SUBCOURSE
OD1651

EDITION
8

WELDING OPERATIONS, I

AIPD

READINESS/
PROFESSIONALISM
THRU
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THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM

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WELDING OPERATIONS, I

SUBCOURSE NO. OD1651

United States Army Combined Arms support Command
Fort Lee, Virginia 23801-1809

6 Credit Hours

GENERAL

The purpose of this course is to introduce the basic requirements involved in metal-arc welding operations.

The scope of this subcourse consists of describing the classification of electrodes and their intended uses; describing automotive welding processes, materials and identification processes; describing the methods of destructive and nondestructive testing of welds and troubleshooting procedures; describing the type and techniques of joint design; and describing the theory, principles, and procedures of welding armor plate.

Six credit hours are awarded for successful completion of this subcourse.

Lesson 1 ELECTRODES CLASSIFICATION AND INTENDED USES; AUTOMOTIVE WELDING PROCESSES, MATERIALS, AND IDENTIFICATION PROCESSES; METHODS OF DESTRUCTIVE AND NONDESTRUCTIVE TESTING OF WELDS AND TROUBLESHOOTING PROCEDURES; TYPES AND TECHNIQUES OF JOINT DESIGN; AND THE THEORY, PRINCIPLES, AND PROCEDURES OF WELDING ARMOR PLATE

TASK 1: Describe the processes for identifying electrodes by classification, and intended uses; and the automotive welding processes, materials, and identification processes; and the types and techniques of joint design.

TASK 2: Describe the theory, principles, and procedures of welding armor plate; and methods of destructive and nondestructive testing of welds, and troubleshooting procedures.

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LESSON 1

ELECTRODES CLASSIFICATION AND INTENDED USES; AUTOMOTIVE WELDING PROCESSES, MATERIALS, AND IDENTIFICATION PROCESSES; METHODS OF DESTRUCTIVE AND NONDESTRUCTIVE TESTING OF WELDS AND TROUBLESHOOTING PROCEDURES; TYPES AND TECHNIQUES OF JOINT DESIGN; AND THE THEORY, PRINCIPLES, AND PROCEDURES OF WELDING ARMOR PLATE

TASK 1. Describe the processes for identifying electrodes by classification, and intended uses; and the automotive welding processes, materials, and identification processes; and the types and techniques of joint design.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within three hours

REFERENCES

No supplementary references are needed for this task.

1. Introduction

Welding is one of the most important functions performed in both an intermediate direct support (IDS) and intermediate general support (IGS) maintenance company. Experience gained during the second world war revealed that many broken parts can be welded and put back into service, thus often saving the expense of fabricating or purchasing a new piece of equipment. As a result of this experience, a service section containing a metalworking shop with welding capabilities is now established within these maintenance organizations.

The first task of this lesson is designed to assist you in learning the processes for identifying electrodes by classification, and intended uses; the automotive welding processes, materials, and identification processes, and the techniques of joint design as they pertain to electric arc welding.

2. Identification and Uses of Electrodes

a. *General*. During electric arc welding operations, when molten metal is exposed to the atmosphere, it will absorb oxygen and nitrogen from the air and will become brittle. To protect it from this damaging reaction, a slag cover over the molten or solidifying metal must be provided. This cover is made by coating the electrode with a substance that will vaporize and defuse in the arc stream to form a protective cover that will stabilize the arc and protect the metal. Because there are several different types of metals used in Army equipment, it is necessary to use the correct electrode whenever welding this equipment. The following subparagraphs describe the classification of electrodes, their intended uses, and the factors to be considered when selecting electrodes.

b. *Factors in Selecting an Electrode*. The purpose of selecting the correct type electrode is to provide arc stability, smoothness of the weld bead, easy slag removal, and minimum spatter that are essential to top quality welding. Factors to be considered when selecting electrodes are:

(1) Specific metal properties required in the weld such as corrosion resistance, ductility, or high tensile strength.

(2) Type of base metal to be welded.

(3) Position of the weld, such as flat or vertical.

(4) The type of electrical current that is available.

(5) Electric current polarity (straight or reverse) which is available.

(6) Dimensions of the section to be welded.

(7) The type of fit that the work permits.

c. *Classification of Electrodes*.

(1) Metal-arc electrodes may be grouped and classified as bare electrodes, thinly coated electrodes, and shielded-arc or heavy coated electrodes. A classification number series, (formulated by the American Welding Society), has been adopted by the welding industry for the identification of electrodes. By means of this numbering system, the following characteristics of a given electrode can be identified:

(a) Whether the electrode has a light or heavy coating.

(b) The composition of the coating.

(c) The recommended welding position.

(d) The type of electric current (direct or alternating current) and the polarity for which the electrode is intended.

(e) The base metal for which the electrode is recommended.

(2) The identification system for steel arc welding electrodes is a four digit number series preceded by a letter as described below:

(a) The symbol E indicates that the electrode is intended for use in electrical welding.

(b) The first two (or three) digits of the number indicate the tensile strength (the resistance of the material to forces trying to pull it apart), in thousands of pounds per square inch, of the deposited metal.

(c) The third (or fourth) digit indicates the position of the weld. The number 0 in either one of these positions indicates the classification is not used. The number 1 indicates the electrode may be used for all welding positions. The number 2 indicates that the electrode may be used only in the flat and horizontal positions. The number 3 indicates the electrode is to be used only in the flat welding position.

(d) The fourth (or last) digit indicates the type of coating on the electrode, and the power supply (either alternating current (ac) or direct current (dc), straight polarity (sp), or reverse polarity (rp)) to be used with the pertinent electrode.

(e) A listing of the types of coatings, welding currents, and polarity requirements of the fourth (or last) identifying digit of the electrode is listed below.

Digit	*Coating*	*Current*
0	*****	*****
1	**Cellulose potassium**	**ac, dcrp, dcsp**
2	**Titania sodium**	**ac, dcsp**
3	**Titania sodium**	**ac, dcrp, dcsp**
4	**Iron powder titania**	**ac, dcrp, dcsp**
5	**Lo-hydrogen sodium**	**dcrp**
6	**Lo-hydrogen potassium**	**ac, dcrp**
7	**Iron powder iron oxide**	**ac, dcsp**
8	**Iron powder lo-hydrogen**	**ac, dcrp, dcsp**

*** When the fourth (or last) digit is 0, the type of coating and current to be used is determined by the third digit.**

(f) The number E6010 identifies an electric welding electrode with a minimum stress relieved tensile strength of 60,000 psi (pounds per square inch). It can be used to weld in all positions, preferably using direct current reverse polarity electricity. However, alternating current and direct current straight polarity can also be used.

(3) The electrode identification system for stainless steel arc-welding is set up as follows:

(a) The symbol E indicates electric welding.

(b) The first three digits indicate the American Iron and Steel Institute type of stainless steel.

(c) The last two digits indicate the current and the welding position in which it is used.

(d) According to this system, the number E-308-16 identifies a stainless steel electrode type 308, for use with alternating or reverse polarity direct current in all welding positions.

d. *Types of Electrodes*. There are three different types of electrodes. They are: bare, thinly coated, and shielded-arc or heavy-coated electrodes.

(1) *Bare Electrodes*. Bare electrodes are made of wire compositions required for specific applications and have no coatings other than those required in wire drawing. These wire drawing coatings have some slight stabilizing effect on the arc, but are otherwise of no consequence. Bare electrodes are used for welding manganese alloy steel, and other purposes where a coated electrode is not required or is undesirable. A diagrammatic sketch of the transfer of metal across the arc of a bare electrode is shown in figure 1, view A, on the following page.

(2) *Thinly Coated Electrodes*.

(a) Thinly coated electrodes are made of a wire of a definite composition. A thin coating is applied on the surface of the electrode by washing, dipping, brushing, spraying, tumbling, or wiping to improve the stability and characteristics of the arc stream. They are listed under the E45 series in the electrode identification system described in paragraph 2c, beginning on page 3.

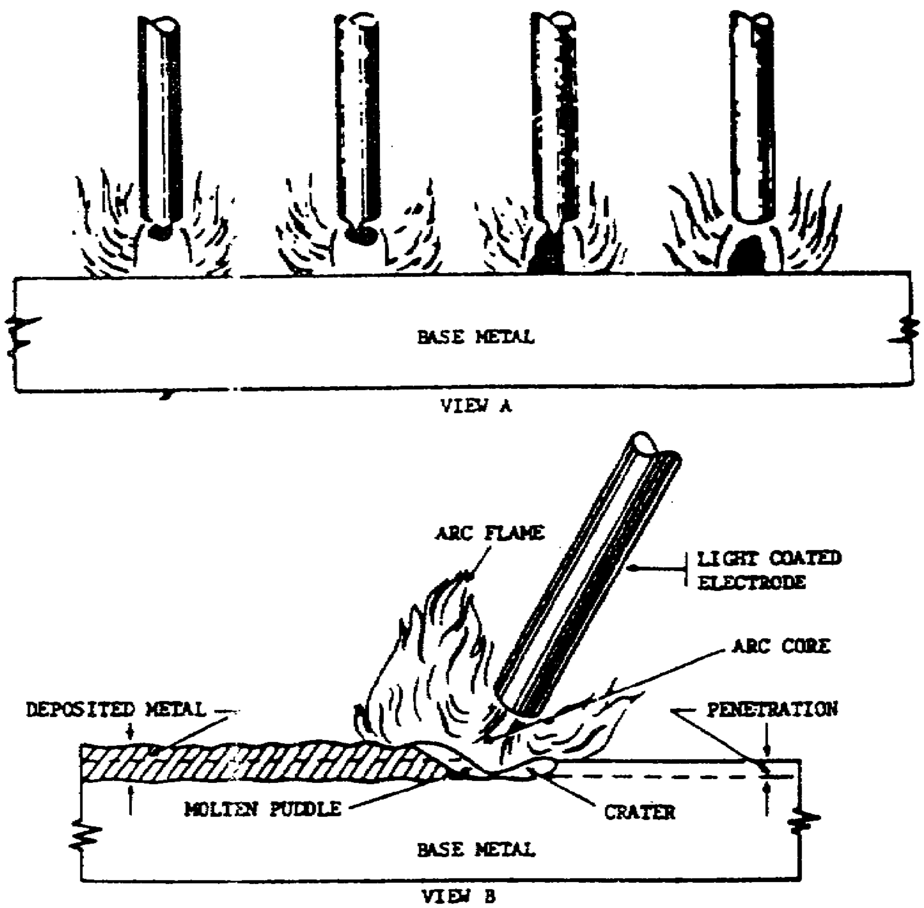
(b) The coating on these types of electrodes generally serves the functions described below:

1 It dissolves or reduces impurities, such as oxides, sulfur, and phosphorous, and thus keeps impurities out of the weld deposit.

2 It reduces the adhesive force between the molten metal and the end of the electrode, or changes the surface tension of the molten metal so that the globules of metal leaving the end of the electrode are smaller and more frequent, thus making the flow of molten metal more uniform and continuous.

3 It increases the stability of the arc by introducing materials readily ionized into the arc stream. That is, the coating fuels the arc by providing smaller particles when the electric charge occurs.

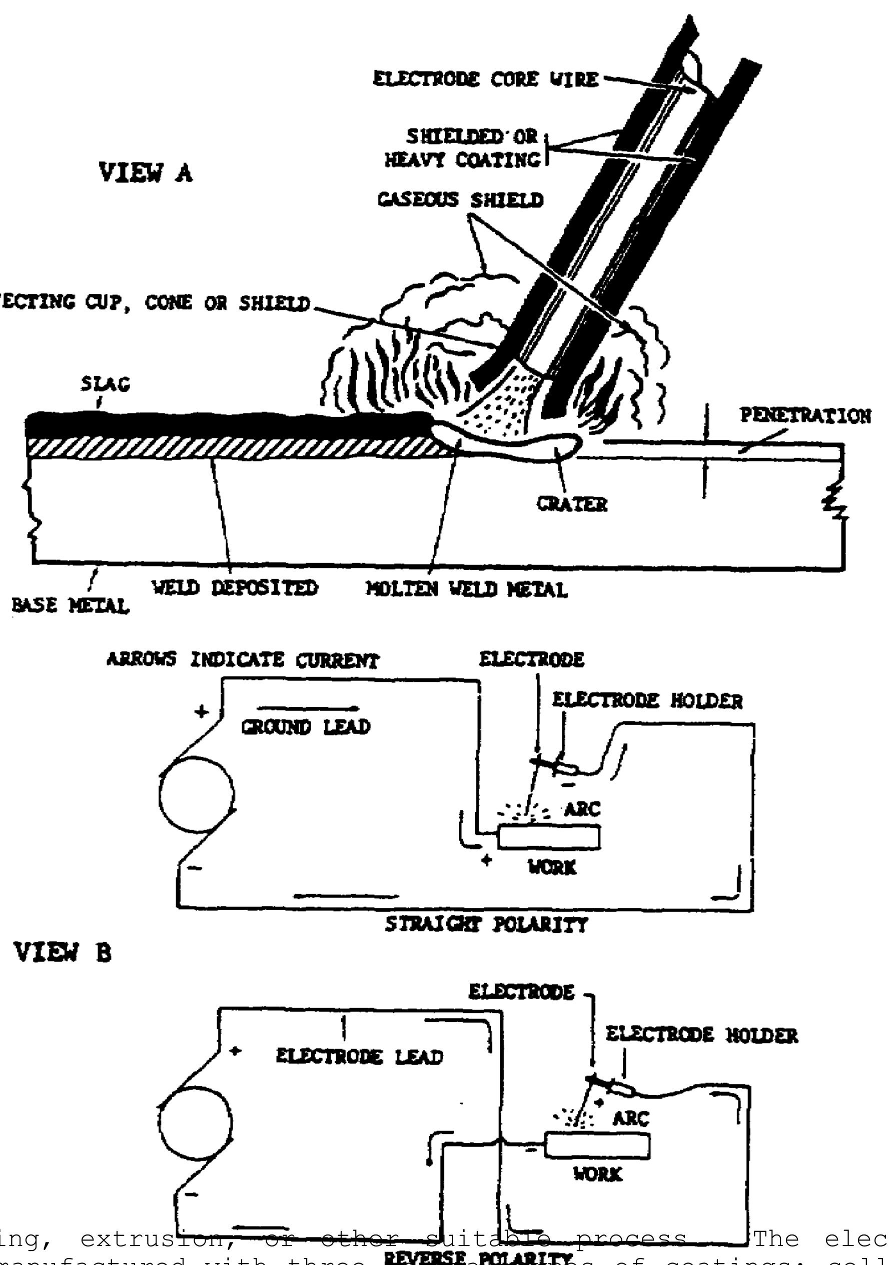
FIGURE 1. BARE ELECTRODE MOLTEN METAL TRANSFER AND LIGHT COATED ELECTRODE ARC ACTION.



(c) Some of the light 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 of an arc obtained with a light-coated electrode is shown in figure 1, view B.

(3) *Shielded-arc or Heavy-coated Electrodes*. Shielded-arc or heavy-coated electrodes are used for welding steels and cast iron. The arc action obtained with a shield-arc or heavy-coated electrode is shown in figure 2, view A, on the following page. This type of electrode is made of wire with a thick coating which has been applied by

FIGURE 2. ARC ACTION AND ELECTRIC WELDING POLARITY.



dipping, extrusion, or other suitable process. The electrodes are manufactured with three general types of coatings: cellulose, mineral, and combinations of mineral and cellulose coating.

(a) The cellulose-coated types are composed of soluble cotton or other forms of cellulose with a small amount of potassium, sodium, or titanium and, in some cases, other minerals. This coating provides protection to the molten or solidifying metal by developing a gaseous zone around the arc and a slag deposit over the weld.

(b) The mineral coatings consist of sodium silicate, metallic oxides, clay, and other inorganic substances or combinations thereof. With the mineral-coated electrode, protection to the molten or solidifying metal is provided only by a slag deposit.

(c) The combination of a mineral and cellulose coating is composed of various quantities of the substances previously described for each of these coatings. These coatings provide various protection effects to the arc, and to the molten or solidifying metal, depending on the type of base metal being welded.

e. *Functions of Electrode Coatings.* Some of the more important functions of the coatings on the shielded-arc or heavy-coated arc electrodes are described in the following subparagraphs.

(1) The coatings produce a reducing or nonoxidizing atmosphere around the arc; thus, preventing the contamination of the metal in the arc by oxygen and nitrogen from the air. Without this coating, the oxygen would readily combine with the molten metal, remove alloying elements from the metal, and cause porosity and oxidation of the weld. The nitrogen would cause brittleness, low ductility and, in some cases, low strength and poor resistance to corrosion.

(2) The coatings reduce impurities such as oxides, sulfur, and phosphorous so that these impurities will not impair the weld deposit.

(3) They provide substance to the arc, which tend to increase its stability, so that the arc can be maintained without excessive spattering.

