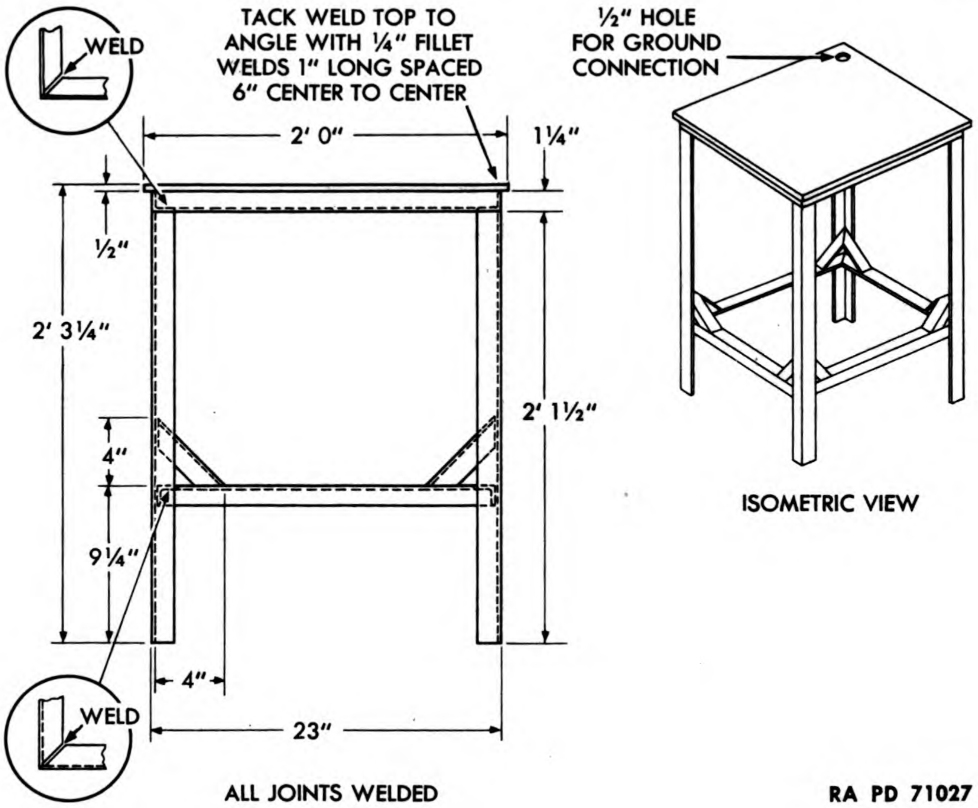

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Figure 69 — Welding Table

and a wire brush to clean each weld bead before further welding. Figure 68 shows a chipping hammer with replaceable wire brushes used for this purpose.

b. **Welding Table.** A welding table should be of all-steel construction. Legs should be made of pipe or angle iron, and the table top should be made of a steel plate. A container for electrodes and an insulated hook to hold the electrode holder when not in use should be provided. A suitable design for a welding table is shown in figure 69.

c. **Clamps and Back-up Bars.** Work for welding should be clamped in position by means of C-clamps or other clamp brackets. Blocks, strips, or bars of copper or cast iron should be available for use as back-up bars in welding light sheet aluminum and in making certain types of joints. Carbon blocks, asbestos, and fire clay should also be available for use in making molds to hold molten metal within given limits when building up sections. A mixture of water glass and fire clay or carbon powder are suitable for making molds when it is desired to make intricate shapes or patterns.

CHAPTER 8

ELECTRIC ARC WELDING: EQUIPMENT, PROCEDURE, AND TECHNIQUE (Cont'd)

Section IV

ELECTRODES AND THEIR USE

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Thinly coated electrodes 189
Shielded-arc or heavy-coated electrodes 190
Polarity of welding current for different electrodes 191
Electrodes for direct-current arc welding 192
Electrodes for alternating-current arc welding 193
Effects of defects in electrodes and base metal 194

186. GENERAL.

a. In order to protect the weld metal from oxygen and nitrogen effects of the air during the time that it is liquid and solidifying, some form of protection must be had in the arc stream. When molten metal is not protected from the atmosphere, it will absorb nitrogen, will be partly oxidized, and will therefore become brittle. To prevent this condition from occurring, the electrodes are designed with a wire core and a suitable coating. The coatings on metal arc welding electrodes are generally more than mere fluxing agents, such as the fluxes employed in certain oxyacetylene welding applications. These fluxes, when used with oxyacetylene welding process, dissolve or reduce the oxide impurities so that the metals can unite more readily to form the weld; they may also contain materials which make the weld metal or filler metal more fluid.

187. TYPES OF ELECTRODE AND ELECTRODE COATING.

a. The various types of metal arc electrodes may be grouped and classified as bare electrodes, thinly coated or light-coated electrodes and shielded-arc or heavy-coated electrodes.

188. BARE ELECTRODES.

a. Bare electrodes are made of wire containing a definite composition, the surface of which has not been treated by the addition of

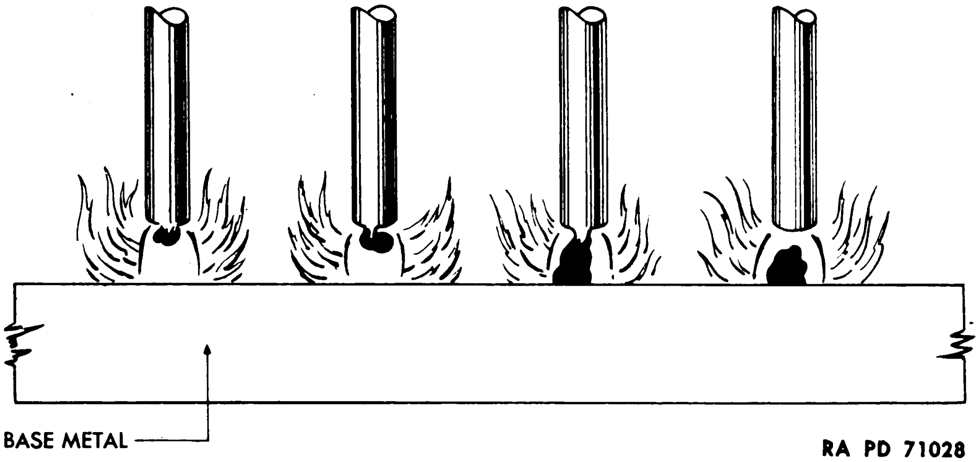

Figure 70 — Molten Metal Transfer with Bare Electrode

special coatings other than those materials retained from wire-drawing operations. These coatings are required in wire-drawing, and their slight stabilizing action on the arc is only incidental. Finished annealed wire is also classified under this type. A diagrammatic sketch of the transfer of metal across the arc with a bare electrode is illustrated in figure 70.

189. THINLY COATED ELECTRODES.

a. Thinly coated or light-coated electrodes are made of wire of a definite composition, the surface of which has a thin coating applied by either a washing, dipping, brushing, tumbling, spraying, or drawing process to improve the stability and characteristics of the arc stream. These coatings are chiefly iron oxides and titanium dioxide.

b. Coatings on the light-coated electrodes will in general serve the following functions:

(1) They dissolve or reduce impurities such as oxides, sulphur, and phosphorus, and thus keep them out of the weld deposit.

(2) They reduce the adhesive force between the molten metal and the end of the electrode, or change the surface tension of the molten metal so that globules of molten metal leaving the end of the electrode are smaller and more frequent, making the flow of molten metal more uniform and continuous.

(3) They increase the arc stability by introducing materials readily ionized (changed to small particles with an electric charge) into the arc stream.

NOTE: Some of these coatings may produce a slag, but it is quite thin and does not act in the same manner as the shielded-arc slag-type electrode. The action in an arc obtained with light-coated electrodes is shown in figure 71.

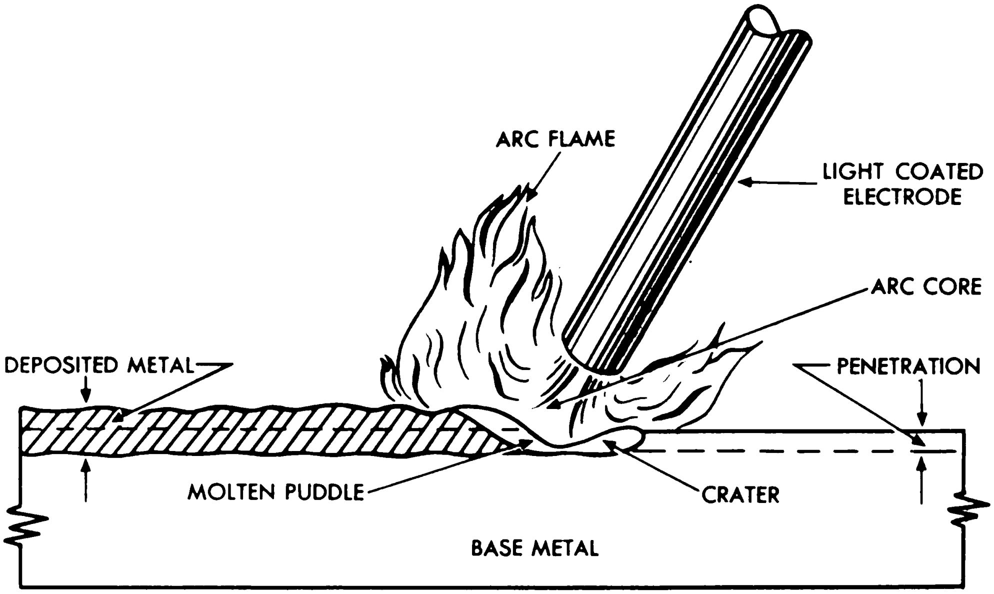

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Figure 71 — Action of Light-coated Electrode

190. SHIELDED-ARC OR HEAVY-COATED ELECTRODES.

a. Shielded-arc or heavy-coated electrodes are made of wire of definite composition, the coating of which is of appreciable thickness. These coatings have been designed to improve the physical properties of the weld deposit. They also control arc stability and, as a result, increase the speed of welding and the ease of welding in the vertical and overhead positions. These electrodes are manufactured by the extrusion, wrapping, or heavy dipping processes, or combinations of these methods, or other means.

b. Shielded-arc or heavy-coated electrodes are easily identified by their heavy extruded coating. This coating performs various functions other than that, previously outlined, of shielding the arc and molten metal. Without this protection, which is quite thorough in the shielded-arc electrode, oxygen would readily combine with the molten metal of the weld deposit, thus removing many of the desirable alloying elements, causing porosity, and oxidizing or burning the weld. Nitrides would also be found in the weld deposit, caused by reactions between nitrogen of the atmosphere and the various electrode alloying elements in the molten state. These nitrides would be in solution with the weld deposit or partly precipitated, that is, separated out in the form of hard particles; oxides and nitrides in the weld deposit cause brittleness, which results in low ductility and, in some cases, low strength and poor resistance to corrosion. The heavy extruded coatings on shielded-arc or heavy-coated electrodes protect the weld deposit by both chemical and mechanical action.

c. Types of Shielded-arc Electrodes. The especially designed coatings of the heavy-coated or shielded-arc electrodes are manufactured in two general types, namely, cellulose coatings and mineral coatings. Combinations of both types are also used. The cellulose-coated shielded types are derived from wood pulp, sawdust, cotton, or, more recently, from the various compositions secured from the manufacture of rayon. The mineral-coated shielded types are manufactured from metallic oxides, which are often used in the form of natural silicates, such as asbestos and clay, or in specially manufactured forms of silicates. Other materials used for electrode coatings are, burnt sugar, gums, starches, and certain low-melting-point spars. To simplify these two types of shielded or heavy-coated electrodes further, it should be pointed out that the first type, cellulose, depends upon a gaseous shielding or covering for protection around the arc stream as well as upon a slag covering over the weld deposit. The second type, mineral, depends entirely on the slag as a shield. The slag is principally composed of silicon dioxide and aluminum oxide and acts to reduce the cooling rate of the molten metal. The action in an arc obtained with the shielded-arc or heavy-coated electrode is illustrated in figure 72.

d. Functions of Coatings on Shielded-arc Electrodes. Some of the outstanding functions of the shielding of the arc stream and weld deposit by shielded-arc electrodes may be summarized as follows:

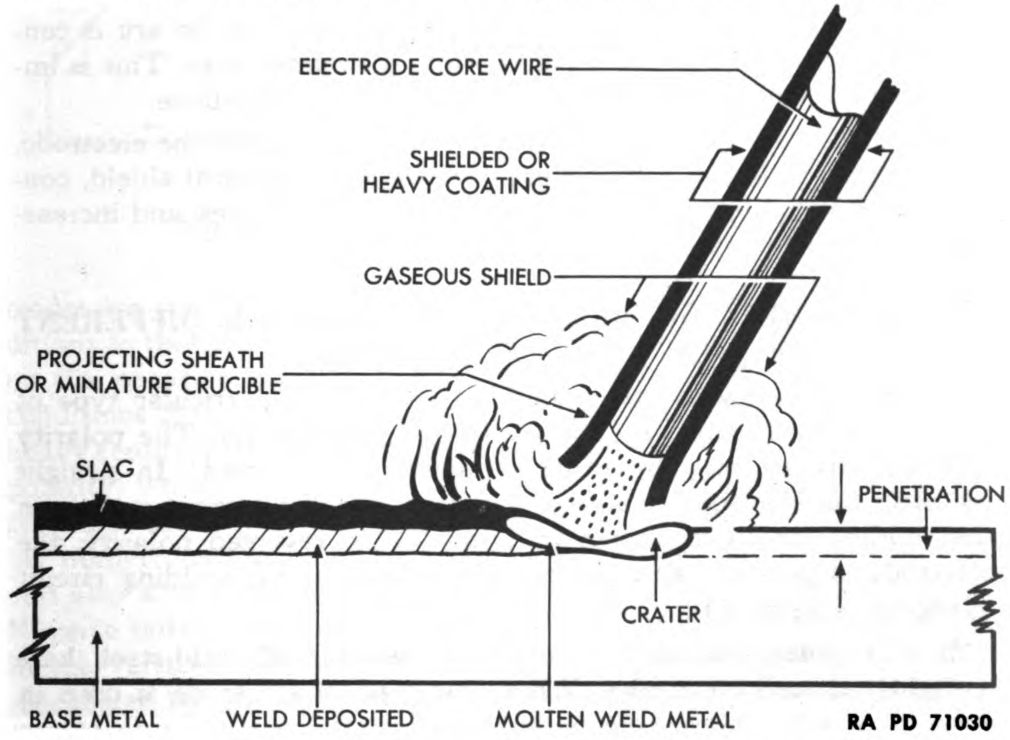

Figure 72 — Arc Characteristics of Heavy-coated Electrode

(1) To produce a reducing or nonoxidizing atmosphere around the arc, so as to avoid contamination of the metal in the arc by oxygen and nitrogen from the air and to preserve the alloying elements which have an important effect on the physical properties of the weld deposit.

(2) To reduce impurities, such as oxides, sulphur, and phosphorus, continuously, so that these impurities will be kept out of the weld deposit. To furnish materials to the arc which will increase the arc stability, and to steady the voltage so that the arc will flow smoothly without spattering or wandering.

(3) To break up the globules of metal leaving the end of the electrode into fine, small particles by reducing the attractive force between the molten metal and the end of the electrode or by changing the surface tension of the molten metal.

(4) To provide those ingredients (oxides and silicates) which, when melted, will form a slag over the molten metal. This slag, being quite slow to solidify, holds the heat and allows the metal to solidify and cool slowly. This slow solidification allows dissolved gases to escape and permits solid impurities to float to the surface. The slow cooling also has an annealing effect on the weld deposit.

(5) To change the physical characteristics of the weld deposit by introducing materials through the coating which will alloy with the weld metal deposited. The fluxing action of the slag, also, will produce better qualities of weld metal and permit welding at higher speeds.

(6) To insulate the sides of the electrode so that the arc is concentrated at the end of the electrode into a confined area. This is important and will facilitate welding in a deep U- or V-groove.

(7) To produce a cup, cone, or sheath at the tip of the electrode, which acts much like a crucible, providing a mechanical shield, concentrating and directing the arc, reducing the heat losses, and increasing the temperature at the end of the electrode.

191. POLARITY OF WELDING CURRENT FOR DIFFERENT ELECTRODES.

a. The polarity recommended for use with a particular type of electrode is established by the electrode manufacturer. The polarity of a welding arc may be either "straight" or "reversed." In straight polarity, the electrode is always negative, and the current travels in the welding circuit as shown in figure 73. In reversed polarity, the electrode is positive, and the current travels in the welding circuit as shown in figure 74.

b. In general, straight polarity is used for all mild-steel, bare or lightly coated electrodes. When this type of electrode is used in straight polarity, more heat is developed at the positive side of the current, which is at the work being welded, however, when coated elec-

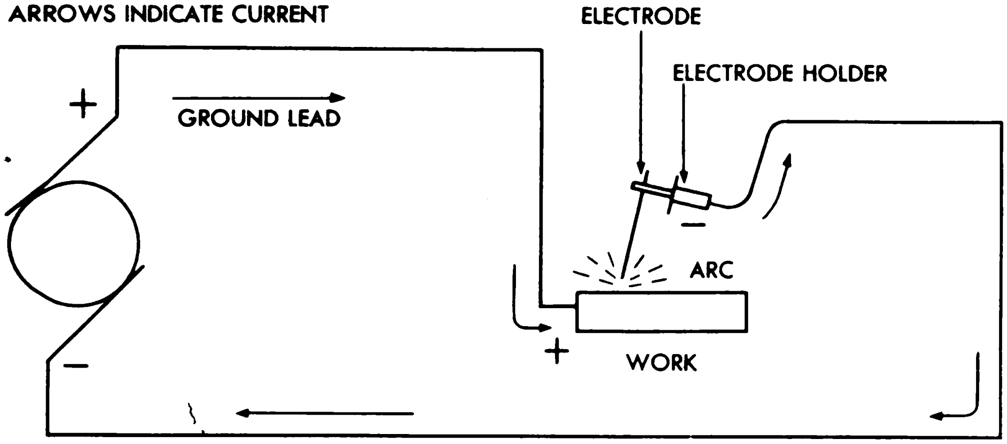

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Figure 73 — Straight Polarity in Arc Welding

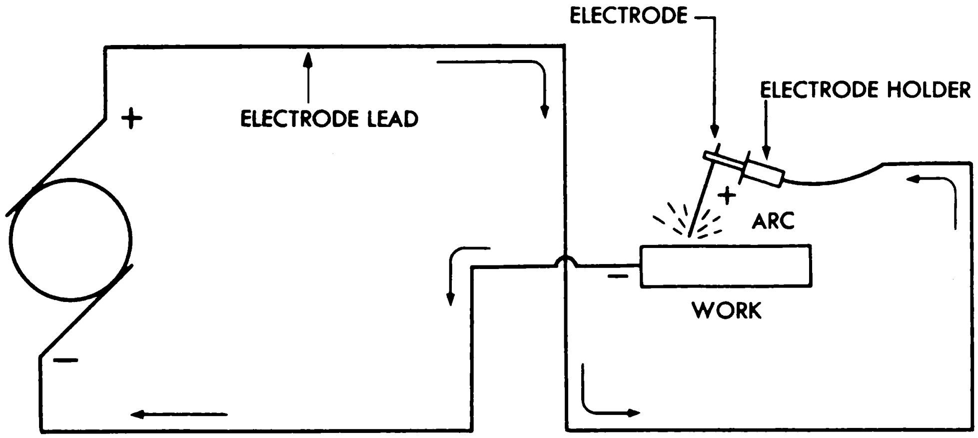

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Figure 74 — Reversed Polarity in Arc Welding

trodes are used, the gases given off in the arc may alter the heat conditions so that the opposite is true, that is, the greater heat is produced on the negative side. In general, electrode coatings affect the heat conditions differently, depending upon their composition. One type of heavy coating may obtain the most desirable heat balance with straight polarity, while another type of coating on the same electrode may provide a more desirable heat balance with reversed polarity. In welding nonferrous metals such as aluminum, bronze, monel, and nickel, and also with some heavy-coated electrodes, reverse polarity is used. Reverse polarity is also used with some electrodes for making welds in the vertical and overhead positions. The proper polarity can be recognized by the sharp cracking sound of the arc. Improper polarity for a given electrode will cause the arc to give off a hissing sound and will make it difficult to control the welding bead.

192. ELECTRODES FOR DIRECT-CURRENT ARC WELDING.

a. The welding procedures and techniques for the different types of shielded-arc electrodes differ to some extent according to the various manufacturers' recommendations. In general, these recommendations should be followed when a specific type and manufacture of shielded-arc electrode is being used. Also, certain shielded-arc electrodes are designed specifically for reversed polarity (electrode positive) in direct-current welding generators, while other types are developed for straight polarity (electrode negative). Therefore, not all shielded-arc electrodes are satisfactory for straight polarity, nor are all of them suitable for alternating current.

b. It is generally true that with direct-current welding, straight polarity electrodes (electrode negative) will, in most cases, give less penetration than the reversed polarity shielded-arc types. Because of this fact, higher welding speeds may be maintained. The shielded-arc type of electrode is more suitable on light-gage or thin material or on types of joints where poor fit-up is encountered. On massive parts or narrow grooves where a harsh arc or deep penetration is desired, a commercial type of reversed polarity should be used. Good penetration can be obtained with either type of electrode with proper welding conditions and arc manipulation.

193. ELECTRODES FOR ALTERNATING-CURRENT ARC WELDING.

a. Alternating current is used in atomic-hydrogen welding and in those carbon arc welding processes which require the use of two carbon electrodes, in order that a uniform rate of welding and electrode consumption may be accomplished. In carbon arc processes where one carbon electrode is used, straight polarity with direct current (electrode negative) is recommended, because the electrode is thus consumed at a lower rate than if alternating current were used or if it were made the electrode positive. Alternating current reduces the amount of magnetic or arc blow, which causes an unstable arc. Arc blow is particularly harmful in welding in corners or restricted places and when high currents, as required in thick sections, are used. This causes the weld to have blowholes and slag inclusions. Direct current is preferred for many types of bare and covered nonferrous and alloy steel electrodes and is used when satisfactory ferrous welds are to be made in the horizontal, vertical, and overhead positions. Covered electrodes are available which may be used for either alternating or direct current or for both.

194. EFFECTS OF DEFECTS IN ELECTRODES AND BASE METAL.

a. Some of the impurities in weld metal can be traced to the filler-metal wire, the electrode, coating or covering, improper shielding, dirty base metal or joint surface, as well as to the properties of the base metal.

b. Electrodes.

(1) Certain elements or their oxides, if present in electrode coatings, will materially affect the stability of the arc. In bare electrodes, the composition of the wire is an important factor in determining arc stability and plays an important part in the physical properties of the weld metal. The presence of impurities will cause the metal arc to become unstable, and, if these impurities are present in large quantities, the use of light- or heavy-coated electrodes will not completely remove the effects of the defective wire. Aluminum and aluminum oxide, even when present in quantities of less than 0.01 percent, will cause the arc to become very unstable. Silicon dioxide, silicon, aluminum, aluminum oxide, and iron sulphate tend to make the arc unstable. Iron oxide, manganese oxide, calcium oxide, and iron sulphide tend to stabilize the arc.

(2) If the heat treatment given the wire core of an electrode is not uniform, the electrode will produce defective welds as compared with wire of the same composition which has been properly heat-treated. When phosphorus or sulphur are present in excess of 0.04 percent to 0.05 percent, they will cause harmful effects in the weld metal, since they are transferred from the electrode to the molten metal with very little loss. Phosphorus causes grain growth, brittleness and "cold shortness" in the weld. These defects increase as the carbon content of the steel increases. Sulphur acts as a slag, breaks up the soundness of the weld metal, and produces "hot shortness." It is particularly harmful in bare, low carbon steel electrodes when the manganese content is low. Manganese promotes the formation of sound welds.

c. Base Metal. In plain carbon steels, the carbon content should not be greater than 0.35 percent if blowholes, poor penetration, and small stress cracks are to be avoided. In alloy steels, the carbon content should not be greater than 0.25 percent. For some low alloy steels, this limit is 0.15 percent. In higher carbon and alloy steels which can be welded, it is sometimes desirable to use preheating or postheating or both. This will prevent high stresses from forming in the weld metal. If an excessive current is used during welding, the hardness in the fusion zone will be reduced. However, high welding speeds will tend to increase the hardness in the fusion zone.

CHAPTER 8

ELECTRIC ARC WELDING: EQUIPMENT, PROCEDURE, AND TECHNIQUE (Cont'd)

Section V

ELECTRIC ARC WELDING PROCEDURE

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195. CHARACTERISTICS OF THE ELECTRIC ARC.

a. **Weld Metal Deposition.** In metal arc welding processes, five separate and distinct forces are responsible for the transfer of molten filler metal and molten slag to the base metal.

(1) GRAVITY. Gravity is the principal force which accounts for the transfer of filler metal in flat position welding. In other positions, smaller electrodes must be used to avoid excessive loss of weld metal and slag, as the surface tension is unable to retain a large volume of molten metal and molten slag in the weld crater.

(2) GAS EXPANSION. Gases are produced by the burning and volatilization of the electrode covering and are expanded by the heat of the boiling electrode tip. This rapid expansion of the gases projects the metal and slag of the electrode in globular form away from the solid electrode tip and into the molten crater. The coating extending beyond the metal tip of the electrode controls the direction of gas expansion and directs the molten metal globule into the weld metal crater formed in the base metal.

(3) ELECTROMAGNETIC FORCES. The electrode tip acts as an electrical conductor, the molten metal globule is also an electrical conductor, and, as such, is affected by magnetic forces acting at 90 degrees to the direction of the current flow. These forces produce a pinching effect on the metal globules and act to speed up the separation of the molten metal from the end of the electrode. It is particularly helpful in transferring metal in horizontal, vertical, and overhead position welding.

(4) ELECTRIC FORCES. The force produced by the voltage across the arc acts to pull the small, pinched-off globule of metal regardless of the position of welding. This force is especially helpful where direct-current, straight-polarity, mineral-coated electrodes (which do not produce large volumes of gas) are used.

(5) SURFACE TENSION. The force which keeps the filler metal and slag globules in contact with molten base or weld metal in the crater is known as surface tension. It helps to retain the molten metal in horizontal, vertical, and overhead welding and also to determine the shape of the weld contours.

b. Arc Crater. By quick withdrawal of the electrode, the crater formed at the base metal can be used as an indication of the depth of penetration or fusion that is obtained during welding; however, after a welded joint is completed, this crater is generally filled up by withdrawing the electrode slowly. Under these conditions, the crater depth cannot be taken as a measure of penetration. These weld craters are formed by the pressure of expanding gases from the electrode tip, forcing the liquid metal towards the edges of the crater. Also, the higher temperature of the center as compared with that of the sides of the crater causes the edges to cool first. Metal is thus drawn from the center to the edges, thereby forming a low spot. All craters should be filled at the end of the weld to prevent cracking upon cooling.

c. Arc Blow. The magnetic forces acting on the welding arc and causing the phenomenon known as "arc blow" are a result of the asymmetric magnetic field induced by, and surrounding the path of, the welding current. The distortion of this magnetic field is caused by three factors, two of which are common to both direct-current and alternating-current welding. These factors are:

(1) ASYMMETRIC POSITION OF MAGNETIC MATERIAL ABOUT THE ARC. The resultant magnetic force on the arc acts toward the strongest magnetic path, and is independent of the electrode polarity. The position of the best magnetic path with respect to the arc will change as welding progresses; consequently the intensity and direction of the force will change. Causes for the change of the strongest magnetic path are:

(a) A change in the position of the arc and electrode with respect to the work as welding progresses along the joint.

(b) The amount of weld metal deposited and the size of the air gap produced by the root or joint opening.

(c) The presence of metal in the vicinity of the arc heated above the temperature at which it becomes nonmagnetic (about 1,350 F).

(2) The change in direction of the welding current as it enters the work and is conducted away at approximately right angles to the electrode. The current will take the easiest path but not always the most direct path through the work to the ground connection. The

resultant force is opposite in direction to the current path away from the arc and is independent of the polarity. In determining the location of the ground connection, care must be exercised in determining the actual path of the current through the work to the ground.

(3) The eddy currents induced by alternating currents in the work tend to neutralize, and therefore decrease but not eliminate, the arc forces produced by the previously mentioned causes. Eddy currents will only be a factor when welding with alternating current and rectified alternating current.

d. Arc Stability.

(1) The welding arc must be stable in order to produce sound welds, free from incomplete fusion, blowholes and slag inclusions. Incomplete fusion is caused by lack of melting of the plate metal surface just prior to contact with the molten weld metal. Blowholes are the result of gas formation in the molten weld metal, this gas having been trapped by the solidification of the weld metal. Slag inclusions, sometimes associated with lack of fusion, result from entrapment of slag particles by the metal solidification. Unstable arcs cause violent fluctuations of current and arc voltage and produce very nonuniform melting and metal deposition. Heavy coated electrodes have been designed with the purpose of eliminating unstable arcs. These electrodes require higher currents than bare electrodes and light coated electrodes, and operate most satisfactorily for welding in the flat position. Care should always be exercised to use proper welding current, polarity, and arc length for the size and type of electrode being used for a particular job.

(2) The composition of the wire in electrodes and the content and kind of certain elements in it will materially affect the stability of the arc (par. 194 **b**).

196. WELDING CURRENT, VOLTAGE, AND OTHER ADJUSTMENTS.

a. The selection of the proper welding currents and voltages depends upon the size of the electrode, the thickness of the plate being welded, the position of welding, and the welder's skill. In flat position welding, higher values for current and voltage may be used than for vertical and overhead welds with an electrode of the same size. In general, the proper current and voltage settings are obtained from experience and should be adjusted to fulfill the requirements of the particular welding operation. Since several factors affect the current and voltage requirements, data published by manufacturers should be used only as a guide. For initial settings, the following table may be used in welding with bare and lightly coated electrodes. The arc voltage will vary from about 17 volts for $^{3}/_{32}$-inch electrodes to 30 volts for $^{3}/_{8}$-inch electrodes of either the bare or lightly coated types.

RANGE OF CURRENT SETTINGS FOR BARE AND LIGHTLY COATED ELECTRODES

Electrode Diameter	Amperes Minimum		Amperes Maximum	Standard Electrode Lengths
1/16 in.	40	-	60	—
3/32 in.	70	-	90	11½ in.
⅛ in.	110	-	135	14 or 18 in.
5/32 in.	150	-	180	14 or 18 in.
3/16 in.	180	-	220	14 or 18 in.
¼* in.	250	-	300	14 or 18 in.
5/16* in.	300	-	425	14 or 18 in.
⅜* in.	450	-	550	14 or 18 in.

* Diameters, ¼-in., 5/16-in., and ⅜-in., are for flat position only.

In general, the electrode of 3/16-inch diameter is the maximum size permissible for vertical and overhead welding positions.

b. The mineral-coated type of shielded-arc electrode, which produces a slag as a shield, requires higher welding currents than the cellulose-coated type, which produces a large volume of gases to shield the arc stream. The following table shows a comparison between the current requirements for the mineral-coated or slag-forming electrode and the cellulose-coated or gaseous type of electrode. The welding voltage will vary from about 20 volts for the 3/32-inch electrodes to 30 volts for the ⅜-inch heavy-coated electrodes of either the gaseous or slag-forming types.

COMPARISON OF CURRENTS USED WITH GASEOUS AND SLAG TYPES OF ELECTRODE

GASEOUS TYPE			SLAG TYPE	
Electrode Diameter	Flat Position (Amperes)	Vertical and Overhead Positions (Amperes)	Electrode Diameter	Flat Position (Amperes)
3/32 in.	60	60	1-	—
⅛ in.	120	110	⅛ in.	130
5/32 in.	150	140	5/32 in.	160
3/16 in.	175	160	3/16 in.	200
¼ in.	250	-	¼ in.	300
5/16 in.	325	-	5/16 in.	400
⅜ in.	425	-	⅜ in.	500

c. The shielded-arc or heavy-coated electrode has replaced the bare and light-coated electrodes for most welding applications. The factors largely responsible for this have been higher welding speeds, better weld-metal quality, and the ability to introduce certain alloying elements into the weld metal through the heavy coatings on the electrode. The so-called modified 18-8 type of stainless steel electrode is a good example. The shielded-arc type of electrode is used almost exclusively for the welding of nonferrous metals and certain alloy steels, particularly the stainless steel alloys. Its use has also simplified the welding technique, afforded better penetration and corrosion resistance, and produced welds with higher physical properties.

d. In preparation for electric arc welding, it is important that the welding machine be adjusted to give proper welding conditions for the particular size and type of electrode being used. The adjustments include proper polarity, current, and voltage settings. The arc welding machines on the ordnance field Welding Truck M3 are dual-control units which make possible the separate control of both the voltage and current delivered to the arc. In single-control units, the control handwheel is used to select the proper welding current, while the voltage is adjusted automatically.

e. **Electrode.** When proper adjustment of the machine is obtained, the exposed end of the electrode should be gripped in the electrode holder so that the entire length can be deposited without breaking the arc. In some cases, in welding with very long electrodes, the center of the electrode is bared for the electrode holder grip. Carbon or graphite electrodes should be gripped short of the full length to avoid overheating the entire electrode.

197. STARTING THE ARC.

a. There are two methods used for starting the arc: the striking or brushing method shown in figure 75, and the tapping method shown in figure 76. When struck by either method, the arc is formed

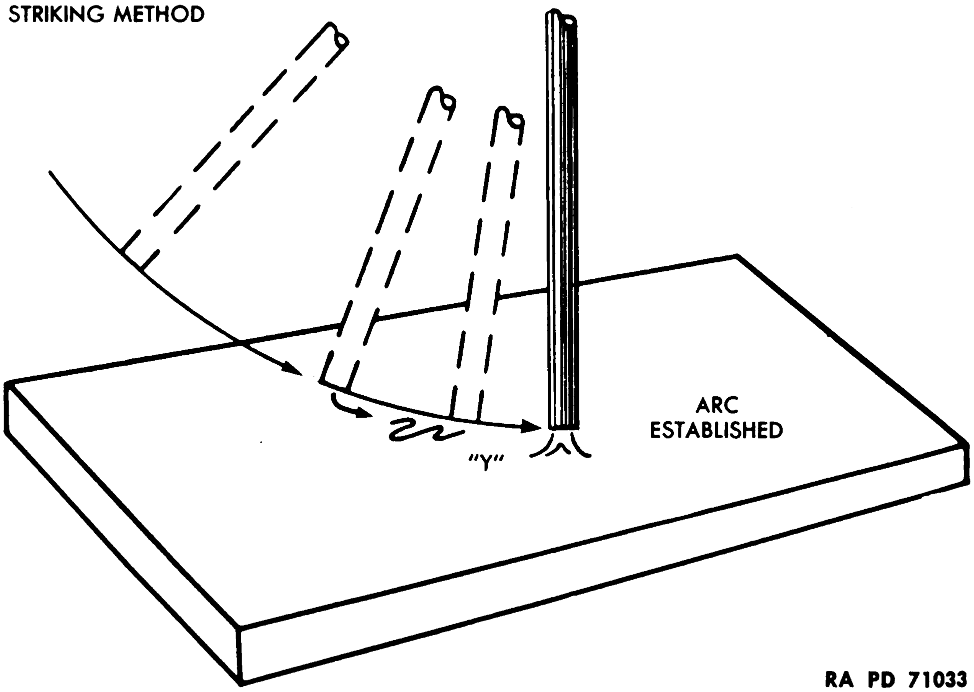


Figure 75 — Striking or Brushing Method of Starting the Arc

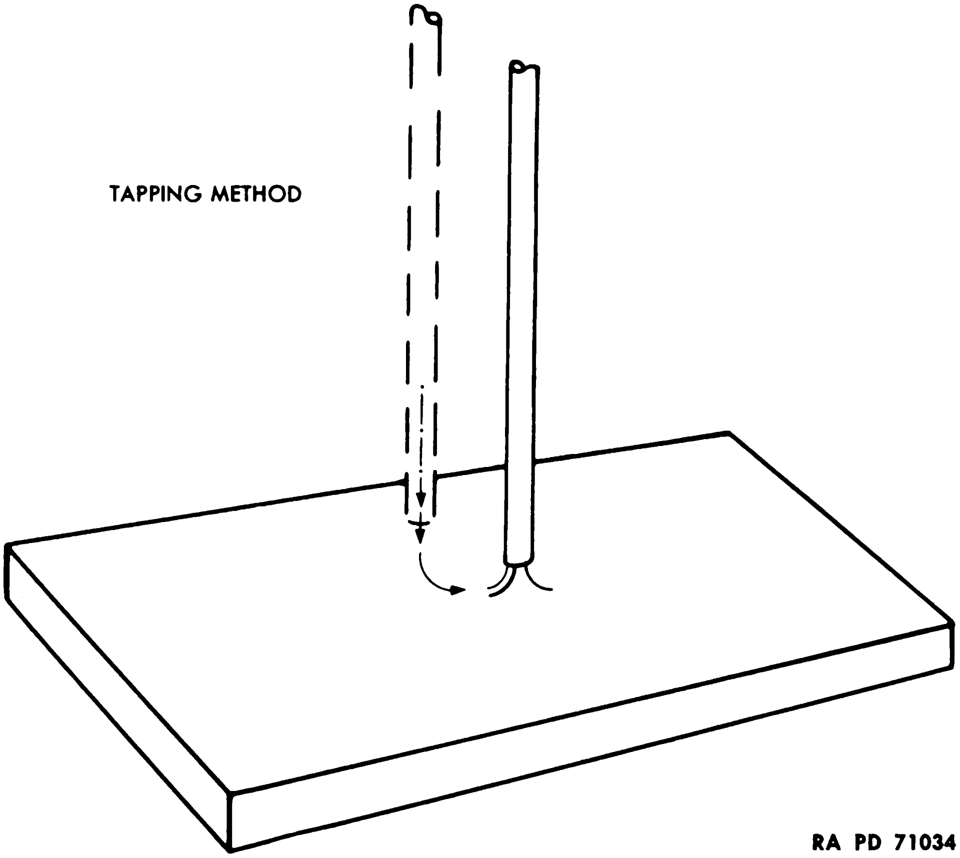


Figure 76 — Tapping Method of Starting the Arc

by short-circuiting the welding current between the electrode and the work plate. The surge of high current at the arc causes both the end of the electrode and a small spot on the plate beneath the electrode to melt instantly.

b. In the striking or brushing method, the end of the electrode is brought down to the work in a continuous motion which describes an arc of a circle. As soon as the electrode touches the plate surface, as indicated by the letter "Y," the downward motion is checked, and the electrode is raised to establish the arc. The arc length or gap between the end of the electrode and the plate should be approximately equal to the diameter of the electrode used. When the proper length of arc is obtained, a sharp crackling sound can be heard.

c. In the tapping method the electrode is held in a vertical position to the plate. The arc is established by lowering the electrode, tapping or bouncing it on the surface of the plate, and then slowly raising it a short distance.

d. In striking the arc, if the electrode is withdrawn too slowly, it will stick or freeze to the plate or base metal. If this occurs, the electrode can usually be freed by a quick sidewise wrist motion to snap the end of the electrode from the plate. When this fails, the electrode holder should be loosened from the electrode, or the welding machine stopped. A light chisel blow will dislodge the electrode, which can again be gripped in the electrode holder. All work to free the electrode should be done with the shield or helmet in front of the eyes. If the electrode is brought upward too quickly, the arc length will be increased by an excessive amount and will go out.

198. BEAD WELDING.

a. Once the arc is struck, particles of metal will melt off the end of the electrode and will be deposited in the molten crater on the plate surface. This will cause the arc to increase in length unless the electrode is fed down to the plate as fast as it is deposited. If the electrode is fed down to the plate and along the surface at a constant rate, a bead of metal will be deposited or welded onto the plate surface. Before advancing forward, the arc should be held for a short time at the starting point to insure good fusion and to allow the bead

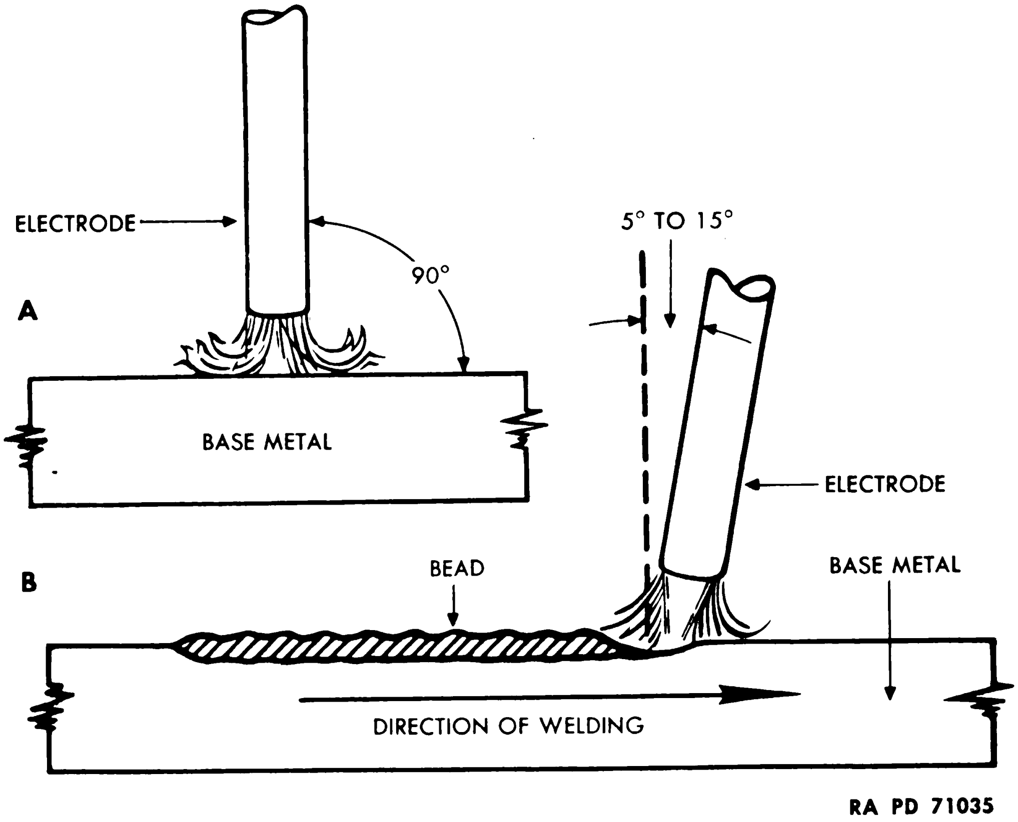


Figure 77 – Positions of Electrode in Making Beads

to build up slightly. Good arc welding depends upon the development of close control over the motion of the electrode down to and along the surface of the plate while a constant arc length is maintained.

b. **Position of Electrode.** In bead welding, the electrode should be held at 90 degrees to the base metal, as shown in A, figure 77. However, in order to obtain a clearer view of the molten puddle, crater, and arc, the electrode should be tilted between 5 and 15 degrees towards the direction of travel, as shown in B, figure 77. The electrode should not be moved from side to side. The speed of welding should be controlled so as to deposit the metal uniformly, and the electrode should be fed down to the work as rapidly as deposited, so as to keep the arc length constant.

ARC WELDING BEAD CHARACTERISTICS

Operating Conditions	Arc Sound	Electrode Rate of Melting	Appearance of Crater	Appearance of Bead	Depth of Fusion	Spatter
High current.	Explosive sounds with pronounced crackling.	Flux coating melts rapidly and irregularly	Deep, long, and irregular.	Wide and thin.	Deep and good.	Very pronounced large drops.
Low current.	Irregular crackling.	Flux coating melts slowly.	Shallow small.	Rounded, high crown some overlap.	Slight and irregular.	Slight.
High voltage.	Some crackling; soft hissing sound.	Flux coating melts rapidly, forming drops at end of electrode.	Deep, though not as long as in No. 1.	Wide and very thin.	Deep and irregular.	Pronounced, but less in No. 1.
Low voltage.	Hissing and steady sputtering sound.	Flux coating melts very slowly. Interferes with welding.	Shallow, longer than in No. 2.	Porous,, rounded, high crown some overlap, wider than No. 2.	Slightly more than in	Slight.
High welding speed.	Sharp crackling sound.	Balanced for good welding.	Long and shallow.	Narrow, irregular, some undercut.	Very slight incomplete.	Slight.
Low welding speed.	Sharp crackling sound.	Balanced for good welding.	Long, wide, and shallow.	Wide, high crown, excessive overlap.	Good.	Some, due to overheating.
Correct welding conditions.	Sharp crackling sound.	Balanced and uniform for good welding.	Rather deep and uniform.	Good fusion, no undercut or overlap.	Deep and good.	Very slight.

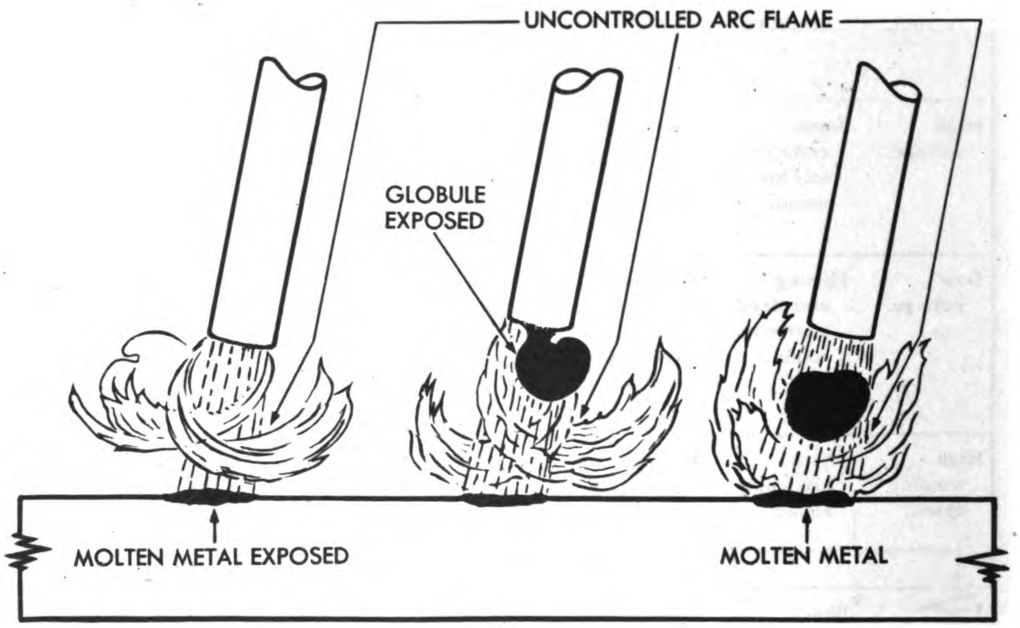
199. EFFECTS OF IMPROPER ARC CONTROL.

a. The effects of improper current, voltage, or welding speed on the welded bead are shown on the preceding page.

b. **Disadvantages of a Long Arc.**

(1) In welding with a long arc, the protecting arc flame, as well as the molten globule leaving the end of the electrode, will whirl from side to side, thus allowing the metal to become oxidized or burned before reaching the molten base metal. It is difficult to control the direction of the molten metal as it passes through the arc, and a considerable portion of the metal is lost as weld-metal spatter. A long arc will melt the electrode more quickly, but the metal is not always deposited at the point desired. In general, the long arc leads to poor penetration, excessive overlap, and poor physical qualities such as burned and porous metal in the welded bead.

(2) If a long arc similar to that shown in figure 78 is used, the penetration into the base metal will be poor, and spatter and overlap will be noticed along the sides of the bead weld, deposited as



RA PD 71036

Figure 78 — Characteristics of the Long Arc

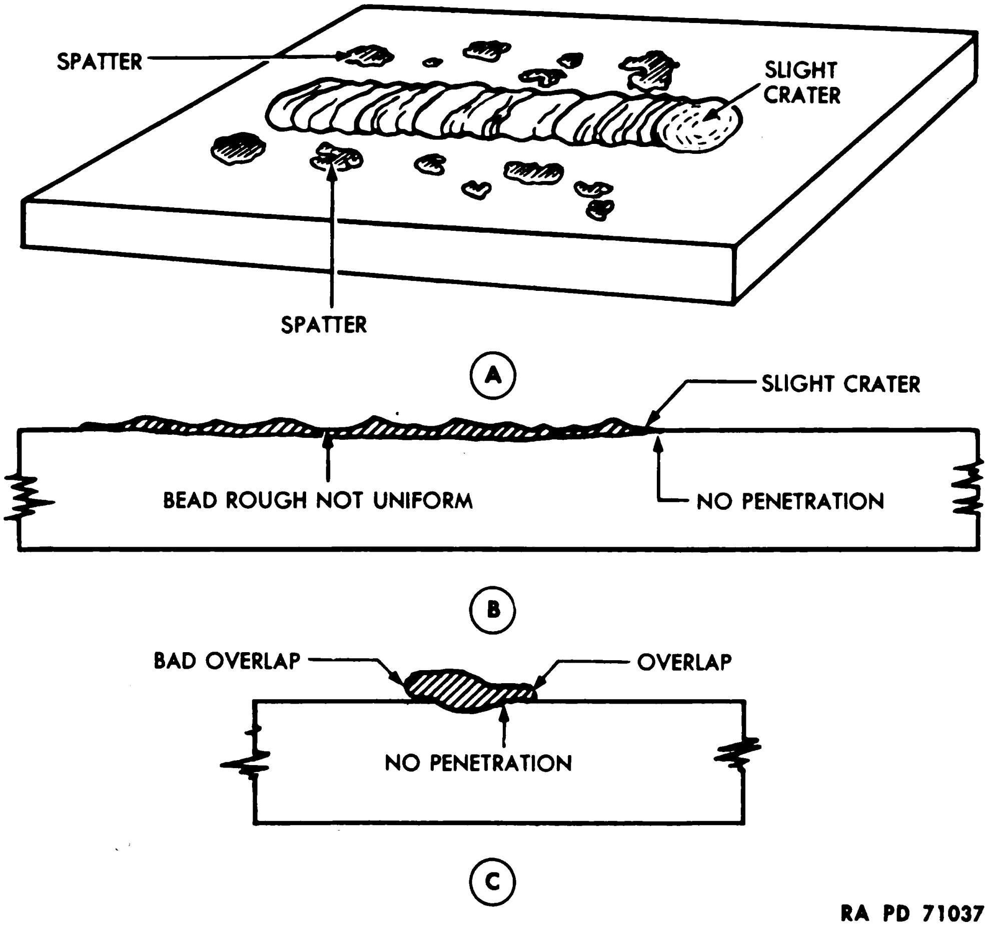


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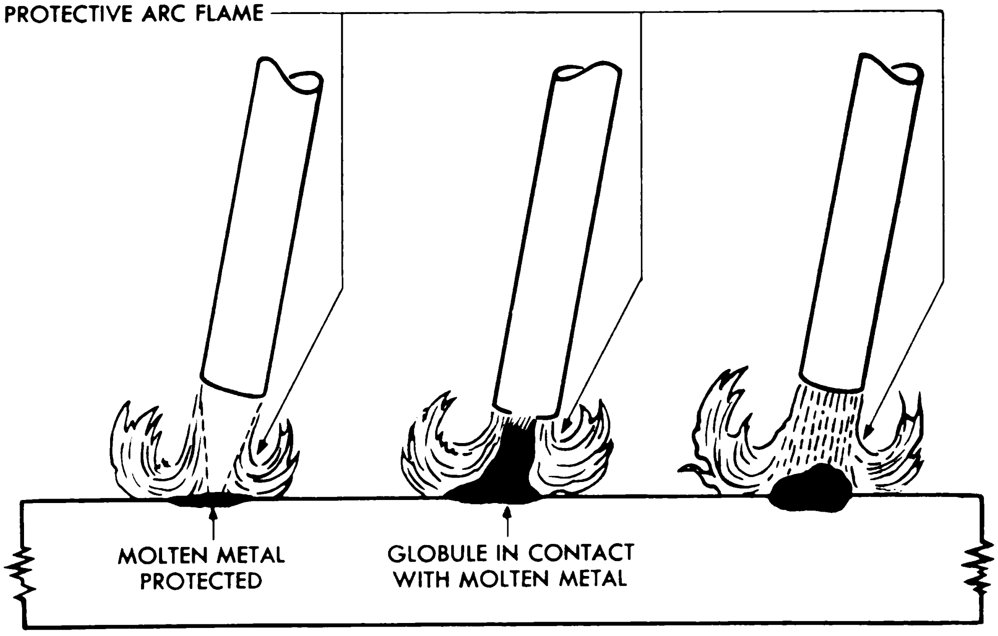
Figure 79 — Defects in Welds Due to Long Arc

shown in figure 79. (Overlap is also caused by too low-current settings and too slow speeds of electrode travel.)

c. Advantages of a Correct Arc Length.

(1) In welding with a short arc, the molten metal leaving the end of the electrode will pass through the arc under good protection from the atmosphere by an enveloping arc flame. Better control of the weld metal deposited on the plate and better weld-metal quality will be obtained in the welded bead. In general, a short arc gives maximum penetration and better physical qualities and deposits the maximum amount of metal at the point of welding. Porosity, overlap, and weld-metal spatter are kept at a minimum.

(2) A very short arc, however, will produce much spatter of weld metal and will keep going out, making continuous welding difficult. The results of welding with a very short arc are similar to those shown in figure 79, top view.



RA PD 71038

Figure 80 – Characteristics of the Correct Arc

200. FLAT POSITION WELDING.

a. Bead Welds.

(1) With the electric welding machine properly adjusted to give the correct current and polarity settings, bead welds can be made by holding a short arc and welding in a straight line at a constant speed.

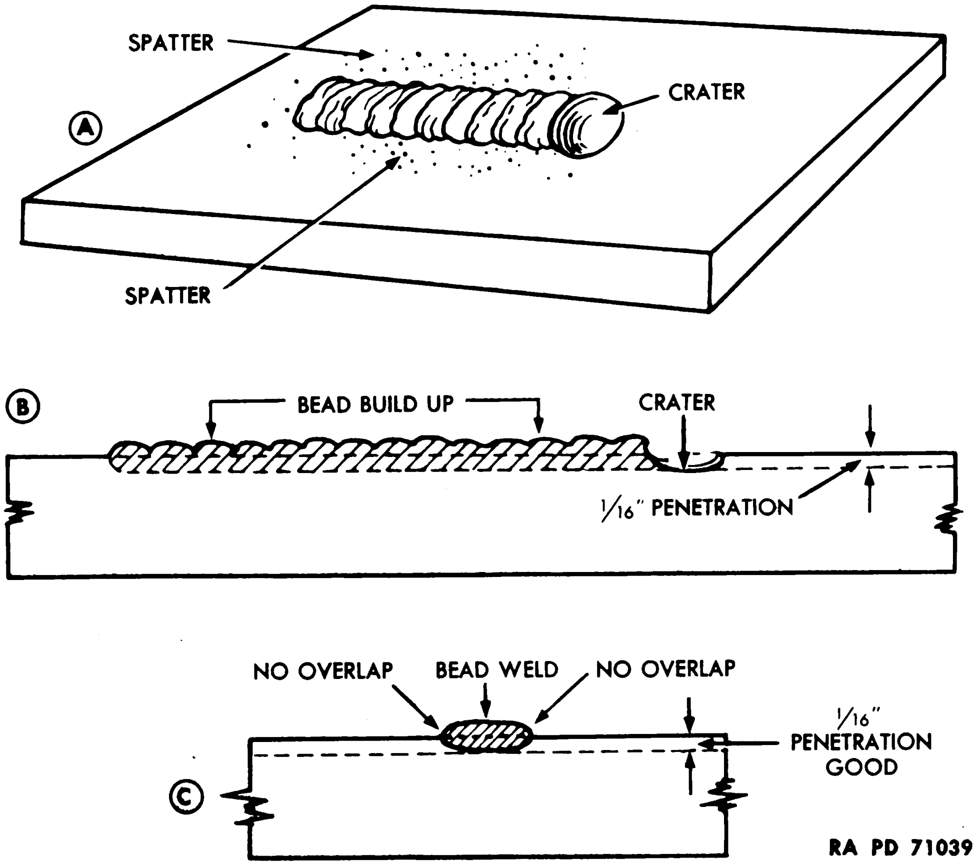
(2) The proper arc length cannot be accurately judged by the eye and should be recognized by sound. In bead welding with a short arc, as shown in figure 80, the typical sharp cracking sound should be heard all during the time the electrode is being moved down to and along the surface of the plate.

(3) A properly made bead weld should leave very little spatter on the surface of the plate, and the arc crater or depression in the bead when the arc has been broken should be approximately $1/16$-inch deep. The bead weld should be built up slightly, but without any weld-metal overlap at the top surface, which would indicate poor fusion. The depth of the crater at the end of the bead can be used as a measure of penetration into the base metal. Examples of good bead welds are shown in figure 81.

b. Butt Joints in the Flat Position.

(1) A butt joint is used to join two plates having their surfaces approximately the same plane with each other (par. 90).

(2) Several types of joints are used to make butt welds in the



RA PD 71039

Figure 81 — Properly Made Bead Welds

flat position. The more important of these types are shown in figure 82.

(3) Plates ⅛ inch thick can be welded in one pass, no special edge preparation being necessary. Plates from ⅛ inch to ¼ inch in thickness can be welded with no special edge preparation by making a bead weld from both sides of the joint, as shown in figure 83. The edges of the plate should be square and spaced 3/32 inch to ⅛ inch apart. Tack welds should be used to keep the plates alined for welding. The electrode motion is the same as that used in making a bead weld.

(4) In welding ¼-inch plates, or heavier, the edges of the plates should be prepared by bevelling or U-grooving, and any of the joint types shown above may be used. Single or double V-bevels may be used, depending upon the thickness of the plate being welded. The first bead should be deposited to seal the space between the two plates and to weld the root of the joint. This bead or layer of weld metal should be thoroughly cleaned to remove all slag before the second layer of metal is deposited. In welding joints in plates, as show

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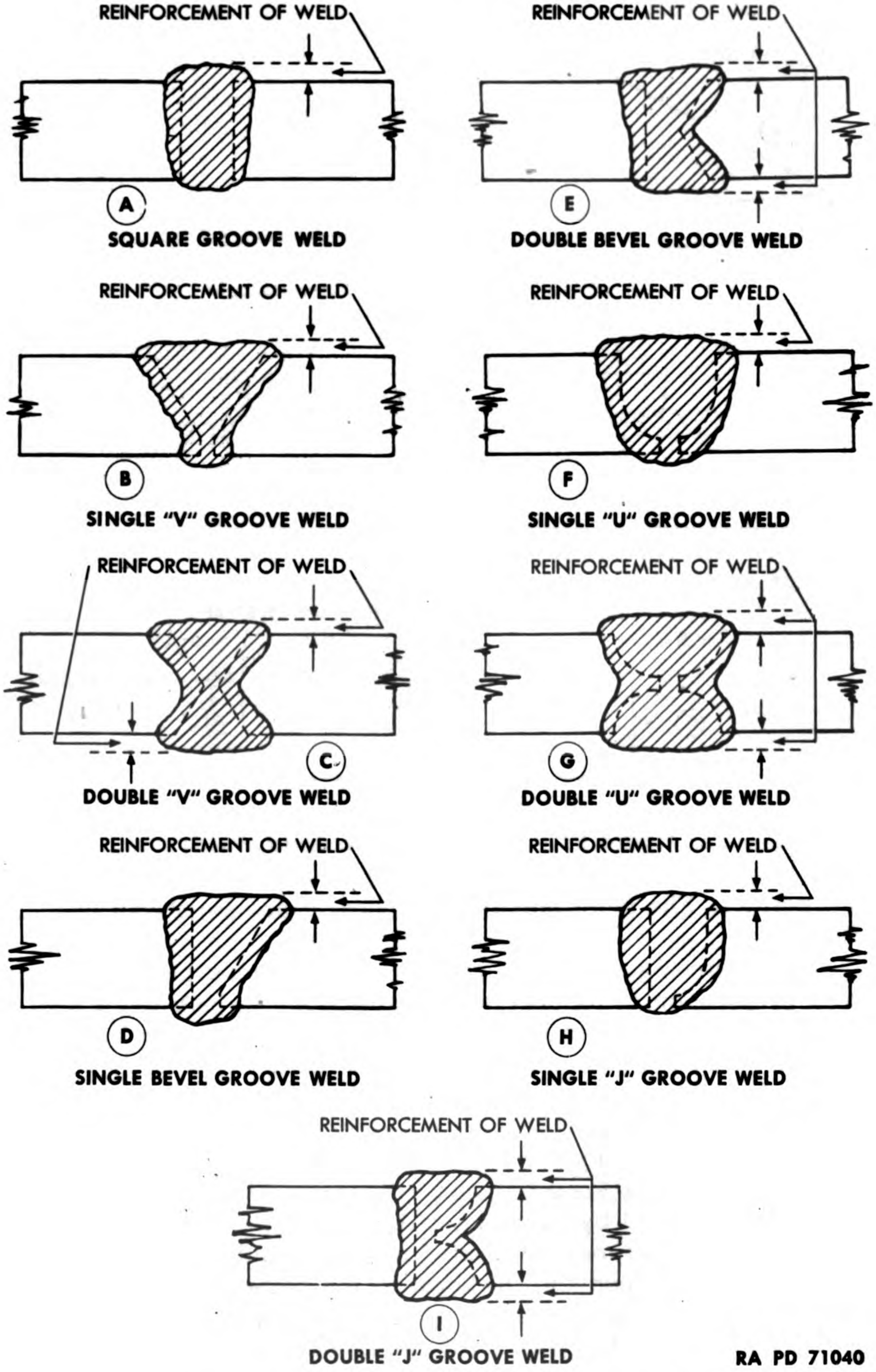

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Figure 82 — Butt Joints in the Flat Position

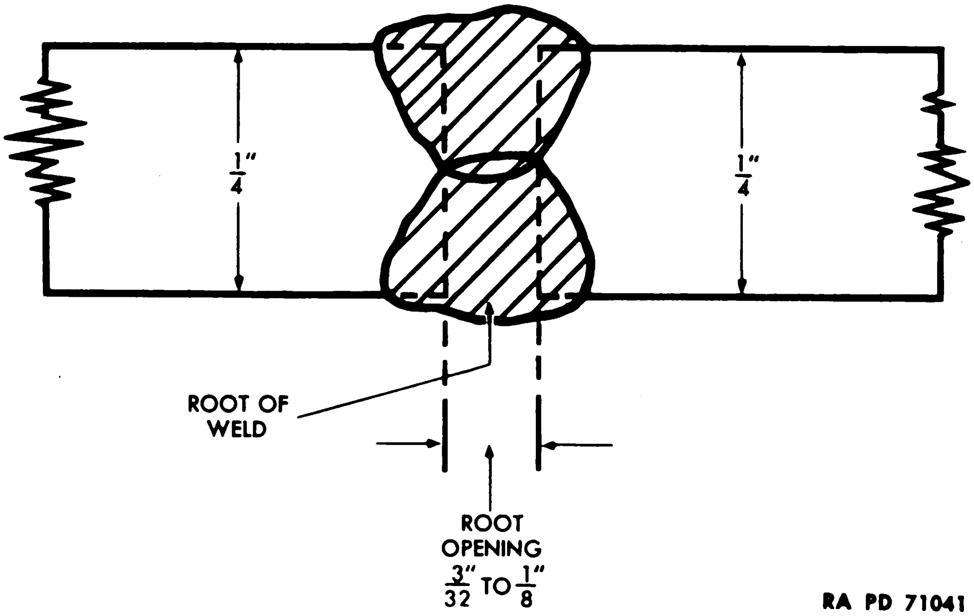


Figure 83 — Butt Weld in Flat Position without Edge Preparation (1/8- to 1/4-in. Plate)

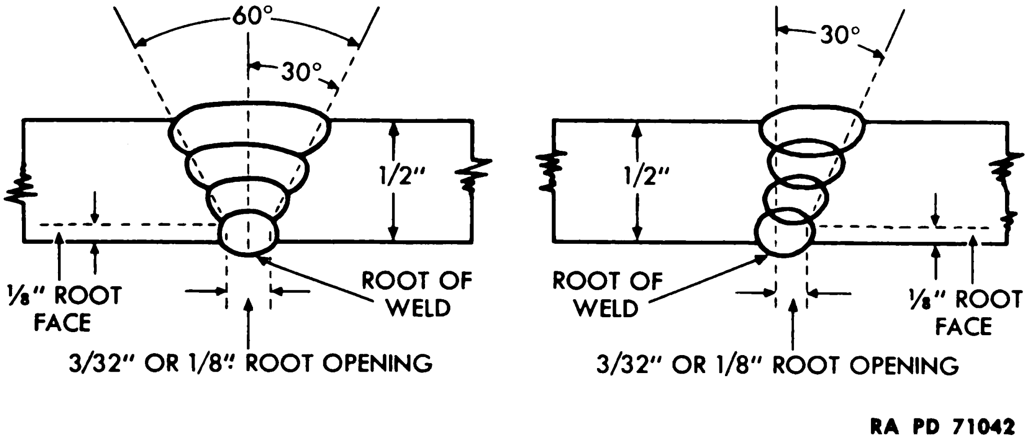
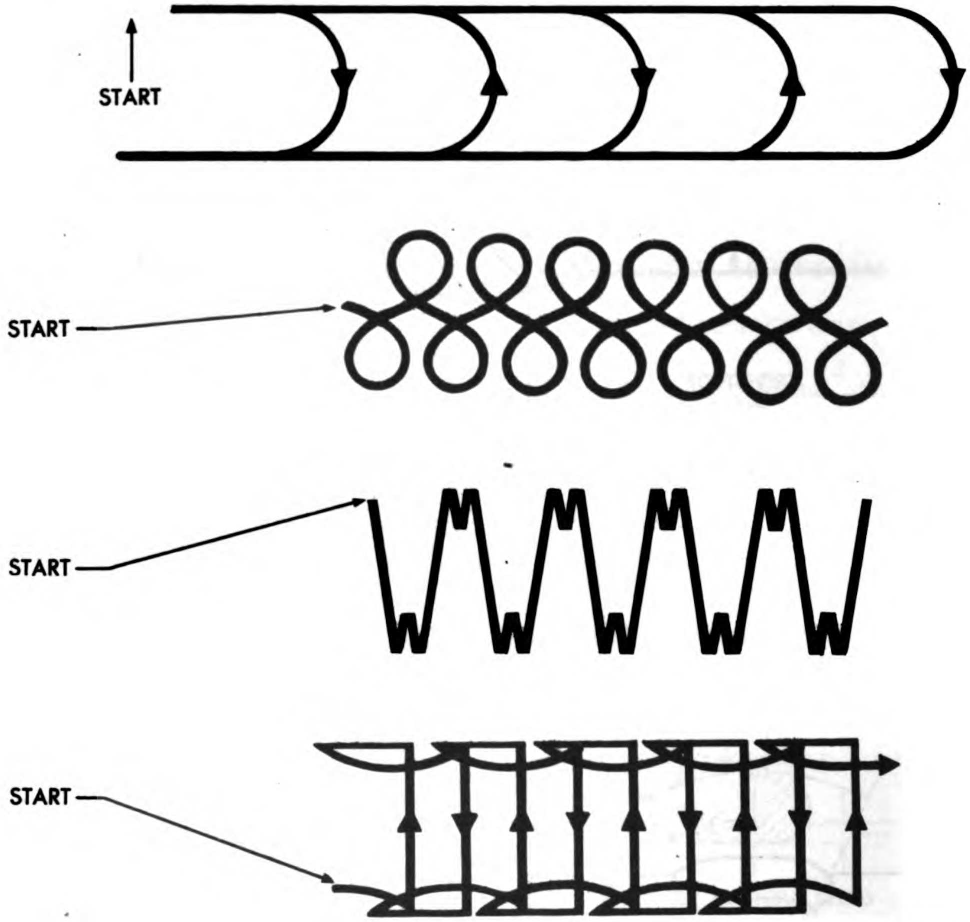


Figure 84 — Butt Welds with Multi-Pass Beads (1/4-in. Plates)

in figure 84, the second, third, and fourth layers of weld metal are deposited in a weaving motion.

(5) Any of the weaving methods illustrated in figure 85 may be used, depending upon the type and size of the electrode.

(6) Each layer of metal should be cleaned before additional layers are deposited. If the weaving motion is not properly performed, undercutting will occur at the joint, as shown in figure 86. To correct these defects, the electrode should be oscillated or moved uniformly from side to side, with a slight hesitation at the end of each oscillation.



RA PD 71043

Figure 85 — Weave Motions

Excessive welding speeds will also cause undercutting and poor fusion at the edges of the weave bead. As in bead welding, the top of the electrode should be inclined between 5 degrees and 15 degrees in the direction of welding.

c. Butt Joints in the Flat Position with Back-up Strips.

(1) In welding butt joints on ¼-inch plates or heavier, back-up, or backing strips are used to obtain complete fusion at the root of the weld and to provide better control of the arc and the weld metal. The edges of the plates to be welded are prepared in a manner similar to that used for butt joints without a back-up strip. The back-up strip should be approximately 1 inch wide and $\frac{3}{16}$ inch thick. It should be tack-welded to the base of the joint, as shown in figure 87.

(2) The back-up strip will act as a cushion for the first bead or layer of weld metal deposited in the joint. The joint should be completed by adding additional layers of metal by means of the technique

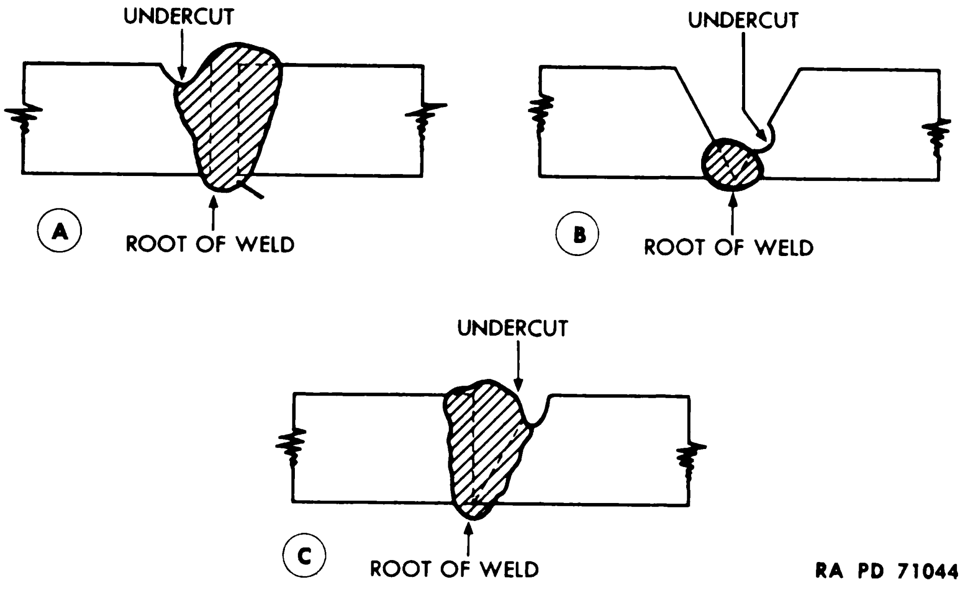


Figure 86 — Undercutting in Butt Joint Welds

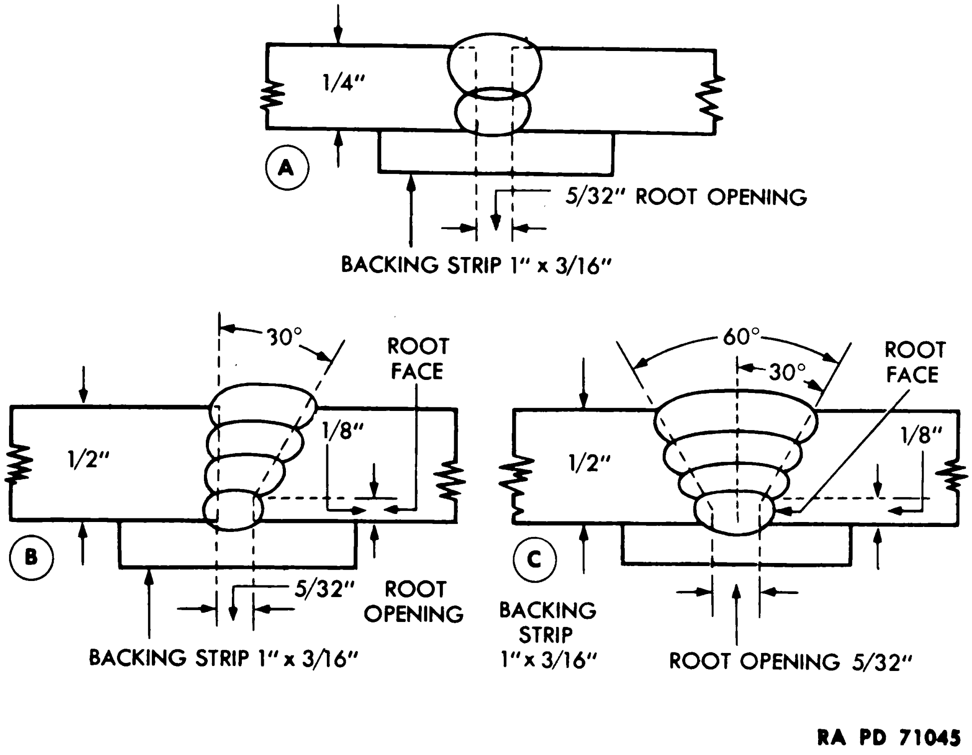


Figure 87 — Butt Welds with Backing Strips

previously described for butt joint (subpar. b, above). After the joint is completed, the back-up strip may be "washed off" or cut away from the plate by means of the cutting torch, and a "seal" bead when necessary, deposited on the back side to correct poor penetration at the root of the joint.

d. **Fillet Welds.** Fillet welds are used to make T-, lap, plug, and slot joints.

(1) T-JOINTS (par. 92).

(a) In making T-joints in the flat position, the two plates are located so as to form an angle of 90 degrees between their surfaces. The edge of one plate is tack-welded in position to the surface of the other, as shown in figure 88.