(4) Coatings reduce the attractive force between the molten metal and the end of the electrode, and reduce the surface tension of the molten metal. Vaporized and melted coatings cause the molten

metal (at the end of the electrode) to break up into fine small particles.

(5) The coatings contain ingredients such as silicates that, when melted, form a slag over the melted weld and base metal. Since the slag solidifies at a relatively slow rate, it holds the heat and allows the underlying metal to cool and solidify slowly. This slow solidification of the metal precludes the trapping of gases within the weld and permits solid impurities to float to the surface. Slow cooling also has an annealing effect on the weld deposit.

(6) The physical characteristics of the weld deposit are modified by incorporating alloying materials in the electrode coating. Also, the fluxing action of the slag will produce a weld of a better quality and permit welding at higher speeds.

(7) The coating insulates the sides of the electrode so that the arc, at the end of the electrode, is concentrated into a confined area. This facilitates welding in a deep "U" or "V" groove.

(8) The coating produces a cup, cone, or sheath, as shown in figure 2, view A, on page 7, at the tip of the electrode, which acts as a shield, concentrates and directs the arc, reduces heat losses, and increases the temperature at the end of the electrode.

f. *Polarity of Welding Current* (figure 2, view B).

(1) The electrode polarity recommendations established by the manufacturer should be followed when a specific type of electrode is being used. The polarity recommended may be either "straight" or "reverse." In straight polarity, the electrode is in the negative side of the circuit. With reverse polarity, the electrode is in the positive side of the circuit.

(2) In general, straight polarity is used for all mild-steel, bare, or lightly coated electrodes. With electrodes of this type, the greater heat is developed at the workpiece being welded which is the positive side of the current. However, when heavy-coated electrodes are used, the gases given off in the arc may alter the heat conditions so

that the opposite is true and the greater heat is produced on the negative side. Electrode coatings affect the heat conditions differently, depending on their composition. One type of heavy coating may provide 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 reverse polarity.

(3) Reverse polarity is used in the welding of nonferrous metals such as aluminum, bronze, monel, and nickel. Reverse polarity is also used with some types of electrodes for making vertical and overhead welds.

(4) The proper polarity for a given electrode can be recognized when attempting a weld by the sharp, cracking sound of the arc. The wrong polarity will cause the arc to emit a hissing sound and the welding bead will be difficult to control.

g. *Direct Current Arc-welding Electrodes*.

(1) In general, direct current (dc), shielded-arc electrodes are designed either for reverse polarity (electrode positive) or for straight polarity (electrode negative) and are not interchangeable. Many, but not all, of the direct current electrodes, both reverse and straight polarity, also can be used with alternating current. Direct current is preferred for many types of bare and covered nonferrous and alloy steel electrodes. These electrodes are used when ferrous welds are to be made in horizontal, vertical, or overhead positions. Recommendations from electrode manufacturers include the type of base metal for which given electrodes are suitable.

(2) In most cases, straight polarity electrodes (electrode negative) will provide less penetration than the reverse polarity electrodes (electrode positive) and, for this reason, will permit greater welding speed. Good penetration can be obtained with either type under proper welding conditions and arc manipulation.

h. *Alternating Current Arc-welding Electrodes*.

(1) Coated electrodes that can be used with either direct or alternating current are available. Alternating current is more desirable under certain operating conditions. Alternating current reduces

arc blow (an unstable arc condition) that is particularly harmful when welding in corners or restricted places and when high currents, as required in thick sections, are used. Arc blow, in these cases, causes blowholes and slag inclusions in the weld as well as a lack of fusion.

(2) Alternating current is used in atomic hydrogen welding, and in those carbon-arc processes that 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 is recommended because the electrode is thus consumed at a slower rate.

i. *Electrode Defects and their Effects*.

(1) If certain elements, or their oxides, are present in electrode coatings, they will materially effect the stability of the arc. If these impurities are present in considerable quantities of light or heavy coatings, the electrodes will not be able to compensate for defects in the wire. In bare electrodes, because there is almost no coating on the wire, the composition and uniformity of the wire is an important factor in the control of arc stability. Impurities in the wire can cause the arc to become unstable.

(2) Aluminum or aluminum oxide, even when present in quantities not exceeding 0.01 percent, will cause the arc to become unstable. Silicon, silicon dioxide, and iron sulfate also tend to make the arc unstable. But, iron oxide, manganese oxide, calcium oxide, and iron sulfide tend to stabilize the arc.

(3) When phosphorous or sulfur are present in excess of 0.04 percent, they will impair the weld metal because they are transferred from the electrode to the molten metal. Phosphorous causes grain growth, brittleness, and "cold shortness" (brittle when below red heat) in the weld, and these defects increase in magnitude as the carbon content of the steel increases. Sulfur acts as a slag, breaks up the soundness of the weld metal, and causes "hot shortness" (brittle when above red heat). Sulfur is particularly harmful to bare, low-carbon steel electrodes with a low manganese

content. Manganese promotes the formation of sound welds.

(4) If the heat treatment given the wire core of an electrode is not uniform, the electrode will produce welds inferior to those produced with an electrode of the same composition which has been properly heat treated.

(5) This completes the discussion of classifying types and uses of electrodes. The succeeding paragraphs describe the welding processes, materials, and identification processes of automotive welding.

3. Automotive Welding Processes, Materials, and Identification

a. *Determining Weldability of Equipment*. Before repairing any damaged materiel, it is necessary to first determine whether or not the material can be satisfactorily welded. This determination can be made by considering the following factors:

(1) The nature and extent of the damage and the amount of straightening and fitting of the metal that will be required.

(2) The possibility of restoring the structure to an operable condition without welding it.

(3) The type of metal used in the damaged part, whether it was heat treated, and if so, what heat treatment was used.

(4) If the welding heat will distort the shape or in any manner impair the physical properties of the part to be repaired.

(5) Determine if heat treating or other equipment or materials will be required in order to make the repair by welding.

b. *Determining Weldable Parts*. Welding operations on Army materiel are restricted largely to those parts whose essential physical properties are not impaired by the welding heat. Successful welded repairs cannot be made on machined parts that carry a dynamic load. This applies particularly to high alloy steels that are heat treated for hardness or toughness, or both. Machined parts such as gears, shafts, anti-friction bearings, springs, connecting rods, pistons, valves, and cams are considered unsuitable for field welding. The principal reason for this is that these parts have been previously heat treated to create desirable performance characteristics (hardness or toughness); welding heat alters or destroys these characteristics.

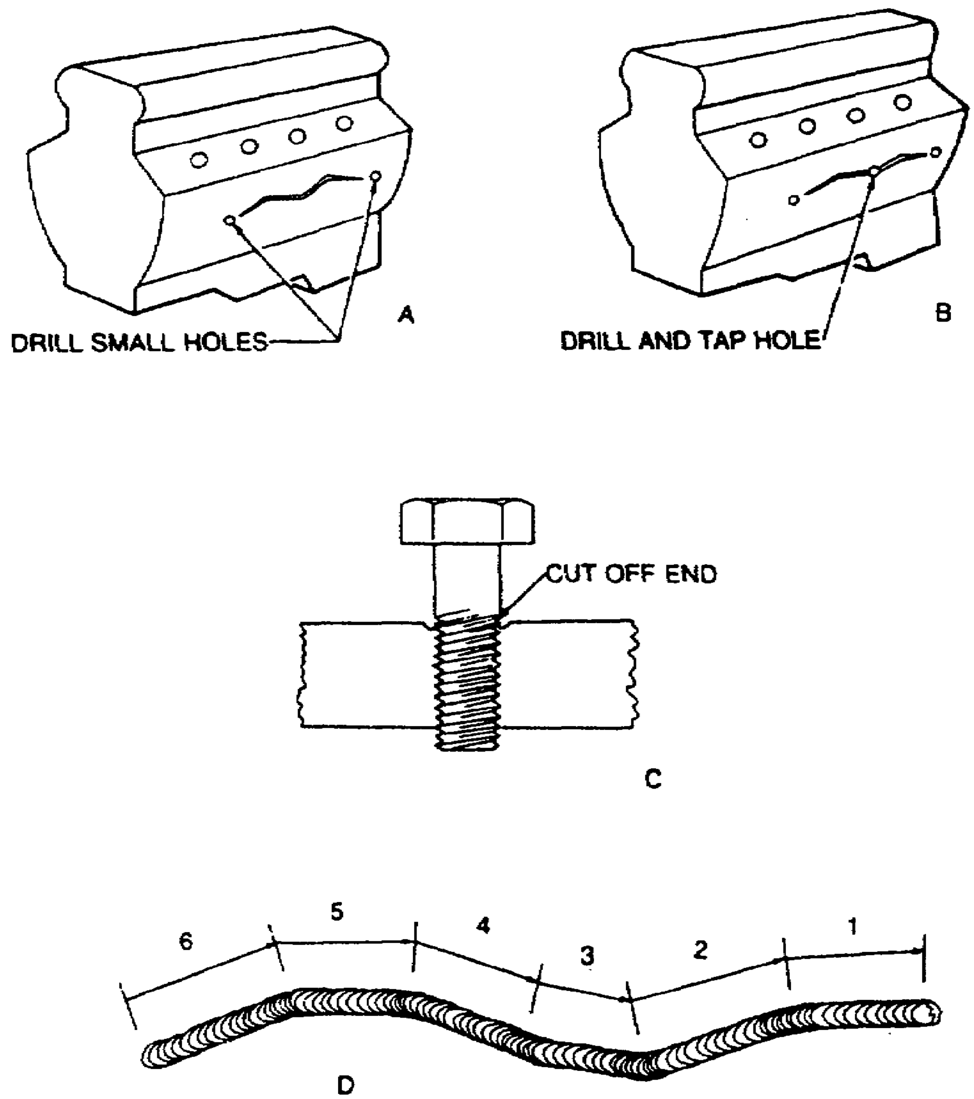
c. *Determining the Welding Method*. Automotive equipment such as trucks, tanks, truck-tractors, and other vehicles, are constructed from a large variety of metals that are heat treated under various processes. The metals used include copper alloys of various types, carbon and alloy steels, titanium, aluminum, magnesium, lead, among others. The principal joining processes that may be used are oxyacetylene, arc welding, brazing, and soldering. Oxyacetylene welding is used for welding of thin metals and brazing of cast iron parts on automotive equipment, while soldering is used for repairing such parts as fuel tanks, radiators, and electrical connections. This lesson, however, concentrates on the arc welding processes for repair of automotive equipment. For further information pertaining to oxyacetylene gas welding and soldering, refer to TM 9-237. The following subparagraphs describe weldable automotive parts and the methods of repair. This listing is an extract. A more complete list of repairable parts can be found in Tables B-2 and B-3 of TM 9-237.

(1) *Cast Iron, Cast Steel, Carbon Steel, and Forgings*. Generally, parts composed of these metals can be repaired by the same procedure as that used for their assembly or by brazing or soldering if the joining equipment originally used is not available or suitable for the purpose. For example, cast iron and cast steel may be repaired by gas welding, arc welding, or by brazing. Parts or sections made of carbon steel originally assembled by spot, projection, or flash welding may be repaired by gas or arc welding. This same procedure is true of forgings.

(2) *Cast Iron Engine Blocks* (figure 3, on the following page).

(a) *General*. Engine blocks may be repaired by welding or brazing in the field only under extreme emergency conditions and if a replacement block is not available. Welding or brazing of engine blocks is limited to those areas described below:

FIGURE 3. PREPARING ENGINE BLOCK FOR WELDING.



1 Accessory mounts such as generator, starter, or engine mounts. Because of possible warpage, mount alignment must be checked after welding.

2 Small sand pits (casting defects) detected at time of ovl usually be too porous and must be removed and the weld repeated until a sound first pass is obtained.

(b) *Procedure*. Both the shielded metal-arc method and brazing with oxyacetylene may be used for repair of cracks in cast iron engine blocks. When using the shielded metal-arc method of repair, a welding rod with a high nickel content of at least 50 to 60 percent must be used. Cracks in a cast iron engine block must be properly prepared prior to welding, otherwise (after cooling), the weld deposit shrinks, which pulls the crack together and results in the formation of internal stress. This stress finally relieves itself by cracking due to continued vibration during engine operation. Subsequent paragraphs provide the steps that should be followed to eliminate this stress and effectively repair the crack.

1 Drill a 1/8 inch diameter hole 1/4 inch beyond each end of the crack as shown in figure 3, view A, on the previous page.

2 Clean and groove the crack and remove the "as cast" surface or skin by grinding or machining.

3 Preheat the casting by baking or locally heating the casting at 1000° Fahrenheit for a few minutes to remove all moisture. (It is imperative that all moisture be removed, otherwise the weld will not adhere to the base metal.)

4 Drill and tap a hole to receive a 1/4 inch bolt in the center of the crack as shown in figure 3, view B. Screw and tighten a bolt slightly deeper than the thickness of the base metal. Stake the sides of the bolt with a center punch so that it will not back out, and cut off the bolt as shown in figure 3, view C.

5 Weld the crack using the backstep method shown in figure 3, view D, and peen each bead with a round nose tool.

6 The minimum preheat and interpass temperature should not be below 400° to 500° F when using a nickel rod, and the weld should not be allowed to cool when applying more than one pass. If all the impregnated oil or gas is not eliminated during preheating, the first pass will usually be too porous and must be removed and the weld repeated until a sound first pass is obtained.

7 Allow the completed weld to cool slowly by placing an asbestos blanket over the welded area.

Nonuniform or rapid cooling will create internal stresses. Welded engine blocks must be leak tested before placing them back in operation. Leak testing procedures are specified in TM 9-237.

(3) *Heat Treated Parts*.

(a) The functions performed by certain parts in automotive equipment require heat treatment during their manufacture. Welding of these parts should not be attempted unless the repair shop is equipped with suitable heat treating equipment for handling these parts after welding.

(b) In some cases, alloy steels, or specially treated parts, may be repaired by using a heat affected zone that is weaker than the original heat treated part. In general, where it is possible to heat treat the parts after welding, they should be annealed prior to welding them. Filler metal of the same composition or properties as the base metal should be used, and the parts heat treated after welding.

(c) In cases where the part to be welded is in a heat treated condition, a stainless steel filler rod and the transition bead welding method may be used as described below:

<u>1</u> Deposit a layer of stainless steel (25 percent chromium, 20 percent nickel, or modified 18 percent chromium, 8 percent nickel stainless steel rod) on the surfaces of the broken edges.

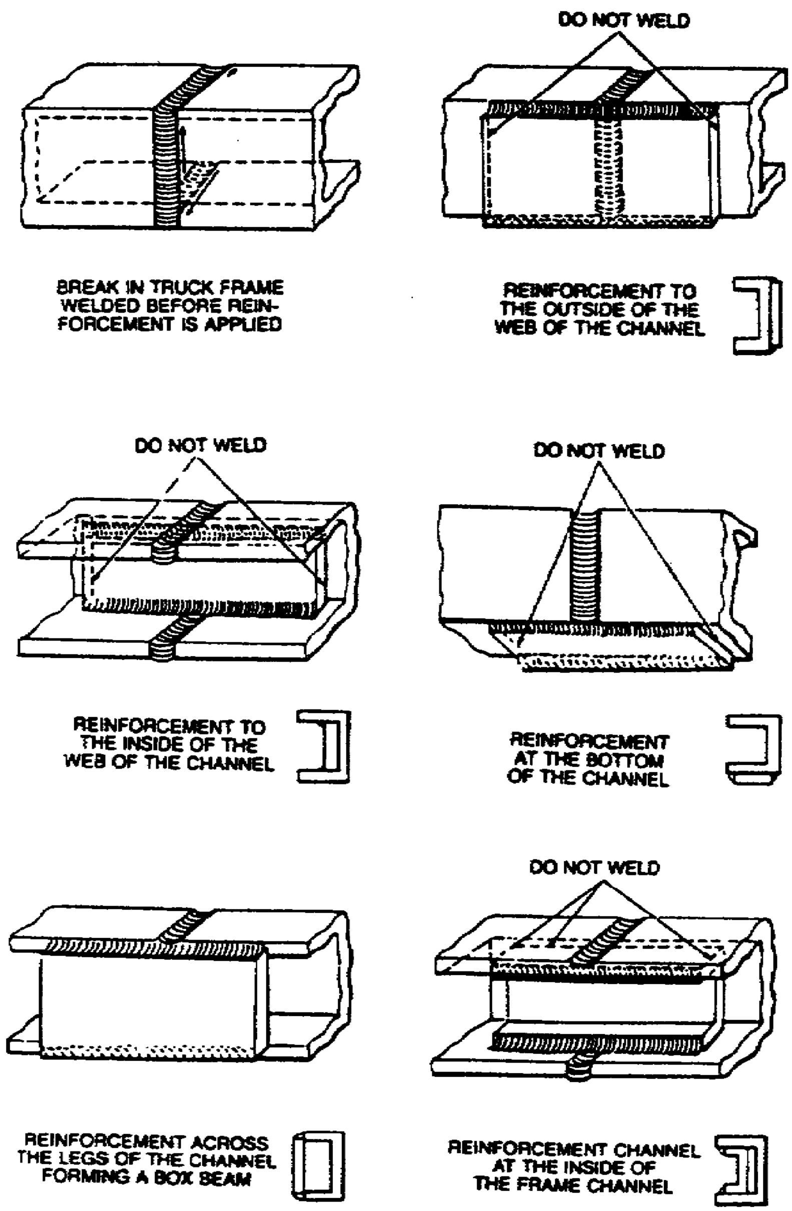
<u>2</u> Weld the prepared edges with mild steel or high strength filler metal. Use 11 to 14 percent manganese or high strength filler metal on the stainless steel layer instead of mild steel where hardness and toughness are required. The weld then may be covered with a layer of hard surfacing metal.