(b) A short arc is necessary for good fusion into the corner or root of the weld. The electrode should be held at an angle of 45 degrees to the plate surfaces, and the top of the electrode should be tilted about 15 degrees in the direction of welding. The electrode position

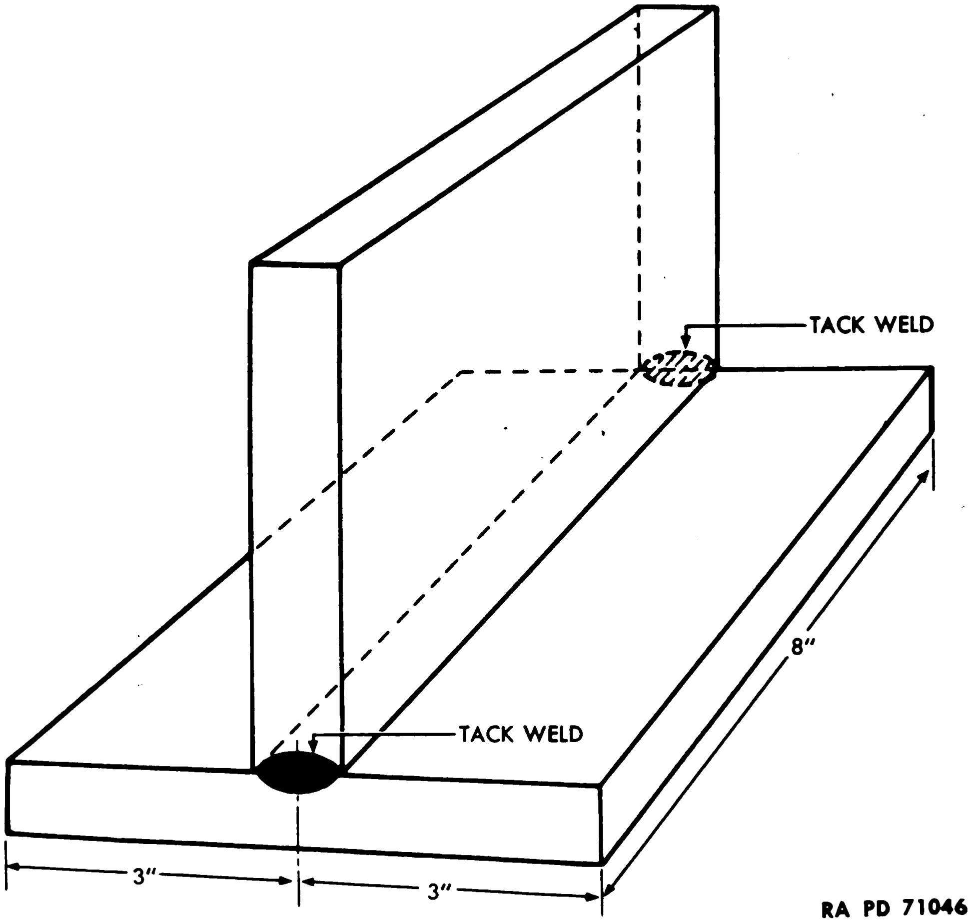


Figure 88 — Tack-weld on T-joint in Horizontal Position

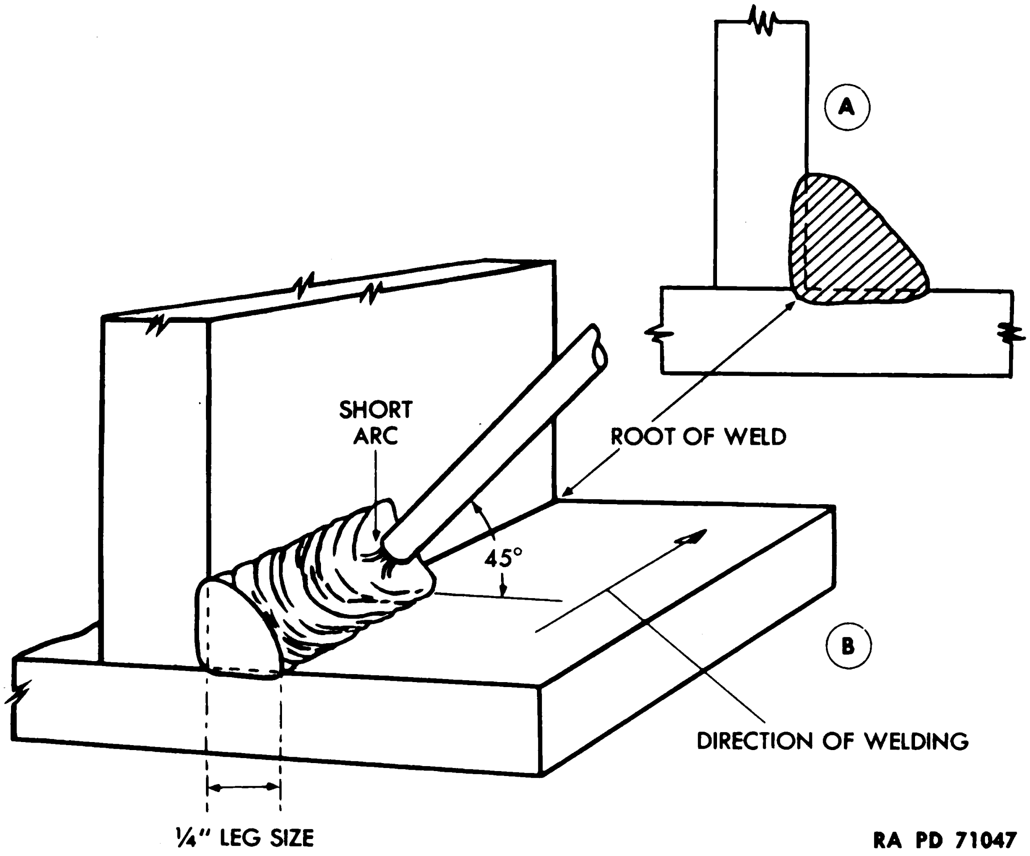


Figure 89 — Electrode Position for Single-pass Fillet Weld on T-joint

is shown in figure 89. Light plates can be welded with little or no weaving motion of the electrode in making the fillet weld in one pass. Welding of heavier plates may require two or more passes, in which case the second pass or layer is made with a semicircular weaving motion, as shown in figure 90. In making the weave bead, there should be a slight pause at the end of each weaving motion so as to obtain good fusion to the edges of the two plates without undercutting them.

(c) Fillet-welded T-joints on ½-inch plate or heavier can be made satisfactorily by using string beads deposited in the order in figure 91. Long fillet-welded T-joints can be made by spacing or staggering the welds in short lengths, as shown in figure 92. These joint designs are used where high strengths are not required of the welded joint; however, the welding beads are so arranged that the finished joint is equal in strength to a fillet weld made along the entire length from one side only. By staggering the welds as shown, the warpage and distortion in the welded parts is held at a minimum.

(2) LAP JOINTS (par. 91).

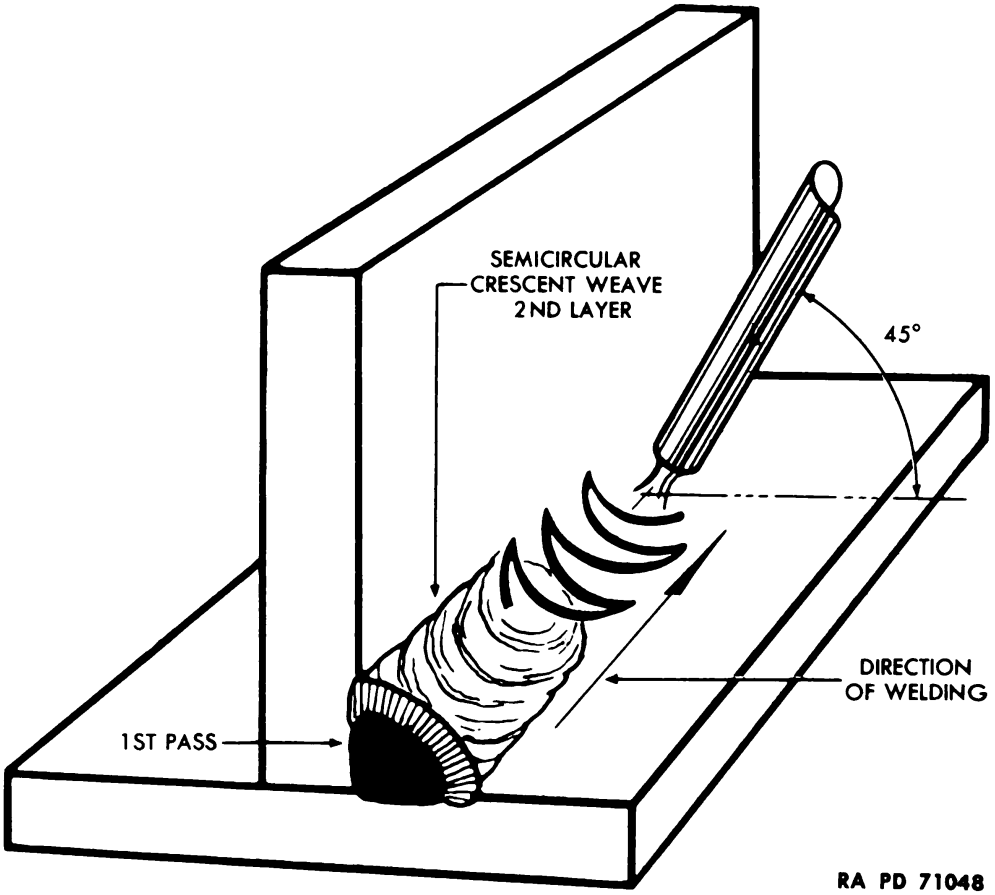


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Figure 90 – Weave Motion for Multi-pass Fillet Weld

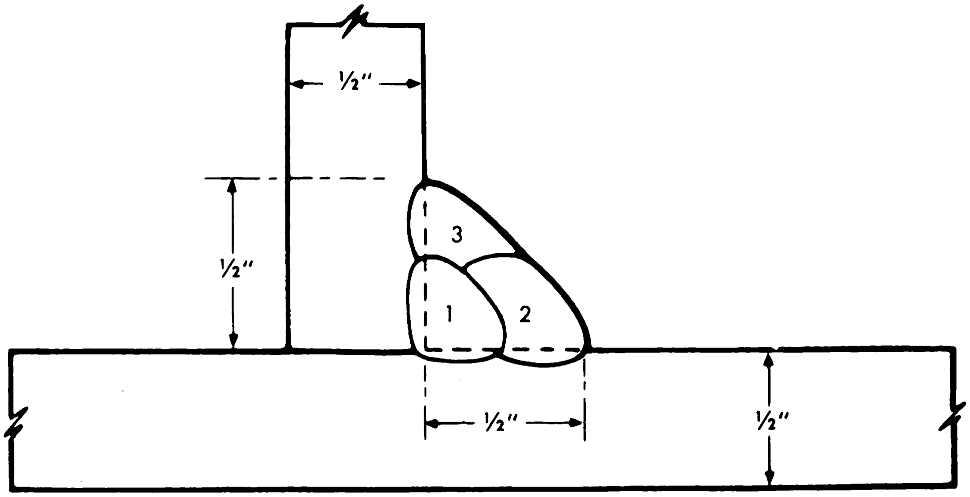

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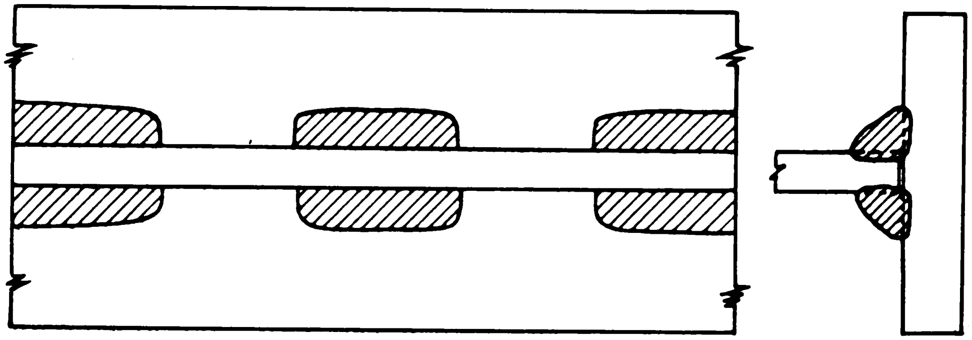
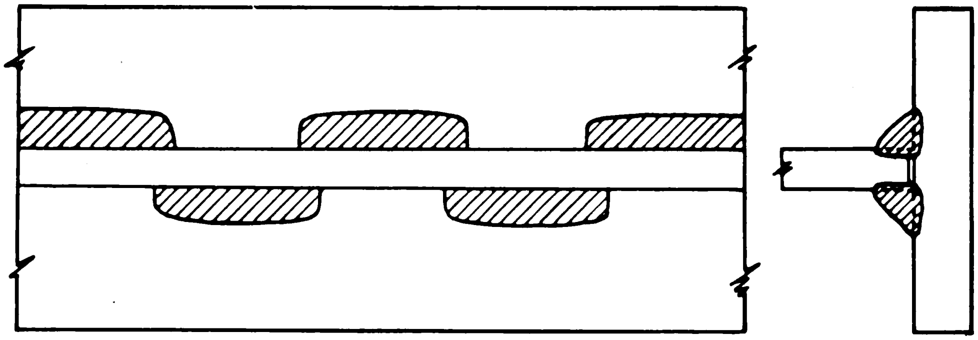
Figure 91 – Fillet-welded T-joints on Heavy Plate



CHAIN INTERMITTENT



STAGGERED INTERMITTENT

RA PD 71050

Figure 92 — Intermittent Spacing in Fillet Welds

(a) In making lap joints in the flat position, two plates are welded together with the edge of one plate overlapping the edge of the other plate. The plates are tack-welded in place as shown in figure 93.

(b) The procedure for making this fillet weld is similar to that used for making fillet welds in T-joints. The electrode should be held so as to form an angle of 30 degrees with the vertical, and the top of the electrode should be tilted to an angle of 15 degrees in the direction of welding. This process is shown in figure 94 for a lap joint on 3/8-inch plate. The weaving motion is the same as that used for T-joints, except that the hesitation at the edge of the top plate is prolonged so as to obtain good fusion with no undercut. Lap joints on 1/2-inch plate or heavier are satisfactorily made by using three or more string beads as shown in figure 95. In making lap joints on plates of different thicknesses, as shown in figure 96, the electrode is held so as to form an angle of between 20 degrees and 30 degrees with the vertical. Care must be taken not to overheat and undercut the thinner plate edge, and the arc must be controlled so as to wash up the molten metal to the edge of this plate.

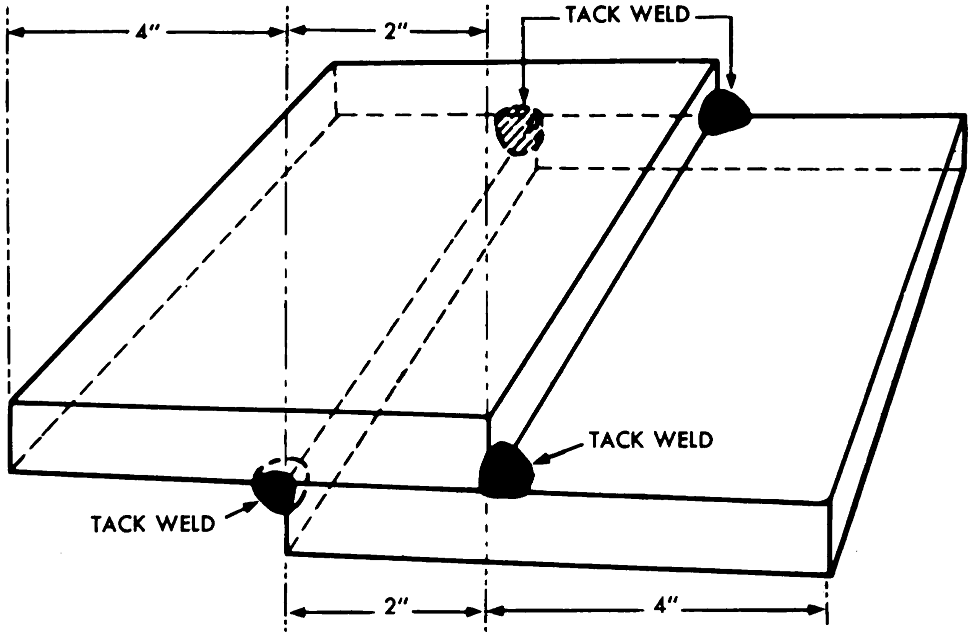


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Figure 93 — Tack Welding a Lap Joint in the Flat Position

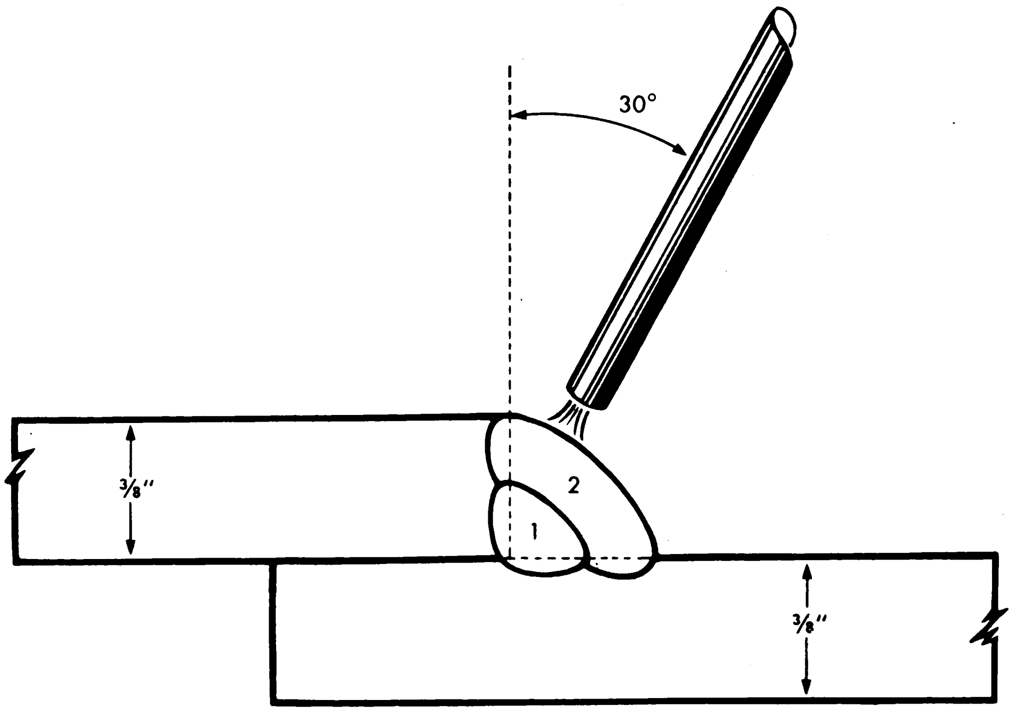

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Figure 94 — Position of Electrode for Fillet Weld on Lap Joint in Horizontal Position (3/8-in. plate)

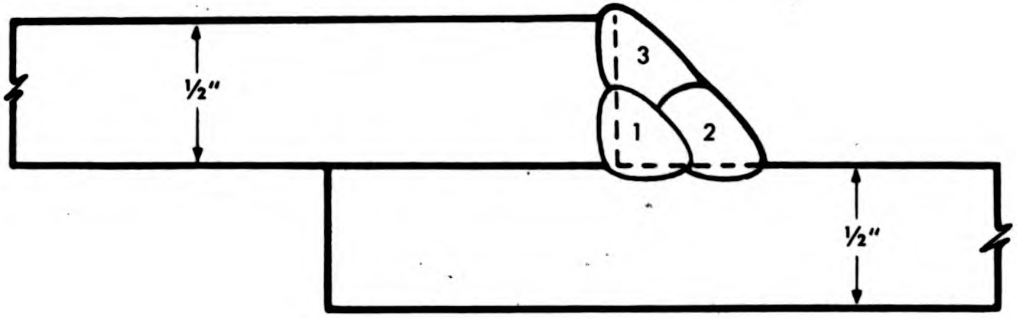

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Figure 95 — Fillet Weld on Lap Joint in Horizontal Position (Heavy Plate)

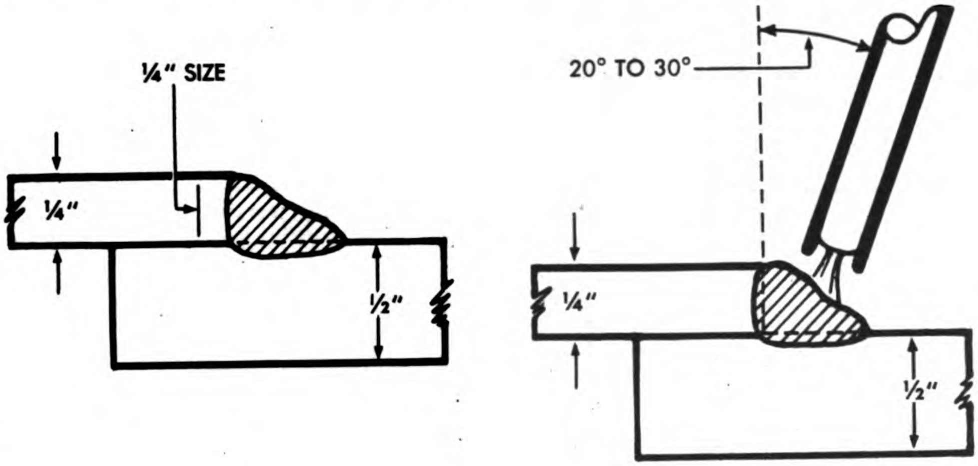

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Figure 96 — Lap Joint on Plates of Different Thicknesses

(3) PLUG AND SLOT JOINTS.

(a) Plug and slot welds are used to join two overlapping plates by welding the upper plate through a hole or slot in its surface to the lower plate. These types of joints are shown in figures 97 and 98, respectively.

(b) Slot welds are used in batten strips to join face-hardened armor-plate edges from the back or soft side. They are also used where it is desired to fill up holes that have been made in plates or to join two overlapping plates where it is impossible to join them by any other method.

(c) A continuous fillet weld is made to obtain good fusion between the sidewalls of the hole or slot in the upper plate and the upper surface in the lower plate. The procedure for this weld is the same as that noted for making lap welds. The hole or slot is then filled in, as required, to develop additional strength at the joint.

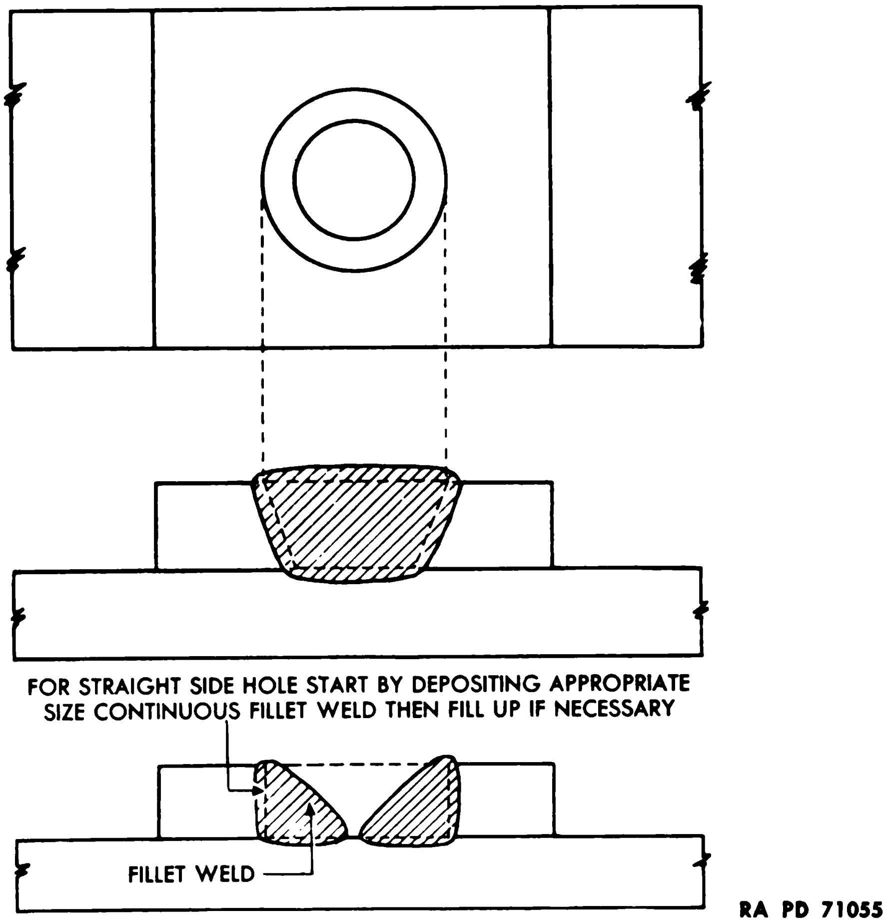

Figure 97 – Plug Joint in Flat Position

(d) Plug welds may be used to remove bolts or studs that have been broken or twisted off flush with the surface of a casting. A nut should be placed on the surface of the casting so as to locate the bolt or stud centrally with the hole in the nut. A heavy-coated steel electrode is lowered into the nut and the arc struck on the upper exposed end of the stud. The stud is thus welded to the inner sidewalls of the nut, and sufficient weld metal is added to fill the hole in the nut completely. A wrench applied to the nut will cause the stud or bolt welded to the nut to turn out easily.

201. OVERHEAD POSITION WELDING.

a. The overhead position is one of the most difficult in welding, since a very short arc must be maintained constantly in order to retain complete control of the molten metal. As in vertical welding, the force of gravity tends to cause the molten metal to drop down or sag on the plate. If a long arc is held, the difficulty in transferring metal from the

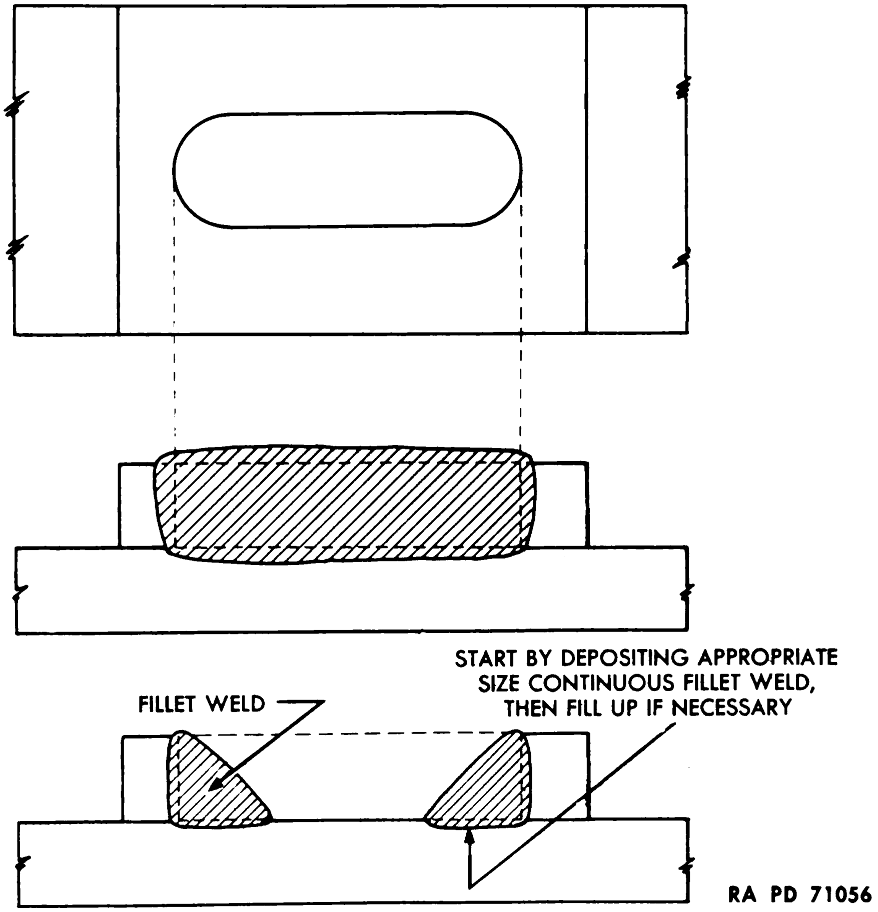

Figure 98 — Slot Joint in Flat Position

electrode to the base metal is increased, and large globules of molten metal will drop from the electrode and the base metal. The transfer of metal is aided by first shortening and then lengthening the arc at intervals; however, care should be taken not to carry too large a pool of molten metal in the weld.

b. For bead welding, the electrode should be held at an angle of 90 degrees to the base metal, as illustrated in A, figure 99. In some cases, however, where it is desirable to observe the arc and the crater of the weld, the electrode may be held at an angle of 15 degrees in the direction of welding, as shown in B, figure 99.

c. Weave beads can be made in the overhead welding position by using the weaving motion illustrated in figure 100. A rather rapid motion is necessary at the end of each semicircular weave in order to control the molten metal deposit. Care should be taken to avoid excessive weaving, as this will cause overheating of the weld deposit and form a large pool of metal, hard to control.

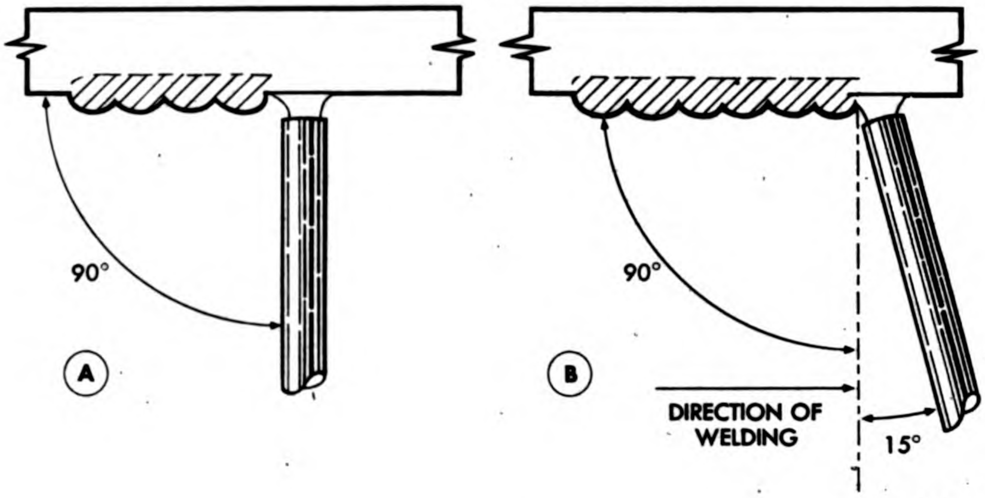

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Figure 99 — Position of Electrode in Overhead Welding

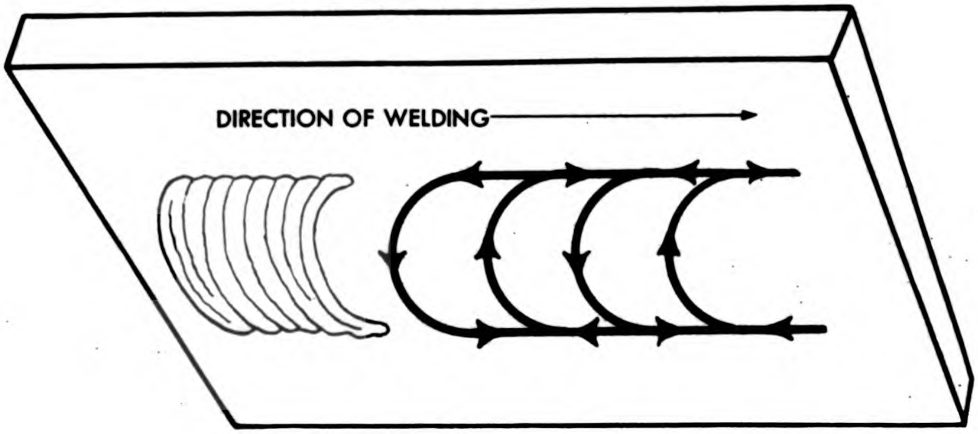

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Figure 100 — Weave Motion in Overhead Position

d. Butt Joints.

(1) Butt joints in the overhead welding position are most satisfactorily made by using back-up strips. The plates should be prepared for welding in a manner similar to that used for welding butt joints in the flat position. If no back-up strip is used, and the plates are bevelled with a feather edge, the weld will burn through repeatedly unless extreme care is used by the operator.

(2) For overhead welding, bead welds are preferred to weave beads. Each bead should be cleaned, and rough areas should be chipped out, before depositing the next bead weld.

(3) The positions of the electrode and the order to be followed in depositing beads on ¼-inch and ½-inch plates are shown in A and B, figure 101.

(4) The electrode should not be too large, as this will prevent holding a short arc while obtaining good penetration at the root of the joint.

(5) The first pass should be made by holding the electrode at 90 degrees to the plate, as shown in C, figure 101.

(6) Excessive currents will create a very fluid puddle in which control of the molten metal is difficult.

e. Fillet Welds.

(1) In making fillet welds in either T- or lap joints in the overhead position, a short arc should be held, and there should be no weaving of the electrode. The electrode should be held at approximately 30 degrees to the vertical plate and moved uniformly in the direction of welding, as shown in A, figure 102. The arc motion should be controlled to secure good penetration to the root of the weld and

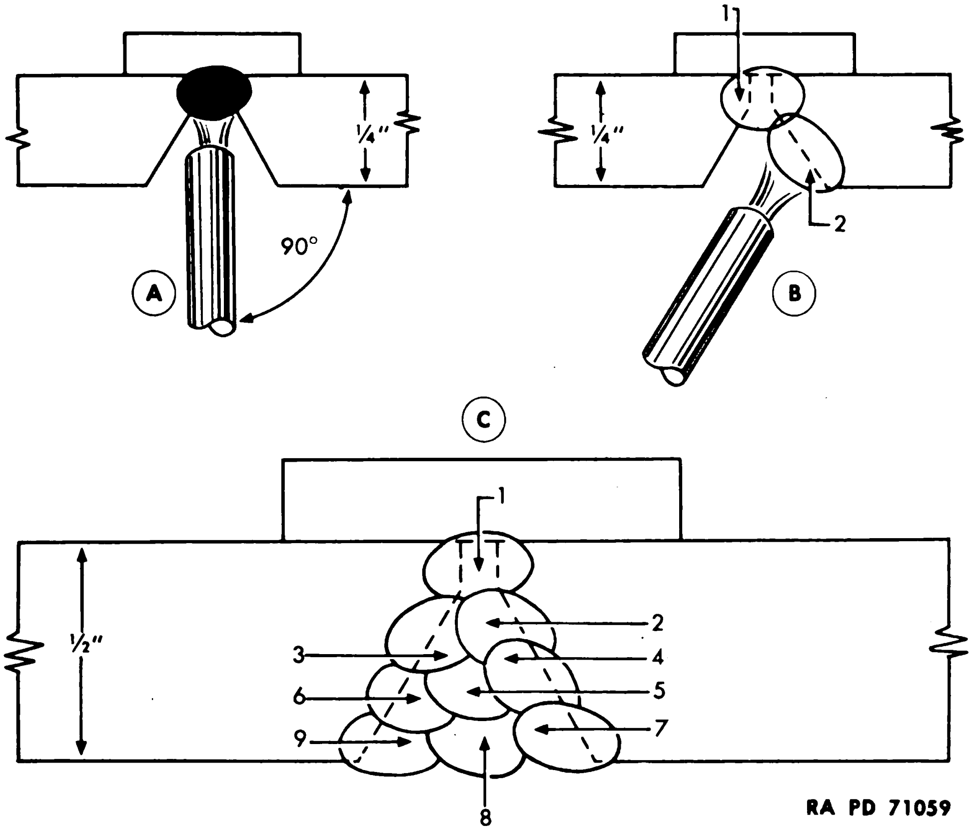

Figure 101 — Welding Butt Joint in the Overhead Position

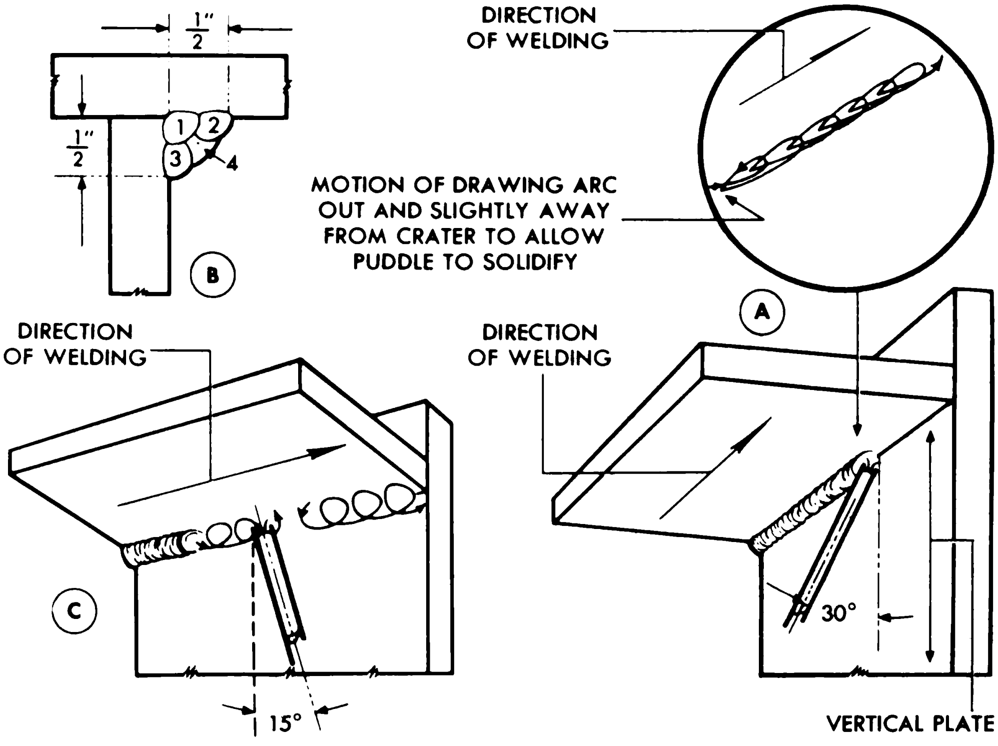

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Figure 102 – Fillet Welding in the Overhead Position

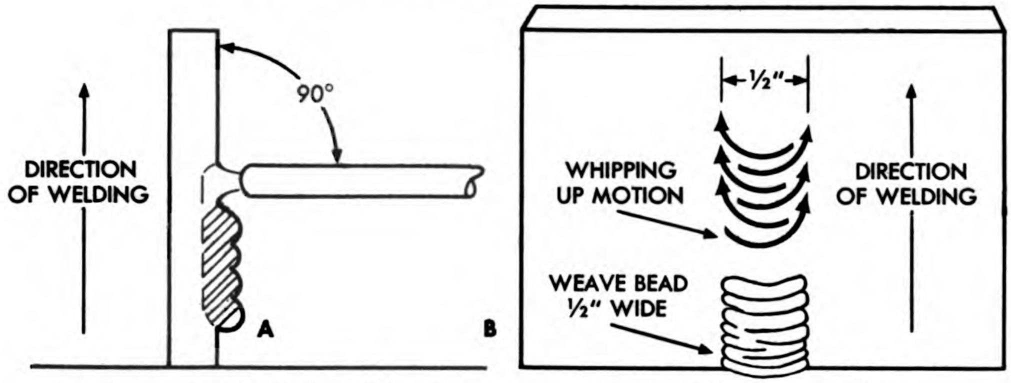
good fusion with the sidewalls of the vertical and horizontal plates. If the molten metal becomes too fluid and tends to sag, the electrode should be whipped away quickly from the crater ahead of the weld, so as to lengthen the arc and allow the metal to solidify. The electrode should then be returned immediately to the crater of the weld and welding continued.

(2) Fillet welds for making either T- or lap joints in the overhead position on heavy plate require several passes or beads to make the joint. The order in which these beads are added to the joint are shown in B, figure 102. The first pass or bead is a string bead with no weaving motion of the electrode. The second, third, and fourth passes are made with a slight circular motion of the end of the electrode while the top of the electrode is held tilted about 15 degrees in the direction of welding, as shown in C, figure 102. This motion of the electrode permits greater control and better distribution of the weld metal being deposited. All slag and oxides should be removed from the surface of each string bead by chipping or wire brushing before additional beads are deposited in the joint.

202. VERTICAL POSITION WELDING.

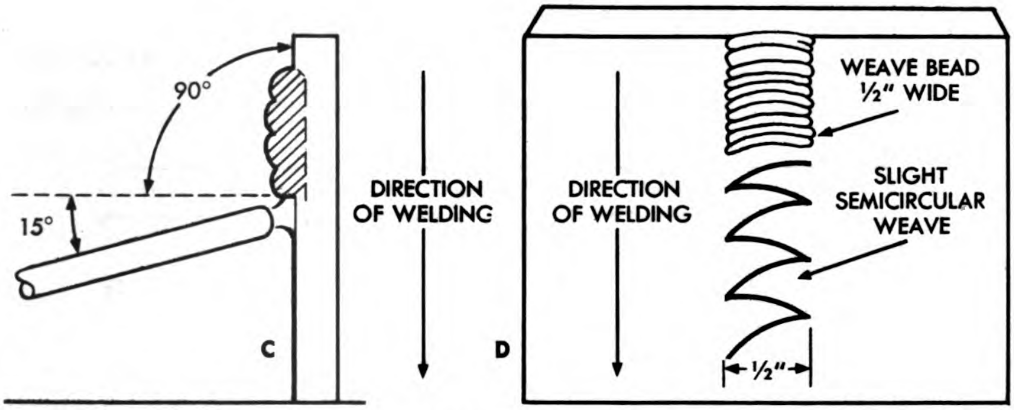
a. Bead Welds.

(1) Welding on a vertical surface is more difficult than welding in



VERTICAL BEAD WELD, WELDING UP

VERTICAL WEAVE BEAD WELD, WELDING UP



VERTICAL BEAD WELD, WELDING DOWN

VERTICAL WEAVE BEAD WELD, WELDING DOWN

RA PD 71060

Figure 103 — Welding in the Vertical Position, Bead in Vertical Position

the flat position. Due to the force of gravity, the molten metal will always have a tendency to run down.

(2) To control the flow of molten metal, a short arc, as well as careful arc voltage and welding current adjustments, is necessary.

(3) In metal arc welding, current settings for welds made in the vertical position should be less than those used for the same electrode size and type on welds made in the flat position. The currents used for welding up on vertical plate are slightly higher than those used for welding down on vertical plate.

(4) The proper angle between the electrode and the base metal is also necessary in order to deposit a good bead weld in vertical welding.

(5) In welding up, the electrode should be held at 90 degrees to the vertical, as shown in A, figure 103. When welding up and weaving is necessary, the electrode should be oscillated as shown in B, figure 103.

(6) In welding down, bead welds on vertical plate should be made by holding the top end of the electrode about 15 degrees below the

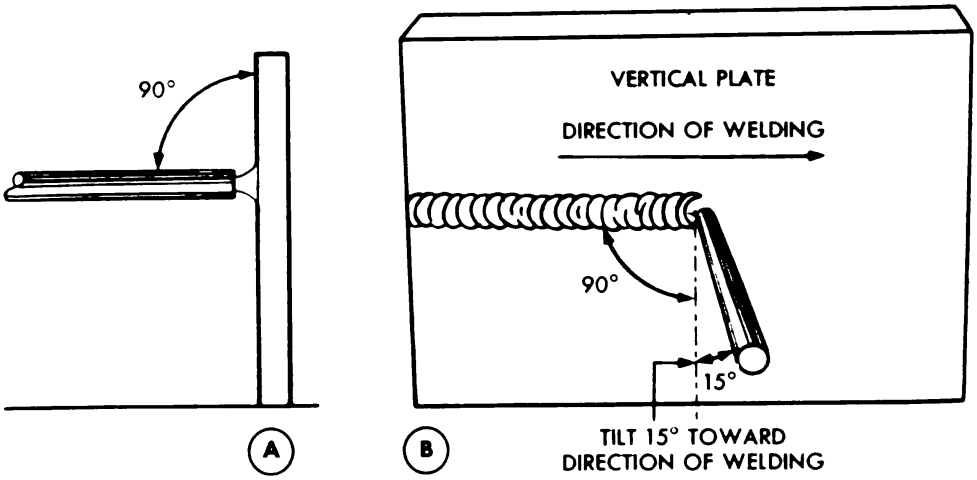


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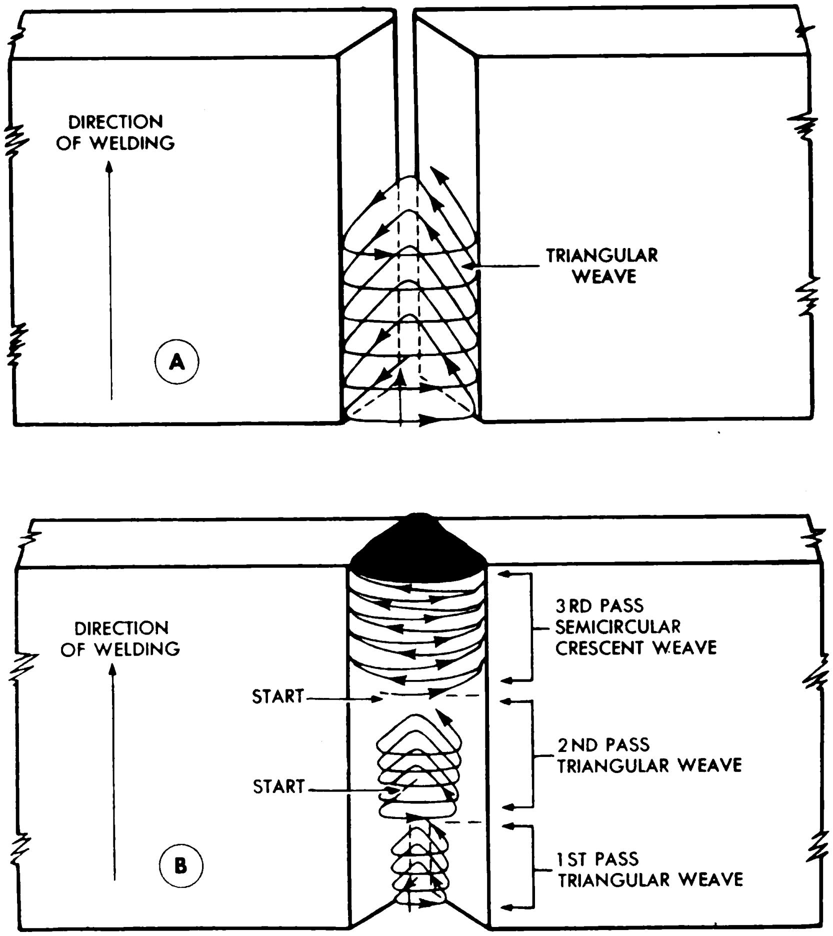
Figure 104—Welding in the Vertical Position, Bead in Horizontal Position



RA PD 71062

Figure 105a — Butt Joint Welding in the Vertical Direction horizontal to the plate with the arc pointed upwards toward the oncoming molten metal, as shown in C, figure 103. When a weave bead is necessary in welding down, the electrode should be moved or oscillated as shown in D, figure 103. In depositing a bead weld in the horizontal plane on a vertical plate, the electrode should be held at right angles to the vertical, as illustrated in A and B, figure 104. The top of the electrode should be tilted about 15 degrees toward the direction of welding so as to obtain a better view of the arc and crater. The welding currents used should be slightly less than those required for the same type and size of electrode in flat position welding.

b. Butt Joints.

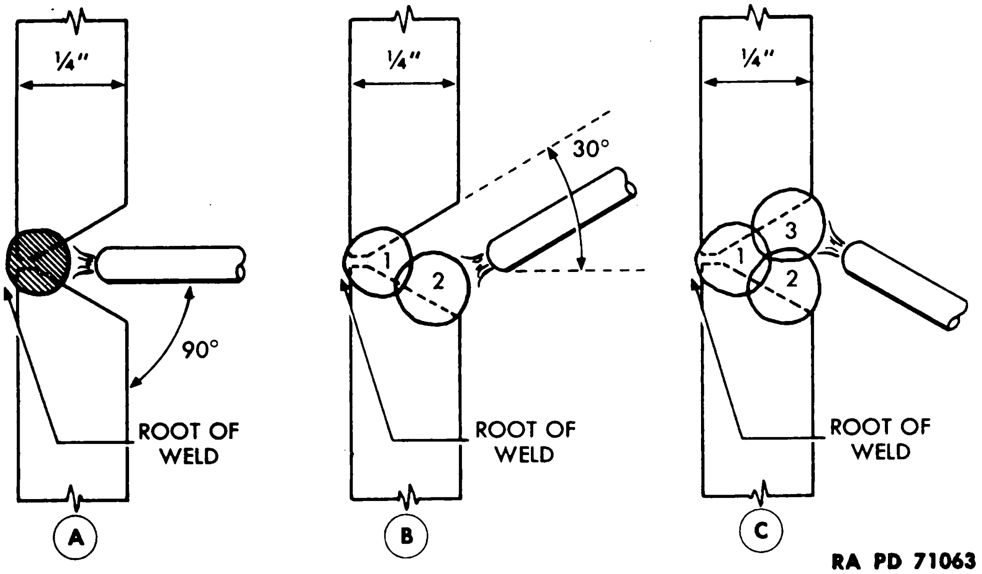
(1) Butt joints on plates in the vertical position are prepared for welding in a manner similar to that used for welding butt joints in the flat position.

(2) In order to obtain good fusion with no undercutting a short arc should be held and the motion of the electrode should be carefully controlled.

(3) Butt joints on bevelled plates ¼ inch in thickness can be made by using a triangular weave motion, as shown in figure 105a.

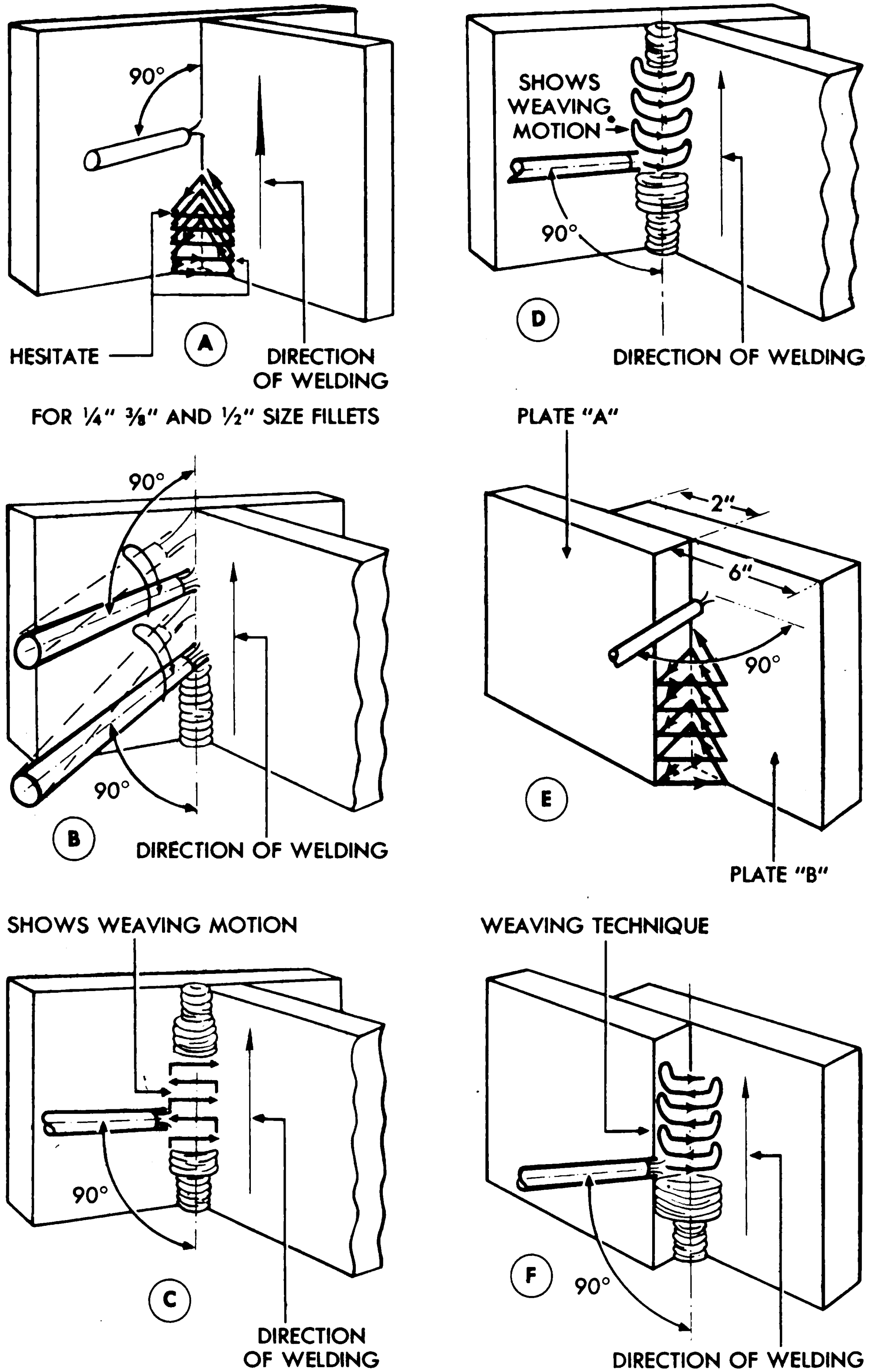
(4) Welds on ½-inch plate should be made in several passes, as shown in figure 105a. The last pass should be deposited with a semicircular weaving motion and a slight "whip-up" and hesitation of the electrode at the edge of the weave bead. Welds with a back-up strip should be made in the same manner.

(5) In welding butt joints in the horizontal direction on vertical



RA PD 71063

Figure 105b — Butt Joint Welding in the Horizontal Direction



RA PD 71064

Figure 106 — Fillet Welds in the Vertical Position

plates, a short arc is necessary at all times. The metal is deposited in beads as shown in figure 106. The first pass is made from left to right or right to left with electrode held at 90 degrees to the vertical plates. The second, third, and other passes are made in alternate steps with the electrode held approximately parallel to the bevelled edge opposite to the one being welded.

c. Fillet Welds.

(1) In making fillet welds in either T- or lap joints in the vertical position, the electrode should be held at 90 degrees to the plates or up to 15 degrees above the horizontal for better molten control, and the arc should be held short to obtain good penetration, fusion, and molten metal control.

(2) In welding T-joints in the vertical position, the electrode should be moved in a triangular weaving motion, as shown in A, figure 106. The joint should be started at the bottom and welded upwards. A slight hesitation in the weave at the points indicated will improve sidewall penetration and allow good fusion at the root of the joint.

(a) If the weld metal should overheat, the electrode should be lifted away quickly at short rapid intervals, as shown in B, figure 106, without breaking the arc. This will allow the molten metal to solidify without running down. The electrode should be returned immediately to the crater of the weld, so as to maintain the desired size of fillet weld.

(b) When more than one layer of metal is necessary to make a vertical T-weld, either of the weaving motions shown in C and D, figure 106, may be used. A slight hesitation at the end of the weave will result in good fusion without undercutting the plate at the edges of the weld.

(3) TO MAKE LAP WELDS IN THE VERTICAL POSITION. The electrode should be moved in a triangular weaving motion, as shown in E, figure 106. The same procedure is followed as outlined for welding vertical T-joints, except that the electrode is directed more toward the vertical plate marked "B." The arc should be held short, and the hesitation of the weave, at the surface of plate "B," should be slightly longer. Care should be taken not to undercut either plate or to allow the molten metal to overlap at the edges of the weave.

(a) On heavy plate, lap joints in the vertical position require more than one layer of metal. The first bead should be thoroughly cleaned and additional layers of weld metal deposited by the procedure shown in F, figure 106. The same precautions for obtaining good fusion and an even bead apply to vertical lap joints as to vertical T-joints.

CHAPTER 8

ELECTRIC ARC WELDING: EQUIPMENT, PROCEDURE, AND TECHNIQUE (Cont'd)

Section VI

HEAT EFFECTS IN ELECTRIC ARC WELDING

	Paragraph
General	203
Factors affecting the heat-disturbed area	204
Hardness in arc welding	205

203. GENERAL.

a. The rate at which heat is applied to the plates being welded is greater in arc welding than in oxyacetylene welding. This causes a higher concentration of heat at a particular point, and, therefore, a steeper temperature gradient and less metal affected by the heat. In bare-wire arc welding, the heat-affected zone is the most narrow; it increases for heavy-coated electrodes and bare-rod gas welds. Stainless steel electrodes produce a smaller area of heat disturbance than the heavy-coated steel electrodes (pars. 88, 100, 101, and 102).

204. FACTORS AFFECTING THE HEAT-DISTURBED AREA.

a. Generally speaking, the amount of heat-affected area will increase with the amount of welding heat used in arc welding. This is a direct function of the voltage and amperage settings. Greater penetration for arc welds is not necessarily obtained with the increase in heat-affected area, since the heat-affected area usually increases in width rather than depth. With the exception of cored and stainless steel electrode arc welds, the smaller the heat-affected area, the greater becomes the removal of heat from this area by the surrounding parent metal.

b. In arc welding, the extent of the heat-disturbed area is increased in the following cases:

(1) In welding with constant current, decreased speed of welding will increase the heat-affected zone.

(2) In welding at constant speed, increased current will increase the heat-affected zone.

(3) With the same setting on the welding machine, the shorter arc length will generally produce greater heat input to the parent metal.

(4) In lighter sections, the heat-affected zone is increased.

(5) Preheating before welding increases the heat-affected zone.

(6) The physical characteristics of the heat-affected zone will be affected by the insulation of the weld.

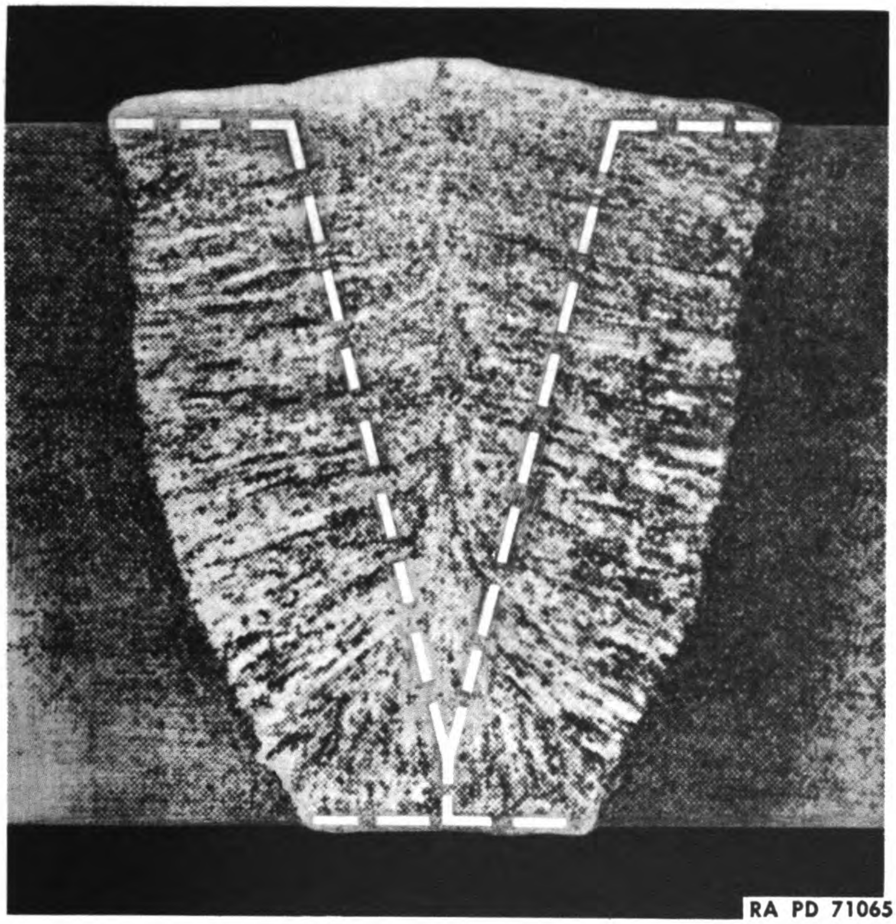


Figure 107 — Etched Cross Section Showing Heat-affected Area

205. HARDNESS IN ARC WELDING.

a. Arc welding produces greater hardness than oxyacetylene welding for the same type of welding operation, and the hardened zone is more concentrated. In general, the greater the hardness produced in arc welds, the more likely is the weld to crack when the molten metal solidifies. Arc welds on plate containing 0.35 percent carbon or higher show a greater rate of increase in hardness than arc welds in steels containing less than 0.35 percent carbon. In alloy steels, certain elements are added to increase the strength, but these also increase the hardness produced by the carbon. The carbon content is usually kept low, therefore, to prevent the formation of excessive hardness by the arc welding operation. In plain carbon steels having 0.25 percent carbon or less, welds made by either gas or arc welding do not change very much in hardness, tensile strength, or ductility.

CHAPTER 9

ELECTRIC ARC WELDING AND CUTTING OF METALS

Section I

ELECTRIC ARC WELDING OF FERROUS METALS

Paragraph
Low-carbon steel (carbon content up to 0.30 percent) 206
Medium-carbon steel (carbon content 0.30 percent to 0.50 percent) 207
High-carbon steel (carbon content 0.50 percent to 0.90 percent) 208
Tool steel (carbon content 0.80 percent to 1.50 percent) 209
Alloy steels 210
Cast iron 211
Welding large iron castings 212
Metal arc brazing of cast iron 213
Carbon arc welding of cast iron 214

206. LOW-CARBON STEEL (CARBON CONTENT UP TO 0.30 PERCENT).

a. Plain Carbon Steels.

(1) These can be readily welded by either the metal or carbon arc processes.

(2) Low-carbon steels do not harden appreciably when welded and therefore do not require preheating or postheating except in special cases.

(3) The heavy-coated type of electrode produces the best results.

b. Metal Arc Welding.

(1) In metal arc welding, the bare, wash-coated, or heavy-coated shielded-arc types of electrode may be used. These electrodes are of the low-carbon type and produce good qualities in the weld metal.

(2) Low-carbon sheet or plate materials which have been exposed to low temperatures should be preheated slightly (up to 200 F) to remove the chill from the plates before welding. As in the case of oxyacetylene welding, the plate edges can be prepared by flame cutting or machining with good results in the welded joint.

(3) In welding sheet metal up to 1/8 inch in thickness, the plain square butt-joint type of edge preparation should be used. When long seams are to be welded in this material, the edges should be spaced to allow for shrinkage, as the deposited metal tends to pull the plates together. Since this shrinkage is less severe in arc welding

than it is in gas welding, the spacing should be approximately 1/8 inch per foot of seam welded.

(4) The step-back or skip-welding procedure should be used in welding short seams that are fixed in place, in order to prevent warpage or distortion.

(5) Heavier plates should be bevelled to give an included angle of 60 degrees to 75 degrees, depending upon the thickness. The parts should be tack-welded in place at short intervals along the seam, and the first or root bead should be made with an electrode small enough in diameter to obtain good penetration and fusion at the base of the joint. A 1/8-inch or 5/32-inch electrode is suitable for this purpose. The bead should be thoroughly cleaned by chipping and wire brushing before additional passes or layers of weld metal are deposited. A 5/32-inch or 3/16-inch electrode should be used to make additional passes of filler metal in the joint. For plates welded in the flat, vertical, or horizontal welding positions, these passes should be made with a weaving motion of the electrode.

(6) For overhead welding, best results are obtained by using string beads throughout the entire thickness of the joint.

(7) In welding heavy sections that are bevelled from both sides, the weave beads should be deposited alternately on one side and the other to reduce the amount of distortion in the welded structure. Care should be taken to clean each bead or layer of weld metal thoroughly so as to remove all scale, oxides, and adhering slag before additional metal is deposited. The motion of the electrode should be controlled so as to make each bead uniform in thickness and to prevent undercutting and overlap at the edges of the weld. All slag and oxides should be thoroughly removed from the surface of the completed weld to prevent rusting. If it is desired to paint the joint after welding, it should be heated by means of an oxyacetylene torch, the flame being played quickly back and forth until the plates are warm to the hand. Painting should be done immediately before moisture has a chance to condense on the surface.

c. **Carbon Arc Welding.** Low-carbon sheet and plate up to 3/4 inch in thickness can be satisfactorily welded by the carbon arc welding process. The carbon arc is struck against the plate edges which have been prepared in a manner similar to that used for metal arc welding. A special flux should be used on the joint, and filler metal added, in a manner similar to that used for oxyacetylene welding. A flux-coated rod should be used to provide a protective atmosphere for the weld, and welding should be done without overheating the molten metal. If these precautions are not taken, the weld metal will absorb an excessively high amount of carbon from the electrode and oxygen and nitrogen from the air, thus producing brittleness in the welded joint.

207. MEDIUM-CARBON STEEL (CARBON CONTENT 0.30 PERCENT TO 0.50 PERCENT).

a. Since the steels in this group are usually heat-treated, preheating from 300 F to 500 F should be used to develop hardness and strength in the finished part before welding with plain carbon steel electrodes. The electrodes should be of the low-carbon, heavily flux-coated, reversed-polarity type, similar to those used for metal arc welding of low-carbon steels. The preheating temperatures will vary, depending upon the thickness of the plates as well as their carbon content. After welding, the entire joint should be heated to from 1,100 F to 1,200 F to relieve the stresses produced in the base metal adjacent to the weld.

b. These steels can also be welded with the modified 18-8 or 25-20 types of stainless steel electrodes, and in this case the plates need not be preheated or postheated.

c. **Welding Technique.** The plates should be prepared for welding in a manner similar to that used for preparing low-carbon steels. In welding with the low-carbon steel electrodes, the welding heat should be carefully controlled to avoid overheating of the weld metal and excessive penetration into the sidewalls of the joint in the base metal. This is accomplished by using the principle of surface fusion whereby the electrode is not directed against the sidewalls of the joint but more against the previously deposited filler metal adjacent to the sidewalls. By using this procedure the weld metal is caused to wash up against the side of the joint and fuse with it without deep or excessive penetration. High welding heats will also cause large areas of the base metal in the fusion zone adjacent to the weld to become hard and brittle. By making the weld with a series of small string or weave beads, the heat input, and therefore the formation of hard zones in the base metal, will be kept at a minimum. Each bead or layer of weld metal will refine the grain in the weld metal immediately beneath it and will anneal or soften the hardness produced in the base metal by the previous bead. When possible, the finished joint should be heat-treated after welding for best results.

d. In welding medium-carbon steels with the stainless electrodes, the metal should be deposited in string beads to prevent weld metal in the fusion zone from cracking. In welding upper layers in joints made on heavy sections, the weaving motion of the electrode should, under no circumstances, exceed two to three electrode diameters.

e. In general, in welding by either of these methods, the same precautions for cleaning the beads should be used as those outlined for welding low-carbon steels.

208. HIGH-CARBON STEEL (CARBON CONTENT 0.50 PERCENT TO 0.90 PERCENT).

a. Because of the higher carbon content and the heat treatment given to these steels, they do not have good properties after arc welding. Preheating from 500 F to 800 F before welding and stress-relieving by heating from 1,200 F to 1,450 F after welding should be used to avoid hardness and brittleness in the fusion zone. Either the mild steel or stainless steel electrodes, discussed under medium-carbon steels can be used with good results, however, the fusion zone will be hard unless the joint is heat-treated after welding. In some cases, it is possible to control the welding procedure so as to keep these hard zones down to a minimum.

b. **Welding Technique.** The welding heat should be adjusted to give good fusion to the sidewalls and root of the joint without excessive penetration. This can be accomplished by keeping the welding heat down and by depositing the metal in small string beads. The same precautions for edge preparation, cleaning of the welds, and sequence of welding beads apply for high-carbon steels as for low- and medium-carbon steels. Excessive puddling of the metal should be avoided since this practice picks up carbon from the base metal and thus causes the weld metal to become hard and brittle. Fusion between the filler metal and sidewalls of the joint should be confined to a narrow zone using the principle of surface fusion as described for welding medium-carbon steels.

c. High-carbon steel surfaces are often built up to repair worn surfaces on small parts. When possible, the piece should be annealed or softened by heating to a red heat and slowly cooling. The weld should be made with medium-carbon or high-strength electrodes, and the entire piece should be heat-treated after welding to restore its original properties.

209. TOOL STEEL (CARBON CONTENT 0.80 PERCENT TO 1.50 PERCENT).

a. Steels in this group are rarely welded by means of arc welding because of the high degree of hardness produced in the fusion zone of the base metal. If arc welding must be done, either the mild steel or stainless steel electrodes can be used to make the joint.

b. **Welding Technique.** If the parts being welded are small, they should be completely annealed or softened before welding. The edges should then be preheated up to 1,000 F, depending upon the carbon content and thickness of the plate, and welding should be done with either a mild steel or a high-strength electrode. High-carbon electrodes should not be used for welding tool steels. The carbon picked up by the filler metal from the base metal being welded will cause the weld to become glasshard. Whereas the mild steel weld metal can absorb additional carbon without becoming excessively hard. The welded part should then be heat-treated to restore its original properties. In welding with the stainless steel electrodes, the edges of the plates should be preheated to prevent the formation of hard zones in the base metal and fusion zone. The metal should be deposited in small string beads to keep the heat input to the base metal down to a minimum. In general, the same procedures should be followed for welding these steels as for welding medium- and high-carbon steels.

210. ALLOY STEELS.

a. A large number and variety of alloy steels have been developed to obtain such special properties as high strength, high hardness, and corrosion resistance (ch. 3, sec. V). Most of these steels depend upon a special heat treatment process in order to develop the desired properties in the finished state. Heat-treated steels should be preheated before welding in order to avoid the formation of hard zones or layers in the base metal adjacent to the weld and in the fusion zone. Many of these steels can be welded with a heavy-coated electrode of the shielded-arc type whose composition is the same as that of the base metal. Low-carbon electrodes are also used with good results. For welding applications where preheating cannot be used or is undesirable, the modified 18-8 or 25-20 stainless steel electrodes should be used. These electrodes give good properties in the finished joint without any special heat treatment. If the welding heat is carefully controlled and the weld metal deposited in narrow string beads, heating of the base metal will be kept down to a minimum. In many cases, the procedure outlined for medium- and high-carbon steels, including the principle of surface fusion, can also be used on alloy steels. Preheating temperatures, electrode types, polarity settings, and electrode materials for welding specific alloy steels are given in paragraph 289.

211. CAST IRON.

a. Gray cast iron has low ductility, that is, it will not stretch a great deal before breaking or cracking. This property should be considered in welding cast iron by the electric arc method. Although preheating is necessary in welding cast iron by the oxyacetylene method, cast iron can be welded satisfactorily with the metal arc without preheating. This requires a very careful control of the welding heat and the procedure used in making the joint. Only short lengths of the joint should be welded at a time and these lengths should be allowed to cool so as to keep the entire casting from expanding and cracking. The heat of welding is thereby confined to a small area of the entire casting, and the danger of cracking is eliminated. Large castings with complicated sections, such as motor blocks, can be welded without dismantling or preheating.

b. **Edge Preparation.** The edges of the joint should be chipped out or cleaned by grinding to form a 60-degree included angle of bevel before welding. The "V" should extend to within approximately ⅛ inch of the bottom of the crack. Where a crack in a casting is to be repaired, a small hole should be drilled into the casting at each end of the crack to prevent it from spreading. All grease, dirt, and other foreign materials should be removed by washing with CARBON TETRACHLORIDE, or a similar cleaning material.

c. Welding Technique.

(1) Cast iron can be welded satisfactorily with a coated electrode having a steel base. In using this type of electrode, care should be taken to consider the contraction of the steel weld metal, the carbon picked up by the weld metal from the cast iron, and the hardness which will result in the weld metal from rapid cooling. Steel shrinks or contracts more than cast iron when cooling from a molten state to a cool state. This uneven shrinkage will cause strains in the joint after welding. When a large quantity of filler metal is applied to the joint, the cast iron may crack just back of the line of fusion. To overcome these difficulties, the prepared joint should be welded by depositing the weld metal using string beads in short lengths of ¾ inch to 1 inch at a time. These short lengths of welds should be made intermittently and in some cases the step-back and skip procedure should be used. To avoid hard spots the arc should be struck in the "V" and not on the surface of the base metal. Each short length of weld metal applied to the joint should be peened with a light ball peen hammer while still hot, and allowed to cool before additional weld metal is deposited. The peening action forges the metal and relieves the cooling strains. This reduces the danger of cracking in weld or base metal, and the cooling between beads reduces the amount of heat applied to the parts being welded. The electrodes used should be ⅛ inch in diameter so as to keep the heat down; the welding should be done with reverse polarity; the welding current should be kept at approximately 80 amperes on the ⅛-inch electrode; and weaving of the electrode should be kept down to a minimum. Each weld metal deposit should be thoroughly cleaned by chipping and wire-brushing before additional metal is added.

(2) Welds made with steel electrodes are generally three to four times as strong as the base-metal casting. In order to insure that the welded joint is liquid or gas tight, the composite sulphur and graphite powder bar described in paragraph 145 **h** should be applied to the finished weld after cleaning and while it is still hot.

(3) Cast iron can also be welded with heavy-coated monel, cast iron, or 18-8 type stainless steel electrodes. The procedure for making these welds is the same as that outlined for welding with mild steel electrodes. Peening of the weld metal is necessary in order to prevent cracking. Stainless steel electrodes give a better bond between the filler metal and the base metal at the joint, however, extreme care should be used to avoid cracking in the weld and fusion zone as stainless steel expands and contracts approximately 50 percent more

than mild steel for the same change in temperature. Welds made with monel or electrodes which contain nickel can be machined to a finished dimension or size after welding.

212. WELDING LARGE IRON CASTINGS.

a. Heavy sections of cast iron can be welded with heavy-coated mild steel electrodes by following the procedure outlined above. Studs or grooves are sometimes used to strengthen the welded joint mechanically. Studs should be made of steel approximately 1/4 inch to 3/8 inch in diameter. The cast iron should be given a V-angle of bevel at the joint, and the studs should be screwed into holes drilled and tapped along the "V." These studs should project about 3/16 inch to 1/4 inch above the cast iron surface and should be long enough to be screwed into the tapped holes in the casting to a depth of at least the diameter of the stud. The studs should be spaced between 1 and 2 inches apart and arranged in a line along the face of the bevel. The projecting ends should be seal-welded in place by one or two beads around each stud. These studs are all tied together by means of the weld metal added to the joint. Welds should be made in short lengths, and each length peened while still hot so as to prevent high stresses or cracking upon cooling. Each bead deposited should be allowed to cool and should be thoroughly cleaned before additional metal is applied to the joint. Where it is difficult to apply studs to the joint, the edges of the castings can be chipped out or machined with a round-nosed tool to form long U-shaped grooves on the surface and face of each bevel at the joint. These grooves serve as anchors for weld metal deposited in the joint and help to increase its strength mechanically.

213. METAL ARC BRAZING OF CAST IRON.

a. Cast iron can be welded with heavy-coated reversed-polarity bronze electrodes. The joints made by this process should be prepared in a manner similar to that used for oxyacetylene brazing of cast iron. The strength of the joint depends upon the quality of the bond between the bronze filler metal and the cast iron base metal.