(d) These methods are useful in the field, but should be used under emergency conditions only.

(4) *Wheel Vehicle Components*.

(a) *Frames*. The repair of frames by welding is not authorized. Crossmembers and horns for the frame may be straightened, repaired, and reinforced. A commonly used method of repairing and strengthening a broken or weakened crossmember or horn is performed by using reinforcing plates as shown in figure 4. This method of repair should be followed when reinforcement plates are welded to angles, tees, box sections, or I-beams. The type of reinforcement selected depends on the location of the repair and possible interference with the

FIGURE 4. REINFORCING FRAME MEMBERS.



operation of components. All protrusions should be ground down flush before reinforcing plates are applied. Reinforcement plates should be approximately the same thickness as the frame section and the width sufficient to bring the weld flush with the top and bottom sections of the channel. It should be noted that the welded ends of the plates produce heat affected areas of decreased strength across the back and legs of the channel.

(b) *Front Axles*. Front axles are made of heat treated alloy drop forgings. Repairs by welding should not be made on these axles except as a temporary measure under extreme emergency conditions.

(c) *Rear Axle Housings*. These components are made of welded pressed steel or malleable cast iron or cast steel. The pressed steel and cast steel housings can be arc welded. The malleable iron housings should be repaired by brazing; although, they can be welded if extreme precautions are maintained. Castings should be kept clean in the vicinity of the weld.

(d) *Drive Shafts*. Drive shafts are usually made of medium carbon steel seamless tubing and are readily weldable by either arc or gas welding.

(e) *Machined Alloy Steel Parts*. These type parts such as crankshafts, connecting rods, gears, and axle drive shafts are not generally repaired by welding because the heat of welding will impair the metal qualities produced by previous heat treatment.

(f) *Radiators*. Radiators can be repaired with an oxyacetylene welding torch containing a proper tip, common 50-50 solder, and flux. The oxyacetylene flame should be adjusted to give a slight carburizing mixture. The areas around the leaks in the copper tubes should be thoroughly cleaned, preferably with a 5 percent solution of hydrochloric acid, and tinned before the joint is made in order to ensure a tight joint. For leaks between copper and cast iron, the surface of the iron should be pickled before the repair is made. Pickling the surface of the iron is done by applying a 5 percent hydrochloric acid solution to it at the joint and heating it until thoroughly cleaned.

(5) *Combat Vehicles*. Tank hulls are constructed of armor plate for protection of the crew and to which the internal and external mechanisms of the tank are fastened to the hull. The suspension system consists largely of castings and forgings. Various castings are used throughout the powertrain. Component parts that do not carry the driving power load can be repaired by welding. In general, the repair of these parts requires special precautions such as preheating, postweld heat treatments, and the proper welding procedure. One of the principal repairs performed on combat vehicles is welding damage sections of armor plate. The technique for welding armor plate will be discussed in Task 2. The following paragraphs describe the type and techniques of joint design.

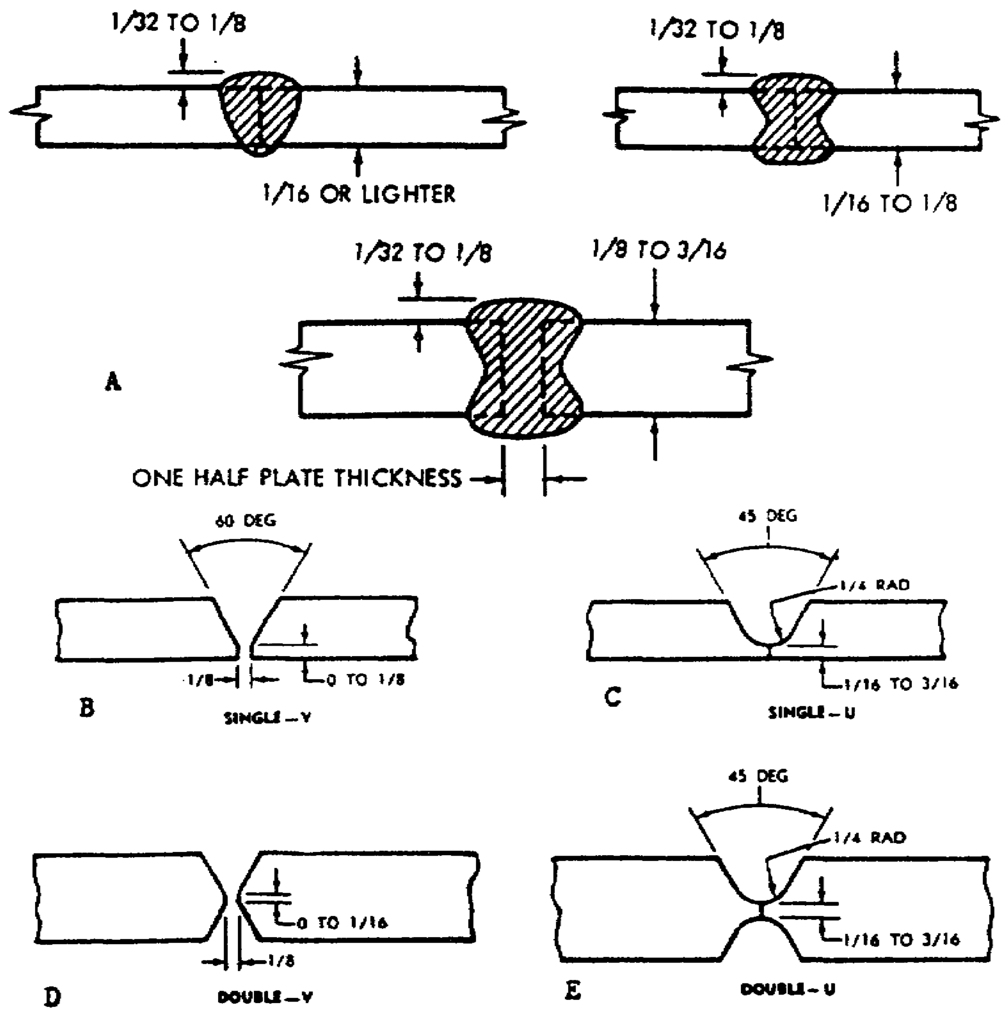
4. Welding Joint Design

a. *General*. The properties of a welded joint depend partly on the correct preparation of the edges being welded. The joint edges should be cleaned of all rust, oxides and other impurities, and prepared to permit fusion without excessive melting. This preparation is governed by the form, thickness, kind of metal, the load to be supported, and the available means for preparing the joint.

b. *Types of Joints*. There are basically five types of joints used to weld various forms of metal. These types of joints are described in the following subparagraphs.

(1) *Butt Joint* (figure 5 on the following page). This type joint is used for joining the edges of two plates or surfaces located approximately in the same plane. Plain square butt joints for thin metal sections are shown in figure 5, view A. These joints are used for butt welding light sheet metal. Butt joints for heavy sections with several types of edge preparation are shown in figure 5, views B through E. These edges can be prepared by flame cutting, shearing, flame grooving, machining, chipping, or grinding. Plate thicknesses of 3/8 to 1/2 inch can be welded using the single V or single U joints as shown in figure 5, views B and C. The edges of heavier sections should be prepared as shown in figure 5, views D and E. In general, butt joints prepared from both sides permit easier welding, produce less distortion, and ensure better weld metal qualities in heavy sections than joints prepared from one side only.

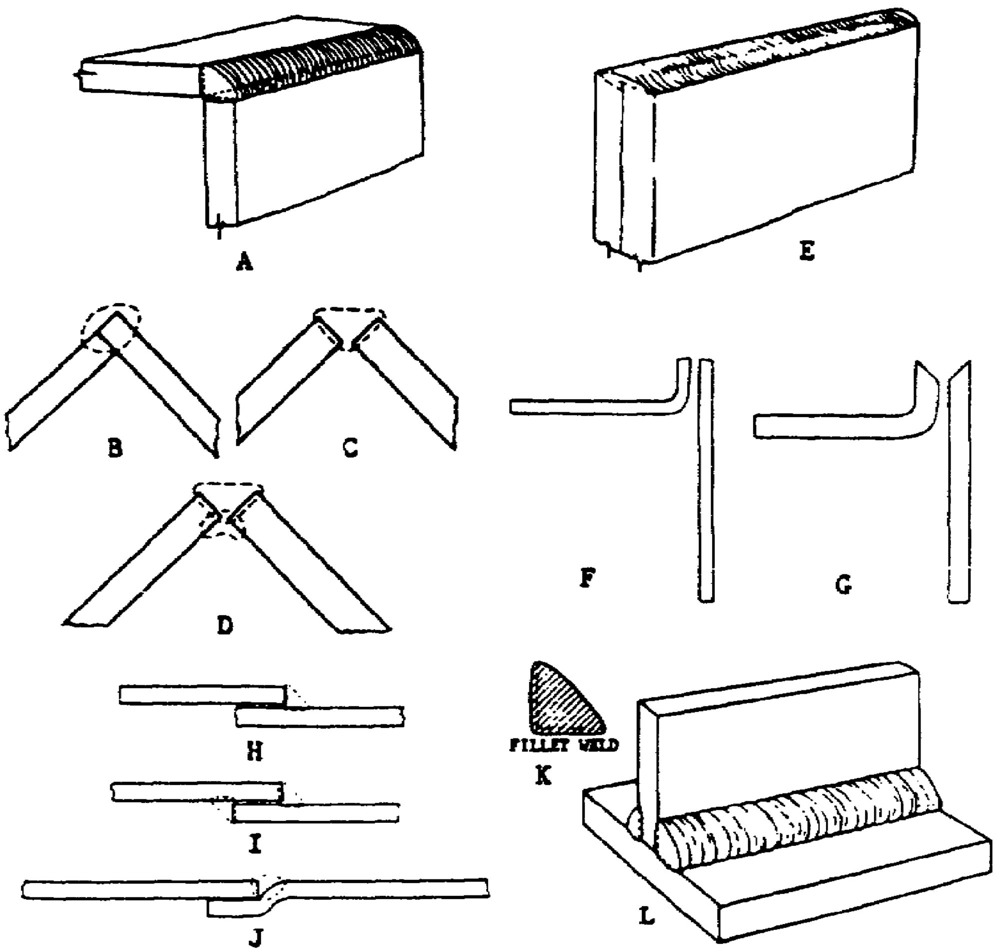
FIGURE 5. BUTT JOINTS.



NOTE: ALL DIMENSIONS SHOWN ARE IN INCHES

(2) *Corner Joint* (figure 6, views A through D, on the following page). This type joint is used to join two members located approximately at right angles to each other in the form of an L. The fillet weld corner joint, shown in figure 6, view A, is used in the construction of boxes, box frames, tank containers and similar fabrications. The closed corner joint, shown in figure 6, view B, is used on lighter sheets when high strength is not required at the joint. When using oxyacetylene welding, the overlapping edge is melted down and

FIGURE 6. CORNER, EDGE, LAP, AND TEE JOINTS.



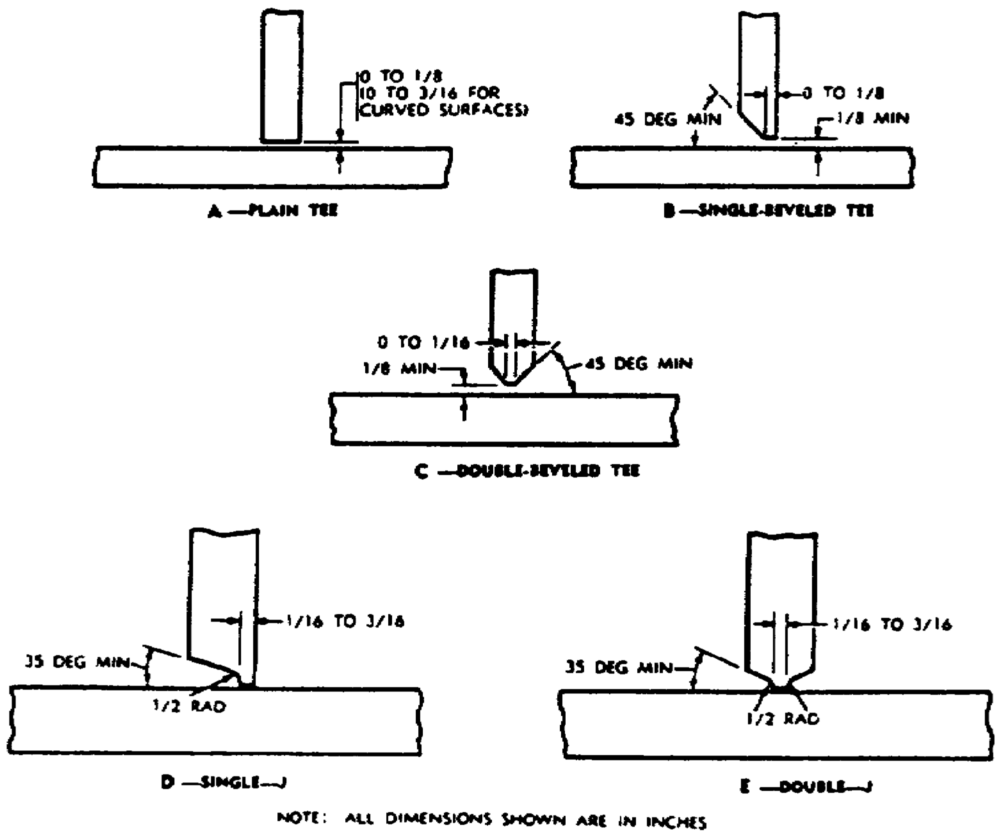
little or no filler metal is added. In arc welding, only a very light bead is required to make the joint. The open corner joint, shown in figure 6, view C, is used on heavier sheets and plates; the two edges are melted down and filler metal is added to fill up the corner. Corner joints on heavy plates are welded from both sides as shown in figure 6, view D. The joint is first welded from the outside, then reinforced from the back side with a seal bead.

(3) *Edge Joint* (figure 6, views E, F, and G on the previous page). This type joint is used to join two or more parallel members such as edges of sheet metal, angles, mufflers, liquid tank containers, assembly housings, and reinforcing plates in flanges of I beams. Two parallel plates are joined together as shown in figure 6, view E. On heavy plates, sufficient filler metal is added to fuse or melt each plate edge completely and to reinforce the joint. Light sheets are welded as shown in figure 6, view F. No preparation is necessary other than to clean the edges and tack weld them in position. The edges can then be fused together without filler metal required. The heavy plate joint shown in figure 6, view G, requires that the edges be beveled for good penetration and fusion of the side walls. Filler metal is used in this joint.

(4) *Lap Joint* (figure 6, views H, I, and J). This type of joint is used to join two overlapping members. A single lap joint, where welding must be done from one side, is shown in figure 6, view H. The double lap joint shown in figure 6, view I, is welded on both sides and develops the full strength of the welded members. The offset lap joint shown in figure 6, view J, is used where two overlapping plates must be joined and welded in the same plane. The offset lap joint is stronger than the single lap type, but is more difficult to prepare.

(5) *Tee Joint*. Tee joints are used to weld two plates or sections whose surfaces are located approximately 90 degrees to each other at the joint. A plain tee joint welded from both sides is shown in figure 6, view L. A plain tee joint, requiring only cleaning the end of the vertical plate and the surface of the horizontal plate, is shown in figure 7, view A, on the following page. The single bevel joint shown in figure 7, view B, is used in plates and sections up to 1/2 inch thick. The double bevel joint shown in figure 7, view C, is used on heavy plates that can be welded from both sides. The single J joint shown in figure 7, view D, is used for welding plates 1 inch thick or heavier where welding is done from one side. The double J joint shown in figure 7, view E, is used for welding very heavy plates from both sides.

FIGURE 7. TEE JOINT EDGE PREPARATION.



c. *Types of Welds*. The type of weld used will determine the manner of seam, joint, or surface preparation. A listing of the different welds used is provided in the following subparagraphs.

(1) *Groove Weld* (figure 8 on the following page). These are welds that are made in a groove between two members to be joined. In this position, the axis of the weld lies approximately in a horizontal plane and the face of the weld lies approximately in a vertical plane.

(2) *Surfacing Weld* (figure 9 on page 25). This type weld is composed of one or more string or weave beads deposited on an unbroken surface to obtain desired properties or dimensions.

FIGURE 8. GROOVE WELDS.

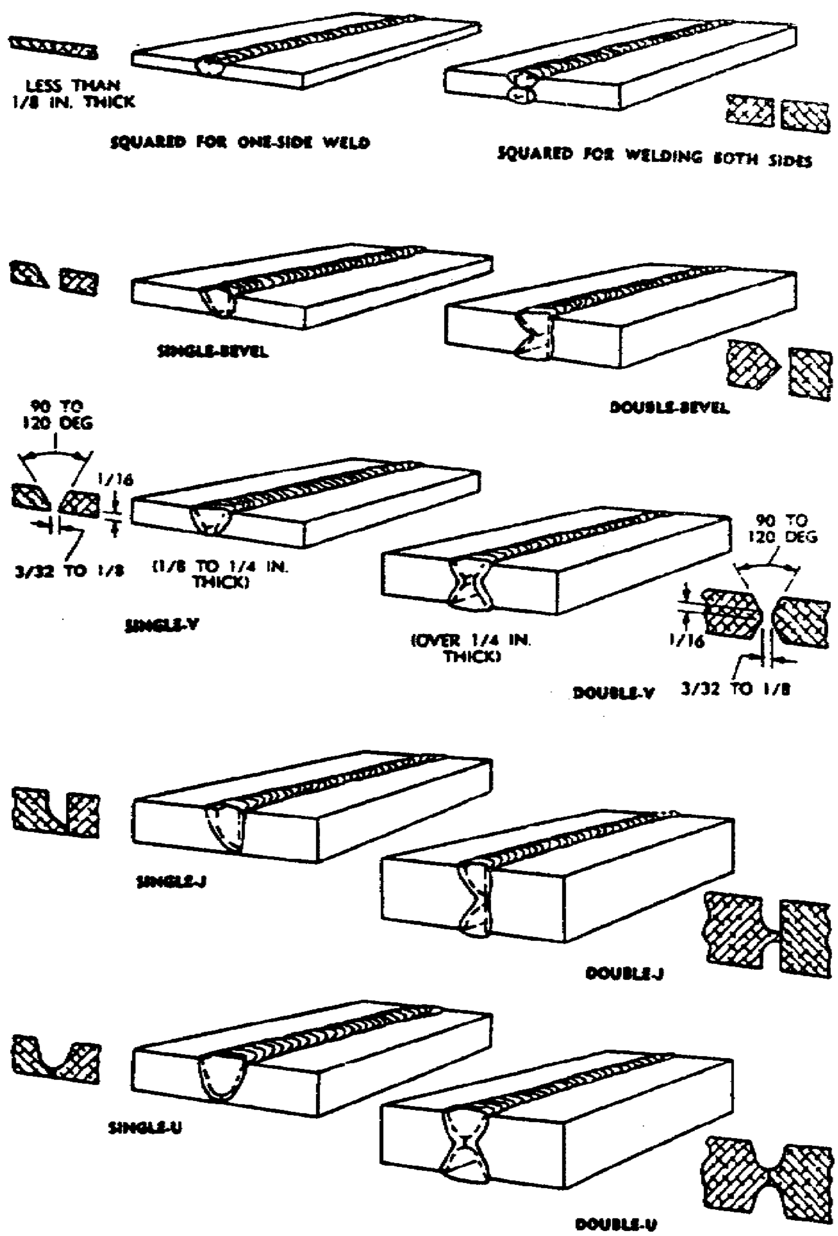
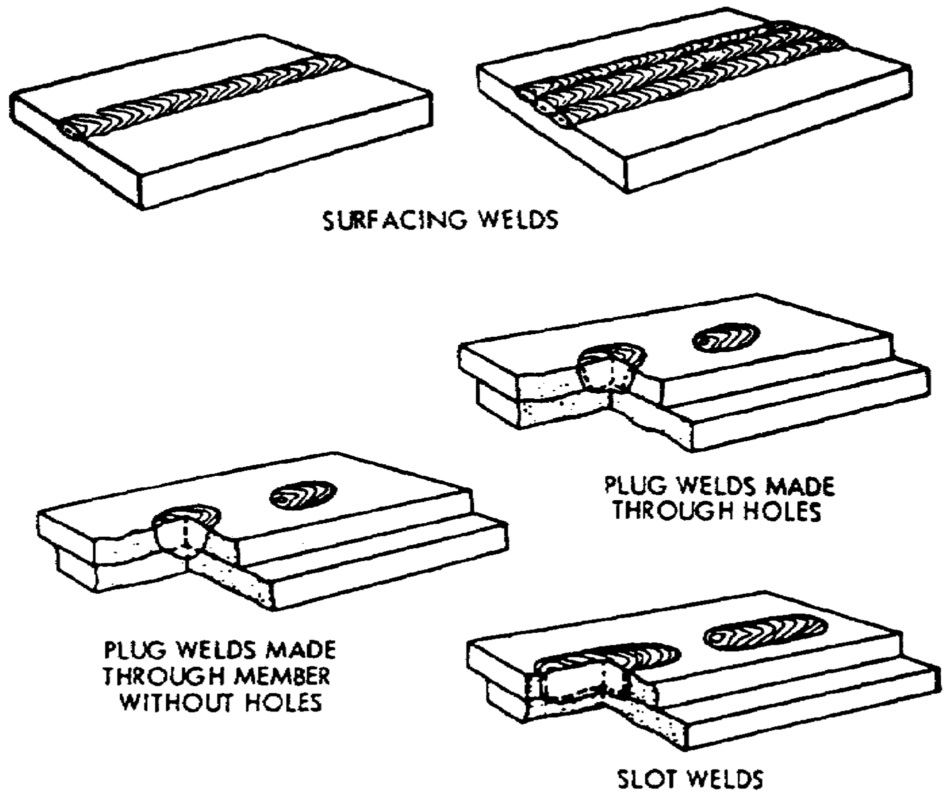


FIGURE 9. SURFACING, PLUG AND SLOT WELDS.



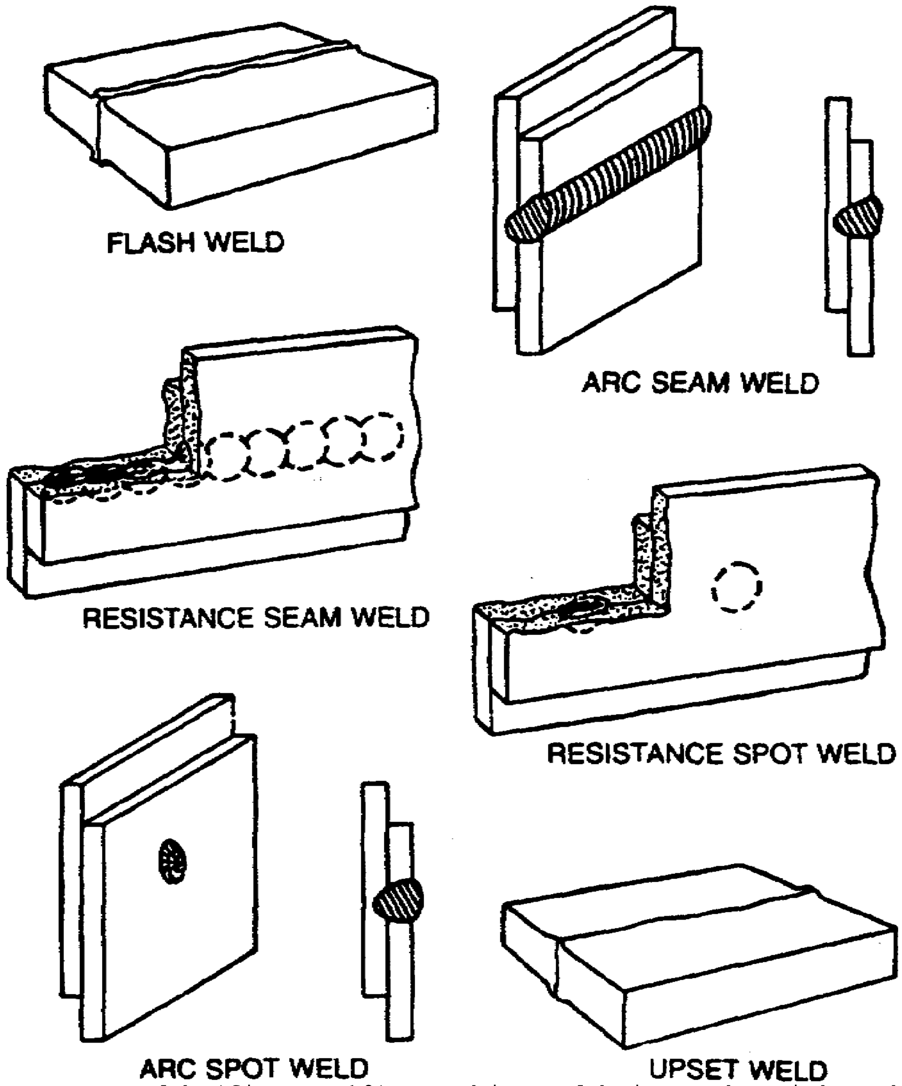
(3) *Plug Weld* (figure 9). This is a circular weld made through one member of a lap or tee joint joining that one member with the other. This type weld may or may not be made through a hole in the first member.

(4) *Slot Weld* (figure 9). This weld is made in an elongated hole in one member of a lap joint or tee joint joining that member to the surface of the other member that is exposed through the hole.

(5) *Fillet Weld*. This type weld is shown in figure 6, view L, on page 21. It is a triangular cross section weld joining two surfaces at right angles to each other.

(6) *Flash Weld* (figure 10 on the following page). This weld is made by the application of pressure over the entire area of abutting surfaces after heating them is completed.

FIGURE 10. SEAM, SPOT, FLASH, AND UPSET WELDS.



(7) *Seam Weld* (figure 10). This weld is made either by arc seam welding in which a continuous weld is made along fraying surfaces by drawing the arc between the electrode and the workpiece, or by resistance seam welding where the weld is a series of overlapping spot welds made progressively along a joint by rotating the circular electrodes.

(8) *Spot Weld* (figure 10 on the previous page). This is a weld made by either arc spot welding where a weld is made in one spot by drawing the arc between the electrode and the workpiece, or resistance spot welding where the size and shape of the individually formed welds are limited by the size and contour of the electrodes.

(9) *Upset Weld* (figure 10). This is a weld made simultaneously over the entire area of abutting surfaces or progressively along a joint while pressure is applied before heating is started and is maintained throughout the heating period.

d. *Welding Positions* (figure 11 on the following page). All welding can be classified according to the position of the workpiece or the position of the joint on the plates or sections being welded. There are four general positions in which welds are required to be made. These positions are designated as flat, horizontal, vertical, and overhead.

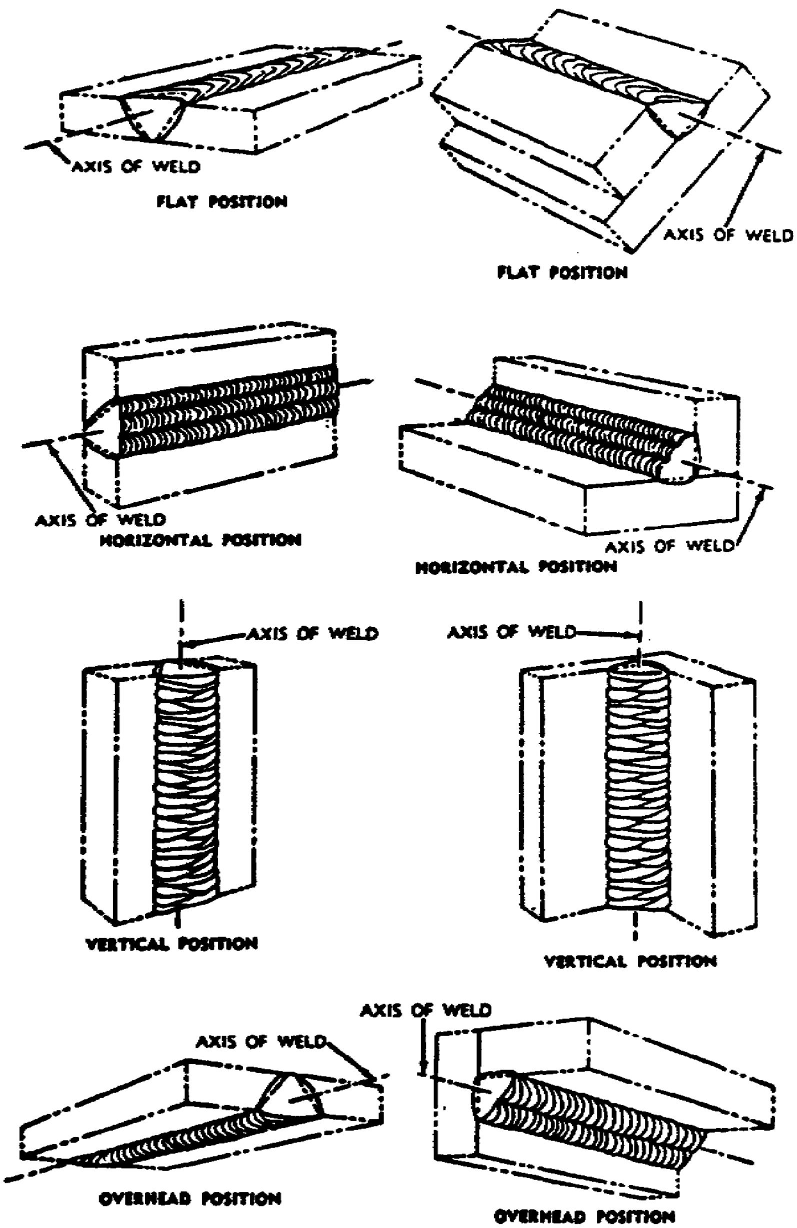
5. Welding Techniques

a. *General*. In metal-arc welding a number of separate factors are responsible for the transfer of molten filler metal and molten slag to the base metal. Among these are the techniques employed in the actual process of welding. The following subparagraphs serve to describe these techniques.

b. *Welding Current, Voltage, and Adjustments*.

(1) The selections of the proper welding currents and voltages depend on the size of the electrode, the thickness of the plate being welded, the welding position, and the welder's skill. Electrodes of the same size can withstand higher current and voltage values when welding in the flat welding position than in vertical or the overhead welding position. In general, the proper current and voltage settings are obtained from experience and should fill the requirements of the particular welding operation. Since several factors affect current and voltage requirements, data provided by welding apparatus and electrode manufacturers should be used. For initial

FIGURE 11. WELDING POSITIONS.



settings, table 1, indicates the current to be used when welding with bare or lightly coated electrodes. The arc voltage will vary from approximately 15 volts for 1/16 inch electrodes to 30 volts for 3/8 inch electrodes of either the bare or lightly coated types. Usually, a 3/16 inch diameter electrode is the maximum size for vertical and overhead welding positions.

TABLE 1. CURRENT SETTINGS FOR BARE AND LIGHTLY COATED ELECTRODES.

Electrode Diameter (inch)	*Amperes Minimum*	*Amperes Maximum*	*Electrode Lengths (inch)*
1/16	**40**	**60**	**11-1/2**
3/32	**70**	**90**	**14 or 18**
1/8	**110**	**135**	**14 or 18**
5/32	**150**	**180**	**14 or 18**
3/16	**180**	**220**	**14 or 18**
***1/4**	**250**	**300**	**14 or 18**
***5/16**	**300**	**425**	**14 or 18**
***3/8**	**450**	**550**	**14 or 18**

*** These diameters are for flat position only.**

(2) The mineral-coated type of shielded-arc electrode, which produces a slag as a shield, requires a higher welding current than the cellulose-coated type, which produces a large volume of gas to shield the arc stream. Table 2 on the following page shows the current requirements for the mineral-coated and the cellulose-coated types of electrodes. The welding voltage will range from 20 volts for the 3/32 inch electrode to 30 volts for the 3/8 inch heavy-coated electrodes of either type.

(3) Shielded-arc or heavy-coated electrodes are used for most welding operations on steel rather than the bare or lightly coated types. The heavy-coated electrodes allow higher welding speeds, provide alloying elements into the weld metal by means of the coating on the electrode, as is done with certain stainless steel electrodes. The shielded-arc type of electrode is used for welding nonferrous metals and certain alloy steels, particularly, stainless steel alloys.

TABLE 2. CURRENT SETTINGS FOR MINERAL AND CELLULOSE COATED ELECTRODES.