214. CARBON ARC WELDING OF CAST IRON.

a. Iron castings may be welded with the carbon arc, a cast-iron rod, and a cast-iron welding flux. The carbon electrode should be moved along the surface of the cast iron to preheat the joint, thereby preventing rapid cooling after welding. The molten puddle formed by adding filler metal can be worked with the carbon electrode so as to move to the surface any slag and oxides formed. Welds made by this process cool slowly and are not as hard as those made with the metal arc and a cast iron electrode. This fact permits the weld to be machined and eliminates hard spots in the deposited metal.

CHAPTER 9

ELECTRIC ARC WELDING AND CUTTING OF METALS (Cont'd)

Section II

ELECTRIC ARC WELDING OF NONFERROUS METALS

Paragraph
Copper 215
Brasses and bronzes 216
Aluminum 217

215. COPPER.

a. Copper may be welded satisfactorily with bare electrodes by either the carbon arc or the metal arc method, since no fluxes are necessary. Due to the high thermal conductivity of copper, the welding currents required are somewhat higher than those ordinarily used for steel, and the base metal should be heated to a black heat of 400 F to 600 F before welding.

b. Welding with Metal Arc. The plates should be prepared for welding in the same manner as that described in subparagraph **c**, below, for carbon arc welding. When phosphor-bronze bare electrodes are used, the polarity should be reversed, that is, the electrode is positive. The requirements for welding current and polarity will vary with each manufacturer's type of electrode. In general, a deoxidized copper or bronze electrode can be used with satisfactory results. The current and polarity should be so adjusted as to obtain a uniform melting of the electrode and base metal which will assure a uniform weld with good penetration.

c. Welding with Carbon Arc. For carbon arc welding, the plates to be welded should be cleaned and clamped or tack-welded securely in place. A copper back-up strip is required, and the welding speed used is 10 to 20 inches per minute. The welding rod selected should be of a diameter which will complete the weld, with suitable reinforcement, when melted at the rate of 1 inch of rod per inch of seam. For plate thicknesses of 1/16 inch to 1/8 inch, a 1/4-inch carbon electrode and 150 to 200 amperes welding current give a satisfactory weld. For plate thicknesses between 3/16 inch and 1/4 inch, a 3/8-inch carbon electrode and 200 to 250 amperes welding current are required. The welding current values will vary, depending upon the set-up and the size of the back-up strip used. The arc should be short and should be directed entirely on the weld metal even at the starting point. If possible, all carbon arc welding should be done with the plate in the flat welding position or on a moderate slope.

216. BRASSES AND BRONZES.

a. Metal Arc Welding. Brasses and bronzes may be successfully welded by the metal arc process. This requires a shielded-arc type of electrode with reversed polarity (electrode positive), and the plates should be prepared in the same manner as for oxyacetylene welding. Electrodes varying in diameter from 1/8 inch to 1/4 inch will require approximately 100 to 225 amperes of welding current. Care should be taken not to use excessively high welding current so that the zinc will not be volatilized.

b. Carbon Arc Welding. The carbon arc process can be used to weld brasses and bronzes with suitable welding rods of approximately the same composition as the base metal. In this process, the welding is accomplished by bonding to the base metal in very much the same way that bronze would bond to steel. The metal in the carbon arc process is superheated, and this very hot metal is alloyed to the base metal to make the joint. This process, when a phosphor-bronze filler rod is used, is comparatively free from zinc fumes, since the brass base metals being welded do not actually melt.

217. ALUMINUM.

a. Aluminum and aluminum alloys can be satisfactorily fusion-welded with the metal or carbon arc. The principal advantage of using these processes is that a highly concentrated heating zone is obtained with the arc, thus preventing excessive expansion and distortion.

(1) METAL ARC WELDING. In welding plates or sections up to 1/8 inch in thickness, butt and fillet welds are relatively difficult to control, and the quality of the welds is not as satisfactory as that obtained with the oxyacetylene process. In welding plate heavier than 1/8 inch the plate should be bevelled, and the weld obtained is equal in strength to oxyacetylene welded joints. The weld metal, however, may be porous and therefore unsuited for liquid or gastight joints. Where the joints must be gas or liquid-tight the composite sulphur and aluminum powder bar described in paragraph 154 **d** (8) should be applied to the welded joint while it is still hot. The same precautions with regard to preheating as for oxyacetylene welding of aluminum are also required in metal arc or carbon arc welding of aluminum. The electrodes should be of the 5 percent silicon and 95 percent aluminum type, and should be either of the heavy-coated or shielded-arc varieties. The flux coating prevents the formation of aluminum oxide and controls the rate of cooling of the molten metal as well. It also acts to remove any impurities in the weld metal. The polarity for the shielded-arc types of electrode should be reversed, that is, the electrode is positive, and the current settings should be adjusted to give good flowing qualities to the weld metal. The current and polarity settings will vary with each manufacturer's type of electrode; however, to weld plate up to 1/8 inch

in thickness, a welding current of 50 to 80 amperes is required with a ⅛-inch electrode. For plate thicknesses of ⅛ inch to ⅜ inch a 3/16-inch or ¼-inch electrode, using 100 to 200 amperes welding current, produces satisfactory welds. The joints for metal arc welding should be backed up with an iron or copper back-up strip which has been grooved directly below the weld.

(2) CARBON ARC WELDING. Aluminum can be welded with a carbon arc and flux-coated rod to produce welds that are free from oxides and porosity. The same procedure should be followed as in metal arc welding. The welding flux should be removed by the methods described for oxyacetylene welding of aluminum; this is important in order to prevent corrosion of the welded joint.

(3) WELDING ALUMINUM CASTINGS. Cracks in castings should be chipped out, leaving a shoulder at the bottom of the joint. The entire casting should be preheated to between 500 F and 800 F before welding. Preheating of heavy sections reduces the welding current required, and less spatter is thereby obtained. This procedure is the same as for oxyacetylene welding of aluminum castings. The current setting should be equal to or greater than that used for welding plain carbon steels. A short arc and a welding speed approximately three times that for steel welding should be used. All slag should be cleaned off the welding bead already deposited before restriking the arc and starting another layer. All slag should be removed from the finished weld with warm water in order to prevent corrosion of the joint. Because of the high coefficient of expansion of aluminum and its alloys, fixtures and braces should be used to prevent distortion and buckling. After welding, the entire piece should be covered with sand or asbestos to cool it slowly.

CHAPTER 9

ELECTRIC ARC WELDING AND CUTTING OF METALS (Cont'd)

Section III

CUTTING WITH THE ELECTRIC ARC

Paragraph
General 218
Metals to which electric arc cutting is applicable 219
Procedure for cutting 220

218. GENERAL.

a. Electric arc cutting is a melting process using the heat of the electric arc to melt the metal along the desired line of cut. It differs from oxygen cutting in that it separates pieces by melting rather than by rapid oxidation. The quality of the cuts produced by arc cutting does not equal that of cuts produced with the oxyacetylene torch; however, it is satisfactory for many applications where smooth cuts are not essential.

b. In general, the oxyacetylene process is the preferred cutting process if equipment is available. The arc cutting process in this case is confined to the cutting of nonferrous metals.

219. METALS TO WHICH ELECTRIC ARC CUTTING IS APPLICABLE.

a. Arc cutting can be used to sever or cut all ordinary ferrous metals, including alloy steels and cast iron. It has a definite advantage over flame cutting in that all types of nonferrous metals can also be cut with the arc, whereas flame or oxygen cutting cannot be easily or economically applied to the cutting of nonferrous metals, and is therefore restricted to cutting of ferrous metals at the present time.

220. PROCEDURE FOR CUTTING.

a. Arc cutting can be performed with either a carbon or graphite electrode or a shielded-arc metallic type of electrode. These processes are illustrated in A, figure 108. The cut is made wide in order to melt and work away the metal in the kerf or slot. Although cuts can be made with the plate in the vertical position, best results are obtained with the plate in the horizontal position. The angle to which the electrode must be adjusted is dependent upon the position of the plate. In cutting heavier plates, the electrode should be worked from the top to the bot-

CUTTING WITH THE ELECTRIC ARC

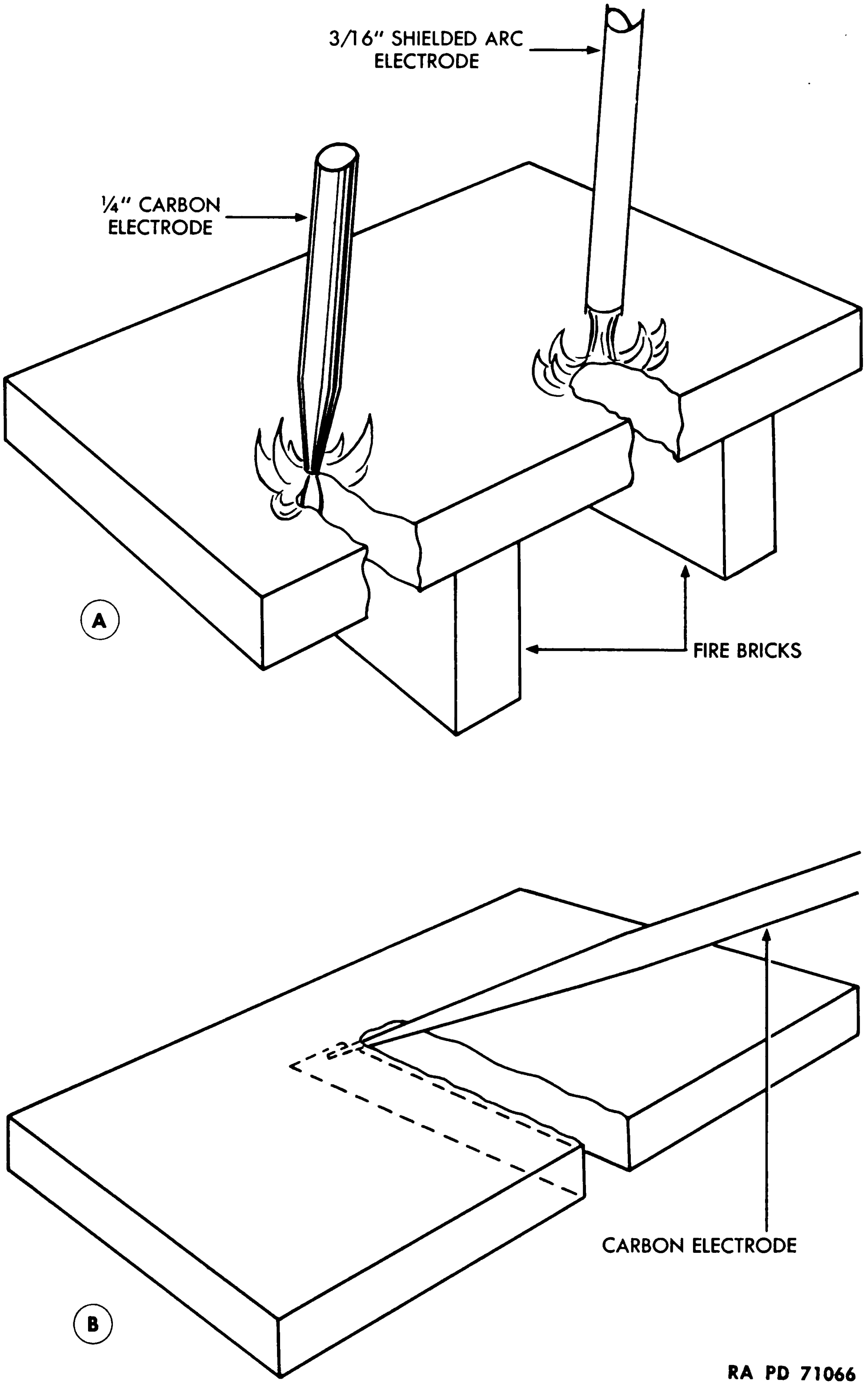


Figure 108 — Carbon and Shielded-arc Cutting

tom of the plate with the bottom of the cut slightly ahead of the top, as shown in B, figure 108.

b. In arc cutting with either the carbon or the shielded-arc type of electrode, straight polarity (electrode negative) and a long arc should be used. The current and voltage settings at the arc are much higher than those required for arc welding. These conditions may require special electrode holders to resist the high heat developed.

c. Rivet cutting and hole piercing are further applications of the arc cutting process. For these operations, as well as for cutting through heavier sections, the shielded-arc electrode is used to better advantage than the carbon electrode. This is primarily due to the electrode coating, which acts as an insulator, thus preventing the arc from shorting against the sidewalls of the hole being cut. In addition, the electrode coating extends beyond the metal core, thus making it possible to push the electrode against the plate or rivet without shorting the circuit.

CHAPTER 10

HARD-SURFACING METALS BY THE ELECTRIC ARC AND OXYACETYLENE PROCESSES

Section I

GENERAL

Paragraph
General 221
Alloys used for hard-surfacing 222
Metals which can be hard-surfaced 223

221. GENERAL.

a. "Hard-surfacing" or "hard-facing" refers to the process of applying extremely hard alloys to the surface of a softer metal in order to increase its resistance to wear, abrasion, cavitation, corrosion, or impact. In most cases, the hard-facing alloys can be applied to the point, surface, or edge of any part by means of either the electric arc or oxyacetylene welding process. The wearing surface of tools, drills, bits, cutters, or other parts, when treated with these special alloys, will outwear the common steels 2 to 25 times, depending on the type of hard-facing alloy used and the service to which the part is subjected.

222. ALLOYS USED FOR HARD-SURFACING.

a. No single hard-facing material is satisfactory for all applications. To meet the various requirements for hardness, toughness, shock and wear resistance, and other special qualities, many types of hard-facing alloys have been developed. These alloys may be generally classified into five groups.

(1) GROUP 1. The alloys in this group consist principally of an iron base and have less than 20 percent of alloying elements. The alloying elements used are mainly chromium, tungsten, manganese, silicon, and carbon. Alloys in this class have a greater wear resistance than any machine steel. Although not as hard, they have greater toughness and shock resistance than other hard-facing alloys. They are used to build up badly worn sections before applying a final harder surface with a better grade of hard-facing alloy.

(2) GROUP 2.

(a) This group consists of iron base alloys having 50 percent to 80 percent iron and more than 20 percent alloying elements. These alloying elements are mainly chromium, tungsten, manganese, silicon, and carbon; small percentages of cobalt and nickel are sometimes added also. Some of the alloys in this class have the property of "red hardness," that is, they remain hard even though operating at a red

heat. These alloys are used for the final hard wear-resisting surface after the part is built up with a high-strength rod. Though not as shock-resistant or as tough as the Group 1 alloys, they are harder and more abrasive-resistant, and they give longer service.

(b) Broken edges of high-carbon or high-tensile low-alloy steels in the heat-treated condition may be repaired by using the transition bead method. This method consists of welding another metal or metals to the base metal before applying the hard-facing material and is performed in the following steps:

1. Grind, chip, or machine the broken or worn surface to clean the break.

2. Deposit a thin layer of stainless steel, such as the 25 percent chromium, 20 percent nickel rod or the 18 percent chromium, 8 percent nickel rod containing columbium.

3. Build up the section to approximately the original dimension, using an 11 percent to 14 percent manganese steel or high-strength rod.

4. Hard-surface with one of the Group 2 alloys.

(3) GROUP 3. This group consists of nonferrous alloys of cobalt, chromium, and tungsten, as well as other nonferrous hard-facing metals. Some of these alloys also have the property of red hardness. They are available in several different grades, all highly resistant to wear but possessing a toughness and spread in strength which gives them a wide variety of applications.

(4) GROUP 4. Alloys in this group consist of the so-called carbide materials or diamond substitutes and are the hardest and most wear-resistant of all hard-facing materials. Some of these alloys contain 90 percent to 95 percent tungsten carbide, the remainer being cobalt, nickel, iron or similar metals. The latter are added to give strength, toughness, heat resistance, and impact strength to the tungsten carbide. Some of these alloys are almost pure tungsten carbide and contain no alloying elements. The materials or alloys in this group are furnished in the form of small castings, which are welded onto the wearing surface by means of other metals. The heat of the oxyacetylene flame or electric arc does not melt the carbide materials, but they are readily "wetted" and thus easily anchored or bonded to other metals or hard-facing alloys. The application of tungsten carbide pieces to wearing surfaces is known as "hard setting." A very good abrasion, and wear-resistant surface, having good red hardness properties, is obtained by setting the tungsten carbide pieces or castings with a hard-facing alloy.

(5) GROUP 5. This group consists of crushed tungsten carbides of various screen sizes. These may be fused to strips of mild or low-alloy steel, embedded in a hard-facing material or high-strength rod, or packed in mild steel tubes of various diameters. All these types are available in short lengths, which may be applied to the wearing surface as welding rods. Crushed tungsten carbides are also available in loose

form as granular pieces or powder, which may be sprinkled onto the wearing surface and melted into it. The materials in this group, although more expensive than the best hard-facing alloys, are used for many applications because of their long life.

b. Application of Hard-facing Alloys.

(1) In general, the hard-facing alloys or materials can be applied by either the oxyacetylene or the electric arc welding process. Alloys in Groups 1 and 2 are welded to the base metal or surface. Care should be taken to avoid puddling or mixing the base metal with the hard-facing material, as this will lower the wear-resistant properties of the surface coating. Those in Group 3 are usually "sweated" to the surface, as in brazing, without melting the base metal. None of the base metal penetrates into the hard surface layer to reduce its resistance to abrasion or wear. The materials or alloys in Groups 4 and 5 are not melted but are bonded by or embedded in mild or low-alloy steels or hard-facing materials, which in turn are welded to the base metal.

(2) Hard-facing alloys are applied with an oxyacetylene flame and rods of suitable design when it is desired to spread the metal over the surface in a thin layer. The electric arc process is used when the surface wear is severe and a somewhat irregular surface of the deposited metal is satisfactory.

223. METALS WHICH CAN BE HARD-SURFACED.

a. Hard-facing materials and rods can be applied satisfactorily to the following metals and alloys:

(1) LOW- AND MEDIUM-CARBON STEELS. All the plain carbon steels with carbon content up to 0.50 percent can be hard-faced by either the oxyacetylene or electric arc process.

(2) HIGH-CARBON STEELS. The high-carbon steels, containing above 0.50 percent carbon, can also be hard-faced by either the oxyacetylene or electric arc process. In some cases, however, care should be taken to heat-treat the base metal before and after hard-facing so as to remove hardness and brittleness and prevent cracking. The transition bead method described may be used to hard-face these steels in the heat-treated condition.

(3) LOW-ALLOY STEELS. Hard-facing can be applied to these steels in the same manner as described for plain carbon steels. In some cases, depending upon the composition of the base metal, heat treatment is required after hard-facing.

(4) HIGH-SPEED STEELS. The hard-facing of these steels is not generally recommended. This is due to the fact that, regardless of heat treatment, brittleness and shrinkage cracks develop in the base metal after hard-facing, thus making the hard-faced piece valueless.

(5) MANGANESE STEELS (11 PERCENT—14 PERCENT MN). The metal arc welding process only is recommended for applying hard-fac

ing materials to manganese steels. Care should be taken to avoid overheating by cooling the manganese base metal only and by applying the welding heat uniformly. The deposit should be peened to relieve cooling stresses.

(6) STAINLESS STEELS. Stainless steels, including the high-chromium and chromium-nickel steels, can be readily hard-faced by means of either the oxyacetylene or electric arc processes. The physical properties of the particular type of stainless steel should be known, in order to avoid brittleness or decreased corrosion resistance after hard-facing. Care should also be taken to avoid, by uniform heating and slow cooling, any warping or cracking due to the higher coefficient of expansion of the stainless steels.

(7) CAST IRON. Gray and alloy cast irons can be hard-faced by means of either the oxyacetylene or electric arc process. Since the melting point of cast iron is lower than that of steel, special precautions should be taken in working on thin edges.

(8) MALLEABLE IRON. Hard-facing alloys can be applied to malleable iron, but the iron underneath the hard-facing layer will be hardened by the heat used in the process. Some of this hardness can be removed by reheating the malleable iron to above 1,500 F.

(9) MONEL METAL. Monel metal can be easily hard-faced.

(10) BRASS AND BRONZE. Since the melting points of brass, bronze, and other alloys are very low, hard-facing cannot be satisfactorily applied to these metals. In some cases, heavy sections preheated to a red heat can be hard-faced by the electric arc process with the Group 3 alloys.

(11) COPPER AND COPPER ALLOYS. These metals have high heat conductivity and relatively low melting points. They can be hard-faced only under the conditions which apply to brasses and bronzes.

(12) ALUMINUM AND ALUMINUM ALLOYS. These metals cannot be hard-faced.

CHAPTER 10

HARD-SURFACING METALS BY THE ELECTRIC ARC AND OXYACTYLENE PROCESSES (Cont'd)

Section II

PROCEDURE FOR HARD-SURFACING METALS

Paragraph
Selection of hard-surfacing material 224
Preparation of base metal for hard-surfacing 225
Hard-surfacing with the electric arc 226
Hard-surfacing with the oxyacetylene flame 227

224. SELECTION OF HARD-SURFACING MATERIAL.

a. Before applying a hard-facing material, the welder should determine the conditions under which the particular piece is to operate and the type of wear expected. There may be present any one or more of the following conditions to increase wear: shock and impact, heat, corrosion, sliding or rolling friction, and abrasion.

(1) In rock-crushing and similar equipment where resistance to shock and impact are most important and hardness is only secondary, the hard-facing alloys of Groups 1 and 2 are used.

(2) Valves designed for handling gas, oil, acids, and high-temperature and high-pressure steam must resist heat, corrosion, and erosion. The Group 3 alloys are used extensively for these applications as well as for valve seats in internal-combustion engines because of their properties of red-hardness and corrosion resistance.

(3) The Group 4 and 5 alloys, being very tough and extremely hard, are used where the wearing parts come in contact with earth, sand, and gravel, as on blades of road scraping and grading equipment, rotary drilling bits, airplane tail skids, steam shovel teeth, and similar applications where high resistance to abrasion is desired.

b. The hard-facing materials classified under group numbers are available under various trade names and in forms suitable for application with either the electric arc or oxyacetylene process. The Stoody Company and the Haynes Stellite Corporation are two of many companies which market these materials, which are identified with the proper group numbers as shown in the following table.

HARD-FACING MATERIALS

Group Number	Stoody Company	Haynes Stellite Corporation
1	"Stoodex" "Stoody Self-Hardening"	"Haschrome"
2	"Stoody Self-Hardening" "Stoodite"	"Haschrome"
3	"Silfram" "Stoodite"	"Stellite"
4	"Borium" "Cobalt Borium"	"Haystellite"
5	"Tube Borium" "Bored"	"Haystellite"

225. PREPARATION OF BASE METAL FOR HARD-SURFACING.

a. The surface of the metal to be hard-faced must be cleaned of all scale, rust, dirt, or other foreign substances by grinding, machining, or chipping. If these methods are not available, the surface may be prepared by filing, wire brushing, or sandblasting. These latter methods are not as satisfactory, since small particles of foreign matter which remain on the surface must be floated out during the hard-surfacing operation. All edges of grooves, corners, or recesses must be well rounded to prevent overheating of the base metal.

b. **Preheating.** The same precautions for preheating should be taken in hard-facing as for welding the particular base metals. Steels in the heat-treated conditions should be annealed, if possible, before the hard-facing layer is applied. After hard-facing, the steels should be heated to their critical temperatures and quenched in oil to restore the original base-metal properties. Quenching in water will crack the hard-facing layer. Where it is impossible or undesirable to anneal these heat-treated steels before hard-facing, the transition bead method is used, as described in paragraph 222 **a** (2) *(b)*.

c. **Use of Fluxes.**

(1) No fluxes are required for applying hard-facing materials by the oxyacetylene process; however, when depositing the hard-facing material in more than one layer, a flux helps to remove any scale and oxides formed on the base metal. This applies particularly to hard-facing cast iron, in which case a cast iron welding flux is satisfactory. The film of flux formed on the molten metal reduces the rate of cooling of the deposited material, thus permitting gas, oxides, and slag inclusions to come to the surface. This process results in a hard and solid surface layer.

(2) In electric arc welding, the hard-facing electrodes are provided with a flux coating which serves the same purpose as the flux used in the oxyacetylene process. No additional flux is necessary.

d. Thickness of Hard-facing Deposit.

(1) In most cases, worn sections are rebuilt with hard-facing deposits ranging from 1/16 inch to 1/4 inch in thickness, depending upon the specific application. Where it is necessary to deposit hard-facing material in thicknesses of more than 1/4 inch, the parts are rebuilt with the Group 1 type of alloys to from 1/16 inch to 1/4 inch of the finished size. The final hard-facing deposit, consisting of Group 2 or 3 alloys, is added with some excess to permit grinding to the desired finished dimensions.

(2) When the harder and more brittle Group 4 and 5 hard-facing materials are applied, either as a final hard-facing deposit or in a single layer, the shape of the deposit should be carefully controlled. This is important in order that impact or shock loads may be transmitted through the hard-facing metal into the tougher base metal. Corners, sharp edges, or built-up sections, when not backed up by tough base metal, will chip or break off in service.

226. HARD-SURFACING WITH THE ELECTRIC ARC.

a. Metal Arc. The base metal should be prepared in a manner similar to that outlined for hard-facing with the oxyacetylene process. Every hard-facing metal, except for some of the Group 5 alloys, is applied, in either coated or bare electrodes, with reversed polarity. The flux coating on the coated electrodes reduces spatter loss, assures good penetration, prevents oxidation of the deposited metal, and helps to stabilize the arc. The bare hard-facing electrodes are used only when it is necessary to apply a heavy bead or to deposit the metal against a copper form. For best results, the metal should be deposited with as long an arc as possible. The voltage should be set as high as possible, and the current should be adjusted for the thickness of base metal and the particular size and type of hard-facing rod used. The following table may be used as a guide for current settings for hard-facing electrodes:

Size of Rod	Current
1/8 in.	100 to 150 amp
3/16 in.	150 to 200 amp
1/4 in.	200 to 250 amp

b. Carbon Arc. The carbon arc process may also be used to apply hard-facing materials to the surface of metals which can be hard-faced by the metal arc process or the oxyacetylene process. The welding machine should be set for straight polarity, and the heat of the arc can be used to melt the hard-facing metals and weld them to the surface being hard-faced. This process is used principally for the application of the Group 5 alloys, in granular or powdered form, to the surface of the steel. In this case, fine particles of tungsten carbide are sprinkled on the surface and welded to the base metal by means of the heat of the carbon arc. In general, the same procedure should be followed in preparing plate surfaces for hard-facing by the carbon arc process as is used for the metal arc and oxyacetylene processes of hard-facing.

227. HARD-SURFACING WITH THE OXYACETYLENE FLAME.

a. General. The oxyacetylene flame allows close control over the operation and produces a smooth deposit. Particles of scale and foreign matter are easily eliminated by this method, and edges and corners are easily formed. This is particularly important where it will be necessary later to grind the hard-facing deposit to close dimensional limits. The degree of penetration of the hard-facing alloy in the base metal is accurately controlled by the flame. This is important, since some of the alloys are puddled into the base metal while others are merely "sweated" onto the base metal. The tip size used for hard-facing should be two sizes larger than that required for welding the same size rod.

b. Applying Hard-facing Alloys.

(1) In applying hard-facing alloy rods of Group 1 to steel, the flame should be adjusted to contain a slight excess of acetylene, since a neutral flame will cause boiling and produce unsatisfactory results. If a higher hardness is desired in the deposit, the amount of excess acetylene used in the flame should be increased. The hard-facing rod should be puddled into the base metal sufficiently to obtain good fusion without diluting the hard-facing metal with the base metal and thereby softening it. The deposited metal should be slowly cooled to give high hardness. If quenched in oil from a high temperature, the hard-facing layer will be tougher than, but not as hard as, the more slowly cooled metal.

(2) The hard-facing alloys in Group 2 are applied to steel by welding them to the surface of the base metal in a manner similar to that used for the Group 1 alloys. "Sweating" is not advisable. The flame should be adjusted to give an excess streamer of acetylene approximately twice the length of the inner cone. The penetration of these hard-facing metals into the base metal does not materially affect the hardness of the deposit, as their carbon content is high.

(3) The hard-facing alloys in Group 3 are nonferrous and should be applied to steel by "sweating" them onto the surface without stirring or puddling the rod or melting the surface of the base metal. The flames should be adjusted to give an excess streamer of acetylene extending to double the length of the inner cone. This excess of acetylene acts to prepare the base metal, to allow free spreading of the hard-facing metal, and to prevent oxidation ahead of the fusion zone. A small area of the surface to be hard-faced should be brought to a "sweating" temperature. At the proper temperature, the hard-facing material will

melt, wet the base metal, and spread evenly over the surface. Additional metal should be melted from the end of the rod and added to the molten metal already in place. The thickness of the deposited layer can be controlled by spreading the molten metal over the surface with the flame.

(4) The Group 4 materials require that the surface of the steel base metal be grooved by means of either the oxyacetylene cutting torch or a forging hammer. The flame should be adjusted to give an excess of acetylene. Since these tungsten carbide materials are available as inserts in various sizes and shapes, they should be spaced evenly over the surface to obtain uniform wearing qualities. One insert should be fastened to the end of a steel welding rod by welding, and the steel in one groove in the base metal should be melted. At this point, the insert should be pushed into place, and enough of the welding rod should be melted to cover the insert completely and weld it to the base metal. This procedure is repeated until the surface to be hard-faced is covered with the desired number of inserts. Where severe wear resistance is required, these inserts are covered with one of the Group 5 alloys.

(5) The alloys in Group 5 are crushed tungsten carbides embedded in steel strip, rod, or tube. The flame should be adjusted to give a slight excess of acetylene. The surface of the base metal should be melted, and the rod puddled or stirred to obtain an even distribution of the crushed carbides in the deposited metal. Care should be taken not to overheat the molten metal, as these rods do not flow as freely as steel welding rods.

c. In applying any of the above hard-facing alloys or materials to steel, the exact amount of excess acetylene in the welding flame should be found by trial deposits on waste material. That flame adjustment should be made which gives a quiet puddle and good flowing qualities for the particular hard-facing metal. In some cases, where a thin edge is to be hard-faced or a desired shape is to be built up with the hard-facing materials, a copper mold or back-up strip or a carbon block should be used.

d. Hard-facing Cast Iron by the Oxyacetylene Process.

(1) Except for minor variations in the adjustment of the carburizing flame, the Group 1, 2, or 3 alloys may be applied satisfactorily to cast iron in the same manner as that outlined for steel. The Group 4 and 5 alloys are rarely applied to cast iron.

(2) In some cases, a cast-iron welding flux helps to break up and float oxides and other foreign materials to the surface. Hard-facing materials do not flow over the surface of cast iron as readily as they do on steel. This often requires working of the molten metal with the end of the rod to distribute the metal and to obtain good fusion to the base metal.

CHAPTER 11

FORGING AND FORGE WELDING

Section I

FORGE WELDING

Paragraph
Forge welding procedure 228
Uses 229

228. FORGE WELDING PROCEDURE.

a. This welding process consists of heating the ends of the metal parts in a forge fire in which coal, coke, or charcoal is used as a fuel. The ends to be joined are heated until the surface of the metal becomes plastic. When this condition is reached, the parts are quickly superimposed, and the weld is made either by pressure or hammering. The hammering may be done either by hand or by machine, and the force of the hammering or pressure is governed largely by the size and mass of the pieces or parts being joined. In this process, the surfaces to be joined must be free from foreign matter, and, in some cases, a flux is used (usually a sand or borax sprinkled on the surfaces to be joined) just before the metal reaches the welding temperature, in order to remove oxide scale and dirt. The flux spreads over the hot metal and forms a protective coating which prevents further oxidation by keeping out the air. It also lowers the melting point of the scale, making it fluid so that it can be squeezed out of the weld when it is hammered. Some common forms of joints used in forge welding are illustrated in figure 109.

229. USES.

a. Forge welding is by far the oldest welding process for joining metal pieces or parts. Hand forge welding is no longer used extensively, because of the great development of oxyacetylene and electric arc welding.

b. With the development of suitable machinery the speed with which the forge weld could be made, as well as the size of the parts to be welded, was greatly increased. Through this process of machine forge welding, long seams in lap- or butt-welded pipe can be made, and the quality of the weld is such as to make its location almost impossible of detection. This process requires the use of a gas flame or other suitable heating method to bring the metal edges up to the fusion temperature. The pressure is applied by mechanical rolls, which press the plastic edges together while the parts to be welded are forced between rolls along the line of welding.

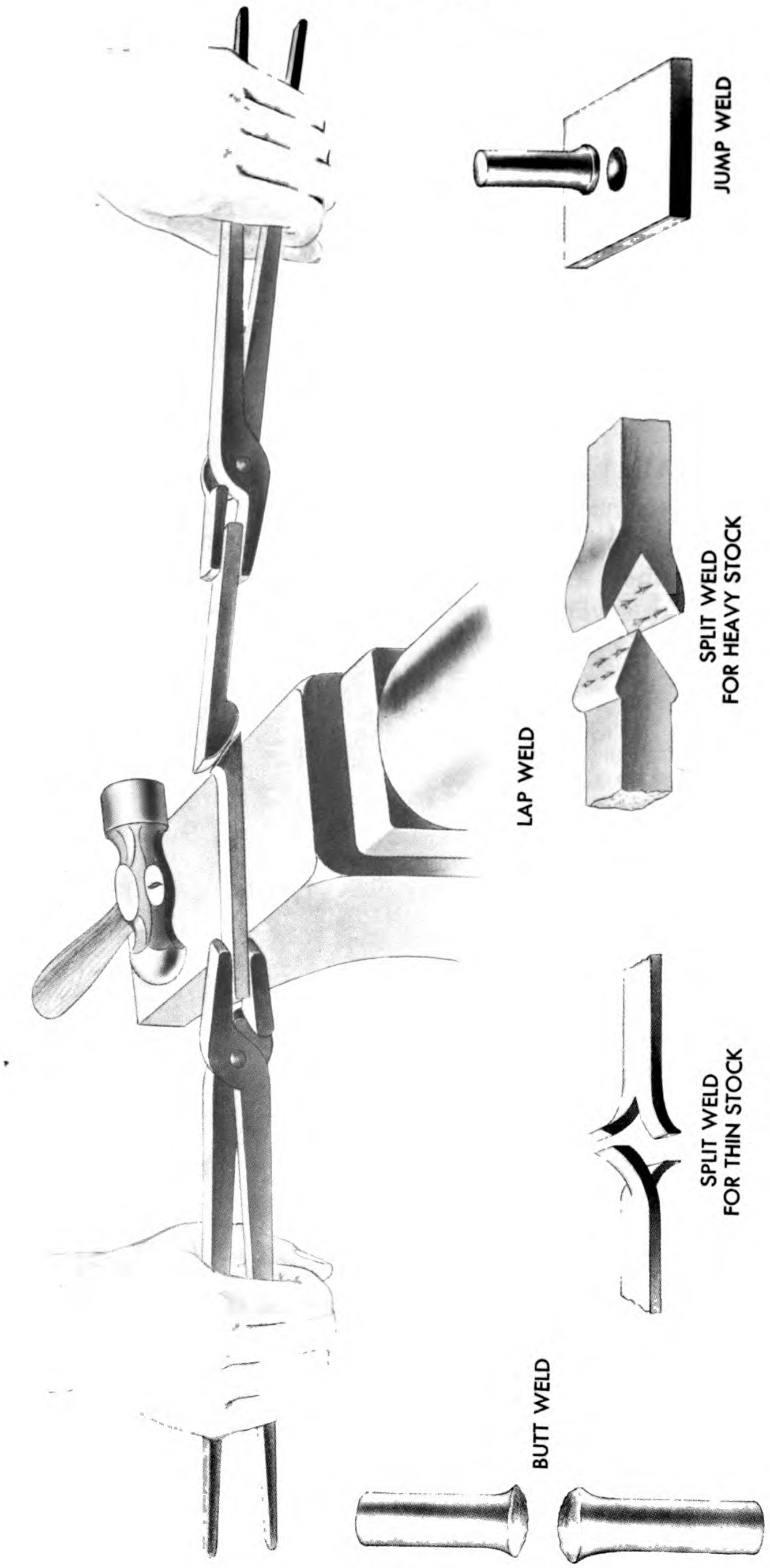


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Figure 109 — Forge Welds

CHAPTER 11

FORGING AND FORGE WELDING (Cont'd)

Section II

FORGING EQUIPMENT

	Paragraph
General	230
Forges	231
Forging tools	232

230. GENERAL.

a. In maintenance work, the equipment available on the welding truck is suitable for many classes of hand forging. Given a forge, an anvil, a hammer, a sledge, a few chisels, and a pair of tongs, the welder can make several types of special tools or parts that may be required.

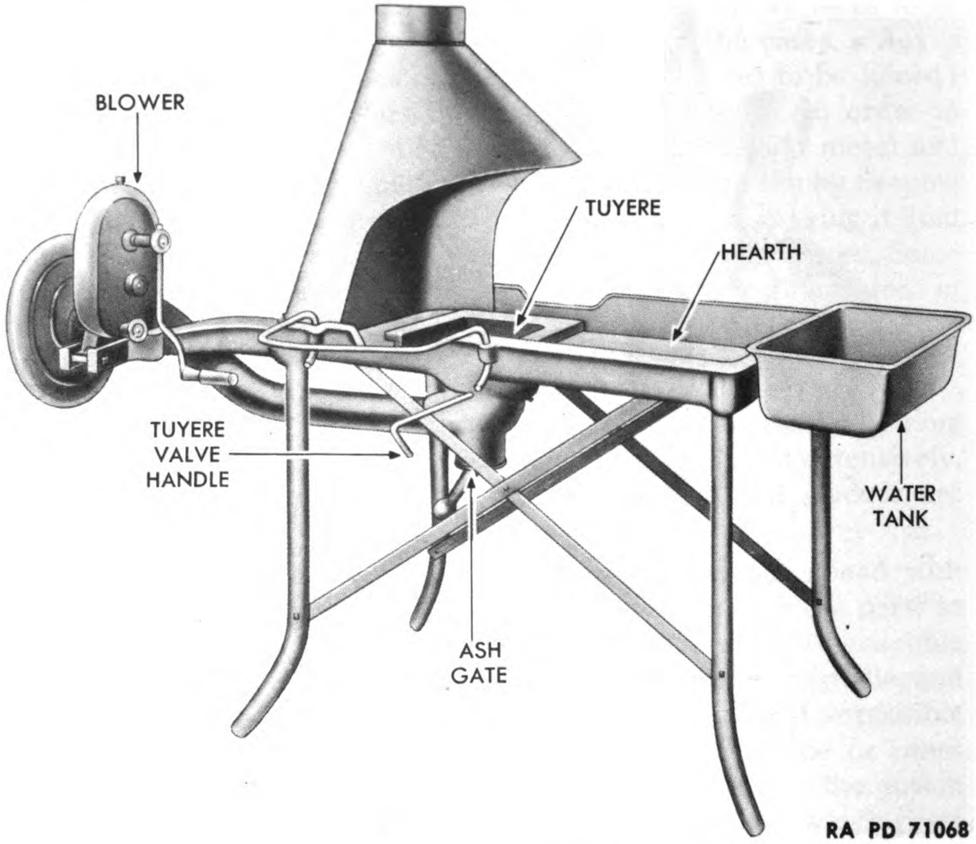

Figure 110 — Portable Forge

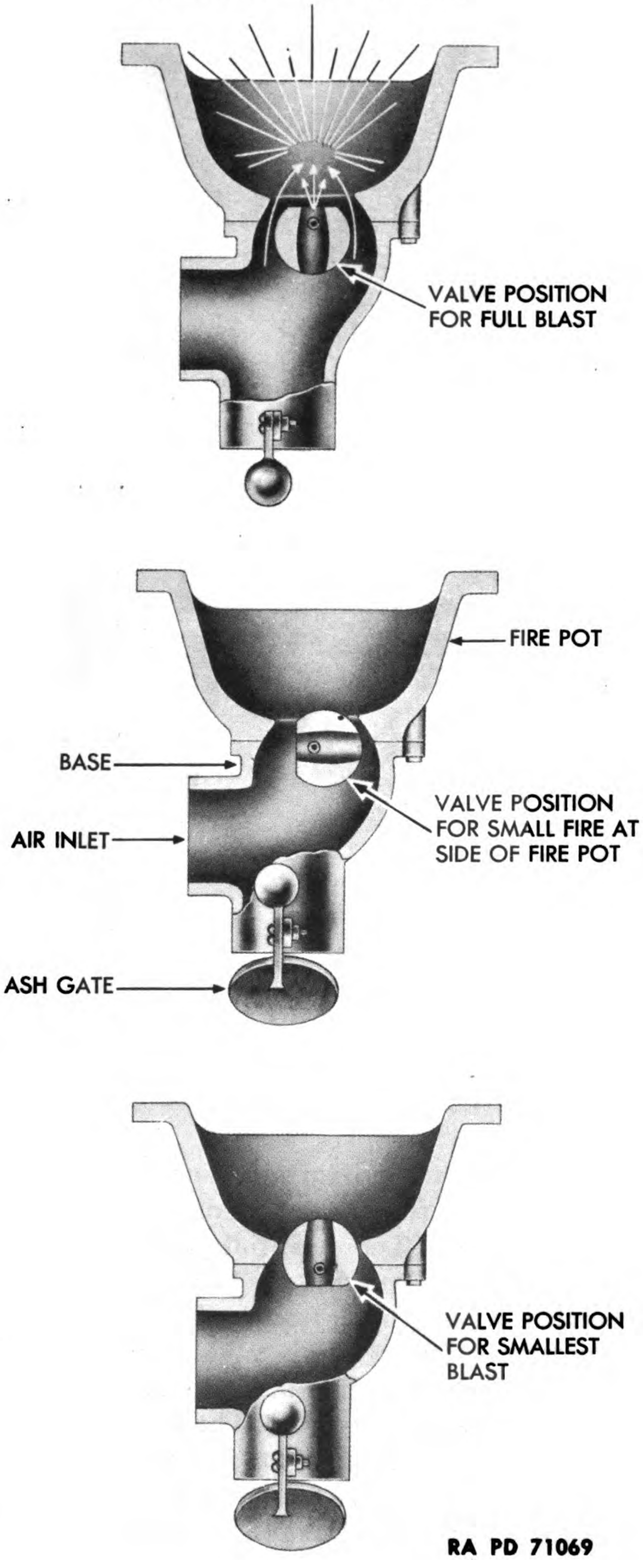

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Figure 111 — Tuyere

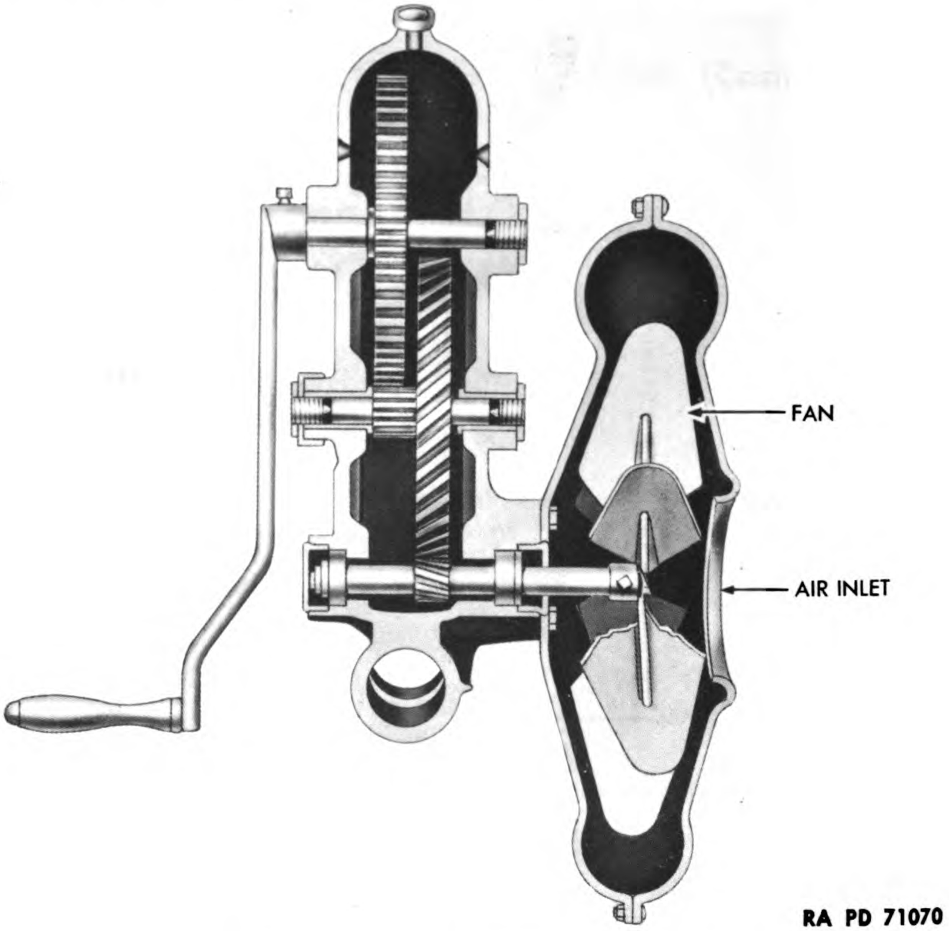

Figure 112 — Hand-operated Blower

231. FORGES.

a. The forge is the most important piece of forge welding equipment. It may be either portable or stationary.

(1) Portable Forge. The essential parts of a portable forge are a hearth, a tuyere, and a blower. Figure 110 shows one type of portable forge. The hearth is a pan, made from rolled steel plate, in which the fire is laid. The tuyere (fig. 111) is a valve mechanism designed to direct an air blast into the fire. It is made of cast iron and consists of a fire pot, base, blast valve, and ash gate. The air blast enters the base as shown in the illustration and is admitted to the fire through the valve. The valve handle turns the valve to free it of ashes and can be located in three different positions, which regulate the size and direction of the blast according to the kind of fire required. A portable forge may have a hand crank blower as shown in figure 112, or it may be equipped with an electric blower. The hand crank blower consists of a fan rotated by

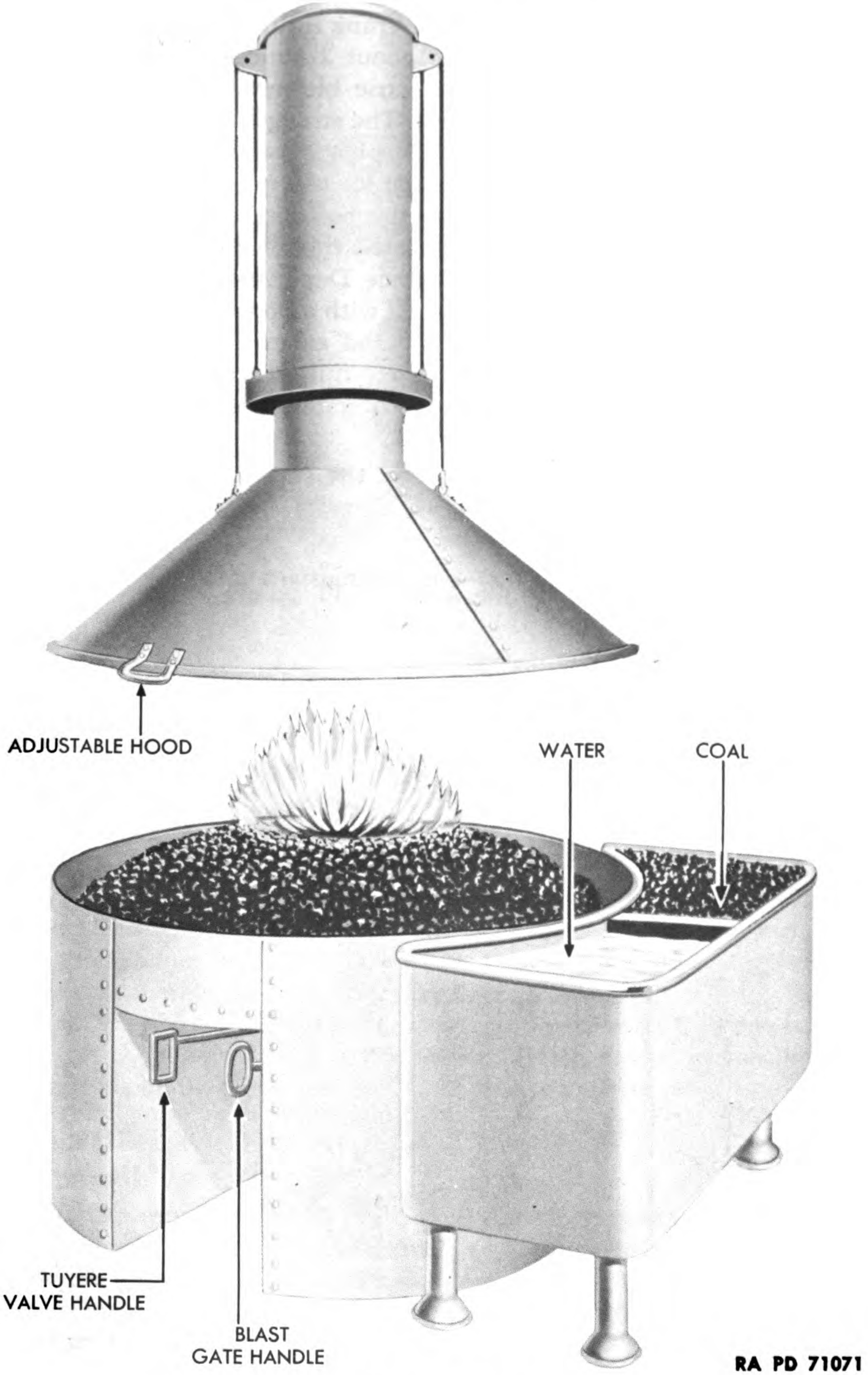

Figure 113 — Updraft Stationary Forge

a crank through two pairs of step-up gears. This fan rotates at about 2,200 revolutions per minute when the crank is turned at easy cranking speed, and produces an air blast of about 2 ounces per square inch. If the forge is equipped with an electric blower, the electric motor drives the fan to produce the air blast. The strength of this blast is controlled by a blast gate located in the pipe between the blower and tuyere. A hood is provided on the forge for carrying away smoke and fumes from the fire. No hood is necessary, however, when the forge can be removed to the open air and operated there, as in the case of the portable forge located on the Ordnance Department welding truck. Portable forges are sometimes provided with a downdraft hood so that the blower intake can remove smoke and ashes. Part of the unconsumed gases are returned to the fire for full combustion. This helps to save coal and keep the shop clean. A water tank is also provided, which hangs at the side of the hearth.

(2) STATIONARY FORGE. In design, the stationary forge is much

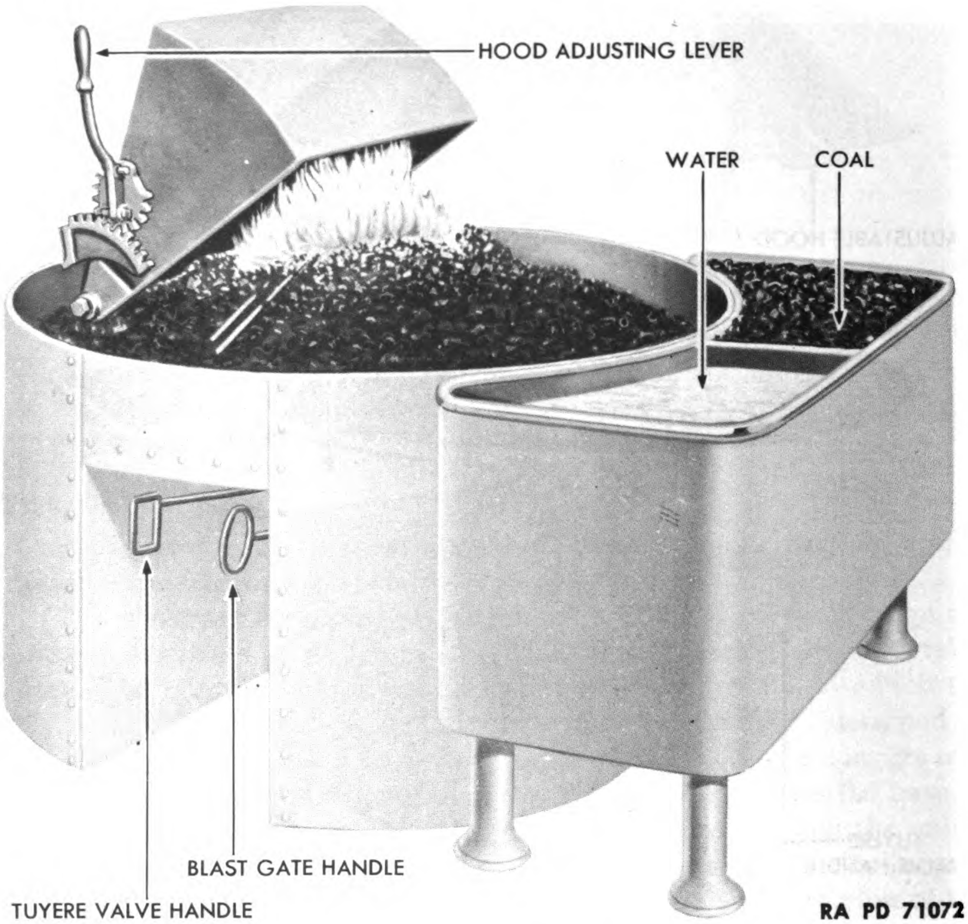

Figure 114 — Downdraft Stationary Forge

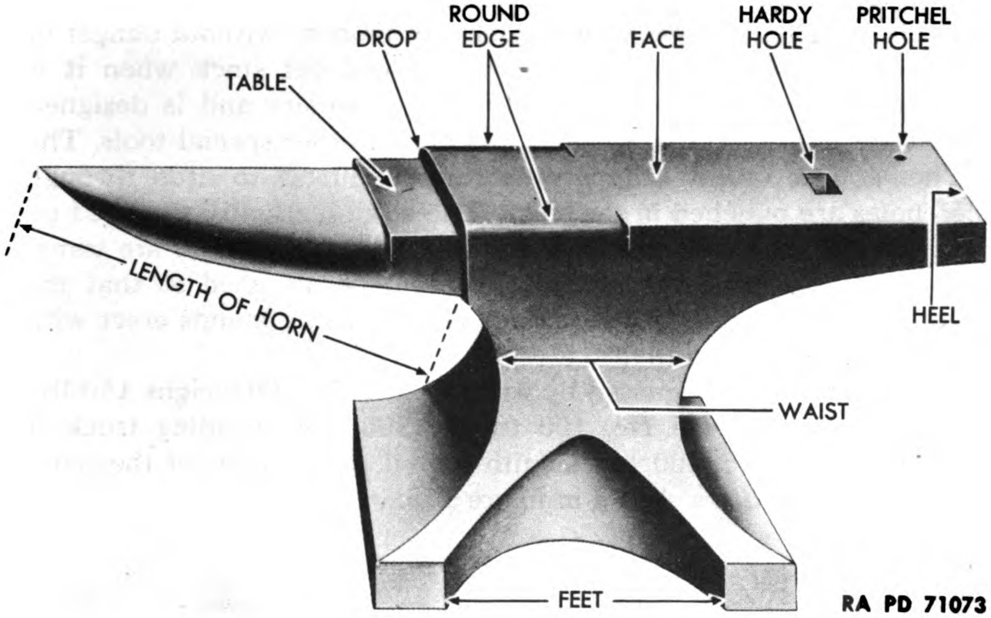

Figure 115 — Blacksmith's Anvil

the same as the portable forge, except that it is usually larger and has larger air and exhaust connections. The forge may have an individual blower or there may be one large blower for a group of forges. The air-blast valve usually has three slots at the top, the positions of which can be controlled by turning the valve around. The number of these slots opened to the fire can be varied to regulate the size of the blast. As in portable forges, there are two types, namely, updraft (fig. 113) and downdraft (fig. 114). In the updraft type the smoke and gases either pass up through the hood and chimney by natural draft or are drawn off by an exhaust fan. In the downdraft forge, the smoke and gases are drawn under an adjustable hood and carried through a duct by an exhaust fan which is entirely separate from the blower. The downdraft forge has the advantage of better air circulation and shop ventilation, brought about by positive removal of smoke and gases.

232. FORGING TOOLS.

a. Anvil.

(1) An anvil (fig. 115) is the next most important piece of forge welding equipment. It is usually made of two forgings or steel castings welded together at the waist. The table or cutting block is soft, so that cutters and chisels will not be dulled by coming in contact with it after cutting through a piece of stock. The face is made of tool steel, hardened and tempered, welded to the top of the anvil. It cannot be damaged easily by hammering.

(2) The edges of an anvil are rounded for about 4 inches back from the table to provide edges where stock can be bent without danger of cutting it. All other edges are sharp and will cut stock when it is hammered against them. The hardy hole is square and is designed to hold the hardy, bottom swages, fullers and other special tools. The pritchel hole is round and permits slugs of metal to drop through when holes are punched in the stock. The anvil is usually mounted on a heavy block of wood, although steel pedestals or bolsters are sometimes used. The height of the anvil should be adjusted so that the operator's knuckles will just touch its face when he stands erect with his arms hanging naturally.

(3) Anvils are designated by weight (e.g., No. 150 weighs 150 lb) and range in size from No. 100 to No. 300. The welding truck is equipped with a No. 100 blacksmith's anvil. The names of the parts of a standard anvil are shown in figure 115.

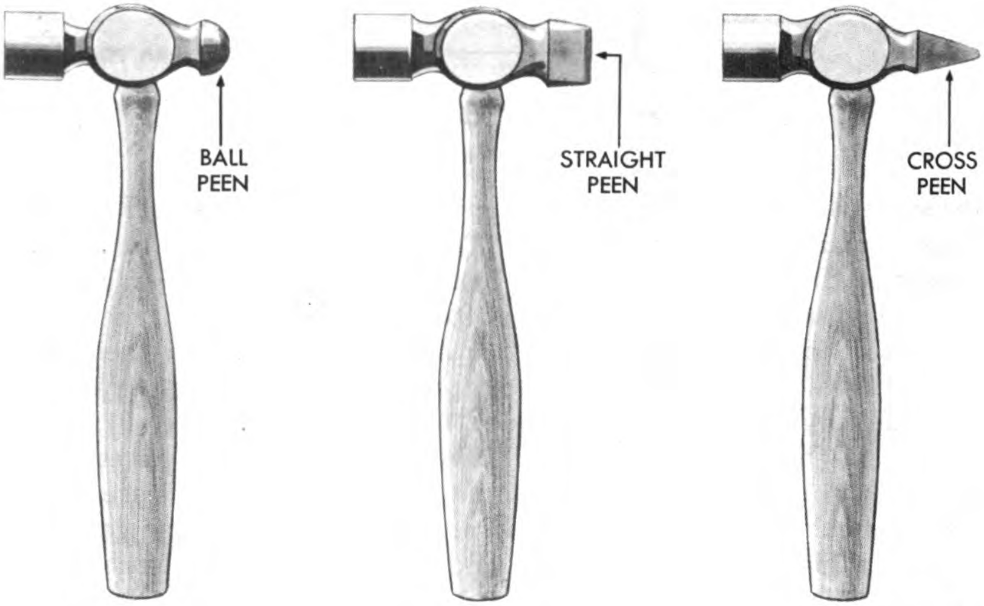

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Figure 116 — Blacksmith's Hammers

b. Hammer. Three types of hammers (fig. 116) are used in forging operations, namely, ball peen, straight peen and cross peen. Of these, the ball-peen hammer is the one most generally used, and is suitable for ordinary light work. The straight-peen hammer is used mainly for drawing out stock at right angles to the hammer. The cross-peen hammer is used to draw out metal in line with the hammer handle.

c. Sledges. A sledge is a hammer weighing from 5 to 20 pounds having a handle 30 to 36 inches long. It is usually of a straight-peen

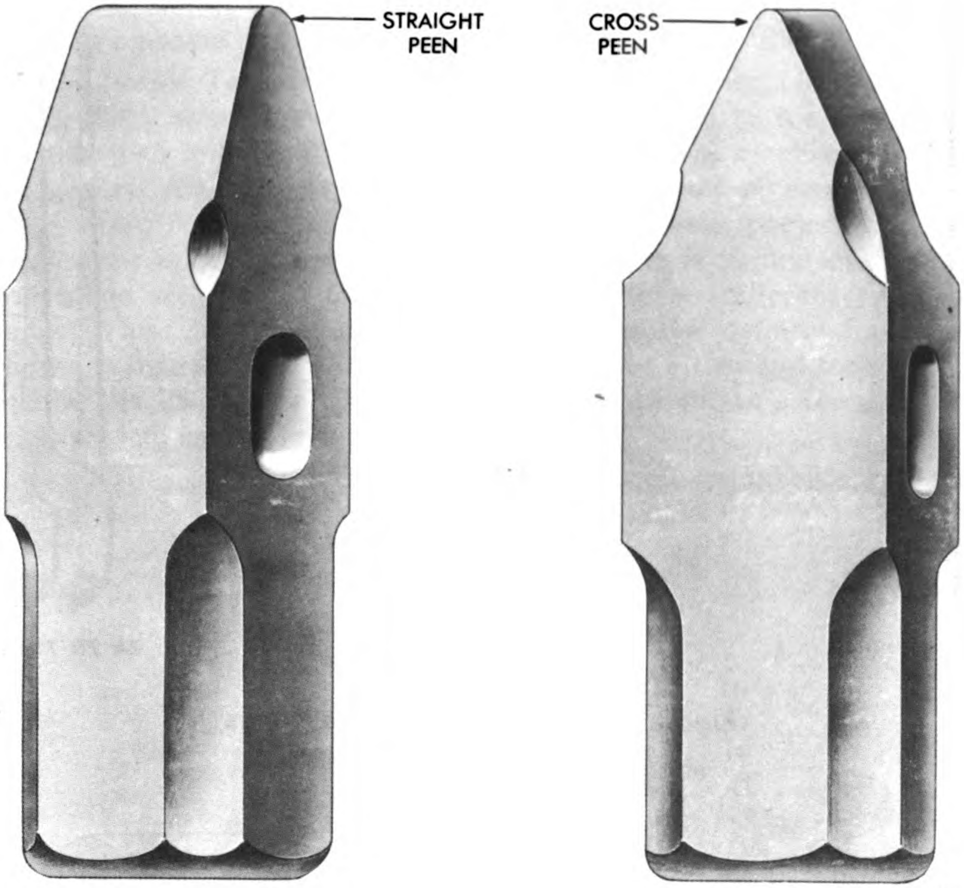

Figure 117 — Sledges

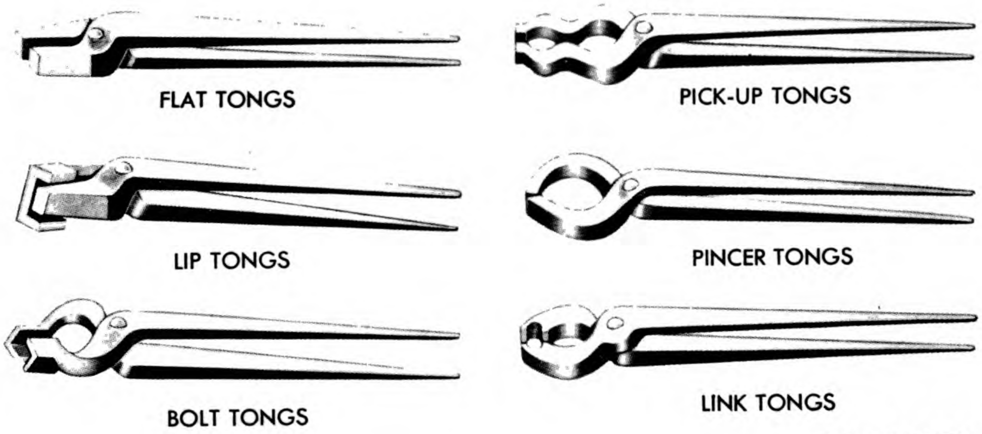

Figure 118 — Common Tongs

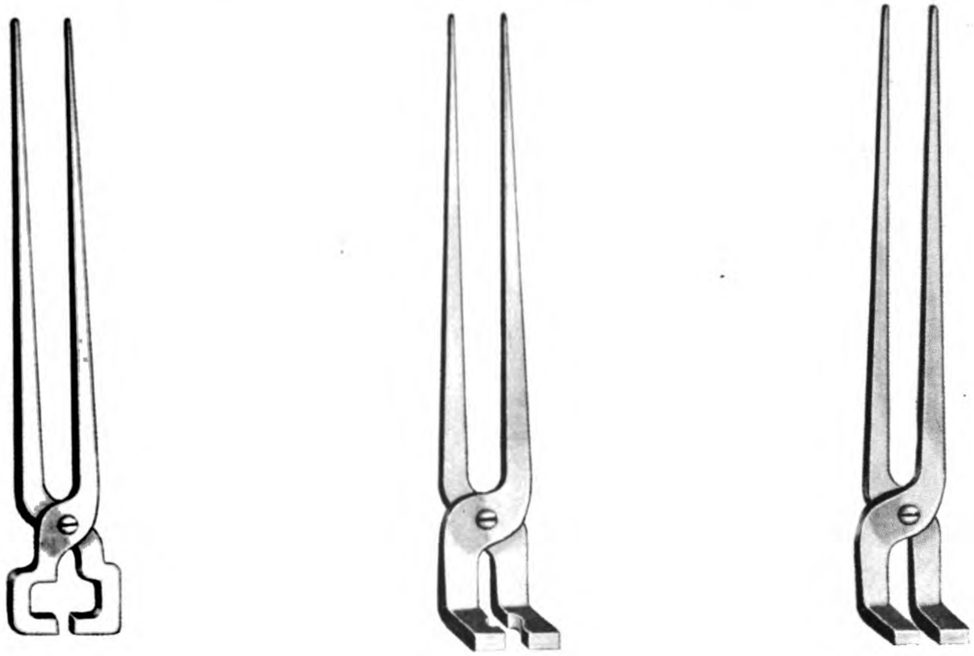

Figure 119 — Special-purpose Tongs

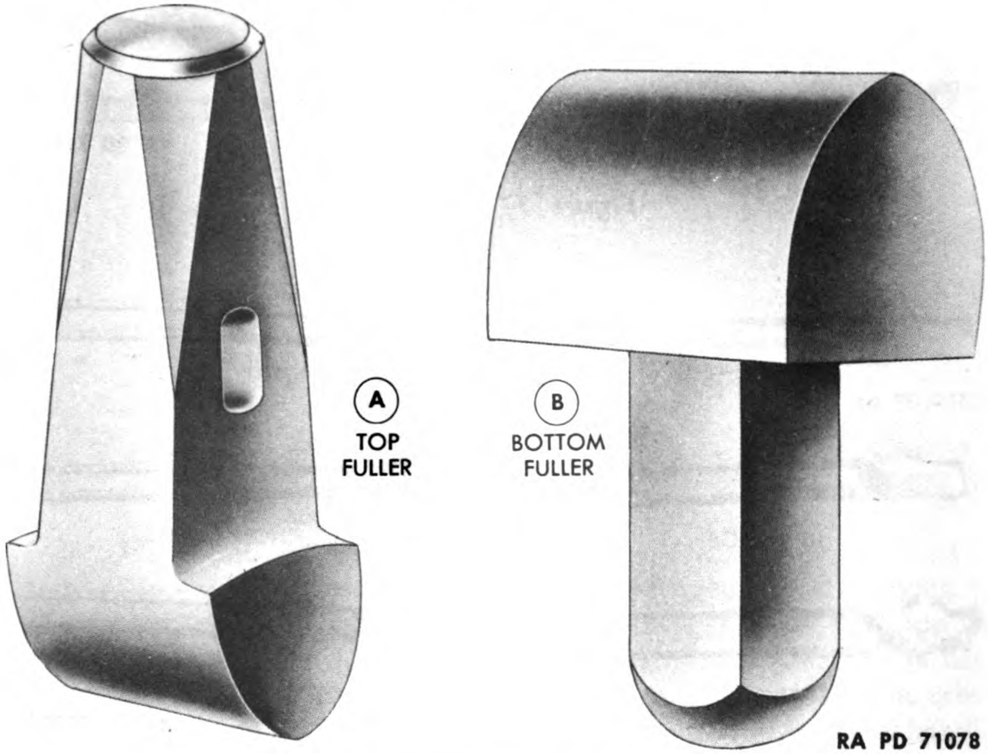

Figure 120 — Fullers

or cross-peen type, as shown in figure 117. Sledges are ordinarily used by the blacksmith's helper to deliver heavy blows, either directly on the work or on some other tool, such as a swage, fuller, or flatter.

d. **Tongs.** Tongs are used to hold hot work during forging on the anvil. They should be well constructed and fitted to the work they are designed to hold. They are usually made by the blacksmith either for general use or for special purposes. Both sides of most pairs of tongs are alike; that is, all the dimensions, offsets, projections, and curves are in the same direction, and one side is turned over when the tongs are riveted together. There are seven different types of tongs in use in the blacksmith's shop. Six have definite forms, as shown in figure 118. The seventh type includes all special tongs made by the blacksmith for special uses. Figure 119 shows a few samples of special tongs made by the blacksmith.

e. **Fullers.** The top fuller (fig. 120) is used to make depressions

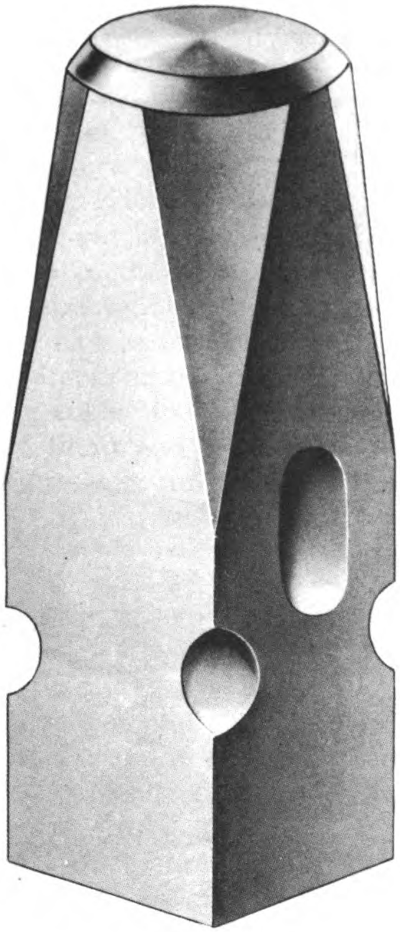

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Figure 121 — Set Hammer

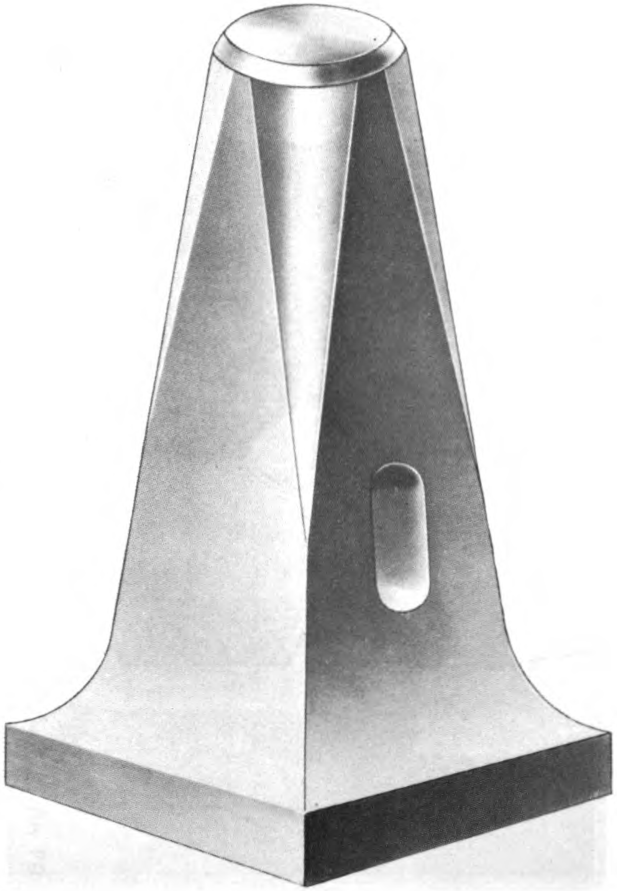

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Figure 122 — Flatter

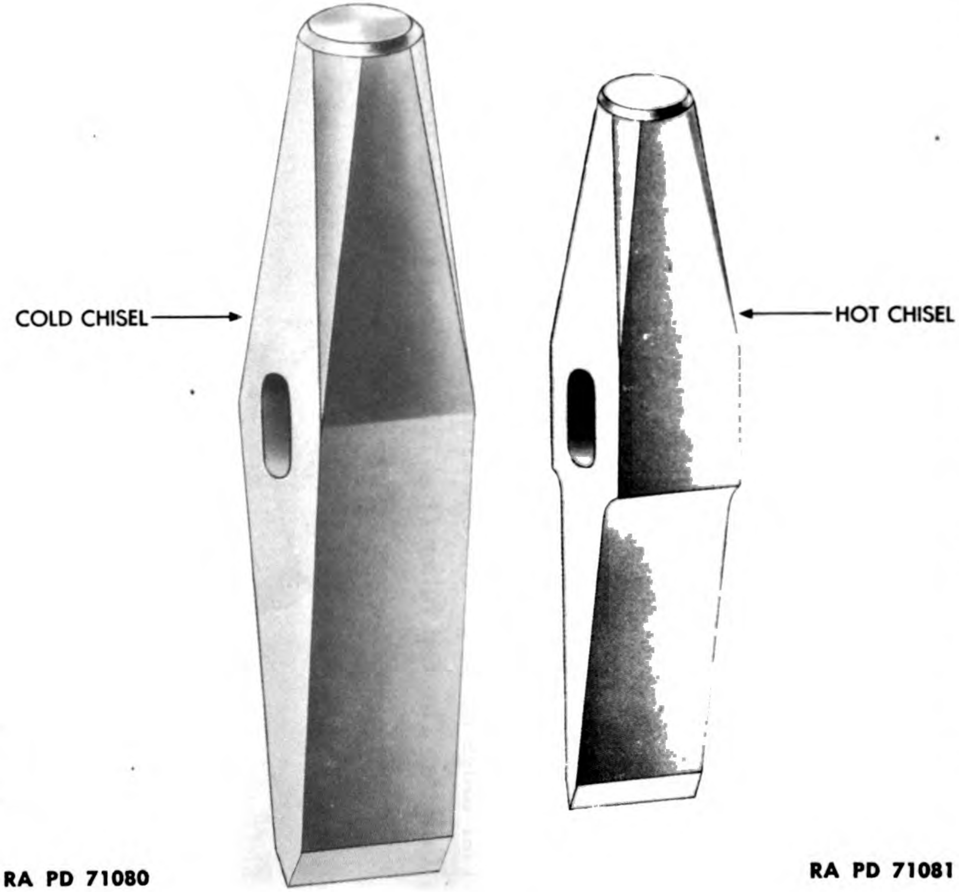

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Figure 123 — Chisels

in the upper side of a forging as it lies flat on the anvil or for drawing or spreading stock. Like other tools described below, it has a handle like a hammer and is held on the work by the blacksmith while his helper strikes it with a sledge. The bottom fuller (fig. 120) fits into the hardy hole of the anvil. It serves the same purposes as the top fuller, except that it works on the bottom of the forging. It is used with the top fuller, or the stock is struck directly on top with a sledge. Fullers are ordinarily made with radii of ½ inch to 1½ inches.

f. **Set Hammer.** The set hammer (fig. 121) is used for setting down work, working in small spaces, or producing sharp inside corners. It is usually made with sharp edges, although some set hammers have rounded edges and are called round-edge set hammers. The top fuller and the set hammer are the most useful tools for forge work. Their use, however, requires a helper.

g. **Flatter.** The flatter (fig. 122) is like the set hammer except that the face is larger than the body. It is used in much the same way, for smoothing work and for producing a finished appearance by taking out the unevenness left on stock by the hammer or other tools. Its use requires a helper.

h. **Chisels.** Chisels (fig. 123) are used for splitting or cutting off stock. The hot chisel is for cutting hot metal, the cold chisel for cutting cold stock. The edge of the hot chisel is made thin so that it will penetrate heated metal quickly without getting hot enough to lose its temper. The edge can be made thin because great strength is not required of a tool for cutting hot metal. The cutting edge of the hot chisel is ground to an angle (included angle) of about 30 degrees. The cold chisel is made blunt and stubby in order to give it great strength. The cutting edge is ground to an angle (included angle) of about 60 degrees.

i. **Hardy.** The hardy (fig. 124) is a hot or cold chisel made to fit into the hardy hole of the anvil. It is used as a bottom-cutting tool.

j. **Swages.** Swages (fig. 125) are used for smoothing and finishing and are made in all shapes and sizes, depending upon the work to be done. They are used in pairs, each pair consisting of a bottom swage and a top swage. The bottom swage is inserted in the hardy hole of the anvil. The groove in the top swage is the same as that in the bottom swage. The grooves are usually half round, octagonal, and square, although they may be any other shape. The hot forging is placed in the groove of the bottom swage, and the top swage is held on top of the work by the blacksmith while his helper strikes it with a sledge.