Electrode Diameter (inch)	Mineral-Coated Position (amperes) Flat	Vertical	Cellulose-coated Position (amperes) Flat	Vertical
3/32	60	60	---	---
1/8	120	110	130	110
5/32	150	140	160	140
3/16	175	160	200	160
1/4	250	---	300	---
5/16	325	---	400	---
3/8	425	---	500	---

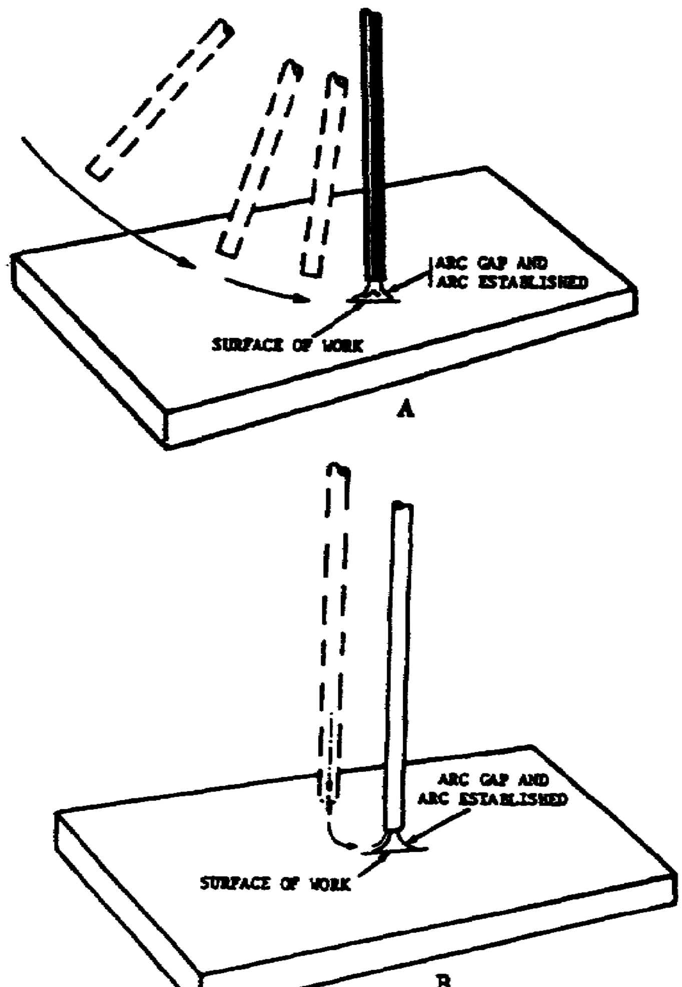
(4) In preparation for welding, the welding machine must be adjusted to provide proper welding conditions for the particular size and type of electrode being used. These adjustments include proper polarity, as well as current and voltage settings. The dual-control machines make possible the separate control of voltage and current that is delivered to the arc. In single-control units, the welding current is controlled manually while the voltage is adjusted automatically.

(5) When proper adjustment of the welding machine is obtained, the exposed end of the electrode should be gripped in the electrode holder so that the entire usable length can be deposited, without breaking the arc. In some cases, when welding with long electrodes, the center of the electrode is bared and gripped in the center. Carbon and graphite electrodes should be gripped short of the full length to avoid overheating the entire electrode.

c. *Starting the Arc* (figure 12 on the following page).

(1) The following are two methods used for starting the arc: (1) the striking or brushing method shown in figure 12, view A, and (2) the tapping method shown in figure 12, view B. In both methods, the arc is formed by short circuiting the welding current between the electrode and the work surface. The surge of high current causes both the end of the electrode and a small spot on the base metal beneath the electrode to melt instantly.

FIGURE 12. STARTING THE ARC.



(2) In the striking and brushing method, the electrode is brought down to the work with a lateral motion similar to that of striking a match. As soon as the electrode touches the work surface, the electrode is raised to establish the arc. The arc length or gap between the end of the electrode and the work should be approximately equal to the diameter of the electrode. When the proper length of the arc is obtained, a sharp crackling sound can be heard.

(3) In the tapping method, the electrode is held in a position vertical to the surface of the work.

The arc is established by lowering the electrode, tapping or bouncing it on the work surface, then slowly raising it a short distance, approximately the diameter of the electrode. When the proper length of arc is obtained, a sharp crackling sound can be heard.

(4) If the electrode is withdrawn too slowly, with either arc starting method described above, it will stick or freeze to the plate or base metal. If this occurs, the electrode can usually be freed by a quick sideways wrist motion to snap the end of the electrode from the plate. When this method fails, remove the electrode holder from the electrode or stop the welding machine and free the electrode with a light chisel blow.

WARNING

If the electrode becomes frozen to the base metal during the process of starting the arc, all work to free the electrode when the current is on should be done with the face shield pulled down over the eyes.

(5) Some electrodes, known as contact electrodes, are normally struck by holding them in contact with the work. These electrodes are used mostly by private industry rather by the Army in the field.

(6) Two procedures, described in the following subparagraphs, are used to break the arc.

(a) In manual welding, when the electrode is changed and the weld is to be continued from the crater, the arc is shortened and the electrode moved quickly sideways out of the crater. When the arc is re-established it is started at the forward or cold end of the crater, moved backward over the crater, then forward again to continue the weld. The crater is also filled by this procedure.

(b) In semiautomatic welding, where filling or partial filling of the crater is required, the electrode is held stationary for a time sufficient to fill the crater and then is gradually withdrawn until the arc breaks.

d. *Proper and Improper Arc Control*.

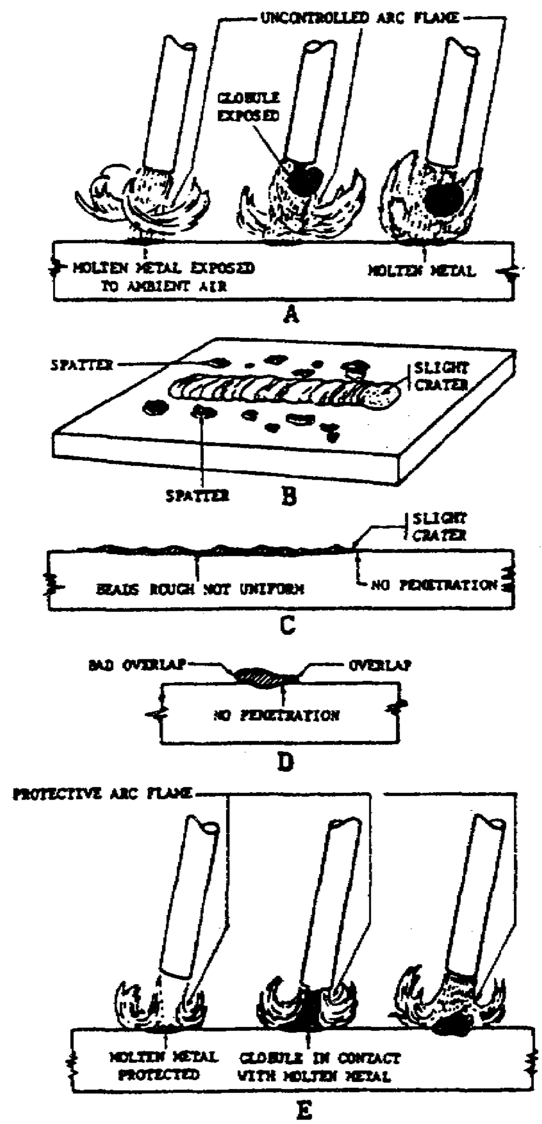
(1) *Maladjustments*. Table 3 provides a listing of the effects on welding as a result of improper current, voltage, and welding speed control.

TABLE 3. EFFECTS OF MALADJUSTMENTS OF WELDING CURRENT VOLTAGE AND SPEED ON THE BEAD CHARACTERISTICS.

Operating Conditions	Arc Sound	Electrode Melting Rate	Crater Appearance	Bead Appearance	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 and 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, but not as deep as with high current weld.	Wide and very thin.	Deep and irregular.	Pronounced but less than with high current.
Low voltage.	Hissing and steady sputtering sound.	Flux coating melts very slowly, interferes with welding.	Shallow, longer than crown, some overlap, wider than with low current.	Porous rounded high crown, some overlap, wider than with low current.	Slight and irregular.	Slight.
High welding speed.	Sharp crackling sound.	Balanced for good welding.	Long and shallow.	Narrow, irregular, some undercutting.	Very slight and 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 no overlap.	Deep and good.	Very slight.

(2) *Long Arc* (figure 13). When welding with a long arc, as shown in figure 13, view A, the protecting arc flame, as well as the molten globule at the end of the electrode, will whirl and oscillate from side to side. The fluctuating flame will permit the molten base metal to become

FIGURE 13. ARC CHARACTERISTICS, AND DEFECTS.



oxidized or burned before reaching the molten metal. The direction of the molten filler metal, as it passes through the arc, will be difficult to control and a considerable portion of this metal will be lost as spatter. The long arc will melt the electrode quickly, and the metal is not always deposited at the point desired. In general, the long arc results in poor weld penetration, excessive overlap, and burned and porous metal in the weld as shown in figure 13, views B through D, on the previous page.

(3) *Short Arc*.

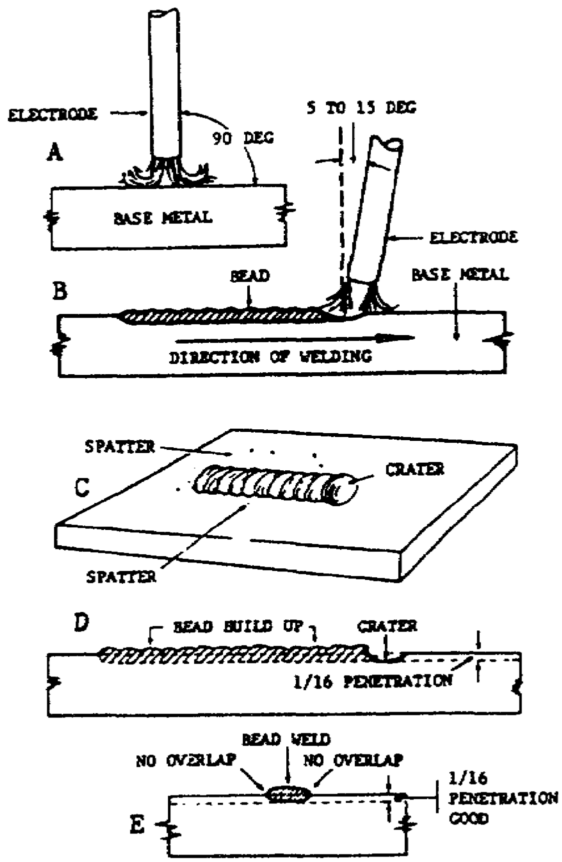
(a) The short arc (figure 13, view E) is the correct and desired procedure for welding. With the short arc, the molten metal leaving the end of the electrode passes from the atmosphere by way of an enveloping arc flame. The short arc permits better control of the weld metal deposited resulting in a welded bead of better quality. Generally, a short arc provides maximum penetration and better physical properties in the weld and deposits the maximum amount of metal at the point of welding. Porosity, overlap, and weld metal spatter are kept to a minimum.

(b) A very short arc, however, is undesirable. It will produce much spatter, will go out frequently, and make continuous welding difficult; the results being similar to those shown in figure 13, view B.

e. *Bead Welding* (figure 14 on the following page).

(1) When the arc is struck, metal particles melt off the end of the electrode and are deposited in the molten puddle on the surface of the work. As the electrode melts it becomes shorter and causes the arc to increase in length unless the electrode is fed down to the work as fast as the end is melted off and deposited. Before moving the electrode forward, the arc should be held at the starting point for a short time to ensure good fusion and to allow the bead to build up slightly. When the welding machine is adjusted for proper current and polarity, good bead welds can be made by maintaining a short arc and welding in a straight line at a constant speed.

FIGURE 14. CORRECT ELECTRODE POSITION FOR WELDS AND PROPER BEAD WELDS.



NOTE: ALL DIMENSIONS SHOWN ARE IN INCHES

(2) For bead welding, the electrode should be held at or near a 90 degree angle to the base metal as shown in figure 14, view A. 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 toward the direction of travel as shown in figure 14, view B.

(3) The proper arc length cannot be accurately judged by the eye, but can be recognized by the sound of the arc. When bead welding with a short arc, the typical sharp, crackling sound should be heard all the time the electrode is in contact and being moved along the surface of the work.

(4) A properly made bead weld should leave little spatter on the surface of the work (figure 14, view C, on the previous page). When the arc is broken, the crater or depression in the bead, shown in figure 14, view C, should be built up slightly. This metal build-up should not overlap the top surface of the weld. An overlap would indicate poor fusion at this point of the weld. The depth of the crater at the end of the bead can also be used as an indication of penetration into the base metal.

f. *Flat Position Welding* (figure 15 on the following page).

(1) *Butt Joints in the Flat Position*. A butt joint is used to join two plates having surfaces in approximately the same plane. Several forms of joints are used to make butt welds in the flat position. The most important of these forms are described in the following subparagraphs.

(a) Plates 1/8 inch thick can be welded in one pass without any special edge preparation being necessary. Plates from 1/8 to 3/16 inch thickness can be welded with no special edge preparation by making a bead weld on both sides of the joint. Tack welds should be used to keep the plates aligned for welding. The electrode motion is the same as that used in making a bead weld.

(b) When welding 1/4 inch or heavier plates, the edges of the plates should be prepared by beveling or by "J," "U," or "V" grooving, whichever is the most applicable. Single or double bevels or grooves may be used depending on 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 (also referred to as a layer or weld metal) must be thoroughly cleaned to remove all slag before the second layer of metal is deposited. When making multipass welds (figure 16, view A, on page 39), the second, third, and fourth layers of weld metal are deposited using any of the weaving motions of the electrode, as shown in figure 16, view B. Each layer of metal must be cleaned before depositing the succeeding layers.

FIGURE 15. FLAT POSITION WELDING.