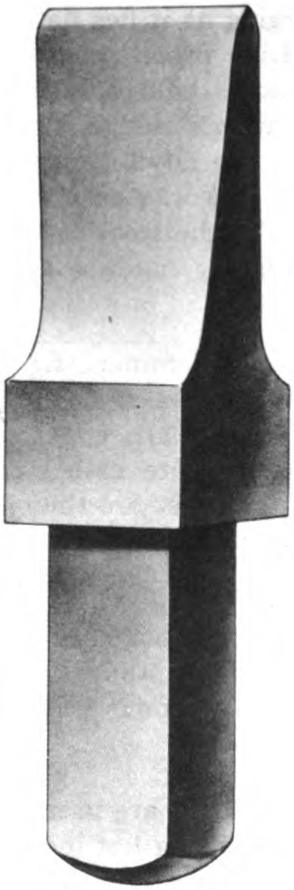

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Figure 124 — Hardy

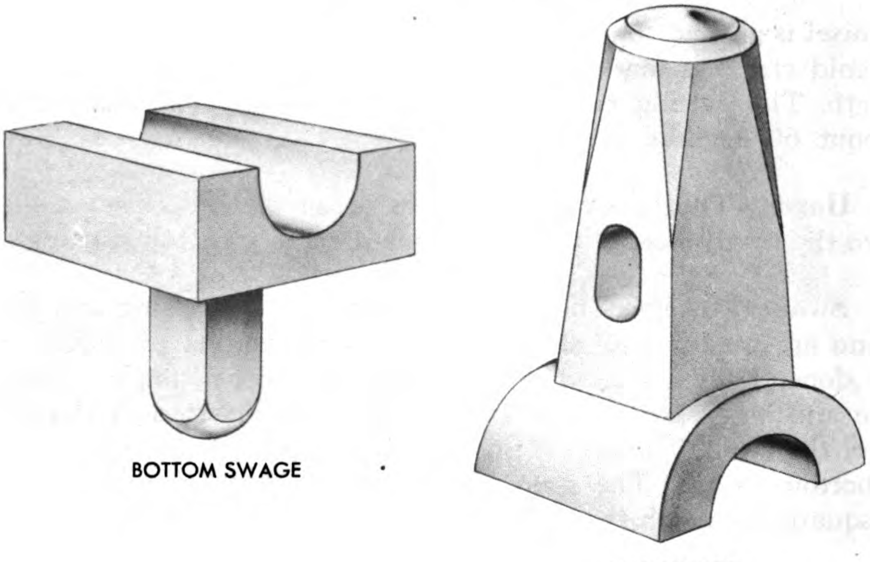

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Figure 125 — Swages

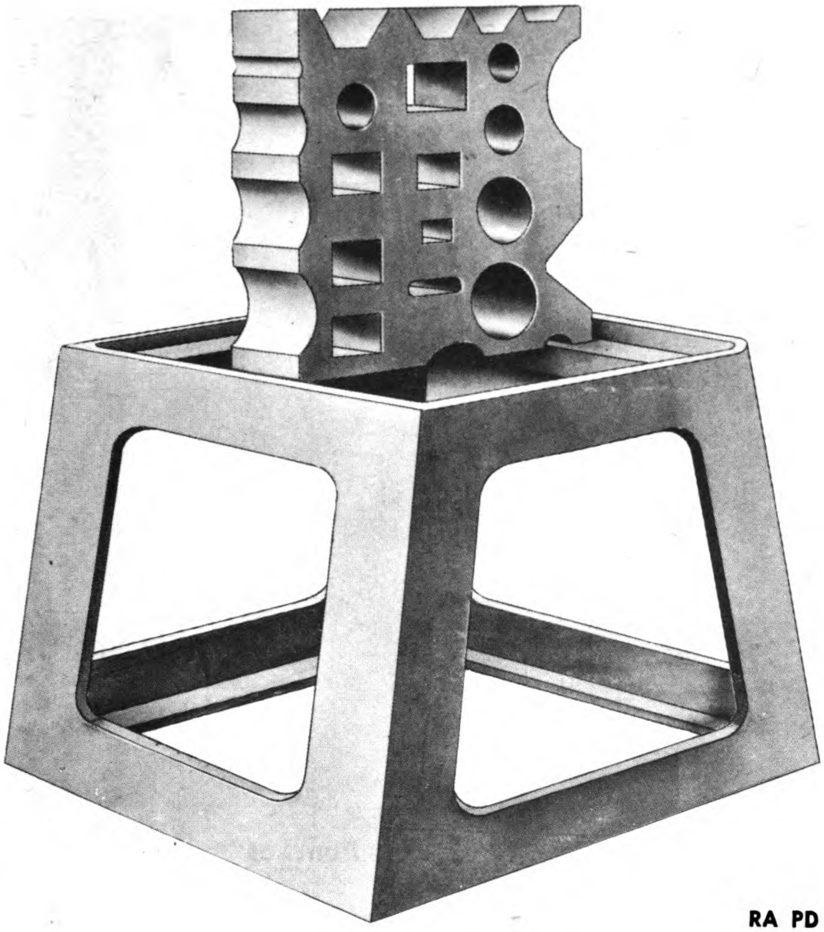

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Figure 126 — Swage Block

k. **Swage Block.** The swage block (fig. 126) is a block commonly made of cast iron, weighing about 150 pounds, usually mounted on a stand. It is pierced with a number of round, square, and rectangular holes and provided with grooves of various shapes and sizes around the edge. The holes are mostly used for the insertion of work that is being headed, such as a bolt. The grooves are used principally as bottom swages.

l. **Punches, Bob, and Cupping Tool.** Punches (fig. 127) are used for making round, square, or odd-shaped holes in hot stock. Like most of the other forging tools described, they are provided with handles and are held on the work by the blacksmith while being struck with a sledge by his helper. When finishing a hole, the punch is held on the work over the pritchel hole in the anvil, which permits the slug of removed stock to drop through. Two other tools are the bob or counterpunch and the cupping tool (fig. 128). The counterpunch is

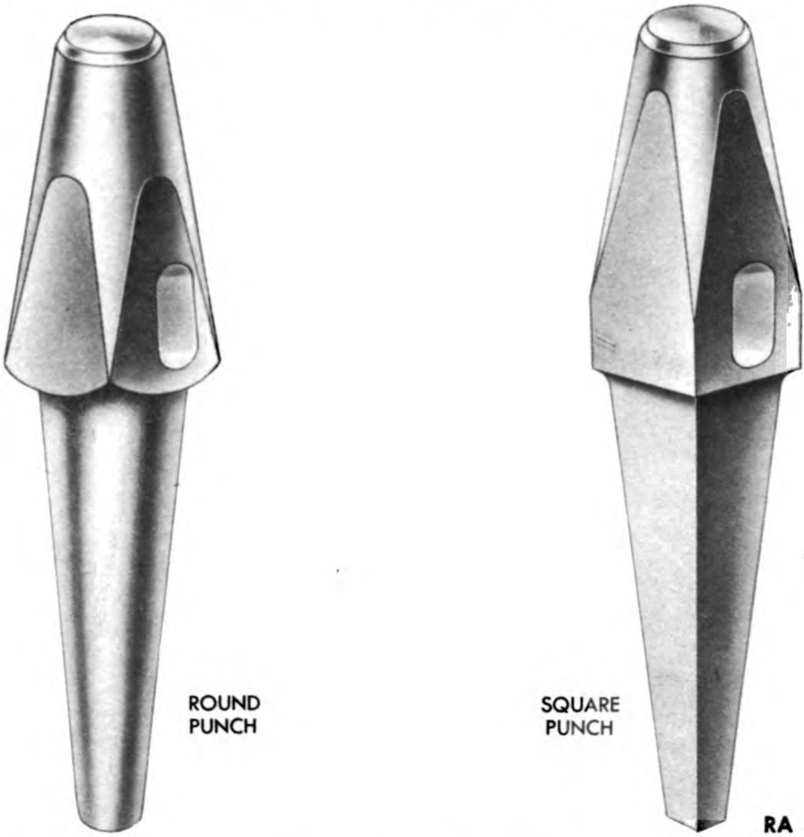

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Figure 127 — Punches

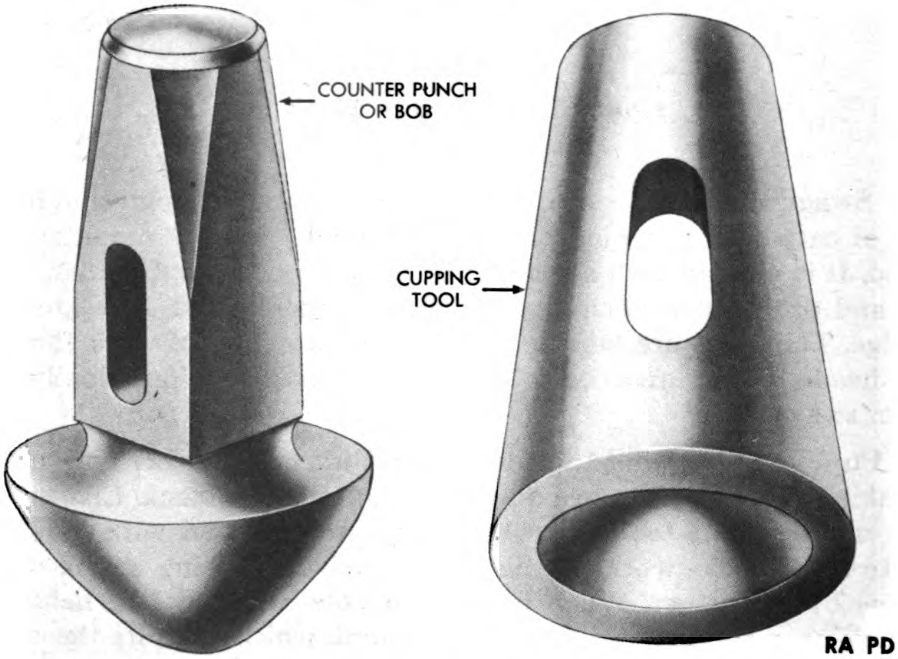

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Figure 128 — Bob and Cupping Tool

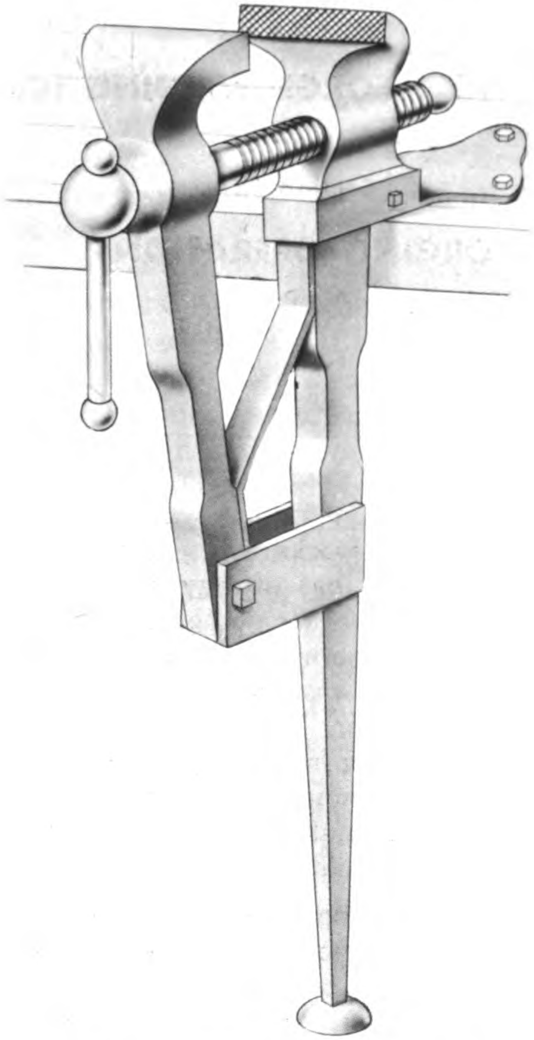

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Figure 129 — Blacksmith's Vise

used mainly for countersinking holes and making depressions for jump welds. The cupping tool is used for rounding off or finishing the heads of rivets.

m. Vise. A vise has many uses in the blacksmith shop, such as holding work while it is being laid out or being bent, twisted, or filed. A good type of vise for this use is shown in figure 129.

CHAPTER 11

FORGING AND FORGE WELDING (Cont'd)

Section III

FORGING OPERATIONS

Paragraph
General 233
Fires 234
Shaping operations 235

233. GENERAL.

a. A blacksmith usually works with wrought iron and steel. Wrought iron is fibrous and has stringy streaks of slag running lengthwise of the bar, giving it a decided grain similar to wood. Low-carbon steel is soft steel, sometimes called mild steel or machine steel. It is much the same as wrought iron except that it lacks the fiber and is somewhat stronger. Tool steel differs from these two materials in that sudden cooling from a high heat makes it very hard. Wrought iron or mild steel cannot be hardened by the same treatment. Tool steel is used for making chisels, punches, cutting tools and practically all forming tools.

b. Metal is forged by heating it until it is soft and by forming it under a hand or power hammer or under pressure applied in a power press. Drop forgings are formed between the dies of a power hammer, and pressure forgings are similarly formed in a power press. These are production processes. The simple forging of light stock, with which the automotive repair or maintenance shop is mainly concerned, is done by striking the red hot metal on an anvil with hand hammers or the other hand tools previously described. Forging breaks up crystals and refines the grain of the iron or steel, making it stronger and tougher. If the work is stopped while the steel is still hot, however, the crystals will form again to some extent. Forging, therefore, should be continued until the metal cools to a low, red heat. Material from which forgings are made usually comes to the shop in the form of round, square, and rectangular bars from 12 to 20 feet in length.

c. Forgings are used mainly where stronger, tougher, and less brittle metal is required than can be obtained by castings. This is often an important safety consideration. For example, hooks for heavy-duty cranes, derricks, or winch cables should always be forgings; otherwise they may break suddenly when heavily loaded, causing serious damage by dropping the load or whipping the cable.

234. FIRES.

a. General. Air is a gas composed mainly of two elements, nitrogen (about four-fifths) and oxygen (about one-fifth). It is the oxygen that is active in burning or supporting combustion. Coal and wood are made up largely of the element carbon. When they burn, the carbon in the wood or coal combines with the oxygen of the air. In a similar manner, hot iron oxidizes when exposed to the oxygen of the air, forming iron oxide, or scale. Proper selection of fuel and care of the fire are essential to first-class work, especially for forge welding and working tool steels.

b. Fuel. The fuel used for forge fires should be coking coal, as free as possible from sulphur, slate, and other impurities. Any soft coal that crumbles easily into many-sided small particles with bright, shiny surfaces is good smithing coal; however, the best way to determine a coal's coking properties is to try and see if it cokes. It is not necessary to bank the fire or make a supply of coke for future use. When forging light work, the coal can be charred around the rim of the fire as fast as it is used. The charred coal, which is constantly being made and used to replenish the fire and cover the heated forging, is soft coke.

c. The bottom of the tuyere is placed about 5 inches below the hearth to allow sufficient depth of fire below the piece being heated when the piece is level with the hearth. The pressure of the air blast should be from 2 to 7 ounces per square inch. This low pressure is not likely to damage the metal that is being heated, since destructive oxidation (scaling) will occur but slowly. The hottest part of the fire is from 5 to 7 inches above the tuyere.

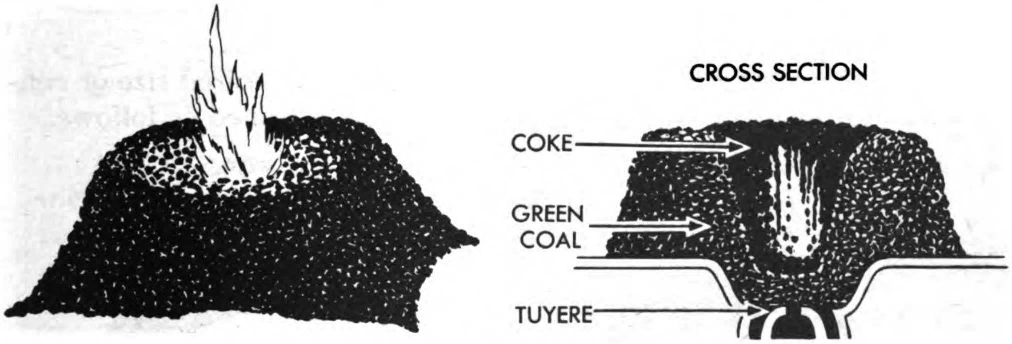

Figure 130a — Plain Open Fire

d. Types of Fires. Three types of fire are used by the blacksmith: the plain open fire, the side-banked fire, and the hollow fire. Each type may be either oxidizing or reducing, according to the depth of the fire and the strength of the blast. When the fire is so thin that the blast can pass through it before all the oxygen is consumed, the oxygen will

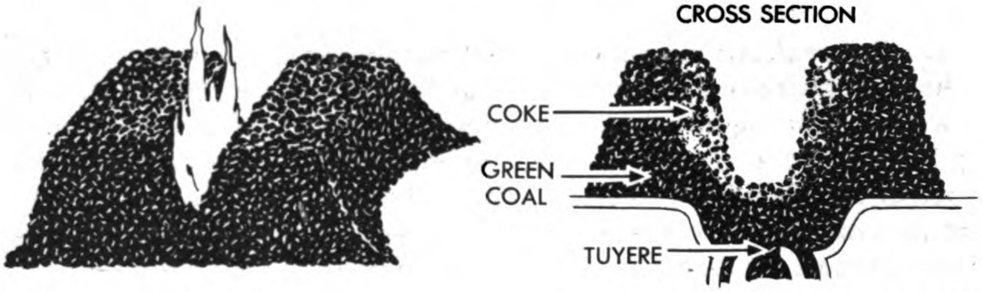

Figure 130b – Side-banked Fire

attack the iron and form scale. A deep fire, in which all the oxygen is consumed by combining with the coal before reaching the metal, is known as a reducing fire. It heats slowly, but will not oxidize the metal. A reasonably thick fire, just large enough to surround the piece being heated with glowing coals, should always be maintained. Unburned wet coal packed around the fire will keep it from spreading.

(1) The plain open fire (fig. 130a) is used for heating flat, wide pieces that cannot be heated in a side-banked fire.

(2) The side-banked fire (fig. 130b) is the type most generally used.

(3) The hollow fire (fig. 130c) is not used extensively but gives an intense heat. This fire is especially useful for forge welding and also for heat-treating high-speed tool steel, which must be heated to a very high temperature (about 2,200 F).

235. SHAPING OPERATIONS.

a. Forging can be used to shape metals to any desired size or contour. The principal shaping operations may be classified as follows:

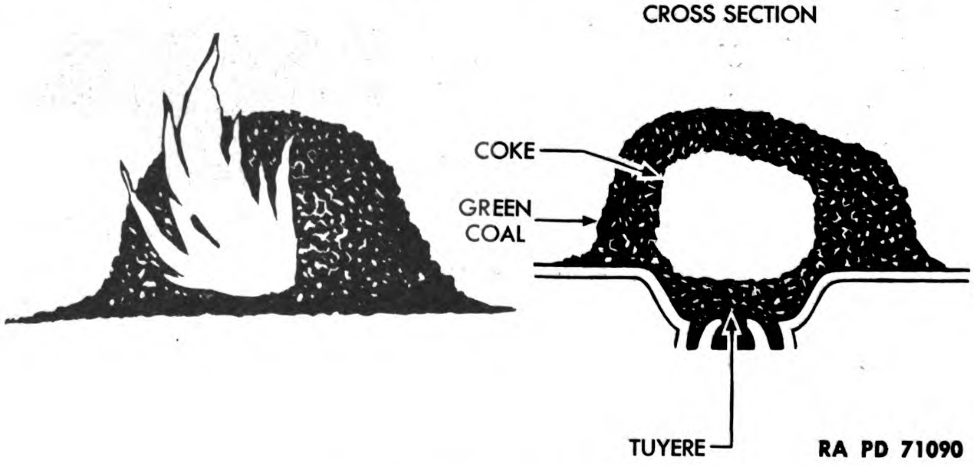

Figure 130c—Hollow Fire

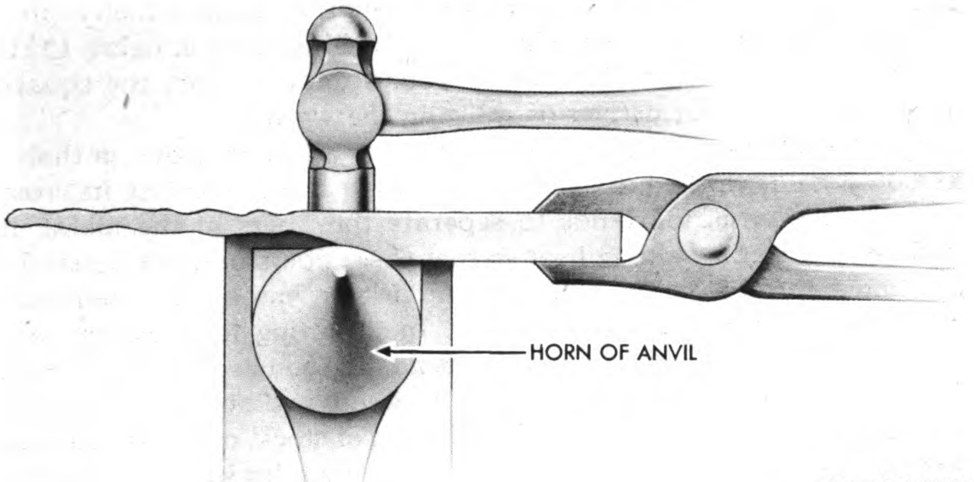

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Figure 131a — Drawing Operation on Flat Stock

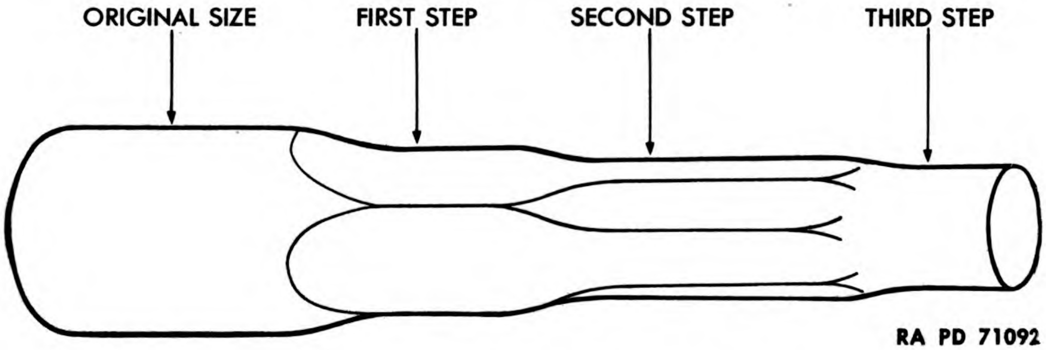

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Figure 131b — Drawing Operation on Round Stock

(1) DRAWING. A drawing operation consists of working a piece of metal to increase its length, or width, or both, and to reduce its cross section. The stock to be drawn out should be heated to the highest temperature it will stand without damage to the metal. When it is desired to increase the length as well as the width of the work, hammering should be done on the face of the anvil. To increase the length only and not the width, the work should be forged by hammering over the horn of the anvil. The horn acts as a blunt wedge to force the metal lengthwise, as shown in figure 131a. Fullers can also be used to increase only the length of the work. When a piece of iron is to be drawn out both in length and width, the flat face of the hammer is used. To increase or stretch a piece of work in either its length or width, the peen of the hammer is used with the peen at right angles to the direction in which the work is to be drawn. When a piece of round stock is to be drawn out or pointed, it should first be forged down square to a little less than the

required diameter, after which it should be made octagonal, then round, with as few blows as possible. This process is illustrated in figure 131b. If an attempt is made to hammer it round directly from the square shape, there is a great danger of splitting the work.

(2) UPSETTING. Upsetting is the reverse of drawing out, in that a piece of metal is worked to decrease its length and to increase its cross section. Since upsetting tends to separate the fibers of the metal, it should be done at a welding heat so that these fibers may be joined. In upsetting a short piece, it is best to stand it on end on the anvil and strike the upper end with a hammer. In upsetting long pieces, care should be taken to straighten out any bends as soon as they start, since additional hammering will increase the bend without upsetting the stock. To upset any portion of a given length of stock, only that portion which is to be upset should be left hot; the remainder should be cooled by quenching in water.

(3) BENDING. Curves and rings of small cross section can easily be bent over the horn or round edge of the anvil or over a suitable mandrel. In bending angles, the point at which the bend is to be made

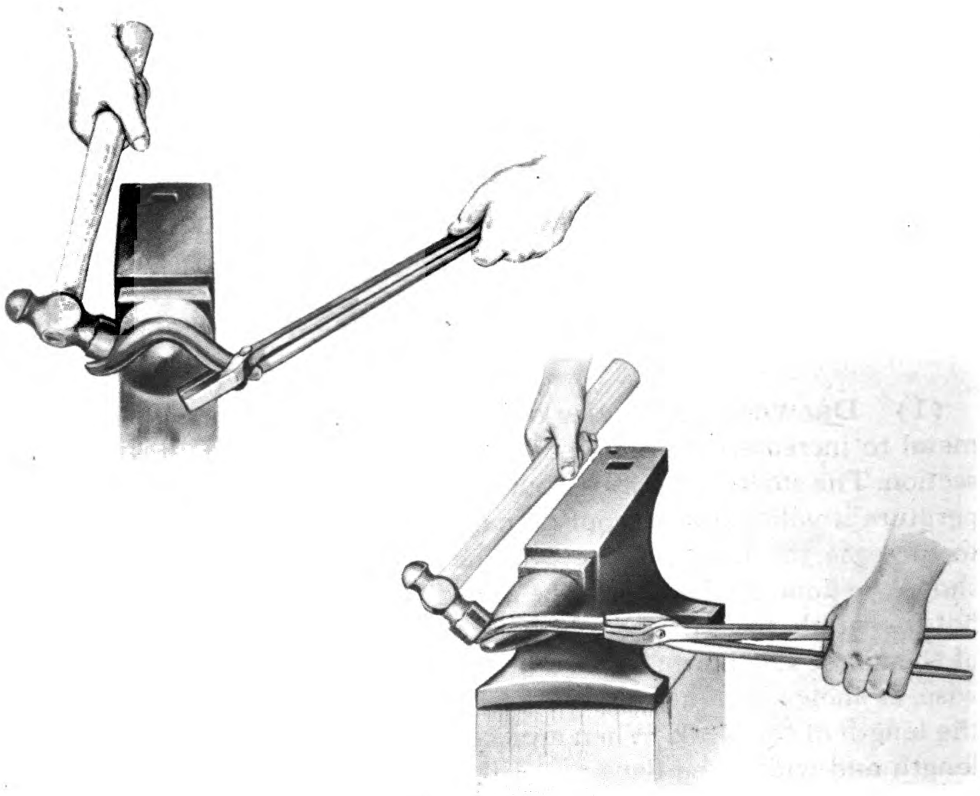
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Figure 132 — Bending

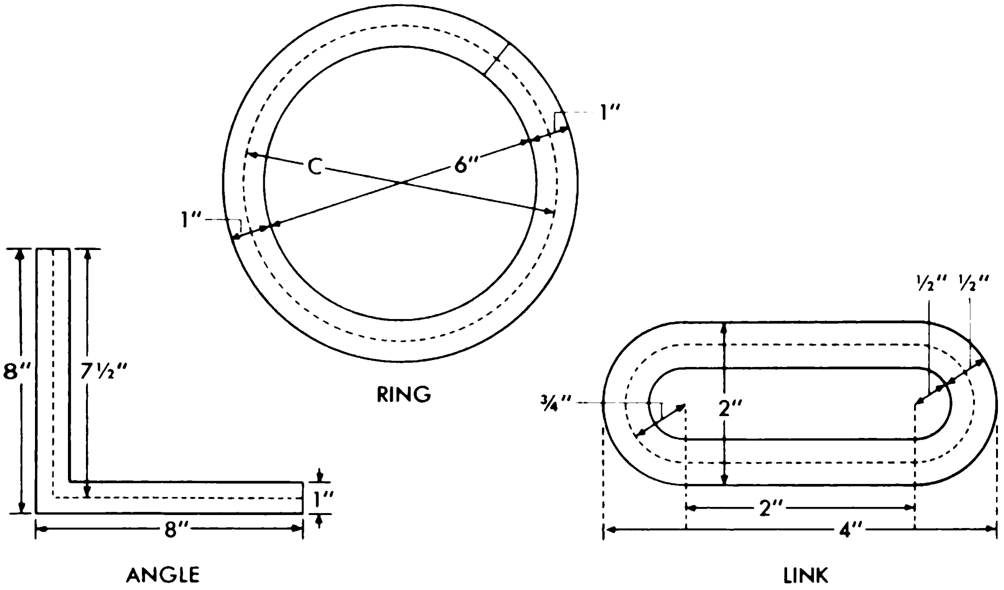

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Figure 133 — Measuring Stock for Bending

should be marked with a center punch on the cold stock. The portion of the stock at the intended bend should be heated, placed in a vise, and hammered to the desired angle. This process is illustrated in figure 132.

(4) TWISTING. In order to twist a piece of stock, it is necessary to heat the work uniformly and to do the job quickly. The end of each twist should be marked with a center punch. The stock should be placed in a vise with one center punch mark even with the top of the jaws. A close-fitting wrench or bending fork should be placed just above the other mark and given the required number of turns. Light stock may be twisted cold, whereas heavier stock must be heated to obtain good twists. It has been found by experiment that if a line is drawn through the center of a piece of stock and the stock is then bent, and the lengths of the inside, center, and outside lines measured, that the outside line will lengthen, the inside line will shorten, and the center line will remain the same. Therefore the length of stock required for making any bent shape can always be determined by measuring the center line of the curve or bend. Three examples of bent stock are the angle, ring, and link shown in figure 133. In the case of the angle, the outside line is 16 inches, the inside line 14 inches, and the center line 15 inches, which is the length of stock required to make it. The circumference or distance around a circle is found by multiplying the diameter by $3\frac{1}{7}$ or, more accurately, 3.1416. Tables giving the circumferences of circles are available. The inside diameter of the ring shown in figure 133 is 6 inches and the stock is 1 inch. Therefore, the

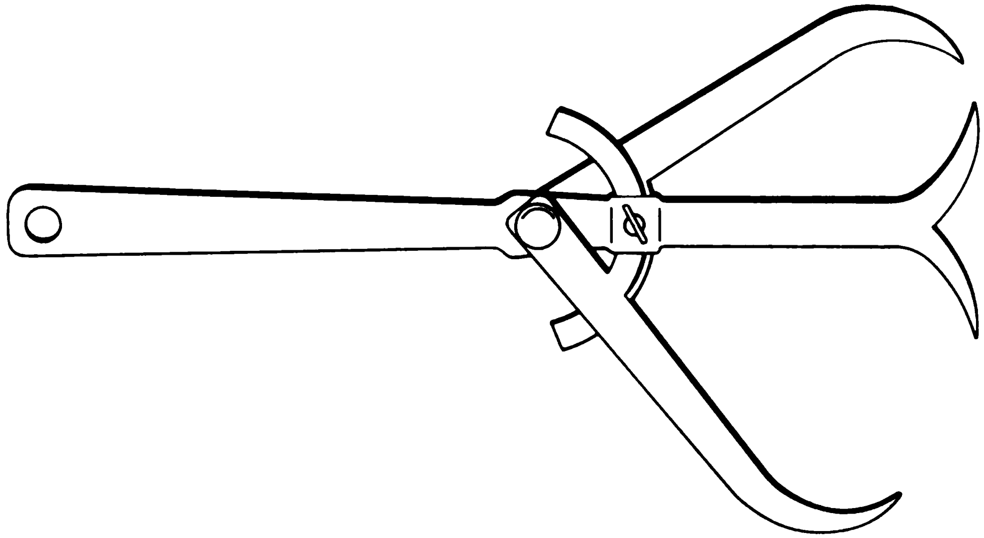
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Figure 134a – Blacksmith's Twin Calipers

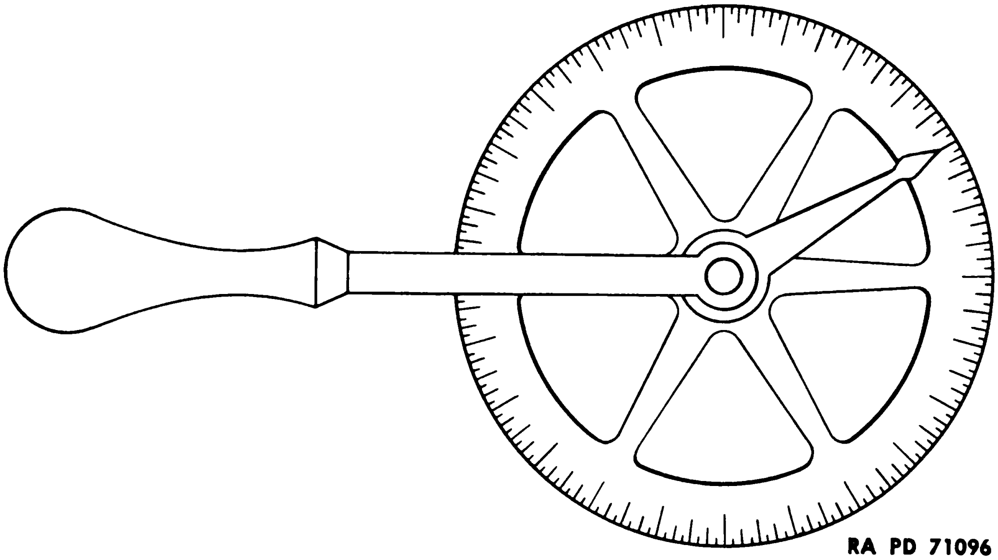
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Figure 134b – Measuring Wheel

diameter of the circle made by the center line would be 7 inches, and the length of stock required would be 7 x 3 1/7 or 22 inches. Other shapes can usually be divided into straight lines and parts of circles. Thus, in the link shown in figure 133, the center line consists of two semi circles, or one circle, 1½ inches in diameter and two 2-inch straight lines. The length of the center line is, therefore, 1½ x 3 1/7 + 2 + 2 = 8.72 inches. With a slight allowance for welding the link, the amount of stock cut should be 8¾ inches.

PART FOUR — Welding as Applied in the Ordnance Department, Testing of Welds and Welded Apparatus

CHAPTER 12

APPLICATION OF WELDING IN THE ORDNANCE DEPARTMENT

Section I

REPAIR OF ORDNANCE EQUIPMENT

Paragraph
General 236
Analyzing the job to be welded 237
Selecting the proper welding procedure 238
Identifying the metal of which the part is made 239
Parts that may be welded 240
Preliminary precautions before operating on ordnance equipment 241

236. GENERAL.

a. The materials used in the manufacture of ordnance materiel as well as the complete equipment are thoroughly tested by the Ordnance Department before it is issued to the using services in the field. This equipment is designed for extreme lightness and mobility and has a structure of sufficient strength to withstand normal service use and wear. Most of the failures or damage to ordnance equipment will be due to accidents, heavy loads, or unusual shocks which the equipment was not designed to withstand. It is in this class of repair work that field-service welding will find most of its applications.

237. ANALYZING THE JOB TO BE WELDED.

a. Before repairing any damaged ordnance materiel by welding, the problem should be studied from the standpoint of engineering design. The officer in charge of the field shop is held responsible for the engineering design and for supervision of the welded repair. It must first be determined whether or not the repair can be made satisfactorily by welding. To establish this point, the following are some of the more important factors that must be considered:

(1) The nature and extent of the damage, and the amount of straightening and fitting of the metal that will be required to make the repair.

(2) The possibility of bringing the structure back into shape without heating.

(3) The type and heat treatment of the metal used in the manufacture of the damaged part or structure (ch. 3).

(4) The effect of welding heat on the shape and physical properties of the structure (ch. 4, secs. IV and V).

(5) The need for special heat-treating or other equipment or materials in order to make the repair by welding.

(a) In emergency cases, some of these heat-treated parts can be repaired in the heat-treated condition by welding with stainless steel electrodes containing 25 percent chromium and 20 percent nickel or modified 18 percent chromium—8 percent nickel electrodes containing manganese or molybdenum. These electrodes will produce a satisfactory welded joint; however, a narrow zone in the base metal located in the vicinity of the welded joint will be affected by the heat of welding. Minor defects on the surfaces of heat-treated parts may be repaired by either hard-facing or bronze welding, depending upon their application in service. In any of the above repairs, it should be remembered that the heat-treated part will lose some of its strength, hardness, or toughness in the vicinity of the welded joint, even though the weld metal deposited has good properties.

(b) The preferred method of repairing these steels consists of annealing the broken part, if possible, and welding with a high-strength rod which produces a welded joint capable of heat treatment. The entire piece should be heat-treated after welding to obtain the properties originally found in the heat-treated piece. This method of welding should not be attempted unless the proper heat-treating equipment is available in the field shop. Repairs on these special alloy heat-treated steels must be approved by the Chief of the Field Service.

238. SELECTING THE PROPER WELDING PROCEDURE.

a. If it is decided by the shop officer that the repair can be made by welding, then he should study the problem further to establish the best welding procedure. In this study the following factors should be considered:

(1) GENERAL. The use of welding equipment and application of welding processes to the different metals have been covered in previous chapters. A thorough working knowledge in this respect and practical experience are a necessity before a welding procedure for any job can be selected.

(2) THE DESIGN OF THE JOINT. This includes the type and size of weld and the welding procedure. For arc welding, the proper type and size of electrode, together with the current and polarity settings, must be selected; for oxyacetylene welding, the proper type of welding rod and flux, where necessary, together with the correct gas pressure, tip size, and flame adjustment.

(3) METHOD OF PREPARING THE JOINT FOR WELDING. In preparing the edges of the plates or parts to be welded, it is important

to consider the cleaning and bevelling of the parts to be joined, as well as their proper location and spacing. The need for back-up strips, tack-welding, quench plates, and preheating must also be determined.

(4) PROCEDURE TO REDUCE INTERNAL STRESSES AND WARPING. This requires the use of a proper sequence for welding, control and proper distribution of the welding heat, spacing of the parts to be joined to permit some movement, control of the size and location of the deposited weld-metal beads, and use of the proper rate of cooling.

(5) NECESSITY FOR REINFORCEMENT. Since ordnance materiel is designed for lightness, the safety factors used are necessarily low in some cases. This necessitates some reinforcement at the joint to make up for the strength lost in the welded piece due to the effect of the welding heat. To accomplish this, it is necessary to consider a proper design for the reinforcement, so that the strength can be increased at the joint without producing high local stiffness. The type and thickness or method of preparing reinforcement for welds, and the use of a proper welding procedure to avoid internal stresses are further considerations in making a good reinforced joint.

239. IDENTIFYING THE METAL OF WHICH THE PART IS MADE.

a. Welding repairs should not be made on ordnance materiel until the type of material used for the different components or sections of ordnance field equipment is determined. It is the responsibility of the personnel making the repairs to obtain this information either from experience or from assembly drawings of different components of ordnance materiel likely to be welded in the field. These drawings should be carried by the maintenance companies in the field and should show the materiel and, if possible, the heat treatment of these parts. When available, these drawings should be studied in all cases before the decision is made to weld ordnance materiel. Those component parts whose repair by welding is not recommended should also be indicated on these drawings (par. 68-85).

240. PARTS THAT MAY BE WELDED.

a. The welding operations on ordnance materiel and standard automotive units is restricted largely to those parts which can be satisfactorily welded without destroying their physical properties. Successful welded repairs cannot be made on machined parts which carry a dynamic load. This applies particularly to high-alloy steels which are heat-treated for hardness, toughness, or both. Gears, shafts, antifriction bearings, springs, connecting rods, piston rods, pistons, valves, levers, rockers, and cams used in ordnance materiel are considered unsuitable for welding, the principal reason for this being that the heat of welding alters or destroys the original heat treatment given to these parts.

241. PRELIMINARY PRECAUTIONS BEFORE OPERATING ON ORDNANCE EQUIPMENT.

a. Before beginning to cut or weld:

(1) Remove all ammunition from the ordnance vehicle or equipment.

(2) Drain the fuel tank and close the fuel- and oil-tank shut-off valves.

(3) Disconnect and remove fuel and oil piping and electrical conduits in the area where welding is to take place.

(4) Have a fire extinguisher available.

(5) If any of the following are near the place in which welding or cutting is to be done, remove them from the vehicle.

(a) Fuel Tanks. An empty gasoline tank may explode with great violence when ignited by a spark from welding, unless it has been completely filled with water or thoroughly steamed out. Do not rely on flushing with water to eliminate the fumes. Removal of the fuel tank from the vehicle is preferred. If removal is not possible, either steam it out thoroughly, or fill it to overflowing with water.

(b) Sighting Equipment. It takes but little heat to melt the balsam used for cementing lenses.

(c) The optical parts of periscopes.

(d) Protectoscope prisms.

(6) Protect the following from heat:

(a) Guns. Many gun parts are heat-treated.

(b) Gun Mounts.

(c) Electrical Control Equipment. Insulation is broken down by heat.

(7) Protect finished surfaces from spatter of drops of molten metal with asbestos cloth, asbestos paper, wood, leather, cloth, or mud.

(8) The welder should take the usual precautions against burns from the arc or globules of hot metal.

(9) See also paragraphs 14 to 18, 106 to 109, and 179 to 181.

CHAPTER 12

APPLICATION OF WELDING IN THE ORDNANCE DEPARTMENT (Cont'd)

Section II

WELDING OPERATIONS ON AUTOMOTIVE EQUIPMENT

Paragraph
General 242
Welding processes to use for various parts 243
Heat-treated parts 244
Parts made of gray cast iron, cast steel, forgings, and carbon steel 245
Welding of truck components 246
Tractor repairs 247
Tank repairs 248

242. GENERAL.

a. The automotive equipment used, as in trucks, tanks, tractors, and other motor vehicles, is constructed from a large number of metals, processed under various heat treatments. In order to repair broken or damaged parts of this equipment, a careful study should be made of the metal used in the particular part and the heat treatment applied to develop strength, hardness, or other properties required for its particular application. The principal methods of repair are bronze welding, steel welding, aluminum welding, lead welding, soldering, hard-facing, and heating.

243. WELDING PROCESSES TO USE FOR VARIOUS PARTS.

a. The chart (par. 290) shows a list of automotive parts, the metals of which they are usually composed, and the recommended welding method for repairing them. In some cases, however, the procedure charts for oxyacetylene and electric arc welding given in paragraphs 288 and 289 should be consulted for further information on welding the particular metal. The first column of the chart in paragraph 290 lists the parts classified under main divisions and subdivided into related groups. The second column shows the usual metal composition of the part. In some cases, where there is more than one metal used for a given part and where this affects the welding procedure, the different classifications are numbered. The third column points out the recommended welding method for repairing the part. In the simpler cases, where a single welding method is used for one or more metal compositions, an "X" is used to indicate both metal composition and welding method. Where the different metal compositions require different welding methods, each composition and the corresponding method are given the same number. The letter "N," when placed in any of the columns which show the usual metal composition, indicates that welding is not recommended. If an "N" is also placed in one of the columns of welding methods, this means that minor areas of the part in question can be built up by the method indicated; but such parts should not be welded. If no "N" appears in the welding-method columns, the part should neither be welded nor built up.

244. HEAT-TREATED PARTS.

a. In the "Welding Not Recommended" column of the chart in paragraph 290, certain parts mentioned depend upon the heat treatment which they undergo during manufacture to give them particular properties. Welding of these parts should not be attempted unless the repair shop is equipped with special heat-treating equipment for handling the parts after welding.

b. In some cases, alloy steels or specially heat-treated parts may be repaired by using a stainless steel filler metal. There will still remain in the vicinity of the welded joint a heat-affected zone which will be weaker than the original heat-treated part. In general, where it is possible to heat-treat the parts after welding, they should first be annealed, and filler metal of the same composition or properties as the base metal should be used.

c. Where the piece is to be welded in the heat-treated condition, a stainless steel or a mild steel filler rod or the transition bead method can be used. This method consists of first depositing a layer of stainless steel on the surfaces of the broken edges by means of a 25 percent chromium– 20 percent nickel, or modified 18 percent chromium– 8 percent nickel stainless steel rod. After this preparation, the edges are welded with either a mild steel or high-strength filler rod. Where hardness and toughness are required in the finished weld, an 11 percent to 14 percent manganese or high-strength filler rod is deposited on the stainless steel layer instead of the mild steel, and the finished weld may be covered with a layer of hard-facing metal. Either of these methods of repairing heat-treated steel will give satisfactory properties in the weld metal deposit; however, there will still be a narrow heat-affected zone in the base metal. These methods of repair are useful in the field, but should be used only under emergency conditions.

245. PARTS MADE OF GRAY CAST IRON, CAST STEEL, FORGINGS, AND CARBON STEEL.

a. It should be noted that the bronze welding process is the principal method used for repairing automotive parts made up of gray cast iron, cast steel, steel forgings, and carbon steels. The lower temperatures used in bronze welding as compared to welding make it possible to weld the broken parts with less heat effect, lower stresses, and less warping in the base metal, however, the lower strength and lower operating temperature limitations should be considered on all joints made by bronze welding (ch. 6, secs. II and III).

246. WELDING OF TRUCK COMPONENTS.

a. Side Frames.

(1) The truck member most frequently repaired by welding is the side frame. In general, these frames are made of heat-treated alloy steel and are subject to high bending, torsion or twisting, and impact loads. The procedure for welding a truck frame or similar member is shown in figure 135. View 1 shows the procedure for welding the under side vertical and horizontal sections of the frame before reinforcement is applied. Views 2 through 6 show various methods of reinforcing the channel frame to increase its strength and stiffness.

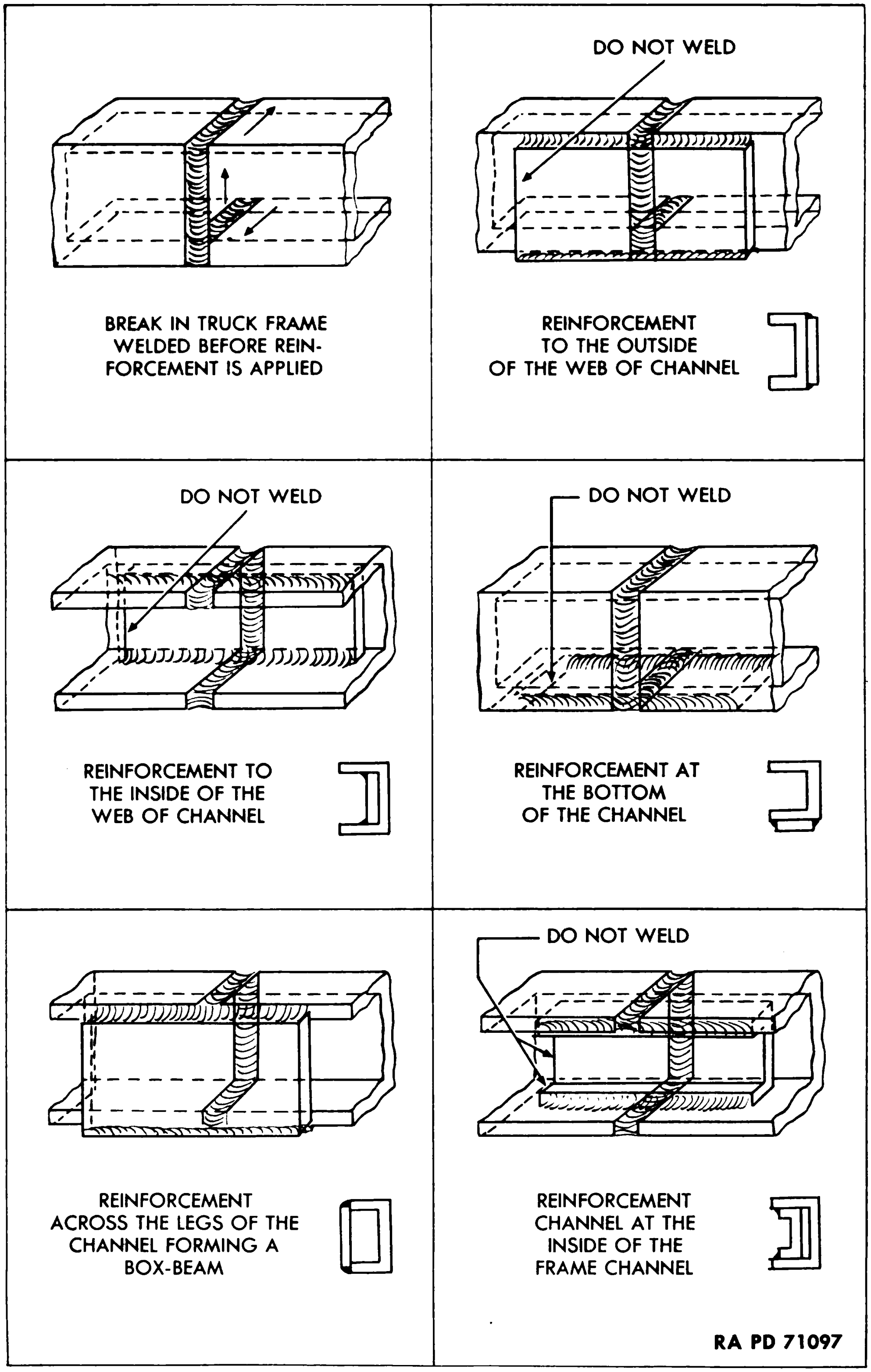
(2) The type of reinforcement selected will depend upon the location of the break and possible interference with the operation of other equipment on the truck. It should be noted that the ends of the reinforcement plates are not welded, as welds across the ends of the plates would produce areas of decreased strength across the back and legs of the channel. Before reinforcement plates are applied, all welds should be ground flush. These reinforcement plates should be approximately of the same thickness as that of the channel. Sufficient allowance should be made on the width of the reinforcement so that, when completed, the welds will be flush with the top and bottom sections of the channel.

(3) The procedure outlined for adding reinforcement to channels should be followed when reinforcement plates are added to angles, T- or box sections, or I-beams.

b. Front Axles. The front axles of standard automotive equipment are made from heat-treated alloy drop-forgings. Unless these axles can be straightened cold, they should be replaced. Repairs by welding should not be made to front axles except as a temporary measure in an emergency.

c. Rear Axle Housings. Rear axle housings are composed of a combination of different metals; the most commonly used are pressed steel, malleable iron, and cast steel. The pressed steel and cast steel parts can be satisfactorily arc-welded, but the malleable iron is most satisfactorily repaired by brazing. It is important that the welder be able to distinguish malleable iron from cast steel. Axle housings made of cast iron are generally repaired in the field by bronze welding or brazing.

d. Drive Shafts. Drive shafts are usually made of medium-carbon seamless tubing. This materiel is readily weldable. Highly stressed alloy steel machined parts, such as crankshafts, connecting rods, gears,



BREAK IN TRUCK FRAME WELDED BEFORE REINFORCEMENT IS APPLIED

REINFORCEMENT TO THE OUTSIDE OF THE WEB OF CHANNEL

REINFORCEMENT TO THE INSIDE OF THE WEB OF CHANNEL

REINFORCEMENT AT THE BOTTOM OF THE CHANNEL

REINFORCEMENT ACROSS THE LEGS OF THE CHANNEL FORMING A BOX-BEAM

REINFORCEMENT CHANNEL AT THE INSIDE OF THE FRAME CHANNEL

Figure 135 — Methods of Reinforcing Truck Frames

and axle drive shafts, are not generally repaired by welding because of the damage done to their heat treatment by the heat of welding.

e. Radiators. Radiators can be repaired with an air acetylene soldering torch or an oxyacetylene welding torch with the proper tip, common 50-50 solder, and a flux. The oxyacetylene flame should be adjusted to give a highly carburizing mixture. Leaks that have developed in copper tubes should be thoroughly cleaned by using a 5 percent solution of hydrochloric acid. The metal adjacent to the crack should be thoroughly "tinned" before the repair is made in order to insure a sound joint. Where the leak is present at joints between copper and cast iron, the surface of the cast iron should be "pickled" before making the repair. This consists of applying the hydrochloric acid solution to the cast iron at the joint and heating until the surface of the cast iron is thoroughly cleaned. This action removes surface oxides, scale, and other impurities and leaves the surface porous. The copper is prepared by using the procedure outlined above. The "pickled" surface of the cast iron will "tin" readily and form a good bond, as the lead penetrates well into the surface pores. After tinning both the cast iron and copper separately, the joint is assembled and soldered by applying heat. In many cases, little additional flux or solder is necessary to complete the joint (par. 158).

247. TRACTOR REPAIRS.

a. The tractors used in the field by ordnance troops are of three types, namely, the light and medium gasoline-driven and the heavy diesel-driven tractors. Except for the frame and suspension, these vehicles follow commercial truck practice. The castings used for housing of the crankcase, clutch transmission, control differentials, and final drive, as well as cast main frames and hollow angle braces, can be repaired, if necessary, by welding. The rolled channel frames, cross members, and track-roller frames are also satisfactorily straightened, built-up, and repaired by welding. In general, welded repairs can be made except for items mentioned under general restrictions (par. 246).

248. TANK REPAIRS.

a. The hull of tanks consists of nickel steel or other alloys, to which armor plate is riveted or welded. The suspension system consists largely of forgings and castings. Various castings are used throughout the power train. Welded repairs on these vehicles can be made to parts which do not carry the driving power load. In general, the repair of these components or parts by welding requires such special precautions as preheating and postheating, as well as proper welding procedure. One of the principal welding repairs required on tanks and other combat vehicles in service will be on damaged armor plate. The technique for welding armor plate is given in chapter 12, section IV.

CHAPTER 12

APPLICATION OF WELDING IN THE ORDNANCE DEPARTMENT (Cont'd)

Section III

WELDING OPERATIONS ON ARTILLERY MATERIEL

Paragraph
Artillery construction 249
Metals used in fabrication of artillery materiel 250
Welding repairs on artillery materiel 251

249. ARTILLERY CONSTRUCTION.

a. The following table lists the guns and howitzers of ordnance field equipment and shows the methods of fabrication used in the construction of their carriages, trails, or mounts.

WEAPON	CARRIAGE OR MOUNT		
Designation	Type Designation	Type of Trail	General Construction
GUN, 37-mm, M3	CARRIAGE, gun, 37-mm, M4	Split trail	Welded
GUN, 37-mm, M1916	CARRIAGE, gun, 37-mm, M1916	Split trail	Riveted
GUN, 75-mm, M1897	CARRIAGE, gun, 75-mm, M1897	Box trail	Riveted
GUN, 75-mm, M1897A4	CARRIAGE, gun, 75-mm, M2A2	Split trail	Welded
	CARRIAGE, gun, 75-mm, M2A3	Split trail	Welded
GUN, 155-mm, M1	CARRIAGE, gun, 155-mm, M1	Split trail	Welded and riveted
GUN, 155-mm, M1918MI	CARRIAGE, gun, 155-mm, M2	Split trail	Riveted
GUN, antiaircraft, 3-in., M3	MOUNT, gun, antiaircraft, 3-in., M2A2	Mobile trailer mount	Welded
GUN, antiaircraft, 90-mm, M1	MOUNT, gun, antiaircraft, 90-mm, M1	Mobile trailer mount	Welded
GUN, automatic, 37-mm, M1A2	CARRIAGE, gun, automatic, 37-mm, M3	Mobile trailer carriage	Welded
HOWITZER, 105-mm, M2A1	CARRIAGE, howitzer, 105-mm, M2	Split trail	Welded
HOWITZER, 155-mm, M1918	CARRIAGE, howitzer, 155-mm, M1918A3	Modified box trail	Riveted
HOWITZER, pack, 75-mm, M1A1	CARRIAGE, howitzer, pack, 75-mm, M1A1	Modified box trail	Welded and riveted
HOWITZER, pack, 75-mm, M1A1	CARRIAGE, howitzer, 75-mm, M3A1		Welded

250. METALS USED IN FABRICATION OF ARTILLERY MATERIEL.

a. The principal metals used for these parts are steels of the low- and medium-carbon and structural nickel-alloy types. The earlier types of carriages and trails were of riveted construction with a trend toward welding in the more recent developments. Before welded repairs are attempted, the personnel responsible for making the repair should identify the piece and determine the type and weldability of the steel in the broken part (ch. 3).

251. WELDING REPAIRS ON ARTILLERY MATERIEL.

a. Under field conditions welding repairs on artillery materiel will be confined mainly to carriages or mounts. Damaged parts of the gun and cradle assembly will rarely be repaired by welding, since the materials of which they are made are usually of such a nature that welding operations destroy or adversely affect the properties of the metals, or entail complicated heat-treatment procedures.

b. In general, when selecting a welding procedure for artillery materiel, follow recommendations given in paragraphs 289 and 290. The low- and medium-carbon steels can be satisfactorily welded with mild steel electrodes or welding rods and, where it is necessary, severely damaged sections can be strengthened with suitable reinforcing plates. Where riveting has been used for the construction of carriages or trails, the rivet heads should be cut or "washed" off with a cutting torch before reinforcing plates are welded, in order to obtain close contact with the damaged sections. Trails that have been bent out of shape and cracked should first be straightened by the careful application of heat. The cracks should be welded and ground flush before reinforcing plates are applied. The reinforcing plates should be thick enough to provide for the necessary strength without making the structure too stiff. Only the seams running along the length of the trail should be welded on all reinforcing plates, the ends of the plates being left unwelded. Welding of the ends would simply transfer to the welded ends of the reinforcing plate the conditions existing in the welded joint before adding reinforcement. This would result in weakness at this section and would defeat the purpose of the reinforcing plate.

c. Trails constructed of structural nickel alloy steels are designed for lightness and specially treated for maximum strength. Welding of structures made of this steel presents a more difficult problem. The top carriages or cradles should not be welded. Other structural members can be welded when approved by the Chief of the Field Service. Field repairs by welding on these structures can be made, when authorized, by proper preheating, by welding with nickel alloy, 25-20 stainless steel, or modified 18-8 stainless steel electrodes, and finally, by slow cooling and uniform stress-relief heat treatment where necessary. For many applications, welds can be made with these stainless steel electrodes without preheating or postheating.

CHAPTER 12

APPLICATION OF WELDING IN THE ORDNANCE DEPARTMENT (Cont'd)

Section IV

ARMOR PLATE WELDING

Paragraph
General 252
Properties of armor plate 253
Types of armor plate 254
Identification of armor plate 255
Cutting armor plate 256
Welding homogeneous armor plate 257
Welding face-hardened armor plate 258
Strengthening riveted joints in armor plate 259

252. GENERAL.

a. Armor plate is used for the protection of personnel and equipment in tanks, armored cars, gun motor carriages, and other combat vehicles against the destructive forces of enemy projectiles. It is fabricated both in the form of castings and rolled plates, which in turn are selectively heat-treated to develop the desired structural and ballistic properties. Industrial manufacture of gun turrets and tank hulls comprehends designs using one piece castings and welded assemblies of cast sections and rolled plates. In certain cases, cast sections of armor are bolted in place to expedite the requirements of maintenance through unit replacement. Welding has replaced riveting as a formative process of structural armor fabrication; however, the latter still finds selective application on vehicles protected by face-hardened armor.

b. The development of a suitable technique for welding armor plate is contingent upon a clear understanding of the factors affecting the weldability of armor plates, the structural soundness of the weld and its ultimate suitability to withstand the forces of penetration and impact in service. From the standpoint of field repair by welding, these considerations can be resolved into the following:

(1) Knowledge of the exact type of armor being welded through suitable identification tests.

(2) Study of alternate repair methods known to be satisfactory for the particular type of armor and type of defect in question.

(3) Design function of the damaged structure.

(4) Selection of welding materials, and repair procedures, from the facilities available to produce optimum ballistic properties and structural strength.

(5) Need for emergency repair to meet exigencies of the existing situation.

(6) Careful analysis of the particular defect in the armor to insure proper disposition of the following operating variables:

(a) Joint preparation and design.
(b) Welding electrodes.
(c) Welding current, voltage and polarity.
(d) Sequence of welding passes.
(e) Welding stresses and warpage.

(7) Proper protection or removal of inflammable materials and equipment located in the vicinity of the welding operation.

c. The advantages of welding as an expedient for field repair to damaged armor plate lie principally in the speed and ease with which the operations can be performed. The procedures for welding used to make repairs in the field, although basically the same as those used for industrial fabrication, must be modified for several reasons. These can be summarized as follows:

(1) The defects encountered in the field depending upon the nature and location of impact are:

(a) Complete shell penetrations.
(b) Bulges or displaced sections.
(c) Surface gouges.
(d) Linear cracks of various widths terminating in the armor or extending to its outside edges.
(e) Linear or transverse cracks in or adjacent to welded seams.

d. From a study of the nature of these defects it can be seen that many of the welding repairs require the selective use of patches obtained by flame cutting sections from completely disabled armored vehicles having similar armor plate. Further, most of the welding, whether around patches or along linear seams, is performed under restricted conditions; that is under conditions which permit no motion of the base metal sections to yield under contraction stresses produced by the cooling weld metal. The complexities of this problem are further enhanced by the highly stressed condition of the base metal adjacent to the damaged sections. These stresses are produced by projecticles physically drifting the edges of the armor at the point of impact or penetration.

e. It is with these considerations in mind that the subsequent armor plate welding procedures were developed.

253. PROPERTIES OF ARMOR PLATE.

a. General. Armor plate is an air-hardening alloy steel; that is, it will harden by normalizing or heating to above its critical temperature and cooling in still air. The base metal quenching effect produced adjacent to a weld in heavy armor plate under normal welding conditions is about halfway between the effect of air cooling and oil quenching. The extremely steep thermal gradients which occur in the region of a weld range from temperatures of 3,000 F or greater in the weld metal to ambient temperature in the base metal. In view of this, a narrow zone each side of the deposited weld metal is heated to above its critical temperature by the welding heat and quenched by the relatively cold base metal, to form a hard, brittle zone. It is in this hard nonductile structure, known as martensite, that cracks are more likely to occur as a result of the sudden application of load. In order to minimize the formation of these hard zones and to limit their effect on the ballistic and structural properties of the welded armor, special precautions must be taken in all welding and cutting operations. Care must also be taken not to rapidly cool armor during welding in order to avoid the formation of cracks in these hard zones.

254. TYPES OF ARMOR PLATE.

a. General. Two types of armor plate are used on combat vehicles, namely, homogeneous (cast or rolled) and face hardened (rolled). It is essential that the armor be specifically identified before any welding or cutting operations are performed. This is important, as the welding procedures outlined for each type of armor are distinctly different and noninterchangeable.

b. Homogeneous Armor. Homogeneous armor is heat-treated throughout its entire thickness to develop good shock or impact-resisting properties. As its name indicates, it is uniform in hardness, composition, and structure throughout and can be welded on either side.

c. Face-hardened Armor Plate. Face-hardened armor plate is designed to have an extremely hard surface layer obtained by carburizing, which extends to a depth of about one-fifth to one-fourth of its thickness facing outward on the tank or armored vehicle. The primary purpose of face-hardened armor is to provide good resistance to penetration. The inner side is comparatively soft and has properties similar to those of homogeneous armor. The inside and the outside of face-hardened armor plate are really two different kinds of steel. Face-hardened armor up to ½ inch in thickness should be welded from the soft side only. Thicknesses above ½ inch can be satisfactorily welded from both sides.

255. IDENTIFICATION OF ARMOR PLATE.

a. File Test. This test is a simple but accurate method of identifying armor plate. A file will bite into homogeneous armor plate on both sides, but will bite only the soft side of face-hardened armor plate. When applied to the face side, a file will slip and break off teeth, acting in much the same manner as case-hardened steel.

b. Appearance of Fracture. The metal edges at holes or cracks in homogeneous armor plate are ragged and bent with the metal drifted in the direction of the forces which damaged the armor. Cracks in homogeneous armor are usually caused by and are present at severe bulges or bends in the plate or section. The metal edges at holes or cracks in face-hardened armor are relatively clean-cut and sharp. The plates do not bulge or bend to any great extent before cracking. By examining the edges of freshly cracked face-hardened armor it will be noted that the metal at the face side is brighter and finer in grain structure than the metal at the soft side. The brighter metal extends to a depth of approximately one-fifth to one-fourth of the thickness from the surface of the face side.

256. CUTTING ARMOR PLATE.

a. Cutting Homogeneous Armor Plate. Either the oxygen cutting torch, which is preferable, or the electric arc can be used to cut homogeneous armor plate. The carbon arc can be used to cut out welds and to cut castings and plates, but the electric (shielded) metal arc is preferred when oxygen and acetylene are not available.

b. Cutting Face-hardened Armor Plate. The procedure for cutting this type of armor is essentially that outlined for homogeneous armor except that every precaution should be taken to keep heat away from the hard, face side of the plate. This is accomplished by performing all cutting operations from the soft side of the armor, thus limiting the extent of heating and therefore softening of the hardened surfaces.

(1) CUTTING WITH THE OXYGEN CUTTING TORCH.

(a) The general practice used for cutting can be applied equally well for cutting armor plate. The tip size, cutting oxygen, and preheating gas pressures should be kept at the minimum consistent with good quality cuts, to prevent overheating. The oxygen cutting torch cannot cut the stainless steel type of weld used on tanks with this procedure. This is due to the fact that oxygen cutting is an oxidation process and is used satisfactorily only on ferrous metals. Since stainless steels are designed to resist oxidation, they therefore cannot be cut by using the methods outlined for steel cutting.

(b) To cut or sever cracked or defective sections of stainless steel welds, a melting process is used. This is accomplished by using the oxygen cutting torch with a steel rod as an energizer, as shown in figure 136. The oxygen combines with the steel rod, and the ensuing exothermic reaction creates high-temperature molten steel. Drops of this molten steel are washed off of the end of the rod against an edge of the weld thus helping to melt it. The kinetic energy of the cutting

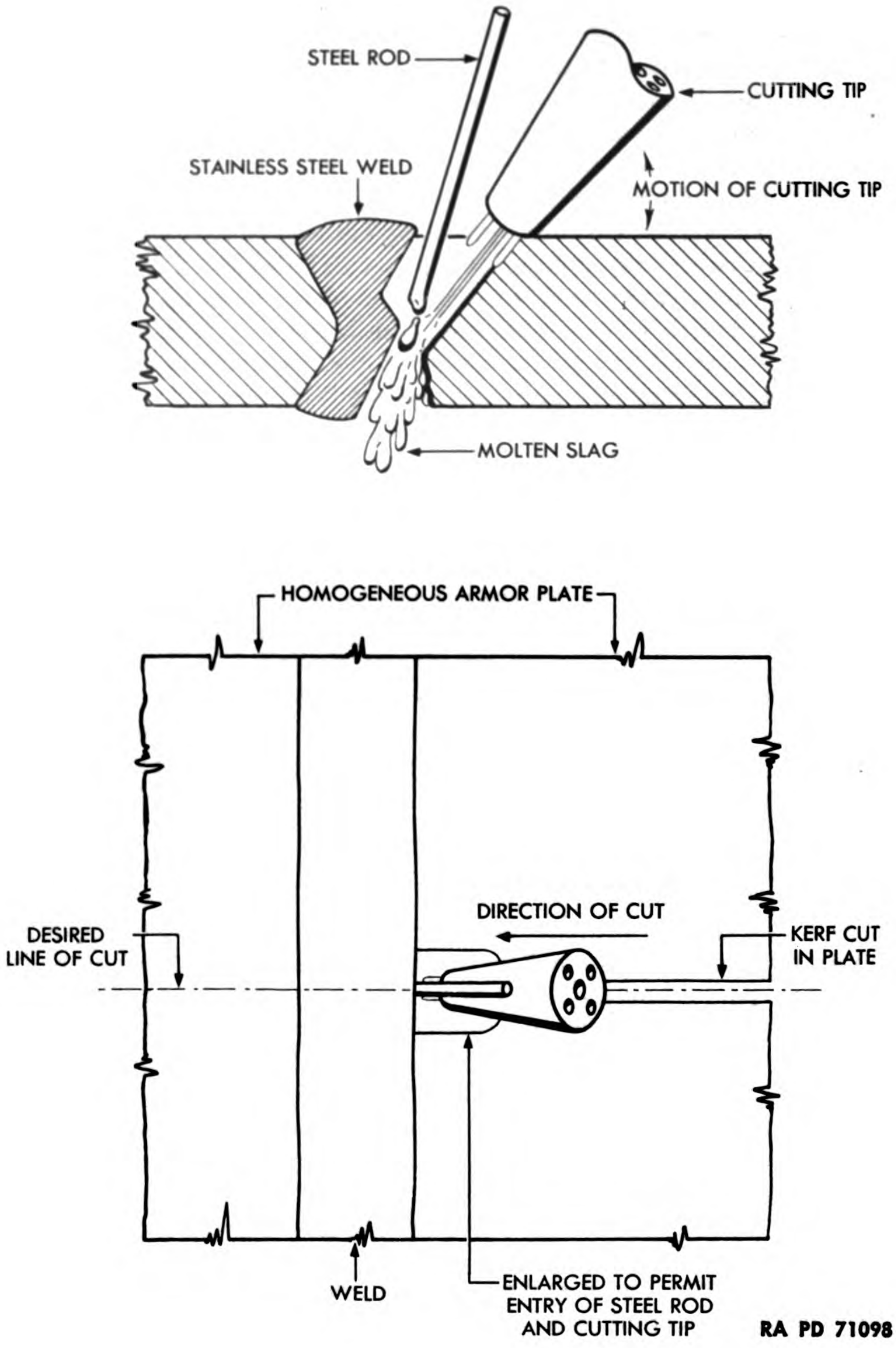


Figure 136 — Method of Cutting Stainless Steel Welds

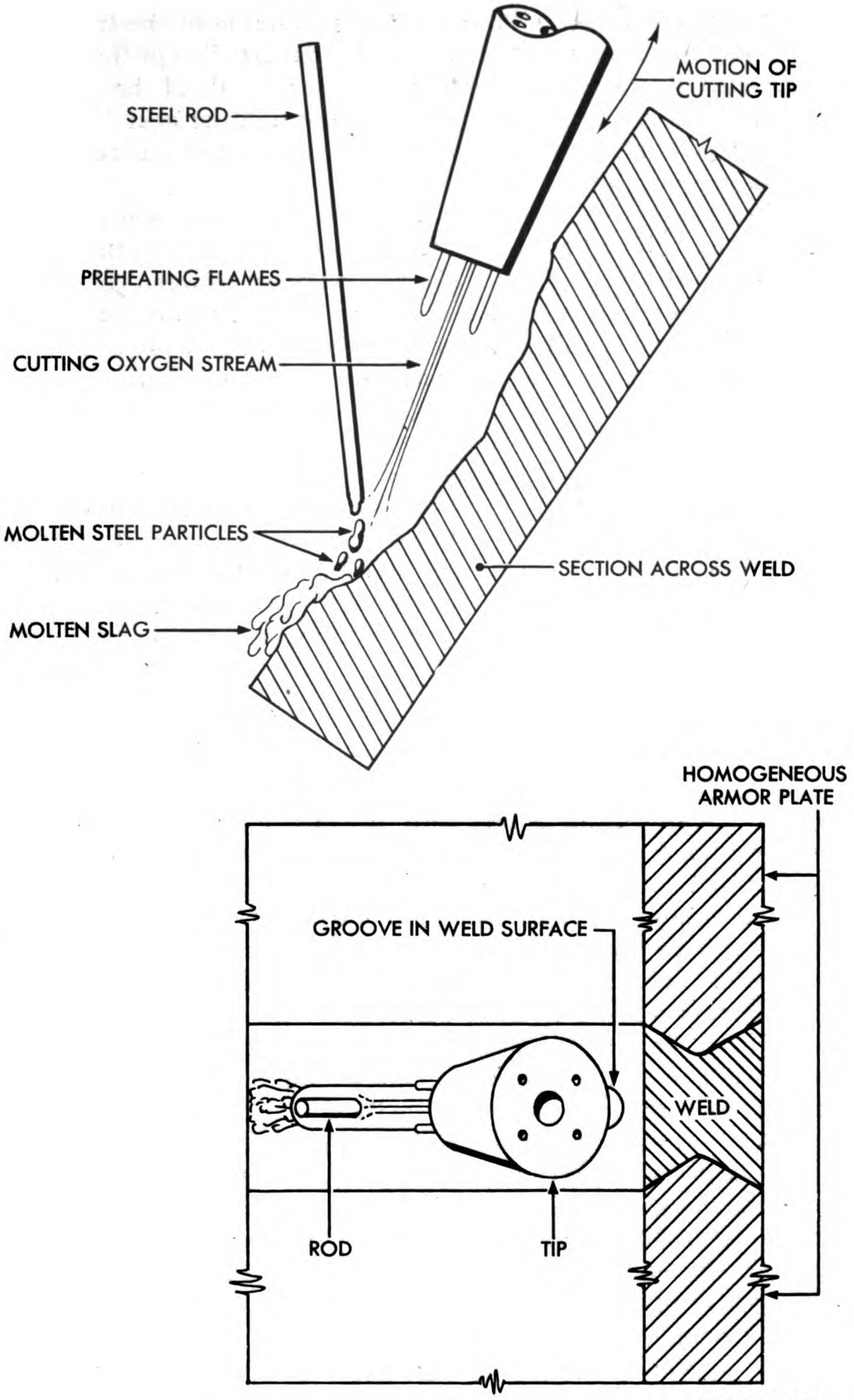


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Figure 137 — Method of Removing Surface Defects From Stainless Steel Welds

oxygen stream combined with an oscillatory motion of the torch help to wash away the molten weld metal in thin layers. To cut thick welds in armor, the steel rod should be held against the side of the weld and fed downward as required to supply sufficient melting heat. The oscillatory torch motion noted above should also be used in this case to aid in the removal of molten weld metal.

(c) Cracks or other defects on the face of stainless steel welds can be removed by holding the cutting tip at a slight angle with the surface of the plate as shown in figure 137. The reaction between the cutting oxygen and a steel rod held on the surface develops sufficient heat to melt the weld metal, while the force of the cutting oxygen stream is used to wash this molten metal away, leaving a groove which can be rewelded.

(2) CUTTING WITH THE ELECTRIC ARC.

(a) The electric arc cutting process is a melting process using the heat of the electric arc to melt the metal along the desired line of cut. It differs from oxygen cutting in that it severs pieces by melting rather than by rapid oxidation. Arc cutting performed with (shielded) metal arc type of electrodes usually requires straight polarity (electrode negative) and a long arc. The current requirements for metal arc cutting are given in the following table:

Electrode Diameter	Current
$\frac{5}{32}$ in.	300 amp
$\frac{3}{16}$ in.	400 amp

(b) Metal arc cutting is best performed using mild steel electrodes of the down-hand deep-groove type with a heavy coating which permits use of high currents. The coating burns off slowly, so that the arc can be used to blow and push molten metal out of the plates to be cut.

(c) It will be noted that the current requirements for metal arc cutting are much higher than those used for metal arc welding. Polarity adjustments made are those consistent with minimum electrode burn-off rates. This factor can be determined by following specific recommendations of the electrode manufacturer, or, lacking this information, through the trial and error method.

(d) Arc cutting with either a carbon or graphite electrode requires straight polarity, a long arc, and high welding currents. Specific current adjustments are governed by the electrode diameter, the plate thickness to be cut and the ease with which the cutting operation proceeds. The carbon should have a pointed end to reduce arc wander and to produce less erratic cuts.

(e) Cuts made by either the metal or carbon arc methods are rough and do not approach the quality of cuts produced by the oxygen cutting torch. Arc cutting with shielded metal arc electrodes has a distinct advantage over the carbon arc cutting process in that there is considerably less arc shorting against the kerf or sidewalls of the cut

edges. This is attributed to the heavy flux coating on shielded metal arc electrodes which acts as an insulator against sidewall shorting.

(f) Arc cutting can be satisfactorily performed on both ferrous and non ferrous metals, consequently, it works equally well on both the armor plate and the stainless steel weld metal.

(g) After completing the cut, the adhering scale, slag, and rough edges should be removed by chipping, hammering, or grinding prior to welding. In general, where an oxygen cutting torch is available with adequate gas supply, the principal use of the arc cutting process is for cutting the stainless steel welds on armor plate.

257. WELDING HOMOGENEOUS ARMOR PLATE.

a. **General.** Initial discussion of armor plate welding has treated certain essential differences between industrial fabrication and field repair methods. Subsequent procedures outlined will cover armor plate welding repair as required to maintain damaged armored vehicles in the field. As a preliminary step, the damaged armor should be checked by applying one of the methods discussed above for identifying the types of armor plate. Armored vehicles that have been exposed to conditions of extreme cold should not be welded until a sufficient preheat has been applied to bring the metal up to 100 F in the zone of welding. At this temperature the armor will be warm to the hand when applied to the surface. If this procedure is not applied, cracking will occur in the zone of welding due to the severe base metal quenching action on the deposited weld.

b. **Procedure.**

(1) In order to weld simple cracks in the homogeneous armor plate, the edges of the crack should be bevelled by means of flame cutting to produce the double bevelled joint shown in C, figure 138. Care should be taken to round off the corners at the toe and nose of the joint. This procedure is necessary in order to eliminate excessive weld metal dilution by the base metal when welding at these points. The included angle of bevel should be made approximately 45 degrees, to provide electrode clearance for making the root welding beads. The root spacing should be 5/16 to 3/8 inches wide.

(2) Since considerable importance must be placed upon the quality of weld beads deposited at the root of the joint, it is essential that extreme care be taken to prevent cracks, oxide and slag inclusions, incomplete penetration, and excessive weld metal dilution. Some of the methods recommended as preparatory steps for root bead welding are shown in figure 139. The double bevelled joint requires a suitable back-up material for the root weld. For narrow gaps, a 3/16-inch stainless steel electrode without coating can be tack-welded in place as shown in A, figure 139. Welding beads Nos. 1, 2, 3, and 4 are then

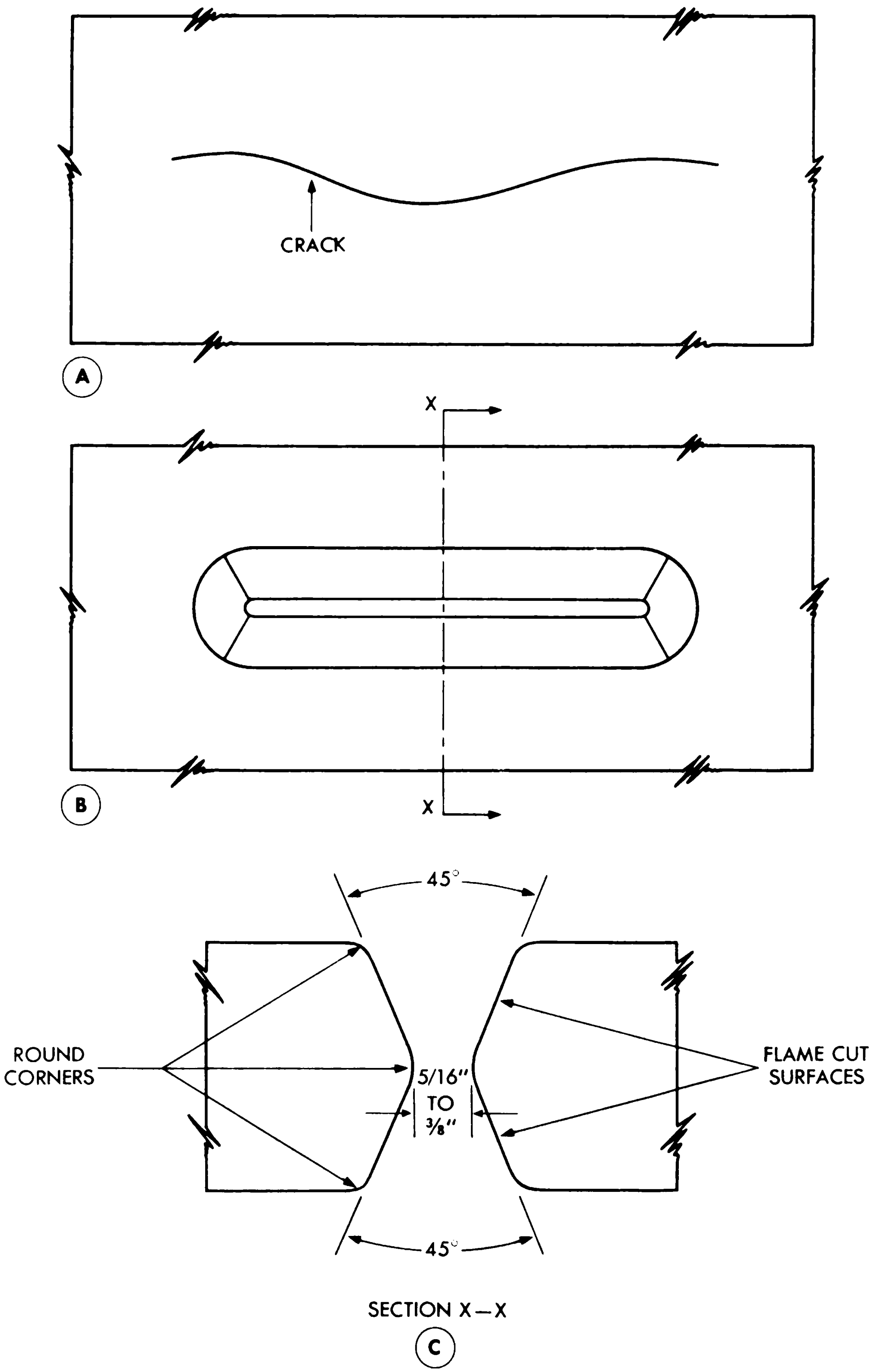

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Figure 138 — Joint Edge Preparation for Welding Cracks in Homogeneous Armor Plate

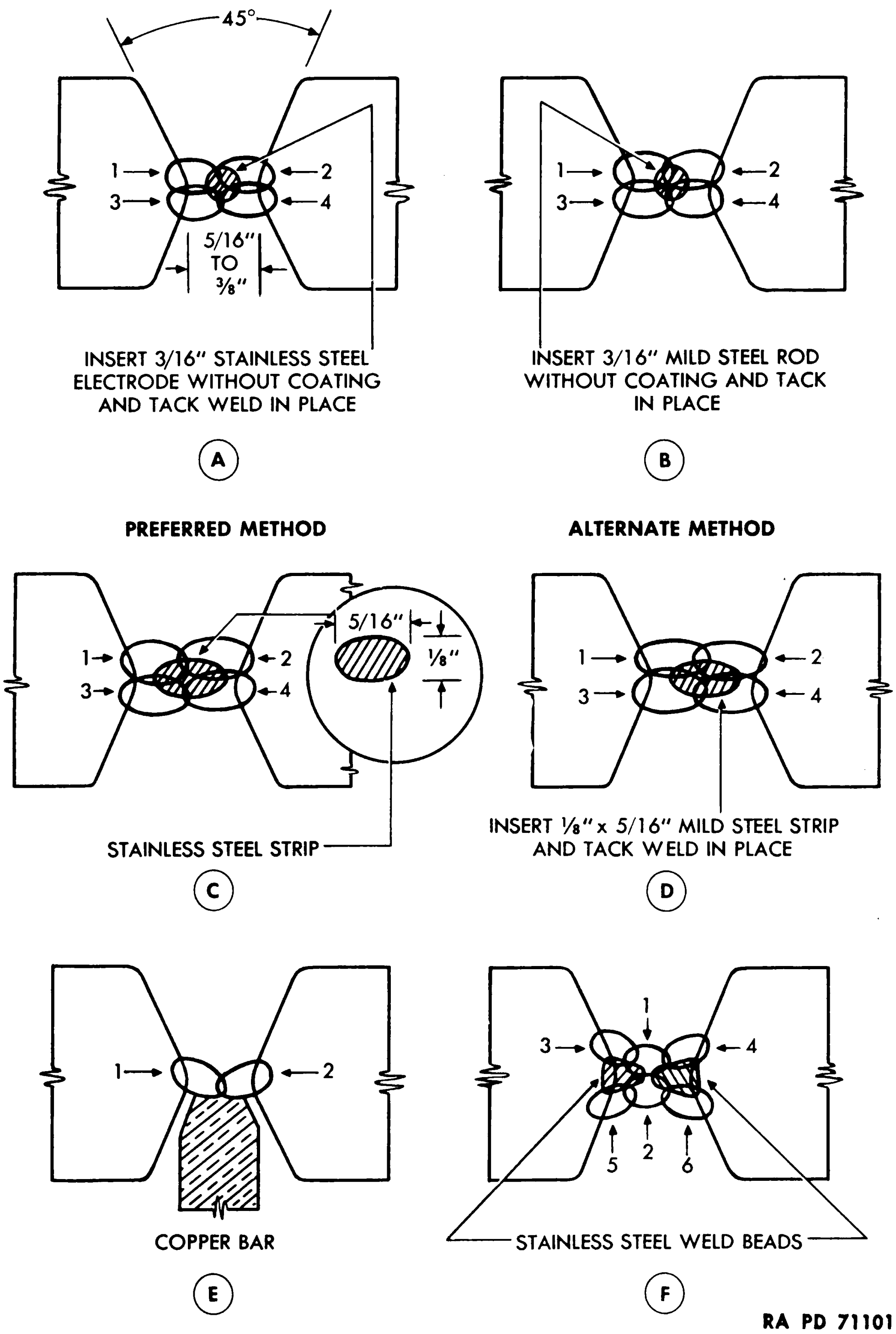

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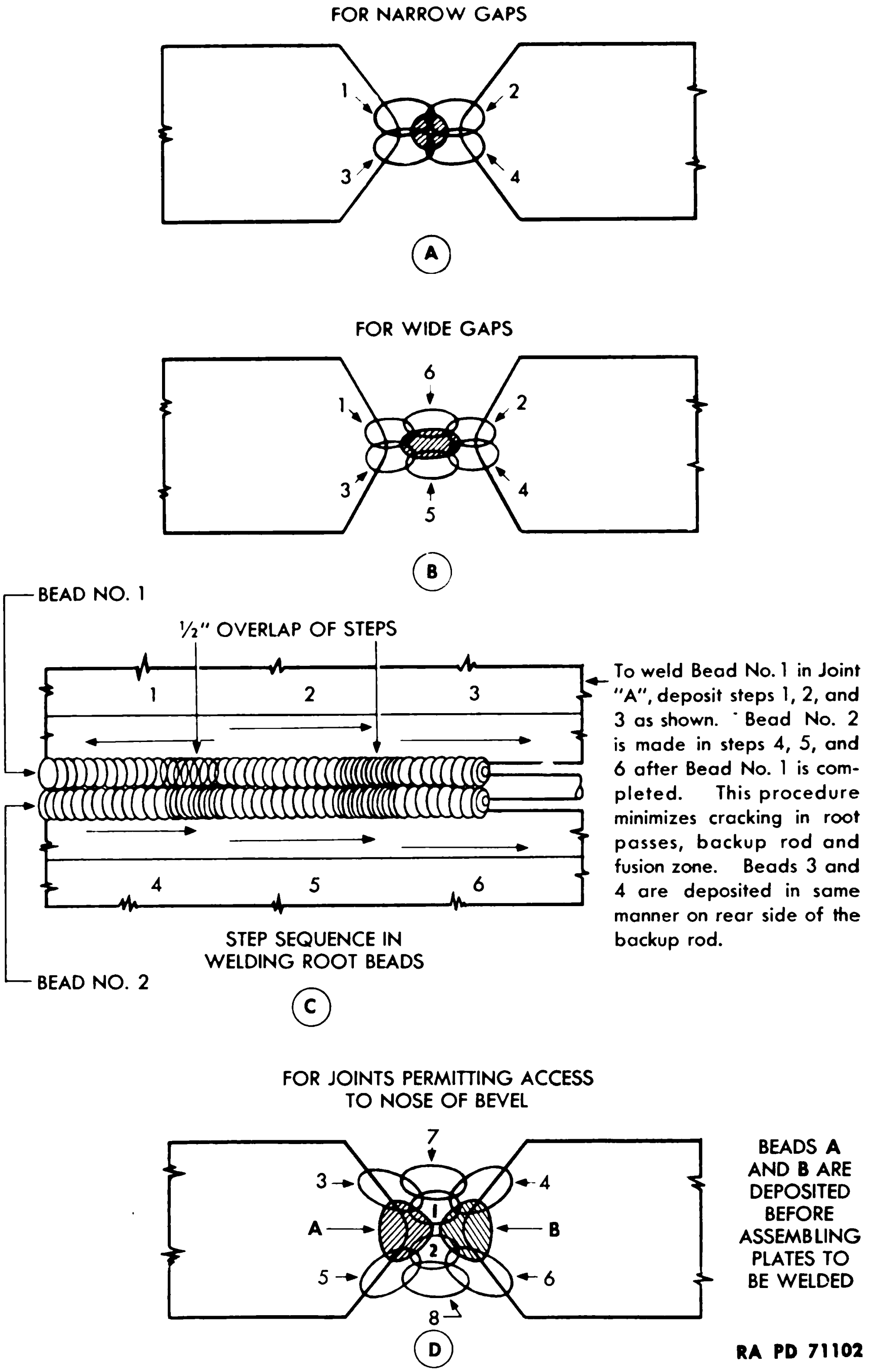
Figure 139 — Back-up Methods for Welding Penetration Zone Root Beads on Homogeneous Armor Plate


FOR NARROW GAPS

FOR WIDE GAPS

STEP SEQUENCE IN WELDING ROOT BEADS

To weld Bead No. 1 in Joint "A", deposit steps 1, 2, and 3 as shown. Bead No. 2 is made in steps 4, 5, and 6 after Bead No. 1 is completed. This procedure minimizes cracking in root passes, backup rod and fusion zone. Beads 3 and 4 are deposited in same manner on rear side of the backup rod.

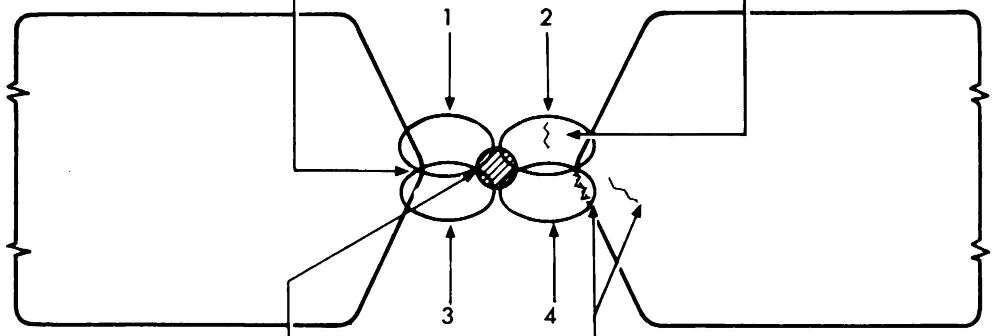
FOR JOINTS PERMITTING ACCESS TO NOSE OF BEVEL

BEADS A AND B ARE DEPOSITED BEFORE ASSEMBLING PLATES TO BE WELDED

RA PD 71102

Figure 140 — Sequence of Passes When Depositing Root Beads on Homogeneous Armor Plate

deposited in that order. All slag and oxides should be removed from the joint before depositing beads Nos. 3 and 4 to insure a sound weld in this zone. C, figure 139, shows the method of using a stainless steel strip as a back-up for root beads where wide gaps are encountered. The root beads Nos. 1, 2, 3, and 4 should be deposited on alternate sides of the back-up strip in the order shown. In the event a mild steel rod or strip is used as shown in B and D, respectively, figure 139, the back side of the back-up rod or strip should be chipped out after depositing beads Nos. 1 and 2 to minimize dilution in beads Nos. 3 and 4 with mild steel. The procedure using a copper back-up bar is shown in E, figure 139. The copper bar is removed after depositing beads Nos. 1 and 2, since these beads do not weld themselves to the bar. Beads Nos. 3 and 4 should then be applied as shown in A, figure 139, after thoroughly cleaning the back side of the deposited metal. In certain cases where plates of homogeneous armor are cracked along their entire length, thus permitting easy access to the entire cross section of



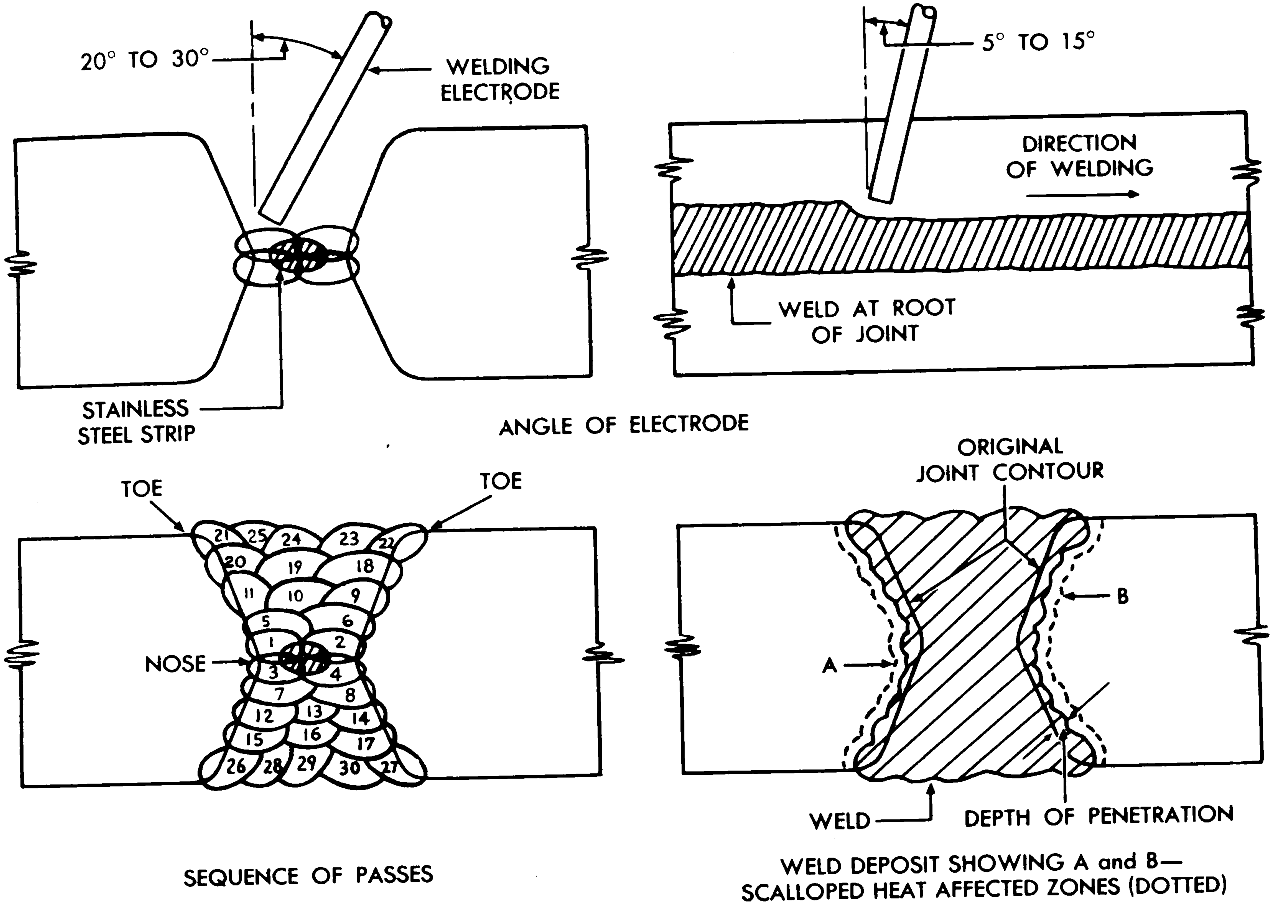
Try to get fusion here between beads 1 and 3, also 2 and 4

Excessive welding current, or open craters, may cause some crater cracks or center bead cracks. Chip out all cracks over ¼" long and correct welding procedure to fill in craters. Use back step welding. Adjust to proper welding current.

Cracks in fusion zone or in heat affected zone indicate excessive welding speed or too small an electrode. Use 3-bead technique for wide root openings—one bead on each side, then one in the middle. Do not use electrodes smaller than 5/32-inch for root passes. Decrease welding speed to prevent rapid base metal quench on welding bead. This type of cracking appears on welds made on the face side of face-hardened armor plate and is the reason such welds are worthless.

RA PD 71103

Figure 141 — Procedure to Correct Common Defects Encountered When Welding Root Beads on Homogeneous Armor Plate



Control depth of penetration of weld metal into base metal to obtain good fusion without excessive dilution of the weld. Proper penetration will give a long irregular heat affected zone on each side of the weld (A and B shown dotted). Excessive penetration of the weld metal into the base metal will cause excessive dilution of the weld making it non-stainless, brittle, and subject to cracking. Insufficient penetration, that is, surface fusion will produce a fairly straight-lined heat affected zone on each side of the weld. This condition is undesirable from the standpoint of good ballistic properties.

RA PD 71104

Figure 142 — Double Bevel Weld on Homogeneous Armor Plate

the plate, the joint preparation shown in F, figure 139, can be used. The stainless steel beads deposited at the nose of the bevel in each case acts as a back-up for the root beads deposited subsequently.

(3) A major consideration when welding cracks in armor which terminate within the plate is weld crater and fusion zone cracking, especially in the root beads. To overcome this hazard an intermittent back-step and over-lap procedure is recommended and is shown in detail in C, figure 140. It should be noted that all of the welding steps necessary to complete bead No. 1 are performed before bead No. 2 is started. By back-stepping the passes, the craters at the end of each pass are located on previously deposited metal and are therefore less subject to cracking. All craters on subsequent passes which do not terminate on previously deposited metal should be filled by a hesitation and drawback technique to avoid the formation of star cracks. These cracks form as a result of rapid solidification of shallow deposits of molten weld metal. Each pass in beads 1, 2, 3, and 4 is limited to from one to two inches in length, and should be peened with a suitable peening hammer while the weld metal is still hot, to help overcome the cooling stresses. No electrode weaving motion should be used in depositing the root beads and the welding should be performed preferably with a 5⁄32-inch electrode. The peening procedure noted above is also beneficial toward eliminating or minimizing warpage in the section being welded. Arc blow should be controlled by properly adjusting the angle of the electrode in the direction of welding.

(4) Some of the more common defects encountered when welding root beads on homogeneous armor plate are shown in figure 141, together with corrective procedures. The sequence of welding beads and the procedure recommended to completely weld the double bevelled joint are shown in figure 142. To perform this welding 5⁄32- or 3⁄16-inch stainless steel electrodes should be used. The electrode is directed against the sidewall of the joint so as to form an angle of approximately 20 to 30 degrees with the vertical. The electrode should also be inclined 5 to 15 degrees in the direction of welding. By this means, the sidewall penetration can be effectively controlled. The electrode weaving motion should not exceed 2½ electrode core-wire diameters. This is important as stainless steel has a coefficient of expansion and contraction approximately 1½ times that of mild steel. If a weaving motion greater than this is used, longitudinal shrinkage cracks in the weld or fusion zone may develop. The thickness of the layer of metal deposited can be varied by controlling the speed of welding. The sequence of passes used for completely filling a double bevelled joint as shown in figure 142 was developed after consideration of these factors. By alternating the deposition of metal first on one side of the joint and then on the other, a closer control of the heat input to the joint is obtained and the shape of the

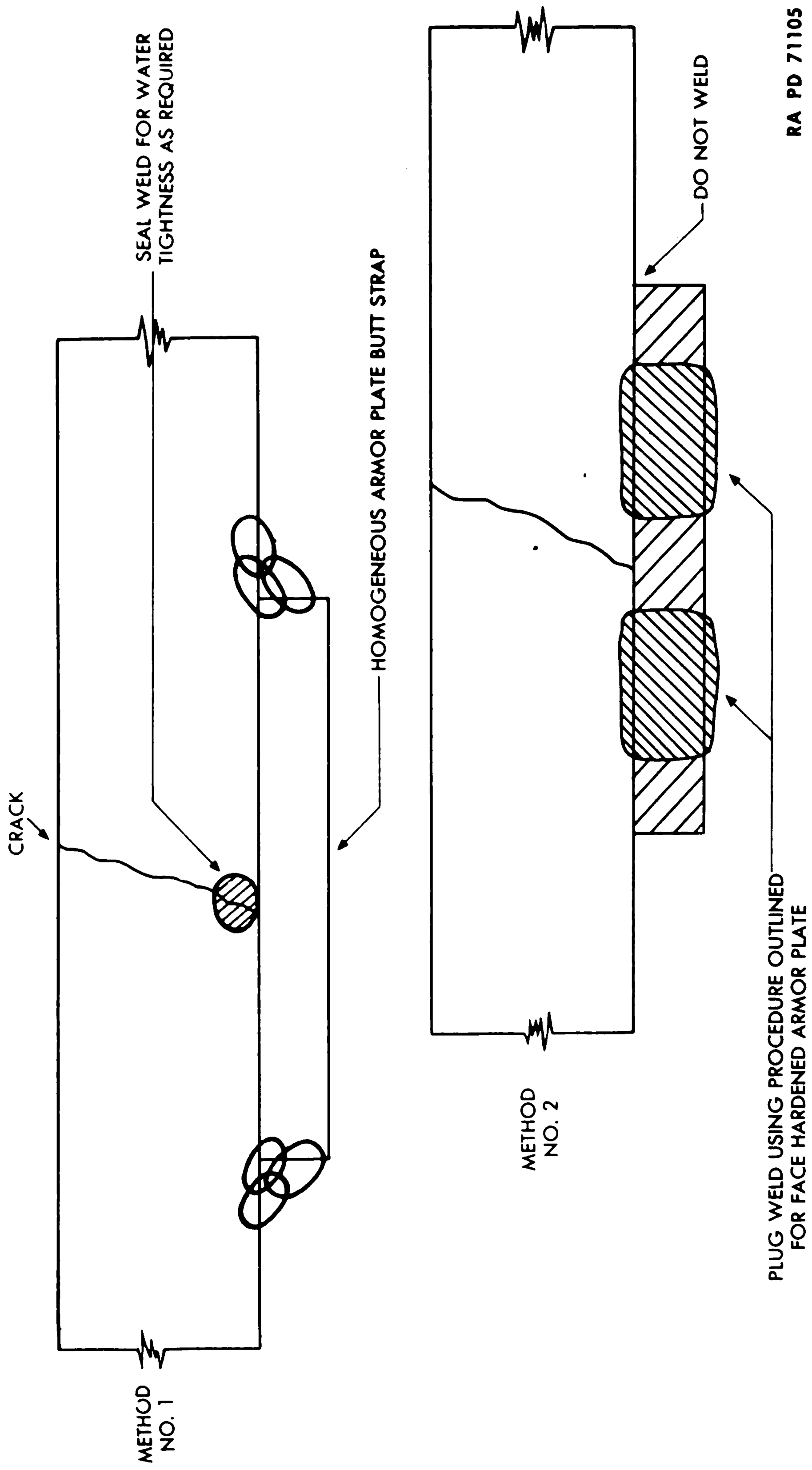
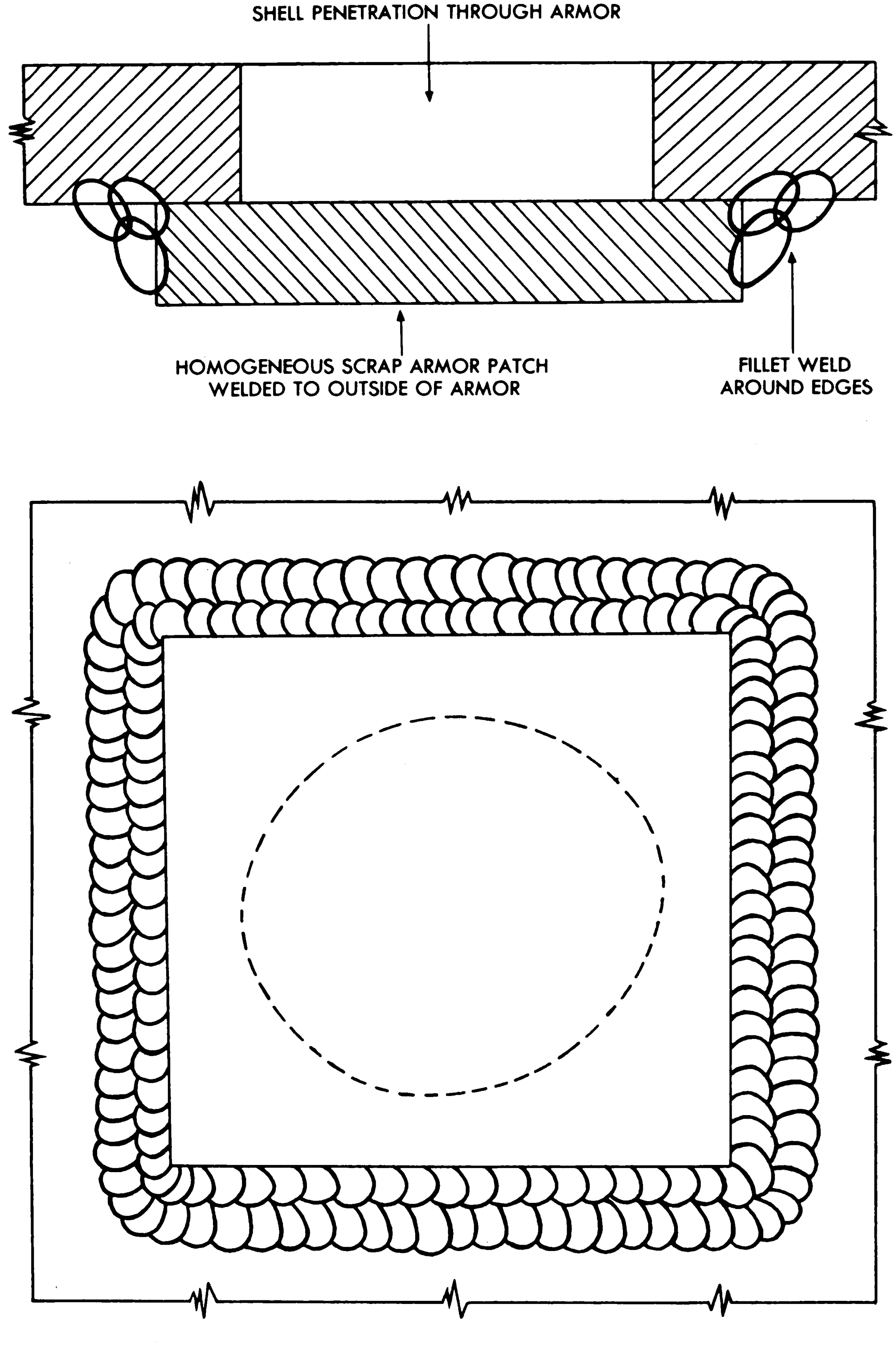
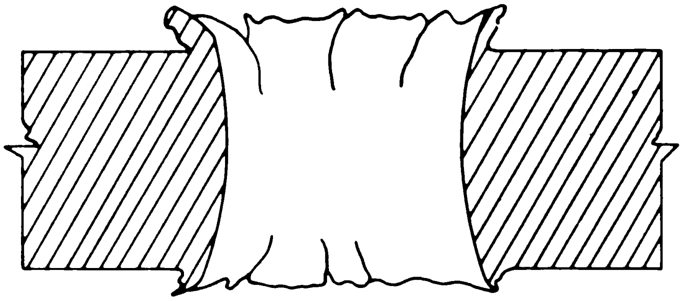


Figure 143a — Emergency Repairs on Cracked or Penetrated Homogeneous Armor Plate Using Butt Strap and Patch-welding Methods

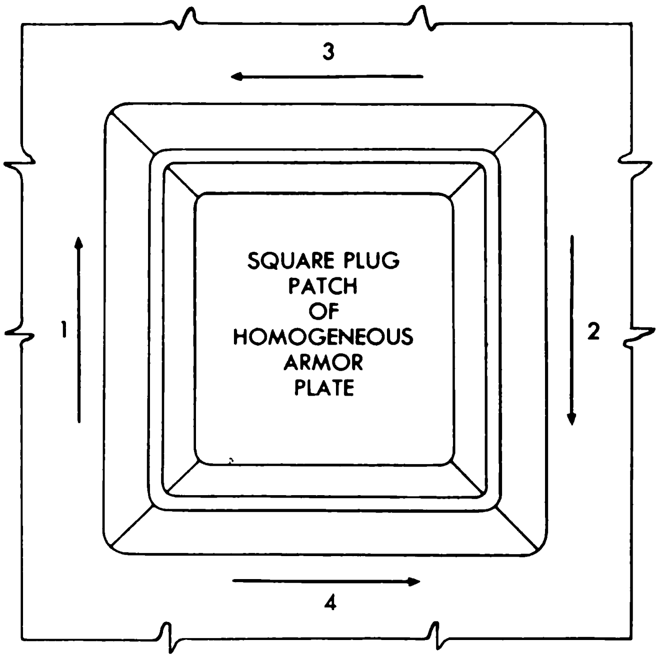


RA PD 71106

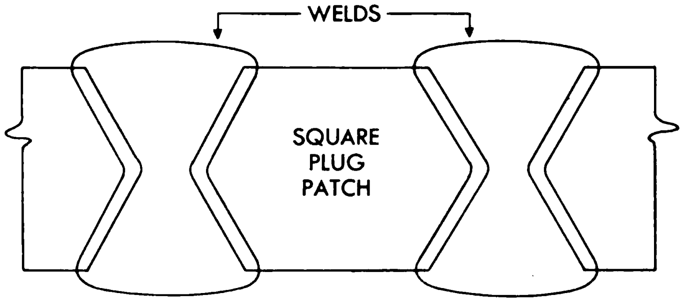
Figure 143b — Emergency Repair on Penetration Through Armor



SHELL PENETRATION IN HOMOGENEOUS ARMOR PLATE. ALL TORN AND IRREGULAR EDGES SHOULD BE FLAME CUT BEFORE BEVELING SIDEWALLS FOR WELDING



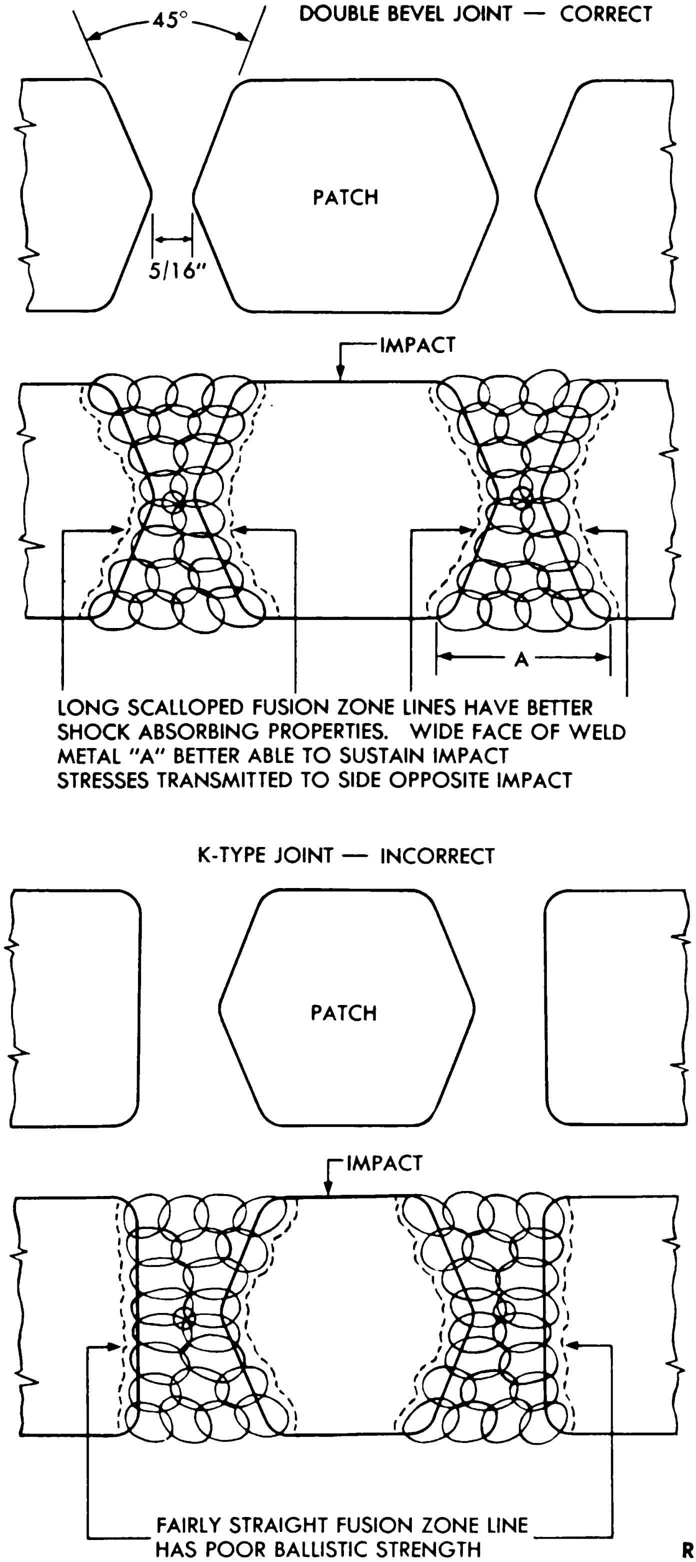
SQUARE PLUG DESIGN HAS DISTINCT ADVANTAGES OVER ROUND PLUG IN THAT STRAIGHT LINE WELDS CAN BE MADE. ROUND PLUGS REQUIRE CONSTANT VARIATION IN ANGLE OF ELECTRODE TO MAKE CURVED WELDS. THIS PROCEDURE PROMOTES ERRATIC PENETRATION AND IRREGULAR WELDS. NUMBERS INDICATE SEQUENCE TO BE USED IN WELDING



DOUBLE BEVEL, PATCH AND SIDEWALLS OF HOLE RA PD 71107

Figure 144a — Double Bevel Plug Welding Procedure for Repairing Shell Penetrations in Homogeneous Armor Plate

ARMOR PLATE WELDING

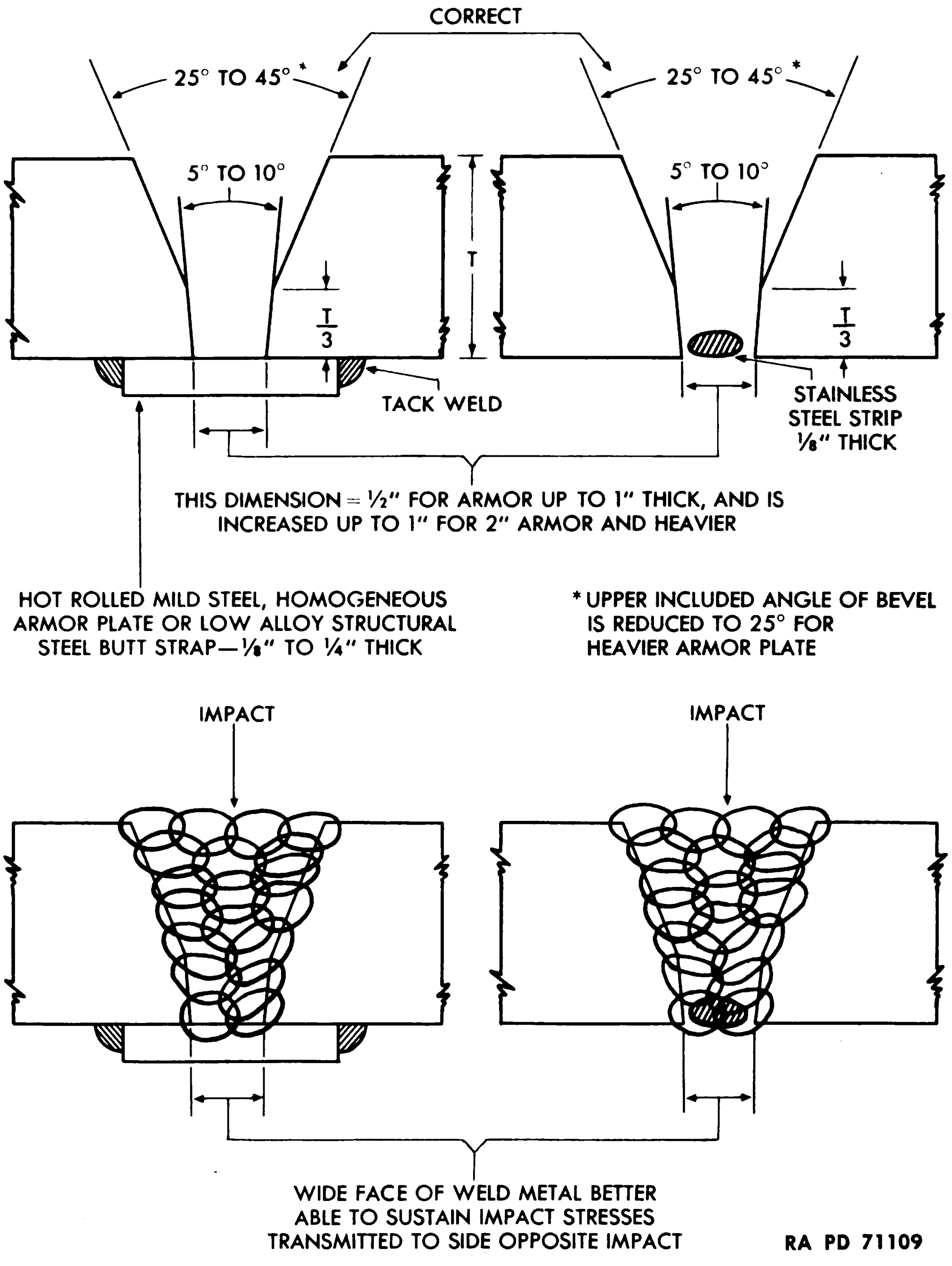


LONG SCALLOPED FUSION ZONE LINES HAVE BETTER SHOCK ABSORBING PROPERTIES. WIDE FACE OF WELD METAL "A" BETTER ABLE TO SUSTAIN IMPACT STRESSES TRANSMITTED TO SIDE OPPOSITE IMPACT

FAIRLY STRAIGHT FUSION ZONE LINE HAS POOR BALLISTIC STRENGTH

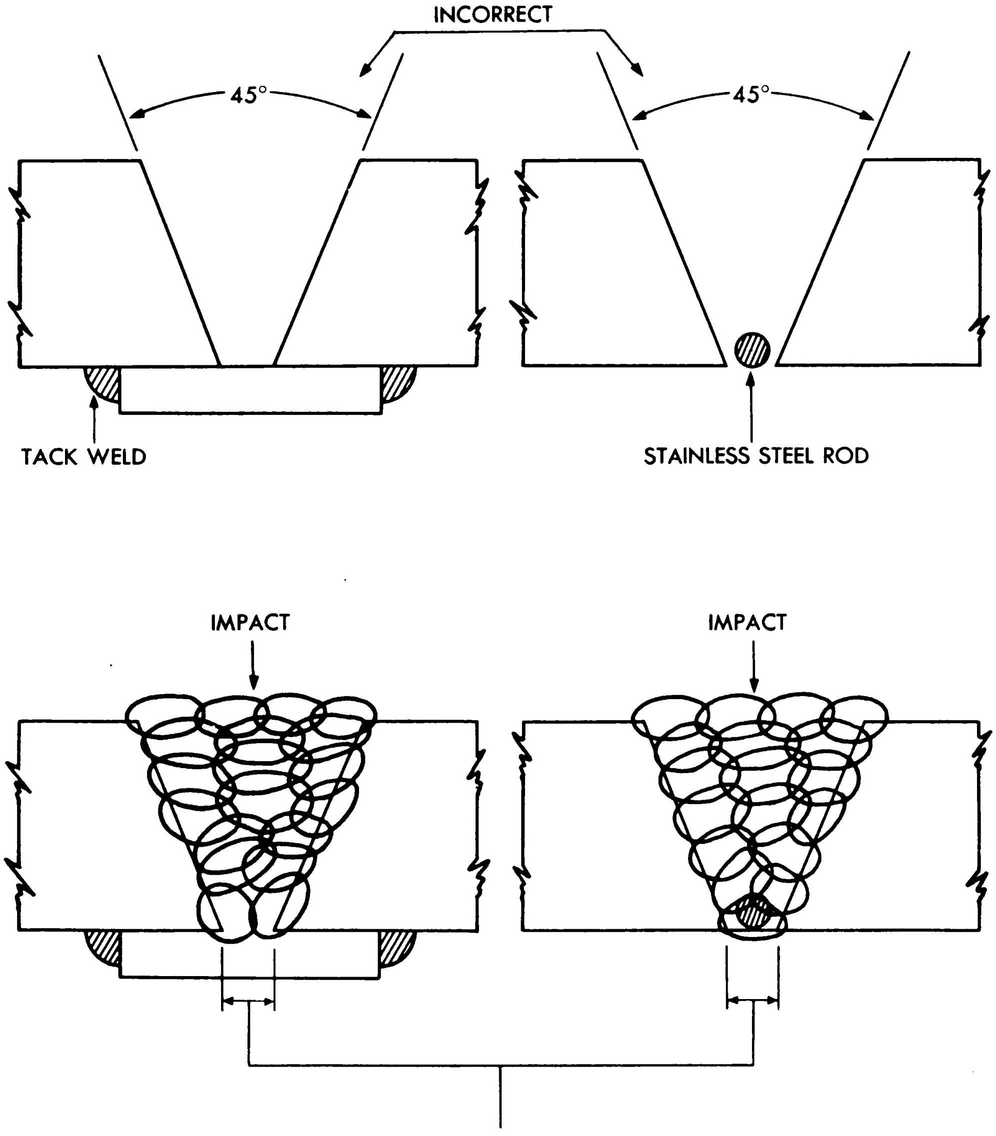
RA PD 71108

Figure 144b — Double Bevel Plug Welding Procedure for Repairing Shell Penetrations in Homogeneous Armor Plate



RA PD 71109

Figure 145a — Double-tapered Single Bevel Joint on Homogeneous Armor Plate — Correct Method



Narrow root weld has low ductility to withstand tensile impact load transmitted by impact from direction shown. Under shock load this joint design results in root weld cracking and subsequent joint failure. To develop a wider root face with a single-taper bevel would require more weld metal per joint and produce a wide outer weld surface exposed to projectile impact.

RA PD 71109A

Figure 145b — Double-tapered Single Bevel Joint on Homogeneous Armor Plate — Incorrect Method

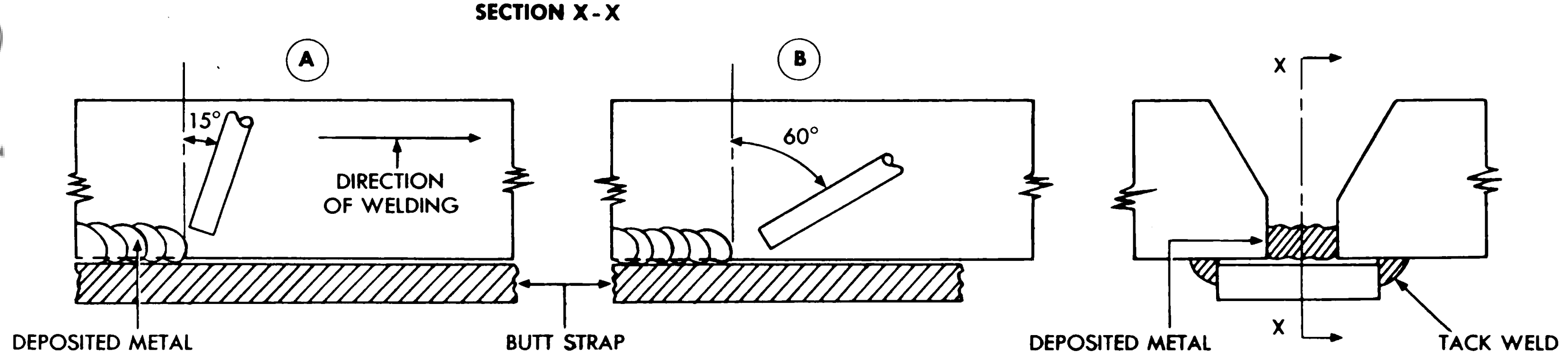
welded structure can be maintained. Each layer of metal deposited serves to stress-relieve the weld metal immediately beneath it, as well as to partially temper the heat-affected zone, in the base metal, produced by the previous welding bead. It will be noted that annealing passes are deposited at the toe of the weld before intermediate layers of weld metal are added to completely fill the surface of the joint. These annealing passes are an important factor in eliminating fusion zone cracks which might start at the surface of the weld. Through careful control of the depth of penetration, a regular heat-affected zone with a scalloped effect is produced.

c. Emergency repairs on cracked homogeneous armor plate can be made by using butt straps on the back of the cracked armor. These can be welded by either of the methods shown in figures 143a or 143b and are intended primarily to strengthen the section weakened by the crack.

d. Complete penetrations in homogeneous armor plate are repaired by using the procedure noted in figures 144a and 144b. It should be pointed out that considerable structural damage is done to the metal immediately adjacent to the shell penetration. A sufficient amount of this metal should be removed to insure complete freedom from subsurface cracks. Where the projectile openings are large relative to the thickness of the plate, a square plug patch of homogeneous armor having the same thickness as the base metal should be used. Smaller penetrations in armor can be repaired by plug welding without the use of patches.

e. Bulges in armor which are also cracked but do not interfere with the operation of internal mechanisms in the vehicle are satisfactorily repaired by merely welding up the cracked section using the procedure previously described. For best repair, however, the bulges should be cut out and a patch inserted. The procedure for welding each side of the patch is essentially the same as that noted for welding a double bevelled joint in a linear seam. In certain cases where bulges interfere with the operation of internal mechanisms, grinding or chipping of the bulged surface can be satisfactorily applied to free the mechanism in question. In all cases the welds should be made to the full thickness of the plate. All cracks over ¼ of an inch long in weld metal should be chipped out before rewelding.

f. In certain sections where it is not feasible to make the welding repair from both sides of the armor, the joint must necessarily be made from one side. Under these conditions the procedure shown in figure 145a can be used with satisfactory results. It will be noted that either a butt strap or a stainless steel strip can be used as a back-up for the root beads of the weld. For applications in which the presence of a butt strap would seriously interfere with the opera-



ANGLE OF ELECTRODE AT END OF WEAVE. ELECTRODE HELD ADJACENT TO SIDE WALL FOR GOOD PENETRATION

ANGLE OF ELECTRODE WITH VERTICAL INCREASED AT MIDDLE OF WEAVE TO DIRECT WELD AT PREVIOUSLY DEPOSITED METAL

This welding technique was developed to permit welding a double-tapered single-bevel joint on homogeneous armor plate without welding the butt strap to the deposited weld metal. After depositing the root passes the butt strap can be removed by simply breaking the tack welds holding it to the bottom face of the armor. This welding procedure consists of changing the angle of the electrode in the direction of welding during the side to side weaving motion of the electrode in making the root pass. By increasing the electrode angle to approximately 60° with the vertical at the middle of the weave and increasing the speed of weaving, all the metal deposited is welded to the previously deposited metal only. At the end of the weave, the weaving speed of the electrode is decreased while simultaneously decreasing the angle to approximately 15° with the vertical and held momentarily to insure good joint side wall penetration. This technique can be mastered with a little practice and has distinct advantages namely:

1. The butt strap can be removed and a finish pass welded to the root of the weld to obtain an all-weld metal joint.

2. In certain sections of the interior of an armored vehicle the presence of a butt strap may materially interfere with the functioning of equipment located nearby.

RA PD 71110

Figure 146 — Welding Homogeneous Armor without Welding Butt Strap to Weld Metal Deposited

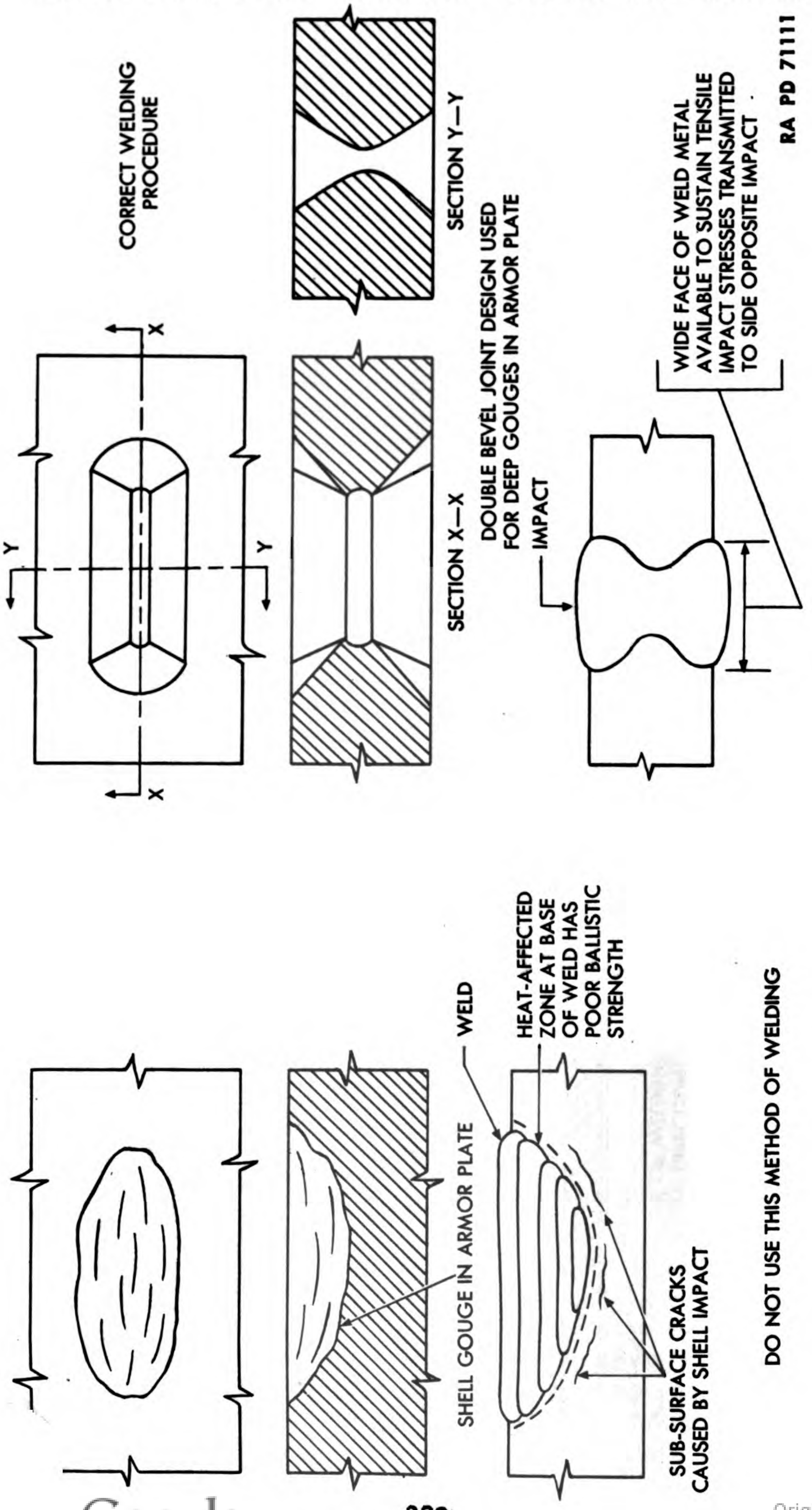


Figure 147 — Welding Repair of Deep Gouges in Surface of Homogeneous Armor Plate

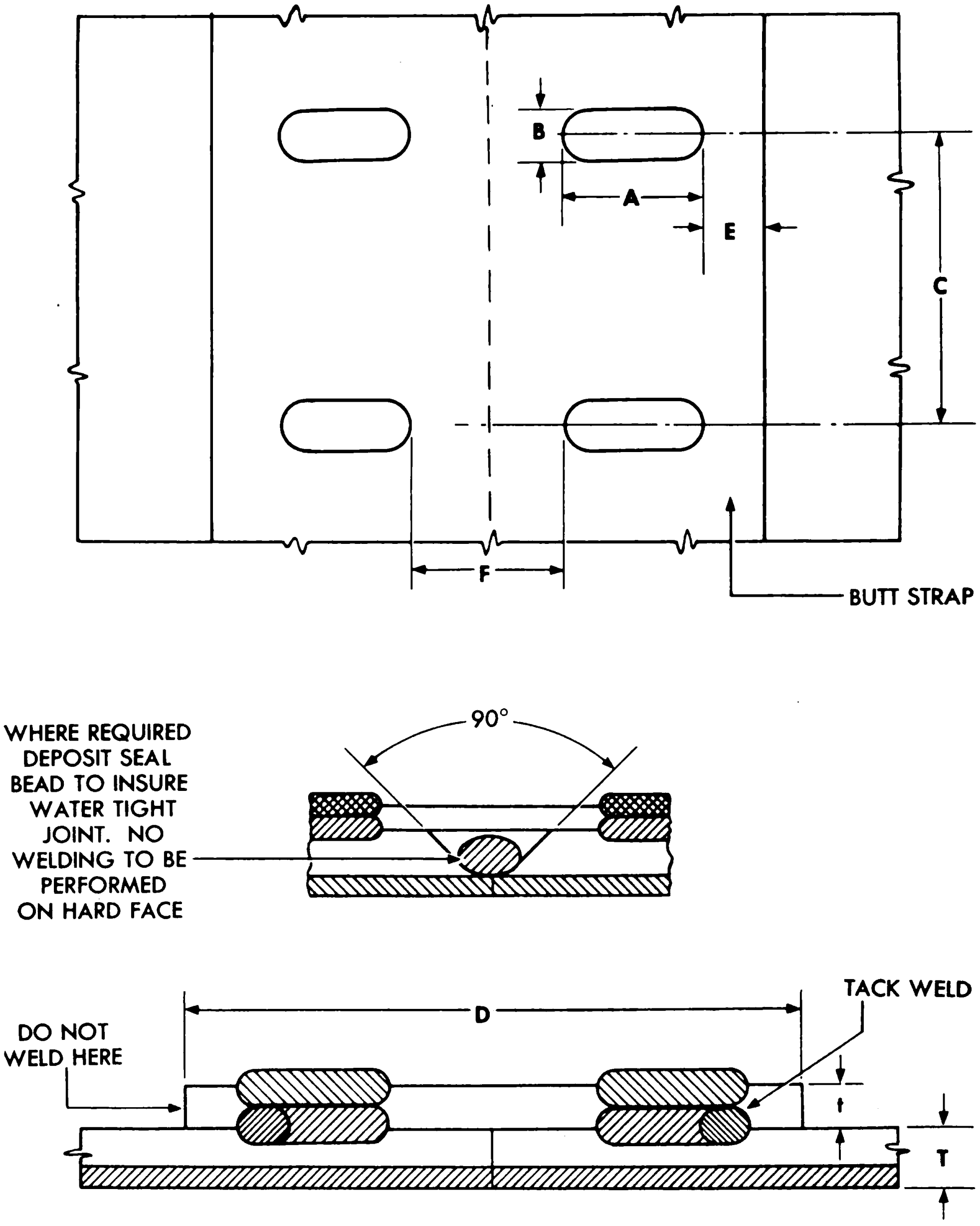
tion of internal mechanisms, the technique shown in figure 146 should be followed. The principal advantage of this method of welding lies in the ability to remove the butt strap after the joint is completed.

g. Armor struck by a projectile impacting at a fairly low angle is merely gouged at the surface as shown in figure 147. In order to produce satisfactory repair, the joint should be prepared to enable welding from both sides as shown; however, where the gouge does not extend over halfway through the plate thickness and does not produce appreciable bulging on the inside, it is recommended to fill the gouge with weld metal.

258. WELDING FACE-HARDENED ARMOR PLATE.

a. General.

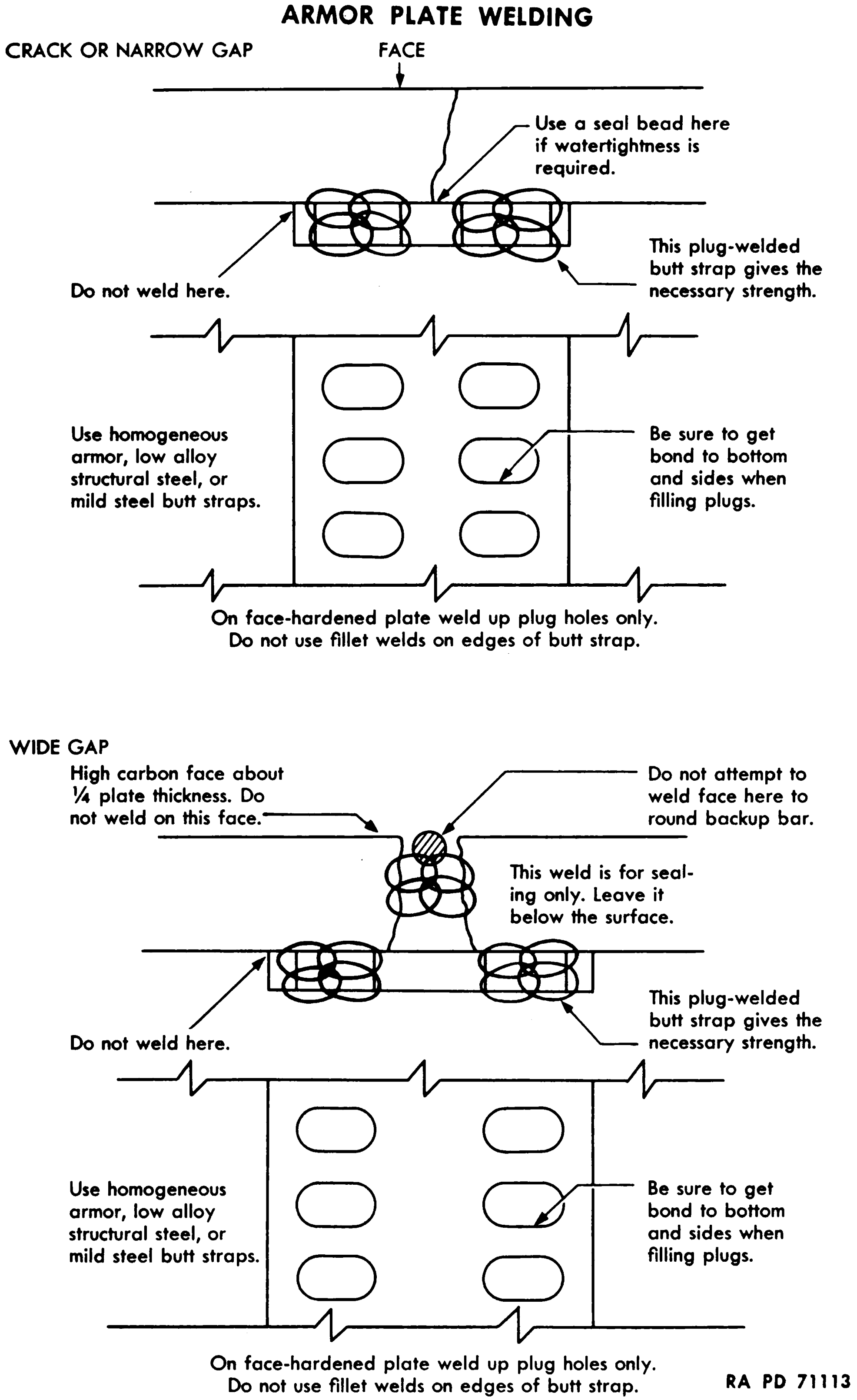
(1) Face-hardened armor plate can be welded satisfactorily using the electric arc welding process and modified 18-8 stainless steel reverse polarity, heavy coated, all position, electrodes. Since the face side of face-hardened armor is extremely hard and brittle, special precautions must be taken to avoid excessive heating and appreciable distortion of the plate to prevent cracking of the face due to stresses applied thereby. A satisfactory method for welding this type of armor has been developed and makes use of the butt strap and plug-weld technique. The welding procedure, for face-hardened armor varying from ¼ to 1 inch in thickness, is illustrated in figures 148a and 148b. It will be noted that all welding is done from the soft side of the armor plate and that the strength of the joint depends upon the soundness of the plug-welds. The butt strap should be cut so as to conform to the dimensions given in the table for the particular thickness of face-hardened armor being welded. The plate is tack-welded to the soft side of the armor through elongated slots cut into the butt strap. The plugs should then be welded to completely fill the slots without excessive weld reinforcement or undercutting at the surface of the plug. These precautions are necessary in order to eliminate surface discontinuities which act as stress raisers and are a good source for crack formations under impact loads. In order to effectively seal the crack in face-hardened armor against lead-spatter and where watertightness is required, a seal-bead weld should be made on the soft side and ground flush before applying the butt strap. Welding should be performed on clean, scale-free surfaces. The previously deposited weld-metal should be thoroughly cleaned by wire brushing and chipping to remove slag and oxides to insure sound welds. Crater-cracks can be eliminated by the back-step and over-lap procedure or by using the electrode hesitation and drawback technique. Crater-cracks are most serious when formed in the initial weld passes and should be chipped out before additional weld metal is applied. They can be welded out successfully on all subsequent passes of the



T	t	A	B	C	D (min.)	E (min.)	F
¼"	3/16"	¾"	7/16"	3"	3"	¼"	1"
⅜"	¼"	1⅛"	½"	3"	4"	⅜"	1"
½"	⅜"	1¼"	⅝"	3"	4¼"	⅜"	1"
⅝"	⅜"	1¼"	⅝"	3"	4¼"	⅜"	1"
¾"	½"	1¼"	⅝"	2"	4½"	7/16"	1"
1"	⅝"	1⅜"	¾"	2"	4¾"	½"	1"

RA PD 71112

Figure 148a — Welding Joint Data for Butt Welds on Face-hardened Armor



Use a seal bead here if watertightness is required.

Do not weld here.

This plug-welded butt strap gives the necessary strength.

Use homogeneous armor, low alloy structural steel, or mild steel butt straps.

Be sure to get bond to bottom and sides when filling plugs.

On face-hardened plate weld up plug holes only. Do not use fillet welds on edges of butt strap.

High carbon face about ¼ plate thickness. Do not weld on this face.

Do not attempt to weld face here to round backup bar.

This weld is for sealing only. Leave it below the surface.

Do not weld here.

This plug-welded butt strap gives the necessary strength.

Use homogeneous armor, low alloy structural steel, or mild steel butt straps.

Be sure to get bond to bottom and sides when filling plugs.

On face-hardened plate weld up plug holes only. Do not use fillet welds on edges of butt strap.

Figure 148b — Use of Butt Strap on Face-hardened Armor to Repair Cracks or Gaps

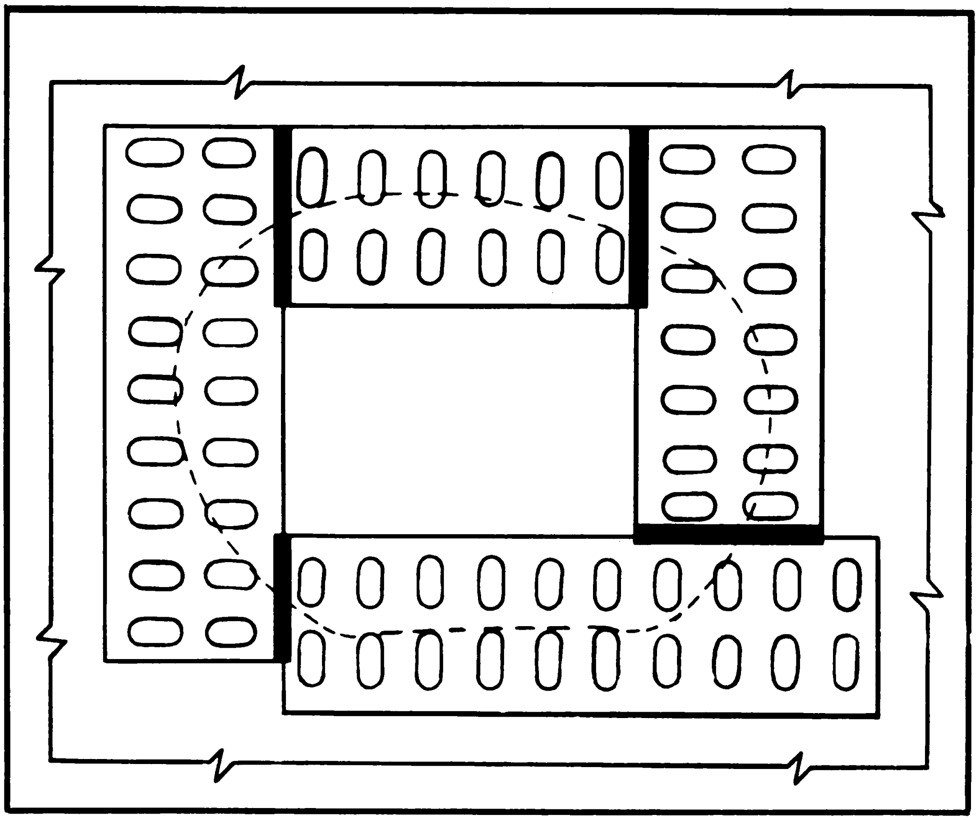

RA PD 71114

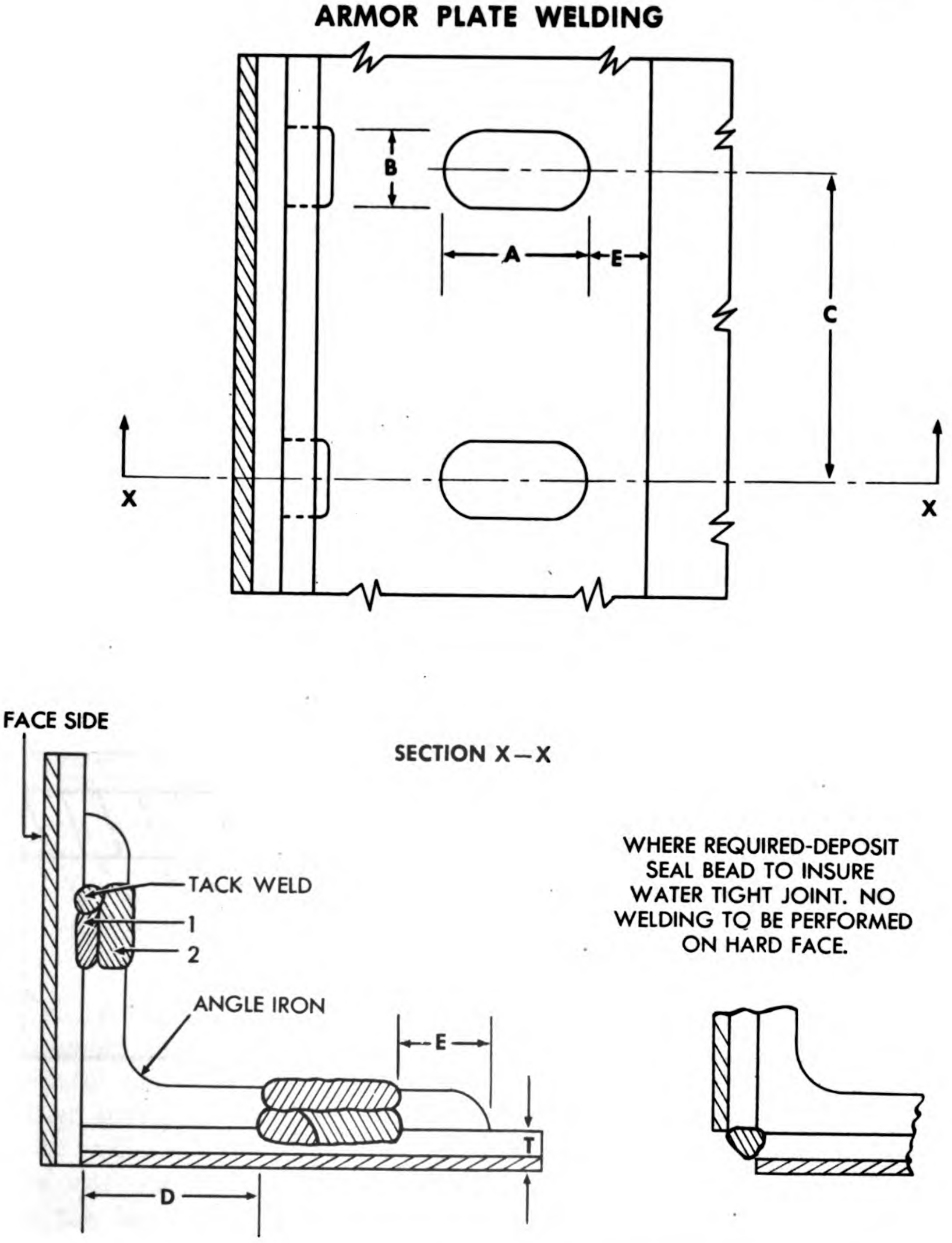
Figure 149 — Butt-strap Weld on Face-hardened Armor — Method of Fitting Patch on Plate

weld. As a further precaution, string beads should be used for the initial passes. For subsequent passes, do not weave the electrode more than 2½ electrode core-wire diameters. The efficiency of the joint welded by this method depends upon good fusion to the base metal and sidewalls of the slots in the butt strap.