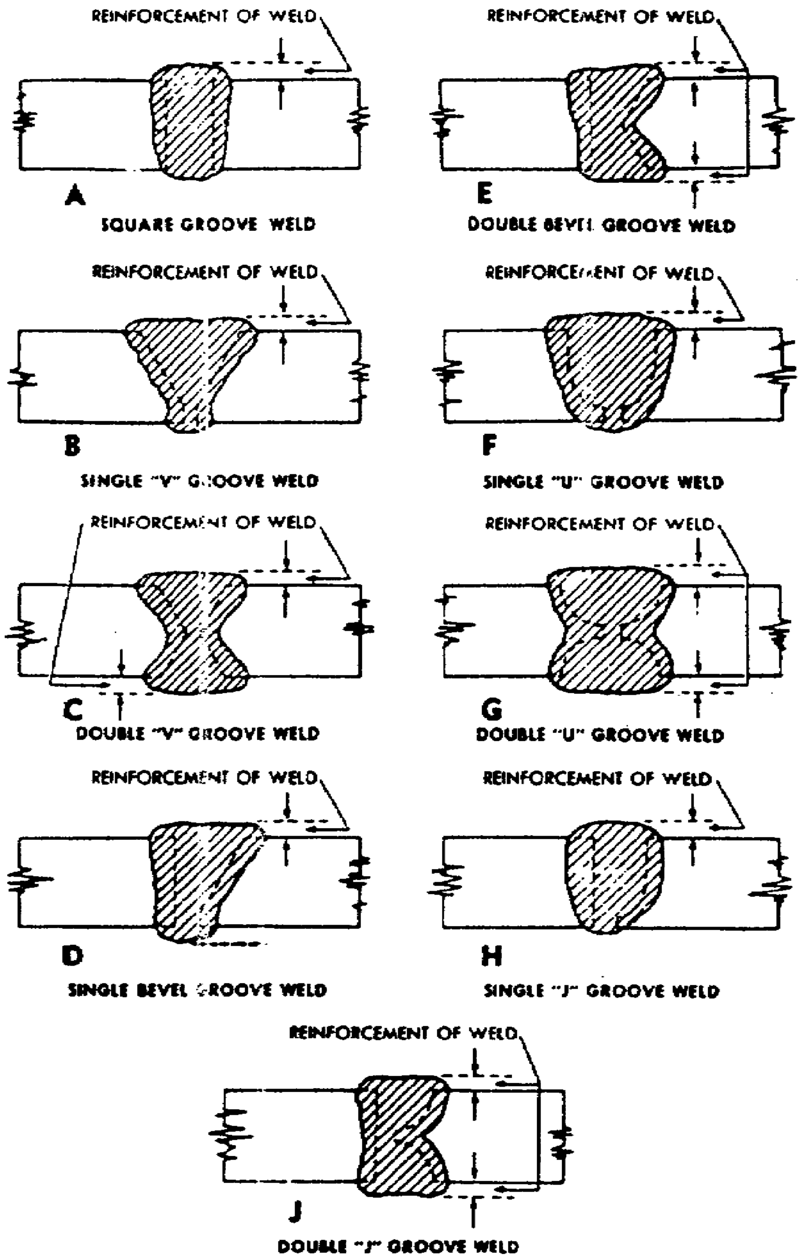
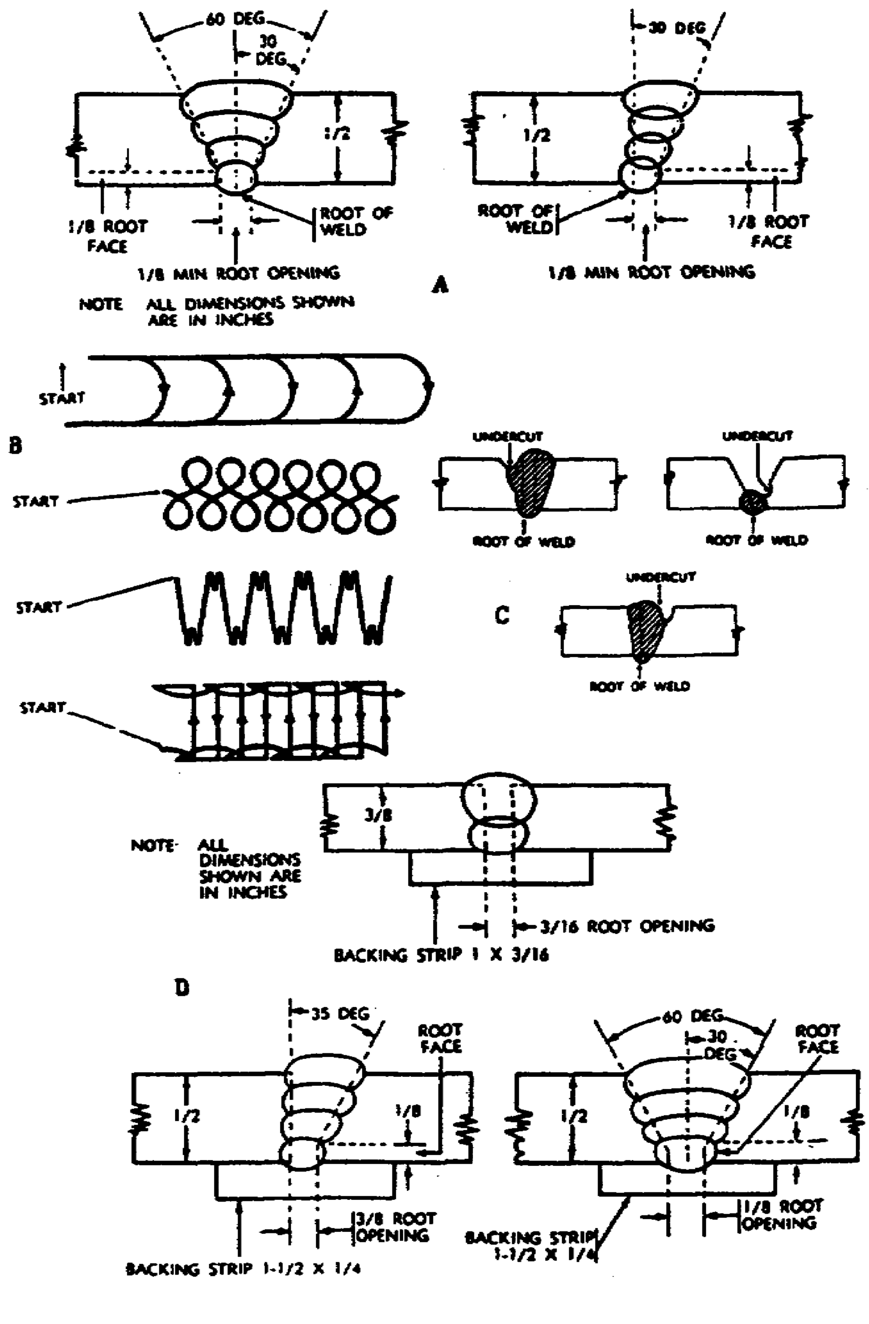


FIGURE 16. MULTIPASS BEAD WELDS, WELDING MOTIONS, UNDERCUTTING, AND WELDS WITH BACKSTRIPS.



(c) When using any of the weaving motions, the electrode should be oscillated or moved uniformly from side to side with slight hesitation at the end of each oscillation and, as in bead welding, the electrode should be inclined 5 to 15 degrees in the direction of welding. If the weaving motion is not properly performed, undercutting will occur at the joint as shown in figure 16, view C, on the previous page. Excessive welding speed will also cause undercutting and poor fusion at the edges of the weave bead.

(2) *Butt Joints in Flat Position with Backup Strips* (figure 16, view D).

(a) Backup or backing strips are used when welding 3/16 inch plate or heavier to obtain complete fusion at the root of the weld and to provide better control of the arc and the weld metal. The edge of the plates to be welded are prepared in the same manner as required for welding without backing strips. The backing strips, 1 inch wide and 3/16 inch thick for plates up to 3/8 inch thick, 1 1/2 inch side, and 1/4 inch thick for plates over 1/8 inch thick, are tack welded to the base of the joint. The backing strip will act as a cushion for the first bead or layer deposited in the joint.

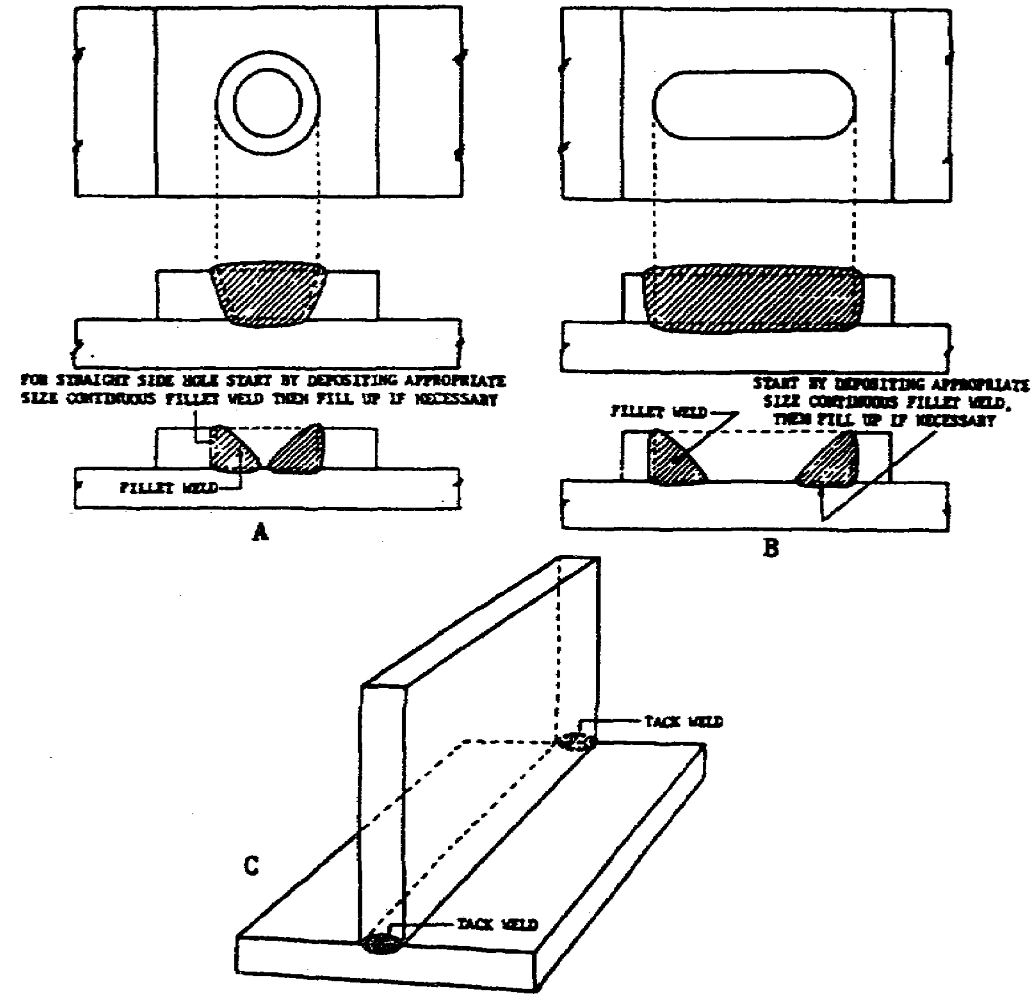
(b) The joint should be completed by adding additional layers of metal using the procedures prescribed in paragraphs 5e, on pages 35 and 36.

(c) After the joint is completed, the backup strip may be washed off or cut away with a cutting torch and, if necessary, a sealing bead may then be applied along the root of the joint.

(3) *Plug and Slot Joints* (figure 17 on the following page).

(a) Plug and slot welds, shown in figure 17, views A and B, are used to join two overlapping plates, by depositing and filling a hole or slot in the upper plate. Slot welds are used in butt straps to join face hardened armor plate edges from the back or soft side. They are also used to fill up holes in plates and to join two overlapping plates where it is impossible to join them by any other method.

FIGURE 17. PLUG AND SLOT JOINTS, AND TACK WELDING TEE JOINTS.



(b) A continuous fillet weld as shown in view B is made to obtain a good fusion between the sidewalls of the hole or slot and the surface of the lower plate. The procedure for this fillet weld is the same as for lap joints, which will be described in paragraph 5g(2) on page 45. The hole or slot is then filled in to provide additional strength in the weld.

(c) The plug weld procedure may be used to remove bolts or studs that have been broken or twisted off flush with the surface of the part. A nut, somewhat smaller than the bolt size, should be centered on the bolt or stud to be removed. A heavy-coated electrode is lowered into the nut and an arc struck on the exposed end of the broken bolt or stud. The nut is then welded onto the broken bolt or stud and sufficient metal is added to fill the hole.. The broken bolt or stud can then be removed with a wrench.

g. *Horizontal Position Welding.*

(1) *Tee Joints* (figure 17, view C, on the previous page). In making tee joints in the horizontal position the two plates are located approximately at right angles to each other in the form of an inverted T. The edge of the vertical plate may be tack welded to the surface of the horizontal plate.

(a) A fillet weld (figure 18, views A and B, on the following page) is used in making the joint by using a short arc to provide good fusion at the root and along the legs of the weld. The electrode should be held at an angle of 45 degrees to the two plate surfaces and inclined approximately 15 degrees in the direction of welding.

(b) Light plates can be fillet welded in one pass with little or no weaving of the electrode. Welding of heavier plates may require two or more passes with the second pass or layer made using a semicircular weaving motion as shown in figure 18, view C. A slight pause is made at the end of each weave to obtain good fusion between the weld and base metal without any undercutting.

(c) A fillet-welded tee joint on 1/2 inch or thicker plate can be made by depositing string beads in the sequence shown in figure 18, view D.

(d) Chain or staggered intermittent fillet weldings as shown in figure 19, view A, on page 44 are used for long tee joints.

Fillet welds of these types are used where high weld strength is not required; however, the short welds are so arranged that the finished joint is equal in strength to a fillet weld along the entire length of a joint from one side only. Also, the warpage and distortion of the welded parts are held to a minimum with intermittent welds.

FIGURE 18. FILLET WELDING.

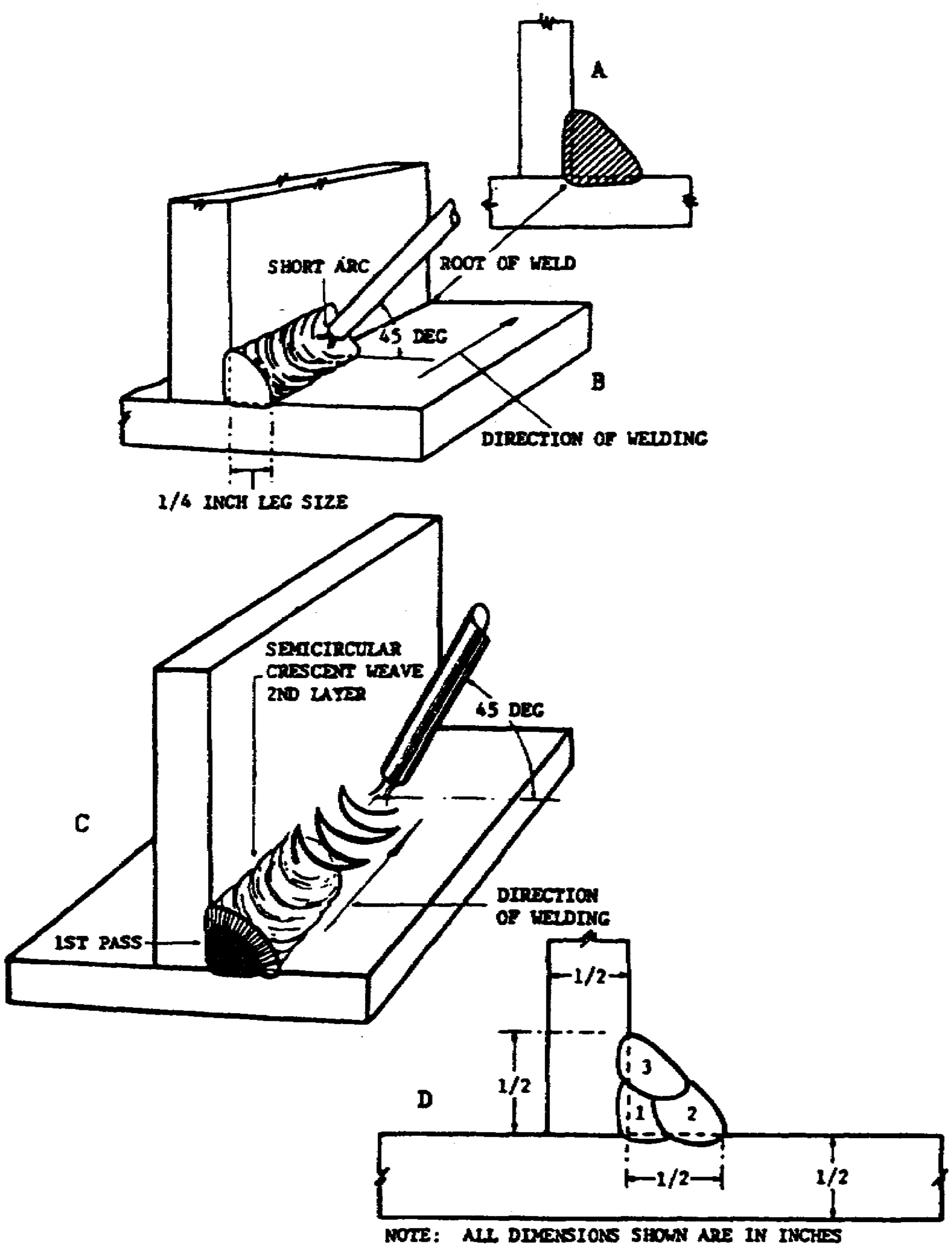
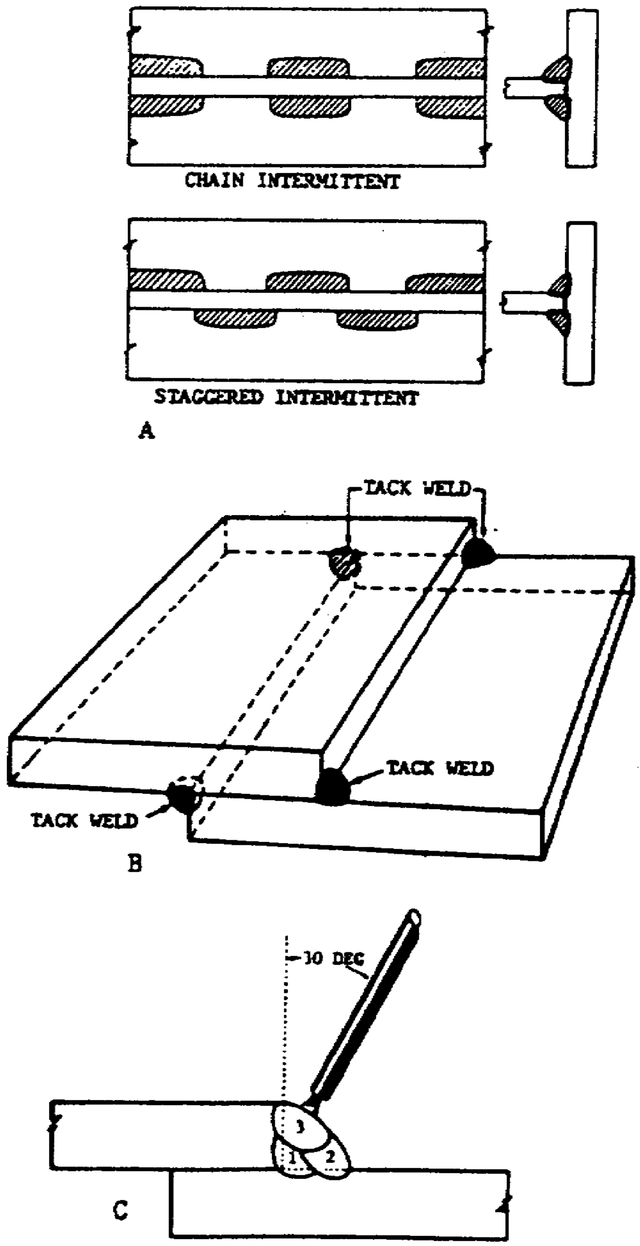


FIGURE 19. INTERMITTENT FILLET WELDS, TACK WELDING, AND ELECTRODE POSITION.