(2) If straightening is necessary, do not hammer on the face side of the armor; all hammering should be done on the soft side, on the back-up strap or on the plug-welds. Force should not be applied to straighten face-hardened armor if the applied force will produce tension on the face side.

(3) Where two or more butt straps are used to make a patch-weld or to repair irregular cracks, the back-up straps should be butt-welded together for additional strength as shown in figure 149.

b. Corner joints can be repaired by using angle iron for butt straps as shown in figure 150. Essentially the same procedure is followed in making the plug-welds as described above for repairing cracked armor. A method of sealing the joint against lead-spatter and to insure watertightness is also shown.

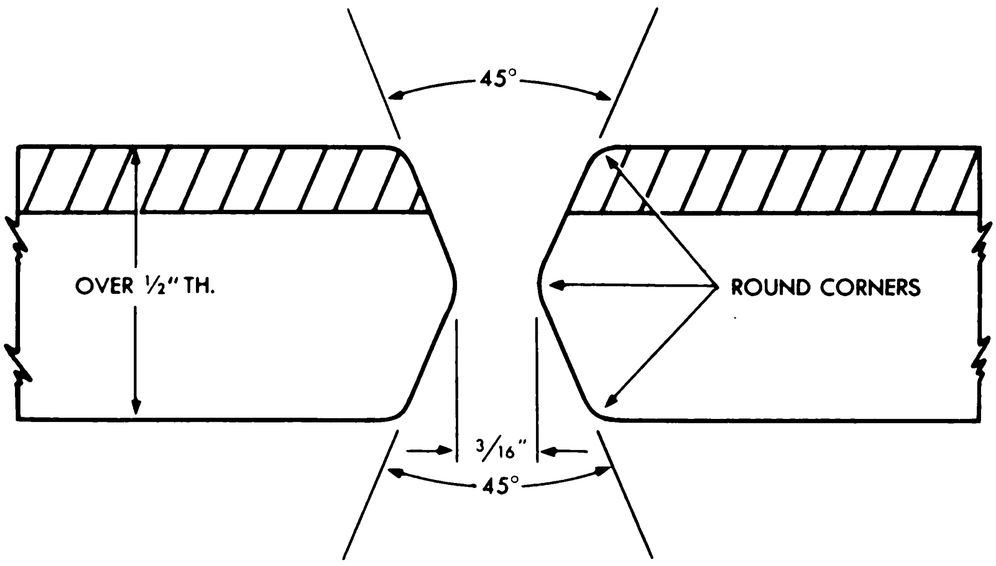


WHERE REQUIRED-DEPOSIT SEAL BEAD TO INSURE WATER TIGHT JOINT. NO WELDING TO BE PERFORMED ON HARD FACE.

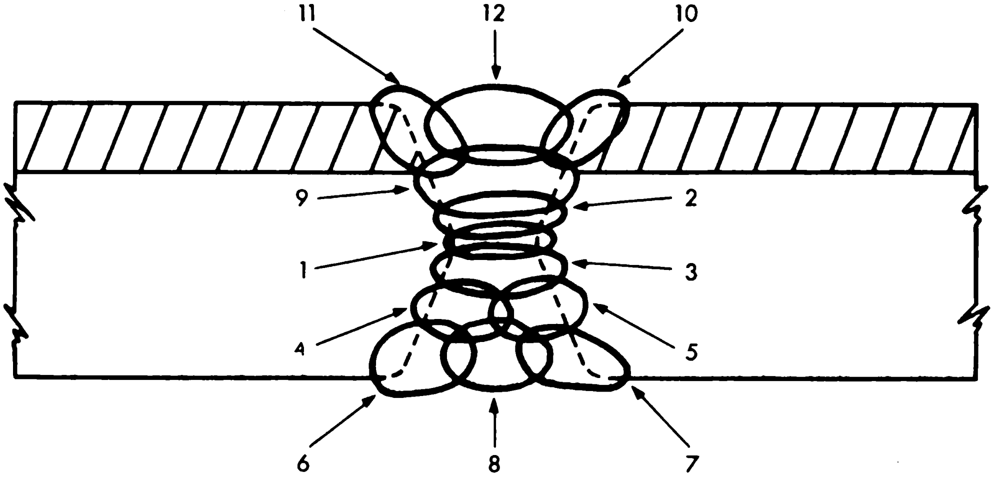
T	A	B	C	D	E (MIN.)	ANGLE IRON
¼"	¾"	7⁄16"	3"	5⁄16"	¼"	1 5⁄16" x 1 5⁄16" x 3⁄16"
⅜"	1⅛"	½"	3"	⅜"	⅜"	1⅞ x 1⅞ x ¼
½"	1¼"	⅝"	3"	½"	⅜"	2⅛ x 2⅛ x ⅜

RA PD 71115

Figure 150 — Welding Joint Data for Corner Welds on Face-hardened Armor Plate



JOINT DESIGN

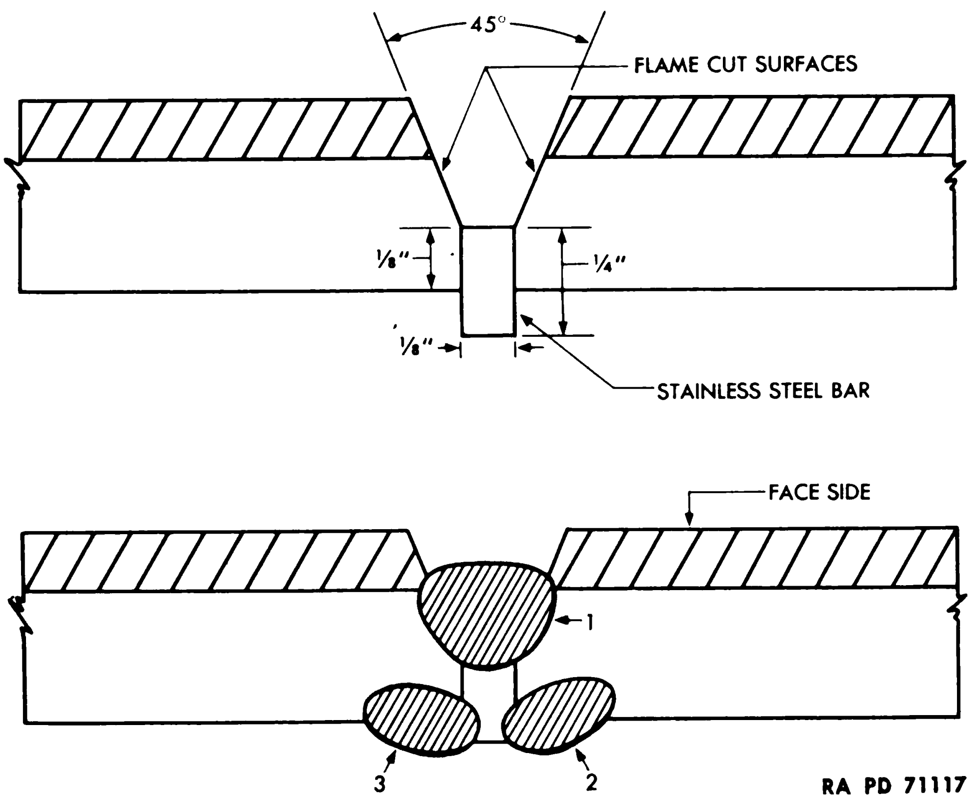


GENERAL SEQUENCE OF WELDING BEADS

Completely weld soft side first with Beads No. 1—8. For Beads No. 1, 10, 11—use 1 8-inch electrodes. For all other Beads—use 5/32 and 3/16-inch electrodes. Beads No. 6, 7, 10 and 11 are annealing beads. Use string bead technique throughout.

RA PD 71116

Figure 151 — Procedure for Welding Face-hardened Armor Plate Above ½ Inch Using the Double Bevel Joint Method



RA PD 71117

Figure 152 — Procedure for Welding Face-hardened Armor Plate up to and Including 1/2 Inch Using the Depressed Joint Method

c. Although the butt-strap method is satisfactory for repairing damaged face-hardened armor up to 1 inch thick and heavier, it is usually used on thicknesses up to and including 1/2-inch plate. Another accepted procedure for welding face-hardened armor above 1/2 inch in thickness is shown in figure 151. This procedure requires that the soft side be completely welded before any welding is attempted on the face side of the plate. By using string-bead welding and the step-back and over-lap procedure for the root passes, the danger of cracking is held at a minimum. Additional passes can be run straight out; however, no weaving should be used on this joint design in order to keep the structure free from warpage. A modified procedure for welding face-hardened armor up to and including 1/2 inch in thickness is shown in figure 152. This is known as the depressed joint and is made by using a stainless steel bar 1/8 x 1/4 inch in cross section inserted in the joint as shown. The principal advantages of this joint are its simplicity and good structural and ballistic properties. Care should be taken to insure that no welding is done on the hard face.

d. Armor Plate Welding Electrodes.

(1) The most satisfactory method for the repair of homogeneous and face-hardened armor plate is in the electric arc welding process with stainless steel electrodes.

(2) The oxyacetylene welding process requires heating of a large section of the base metal on either side of the prepared joint in order to maintain a welding puddle of sufficient size at the joint to weld satisfactorily. This of necessity destroys the heat treatment imparted to armor plate, thus causing large areas to become weak structurally and ballistically. In addition, the process is slow and produces considerable warpage in the welded sections.

(3) Initial developments in armor plate welding have specified stainless steel electrodes containing 25 percent chromium and 20 percent nickel. More recently, in an effort to conserve chromium and nickel, electrodes containing 18 percent chromium and 8 percent nickel in the core wire and small percentages of either manganese, or molybdenum, or both, added in the electrode coating, have been developed and produce excellent results. These electrodes are recommended for welding all types of armor plate by the electric arc process without preheating or postheating the structure welded and should be the all welding position type. By convention, these electrodes are known as manganese modified 18-8 stainless and molybdenum modified 18-8 stainless steel electrodes.

e. Recommended Welding Current Settings for Direct-current, Reversed Polarity, All-position, Heavy-coated, Modified 18-8 Stainless Steel Electrodes.

Electrode Diameter	Current Range
$\frac{1}{8}$ in.	90 to 100 amp
$\frac{5}{32}$ in.	110 to 130 amp
$\frac{3}{16}$ in.	150 to 180 amp

(1) The exact current requirements will be governed to some extent by the joint type, electrode design, and position of welding.

f. Field repair units will probably require about the following proportions of each type.

Electrode Diameter	Percentage
$\frac{1}{8}$ in.	20
$\frac{5}{32}$ in.	60
$\frac{3}{16}$ in.	20

g. Very recent developments have been directed toward the design of a suitable ferritic electrode for armor plate welding. Some initial successes on armor plate up to ½ inch in thickness have been realized without the use of preheat or postheat. Welds on armor plate above ½ inch in thickness require a 350 F preheat, maintain-

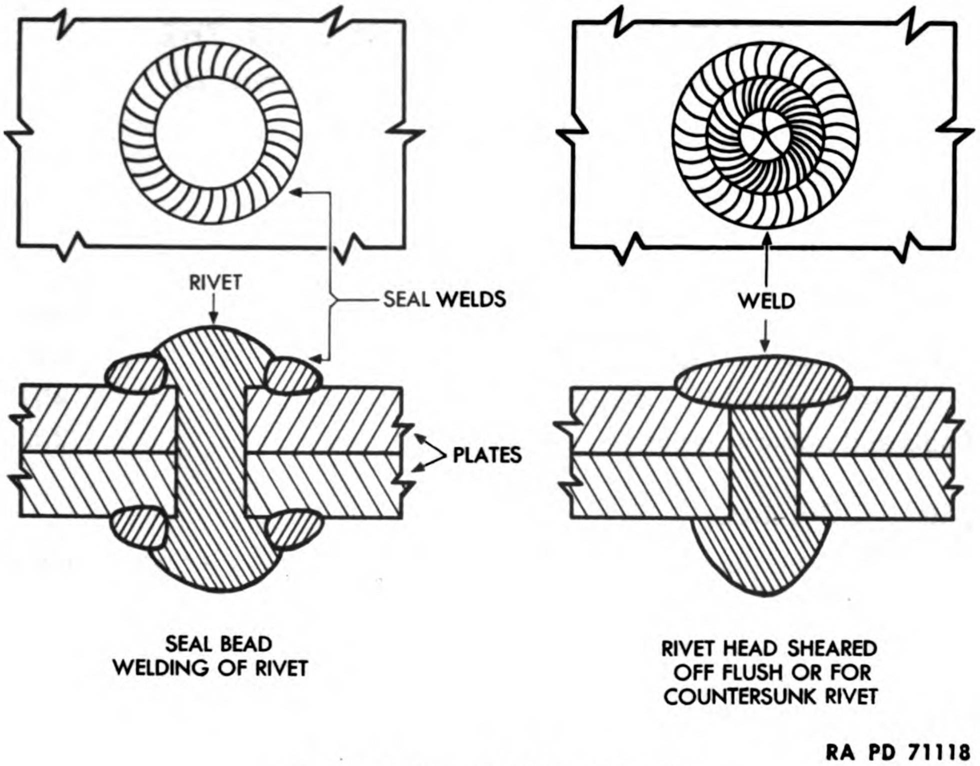


Figure 153 — Seal Bead Weld

ing this temperature during welding, and, without intermediate cooling, postheating at 1,150 F for purposes of stress-relieving the weld. This is not a satisfactory welding procedure; however, future low alloy ferritic electrode developments which obviate the use of the 1,150 F postheat treatment will still require the maximum tolerable 350 F preheat and concurrent heating followed by slow cooling to produce satisfactory results in armor plate welding.

259. STRENGTHENING RIVETED JOINTS IN ARMOR PLATE.

a. In order to strengthen riveted joints in armor plate which have been made with buttonhead rivets, a seal bead weld is recommended as shown in figure 153. The arc is struck at the top of the rivet with a stainless steel electrode and held there for a length of time sufficient to melt approximately ½ inch of the electrode. A bead is then deposited along the curved surface of the rivet to the armor plate and continued around the edge of the rivet until the rivet is completely welded to the armor plate. The seal bead weld prevents the rivet head from being easily sheared off and the shank of the rivet from being punched through the plate. Countersunk rivets are sealed in the same general manner. The rivets in joints made in face-hardened armor should be seal-welded only on the soft side of the plate.

CHAPTER 12

APPLICATION OF WELDING IN THE ORDNANCE DEPARTMENT (Cont'd)

Section V

FIELD WELDING EQUIPMENT

	Paragraph
General	260
Description of welding trucks M3 and M12	261
Tools and apparatus carried on welding trucks	262

260. GENERAL.

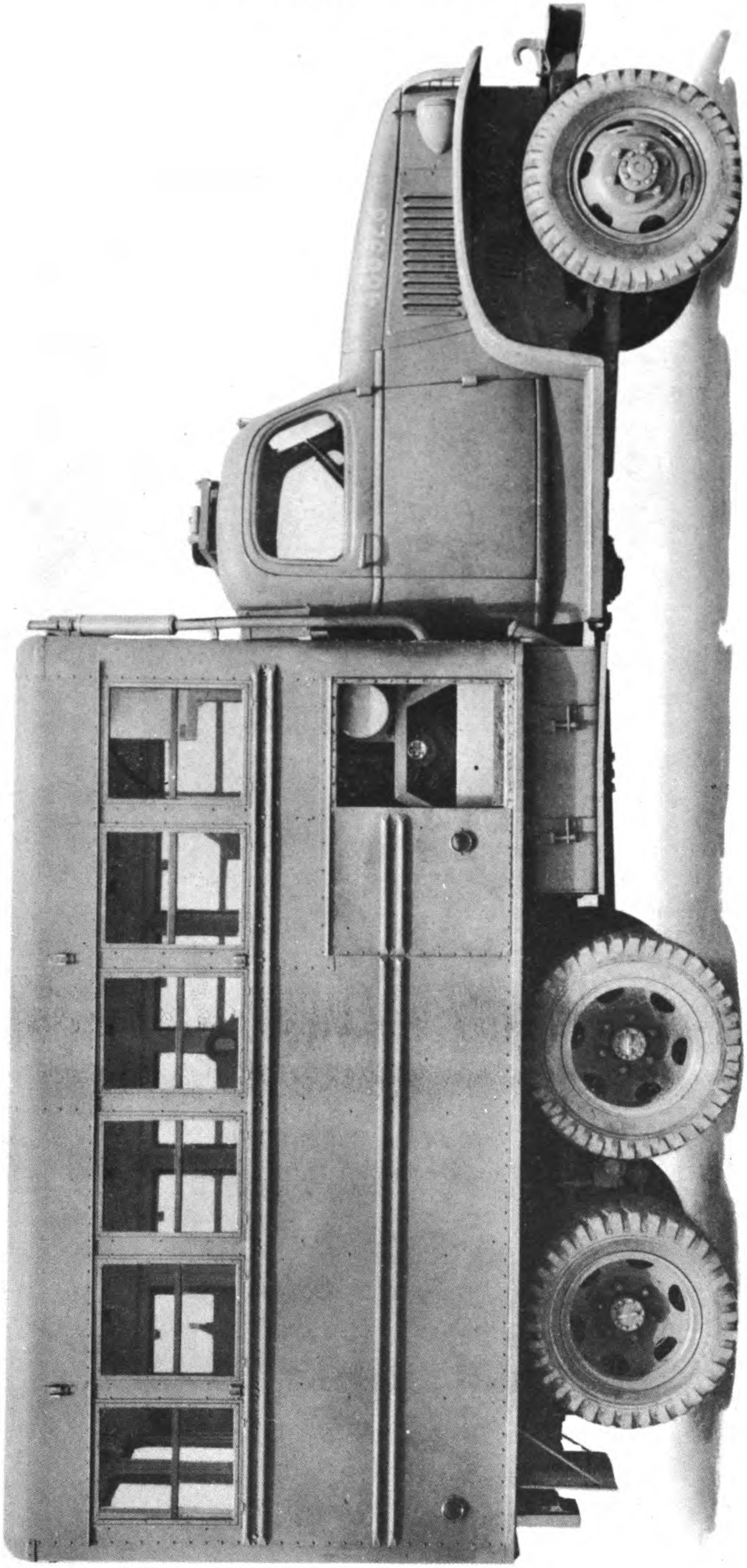
a. It is the purpose of this section to give the reader some idea as to what facilities are available for performing welding operations in the field.

b. In order to repair and maintain ordnance equipment in the field, the service sections of medium and heavy maintenance companies are equipped with welding trucks. Medium maintenance companies have one welding truck, in addition to the machine shop truck, and the tool-and-bench truck. Heavy maintenance companies have two welding trucks, two machine shop trucks, and two tool-and-bench trucks.

c. The welding trucks are equipped with the necessary welding apparatus for oxyacetylene, electric arc, and forge welding operations. The welding personnel are trained specialists capable of using this equipment to make repairs to broken parts or damaged materiel, to fabricate certain replacement parts, to build up sections, to hard-surface worn parts, and to perform other welding and cutting jobs. Many of the welding operations may be performed by the personnel with little or no supervision. It is important that the welding operators understand the use of the welding equipment on the truck and its application to all types of ordnance metals.

261. DESCRIPTION OF WELDING TRUCKS M3 AND M12.

a. **Welding Truck M12.** The Welding Truck M12 (fig. 154) is classified as "Standard" equipment. It is a 6 x 6 truck, somewhat larger than the Welding Truck M3 and incorporates certain new improvements. The equipment and accessories are essentially the same on the Truck M12 as for the Truck M3. The main difference being that a 300-ampere arc welding generator (figs. 155a, 155b) is installed, and this generator is driven by a separate gasoline engine instead of through a power take off as on the Truck M3.



RA PD 71119

Figure 154 — Welding Truck M12 — Right Side

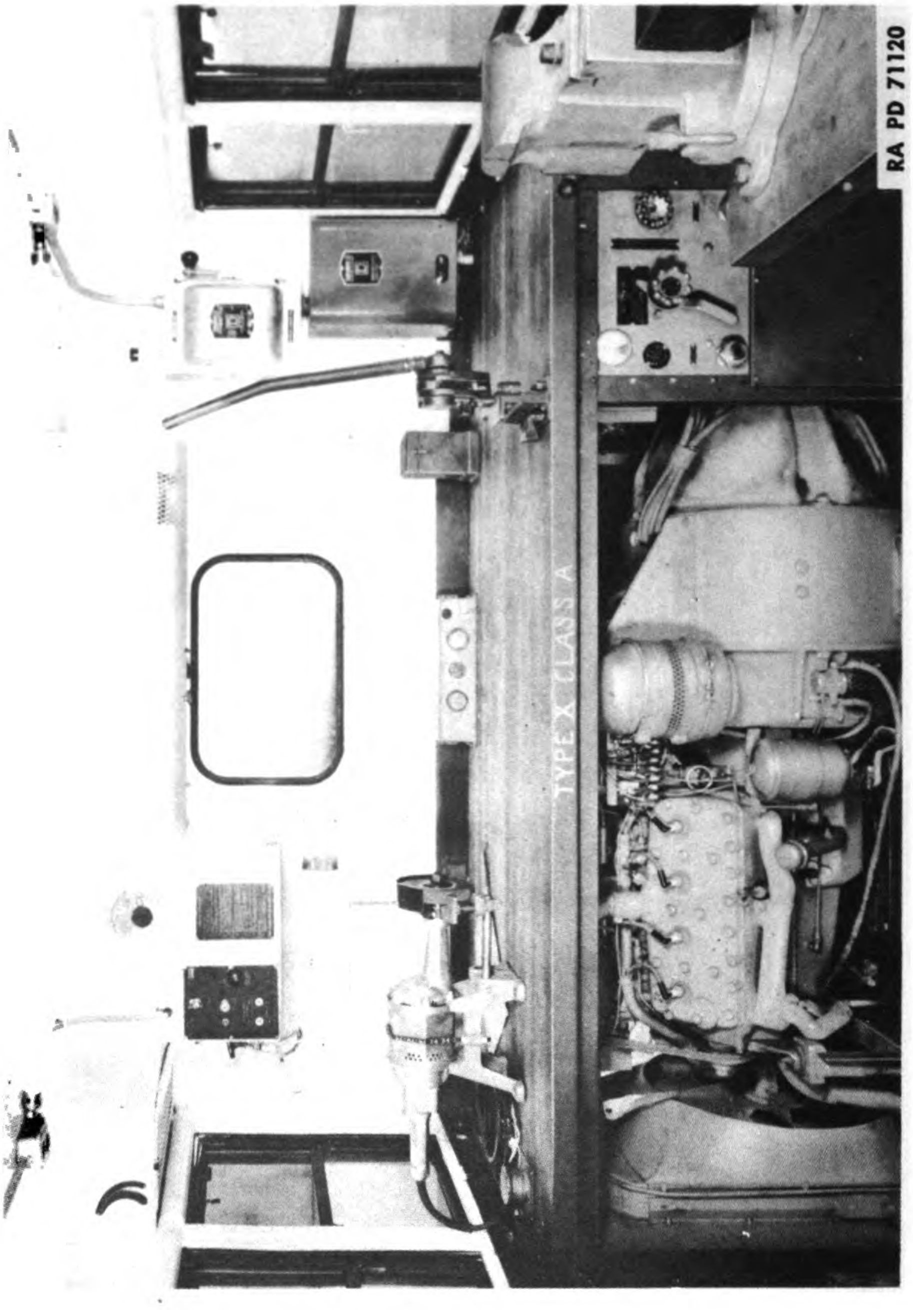
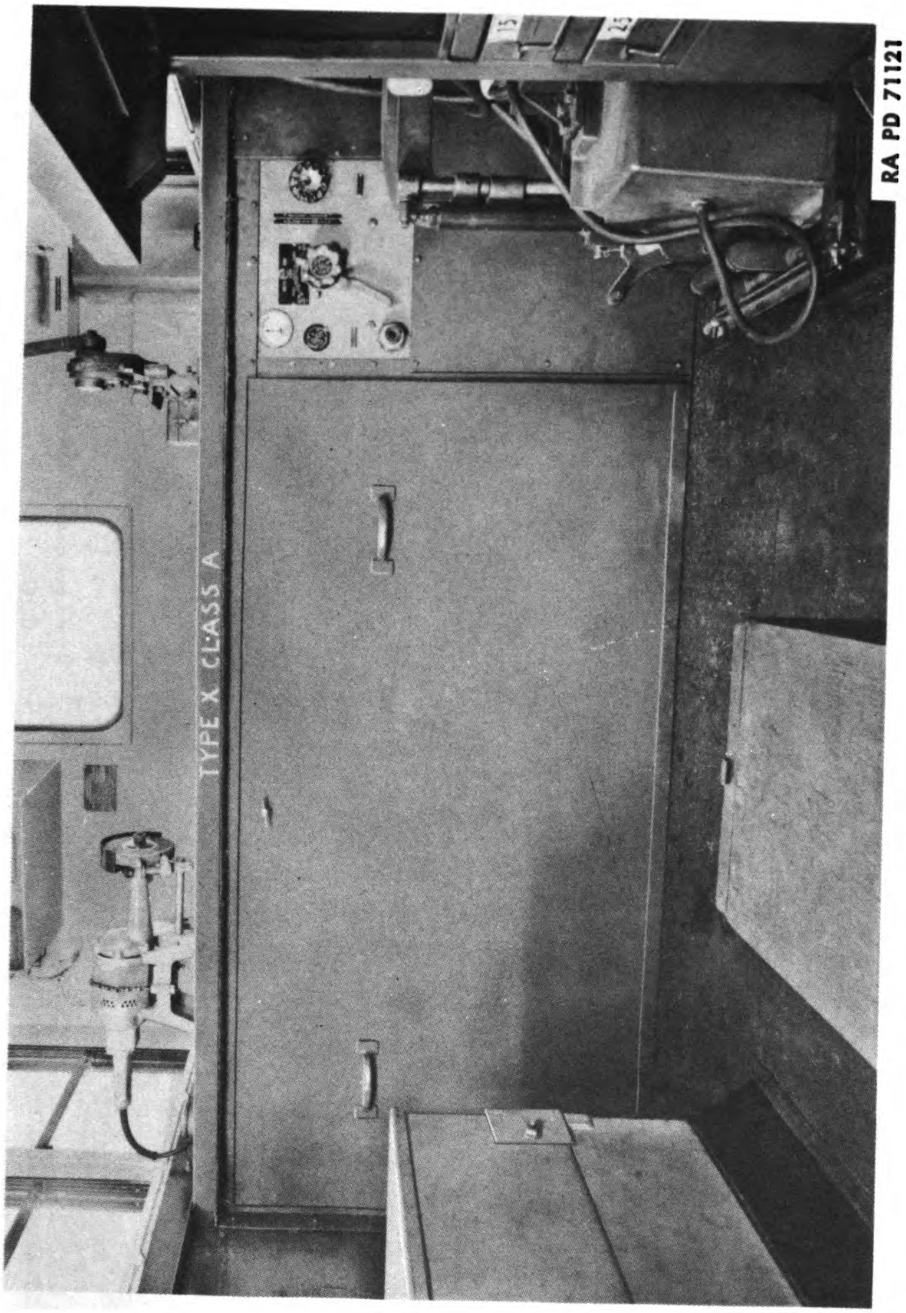


Figure 155a — 300-ampere Welding Generator and Controls — Welding Truck M12 — Cover Removed

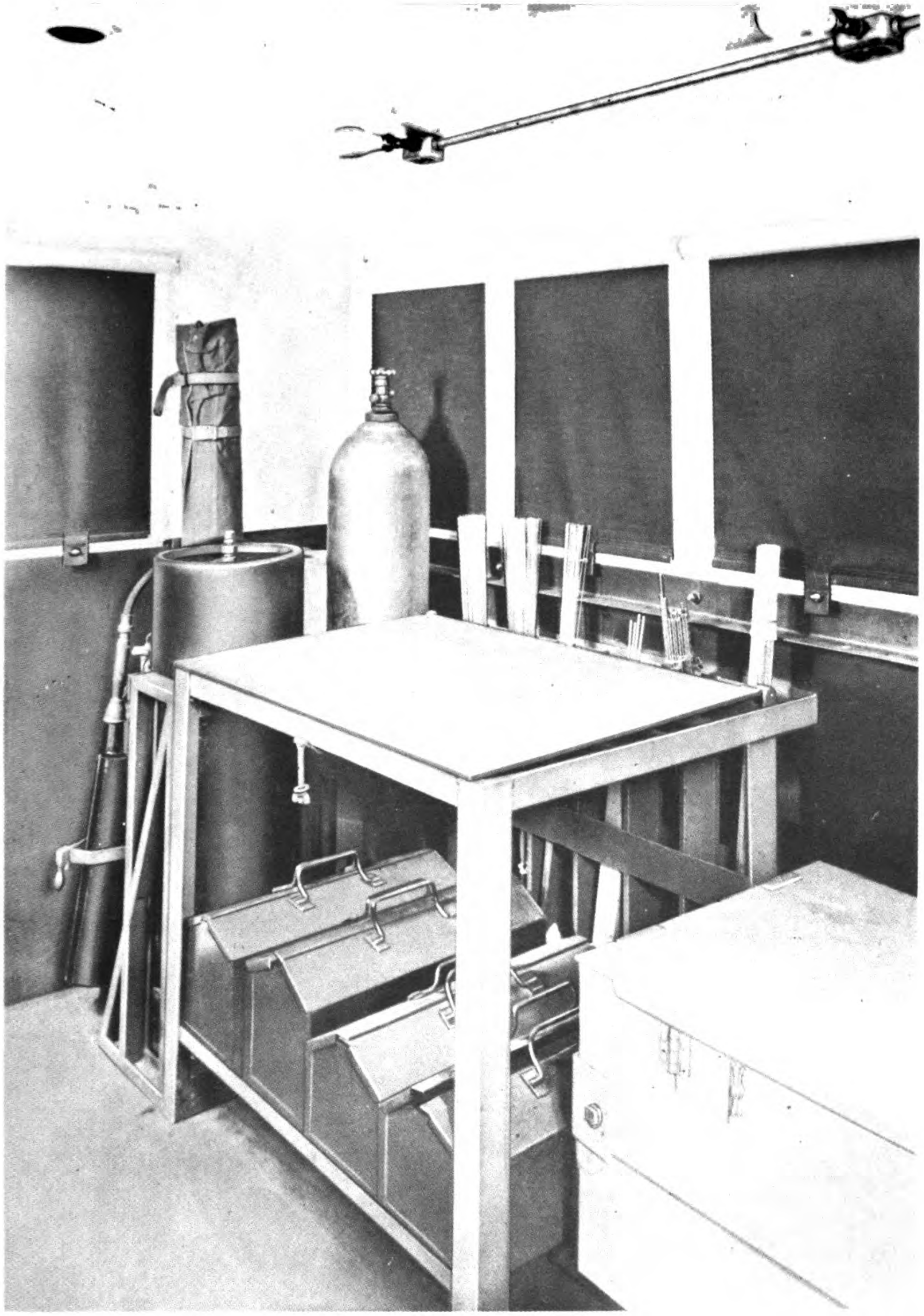


RA PD 71121

Figure 155b — Welding Truck M12 with Cover in Place over Engine and Generator

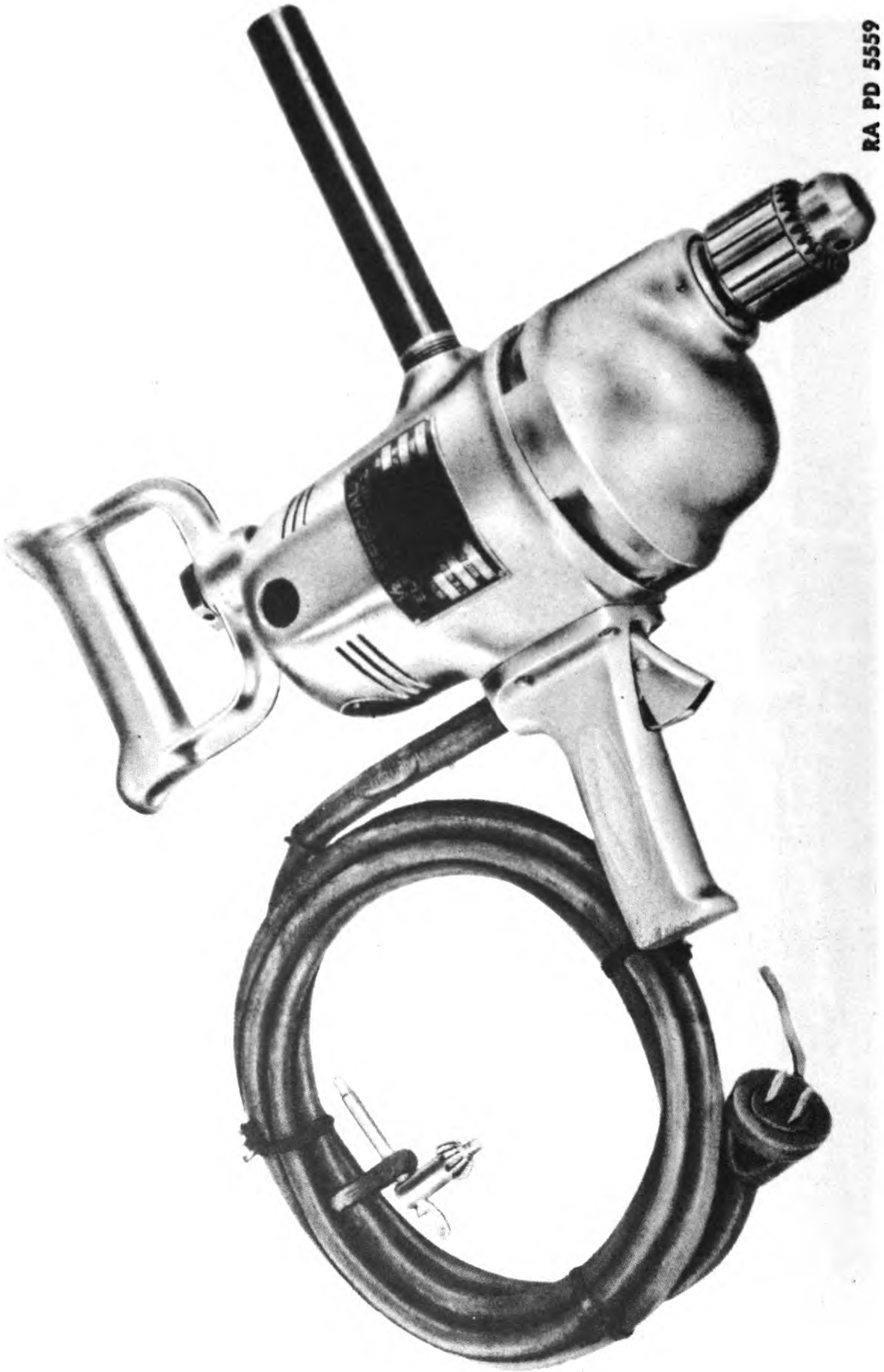
RA PD 71122

Figure 156a — Interior of Welding Truck M12 Showing Anvil and Block in Traveling Position



RA PD 71123

Figure 156b — Interior of Welding Truck M12 Showing Welding Table and Arrangement of Equipment



RA PD 5559

Figure 157a — Portable Electric Drill

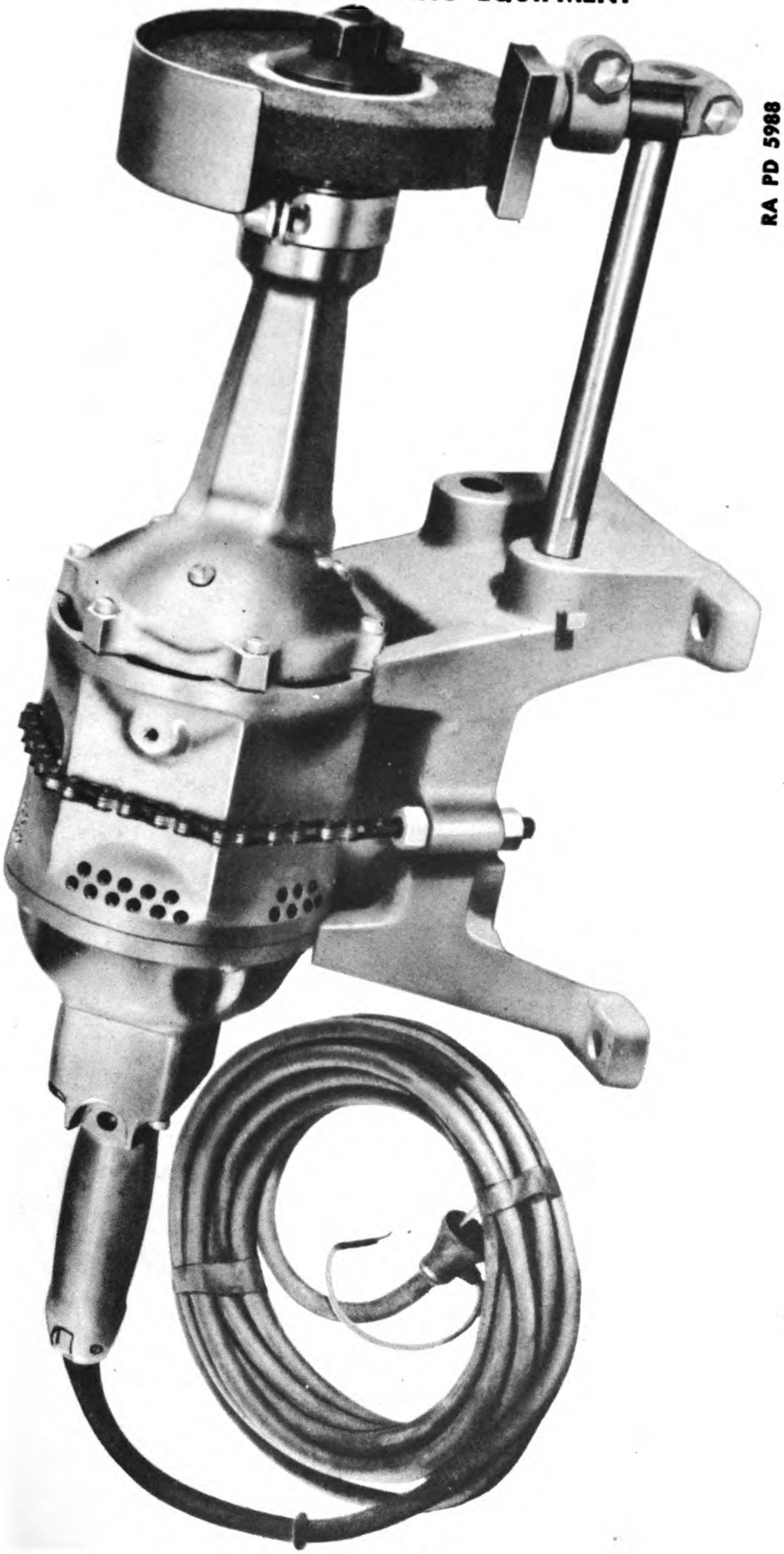
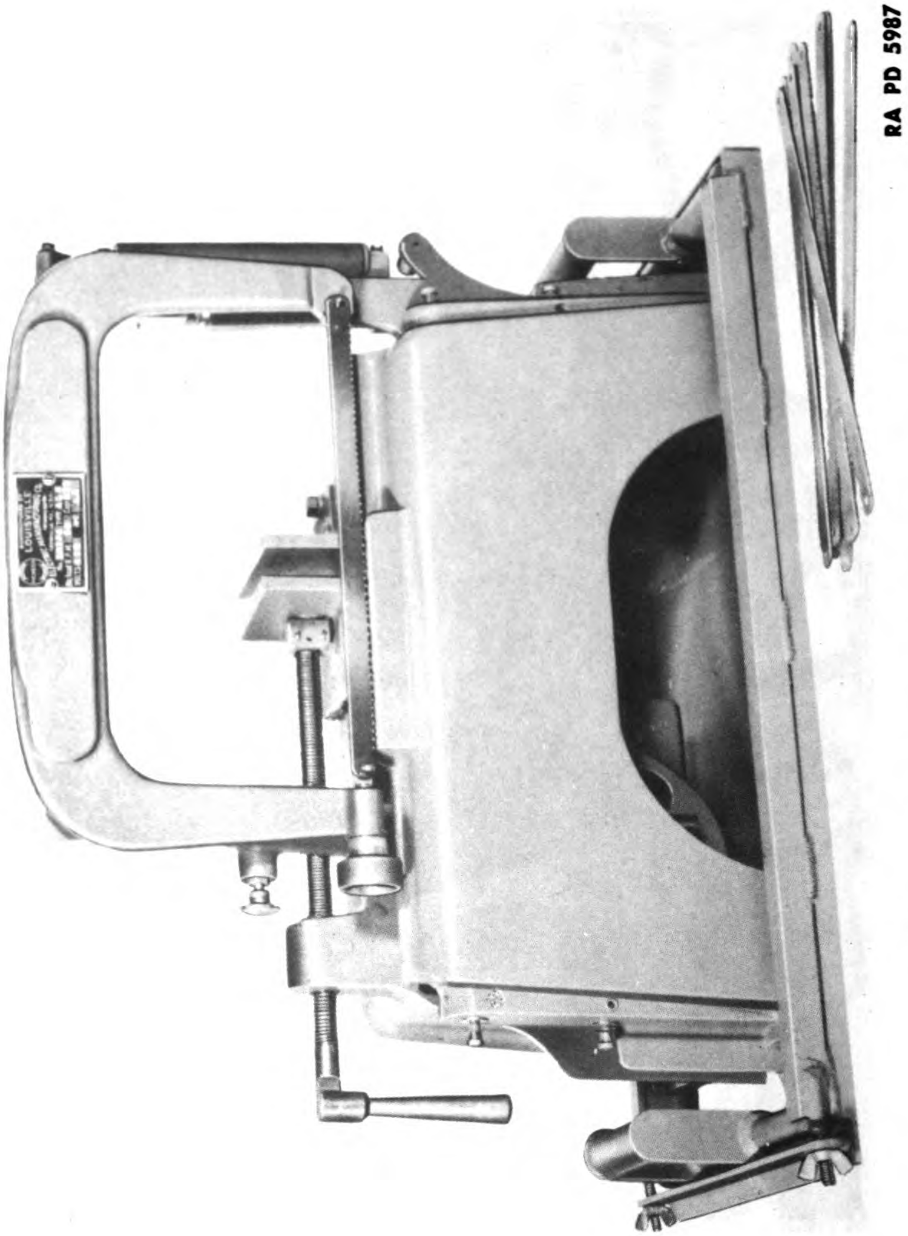


Figure 157b — Portable Grinder on Stand



RA PD 5987

Figure 157c — Power Hacksaw with Base

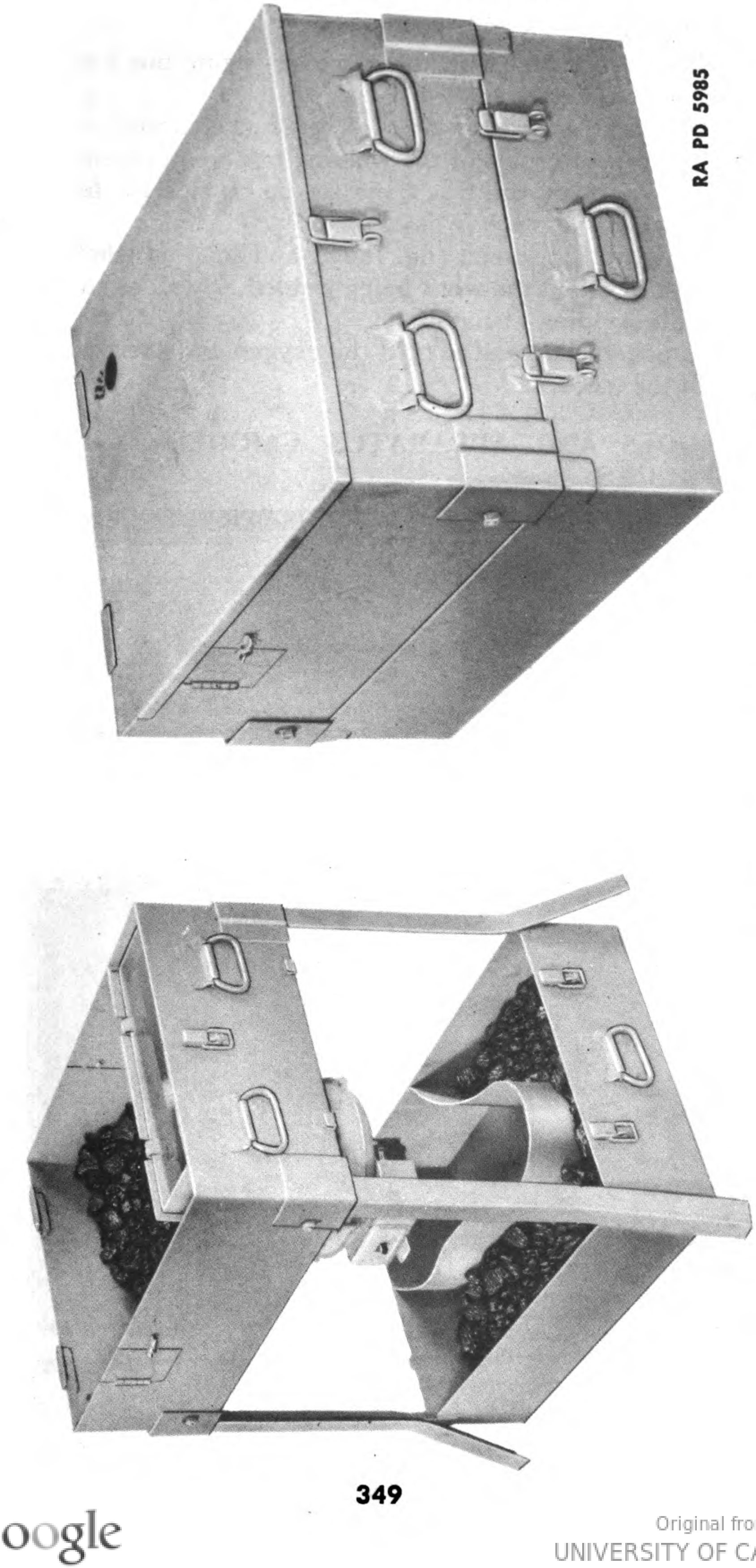


Figure 158a — Portable Forge

b. Welding Truck M3.

(1) The Truck M3 with the cab-over-engine bus body has been classified as "Limited Standard."

(2) A portable updraft type of forge (fig. 158a) with electric driven blower, is also part of the welding truck equipment. This forge can be removed from the truck and set up outside for forge welding operations when the truck is in bivouac.

(3) A lightproof screen (fig. 158b) and snap-on window curtains are supplied to shield the work being welded as well as to prevent detection while welding at night.

(4) Brackets designed to hold the oxygen and acetylene cylinders are part of the truck.

262. TOOLS AND APPARATUS CARRIED ON WELDING TRUCKS.

a. The tools carried on this truck are approximately the same as carried on the Welding Truck M3.

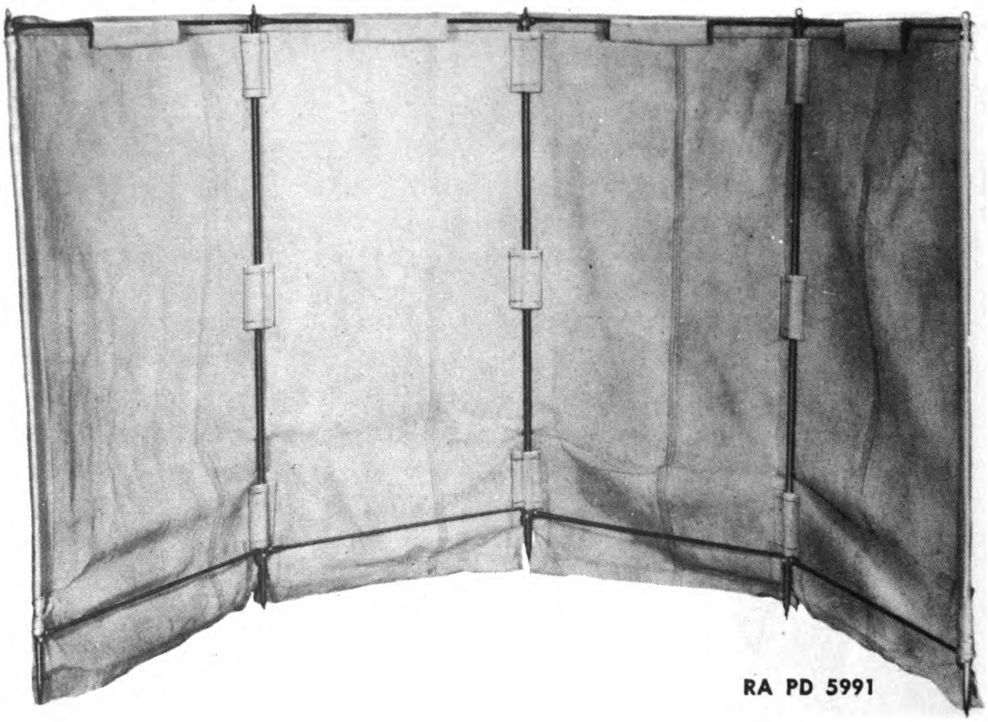
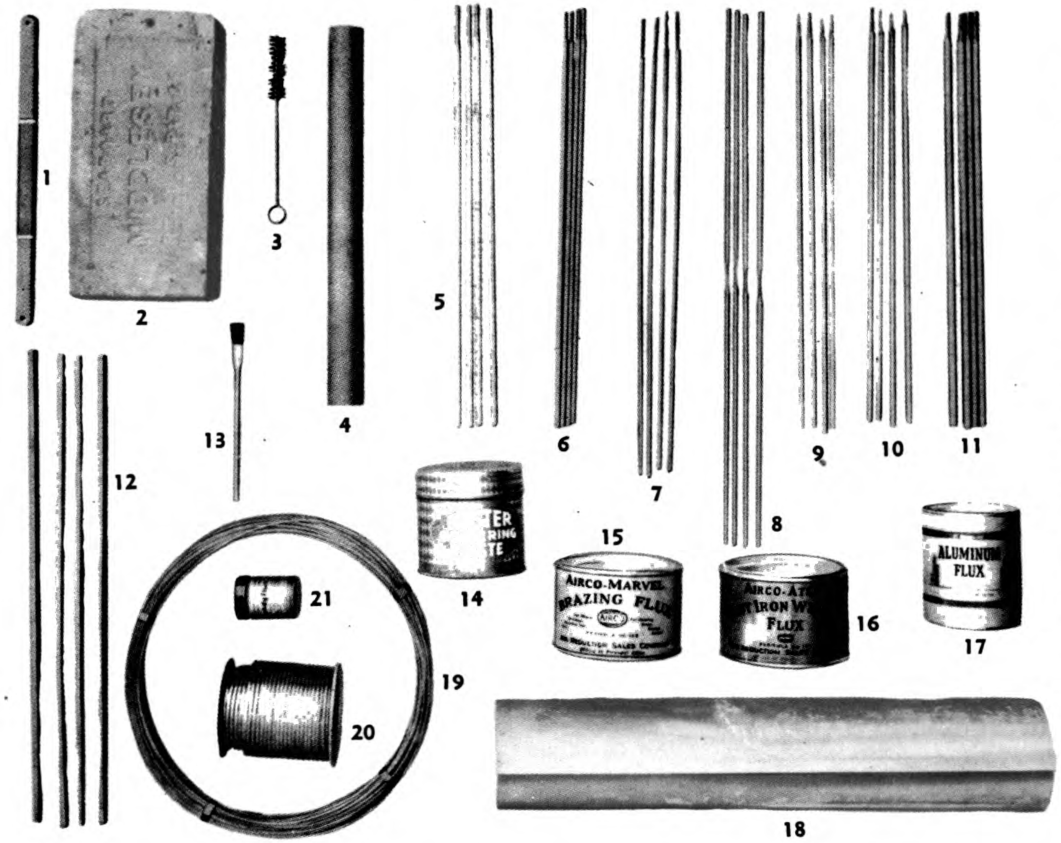


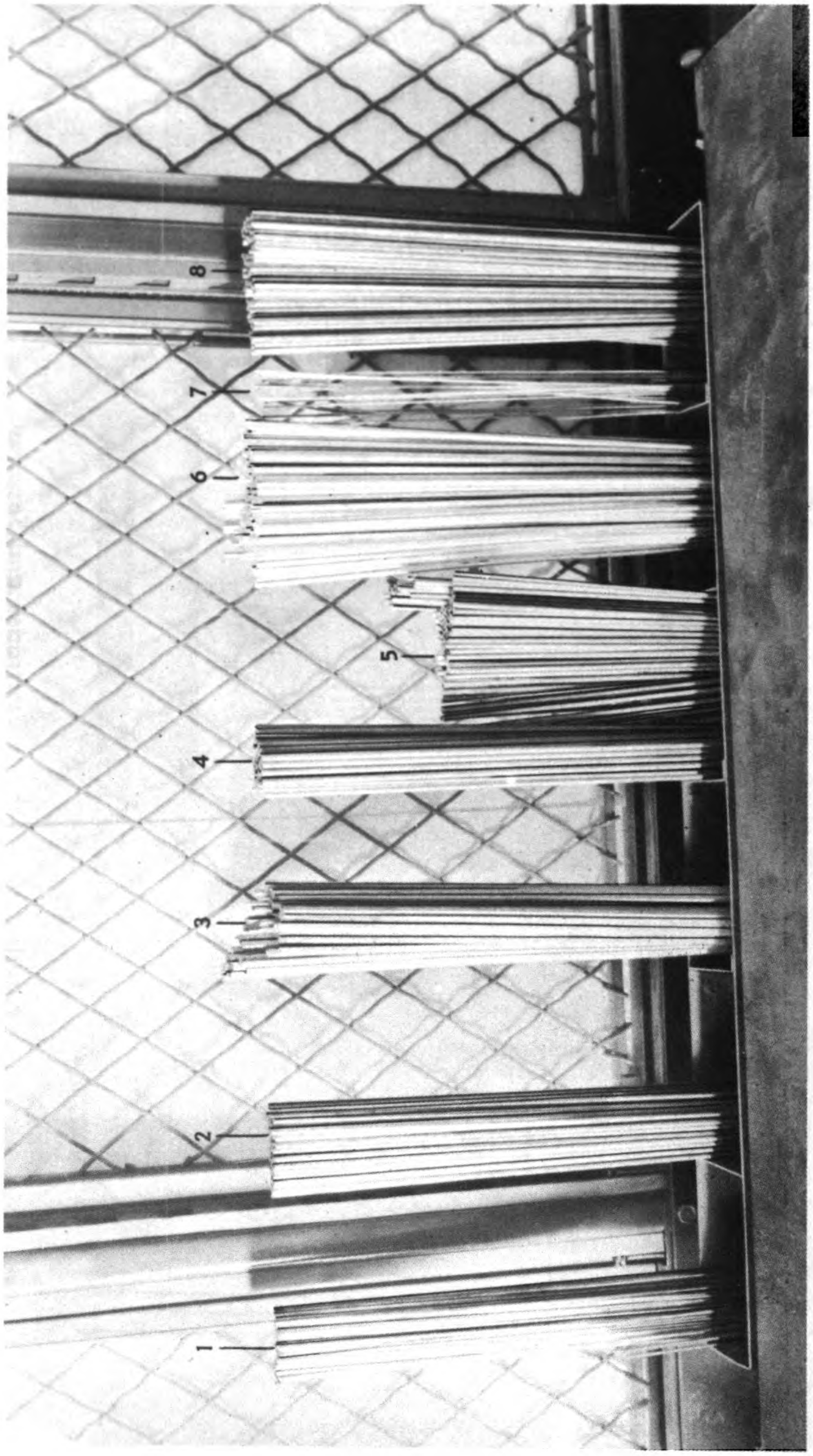
Figure 158b — Welding Screen



1 — BLADES, HACKSAW, 10 IN., 24 TEETH
2 — BRICK, FIRE, COMMON, HIGH HEAT
3 — BRUSH, ACID, TWISTED WIRE HANDLE, 6 IN.
4 — CARBON RODS, 1¼ X 12 IN.
5 — ELECTRODE, WELDING, ALUMINUM, HV-COATED., 5/32 IN.
6 — ELECTRODE, WELDING, BRONZE, HV-COATED., ⅛ IN.
7 — ELECTRODE, WELDING, HV-COATED., FOR MACH. WELD ON C.I. ⅛ IN.
8 — ELECTRODE, WELDING, MILD STEEL, ALL POSITION, 3/32 IN.
9 — ELECTRODE, WELDING, MILD STEEL, ALL POSITION, ⅛ IN.
10 — ELECTRODE, WELDING, MILD STEEL, ALL POSITION, 5/32 IN.
11 — ELECTRODE, WELDING, MILD STEEL, ALL POSITION, 3/16 IN.
12 — SOLDER, TIN-LEAD, HALF AND HALF, ¼ X ¼ IN. BARS
13 — BRUSH, ACID, TIN HANDLE, 6 IN.
14 — PASTE, SOLDERING
15 — FLUX, BRAZING, GENERAL PURPOSE
16 — FLUX, (FOR C.I. WELDING)
17 — FLUX, ALUMINUM, ¼ LB. CONTAINER
18 — PAPER, ASBESTOS, 1/16 THICK
19 — SOLDER, "SIL-FOS.", WIRE 1/16 IN.
20 — SOLDER, TIN-LEAD, WIRE
21 — FLUX, "SIL-FOS.", WELDING AND BRAZING

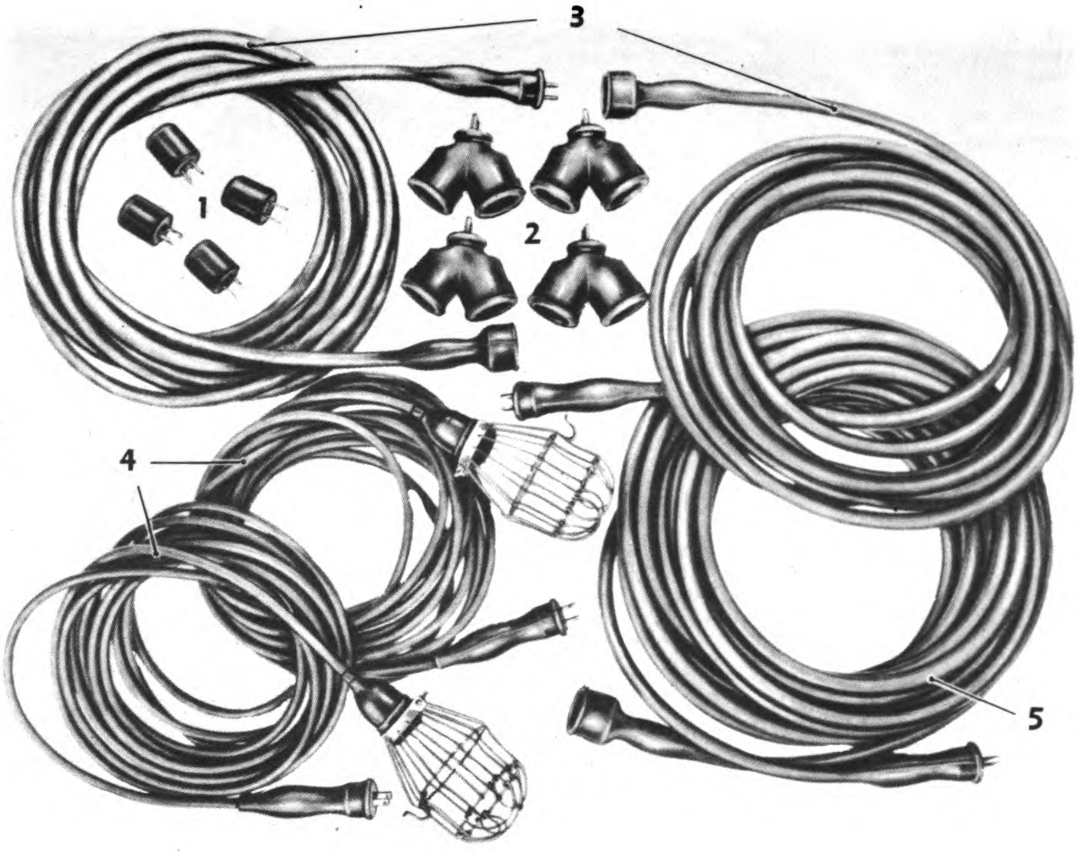
RA PD 5995

Figure 159 — Welding Electrodes and Supplies



RA PD 5996

Figure 160 — Welding Rods and Electrodes in Place on Welding Table



1 — PLUG, ADAPTER

2 — PLUG, DBLE-OUTLET

3 — CORD, EXTENSION, HV-DUTY., RUBBER, 2-COND., #12-AWG, 25 FT., W/MALE AND FEMALE CONNECTOR

4 — CORD, EXTENSION, LIGHT, RUBBER 2-COND., #18-AWG, 25 FT., W/MALE CONNECTOR AND SOFT RUBBER MED BASE SCREW SOCKET

5 — CORD, EXTENSION, HV-DUTY., RUBBER 2-COND., #12-AWG. 50 FT., W/MALE AND FEMALE CONNECTOR

RA PD 5564

Figure 161 — Extension Cords and Accessories

1 — CABLE, ARC-WELDING, RUBBER, FLEX., 200 AMP. CAP., W/GROUND CLAMP

2 — CABLE, ARC-WELDING, RUBBER, FLEX., 200 AMP. CAP., W/ELECTRODE HOLDER

3 — HELMET, WELDERS, WITH GLASS

4 — BRUSHES, WELDING GENERATOR

5 — SHIELD, WELDERS, HAND, W/GLASS

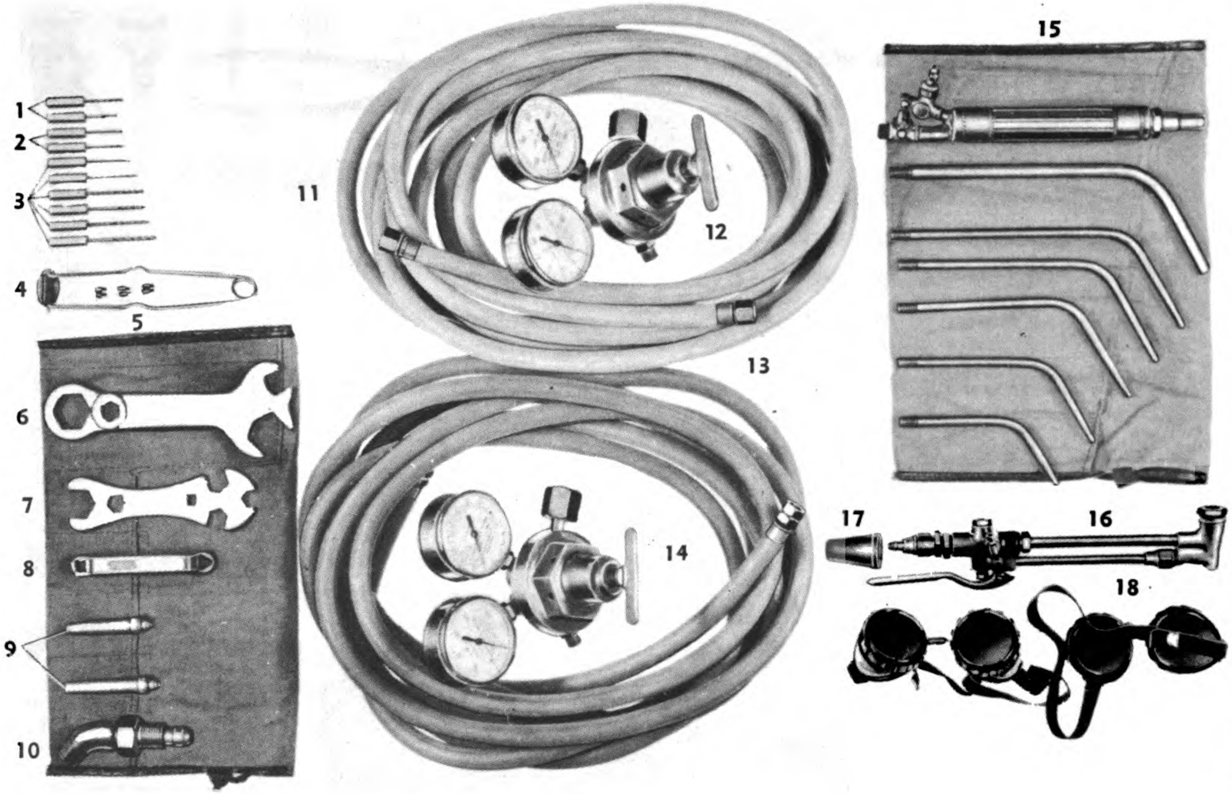
6 — GLOVES, WELDERS, GAUNTLET, 14 IN.

7 — WRENCHES, DBLE-HEAD., ASSTD.

8 — SLEEVE, WELDERS, 18 IN.

RA PD 5992

Figure 162 — Arc Welding Accessories



1 — CLEANERS, CUTTING TIP, CUTTING JET (2)
2 — CLEANERS, CUTTING TIP, PREHEATING JET (2)
3 — CLEANERS, WELDING TIPS (6)
4 — LIGHTER, TORCH W/FLINTS
5 — CASE, CANVAS
6 — WRENCH, REGULATOR
7 — WRENCH, WELDING TORCH
8 — KEY, ACETYLENE CYLINDER VALVE
9 — TIPS, CUTTING (2)
10 — ADAPTER, REGULATOR, ACETYLENE
11 — HOSE, ACETYLENE, 14 IN., TWO RED BRAID 25 FT., W/CONNECTIONS
12 — REGULATOR, ACETYLENE, MULTI-STAGE, W/1 - 80 LB. AND 1 - 500 LB. 2½ IN. DIAM. PRESSURE GAGES
13 — HOSE, OXYGEN, ¼ IN., TWO GREEN BRAID, 25 FT., W/CONNECTIONS
14 — REGULATOR, OXYGEN, MULTI-STAGE, W/1 - 150 LB. AND 1 - 3000 LB. 2½ IN. DIAM. PRESSURE GAGES
15 — CASE, CANVAS, W/WELDING TORCH AND WELDING TIPS (6)
16 — CUTTING ATTACHMENT, WELDING TORCH
17 — CAP, THREAD GUARD
18 — GOGGLES, WELDERS

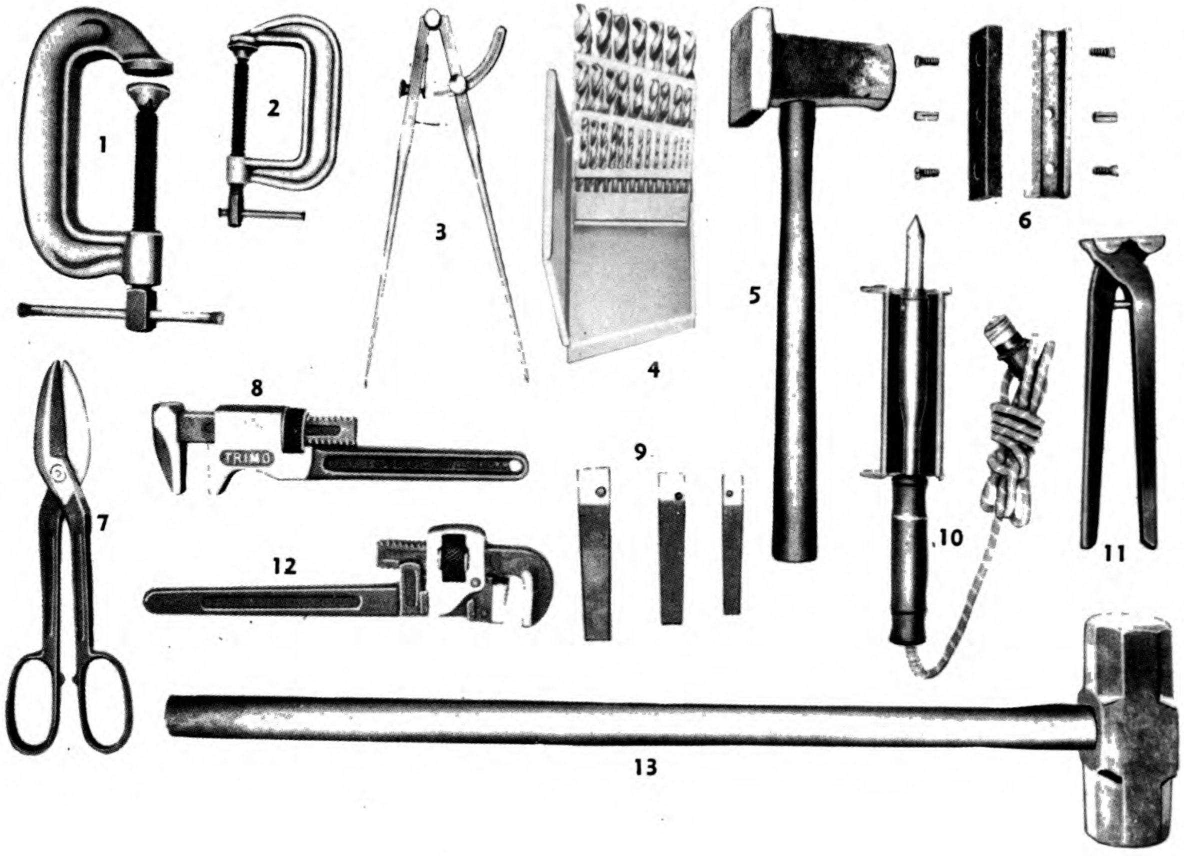
RA PD 5998

Figure 163 — Combination Oxyacetylene Welding and Cutting Outfit

1 — PUNCH, CENTER, 4 IN.
2 — PUNCH, DRIVE PIN, SOLID, ¼ IN. PT.
3 — SCRIBER, MACHINISTS, POCKET, SINGLE POINT, 2⅞ IN. BLADE
4 — SCREWDRIVER, MACHS., HV-DUTY., PYRALIN HANDLE, 4 IN. BLADE
5 — SCREWDRIVER, MACHS., HV-DUTY., PYRALIN HANDLE, 8 IN. BLADE
6 — SQUARE-SET, COMBINATION, 12 IN. BLADE, WITH CENTERING HEAD AND SQUARE HEAD
7 — RULE, STLS-STEEL., TAPE, 6 FT., MEZURALL TYPE
8 — BLADES, HACKSAW, HAND, FLEX., 10 IN., 24 TEETH
9 — GOGGLES, EYE-CUP, CHIPPERS, W/50 MM LENS
10 — GLOVES, WELDERS, GAUNTLET TYPE, 14 IN.
11 — HAMMER, MACHS., BALL PEEN, 12 OZ.
12 — HAMMER, MACHS., BALL PEEN, 24 OZ.
13 — HAMMER, SLAG COMB., CHIPPER AND WIRE BRUSH
14 — WRENCH, ADJ., END, CRESCENT, 8 IN.
15 — WRENCH, ADJ., END, CRESCENT, 10 IN.
16 — PLIERS, COMBINATION, SLIP-JOINT, 10 IN.
17 — HANDLES, FILE, 1¼ IN. X 4¼ IN.
18 — BRUSH, SCRATCH, PAINTERS, HANDLED
19 — CHISEL, MACHINISTS, HAND, CAPE, ¼ IN.
20 — CHISEL, MACHINISTS, HAND, CAPE, ½ IN.
21 — CHISEL, MACHINISTS, HAND, COLD, ¼ IN.
22 — CHISEL, MACHINISTS, HAND, COLD, ⅜ IN.
23 — CHISEL, MACHINISTS, HAND, COLD, ½ IN.
24 — CHISEL, MACHINISTS, HAND, COLD, ¾ IN.
25 — CHISEL, MACHINISTS, HAND, DIAMOND POINT, ⅜ IN. PT.
26 — CHISEL, MACHINISTS, HAND, RD.-NOSE, ¼ IN.
27 — CHISEL, MACHINISTS, HAND, RD.-NOSE., ⅜ IN.
28 — DRIFT, BR. STRAIGHT, ¾ IN. RD. X 6 IN. LONG
29 — FILE, FLAT, BASTARD, 12 IN.
30 — FILE, HALF-ROUND, SECOND CUT, 10 IN.
31 — FILE, ROUND, SECOND CUT, 10 IN.
32 — FRAME, HACKSAW, PISTOL-GRIP HANDLE, ADJ. 8 IN. TO 12 IN.