(2) *Lap Joint* (figure 19, views B and C, on the previous page).

(a) In making lap joints, two overlapping plates are tack welded in place and a fillet weld in the horizontal position is deposited along the joint.

(b) The procedure for making this weld is similar to that used for making fillet welds in tee joints. The electrode should be held so as to form an angle approximately 30 degrees from the vertical and tilted 15 degrees in the direction of welding. The position of the electrode in relation to the plates is shown in figure 19, view C. The weaving notion is the same as that used for tee joints, except that the pause at the edge of the top plate is sufficiently long to ensure good fusion and no under cut. Lap the joint by depositing a series of overlapping beads on top of each other.

(c) In making lap joints on plates of different thicknesses as shown in figure 20, view A, on the following page, the electrode is held so as to form an angle of 20 to 30 degrees from the vertical. Care must be taken not to overheat or undercut the thinner plate edge. Also, the arc must be controlled to wash up the molten metal to the edge of this plate.

h. *Vertical Position Welding*.

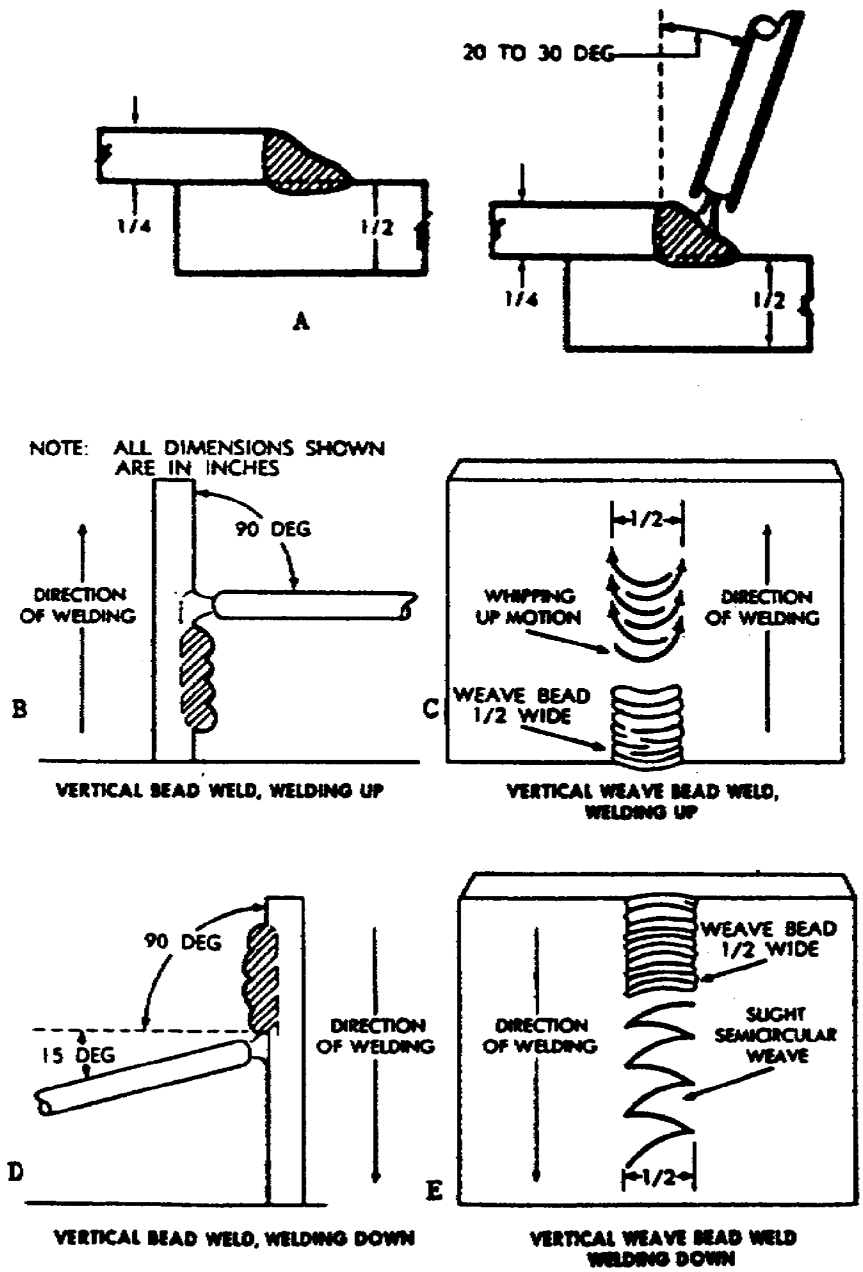
(1) *Bead Welds* (figure 20, views B through E).

(a) Welding on a vertical surface is more difficult than welding in the flat position. Because of the force of gravity, the molten metal tends to flow downward.

(b) When metal-arc welding in the vertical position, current settings should be less than those used for the same electrode in the flat position. The currents used for welding upward on a vertical surface are slightly higher than those used for welding downward on the same surface.

(c) The proper angle between the electrode and the base metal is also necessary in order to deposit a good bead weld when welding vertically.

FIGURE 20. LAP JOINTS AND WELDING VERTICALLY.



(d) When welding upward, the electrode should be held at 90 degrees to the vertical as shown in figure 20, view B, on the previous page. When welding upward and weaving is necessary, the electrode should be oscillated as shown in figure 20, view C.

(e) When welding downward, the outer end of the electrode should be inclined downward about 15 degrees from the horizontal with the arc pointing upward toward the deposited molten metal as shown in figure 20, view D. When welding downward, in the vertical position, and a weave bead is required, the electrode should be oscillated as shown in figure 20, view E.

(f) When depositing a bead weld in the horizontal direction on a vertical plate, the electrode should be held at right angles to the vertical as shown in figure 21, view A, on the following page and tilted 15 degrees toward the direction of welding so as to provide a better view of the arc and crater.

(2) *Butt Joints*.

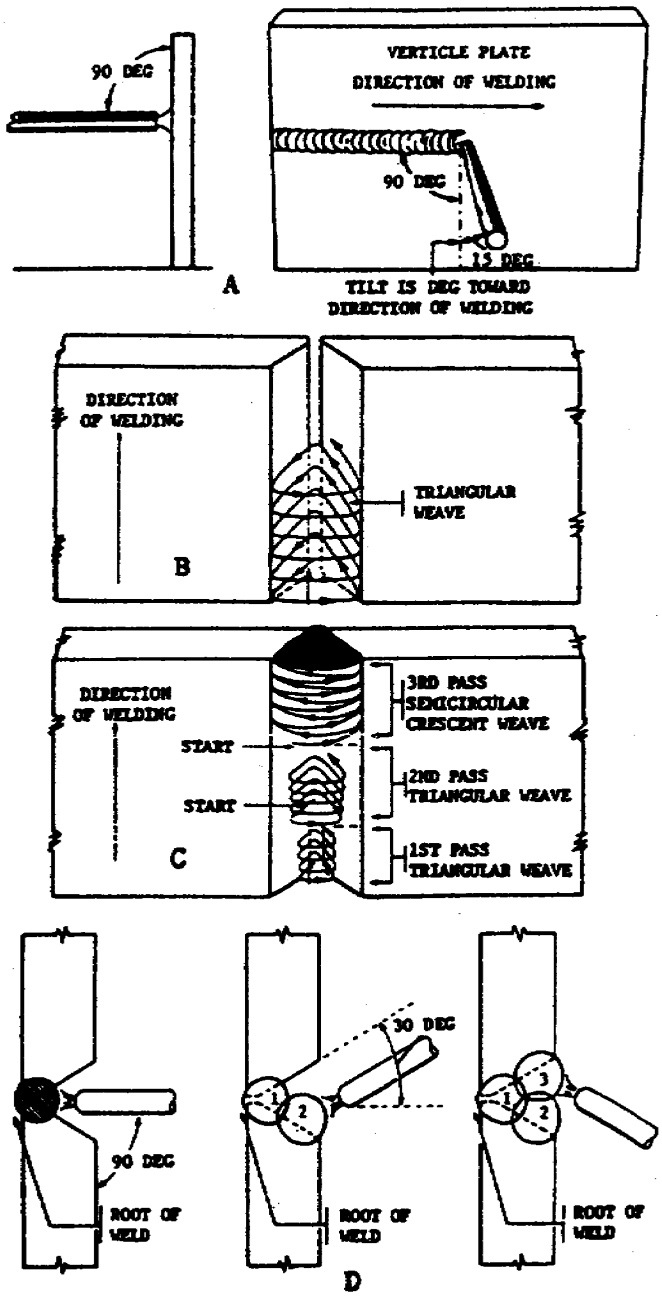
(a) Butt joints on plates in the vertical position are prepared for welding in the same way as those required for butt joints in the flat position.

(b) In order to obtain good fusion and penetration with no undercutting, a short arc should be held and the motion of the arc should be carefully controlled.

(c) Butt joints on beveled plates 1/4 inch thick can be made by using a triangular weave motion as shown in figure 21, view B. Welds on 1/2 inch plate or heavier should be made in several passes as shown in figure 21, view C. The last pass should be deposited with a semicircular weaving motion with a slight whip-up and pause to the electrode at the edge of the bead.

(d) When welding butt joints in the horizontal direction on vertical plates, a short arc is necessary at all times and the metal is deposited in multipass beads as shown in figure 21, view D. The first pass is made with the electrode held at 90 degrees to the vertical plates. The second, third, and subsequent passes are made with the electrode held parallel to the beveled edge opposite the edge on which the bead is being deposited.

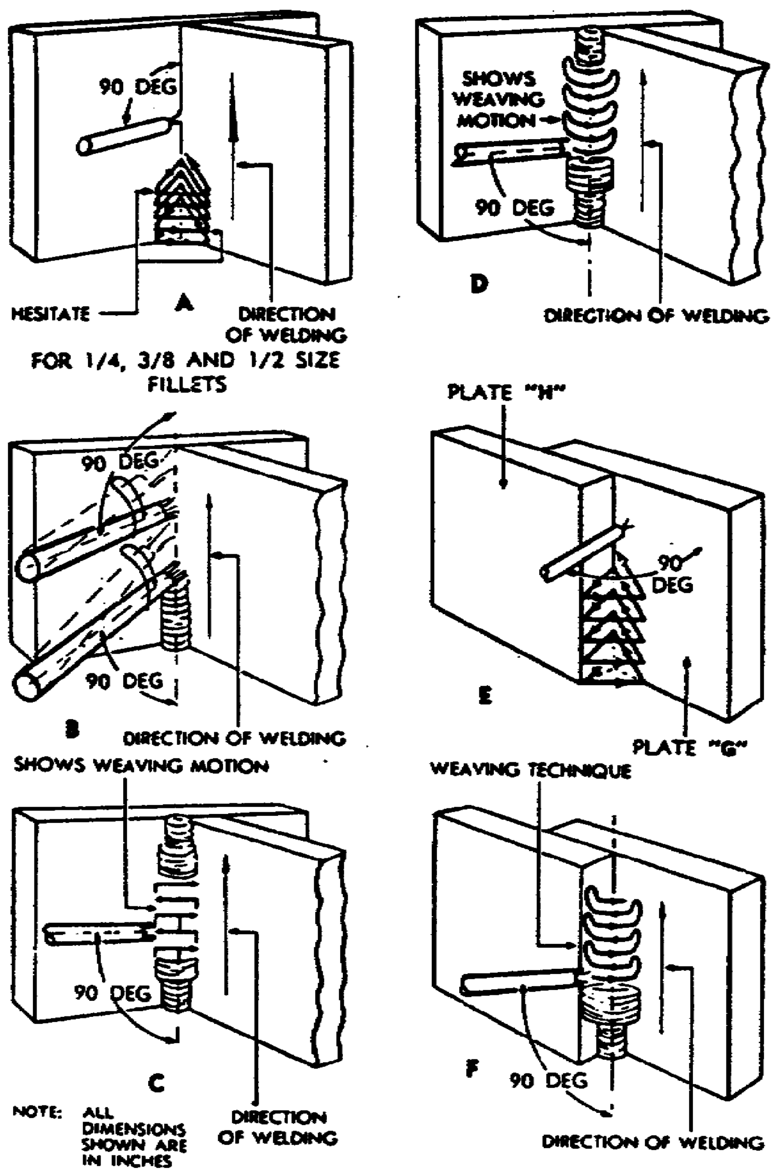
FIGURE 21. VERTICAL WELDING AND BUTT JOINTS.



(3) *Fillet Welds* (figure 22).

(a) When making fillet welds in either tee or lap joints in the vertical position, the electrode should be held at 90 degrees to the plates or not

FIGURE 22. VERTICAL FILLET WELDS.



more than 15 degrees above the horizontal for proper molten metal control. The arc should be held short to obtain good fusion and penetration.

(b) When welding tee joints in the vertical position, the joint should be started at the bottom and welded upward and the electrode should be moved in a triangular weaving motion as shown in figure 22, view A, on the previous page. A slight pause in the weave, at the points indicated, will improve the sidewall penetration and provide good fusion at the root of the joint.

<u>1</u> If the weld metal should overheat, the electrode should be quickly shifted away from the crater without breaking the arc as shown in figure 22, view B. This will permit the molten metal to solidify without running downward. The electrode should be returned immediately to the crater of the weld in order to maintain the desired size of the weld.

<u>2</u> When more than one pass is necessary to make a tee weld, either of the weaving motions shown in figure 22, views C and D, may be used. A slight pause at the end of the weave will develop good fusion without undercutting at the edges of the plates.

(c) To make welds on lap joints in the vertical position, the electrode should be moved in a triangular weaving motion as shown in figure 22, view E. The same procedure for making the tee joint is used except the electrode is directed toward the vertical plate marked "G" in figure 22, view E. The arc should be held short, and the pause at the surface of plate "G" should be slightly longer. Care should be taken not to undercut either of the plates or to allow the molten metal to overlap at the edges of the weave.

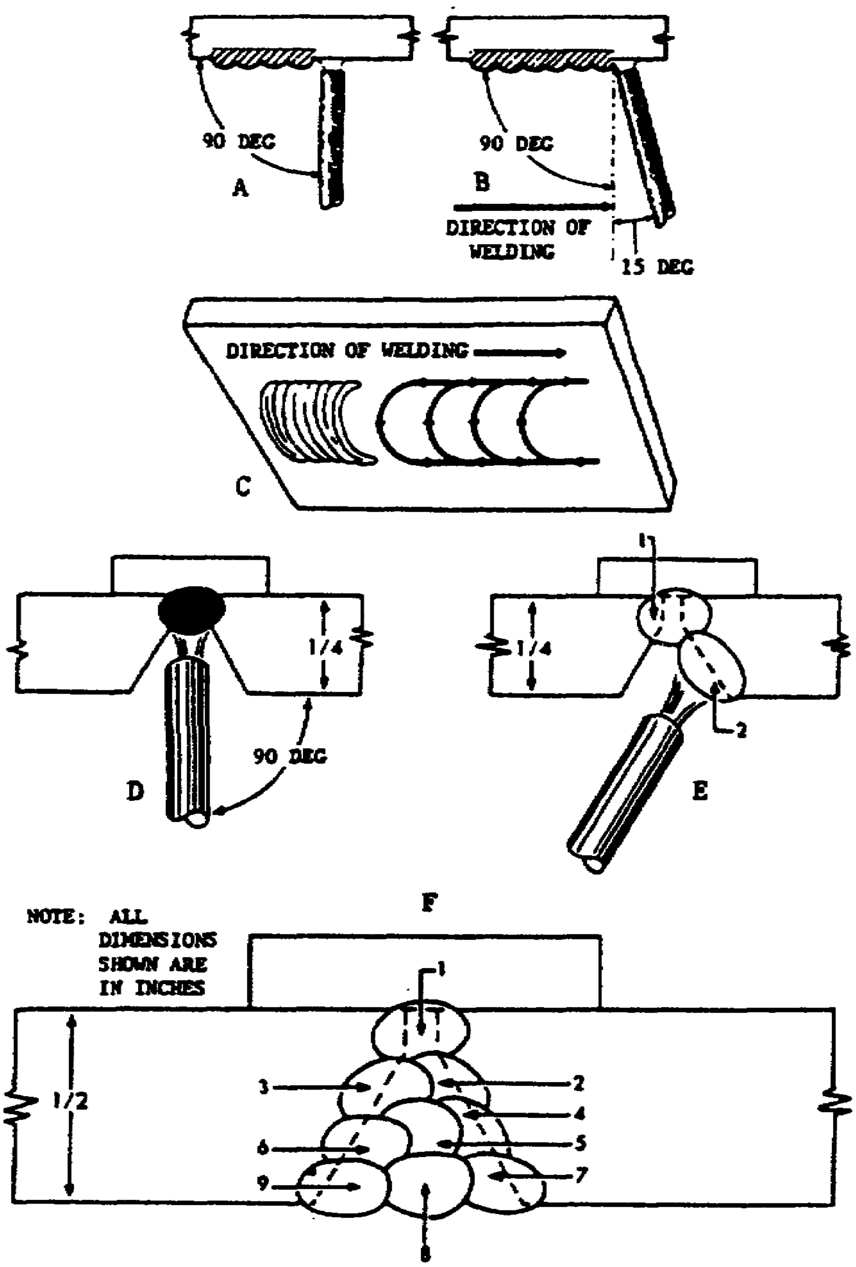
(d) Lap joints in the vertical position on heavy plate require more than one layer of metal. The deposited bead should be thoroughly cleaned and subsequent beads deposited as shown in figure 22, view F.

i. *Overhead Position Welding* (figure 23 on the following page).