RA PD 5997

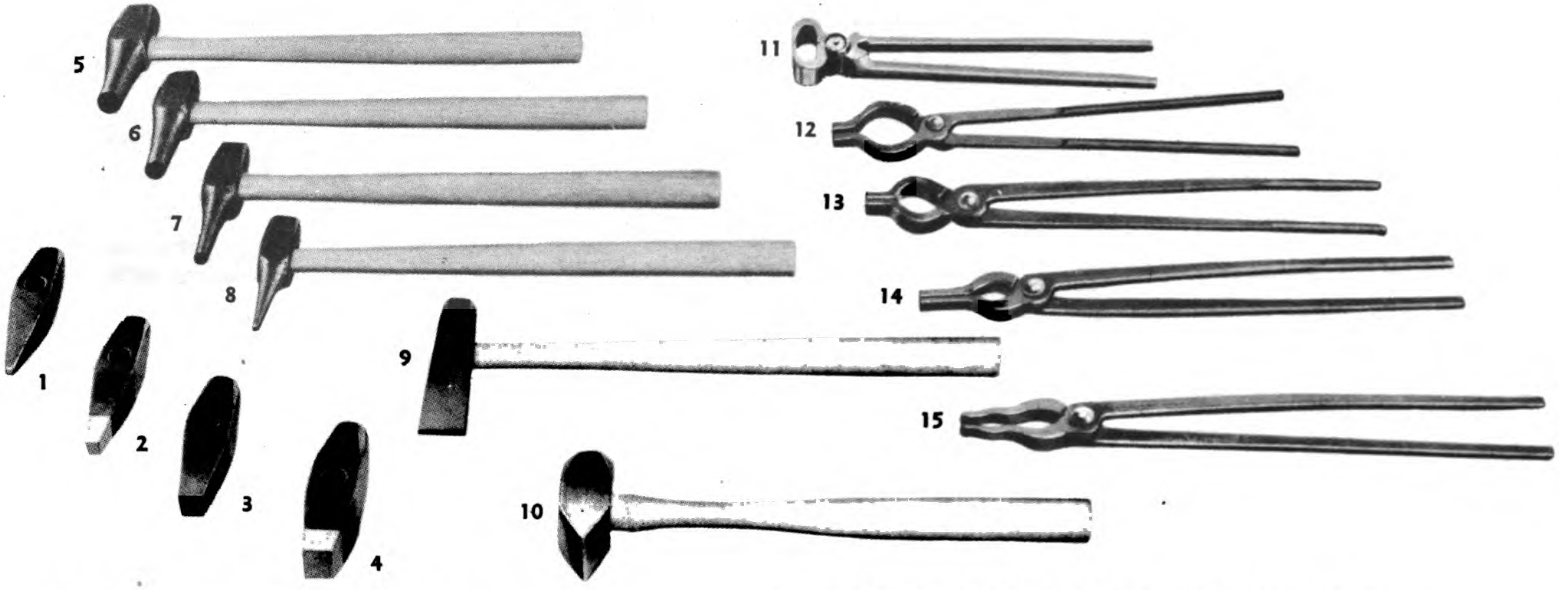
Figure 164 — Welder's Kit



1 — CLAMP, "C", MEDIUM SERVICE, 4 IN.
2 — CLAMP, "C", LIGHT SERVICE, 3 IN.
3 — DIVIDERS, WING, 12 IN.
4 — DRILL-SET, TWIST, STGHT-SHK., H.S.S., 1/16 TO ½ BY 64THS W/CASE
5 — FLATTER, BLACKSMITHS, 3 IN. SQUARE, W/HANDLE
6 — JAW-FACE, FOR 5¼ IN. VISE, W/SCREWS
7 — SHEARS, TINNERS, HAND, STRAIGHT CUTTING, 12 IN.
8 — WRENCH, SCREW, ADJ., STEEL HANDLE, 12 IN.
9 — RIVET-SET AND HEADER, SADDLERS, NO. 00, 2, 5
10 — IRON, SOLDERING, ELECTRIC, 110-120 V. ⅝ - 1 IN. DIAM. TIP, W/CORD
11 — NIPPERS, END CUTTING, 10 IN.
12 — WRENCH, PIPE, ADJUSTABLE, STEEL HANDLE, 14 IN.
13 — SLEDGE, BLACKSMITHS, DOUBLE FACE, 10 LB., W/HANDLE

RA PD 5994

Figure 165 — Tools and Accessories



1 — PUNCH, BLACKSMITHS, SQUARE, ¼ IN.
2 — PUNCH, BLACKSMITHS, SQUARE, ½ IN.
3 — PUNCH, BLACKSMITHS, SQUARE, ¾ IN.
4 — PUNCH, BLACKSMITHS, SQUARE, 1 IN.
5 — PUNCH, BLACKSMITHS, ROUND, 1 IN., W/HANDLE
6 — PUNCH, BLACKSMITHS, ROUND, ¾ IN., W/HANDLE
7 — PUNCH, BLACKSMITHS, ROUND, ½ IN., W/HANDLE
8 — PUNCH, BLACKSMITHS, ROUND, ¼ IN., W/HANDLE
9 — CHISEL, BLACKSMITHS, HAND, HOT, 1¼ IN., W/HANDLE
10 — HAMMER, BLACKSMITHS, HAND, CROSS PEEN, SIZE NO. 2
11 — NIPPERS, BLACKSMITHS, END CUTTING, 14 IN.
12 — TONGS, BLACKSMITHS, BOLT, ¼ IN. SIZE, 18 IN. LONG
13 — TONGS, BLACKSMITHS, GAD, 18 IN. LONG
14 — TONGS, BLACKSMITHS, SINGLE PICK UP, 18 IN. LONG
15 — TONGS, BLACKSMITHS, DOUBLE PICK UP, 18 IN. LONG

RA PD 5993

Figure 166 — Blacksmith's Tools

CHAPTER 13

TESTING OF WELDS AND WELDED EQUIPMENT

Section I

PERFORMANCE TESTING OF MATERIEL

Paragraph
General 263
Testing of ordnance materiel 264
Field testing of welds and equipment repaired by welding 265

263. GENERAL.

a. In order to guarantee the performance of a welded structure, it is proof-tested under operating conditions which are the same as or more severe than those under which it would operate in the field. These tests reveal weak or defective sections which can be corrected before the piece is sent out for use in the field. They not only determine the proper welding design for a piece of ordnance equipment but also insure that the welds are properly made. By this procedure, danger and inconvenience to the operating personnel of the service is kept at a minimum.

264. TESTING OF ORDNANCE MATERIEL.

a. Guns can be proof-tested by firing with an extra heavy charge to determine the safety of the piece in firing.

b. Automotive materiel and gun carriages in traveling position can be tested at high speeds over rough ground in order to determine their road safety.

c. Welded armor plate and other structural members can be tested by firing at them with projectiles from guns of various calibers to determine their strength under shock loads.

d. These and similar tests are used to determine the performance of the completed structure; however, since the piece of materiel may consist of several types of metals welded together with various filler metals, the successful operation of the entire structure requires that each weld be made properly to withstand the particular load for which it was designed. As a solution to this problem, a number of physical tests have been devised, which are discussed in section II.

265. FIELD TESTING OF WELDS AND EQUIPMENT REPAIRED BY WELDING.

a. General. A definite procedure for testing of welds, and equipment that has been repaired by welding, is not set up as a part of the normal routine of Ordnance units which are operating under field conditions. The shop officer of such units can, however, institute such testing procedure as he may deem necessary. Such tests may be of the type described in paragraphs 266 to 278, or modifications thereof. Since facilities for conducting all of these tests will not normally be available in the field only those tests described in paragraphs 268, 269, 270, 271, 275, 276 and 278**b** will be found practical. In general, however, the item repaired by welding is simply subjected to a thorough visual examination by a qualified inspector and then returned to the using arms or services if found satisfactory. Experience of personnel in making repairs by welding is essential therefore in guaranteeing the success of any particular job.

b. **Responsibility for Proper Conduct of Welding Operations.** It is the shop officer's responsibility that apparatus sent in for repair work is given the best possible attention available under the circumstances. He should assure himself that the welders are qualified for the work in hand and must see to it that established procedures for operating on ordnance materiel are always adhered to as these procedures have been tried and proven.

c. **Welding Inspector's Duties.** The shop officer or qualified welder delegated to supervise the welding repair should insure that the proper procedure is used in preparing and welding the damaged parts. He should note any departure from the prescribed procedure for the particular metal being welded and correct these to insure good, welded, joint efficiency. The finished weld should be inspected for undercut, overlap, surface checks, cracks, and similar defects. The degree of sidewall fusion, extent of reinforcement, the size and position of the weld are also factors in determining whether a completed job should be accepted or rejected since they all reflect the quality of the weld. Only metals that are weldable should be welded. No attempt should be made to weld parts which the Chief of Ordnance has specifically ordered not to be repaired by welding. Such parts should be replaced with new parts.

d. **Destructive Tests of Experimental Welds Made on Unsalvageable or Scrap Materiel.** In the event special circumstances require the use of a new or novel procedure or new welding material and apparatus, and when welding operators are inexperienced in their use, it is well to conduct welding experiments with scrap or unsalvageable materiel, subjecting the welds or welded material to destructive tests, to determine the suitability of the new procedure or to help improve the welding operators ability in its use.

e. **Performance Tests by Using Personnel.** In the case of materiel which has been repaired by welding by standard procedures in the recommended manner, the visual inspection should be sufficient to determine the efficiency of the weld; however, after the repaired item has been returned to the using arm or service, the latter should immediately give the item such practical tests as would subject it to stresses and strains that would be encountered in normal service. This would involve the towing of mobile materiel over terrain that it is normally expected to traverse, and firing of artillery pieces to insure that the repair will stand up under the forces of recoil. Vehicles may be loaded to their maximum capacity and given a trial run under actual operating conditions. Time need not necessarily be used in making these tests, but in most cases it is possible to place the item in normal service at once with instructions to the using personnel to make a few thorough examinations after the item has been in service a short time and to report signs of possible failure or unatisfactory performance. Signs of failure of a repaired part can thus be detected before serious trouble results and steps can be taken to use the item under reduced service conditions until corrective measures can be taken.

CHAPTER 13

TESTING OF WELDS AND WELDED EQUIPMENT (Cont'd)

Section II

PHYSICAL TESTING OF WELDS

Paragraph
General 266
Tensile test 267
Free bend test 268
Guided bend test 269
Back bend test 270
Nick break test 271
X-ray test 272
Gamma-ray test 273
Electrical resistance test 274
Magna-flux test 275
Hydrostatic test 276
Acid-etch test 277
Hardness tests 278

266. GENERAL.

a. The following physical tests have been developed to check the skill of the welding operator, as well as the quality of the weld metal and the strength of the welded joint for each type of metal used in ordnance materiel. The purpose and scope of these tests are given in paragraphs 267 to 278.

b. All of the tests described in paragraphs 266 to 270 may be classified as destructive, in that the test specimens are loaded until they fail before the desired information can be gained. The tensile test is the oldest and most commonly used, but the free bend, back bend, and guided bend tests reveal the most valuable information as to the quality and properties of the welded joint.

c. Other methods of testing, in which the piece tested is not destroyed, include X-ray, gamma-ray, electrical resistance, magna-flux, hydrostatic, and acid-etch tests.

267. TENSILE TEST.

a. This test is used to measure the strength of a welded joint. A portion of a welded plate is machined out so as to locate the weld in

PHYSICAL TESTING OF WELDS

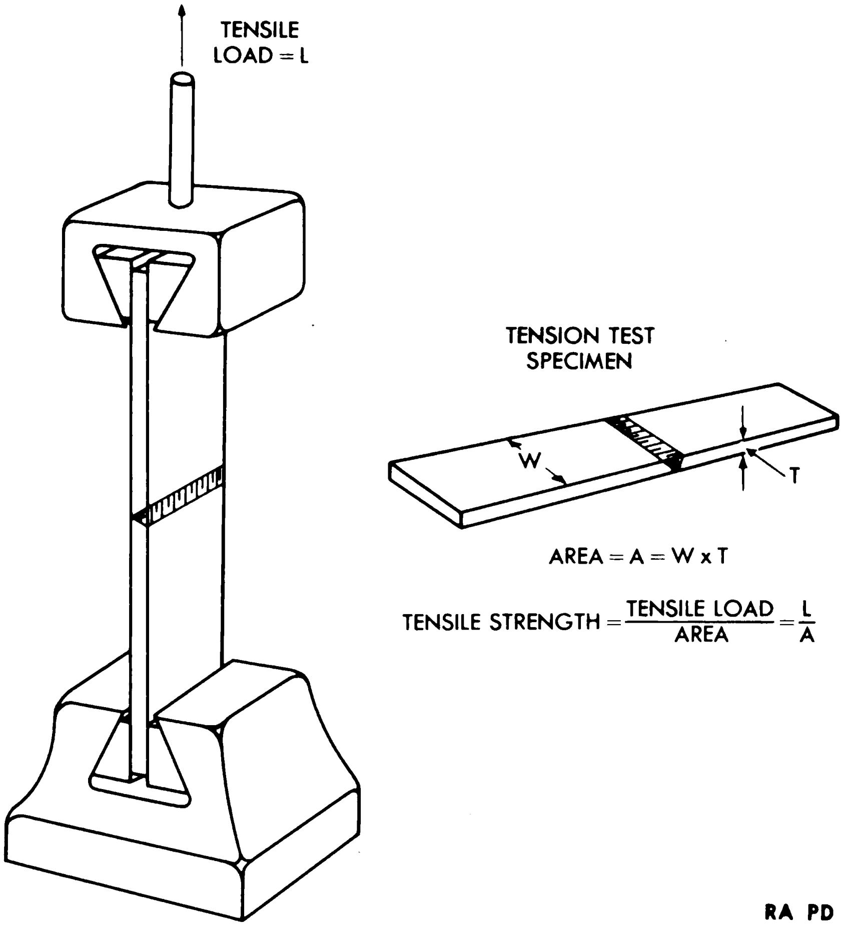
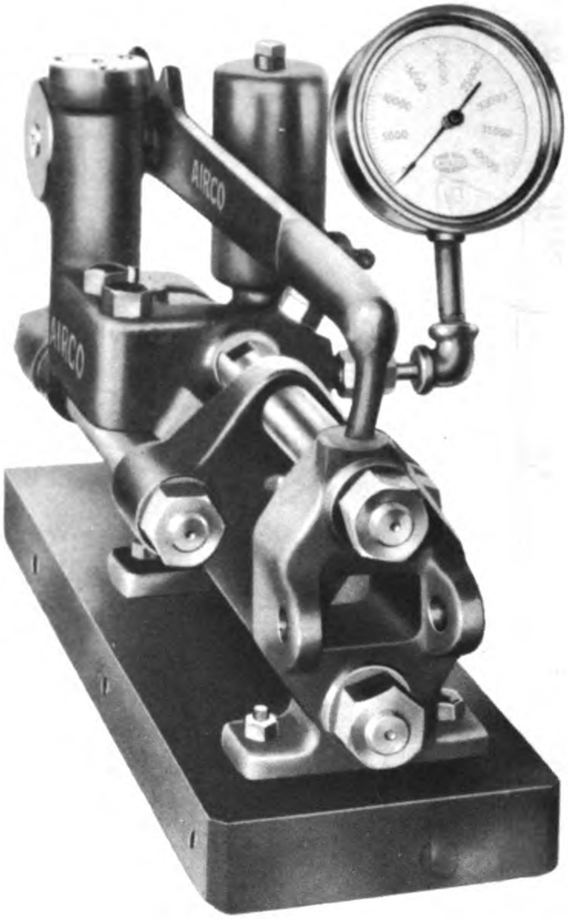


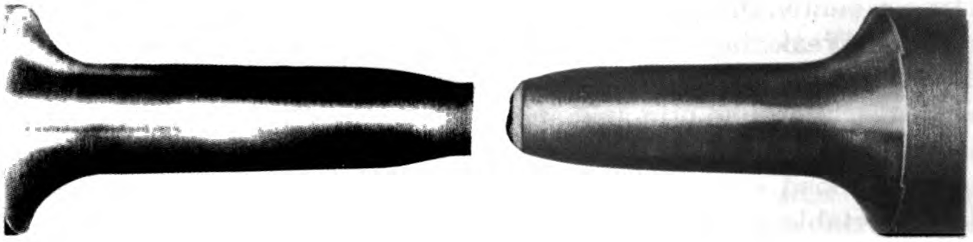
Figure 167 — Tension Test of Welded Metal

the center, as shown in figure 167. The width and thickness of the test specimen are measured before testing, and the area in square inches is calculated by multiplying these two figures. The tensile test specimen is then mounted in a machine which will exert a pull on the piece sufficient to break the specimen. The testing machine may be either a stationary or a portable type. A machine of the portable type, operating on the hydraulic principle and capable of pulling as well as bending test specimens, is shown in figure 168. As the specimen is being tested, the load in pounds is registered on a gage located on one side of the portable type of machine. In the stationary type of machine, the load applied to the test specimen is registered on a balancing beam. In either case, the load at the point of breaking is recorded. The tensile strength, which is defined as stress in pounds per square inch, can be calculated by dividing the breaking load of the test piece by the original cross section area of the specimen. The usual requirement for tensile test of welds is that the specimen pull not less than



RA PD 71125

Figure 168 — Portable Tensile and Bend Testing Machine



RA PD 71126

Figure 169 — Tension Test Specimen

90 percent of the base metal tensile strength. Figure 169 shows a tension test specimen, machined round, composed entirely of alloy steel weld metal. Before breaking in a typical "cup" and "cone" fracture, the specimen "necked" or drew down and stretched or elongated considerably. This indicates good ductility in the weld metal.

268. FREE BEND TEST.

a. In order to measure the ductility of the weld metal deposited in a welded joint, the free bend test has been devised. A test specimen is machined from the welded plate, with the weld located as shown in figure 170. Two scribed lines are placed on the face 1/16 inch in from the edges of the weld. The distance between these lines is measured in inches and recorded as the initial distance "X." The ends of the piece are then bent through angles of about 30 degrees. These bends are located approximately 1/3 of the length in from each end. The weld is thus located centrally to insure that all of the bending occurs in the weld. The initially bent specimen is then placed in a machine capable of exerting a large compressive force and bent until a crack or cracks greater than 1/16 inch in any dimension appear on the face of the weld. If no cracks occur, bending is continued until the specimen is bent 180 degrees and flattened. Test specimens 1/4 inch thick or under can be tested in a vise. Heavier plate is usually tested in a press or bending jig. After testing, the distance between the scribed lines is again measured on the specimen with a flexible steel scale and recorded as the distance "Y." To find the percentage of elongation, subtract the initial from the final distance, divide by the initial distance and multiply by one hundred. $\frac{(y - x)}{x} 100$. The usual requirements for passing this test are that the minimum elongation shall be 15 percent and that no cracks greater than 1/16 inch shall exist on the face of the weld.

269. GUIDED BEND TEST.

a. The quality of the weld metal at the face and root of the welded joint, as well as the degree of penetration and fusion to the base metal, is determined by means of guided bend tests. These tests are made in a jig, the design and dimensions of which are shown in figure 171. The test specimens are machined from welded plate, the thickness of which should be within the capacity of the bending jig. The test specimen is placed across the supports of the die which is the lower portion of the jig. The plunger, operated from above by a hydraulic jack or other device, causes the specimen to be depressed into and to assume the shape of the die. To fulfill the requirements of this test, the test specimen must bend to the capacity of the jig or 180 degrees. To be accepted as passable, no cracks greater than 1/8 inch in any dimension should appear on the surface. The face bend tests are made

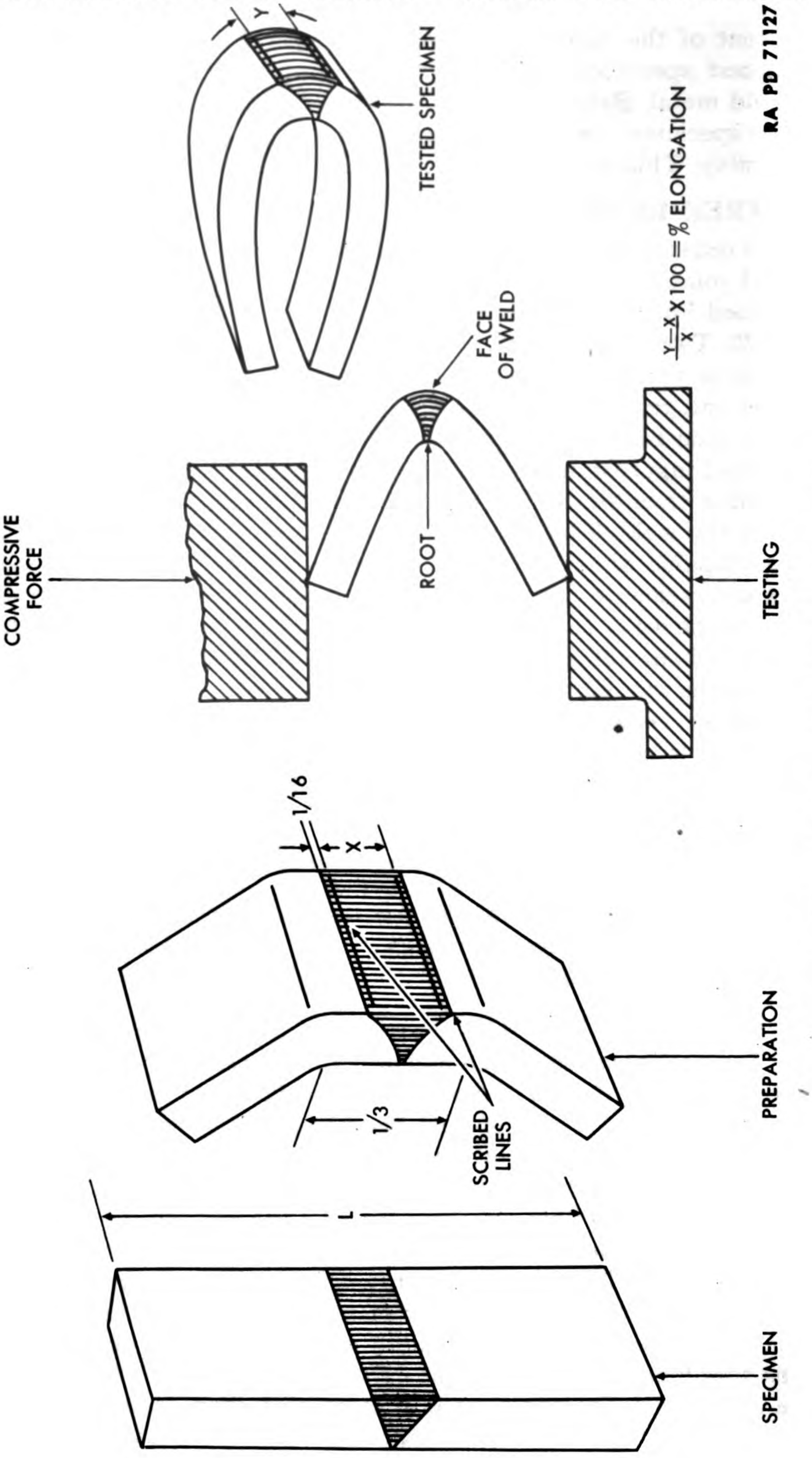
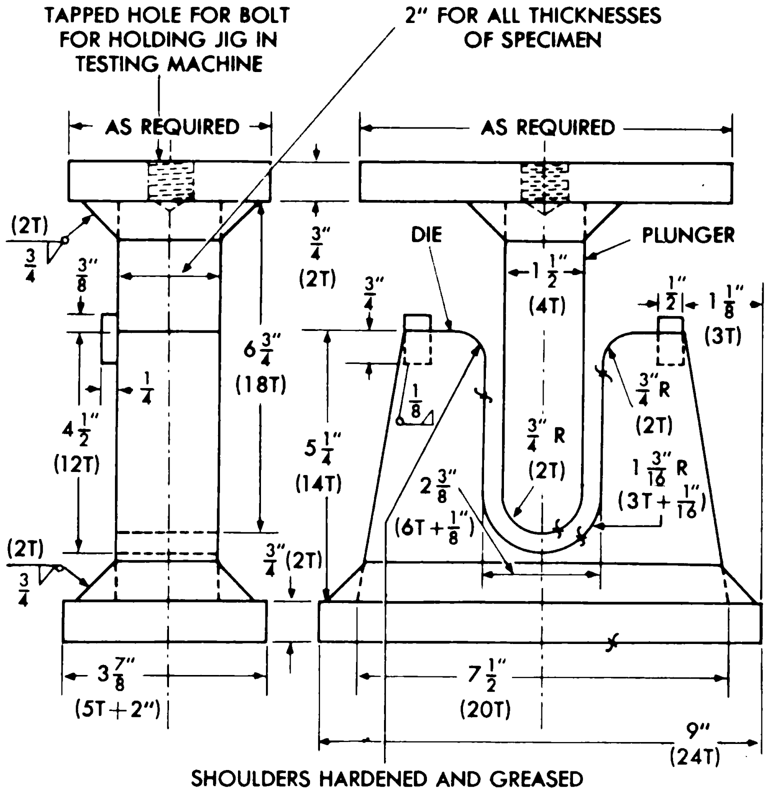


Figure 170 — Free Bend Test of Welded Metal



NOTES:
1—T = TEST PLATE THICKNESS
2—HARDENED ROLLS MAY BE USED ON SHOULDERS IF DESIRED
3—SPECIFIC DIMENSIONS FOR ⅜" PLATE

RA PD 71128

Figure 171 — Guided Bend Test Jig

in this jig with the face of the weld in tension (outside). The root bend tests are made in this jig with the root of the weld in tension. These are illustrated in figure 172. Guided bend test specimens for bronze welded steel joints are shown in figure 173 together with tensile test specimens showing fractures outside of the brazed joint. These tests reveal good face bend and root bend properties and establish the fact that the bronze welded joint is stronger than the steel plate material.

270. BACK BEND TEST.

a. The back bend test is used to determine the quality of the weld metal and the degree of penetration into the root of the "V" of the welded joint. The specimens used are similar to those required for the free bend test, except that they are bent with the root of the weld on the tension side (outside) of the bend. The specimens tested are

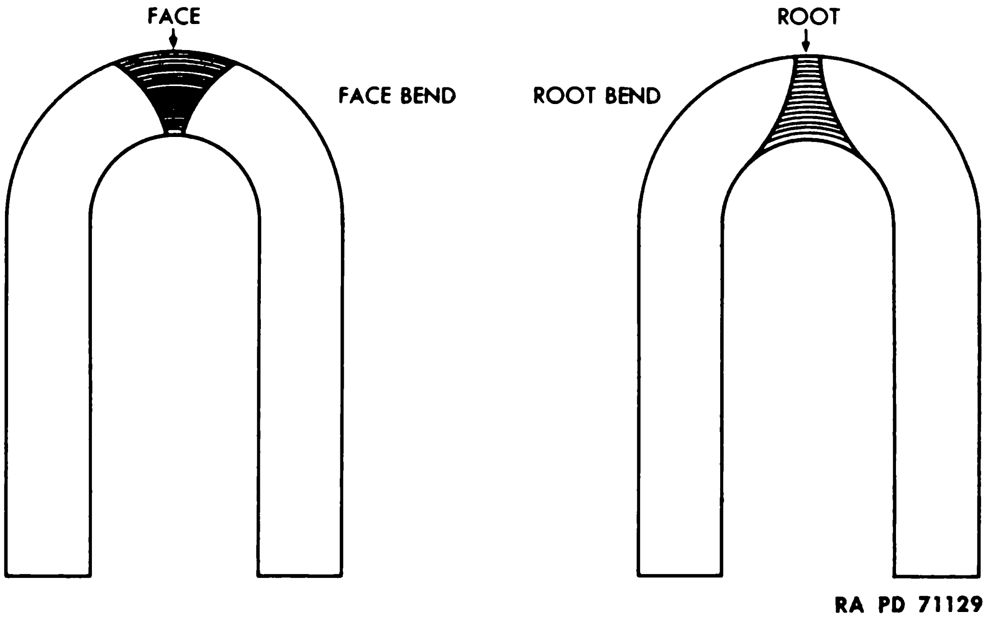


Figure 172 — Guided Bend Tests

required to bend 90 degrees without breaking apart. The back bend test as well as the free bend test are being largely replaced by the guided bend test.

271. NICK BREAK TEST.

a. To determine whether the weld metal has any internal defects, such as slag inclusions, gas pockets, lack of fusion, and oxidized or burnt metal, the nick break test has been devised. The specimen is obtained from a welded joint either by machining or by cutting with an oxyacetylene torch. Each edge of the weld at the joint is slotted by means of a saw cut through the center. The piece thus prepared is supported on two steel blocks and struck with a hammer as shown in figure 174. After repeated hammering with a large hammer, the portion of the weld between the slots will fail, thus exposing the interior of the weld metal. The weld metal so exposed should be completely fused and be free from slag inclusions. The size of any gas pocket must not be greater than $\frac{1}{16}$ inch across the greatest dimension. The number of pores or gas pockets found per square inch of weld surface should not exceed six.

272. X-RAY TEST.

a. This test is used to reveal certain types of internal defects, such as cracks, slag inclusions, blowholes, and zones where fusion is lacking in the weld metal. The method consists of placing an X-ray tube on one side of the plate and a photographic film on the other side. An exposure ranging from a fraction of a minute to 15 minutes is used,

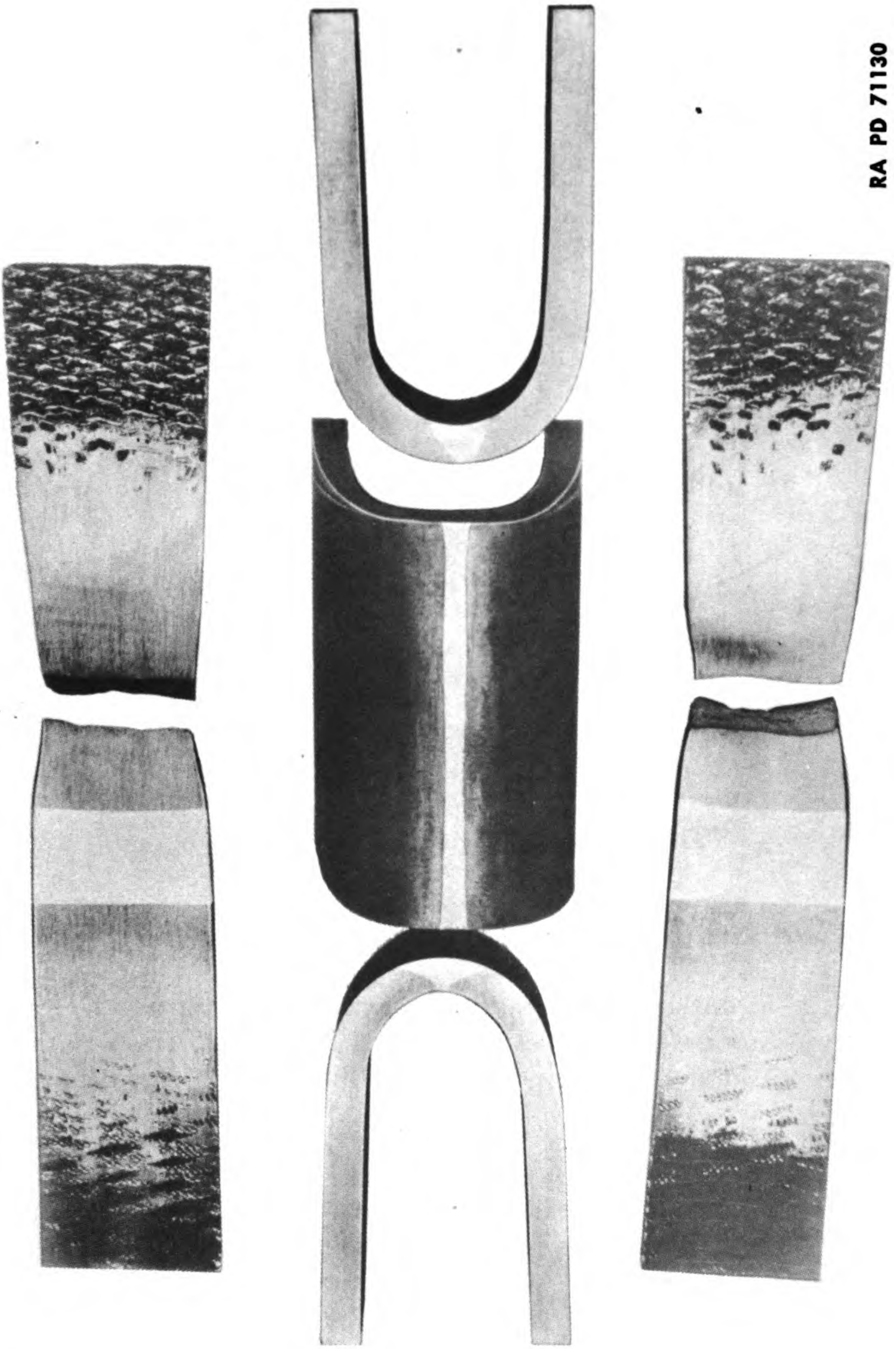


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Figure 173 — Guided Bend and Tensile Test Specimens

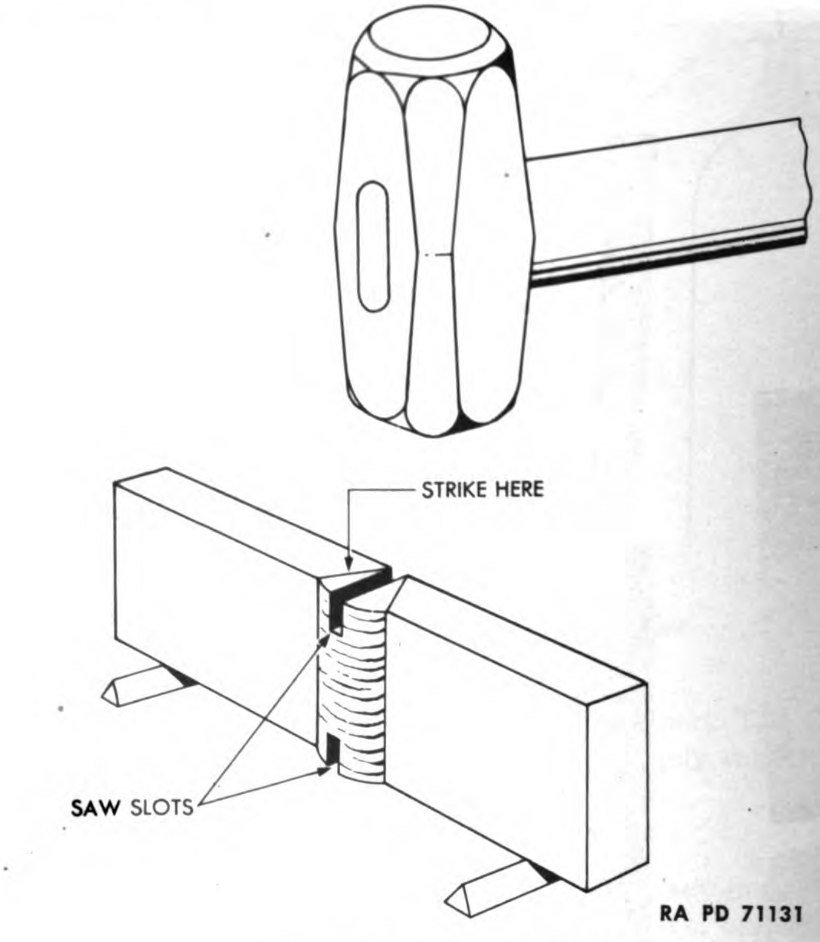

Figure 174 — Nick Break Test

depending upon the thickness of the plate being examined and the power of the tube. When developed, the film reveals the defects, which show up as dark spots or bands. This method is considered the most important nondestructive test for welds. Figure 175 is an X-ray of a butt-welded joint, showing porosity and poor root penetration.

273. GAMMA-RAY TEST.

a. The principle of these tests is the same as that of X-ray tests, except that the gamma-rays emanate from a particle of radium instead of an X-ray tube. Heavy sections are successfully examined by use of these rays, but the exposure time is considerably longer than that required for X-rays. Operators using either the X-ray or gamma-ray testing apparatus should be thoroughly familiar with the properties of X-rays and radium.

274. ELECTRICAL RESISTANCE TEST.

a. This test has been used on small welds and small welded sec-

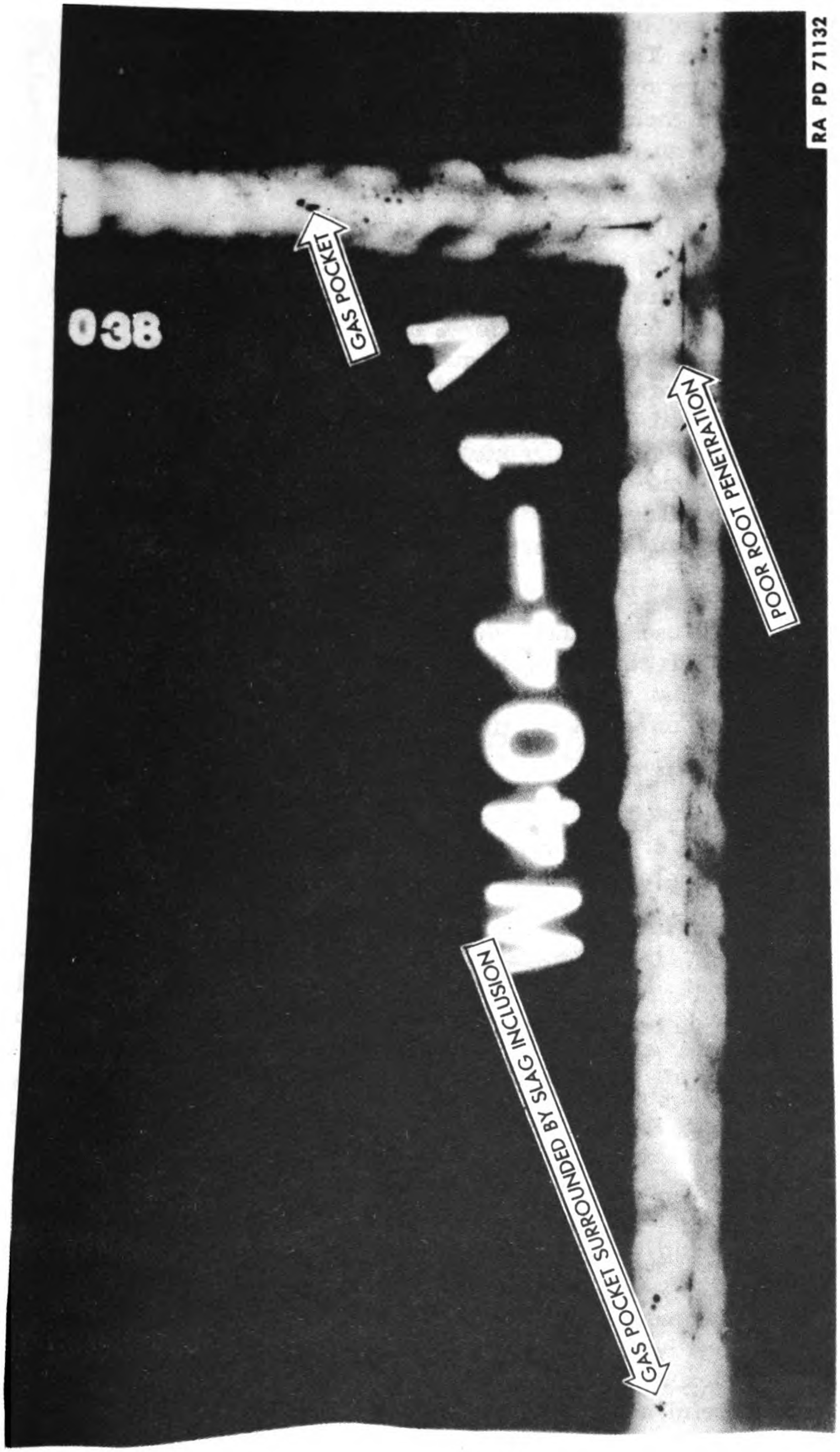

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Figure 175 — X-ray Test

tions, but it has not been successfully applied to large sections or to long welded joints. The resistance to the flow of electric current is affected by foreign matter in the weld metal. The current-carrying capacity for pure metal is compared with that of the weld metal of similar cross section. The relative changes in the electrical properties of the weld metal are used as a measure of its quality.

275. MAGNA-FLUX TEST.

a. This method of testing reveals fine hair-like cracks on the surface of welds or plates and also shows defects below the surface to a depth of approximately 3/8 inch to 1/2 inch. The piece must be magnetized so that the direction of the magnetic field lies across the direction of the defects located on or beneath the surface of the weld metal or plate being tested. Under these conditions, the presence of defects interrupts the flow of the magnetic field and sets up north and south magnetic poles. These poles attract a finely divided magnetic powder used in this test and retain it at the defect on the surface thus making the location of the defect clearly visible.

276. HYDROSTATIC TEST.

a. This test is used to check the quality of welds on a closed vessel such as a tank. It consists of filling the tank with water, applying a pressure greater than the working pressure of the vessel, and noting any pressure drop or leakage at the joints over a period of time.

277. ACID-ETCH TEST.

a. This test is used to detect fine cracks at the bottom of chipped-out areas in casings or welds. The acid attacks or reacts with the edges of cracks present in the steel or weld metal, thus making them visible.

278. HARDNESS TESTS.

a. Hardness may be defined as the power of metal to resist indentation or local displacement. The hardness test as usually applied is a nondestructive test, used primarily in the laboratory and not to any great extent in the field.

b. There are a great many methods for determining hardness, the simplest one being the file test. At best, this is a rough comparative test and is performed by running a file over the piece being tested. Information may thus be obtained as to whether the material is harder or softer than the file or than other materials which have been given the same treatment.

c. Hardness tests are used effectively as a means of controlling the properties of materials designed for a specific purpose once the desirable hardness has been established for the particular application. The hardness test is used to determine the hardness of the weld metal. By a careful analysis of a welded joint the hard areas can be isolated and the extent of the effects of the welding heat on the properties of the base metal determined.

d. **Hardness Testing Machines.** There are several types of hardness testing machines used for these tests. Each of them is singular in that its functional design best lends itself to the particular field of application for which it was intended; however, more than one type of hardness testing machine can be used on a given metal, and the hardness values obtained can be satisfactorily correlated. There are two types of hardness testing machines most generally used for hardness testing in the laboratory. These are the Brinell and the Rockwell machines.

(1) BRINELL TESTING MACHINES.

(a) In the Brinell tests the specimen is mounted on an anvil and a pressure of 3,000 kilograms (6,620 lb) is applied against the specimen through the medium of a hardened steel ball 10 millimeters (0.4 inch) in diameter. After the load is allowed to remain for a period of ½ minute, the pressure is released, and the depth of the impression made by the ball on the specimen is measured. The results are expressed in Brinell hardness numbers, which are obtained by applying the following formula:

$$\text{B.H.N.} = \frac{P}{\frac{\pi D}{2}\left(D - D^2 - d^2\right)}$$

B.H.N.: Brinell hardness number.
P: Applied load in kilograms.
D: Diameter of steel ball in millimeters.
d: Diameter of impression in millimeters.

(b) It should be noted that in order to facilitate the determination of Brinell hardness the diameter of the impression rather than its depth is actually measured. Charts of Brinell hardness numbers have been prepared for a range of impression diameters, the Brinell hardness formula being used for the calculations. These charts simplify the conversion of impression diameters into Brinell hardness numbers.

(2) ROCKWELL HARDNESS TESTER. The principle of the Rockwell hardness tester is essentially the same as that of the Brinell tester. The Rockwell test differs from the Brinell test in that a lesser load is impressed on a smaller hardened steel ball or cone-shaped diamond. The depth of the indentation is measured and indicated on a dial attached to the machine. The hardness is expressed in arbitrary figures called Rockwell numbers. These are prefixed with a letter notation such as "B" or "C" to indicate the size of the ball, load, and scale used in the test.

INSTRUCTION GUIDE — WELDING — THEORY AND APPLICATION

PART FIVE — References and Data

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REFERENCES

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279. STANDARD NOMENCLATURE LISTS.

a.	Soldering, brazing and welding material, gases and related items	SNL K-2
b.	Truck, welding, M3	SNL G-59
c.	Truck, welding, M12	SNL G-142

280. EXPLANATORY PUBLICATIONS:

a. **Commercial Publications Used in the Preparation of this Manual.**

Arc welding instruction course (exercises)—Air Reduction, New York, N. Y., 1940.

Arc welding instruction course (lectures)—Air Reduction, New York, N. Y., 1940.

Instructions in aircraft welding—oxyacetylene (exercises)—Air Reduction, New York, N. Y., 1940.

Instructions in oxyacetylene welding and cutting processes (lectures)—Air Reduction, New York, N. Y., 1940.

Instructions in oxyacetylene welding and cutting processes (work sheets)—Air Reduction, New York, N. Y., 1940.

Oxyacetylene welding and cutting instruction course (exercises)—Air Reduction, New York, N. Y., 1942.

Welding handbook, American Welding Society, New York, N. Y., 1942.

Welding procedures—Air Reduction, New York, N. Y., 1941.

b. **Publications Recommended for Further Study of Welding Practice and Procedures.**

Arc welding handbook by C. J. Holslag.

How to weld 29 metals by C. H. Jennings, Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.

Lessons in arc welding by Lincoln Electric Company, Cleveland, Ohio.

Manual for electric arc welding, E. H. Hubert, 1932 edition.

Procedure handbook of electric arc welding, design and practice, by Lincoln Electric Company, Cleveland, Ohio.

REFERENCES

The oxwelder's handbook published by Linde Air Products Company, New York, N. Y.

The welding handbook and the welding journal published by The American Welding Society, 29 West 39th St., New York, N. Y.

Welding by J. A. Moyer, McGraw-Hill Book Company, New York, N. Y.

Welding and its application by B. E. Rossi, McGraw-Hill Book Company, New York, N. Y.

Welding encyclopedia by Welding Engineering Publishing Company, 10th edition.

Welding metallurgy, vols. I and II, by O. H. Henry and G. E. Claussen, 1940 edition.

41 lessons in arc welding by Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.

c. **Welding.**

Cleaning, preserving, lubricating, and welding materials and similar items issued by the Ordnance Department	TM 9-850
Electric and oxyacetylene welding	OFSB 5-2
Truck, welding, M3	(Ser. 1942) OFSC 22
Welding	TM 1-430
Welding; joint design	AXS-800 Sept. 28, 1942
Welding; nomenclature and definitions	AXS-770 June 27, 1942
Welding; symbols	AXS-799, Sept. 28, 1942

Section II

DATA

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Procedure guide for electric arc welding 289
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281. DEFINITIONS OF WELDING TERMS AND PROCESSES.

a. Some of the more common welding terms and processes used in the description of the various welding operations may be defined as follows:

ACETONE: An inflammable and very volatile liquid used as a solvent in acetylene cylinders to dissolve and stabilize acetylene under high pressure.

ACETYLENE: A highly combustible gas composed of carbon and hydrogen (C_2H_2) and used as a fuel gas in oxyacetylene welding.

ADHESION: A condition existing in a welded joint when the molten metal merely sticks to the adjacent metal without actually being fused with it.

AIR-ACETYLENE WELDING: A gas welding process in which the welding heat is obtained from the burning of acetylene and air.

ALINEMENT: The arrangement of parts in a straight line or proper position in relation to each other to restore the original shape as nearly as possible.

ALLOY: A mixture of two or more entirely different metals intimately united by melting them together.

ALTERNATING-CURRENT ARC WELDING: An arc welding process in which the power supply at the arc is alternating current.

ARC BRAZING: An electric brazing process in which the heat is obtained from an electric arc, formed between the base metal and an electrode or between two electrodes.

ARC VOLTAGE: The voltage across the arc.

ARC WELDING: A nonpressure (fusion) welding process in which the welding heat is obtained from an arc either between the base metal and an electrode or between two electrodes.

DATA

ASBESTOS: A fibrous material refractory to heat, used in welding as insulation against transmission of heat from one body of metal to another.

ATOMIC HYDROGEN WELDING: An alternating-current arc welding process in which the welding heat is obtained from an arc between two tungsten electrodes in an atmosphere of hydrogen.

AUTOGENOUS WELDING: The process of joining two or more pieces of metal by fusing, without additional metal being added, and without the aid of hammering or pressure.

BACKFIRE: The popping out of the torch flame or momentary burning of the gases within the torch tip.

BACKHAND WELDING: A method of gas welding in which the flame is directed toward the finished weld.

BACKING STRIP: Material (metal, asbestos, carbon, etc.), used to back up the root of the weld and retain the molten metal.

BACK-STEP WELDING: A welding technique in which the beads of weld metal are deposited opposite to the direction of progress of the weld along the joint.

BARE, LIGHTLY COATED ELECTRODE: A solid metal electrode with no coating other than that necessary to manufacture the electrode, or with a light coating.

BASE METAL (PARENT METAL): The metal to be welded or cut.

BEAD WELD: A type of weld made by one passage of the electrode or rod.

BEVELLING: The cutting or forming of angles on the edges or end of metal plates, shapes, or sections.

BLOWHOLE: A hole or cavity formed in the weld by entrapped gases, dirt, grease, or other foreign matter. Usually caused by welding too fast.

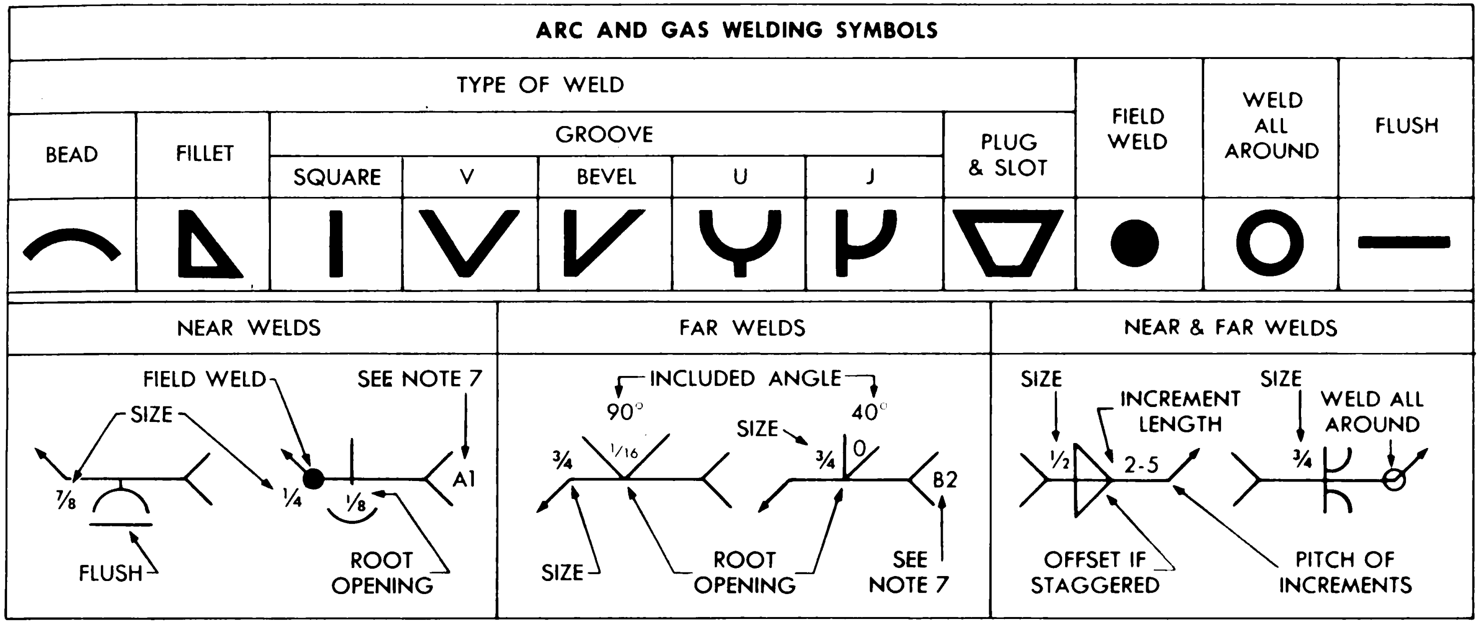
BOND: The junction of the weld metal and the base metal.

BOURDON TUBE: A curved metal elastic tube, oval in cross section, open at one end to gas, steam, or other fluid pressure and closed at the other. Changes in pressure cause it to move, and this movement is used to indicate the pressure.

BRAZING: A group of joining processes in which the filler metal is a nonferrous metal or alloy whose melting point is higher than 1,000 F but is lower than that of the metals or alloys to be joined. The application of brasses or bronzes on steel, cast iron, or malleable iron is an example of the brazing process.

BRONZE WELDING: A brazing process in which the filler metal is a bronze rod which is used in the same manner and on the same joint design as would be used if a fusion weld were being made.

BUCKLING: Distortion of sheet or plate, due to the forces of expansion and contraction caused by the application of heat or excessive loading.



1. Welds parallel to the plane of the paper or nearly so, with faces toward reader, are near welds; those with faces away from reader are far welds. (Use sufficient views to make meaning clear.)
2. Welds in section or end views with faces toward the arrow are near welds, those with faces away from the arrow are far welds. (Use sufficient arrows to make locations clear.)
3. When only one member is to be grooved, arrow points to that member.
4. Near and far welds are same size unless otherwise shown.
5. Symbols apply between abrupt changes in direction of weld, or as dimensioned.
6. All welds are continuous and of user's standard proportions and all except "V" and bevel-groove welds are closed unless otherwise shown.
7. Tail of arrow used for specification reference. (Omit tail when reference not used.)

NOTE: All dimensions are in inches.

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Figure 176 — Arc and Gas Welding Symbols

DATA

BUTT WELD: A weld made between the ends or edges of two plates or surfaces approximately in the same plane with each other.

CAPILLARY ATTRACTION: The action by which the surface of a liquid where it is in contact with a solid (as in a capillary tube) is elevated or depressed.

CARBON ARC CUTTING: The process of cutting or severing metals by melting with the heat of the carbon arc.

CARBON ARC WELDING: An arc welding process in which a carbon or graphite electrode or electrodes are used, with or without filler metal.

CARBON DIOXIDE: A heavy, colorless gas (CO_2) composed of carbon and oxygen, which has the property of extinguishing flame. It is more properly called carbonic acid gas. Water will absorb more than its own volume of carbon dioxide under pressure, becoming soda or carbonated water. Compressed to a liquid, it is used in some fire extinguishers, and, when frozen, it becomes dry ice. It is present in the gases given off by an oxyacetylene welding flame.

CARBON MONOXIDE: A colorless, odorless gas (CO) composed of carbon and oxygen. It burns with a pale blue flame to form carbon dioxide. It is very poisonous when inhaled because it drives oxygen from the blood. It is present in the exhaust gases of internal combustion engines.

CARBURIZING (CARBONIZING) FLAME: A gas flame having the property of introducing carbon into the metal heated.

CAST-IRON THERMIT: A thermit mixture containing additions of ferro-silicon and mild steel.

COHESION: The molecular attraction exerted between the particles of a body which unites them.

COLD SHUT: Poor fusion between the layers of weld metal or between the weld metal and the base metal.

COMBUSTION: The process of rapid oxidation or burning.

CONCURRENT HEATING: Supplementary heating applied to a structure during the course of welding.

CONDUCTIVITY: The rate at which a metal body will transmit electrical current or heat through its mass.

CONE: The part of the welding flame that is conical in shape and located at the end of the welding tip.

CONTRACTION: The shrinkage of metal due to cooling from an elevated temperature.

COVERED (SHIELDED-ARC) ELECTRODE: A metal electrode which has a relatively thick covering material serving the dual purpose of stabilizing the arc and improving the properties of the weld metal.

COVER GLASS: A clear glass used to protect the lens in goggles, face shields, and helmets from spattering material.

CRATER: A depression in the deposited weld metal at the end of an arc weld.

CURRENT DENSITY: Amperes per square inch of surface.

CUTTING PROCESS: The process of severing or cutting metals by means of oxidation or melting. Oxygen cutting is an oxidation process of cutting. Metal-arc and carbon-arc cutting are melting processes.

CUTTING TIP: A gas torch tip especially designed for oxygen cutting.

CUTTING TORCH OR BLOWPIPE: An apparatus used in oxygen cutting. It is designed to control the gases used for preheating as well as the oxygen used for cutting.

CYLINDER (BOTTLE): A portable container used for storage of a compressed gas.

DEPOSITED METAL: Metal that has been added to a weld from an electrode or welding rod by a welding process.

DIAPHRAGM: A thin, flexible partition.

DIES: A pair of cutting or shaping tools, which, when moved toward each other, shape an object or surface between them by pressure or by a blow.

DIP BRAZING: A group of brazing processes in which the heat is obtained from a bath of molten metal or chemical. The filler metal may or may not be obtained from the bath.

DIRECT-CURRENT ARC WELDING: An arc welding process in which the power supply at the arc is direct current.

DRAG: In oxyacetylene cutting, the amount by which the point where the oxygen jet leaves the kerf departs from the perpendicular through the point at which the jet enters the kerf, often expressed as a percentage of the plate thickness.

DUCTILITY: The property which permits a metal to be drawn, formed, or shaped.

EDGE WELD: The joining of two or more parallel pieces of metal by welding their edges together.

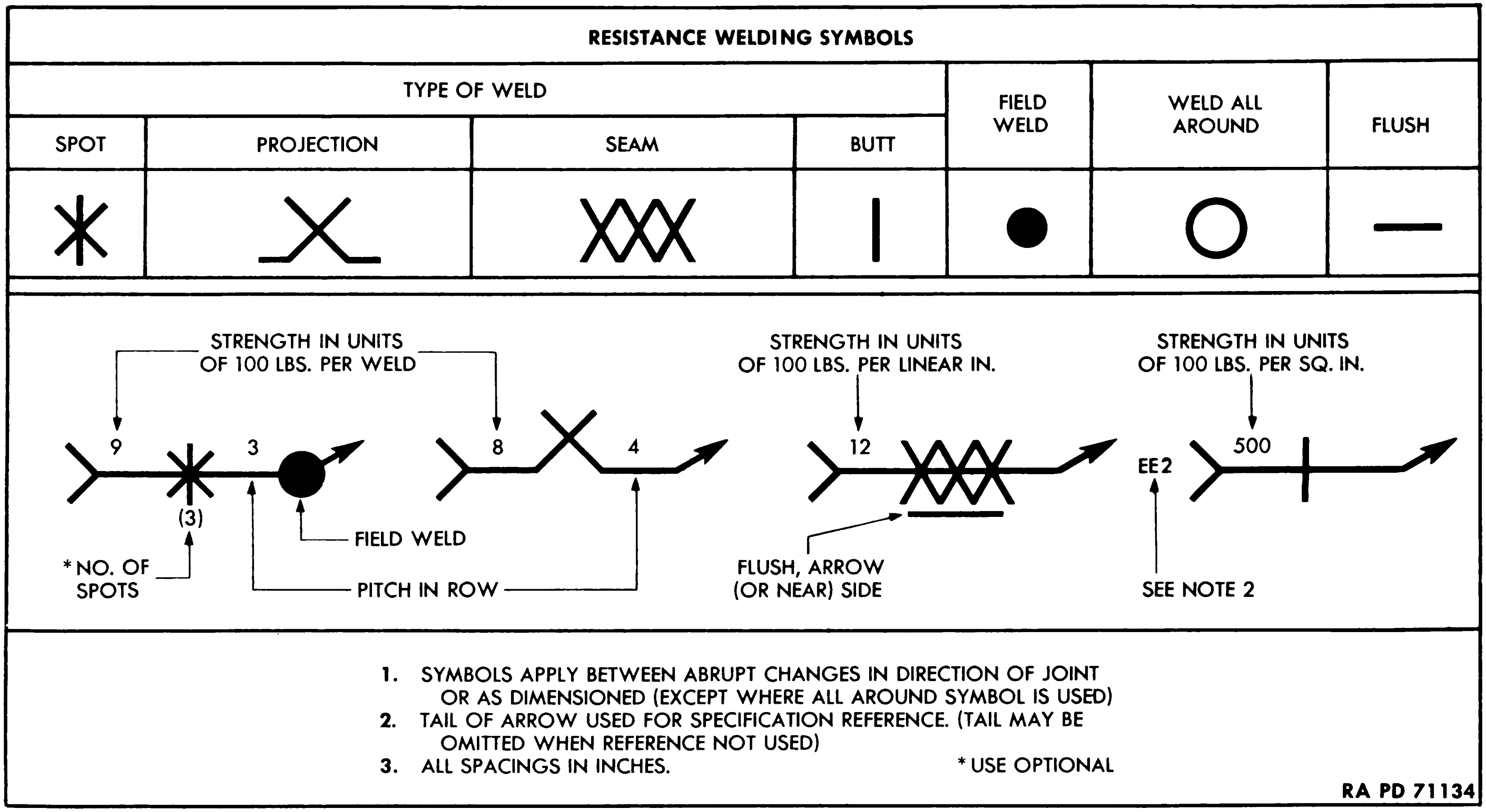
ELASTIC LIMIT: The maximum load that a metal will sustain before it takes a permanent set.

ELECTRIC BRAZING: A group of brazing processes in which the heat is obtained from electric current.

ELECTRODE:

ATOMIC HYDROGEN WELDING: One of two tungsten rods through which current is conducted between the electrode holder and the arc.

CARBON ARC WELDING: A carbon or graphite rod through which current is conducted between the electrode holder and the arc.



1. SYMBOLS APPLY BETWEEN ABRUPT CHANGES IN DIRECTION OF JOINT OR AS DIMENSIONED (EXCEPT WHERE ALL AROUND SYMBOL IS USED)
2. TAIL OF ARROW USED FOR SPECIFICATION REFERENCE. (TAIL MAY BE OMITTED WHEN REFERENCE NOT USED)
3. ALL SPACINGS IN INCHES.

*USE OPTIONAL

Figure 177 — Resistance Welding Symbols

METAL ARC WELDING: Filler metal in the form of a wire or rod, either bare or covered, through which current is conducted between the electrode holder and the arc.

RESISTANCE WELDING: A bar, wheel, or die through which the current is conducted and the pressure applied to the work.

ELECTRODE HOLDER: A device used for mechanically holding the electrode.

ELONGATION: The amount that a metal will stretch before it is pulled apart.

FILLER ROD: A rod or wire used to supply additional metal to a weld.

FILLET WELD: A weld made in a corner, as in a lap or T-joint.

FILTER LENS: A colored glass used in goggles, helmets, and shields to exclude harmful light rays.

FLAME BORING: A flame machining process which combines flame drilling with flame turning to produce a round hole in the surface of a piece. This process is used to remove metal from the ends of steel billets in preparation for centering or piercing operations.

FLAME CLEANING: A process of dehydrating and removing scale and foreign matter from surfaces preparatory to painting, by passing oxyacetylene flames rapidly over the surface.

FLAME CUTTING PROCESS: See CUTTING PROCESS.

FLAME DRILLING: A flame machining process in which to drill or punch holes in metal, a flame machining tip or oxygen lance is moved axially (in the same direction as that of the stream of oxygen from the tip). This process also serves to remove countersunk rivets or long bolts frozen in place without scoring the sidewalls of the hole.

FLAME GROOVING: A flame machining process in which a hand- or machine-guided torch is used to produce U-shaped grooves in steel surfaces. This process will remove rivet heads, defective welds, and surface defects, will cut fillets, and will prepare plate edges for welding. The deep narrow grooves produced by this process can be easily welded where this is required.

FLAME MACHINING PROCESS: The process of controlled removal of metal by surface oxidation to develop a desired surface contour. It differs from oxygen cutting in that it is not used to cut or sever pieces of metal but to process or shape metal surfaces. In some cases, flame machining is combined with flame cutting operations to develop a desired surface contour or shape.

FLAME MACHINING TIP: A gas torch tip especially designed for flame machining.

FLAME PLANING: A flame machining process used to remove surface defects from steel plates, billets, and other steel sections by means of wide and relatively shallow surface cuts. The flame-planed surface is either machined further or hot-rolled to the desired finished dimensions.

FLAME TURNING: A flame machining process in which a flame machining tip is used to remove metal in shallow layers from a rotating piece. By also feeding the torch along the rotating surface at various speeds, a single deep groove, a thread-like spiral, or the entire surface can be removed satisfactorily.

FLASHBACK: The disappearance of the flame from the end of the welding tip into or back of the mixing chamber of the torch. This differs from a backfire in that the flame continues to burn inside the torch without popping back out to the end of the tip, and the burning is generally accompanied by a squealing noise.

FLASH-BUTT WELDING: A resistance butt-welding process in which the potential (voltage) and current are applied before the parts to be welded are brought in contact. The heat for welding is obtained mainly from a series of arcs between the parts to be welded. The parts are pushed or drawn together when the welding temperature is reached.

FLAT POSITION WELDING (DOWNHAND): A welding position in which the plates to be welded are in the horizontal plane and the weld is made on the top side of the plates.

FLUX: A chemical powder or paste used to dissolve oxides, clean the metal of undesirable inclusions, and prevent oxidation of the molten metal during welding or brazing operations.

FOREHAND WELDING: A method of gas welding in which the flame is directed toward the base metal ahead of the finished weld.

FORGE WELDING (BLACKSMITH, ROLL, HAMMER): A group of pressure welding processes in which the parts to be welded are brought to a suitable temperature by means of external heating and the weld is made by pressure or blows.

FREEHAND FLAME CUTTING: A cutting process in which the operator both holds and guides the hand cutting torch.

FREEHAND GUIDED FLAME CUTTING: A cutting process in which the operator holds the torch while guiding it along the line of cut by some mechanical means. These guides may be a straight edge or bar for cutting straight lines, a radius rod with pivot for cutting circles, or roller attachments for cutting plate with irregular surfaces. Bevel cuts can be made with any of the above attachments or guides.

FURNACE BRAZING: A brazing process which obtains its heat from a suitable furnace. The parts to be joined are assembled with filler metal and flux in place and require only the furnace heat at brazing temperature to complete the joint.

FUSION WELDING: A group of processes in which the metals are welded together by bringing them to the molten state at the surfaces to be joined without the application of mechanical pressure or blows. Filler rod may or may not be used, depending upon the joint design and the thickness of the parts to be welded.

GAS BRAZING: A brazing process in which the heat is obtained from a gas flame.

GAS CUTTING (OXYGEN CUTTING): The process of severing or cutting ferrous metals by means of chemical action on elements in the base metal.

GAS WELDING: A nonpressure (fusion) welding process in which the welding heat is obtained from a gas flame.

GUIDED BEND TEST: A bending test in which the test piece is bent to a definite shape by means of a jig.

HAND (FACE) SHIELD: A protective device used in arc welding for shielding the face and neck, equipped with suitable filter glass lenses and designed to be held by hand.

HARDENING: The process of increasing the hardness of metals by heat treatment, cold working, or the addition of alloying elements.

HARD SURFACING (HARD FACING): The process of applying extremely hard alloys to the surface of a softer metal in order to increase its resistance to wear, abrasion, corrosion, or impact.

HEAT-AFFECTED ZONE: The portion of the base metal whose structure or properties have been changed by the heat of welding or cutting.

HELMET SHIELD: A protective device used in arc welding for shielding the face and neck, equipped with suitable filter glass lens and designed to be worn on the head.

HORIZONTAL POSITION OF WELDING: A welding position in which the plates to be welded are in the vertical plane and the welded joint is in the horizontal plane.

HYDROGEN: An inflammable, colorless, tasteless, and odorless gas, which burns with an almost invisible flame to form water. It is the lightest known substance.

INCLUDED ANGLE: The total angle formed between the bevelled edges of two plates butted together in position for the welded joint.

INDUCTION BRAZING: An electric brazing process in which the heat is obtained from the resistance to the flow of an electric current.

INFRARED: Light rays that are outside of the red end of the visible spectrum. These rays are given off by the arc of an electric arc welding process and by the oxyacetylene flame.

INTERMITTENT WELD: A weld which is not continuous but is broken by unwelded spaces in the joint.

KERF: The space from which the metal has been removed by a cutting process.

LANCE: A long steel pipe, usually ¼ inch or ⅜ inch normal pipe size, used to direct a stream of oxygen against a heated surface to cut or pierce heavy steel sections.

LAP JOINT: A type of joint formed by two overlapping plates with the edge of each plate welded to the face of the other.

LAYER: A quantity of filler metal deposited in a joint to cover completely the filler metal previously deposited. A welded joint on heavier plate may require several layers of weld metal to weld the plate completely.

LEAD WELDING (LEAD BURNING): A welding process in which both the base metal and the filler metal are lead.

MACHINE FLAME CUTTING: A flame cutting process in which the speed, angle, and direction of the cutting torch is controlled by a motor-driven variable-speed machine to produce the desired cut. One or more cutting torches, mounted on adjustable arms or brackets of the machine, can be used to duplicate accurately any shape, contour, or bevel desired.

MALLEABLE: Capable of being drawn out into sheets by hammering or by pressure of rollers.

MANDREL: An axle, spindle or arbor, usually tapered or cylindrical, forced into a piece of work having a hole in it, to support it while the work is machined or worked upon.

MANIFOLD: A header with outlets or branches to which several cylinders of gas may be connected to supply gas to a number of outlets or stations.

MANUAL WELD: A weld in which the arc or the torch motion is controlled by hand.

MELTING POINT: The temperature at which a metal changes from the solid to the liquid form.

METAL ARC BRAZING: An electric arc brazing process in which bronze, brass, or other copper alloy electrodes supply the filler metal.

METAL ARC CUTTING: The process of severing or cutting metals with the heat of the metal arc. Nonferrous metals can be cut by this process.

METAL ARC WELDING: An arc welding process in which the electrode supplies the filler metal in the weld.

MIXING CHAMBER: That part of a gas welding or cutting torch in which the gases are mixed for combustion.

NEUTRAL FLAME: A gas welding flame in which the inner cone or that portion of the flame used is neither oxidizing nor carburizing.

NITRIDE: A compound of nitrogen with another element, as boron, silicon, and many metals, injurious to metal.

NONFERROUS: Metals containing no ferrite or iron. Copper, brass, bronze, aluminum, and lead are examples of nonferrous metals.

NOZZLE: See WELDING AND CUTTING TIP.

OVERHEAD POSITION OF WELDING: A welding position in which the plates to be welded are in a horizontal plane and the weld is made on the bottom side of the plates.

OVERLAP: A defect in the welded joint in which an excess of weld metal extends beyond the zone of fusion.

OXIDE: A compound of oxygen with another element or substance. Rust and mill scale are examples of oxides.

OXIDIZING FLAME: A gas welding flame in which the inner cone or that portion of the flame used, produces an oxidizing effect or has an excess of oxygen for balanced combustion.

OXYACETYLENE WELDING: A gas welding process which depends upon the combustion of oxygen and acetylene for the welding heat.

OXYGEN: A tasteless, colorless, and odorless gas which supports combustion. It forms about 23 percent by weight and 21 percent by volume of the atmosphere and is the most abundant of all the elements in the earth's surface.

OXY-OTHER FUEL GAS WELDING: A gas welding process in which the welding heat is obtained from the combustion of oxygen and any fuel gas other than acetylene. Some of these fuel gases are hydrogen, propane, city gas, and natural gas.

PASS: The weld metal deposited by one general welding progression along the joint to be welded. Several passes may be necessary to complete a layer of weld metal, as in arc welding.

PEENING: Mechanical working or stretching of a cold metal surface by means of hammer blows.

PENETRATION: The depth of fusion obtained in a welded joint. It is the distance from the original surface of the base metal to that point at which fusion ceases.

PLAIN THERMIT: A mixture of iron oxide and finely divided aluminum.

PLASTIC: Capable of being molded in solid form by outside force, retaining that form after outside force is removed.

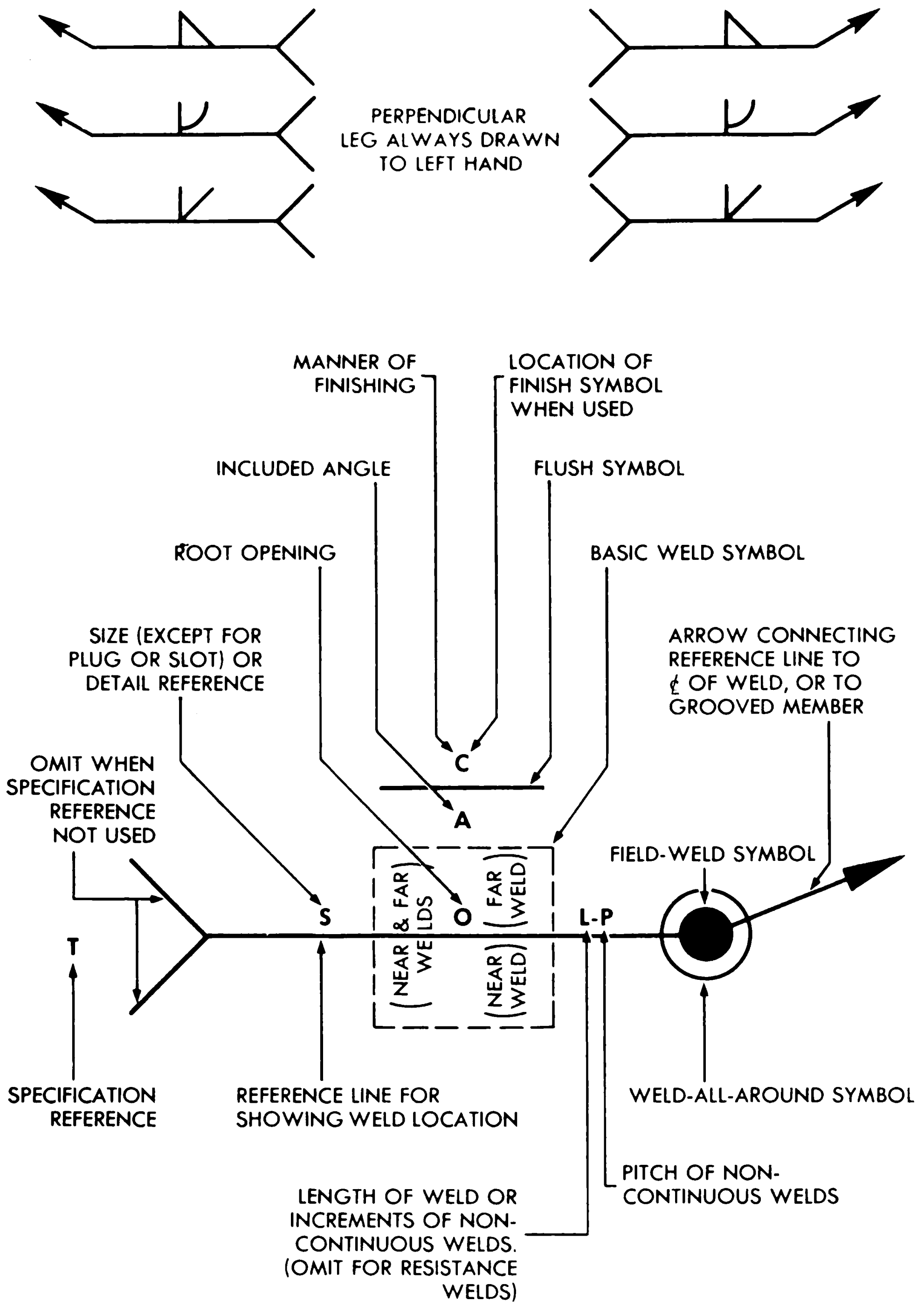
PLUG WELD: A type of weld used to join two overlapping plates. The upper plate is welded through a hole in its surface to the lower plate.

POROSITY: The presence of gas pockets or inclusions in weld metal.

POSTHEATING: Heat applied after welding or cutting operations are completed.

PREHEATING: Heat applied before welding or cutting operations are started.

PRESSURE THERMIT WELDING: A pressure welding process in which the heat for welding is obtained from the liquid products (molten metal and slag) of a thermit reaction and the weld is made by pressure.



NOTE:

RELATIVE POSITION OF DATA AND SYMBOLS SHOWN; NEAR AND FAR SIGNIFICANCE AS GIVEN IN INSTRUCTIONS, AND ILLUSTRATIONS

RA PD 71135

Figure 178 — Use of Welding Symbols

PRESSURE WELDING PROCESS: A group of welding processes which require pressure to complete the weld.

PROJECTION WELDING: A resistance welding process in which the heat for welding is localized between the ends of one part and the surface of another, by means of projections.

REDUCING FLAME: A gas welding flame in which the inner cone or that portion of the flame used has a reducing or deoxidizing effect (i.e., is capable of removing oxygen).

REINFORCEMENT OF WELD: Excess weld metal added to strengthen a welded joint.

RESISTANCE BRAZING: An electric brazing process in which the heat is obtained from the resistance to the flow of an electric current.

RESISTANCE WELDING: A pressure welding process in which the heat for welding is obtained from the resistance to the flow of an electric current.

REVERSED POLARITY (ELECTRODE POSITIVE): The arrangement of direct current arc welding leads so that the work is the negative pole and the electrode is the positive pole in the arc circuit.

ROOT OF WELD: That portion of the weld metal deposited at the bottom of the welded joint.

ROUGH-FLAME MACHINING: A flame machining process in which a hand- or machine-guided torch is used to remove large quantities of excess metal in preparation for finish machining with machine tools.

SCARF: Bevel or chamfer.

SEAM WELDING: A resistance welding process in which a row of spot welds is made progressively along the seam of two overlapping sheets. These spot welds may either be adjacent to each other or overlap to make a continuous weld.

SHAPE CUTTING: A flame cutting process in which the cutting torch is guided by hand or machine to cut irregular shapes from steel plates.

SHIELDED METAL ARC WELDING: A metal arc welding process in which the arc and weld metal are protected from the atmosphere by a shielding gas given off during welding by an electrode coating or flux.

SILVER ALLOY BRAZING (SILVER SOLDERING): A low temperature brazing process in which a silver alloy is used as filler metal.

SLAG: Excess foreign matter which floats on molten metal and acts to protect the weld metal as well as clean it of impurities.

AG INCLUSION: Nonmetallic material entrapped in a weld.

SLOT WELD: A type of weld used to join two overlapping plates. The upper plate is welded through a slot in its surface to the lower plate.

SOLDERING: A process for joining metals by alloys that are fusible and are applied at temperatures below 1000 F.

SPOT WELDING: A pressure welding process in which the fusion is confined to a relatively small portion of the area of the lapped parts to be joined. The heat for this process is obtained from the resistance to the flow of electric current in the parts being welded. Pressure is applied by copper electrodes to complete the weld.

STACK CUTTING: A flame cutting process in which several thin steel sheets or plates are clamped together and cut in one operation.

STRAIGHT POLARITY: The arrangement of direct-current arc welding leads so that the work is the positive pole and the electrode is the negative pole of the arc current.

STRESS: The intensity of forces acting on or within a body to produce tension, compression, or shear. When present in welded joints they are known as residual stresses due to welding.

STRESS-RELIEF HEAT TREATMENT: Uniform heating of a structure to a certain temperature below the critical range, followed by a uniform cooling, to relieve or remove a major portion of the residual stresses.

SURFACING: A process of building up metal surfaces with the choice of surfacing metal depending upon the properties desired.

TACK WELD: A short weld used to hold assembled pieces in place for welding. By this method of preparation for welding, a desired shape in the welded piece can be maintained.

THERMIT WELDING: A nonpressure (fusion) welding process for which the heat is obtained from highly superheated liquid steel produced by chemical reaction between iron oxide and aluminum. This steel acts as a filler metal, and the aluminum oxide formed is removed as slag.

T-JOINT: A weld made at the joint of two plates located at an angle of approximately 90 degrees to each other.

TOE OF WELD: That portion of the weld located at the intersection of the filler metal and base metal on the surface of the weld.

TUYERE: A nozzle through which the air blast is delivered to a forge, blast furnace, etc.

ULTRAVIOLET: Light rays outside the visible spectrum at its violet end. These rays are given off by the arc of an electric arc welding process and by the oxyacetylene flame.

UNAFFECTED ZONE: That portion of the base metal which is outside of the heat-affected zone and in which no change in physical properties such as strength, hardness, or ductility has taken place as a result of welding.

UNDERCUT: A defect produced in welding in which a portion of the base metal is melted away without the addition of filler metal. This causes a decrease in the thickness of the base metal at this point and therefore weakens the structure.

UNSHIELDED CARBON ARC WELDING: A carbon arc welding process in which no gas or other shielding medium is present.

UNSHIELDED METAL ARC WELDING: A metal arc welding process in which no gas or other shielding medium is present.

UPSET-BUTT WELDING: A resistance butt welding process in which the potential (voltage) and current are applied after the parts to be welded are brought in contact. The heat for welding is obtained mainly from the resistance offered to the flow of current by the metal parts at the joint.

VERTICAL POSITION OF WELDING: A welding position in which the plates to be welded as well as the joint are in the vertical plane.

VOLATILE: Readily changed to a vapor.

WEAVING: A method of depositing metal in which the electrode is oscillated, that is, moved from side to side.

WELD: A joint made by a welding process in which two or more metal parts are heated to melting and form one solid piece when they solidify.

WELD METAL: The metal in the joint which has been melted in making the weld, including both the added and base metal.

WELDING GROUND: The side of the circuit opposite the welding electrode in electric arc welding.

WELDING LEADS: Electrical conductors, usually insulated cables, used to furnish an electrical path between the generator or other source of electrical power and the electrodes.

WELDING ROD: Filler metal in wire or rod form, used in the gas welding process and in those arc welding processes in which the electrode does not furnish the filler metal.

WELDING TIP: A gas torch tip especially designed for welding.

WELDING TORCH OR BLOWPIPE: An apparatus used in gas welding for mixing and controlling the gases.

WELDMENT: An assembly, the component parts of which are joined by welding.

DATA

282. MELTING POINTS OF METALS AND ALLOYS.

Metal or Alloy	Melting Point
Aluminum, pure	1,220 F
Aluminum, 5 percent silicon	1,118 F
Brass, yellow	1,625/1,675 F
Bronze, manganese	1,600 F
Bronze, naval	1,625 F
Bronze, phosphor	1,830/1,922 F
Bronze, silicon	1,625 F
Bronze, tobin	1,625 F
Chromium	2,740 F
Copper	1,981 F
Hard-facing metals	2,000/2,400 F
Iron, cast	2,200/2,500 F
Iron, malleable	2,300 F
Iron, pure	2,786 F
Iron, wrought	2,750 F
Lead	621 F
Manganese	2,246 F
Molybdenum	4,532 F
Monel metal	2,425/2,480 F
Nickel	2,650 F
Nickel silver (18 percent nickel)	1,955 F
Phos-copper	1,475 F
Silver, pure	1,762 F
Sil-fos	1,300 F
Silver solders	1,175/1,500 F
Solder, 50-50	437 F
Steel, hard (0.40-0.70 percent C.)	2,500/2,550 F
Steel, low carbon (less than 0.15 percent C.)	2,700/2,750 F
Steel, med. carbon (0.15-40 percent C.)	2,600 F
Steel, manganese	2,450 F
Steel, cast	2,600/2,750 F
Steel, nickel (3.5 percent Ni.)	2,600 F
Stainless steel, low C. (18-8)	2,640 F
Tin	450 F
Tungsten	6,152 F
Vanadium	3,182 F
White metal	430/490 F
Zinc	786 F

283. TEMPERATURES FOR PROCESSING METALS.

Process	Temperature Range
Soft soldering	300 to 700 F
Silver soldering (low-temperature brazing)	1,175 to 1,600 F
Case-hardening	1,600 to 1,725 F
Bronze welding (high-temperature brazing)	1,600 to 1,800 F
Forging	1,700 to 2,150 F
Fusion welding	1,800 to 2,700 F
Forge welding	2,500 F
Hardening	
Carbon steel	1,350 to 1,550 F
Alloy steel	1,400 to 1,850 F
High-speed steel	2,150 to 2,400 F
Tempering	
Carbon steel	300 to 1,050 F
Alloy steel	300 to 1,300 F
High-speed steel	350 to 1,100 F

284. COMBUSTION CONSTANTS OF FUEL GASES.

Name of Gas	Heat Value BTU Per Cu Ft	Flame Temp. with Oxygen
Acetylene	1,433 net	6,300 F
Hydrogen	275.1 net	5,400 F
City gas	300 to 800 net	4,600 F
Natural gas	800 to 1,200 net	4,600 F
Coke oven gas	500 to 550 net	4,600 F
Methane	913.8 net	5,000 F
Ethane	1,631 net	5,100 F
Propane	2,309 net	5,300 F
Butane	2,999 net	5,300 F
Ethylene	1,530 net	5,100 F

285. TEMPER AND HEAT COLORS.

a. Temper Colors:

Color	Temperature	Uses
Faint straw	400 F	
Straw	440 F	Scrapers, hammer faces, lathe, shaper and planer tools
Dark straw	460 F	Milling cutters, taps and dies
Very deep straw	480 F	Punches and dies, knives and reamers
Brown yellow	500 F	Stone cutting tools, twist drills
Bronze or brown purple	520 F	Drift pins
Peacock or full purple	540 F	Augers, cold chisels for steel
Bluish purple	550 F	Axes, cold chisels for iron, screwdrivers, springs
Blue	570 F	Saws for wood
Full blue	590 F	
Very dark blue	600 F	
Light blue	640 F	

b. Heat Colors in Moderate Diffused Light with Approximate Temperatures:

Color	Temperature
White	2,200 F
Light yellow	1,975 F
Lemon	1,825 F
Orange	1,725 F
Salmon	1,650 F
Bright red	1,550 F
Bright cherry or dull red	1,450 F
Cherry or full red	1,375 F
Medium cherry	1,250 F
Dark cherry	1,175 F
Blood red	1,050 F
Faint red	900 F
Faint red (visible in dark)	750 F

286. UNITED STATES STANDARD GAGE FOR SHEET AND PLATE.

No. of Gage	Thickness in Fractions of an Inch	Thickness in Decimal Part of an Inch
0000000	1/2	0.5000
000000	15/32	0.4687
00000	7/16	0.4375
0000	13/32	0.4062
000	3/8	0.3750
00	11/32	0.3437
0	5/16	0.3125
1	9/32	0.2812
2	17/64	0.2656
3	1/4	0.2500
4	15/64	0.2344
5	7/32	0.2187
6	13/64	0.2031
7	3/16	0.1875
8	11/64	0.1719
9	5/32	0.1562
10	9/64	0.1406
11	1/8	0.1250
12	7/64	0.1093
13	3/32	0.0937
14	5/64	0.0781
15	9/128	0.0703
16	1/16	0.0625
17	9/160	0.0562
18	1/20	0.0500
19	7/160	0.0437
20	3/80	0.0375
21	11/320	0.0344
22	1/32	0.0312
23	9/320	0.0281
24	1/40	0.0250
25	7/320	0.0219
26	3/160	0.0187
27	11/640	0.0172
28	1/64	0.0156
29	9/640	0.0140
30	1/80	0.0125
31	7/640	0.0109

DATA

No. of Gage	Thickness in Fractions of an Inch	Thickness in Decimal Part of an Inch
32	13/1280	0.0101
33	3/320	0.0094
34	11/1280	0.0086
35	5/640	0.0078
36	9/1280	0.0070
37	17/2560	0.0066
38	1/160	0.0062

287. DECIMAL EQUIVALENTS OF FRACTIONS OF AN INCH.

Inch Fraction	Decimal Equivalent	Inch Fraction	Decimal Equivalent
1/64	0.015625	33/64	0.515625
1/32	0.03125	17/32	0.53125
3/64	0.046875	35/64	0.546875
1/16	0.0625	9/16	0.5625
5/64	0.078125	37/64	0.578125
3/32	0.09375	19/32	0.59375
7/64	0.109375	39/64	0.609375
1/8	0.125	5/8	0.625
9/64	0.140625	41/64	0.640625
5/32	0.15625	21/32	0.65625
11/64	0.171875	43/64	0.671875
3/16	0.1875	11/16	0.6875
13/64	0.203125	45/64	0.703125
7/32	0.21875	23/32	0.71875
15/64	0.234375	47/64	0.734375
1/4	0.25	3/4	0.75
17/64	0.265625	49/64	0.765625
9/32	0.28125	25/32	0.78125
19/64	0.296875	51/64	0.796875
5/16	0.3125	13/16	0.8125
21/64	0.328125	53/64	0.828125
11/32	0.34375	27/32	0.84375
23/64	0.359375	55/64	0.859375
3/8	0.375	7/8	0.875
25/64	0.390625	57/64	0.890625
13/32	0.40625	29/32	0.90625
27/64	0.421895	59/64	0.921875
7/16	0.4375	15/16	0.9375
29/64	0.453125	61/64	0.953125
15/32	0.46875	31/32	0.96875
31/64	0.484375	63/64	0.984375
1/2	0.5	1	1.0

288. PROCEDURE GUIDE FOR OXYACETYLENE WELDING.

BASE METAL OR ALLOY	Welding Process	Flame Adjustment	Welding Rod	Flux Required	Preheating Required
Iron					
1. Wrought iron	F.W.	Neutral	Low-carbon or high strength steel	No	No
	B.W.	Sl. oxidizing	Bronze	Brazing	No
2. Low-carbon iron	F.W.	Neutral	Low-carbon	No	No
	B.W.	Sl. oxidizing	Bronze	Brazing	No
Carbon Steels					
1. Low-carbon (Up to 0.30% C)	F.W.	Neutral	Low-carbon	No	No
	B.W.	Sl. oxidizing	Bronze	Brazing	No
2. Medium-carbon (0.30% to 0.50% C)	F.W.	Neutral to Sl. carburizing	Low-carbon or high strength steel	No	300 to 500 F
	B.W.	Sl. oxidizing	Bronze	Brazing	200 to 400 F
3. High-carbon (0.50% to 0.90% C)	F.W.	Carburizing	High-carbon	No	500 to 800 F
	B.W.	Sl. oxidizing	Bronze	Brazing	300 to 500 F
4. Tool steel (0.80% to 1.50% C)	F.W.	Carburizing	Drill rod	Some C.I. flux	Up to 1,000 F
	B.W.	Sl. oxidizing	Bronze	Brazing	500 to 600 F
Cast Steels					
1. Plain carbon (Up to 0.25% C)	F.W.	Neutral	Low-carbon	No	200 F
	B.W.	Sl. oxidizing	Bronze	Brazing	200 F
2. High manganese (12% Mn.)	F.W.	Sl. carburizing	Nickel mang. steel	Wrap rod with al. wire	No
	B.W.	Sl. oxidizing	Bronze	Brazing	No
3. Other alloys	F.W.	Neutral to Sl. carburizing	Same as base metal	No	In some cases
	B.W.	Sl. oxidizing	Bronze	Brazing	In some cases
Cast Irons					
1. Gray cast iron	F.W.	Neutral	Cast iron	Cast iron flux	700 to 800 F
	B.W.	Sl. oxidizing	Bronze	Brazing	Locally to 500 F
2. Malleable iron	F.W.(a)	Neutral	White cast iron	Cast iron flux	700 to 800 F
	B.W.*	Sl. oxidizing	Bronze	Brazing	Locally to 500 F
3. Alloy cast irons	F.W.	Neutral	Same as base Metal, or cast iron	Cast iron flux	500 to 1,000 F
	B.W.	Sl. oxidizing	Bronze	Brazing	Locally to 500 F
Low-alloy High-tensile Steels					
(General)	F.W.	Neutral to sl. carburizing	Same as base metal, or high strength steel	No	Yes
1. Nickel alloy steel (3-3½% Ni) (Up to 0.25% C)	F.W.	Neutral to sl. carburizing	Same as base metal, or high strength steel	No	No preheating Slow cool
(More than 0.25% C)	F.W.	Neutral to sl. carburizing	Same as base metal, or high strength steel	No	300 to 600 F Slow cool

DATA

BASE METAL OR ALLOY	Welding Process	Flame Adjustment	Welding Rod	Flux Required	Preheating Required
Low-alloy High-tensile Steels—Cont'd					
2. Nickel-copper alloy steels	F.W.	Neutral to sl. carburizing	Same as base metal, or high strength steel	No	250 to 300 F
3. Manganese-molybdenum alloy steels	F.W.	Neutral to sl. carburizing	Same as base metal, or high strength steel	No	250 to 300 F
4. Carbon-molybdenum alloy steels (0.10% to 0.20% C)	F.W.	Neutral to sl. carburizing	Carbon molybdenum or high strength rod	No	300 to 400 F
(0.20% to 0.30% C)	F.W.	Neutral to sl. carburizing	Carbon molybdenum or high strength rod	No	400 to 500 F Slow cool
5. Nickel-chromium alloy steels (Up to 0.20% C)	F.W.	Neutral to sl. carburizing	Same as base metal, or high strength rod	No	200 to 300 F Slow cool
(0.20% to 0.55% C)	F.W.	Neutral to sl. carburizing	Same as base metal, or high strength rod	No	600 to 800 F Slow cool
(High alloy content)	F.W.	Neutral to sl. carburizing	Same as base metal, or high strength rod	No	900 to 1,100 F Slow cool
6. Chrome-molybdenum alloy steels	F.W.	Neutral to sl. carburizing	Same as base metal, or high strength rod	No	300 to 800 F Slow cool
7. Chromium alloy steels	F.W.	Neutral to sl. carburizing	Same as base metal, or high strength rod	No	300 to 800 F
8. Chromium-vanadium alloy steels	F.W.	Neutral to sl. carburizing	Same as base metal, or high strength rod	No	200 to 800 F
9. Manganese alloy steels (1.6% - 1.9% Mn)	F.W.	Neutral to sl. carburizing	Same as base metal, or high strength rod	No	300 to 800 F
Stainless Steels					
1. Chromium alloys (12% - 28% Cr) (Stainless irons)	F.W.	Neutral	Same as base metal, or (18-8) stainless	Stainless	No
2. Chromium nickel alloys	F.W.	Neutral to sl. carburizing	(18-8) stainless steels	Stainless	No
Copper and Copper Alloys					
1. Deoxidized copper	F.W.	Neutral	Deoxidized copper	No	500 to 800 F
	B.W.	Sl. oxidizing	Bronze	Brazing	400 to 600 F
2. Commercial bronze and low brass	F.W.	Oxidizing	Same as base metal	Brazing	200 to 300 F
	B.W.	Sl. oxidizing	Bronze	Brazing	200 to 300 F
3. Spring, admiralty, and yellow brass	F.W.	Oxidizing	Same as base metal, or bronze	Brazing	200 to 300 F
4. Muntz metal, Tobin bronze, naval brass, manganese bronze	F.W.	Oxidizing	Bronze	Brazing	200 to 300 F
5. Nickel silver	F.W.	Neutral	Nickel silver	Brazing	200 to 300 F
6. Phosphor bronze	F.W.	Neutral	Bronze	Brazing	300 to 500 F
	B.W.	Neutral or sl. oxidizing	Bronze	Brazing	200 to 300 F
7. Aluminum bronze	F.W.	Sl. carburizing	Aluminum bronze	Brazing	200 to 300 F
8. Beryllium copper	Oxyacetylene welding or brazing not recommended; use silver solder and flux.				

BASE METAL OR ALLOY	Welding Process	Flame Adjustment	Welding Rod	Flux Required	Preheating Required
Aluminum and Aluminum Alloys					
1. Pure aluminum (2S)	F.W.	Neutral	Pure aluminum	Aluminum	500 to 800 F
2. Aluminum alloys (General)	F.W.	Neutral	Same as base metal, or 95% aluminum, 5% silicon rod	Aluminum	500 to 800 F
3. Aluminum-manganese alloy (3S)	F.W.	Neutral	Pure aluminum	Aluminum	500 to 800 F
4. Aluminum-magnesium-chromium alloy (52S)	F.W.	Neutral	95% aluminum-5% silicon rod	Aluminum	500 to 800 F
5. Aluminum-magnesium manganese alloy (4S)	F.W.	Neutral	95% aluminum-5% silicon rod	Aluminum	500 to 800 F
6. Aluminum-silicon-magnesium alloy (51S) (53S)	F.W.[b]	Neutral	95% aluminum-5% silicon rod	Aluminum	Up to 400 F
7. Aluminum-copper-magnesium-manganese alloy (duraluminum) (17S) (24S)		Welding not recommended.			
8. Aluminum clad		Welding not recommended.			
Nickel and Nickel Alloys					
1. Nickel	F.W. B.W.	Carburizing Sl. oxidizing	Nickel Bronze	No Brazing	200 to 300 F 200 to 300 F
2. Monel (67% Ni-29% Cu)	F.W. B.W.	Carburizing Sl. oxidizing	Monel Bronze	Brazing Brazing	200 to 300 F 200 to 300 F
3. Inconel (79% Ni-13% Cr-6% Fe)	F.W. B.W.	Carburizing Sl. oxidizing	Inconel Bronze	Brazing Brazing	200 to 300 F 200 to 300 F
Lead	F.W.	Neutral to sl. carburizing	Lead	Soldering acid	No
Magnesium Alloys[c]	F.W.	Sl. carburizing	Same as base metal	Special flux	500 to 600 F
White Metal	F.W.	Carburizing	White metal	No	No

KEY

* Preferred method.

[a] Welded as white cast iron only and should be followed by treatment for malleability. Fusion welding is not recommended for malleable iron.

[b] Heat-treat (51S) and (53S) after welding. Properties of (17S) and (24S) alloys cannot be restored by heat treatment after welding.

[c] Welding is not recommended on some magnesium alloys.

F.W. — Fusion Welding.

B.W. — Bronze Welding.

In general, in welding low-alloy high-tensile steels, it is recommended that the filler metal used should be of the same composition as the base metal to obtain good corrosion resistance at the welded joint.

In welding low-alloy high-tensile steels in the heat-treated condition, it is recommended that the filler metal used should be of the austenitic type, such as the 18 percent chromium-8 percent nickel stainless steel welding rod.

In all cases where the low-alloy high-tensile steels are to be heat-treated after welding, the filler metals used should be of the same composition as the base metal or other suitable high-strength welding rod.

289. PROCEDURE GUIDE FOR ELECTRIC ARC WELDING.

BASE METAL OR ALLOY	Welding Process	Polarity	WELDING ELECTRODE		Preheating Required
			Material	Type	
Iron					
1. Wrought iron	M.A.W.	Reverse	Mild steel	*Shielded arc	No
	C.A.W.	Straight	Mild steel	Use a flux	No
	M.A.B.	Reverse	Bronze	Shielded arc	No
2. Low-carbon iron	M.A.W.	Reverse	Mild steel	Shielded arc	No
Carbon Steels					
1. Low-carbon (Up to 0.30% C)	M.A.W.	Straight	Mild steel	Bare or light coated	Up to 300 F
	M.A.W.	Reverse	Mild steel	Shielded arc	Up to 300 F
	C.A.W.	Straight	Mild steel	Use a flux	Up to 300 F
	M.A.B.	Reverse	Bronze	Shielded arc	Up to 300 F
2. Medium-carbon (0.30% to 0.50% C)	M.A.W.	Reverse	25-20 or modified 18-8 stainless steel	Shielded arc	
	M.A.W.	Reverse	Mild steel or high strength	Shielded arc	300 to 500 F
3. High-carbon (0.50% to 0.90% C)	M.A.W.(a)	Reverse	25-20 or modified 18-8 stainless steel	Shielded arc	
	M.A.W.	Reverse	Mild steel or high strength	Shielded arc	500 to 800 F
4. Tool steel (0.80% to 1.50% C)	M.A.W.	Reverse	25-20 or modified 18-8 stainless steel	Shielded arc	Up to 800 F
	M.A.W.	Reverse	Mild steel or high strength	Shielded arc	Up to 1,000 F
Cast Steels					
1. Plain carbon	M.A.W.	Reverse	Mild steel	Shielded arc	200 F
(Up to 0.25% C)	M.A.B.	Reverse	Bronze	Shielded arc	200 F
2. High manganese (12% Mn)	M.A.W.	Reverse	Weld with 25-20 stainless steel and surface with nickel manganese	Shielded arc	No
	To build up sections	Reverse	Nickel manganese	Shielded arc	No preheating Quench and peen-weld
3. Other alloys	M.A.W.	Reverse	Mild steel	Shielded arc	In some cases
Cast Irons					
1. Gray cast iron (Machinable welds)	M.A.W.	Reverse	Monel, 18-8 stainless steel, or mild steel	Shielded arc	700 to 800 F or no preheating but peen-weld
(Nonmachinable welds)	M.A.W.	Straight	Cast iron	Shielded arc	700 to 800 F
	M.A.B.	Reverse	Bronze	Shielded arc	Up to 500 F
	C.A.B.	Straight	Bronze	Shielded arc	Up to 500 F

BASE METAL OR ALLOY	Welding Process	Polarity	WELDING ELECTRODE		Preheating Required
			Material	Type	
Cast Irons (Cont'd)					
2. Malleable iron					
(Machinable welds)	M.A.W.	Reverse	Monel, 18-8 stainless steel, or mild steel	Shielded arc	700 to 800 F Anneal weld
(Nonmachinable welds)	M.A.W.	Straight	Cast iron	Shielded arc	700 to 800 F
	M.A.B.	Reverse	Bronze	Shielded arc	Up to 500 F
	C.A.B.	Straight	Bronze	Shielded arc	Up to 500 F
3. Alloy cast irons		(Same as gray cast iron.)			
Low-Alloy High-Tensile Steels					
General	M.A.W.(b)	Reverse	Same as base metal; or high strength or mild steel, or 25-20 stainless steel	Shielded arc	Yes
1. Nickel alloy steel (3 - 3½% Ni) (Up to 0.25% C)	M.A.W.	Reverse	Nickel alloy or 25-20 stainless steel	Shielded arc	No preheating Slow cool
(More than 0.25% C)	M.A.W.	Reverse	Nickel alloy or 25-20 stainless steel	Shielded arc	300 to 600 F
2. Nickel copper alloy steels	M.A.W.	Reverse	Nickel alloy or 25-20 stainless steel	Shielded arc	250 to 300 F
3. Manganese molybdenum alloy steels	M.A.W.	Reverse	Carbon molybdenum or special electrode	Shielded arc	250 to 300 F
4. Carbon molybdenum alloy steels (0.10% to 0.20% C)	M.A.W.	Straight or reverse	Carbon molybdenum	Shielded arc	300 to 400 F
(0.20% to 0.30% C)	M.A.W.	Straight or reverse	Carbon molybdenum	Shielded arc	400 to 500 F Slow cool
5. Nickel chromium alloy steels (1% - 3½% Ni) (Up to 0.20% C)	M.A.W.	Reverse	Same as base metal, or 25-20 stainless steel	Shielded arc	200 to 300 F Slow cool
(0.20% to 0.55% C)	M.A.W.	Reverse	Same as base metal, or 25-20 stainless steel	Shielded arc	600 to 800 F
(High alloy content)	M.A.W.	Reverse	Same as base metal, or 25-20 stainless steel	Shielded arc	900 to 1,000 F Slow cool
6. Chrome-molybdenum alloy steels	M.A.W.	Straight or reverse	Chrome molybdenum or carbon molybdenum	Shielded arc	300 to 800 F Slow cool
	C.A.W.	Straight	Same as base metal	Use a flux	300 to 800 F Slow cool
7. Chromium alloy steels	M.A.W.	Reverse	Same as base metal, or 25-20 or 18-8 stainless steel	Shielded arc	300 to 800 F
8. Chromium vanadium alloy steels	M.A.W.	Reverse	Chrome molybdenum or carbon molybdenum	Shielded arc	200 to 800 F
9. Manganese alloy steels (1.6%-1.9% Mn)	M.A.W.	Reverse	Carbon molybdenum or mild steel	Shielded arc	300 to 800 F

DATA

BASE METAL OR ALLOY	Welding Process	Polarity	WELDING ELECTRODE		Preheating Required
			Material	Type	
Stainless Steels					
1. Chromium alloys (12%-28% Cr) (Stainless irons)	M.A.W.	Reverse	25-20 or columbium-bearing 18-8 stainless steel	Shielded arc	No
2. Chromium-nickel alloys	M.A.W.	Reverse	25-20 or columbium-bearing 18-8 stainless steel	Shielded arc	No
Copper and Copper Alloys					
1. Deoxidized copper	M.A.W.	Reverse	Deoxidized copper, phosphor bronze, or silicon copper	Shielded arc	500 to 800 F
	C.A.W.	Straight	Deoxidized copper, phosphor bronze, or silicon copper	Shielded arc	500 to 800 F
2. Commercial bronze and low brass	M.A.W.	Reverse	Phosphor bronze or silicon copper	Shielded arc	200 to 300 F
	C.A.W.	Straight	Phosphor bronze or silicon copper	Use a flux	200 to 300 F
3. Spring, admiralty, and yellow brass	C.A.W.	Straight	Phosphor bronze	Use a flux	200 to 300 F
4. Muntz metal, Tobin bronze, naval bronze, manganese bronze	C.A.W.	Straight	Phosphor bronze	Use a flux	200 to 300 F
5. Nickel silver	M.A.W. C.A.B.	Reverse Straight	High nickel alloy, phosphor bronze, or silicon copper	Shielded arc Use a flux	300 to 500 F 300 to 500 F
6. Phosphor bronze	M.A.W. C.A.W.	Reverse Straight	Phosphor bronze Phosphor bronze	Shielded arc Use a flux	200 to 300 F 200 to 300 F
7. Aluminum bronze	M.A.W.	Reverse	Aluminum bronze or phosphor bronze	Shielded arc	200 to 300 F
	C.A.W.	Straight	Aluminum bronze or phosphor bronze	Use of flux (Optional)	200 to 300 F
8. Beryllium copper	C.A.W.	Straight	Beryllium copper	Use of flux (Optional)	500 to 800 F
Aluminum and Aluminum Alloys					
1. Pure aluminum (2S)	M.A.W.	Reverse	Pure aluminum or 95% aluminum-5% silicon electrode	Shielded arc	500 to 800 F
	C.A.W.	Straight	Pure aluminum or 95% aluminum-5% silicon electrode	Flux-coated	500 to 800 F
2. Aluminum alloys (General)	M.A.W.	Reverse	95% aluminum-5% silicon electrode	Shielded arc	500 to 800 F
	C.A.W.	Straight	95% aluminum-5% silicon electrode	Flux-coated	500 to 800 F
3. Aluminum manganese alloy (3S)	M.A.W.	Reverse	95% aluminum-5% silicon electrode	Shielded arc	500 to 800 F
	C.A.W.	Straight	95% aluminum-5% silicon electrode	Flux-coated	500 to 800 F

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BASE METAL OR ALLOY	Welding Process	Polarity	WELDING ELECTRODE		Preheating Required
			Material	Type	
Aluminum and Aluminum Alloys (Cont'd)					
4. Aluminum-magnesium-chromium alloy (52S)	M.A.W.	Reverse	95% aluminum-5% silicon electrode	Shielded arc	500 to 800 F
	C.A.W.	Straight	95% aluminum-5% silicon electrode	Flux-coated	500 to 800 F
5. Aluminum magnesium manganese alloy (4S)	M.A.W.	Reverse	95% aluminum-5% silicon electrode	Shielded arc	500 to 800 F
	C.A.W.	Straight	95% aluminum-5% silicon electrode	Flux-coated	500 to 800 F
6. Aluminum-silicon-magnesium alloys	M.A.W.	Reverse	95% aluminum-5% silicon electrode	Shielded arc	Up to 400 F
(51S) (53S)	C.A.W.	Straight	95% aluminum-5% silicon electrode	Flux-coated	Up to 400 F
7. Aluminum-copper-magnesium-manganese alloys Duraluminum (17S) (24S)		Arc welding not recommended.			
8. Aluminum clad		Arc welding not recommended.			
Nickel and Nickel Alloys					
1. Nickel	M.A.W.	Reverse	Nickel	Shielded arc	200 to 300 F
	C.A.W.	Straight	Nickel	Lightly flux-coated	200 to 300 F
2. Monel (67% Ni-29% Cu)	M.A.W.	Reverse	Monel	Shielded arc	200 to 300 F
	C.A.W.	Straight	Monel	Lightly flux-coated	200 to 300 F
3. Inconel (79% Ni-13% Cr-6% Fe)	M.A.W.	Reverse	Same as base metal	Shielded arc	200 to 300 F
Lead		Lead cannot be arc-welded.			
Magnesium Alloys		Arc welding not recommended.			

KEY

*Shielded-arc electrodes are heavy-coated and usually require reverse polarity; however, manufacturer's recommendations specify the preferred polarity for special electrodes, which may differ from the polarity recommended above in some cases.

(a) Stress-relieve by heating 1,200 F to 1,450 F for 1 hour per inch of thickness and cool slowly.

(b) A large number and variety of low-alloy high-tensile steels are used in ordnance construction. In arc welding these steels, certain special precautions are required, such as preheating before welding, use of special electrodes, and a postheating treatment. In general, where good corrosion resistance is required or when the welded joint is to be heat-treated after welding, electrodes having the same composition or properties as the base metal are used. Where these steels are in the heat-treated condition, it is recommended that the filler metal used should be of the austenitic type, such as 25 percent chromium—12 percent nickel, 25 percent chromium—20 percent nickel or 18 percent chromium—8 percent nickel stainless steel, in order to obtain good weld metal properties. Some of these stainless steel electrodes have columbium or other alloying elements added to retain their properties after welding. An example of this is the so-called modified 18-8 stainless steel electrode, which contains small percentages of either manganese or molybdenum. This electrode may be used in place of the 25-20 type of electrode in any of the welding processes for which 25-20 electrodes are specified. Usually no preheating is required in welding with these electrodes.

M.A.W. — Metal arc welding C.A.W. — Carbon arc welding M.A.B — Metal arc brazing
C.A.B. — Carbon arc brazing

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THE AUTOMOTIVE PART	USUAL METAL COMPOSITION											RECOMMENDED WELDING METHOD						
	Grey Cast Iron	Malleable Iron	Cast Steel	Steel Forgings	To .40 Carbon Steel	Over .40 Carbon Steel	Alloy Steels	Aluminum	Brass, Copper or Bronze	Miscellaneous	Babbitt	Bronze-welding	Welding With Rod of Similar Composition	No. 1 H. T.	Soldering	Heating	Haynes Stellite	Welding Not Recommended
DIVISION I — CYLINDERS																		
Group 1—Cylinders																		
Cylinder block	x											x						
Cylinder head	x											x						
Water jacket covers	x											x						
Valve spring cover					x							x						
Valve stem guide	N				N					*		*						N
Group 2—Crank Case																		
Crank case (various types)	1							2				1	2					
Oil pan					x							x						
Breather					x							x						
Crankshaft bearings									1		2	1				2		
Crankshaft bearing cap			x		x							x						
Crankshaft bushing supports			x		x							x						
Handhole cover					x							x						
Timing gear cover					x							x						
Flywheel housing	1							2				1	2					
Generator bracket	x											x						
Group 3—Crankshaft																		
Crankshaft				N														N
Flywheel	x		x	x								x						
Crankshaft timing gear					N	N						N						N
Flywheel starter gear					x	x	x					x						
Crankshaft starter sprocket					x		x					x						
Crankshaft starting jaw (or pin)					x							x						
Group 4—Starting Crank																		
Starting crank jaw					x							x						
Starting crankshaft					x							x						
Starting crankshaft spring						N	N											N
Starting crank handle					x							x						
Group 5—Connecting Rods																		
Connecting rod				N			N	N										N
Connecting rod cap				N				N										N
Connecting rod bushing									1		2	1				2		
Connecting rod dipper					1			2				1	2					
Piston pin bushing						N			N									N
Group 6—Pistons and Parts																		N
DIVISION II — VALVES																		
Group 1—Camshaft																		
Camshaft					N		N					N						N
Eccentric shaft				N														N
Camshaft timing gear					x		x					x						
Camshaft idler gear					x		x					x						
Camshaft oil pump gear					x		x					x						
Camshaft ignition distributor gear					x		x					x						

THE AUTOMOTIVE PART	USUAL METAL COMPOSITION											RECOMMENDED WELDING METHOD						
	Grey Cast Iron	Malleable Iron	Cast Steel	Steel Forgings	To .40 Carbon Steel	Over .40 Carbon Steel	Alloy Steels	Aluminum	Brass, Copper or Bronze	Miscellaneous	Babbitt	Bronze-welding	Welding With Rod of Similar Composition	No. 1 H. T.	Soldering	Heating	Haynes Stellite	Welding Not Recommended
DIVISION II—VALVES—*Cont.*																		
Group 1—*Camshaft—Cont.*																		
Camshaft timer drive gear					x		x					x						
Oil pump eccentric (or cam)				N	N							N						N
Group 2—*Valves*																		
Poppet valve	N						N											N
Inlet valve	N						N											N
Exhaust valve	N						N											N
Valve spring						N	N											N
Valve spring retainer					x							x						
Valve lifter					x		x					x						
Valve lifter guide	N				N													N
Valve rocker					x		x					x						
Valve push rod					x	x						x					x	
DIVISION III — COOLING SYSTEM																		
Group 1—*Fan*																		
Fan bracket	x		x									x						
Fan spindle					x							x						
Fan hub					x							x						
Fan hub bushing (or bearing)	x								x			x						
Fan blades					x							x						
Fan pulley					x							x						
Fan driving pulley	x		x		x							x						
Group 2—*Radiator*																		
Radiator core					x				x						x			
Radiator core header sheets					x				x						x			
Radiator upper tank					x				x						x			
Radiator filler neck					x				x			x						
Radiator filler neck sleeve					x							x						
Radiator filler cap					1		2		3	D, N		1,2,3						N
Radiator tie rod fitting					x							x						
Radiator baffle					x				x						x			
Radiator inlet fitting	x								x			x						
Radiator lower tank					x				x						x			
Radiator outlet fitting	x											x						
Radiator drain flange					x				x			x						
Radiator anchor plate					x							x						
Radiator overflow tube					x				x						x			
Radiator side bolting member					x							x						
Radiator shell anchorage clips					x							x						
Radiator shell					1		2		3			1	2, 3					
Radiator supports					x							x						
Radiator support reinforcement					x							x						

DATA

THE AUTOMOTIVE PART	USUAL METAL COMPOSITION											RECOMMENDED WELDING METHOD					
	Grey Cast Iron	Malleable Iron	Cast Steel	Steel Forgings	To .40 Carbon Steel	Over .40 Carbon Steel	Alloy Steels	Aluminum	Brass, Copper or Bronze	Miscellaneous	Babbitt	Bronze-welding	Welding With Rod of Similar Composition	No. 1 H. T.	Soldering	Heating	Haynes Stellite
DIVISION III—COOLING SYSTEM—*Cont.*																	
Group 2—Radiator—*Cont.*																	
Radiator hinge rod fitting					x							x					
Radiator brace rod fitting					x							x					
Radiator hood ledge liner strip					x							x					
Radiator starting crank hole cover					1		2					1	2				
Group 3—Water Pump																	
Water pump impellor	x						x		x			x					
Water pump body	1									D, N		1					
Water pump cover					x							x					
Water pump shaft					x		x					x					x
Water pump gland					x							x					
Water pump shaft gear					x		x					x					
Water pump shaft bushing	x								x			x					
Group 4—Pipes																	
Engine water outlet	x											x					
Engine water inlet	x											x					
Radiator water fitting					x							x					
Water pump outlet pipe	x											x					
DIVISION IV—FUEL SYSTEM																	
Group 1—Carburetor and Inlet Pipe																	
Carburetor	1		2						3	D, N		1,2,3					
Inlet manifold	x											x					
Inlet pipe									x			x					
Group 2—Carburetor Control																	
Accelerator pedal					1			2				1	2				
Accelerator pedal bracket	x		x									x					
Accelerator pedal rod					x							x					
Carburetor mixture hand regulator					x							x					
Carburetor choke					x							x					
Group 3— Carburetor Air Heater																	
Carburetor air heater	x				x							x					
Carburetor hot air pipe	x				x							x					
Group 4—Fuel Tank																	
Fuel tank					x							x					
Fuel tank outlets					x							x					
Group 5—Fuel Pipes and Feed Systems																	
Fuel pipes									x			x					
Fuel pressure pump					x							x					
Fuel hand pump					x							x					
Fuel pressure pipes									x			x					

THE AUTOMOTIVE PART	USUAL METAL COMPOSITION											RECOMMENDED WELDING METHOD						
	Grey Cast Iron	Malleable Iron	Cast Steel	Steel Forgings	To .40 Carbon Steel	Over .40 Carbon Steel	Alloy Steels	Aluminum	Brass, Copper or Bronze	Miscellaneous	Babbitt	Bronze-welding	Welding With Rod of Similar Composition	No. 1 H. T.	Soldering	Heating	Haynes Stellite	Welding Not Recommended
DIVISION V—EXHAUST SYSTEM																		
Group 1—Exhaust Manifold																		
Exhaust manifold	X												X					
Group 2—Exhaust Pipe and Muffler																		
Muffler					X							X						
Exhaust pipe					X							X						
Muffler outlet pipe					X							X						
DIVISION VI—LUBRICATION SYSTEM																		
Group 1—Oil Pan or Reservoir																		
Oil pan					X							X						
Oil filler strainer									X						X			
Oil filler cap					X							X						
DIVISION VI—LUBRICATION SYSTEM—*Cont.*																		
Group 2—Oil Pump																		
Oil pump body	X											X						
Oil pump plunger	X				X				X			X						
Oil pump plunger spring						N	N					N						N
Oil pump valves					X													
Oil pump shaft					X	X	X					X						
Oil pump shaft gears					N		N					N						N
Oil pump following gear					N		N					N						N
Oil pump cover					X							X						
Group 3—Oil Pipes, Strainers, Gages																		
Oil pipes									X			X						
Circulating oil strainer									X						X			
Oil strainer cap					X							X						
Oil level gage					X				X			X						
DIVISION VII—IGNITION SYSTEM																		
Group 1—Spark Plugs, Cables																		
Spark plug cables									X						X			
Coil high-tension cable									X						X			
Low-tension cables									X						X			
Group 2—Battery Ignition Equipment																		
Timer-distributor shaft					1		N					1, N						N
Timer-distributor shaft gear					1		N					1, N						N
Ignition drive shaft					X		X					X						
Ignition drive shaft gear					X		X					X						
Manual advance arm					X							X						
Automatic advance element					X							X						
Ignition unit, magneto-base mounting	X		X		X							X						

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THE AUTOMOTIVE PART	USUAL METAL COMPOSITION											RECOMMENDED WELDING METHOD						
	Grey Cast Iron	Malleable Iron	Cast Steel	Steel Forgings	To .40 Carbon Steel	Over .40 Carbon Steel	Alloy Steels	Aluminum	Brass, Copper or Bronze	Miscellaneous	Babbitt	Bronze-welding	Welding With Rod of Similar Composition	No. 1 H. T.	Soldering	Heating	Haynes Stellite	Welding Not Recommended
DIVISION VIII—STARTING AND GEN. EQUIP.																		
Group 1—Generator																		
Generator driving gear or sprocket									X			X						
Generator shaft					X							X						
Generator coupling					X							X						
Group 2—Starting Motor																		
Starting motor pinions						N	N					N						N
Starting motor gear						N	N					N						N
Starting motor gear shaft					N		N					N						N
Group 3—Starter Generator (See VIII—1, 2)																		
Group 4—Ignition Generator (See VII—2, VIII—1)																		
Group 5—Ignition Starter Generator (See VII—2, VIII—1, 2)																		
Group 6—Storage Battery																		
Terminal post										1			X					
Plates										1,N								N
Post straps										L			X					
Battery hold-down					X							X						
Handles					X							X						
Terminals										L			X					
Through bolt					X							X						
DIVISION IX—MISC. ELECTRICAL EQUIP.																		
Group 1—Lamps and Wiring																		
Head lamp housing					1		2		3			1, 3	2					
Head lamp housing flange					X				X			X						
Head lamp door					1		2		3			1, 3	2					
Head lamp reflector									N									N
Auxiliary light parts are similar to head lamp parts																		
Head lamp support tie rod					X							X						
Tail light support					X							X						
Group 2—Switches and Instruments																		
Starting switch lever					X							X						
Switches and instruments									X						X			
Group 3—Horn																		
Horn projector					X							X						

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THE AUTOMOTIVE PART	USUAL METAL COMPOSITION											RECOMMENDED WELDING METHOD						
	Grey Cast Iron	Malleable Iron	Cast Steel	Steel Forgings	To .40 Carbon Steel	Over .40 Carbon Steel	Alloy Steels	Aluminum	Brass, Copper or Bronze	Miscellaneous	Babbitt	Bronze-welding	Welding With Rod of Similar Composition	No. 1 H. T.	Soldering	Heating	Haynes Stellite	Welding Not Recommended
DIVISION X—CLUTCH																		
Group 1—Clutching Parts																		
Clutch case (rotating member)	X											X						
Clutch housing	1		2					3				1, 2	3					
Clutch cover					1			2				1	2					
Clutch housing cover					X							X						
Clutch driving disk					N													N
Clutch pressure plates	X		X		X							X						
Clutch driver spider (or drum)					X							X						
Clutch facing spring							N	N										N
Clutch spring							N	N										N
Clutch shaft					X							X						
Clutch pilot bearing							N											N
Clutch driven plate	X		X									X					X	
Clutch driving plate					N													N
Clutch pressure levers		X	X	X	X							X						
Group 2—Releasing Parts																		
Clutch release sleeve	X				X							X						
Clutch release bearing housing					X							X					X	
Clutch release bearing							N											N
Clutch release yoke		X	X									X					X	
Clutch release yoke shaft					1		N					1, N						N
Clutch pedal shaft					1		N					1, N						N
Clutch pedal adjusting link					X							X						
Clutch release yoke lever				X								X						
Clutch pedal		X		X								X						
Clutch brake					X				X			X						
DIVISION XI—TRANSMISSION																		
Group 1—Transmission																		
Transmission case and cover	1							2				1	2					
Transmission gears						N	N					N						N
Transmission bearings and bearing parts						N	N											N
Transmission shafts and counter shafts					N		N					N						N
Transmission shaft pilot bushings							N		1			1						N
Group 2—Shifting Mechanism																		
Control housing	X											X						
Control shift frame		X		X								X						
Transmission shift forks		X		X	X		X					X					X	
Transmission shift rails					1		N					1, N						N
Transmission interlock rail				1	2		N					1,2,N						N

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THE AUTOMOTIVE PART	USUAL METAL COMPOSITION											RECOMMENDED WELDING METHOD						
	Grey Cast Iron	Malleable Iron	Cast Steel	Steel Forgings	To .40 Carbon Steel	Over .40 Carbon Steel	Alloy Steels	Aluminum	Brass, Copper or Bronze	Miscellaneous	Babbitt	Bronze-welding	Welding With Rod of Similar Composition	No. 1 H. T.	Soldering	Heating	Haynes Stellite	Welding Not Recommended
DIVISION XI—TRANSMISSION —*Cont.*																		
Group 3—Control																		
Control lever					X							X						
Control lever fulcrum ball					X	X	X					X					X	
Group 4—Propeller Shaft																		
Propeller shaft					1		N					N		1				N
Propeller shaft universal joints				X	X		X					X						
Propeller shaft bearings and bearing parts						N	N											N
Transmission shaft universal joint flange				X	X							X						
Universal joint yoke		N	N	N								N						N
Universal joint center cross, ring or block				N								N						N
Universal joint bearing bushing									X			X						
Universal joint pin						N	N											N
Universal joint casings			X		X							X						
Universal joint trunnion					N		N					N					N	N
Universal joint trunnion block					N		N					N						N
DIVISION XII—REAR AXLE																		
Group 1—Housing																		
Rear axle housing	X				X							X						
Bevel or worm gear housing	X		X		X							X						
Rear axle tubes					X		X					X						
Differential carrier	X		X	X	X							X						
Rear axle spring seat		X	X	X								X						
Axle brake shaft bracket			X	X	X							X						
Brake support			X	X	X							X						
Brake shield					X							X						
Group 2—Torque Arm and Radius Rod																		
Radius rods					X									X				
Group 3—Drive Pinion																		
Axle drive bevel pinion					N	N	N					N						N
Axle drive pinion shaft					N		N					N						N
Axle drive pinion bearings and bearing parts						N	N											N
Axle drive pinion adjusting sleeves				N	N													N
Axle drive pinion (or worm) carrier	X	X	X		X							X						
Group 4—Differential																		
Bevel drive pinion					N	N	N					N						N
Bevel drive gear					N		N					N						N

THE AUTOMOTIVE PART	USUAL METAL COMPOSITION											RECOMMENDED WELDING METHOD						
	Grey Cast Iron	Malleable Iron	Cast Steel	Steel Forgings	To .40 Carbon Steel	Over .40 Carbon Steel	Alloy Steels	Aluminum	Brass, Copper or Bronze	Miscellaneous	Babbitt	Bronze-welding	Welding With Rod of Similar Composition	No. 1 H. T.	Soldering	Heating	Haynes Stellite	Welding Not Recommended
DIVISION XII—REAR AXLE—Cont.																		
Group 4—Differential—Cont.																		
Differential case flange half			N				N					N						N
Differential case plain half			N				N					N						N
Differential bearing sleeve						N	N											N
Differential side gear					N		N					N						N
Differential spider pinion					N	N	N					N						N
Differential spider					N	N	N					N						N
Differential cross pin pinion					N	N	N					N						N
Differential cross pin						N	N					N						N
Differential side gear spacer					X							X						
Worm or worm gear					N	N	N		N			N						N
Group 5—Axle Shafts																		
Axle shaft					N		N					N						N
Axle shaft wheel flange		X	X		X							X						
DIVISION XIII—BRAKES																		
Group 1—Outer Brake																		
Outer brake band					N		N											N
Outer brake band lever		X		X	X							X						
Outer brake lever shaft				1	2		N					1, 2						N
Outer brake shaft end levers				X	X							X						
Group 2—Inner Brake																		
Inner brake shoe	X			X								X						
Inner brake toggle		X		X	X							X						
Inner brake toggle lever		X		X	X							X						
Inner brake toggle shaft					X							X						
Inner brake cam					1	2	N					1,2,N						N
Inner brake camshaft					1		N					1, N						N
Inner brake camshaft lever				X	X							X						
Group 3—Pedal (or Outer) Brake Control																		
Pedal brake rod					X							X						
Pedal brake rod yoke					X							X						
Pedal brake intermediate shafts				X	X							X						
Pedal brake equalizer levers				X	X							X						
Pedal brake equalizer				X	X							X						
Brake pedal				X	X							X						
Brake pedal rod					X							X						
Brake pedal rod yokes				X	X							X						
Brake pedal shaft					1		N					1, N						N

DATA

THE AUTOMOTIVE PART	USUAL METAL COMPOSITION											RECOMMENDED WELDING METHOD						
	Grey Cast Iron	Malleable Iron	Cast Steel	Steel Forgings	To .40 Carbon Steel	Over .40 Carbon Steel	Alloy Steels	Aluminum	Brass, Copper or Bronze	Miscellaneous	Babbitt	Bronze-welding	Welding With Rod of Similar Composition	No. 1 H. T.	Soldering	Heating	Haynes Stellite	Welding Not Recommended
DIVISION XIII—BRAKES—*Cont.*																		
Group 4—Hand Brake (or Inner) Control																		
Hand brake rod					X							X						
Hand brake rod yoke				X	X							X						
Hand brake intermediate shafts				X	X							X						
Hand brake equalizer levers				X	X							X						
Hand brake equalizer				X	X							X						
Brake hand lever rod					X							X						
Brake hand lever rod yoke				X	X							X						
Brake hand lever				X	X							X						
DIVISION XIV—FRONT AXLE AND STEERING																		
Group 1—Axle Center																		
Front axle center				N			N											N
Front spring seats						N	N					N						N
Front axle bushing						N	N		1			1						N
Wheel spindles			N									N						N
Group 2—Steering Knuckles																		
Steering knuckles		N	N	N		N	N											N
Steering knuckle bushing	X								X			X						
Steering knuckle pivot					N		N											N
Steering knuckle thrust bearing						N	N											N
Steering knuckle arms		N		N	N		N											N
Steering knuckle gear rod arm				N	N		N											N
Group 3—Steering Rods																		
Steering knuckle tie rod					N													N
Steering gear connecting rod					N													N
Group 4—Steering Gear																		
Steering gear case					X							X						
Steering gear bracket		X	X		X							X						
Steering gear arm		N		N														N
Steering gear shaft					N													N
Steering wheel spider					X							X						
Steering wheel tube (or shaft)					N													N
Spark and throttle sector	X		X		X							X						
Spark and throttle sector tube					X							X						
Spark hand lever					X							X						
Spark hand lever tube (or rod)					X							X						
Throttle hand lever					X							X						

THE AUTOMOTIVE PART	USUAL METAL COMPOSITION											RECOMMENDED WELDING METHOD						
	Grey Cast Iron	Malleable Iron	Cast Steel	Steel Forgings	To .40 Carbon Steel	Over .40 Carbon Steel	Alloy Steels	Aluminum	Brass, Copper or Bronze	Miscellaneous	Babbitt	Bronze-welding	Welding With Rod of Similar Composition	No. 1 H. T.	Soldering	Heating	Haynes Stellite	Welding Not Recommended
Group 4—Steering Gear—Cont.																		
Throttle hand lever tube (or rod)					X							X						
Steering column bracket			1		2					D,N		1, 2						N
Steering worm					N		N		N									N
Steering worm sector (or gear)					N		N		N									N
Steering worm shaft					N													N
DIVISION XV—WHEELS																		
Group 1—Wheels																		
Wheel rims					X									X				
Wheel hub			N				N					N						N
Wheel hub flanges					X							X						
Wheel bearings and bearing parts						N	N											N
Wheel brake drums	X		X		X							X						
DIVISION XVI—FRAME AND SPRINGS																		
Group 1—Frame																		
Frame members					X									X		X		
Gussets					X									X		X		
Group 2—Frame Brackets and Sockets																		
Spring brackets					X							X						
Running board brackets					X							X						
Engine support brackets					X									X				
Torque arm bracket					X							X						
Radius rod bracket					X									X				
Group 3—Front Springs																		
Front springs						N	N											N
Front spring shackle					X									X				
Front spring seat					X							X						
Front spring clip plate					X							X						
Group 4—Rear Springs																		
Rear springs						N	N											N
Rear spring pivot seat					X							X						
Rear spring double shackle					X									X				
(Other parts as for front spring)																		
DIVISION XVII—HOOD, FENDERS AND SHIELDS																		
Group 1—Hood																		
Hood					X			X					X					
Hood sill					X							X						
Hood handle					X							X						
Hood fastener					X							X						
Hood fastener bracket	X		X		X							X						

THE AUTOMOTIVE PART	USUAL METAL COMPOSITION											RECOMMENDED WELDING METHOD						
	Grey Cast Iron	Malleable Iron	Cast Steel	Steel Forgings	To .40 Carbon Steel	Over .40 Carbon Steel	Alloy Steels	Aluminum	Brass, Copper or Bronze	Miscellaneous	Babbitt	Bronze-welding	Welding With Rod of Similar Composition	No. 1 H. T.	Soldering	Heating	Haynes Stellite	Welding Not Recommended
DIVISION XVII—HOOD, FENDERS AND SHIELDS—*Cont.*																		
Group 2—Engine Shield																		
Engine shield					X							X						
Engine shield bracket					X							X						
Group 3—Fenders and Running Boards																		
Running boards					X								X					
Running board shield					X								X					
Fenders					X								X					
Fender support socket					X							X						
Fender supports					X							X						
DIVISION XVIII—BODY																		
Group 1—Floor boards and Dash																		
Floor boards (metal parts)					X								X					
Dash					X								X					
Instrument board					X								X					
Group 2—Body Parts (Metal)																		
All metal panels					X								X			X		
Body posts and braces					X								X			X		
Window frames					X								X			X		
Group 3—Seat Frames					X								X			X		
DIVISION XIX—ACCESSORIES																		
Group 1—Speedometer (and parts)										N								N
Group 2—Tire Pump																		
Tire pump driving gear					X		X					X						
Tire pump shaft gear					X		X					X						
Tire pump idler gear					X		X					X						
Group 3—Body Furnishings																		
Door and Window Handles					1		2		3	D,N			1,2,3					N
Bumpers						X	X					X						
Bumper brackets					X							X						

X—Indicates the Metal Composition and the Recommended Welding Method.
1, 2, 3—Indicates corresponding Composition and Method.
N—Welding not recommended. Minor areas may be built up if an N is placed in one of the Welding Method columns. Otherwise do not weld and do not build up.
L—Lead.
D—Die Cast Metal.

291. SHORT CUTS TO IMPROVE WELD QUALITY IN OXY-ACETYLENE WELDING.

a. Distortion.

Cause	Cure
(1) Shrinkage of deposited metal pulls welded parts together and changes their relative position.	(1) Properly clamp or tack parts to resist shrinkage. *(a)* Separate or preform parts sufficiently to allow for shrinkage of welds. *(b)* Peen the deposited metal while still hot.
(2) Nonuniform heating of parts during welding causes them to distort or buckle before welding is finished. Final welding of parts in distorted position prevents control of desired dimensions.	(2) Support parts of structure to be welded to prevent buckling in heated sections due to weight of parts themselves. *(a)* Preheating is desirable in some heavy structures. *(b)* Removal of rolling or forming strains before welding is sometimes helpful.
(3) Improper welding sequence.	(3) Study the structure and develop a definite sequence of welding. *(a)* Distribute welding to prevent excessive local heating.

b. Welding Stresses.

(1) Joints too rigid.	(1) Slight movement of parts during welding will reduce welding stresses. *(a)* Develop welding procedure that permits all parts to be free to move as long as possible.
(2) Improper welding procedure.	(2) Make weld in as few passes as practicable. *(a)* Use special intermittent or alternating welding sequence and step-back or skip procedure. *(b)* Properly clamp parts adjacent to the joint. Use

Cause	Cure
	back-up to cool parts rapidly.
(3) Inherent in all welds, especially in heavy parts.	(3) Peen each deposit of weld metal. *(a)* Stress-relieve finished product at 1,100 to 1,250 F, 1 hour per inch of thickness.
c. **Warping.** (Thin Plates)	
(1) Shrinkage of deposited weld metal.	(1) Distribute heat input more evenly over full length of the seam.
(2) Excessive local heating at the joint.	(2) Weld rapidly with a minimum input to prevent excessive local heating of the plates adjacent to the weld.
(3) Improper preparation of joint.	(3) Do not have excessive space between the parts to be welded. *(a)* Prepare thin plate edges with flanged joints, making off-set approximately equal to the thickness of the plates. No filler rod is necessary for this type of joint. *(b)* Fabricate a U-shaped corrugation in the plates parallel to and approximately ½ inch away from the seam. This will serve as an expansion joint to take up movement during and after the welding operation.
(4) Improper welding procedure.	(4) Use special welding sequence and step-back or skip procedure.
(5) Improper clamping of parts.	(5) Properly clamp parts adjacent to the joint. Use back-up to cool parts rapidly.

Cause	Cure
d. Poor Weld Appearance.	
(1) Poor welding technique—improper flame adjustment or welding rod manipulation.	(1) Insure the use of the proper welding technique for the welding rod used. *(a)* Do not use excessive heat. *(b)* Use of a uniform weave and welding speed at all times.
(2) Inherent characteristic of welding rod used.	(2) Use a welding rod designed for the type of weld.
(3) Improper joint preparation.	(3) Prepare all joints properly.
e. Cracked Welds.	
(1) Joint too rigid.	(1) Design the structure and develop a welding procedure to eliminate rigid joints.
(2) Welds too small for size of parts joined.	(2) Do not use too small a weld between heavy plates. Increase the size of welds by adding more filler metal.
(3) Improper welding procedure.	(3) Do not make welds in string beads. Make welds full-size in short sections 8 to 10 inches long. *(a)* Welding sequence should be such as to leave ends free to move as long as possible. *(b)* Preheating parts to be welded sometimes helps to reduce high contraction stresses caused by localized high temperatures.
(4) Poor welds.	(4) Make sure welds are sound and the fusion is good.
(5) Improper preparation of joints.	(5) Prepare joints with a uniform and proper free space. In some cases, a free space is essential. In other cases, a shrink or press fit may be required.

f. Undercut.

Cause	Cure
(1) Excessive weaving of the bead, improper tip size, and insufficient welding rod added to molten puddle.	(1) Modify welding procedure to balance weave of bead and rate of welding rod deposition, using proper tip size. *(a)* Do not use too small a welding rod.
(2) Improper manipulation of the welding rod.	(2) Avoid excessive and nonuniform weaving. *(a)* A uniform weave with unvarying heat input will aid greatly in preventing undercut in butt welds.
(3) Poor welding technique—improper welding rod deposition with nonuniform heating.	(3) Do not hold a welding rod too low near the lower edge of the plate in the vertical plane when making a horizontal fillet weld, as undercut on the vertical plate will result.

g. Incomplete Penetration.

(1) Improper preparation of joint.	(1) Be sure to allow the proper free space at the bottom of the weld. *(a)* Deposit a layer of weld metal on the back side of the joint, where accessible, to insure complete fusion in lower "V."
(2) Use of too large a welding rod.	(2) Select proper-sized welding rod to obtain a balance in the heat requirements for melting welding rod, breaking down sidewalls, and maintaining the puddle of molten metal at the desired size. *(a)* Use small-diameter welding rods in a narrow welding groove.
(3) Welding tip too small—insufficient heat input.	(3) Use sufficient heat input to obtain proper penetration for the plate thickness being welded.

Cause	Cure
(4) Too fast a welding speed.	(4) Welding speed should be slow enough to allow welding heat to penetrate to the bottom of the joint.

h. Porous Welds.

Cause	Cure
(1) Inherent properties of the particular type of welding rod.	(1) Use welding rod of proper chemical analysis.
(2) Improper welding procedure and flame adjustment.	(2) Avoid overheating of molten puddle of weld metal. *(a)* Use the proper flame adjustment and flux, if necessary, to insure sound welds.
(3) Insufficient puddling time to allow entrapped gas, oxides, and slag inclusions to escape to the surface.	(3) Use the multi-layer welding technique to avoid carrying too large a molten puddle of weld metal. *(a)* Puddling keeps the weld metal molten longer and often insures sounder welds.
(4) Poor base metal.	(4) Modify the normal welding procedure to weld poor base metals of a given type.

i. Brittle Welds.

Cause	Cure
(1) Unsatisfactory welding rod producing air-hardening weld metal.	(1) Avoid welding rods producing air-hardening weld metal where ductility is desired. High-tensile low-alloy steel rods are air-hardening and require proper base metal preheating, postheating or both, to avoid cracking due to brittleness.
(2) Excessive heat input with over sized welding tip, causing coarse-grained and burnt metal.	(2) Do not use excessive heat input, as this may cause coarse grain structure and oxide inclusions in weld metal deposits.
(3) High-carbon or alloy base metal which has not been taken into consideration.	(3) A single-pass weld may be more brittle than a multi-layer weld, because it has

Cause	Cure
	not been refined by successive layers of weld metal.
	(a) Welds may absorb alloy elements from the parent metal and become hard. Do not weld a steel unless the analysis and characteristics are known.
(4) Improper flame adjustment and welding procedure.	(4) Adjust the flame so that molten metal does not boil, foam, or spark.

j. Poor Fusion.

Cause	Cure
(1) Improper size of welding rod.	(1) When welding in narrow V's, use a welding rod small enough to reach the bottom.
(2) Improper size of tip and heat input.	(2) Use sufficient heat to melt welding rod and to break down sidewalls of plate edges.
(3) Improper welding technique.	(3) Be sure the weave is wide enough to melt the sides of a joint thoroughly.
(4) Improper preparation of joint.	(4) The deposited metal should completely fuse with the sidewalls of plate to form a consolidated joint of base and weld metal.

k. Corrosion.

Cause	Cure
(1) Type of welding rod used.	(1) Select welding rods with the proper corrosion-resisting properties, which are not changed by the welding process.
(2) Improper weld deposit for the corrosive fluid or atmosphere.	(2) Use the proper flux on both parent metal and welding rod to produce welds with the desired corrosion resistance.
	(a) Do not expect more from the weld than you do

Cause	Cure
	from the parent metal. On stainless steels, use welding rods that are equal or better than the base metal. *(b)* For best corrosion resistance use a filler rod whose composition is the same as the base metal.
(3) Metallurgical effect of welding.	(3) When welding 18-8 austenitic stainless steel, be sure the analysis of the steel and the welding procedure is correct, so that the butt welding does not cause carbide precipitations. This condition can be corrected by annealing at 1,900 F to 2,100 F.
(4) Improper cleaning of weld.	(4) Certain materials such as aluminum require careful cleaning of all slag to prevent corrosion.
l. **Brittle Joints.**	
(1) Air-hardening base metal.	(1) In welding on medium carbon steel or certain alloy steels, the fusion zone may be hard as the result of rapid cooling. Preheating at 300 to 500 F should be resorted to before welding.
(2) Improper welding procedure.	(2) Multi-layer welds will tend to anneal hard zones. *(a)* Stress-relieving at 1,100 F to 1,250 F after welding will generally reduce hard areas formed during welding.
(3) Unsatisfactory welding rod.	(3) The use of austenitic welding rods will often work on special steels, but the fusion zone will generally contain an alloy which is hard.

292. SHORT CUTS TO IMPROVE WELD QUALITY IN ELECTRIC ARC WELDING.

a. Distortion.

Cause	Cure
(1) Shrinkage of deposited metal pulls welded parts together and changes their relative positions.	(1) Properly tack or clamp parts to resist shrinkage. *(a)* Separate or preform parts so as to allow for shrinkage of welds. *(b)* Peen the deposited metal while still hot.
(2) Nonuniform heating of parts during welding causes them to distort or buckle before welding is finished. Final welding of parts in distorted position prevents the maintenance of proper dimensions.	(2) Preheating is desirable in some heavy structure. *(a)* Removal of rolling or forming strains before welding is sometimes helpful.
(3) Improper welding sequence.	(3) Study structure and develop a definite sequence of welding. *(a)* Distribute welding to prevent excessive local heating.

b. Welding Stresses.

(1) Joints too rigid.	(1) Slight movement of parts during welding will reduce welding stresses. *(a)* Develop welding procedure that permits all parts to be free to move as long as possible.
(2) Improper welding procedure.	(2) Make weld in as few passes as practicable. *(a)* Use special intermittent or alternating welding sequence and step-back or skip procedure. *(b)* Properly clamp parts adjacent to the joint. Use back-up to cool parts rapidly.
(3) Inherent in all welds, especially in heavy parts.	(3) Peen each deposit of weld metal.

Cause	Cure
	(a) Stress-relieve finished product at 1,100 F to 1,250 F 1 hour per inch of thickness.
c. **Warping.** (Thin plates)	
(1) Shrinkage of deposited weld metal.	(1) Select electrode with high welding speed and moderate penetrating properties.
(2) Excessive local heating at the joint.	(2) Weld rapidly to prevent excessive local heating of the plates adjacent to the weld.
(3) Improper preparation of joint.	(3) Do not have excessive spaces between the parts to be welded. *(a)* Hammer joint edges thinner than rest of plate before welding. This elongates edges and the weld shrinkage causes them to pull back to the original shape.
(4) Improper welding procedure.	(4) Use special intermittent or alternating welding sequence and step-back or skip procedure.
(5) Improper clamping of parts.	(5) Properly clamp parts adjacent to the joint. Use back-up to cool parts rapidly.
d. **Poor Weld Appearance.**	
(1) Poor welding technique—improper current or electrode manipulation.	(1) Insure the use of the proper welding technique for the electrode used. *(a)* Do not use excessive welding current. *(b)* Use a uniform weave or rate of travel at all times.
(2) Inherent characteristic of electrode used.	(2) Use an electrode designed for the type of weld and the position in which the weld is to be made.

Cause	Cure
(3) Welding in position for which electrode is not designed.	(3) Do not make fillet welds with downhand (flat position) electrodes unless the parts are positioned.
(4) Improper joint preparation.	(4) Prepare all joints properly.
e. Cracked Welds.	
(1) Joint too rigid.	(1) Design the structure and develop a welding procedure to eliminate rigid joints.
(2) Welds too small for size of parts joined.	(2) Do not use too small a weld between heavy plates. Increase the size of welds by adding more filler metal.
(3) Improper welding procedure.	(3) Do not make welds in string beads. Make weld full size in short section 8 to 10 inches long. *(a)* Welding sequence should be such as to leave ends free to move as long as possible. *(b)* Preheating parts to be welded sometimes helps to reduce high contraction stresses caused by localized high temperature. *(c)* Fill all craters at the end of the weld pass by moving the electrode back over the finished weld for a short distance equal to the length of the crater.
(4) Poor welds.	(4) Make sure welds are sound and the fusion is good. Be sure arc length and polarity are correct.
(5) Improper preparation of joints.	(5) Prepare joints with a uniform and proper free space. In some cases, a free space is essential. In other cases, a shrink or press fit may be required.

f. Undercut.

Cause	Cure
(1) Excessive welding current.	(1) Use a moderate welding current and do not try to weld at too high a speed.
(2) Improper manipulation of electrode.	(2) Do not use too large an electrode. If the puddle of molten metal becomes too large, undercut may result. *(a)* Excessive weaving will cause undercut and should not be used. *(b)* A uniform weave will aid greatly in preventing undercut in butt welds. *(c)* If an electrode is held too near the vertical plate in making a horizontal fillet weld, undercut on the vertical plate will result.
(3) Attempting to weld in a position for which the electrode is not designed.	(3) Electrodes should be used for welding in the position for which they were designed.

g. Incomplete Penetration.

(1) Improper preparation of joint.	(1) Be sure to allow the proper free space at the bottom of a weld. *(a)* Use a back-up bar, if possible. *(b)* Chip or cut out the back of the joint and deposit a bead of weld metal at this point.
(2) Use of too large an electrode.	(2) Do not expect excessive penetration from an electrode. *(a)* Use small-diameter electrodes in a narrow welding groove.
(3) Insufficient welding current.	(3) Use sufficient welding current to obtain proper penetration. Do not weld too rapidly.

(4) Too fast a welding speed.	(4) Control the welding speed to penetrate to the bottom of the welded joint.

h. Porous Welds.

(1) Inherent properties of electrodes.	(1) Some electrodes inherently produce sounder welds than others. Be sure that proper electrodes are used.
(2) Improper welding procedure and current setting.	(2) A weld made of a series of string beads is apt to contain small pinholes. Weaving will often eliminate this trouble. *(a)* Do not use excessive welding currents.
(3) Insufficient puddling time to allow entrapped gas to escape.	(3) Puddling keeps the weld metal molten longer and often insures sounder welds.
(4) Poor base metal.	(4) In some cases, the base metal may be at fault. Check this for segregations and impurities.

i. Brittle Welds.

(1) Unsatisfactory electrode.	(1) Bare electrodes produce brittle welds. Shielded-arc electrodes must be used if ductile welds are required.
(2) Excessive welding current causing coarse-grained and burnt metal.	(2) Do not use excessive welding current, as this may cause coarse-grain structure and oxidized deposits.
(3) High-carbon or alloy base metal which has not been taken into consideration.	(3) A single-pass weld may be more brittle than a multiple-layer weld because it has not been refined by successive layers of weld metal. *(a)* Welds may absorb alloy elements from the parent metal and become hard. Do not weld a steel unless the analysis and characteristics are known.

j. Poor Fusion.

Cause	Cure
(1) Improper diameter of electrode.	(1) When welding in narrow V's use an electrode small enough to reach the bottom.
(2) Improper welding current.	(2) Use sufficient welding current to deposit the metal and penetrate into the plates. Heavier plates require lighter current for a given electrode than light plates.
(3) Improper welding technique.	(3) Be sure the weave is wide enough to melt the sides of a joint thoroughly.
(4) Improper preparation of joint.	(4) The deposited metal should tend to fuse with the plates and not curl away from it or merely adhere to it.

k. Corrosion.

(1) Type of electrode used.	(1) Bare electrodes produce welds that are less resistant to corrosion than the parent metal. *(a)* Shielded-arc electrodes produce welds that are more resistant to corrosion than the parent metal. *(b)* For the best corrosion resistance, use a filler rod whose composition is the same as the base metal.
(2) Improper weld deposit for corrosive fluid or atmosphere.	(2) Do not expect more from the weld than you do from the parent metal. On stainless steels, use electrodes that are equal to or better than the parent metal.
(3) Metallurgical effect of welding.	(3) When welding 18-8 austenitic stainless steel, be sure the analysis of the steel and welding procedure is

Cause	Cure
	correct, so that the butt welding does not cause carbide precipitations. This condition can be corrected by annealing at 1,900 F to 2,100 F.
(4) Improper cleaning of weld.	(4) Certain materials, such as aluminum, require careful cleaning of all slag to prevent corrosion.

l. Brittle Joints.

Cause	Cure
(1) Air-hardening base metal.	(1) In welding on medium carbon steel or certain alloy steels, the fusion zone may be hard as a result of rapid cooling. Preheating at 300 F to 500 F should be resorted to before welding.
(2) Improper welding procedure.	(2) Multiple-layer welds will tend to anneal hard zones. *(a)* Stress-relieving at 1,100 F to 1,250 F after welding will generally reduce hard areas formed during welding.
(3) Unsatisfactory electrode.	(3) The use of austenitic electrodes will often work on special steels, but the fusion zone will generally contain an alloy which is hard.

m. Magnetic Blow.

Cause	Cure
(1) Magnetic field causing a direct-current arc to blow away from the point at which it is directed. Magnetic blow is particularly noticeable at ends of joints and in corners.	(1) Proper location of the ground on the work. Placing the ground in the direction the arc blows from the point of welding is often helpful. *(a)* Separating the ground in two or more parts is helpful. *(b)* Weld toward the direction the arc blows.

Cause	Cure
	(c) Hold a short arc.
	(d) Changing the angle of the electrode relative to the work will stabilize the arc.
	(e) Magnetic blow is held to a minimum in alternating-current welding.
n. Spatter.	
(1) Inherent property of some electrodes.	(1) Select proper type of electrode.
(2) Excessive welding current used for the type or diameter of electrode.	(2) Use a short arc but do not use excessive welding current.
(3) Coated electrodes produce larger spalls than bare electrodes.	(3) Paint parts adjacent to weld with whitewash or other protective coating. This prevents spalls from welding to parts and they can be easily removed.

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