(1) *Bead Welds*. The overhead position is the most difficult position to weld in because it

requires a very short arc which must be maintained in order to retain complete control of the molten metal. As in vertical position welding, the force of gravity tends to cause the molten metal to drop

FIGURE 23. OVERHEAD POSITION WELDING.



down or sag on the plate. If the arc is too long, the difficulty in transferring metal from the electrode to the base metal is increased and large globules of molten metal will drop from the electrode and the base metal. This action can be prevented by first shortening and then lengthening the arc at intervals. Care must be taken not to carry too large a pool of molten metal in the weld.

(a) When bead welding, the electrode should be held at an angle of 90 degrees to the base metal as shown in figure 23, view A, on the previous page. The electrode may be tilted approximately 15 degrees in the direction of welding as shown in figure 23, view B to provide a better view of the arc and crater of the weld.

(b) Weave beads can be made in the overhead position by using the motion illustrated in figure 23, view C. A rapid motion is necessary at the end of each semicircular weave in order to control the molten metal deposit. Excessive weaving should be avoided because this will cause overheating of the weld deposit and the formation of a large pool of metal which will be hard to control.

(2) *Butt Joints.*

(a) The plates should be prepared for butt welding in the overhead position in the same manner as that required in the flat position, and the most satisfactory results are obtained if backup strips are used. If the plates are beveled with a feather edge and no backup strip is used, the weld will tend to burn through repeatedly unless extreme care is taken by the operator.

(b) For overhead butt welding, bead rather than weave welds are preferred. Each bead should be cleaned and the rough areas chipped out before the following pass is deposited. The first pass should be made with the electrode held at 90 degrees to the plate as shown in figure 23, view D.

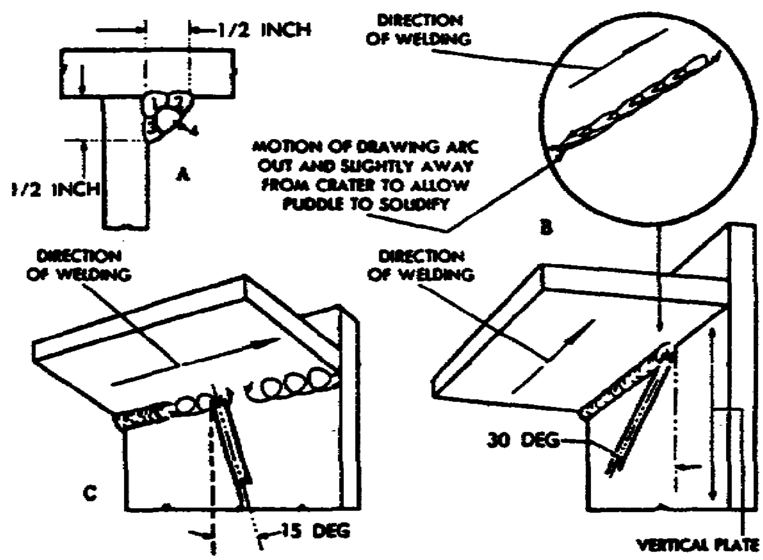
(c) The position of the electrode and the order to be followed in depositing beads on 1/4 and 1/2 inch plates are illustrated in figure 23, views E and F.

(d) Fairly small diameter electrodes should be used to assist in holding a short arc and developing a good penetration at the root of the joint. Excessive current will create a very fluid puddle, which will be difficult to control.

(3) *Fillet Welds* (figure 24).

(a) In making fillet welds in either tee or lap joints in the overhead position, a short arc should be held and there should be no weaving of the electrode. The order in which the beads are deposited is shown in figure 24, view A. The electrode should be held approximately 30 degrees to the vertical plate and moved uniformly in the direction of the welding as shown in figure 24, view B. The arc motion should be controlled to secure good penetration to the root of the weld and 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 and 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 and the welding continued.

FIGURE 24. OVERHEAD POSITION FILLET WELDING.



(b) Fillet welds for either tee or lap joints, on heavy plate in the overhead position, require several passes to make the joint. The first pass 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 electrode with its top tilted about 15 degrees in the direction of welding as shown in figure 24, view C, on the previous page. This motion of the electrode permits greater control and better distribution of the weld metal being deposited. All slag and oxides must be removed from the surface of each pass by chipping or wire-brushing before applying additional beads.

6. Electric Arc Welding of Ferrous Metals

a. *General*. All of the ferrous metals used on Army ground equipment can be successfully electric arc welded, provided normal care is used and the correct procedure followed. The following subparagraphs provide the welding techniques for four of the most common types of ferrous metals found on this equipment. The description of welding techniques for other ferrous metals may be found in TM 9-237.

b. *High-Carbon Steels*.

(1) *General*. High-carbon steels include those that have a carbon content exceeding 0.45 percent. Because of the high carbon content and the heat treatment usually given to these steels, their basic properties are to some degree impaired by arc welding. Preheating the metal between 500° to 800° Fahrenheit before welding and stress relieving it by heating from 1200° to 1450° with slow cooling should be used to avoid hardness and brittleness in the fusion zone. Either mild-steel or stainless steel electrodes can be used to weld these steels.

(2) *Welding Technique*.

(a) The welding heat should be adjusted to provide good fusion at the sidewalls and root of the joint without excessive penetration. High welding heat will cause excessive penetration and puddling which in turn can cause large areas in the fusion zone to become hard and brittle. Control of the welding heat and excessive penetration can be accomplished by depositing the weld metal in small string beads. The area of these hard zones in the base metal can be reduced by making the weld with a series of small string or weave beads. Fusion between the filler metal and the sidewalls should be confined to a narrow zone. This can be accomplished by directing the electrode toward the previously deposited filler metal adjacent to the side walls than toward the side walls directly. This procedure causes the weld metal to wash up against the side of the joint and fuse with it without deep or excessive penetration.

(b) When welding sheet metal up to 1/8 inch in thickness, the plain square butt joint type of edge preparation may be used. Heavy plates should be beveled up to 60 degrees, depending on the thickness. The parts should be tack welded and the root weld made with a 1/8 to 5/32 inch electrode. Additional passes of filler metal should be made with a 5/32 or 3/16 electrode. Heavy sections that have been beveled from both sides should be welded by depositing weave beads alternately on one side and then the other to reduce the amount of distortion in the weld structure.

(c) Small high-carbon steel parts are sometimes repaired by building up worn surfaces. When this is done, the piece should be annealed or softened by heating to a red heat and cooling slowly. Then the piece should be welded or built up with medium-carbon or high-strength electrodes and heat treated, after welding, to restore its original properties.

c. *Tool Steels*.

(1) *General*. Steels in this group have a carbon content ranging from 0.80 to 1.5 percent. They are rarely welded by arc welding because of the excessive hardness produced in the fusion zone of the base metal. If arc welding must be done, either mild-steel or stainless-steel electrodes can be used.

(2) *Welding Technique*.

(a) If the parts to be welded are small, they should be annealed or softened before welding. The edges should then be preheated up to 1,000°, depending on the carbon content and thickness of the plate, and the welding done with either a mild-steel or high-strength electrode.

(b) High-carbon electrodes should not be used for welding tool steels. The carbon picked up from the base metal by this filler metal will cause the weld to become glass hard; 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.

(c) When welding with stainless steel electrodes, the edges of the plates should be preheated to prevent the formation of hard zones in the base metal. The weld metal should be deposited in small string beads to keep the heat input down to a minimum. In general, the application procedure is the same as that required for high-carbon steels described in paragraph 6b(2) beginning on page 54.

d. *High Yield Strength, Low Alloy Structural Steels*.

(1) *General*. High yield strength, low alloy structural steels are special steels that are tempered to obtain extreme toughness and durability. The special alloys and general make-up of these steels require special treatment to obtain satisfactory weldments.

(2) *Welding Techniques*.

(a) Reliable welding of high yield strength, low alloy structural steels can be performed by using the correct electrodes. Hydrogen is the number one enemy of sound welds in alloy steels. Therefore, use only low hydrogen (MIL-E-18038 or MIL-E22200/1) electrodes to prevent cracking. Underbead cracking is caused by hydrogen picked up in the electrode coating, released into the arc, and absorbed by the molten metal.

(b) Electrodes must be kept dry to eliminate absorption of hydrogen. If the electrodes are in an airtight container, immediately upon opening the container, place the electrodes in a ventilated holding oven set at 250° to 300° F. In the event that the electrodes are not in an airtight container, put them in a ventilated baking oven and bake for 1 to 1 1/4 hours at 800° F. Baked electrodes should, while still warm, be placed in a holding oven until used. Electrodes must be kept dry to eliminate absorption of hydrogen.

(c) Electrodes are identified by classification numbers which are always marked on the electrode containers. For low hydrogen coatings, the last two numbers of the electrode classification should be 15, 16, or 18. Electrodes of 5/32 and 1/8 inch in diameter are the most commonly used since they are more adaptable to all types of welding of this type steel.

(3) It is important to avoid excessive heat concentration when welding in order to allow the weld area to cool rather quickly. For satisfactory welds, along with good welding practices, use a straight stringer bead whenever possible. Restrict the weave to a partial weave pattern. Best results are obtained by a slight circular motion of the electrode with the weave area never exceeding two electrode diameters. Never use a full weave pattern. Skip weld as practical, and peen the weld to relieve stresses while cooling larger pieces. Avoid toe cracks and undercutting. A soft steel wire pedestal can help to absorb shrinkage forces. Butter welding (laying a bead, then grinding it off) in the toe area before fillet welding strengthens the area where a toe crack may start.

e. *Cast Iron*.

(1) *General*. Gray cast iron has low ductility; therefore, it will neither expand, nor stretch, to any considerable extent before breaking or cracking. Because of this characteristic, preheating is necessary when cast iron is welded by the oxyacetylene welding process. However, it can be welded with the metal arc without preheating if the welding heat is carefully controlled. This can be accomplished by welding only short lengths of the joint and allowing these sections to cool. By this procedure, the heat of welding is confined to a small area and the danger of cracking the casting is eliminated. Large castings with complicated sections, such as motor blocks, can be welded without dismantling or preheating. Special electrodes designed for this purpose are usually desirable.

(2) *Welding Techniques*.

(a) Cast iron can be satisfactorily welded with a coated steel electrode, but this method should be used as an emergency measure only. When using a steel electrode the contraction of the steel weld metal, the carbon picked up from the cast iron by the weld metal, and the hardness of the weld metal caused by rapid cooling must be considered. Steel shrinks more than cast iron when cooled from a molten to a solid state and, when a steel electrode is used, this uneven shrinkage will cause strains at 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 unless preventive steps are taken. To overcome these difficulties, the prepared joint should be welded by depositing the weld in short string beads, 3/4 to 1/4 inch long, made intermittently and, in some cases, by the step-back or skip-welding procedure. 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 lightly peened, while hot, with a small ballpeen hammer and allowed to cool before additional weld metal is applied. The peening action forges the metal and relieves metal strain during cooling.

(b) The electrodes used should be 1/8 inch in diameter so as to prevent generating excessive welding heat. The welding should be done with reverse polarity. Weaving of the electrode should be held to a minimum. Each metal deposit should be thoroughly cleaned before additional metal is deposited.

(c) Cast iron electrodes are used where subsequent machining of the welded joint is required. Stainless steel electrodes are used when machining of the weld is not required. The procedure for making welds with these electrodes is the same as that outlined for welding with mild-steel electrodes. Stainless steel electrodes provide excellent fusion between the filler and base metals; however, great care must be taken not to overheat the base metal. Overheating the base metal will cause cracking of the base metal alongside the weld metal. The reason for this cracking of the base metal is that stainless steel expands and contracts approximately 50 percent more than mild steel in equal changes of temperature.

7. Electric Arc Welding of Nonferrous Metals

a. *General*. Most of the nonferrous metals used in Army ground equipment can be successfully electric arc welded provided the proper procedures are adhered to. The following subparagraphs describe the welding techniques used only for aluminum. Aluminum and aluminum alloys can be satisfactorily welded by metal-arc, carbon-arc, and other arc-welding processes. The principal advantage of using the arc-welding processes is that a highly concentrated heating zone is obtained with the arc and, for this reason, excessive expansion and distortion of the metal is prevented. With the exception of the welding rod used, the welding techniques used for other nonferrous metals, namely titanium, nickel, bronze, brass, magnesium, and monel, are the same as those used for aluminum.

b. *Welding Techniques*.

(1) Because of the difficulty of controlling the arc, butt and fillet welds are difficult to produce in plates less than 1/8 inch thick. In welding plate heavier than 1/8 inch, a plate with a 30° bevel will have strength equal to a weld made by the oxyacetylene process, but this weld may be porous and unsuited for liquid- or gas-tight joints. Metal arc welding is, however, particularly suitable for heavy material and is used on plates up to 2 1/2 inches thick.

(2) The current and polarity settings will vary with each manufacturer's type of electrodes, and the polarity to be used should be determined by trial on the joints to be made.

(3) Before being welded, a broken aluminum casting should be carefully cleaned by wire brushing with mineral spirits, paint thinner, or dry cleaning solvent used to remove all oil, grease, and other foreign matter. If the casting has a heavy cross section, the crack should be tooled out to form a "V."

(4) Either metal arc or carbon arc welding can be used for aluminum castings, but the carbon arc is preferred because it produces welds free of oxides and porosity. Flux-coated rods are essential for good arc welds. All slag and flux must be removed from the finished weld to prevent corrosion of the joint and the entire piece should be covered with sand or asbestos to afford slow cooling.

8. Conclusion

This task served to describe methods for identifying electrodes by type and intended use; the automotive welding processes, materials, and identification processes; and the types and techniques of joint design. This information provides a basis for the following task. The next task will describe the theory, principles, and procedures of welding armor plate; and the methods of destructive and nondestructive testing welds, and troubleshooting procedures.

LESSON 1

ELECTRODES CLASSIFICATION AND INTENDED USES; AUTOMOTIVE WELDING PROCESSES, MATERIALS, AND IDENTIFICATION PROCESSES; METHODS OF DESTRUCTIVE AND NONDESTRUCTIVE TESTING OF WELDS AND TROUBLESHOOTING PROCEDURES; TYPES AND TECHNIQUES OF JOINT DESIGN; AND THE THEORY, PRINCIPLES, AND PROCEDURES OF WELDING ARMOR PLATE

TASK 2. Describe the theory, principles, and procedures of welding armor plate; and methods of destructive and nondestructive testing of welds, and troubleshooting procedures.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within two hours

REFERENCES

No supplementary references are needed for this task.

1. Introduction

The previous task described the methods for classifying electrodes by type and intended uses; the automotive welding processes, materials, and identification processes; and the types and techniques of joint design. The previous information provided the basis for this task, which describes the theory, principles, and procedures for welding armor plate, the methods of destructive and nondestructive testing, and troubleshooting of welds.

2. General

a. *Armor Plate Uses*. Armor plate is used on tanks, self-propelled guns, and other combat vehicles for the protection of personnel and equipment from the destructive force of enemy projectiles. It is fabricated both in the form of castings and rolled plates, which are heat treated to develop the desired structural and protective properties. The manufacture of gun turrets and combat tank hulls includes one-piece castings and welded assemblies of rolled plates and sections that have been cast.

b. *Repair of Armor Plate*. Welding has replaced riveting for the repair of armor plate although, in some cases, riveting is still used on some vehicles protected by face hardened armor. Developing a suitable technique for welding armor plate depends upon consideration of the following factors affecting the weldability of armor plate:

(1) knowledge of the exact types of armor being welded;

(2) knowledge of the proper repair methods;

(3) the function of the damaged structure;

(4) proper selection of welding materials and repair procedures;

(5) urgency of the repair required to accomplish the combat mission;

(6) careful analysis of the defect in terms of the proper joint, electrode, current, voltage, polarity, and minimum welding stresses and warpage during repair; and

(7) knowledge of safety hazards fire and safety hazard procedures.

The theory, principles, and procedures for welding armor plate are basically the same as those used for industrial fabrication, but must be modified at times because of the varying types of damage that can occur in the battlefield.

3. Welding Armor Plate

a. *Properties of Armor Plate*. Armor plate is hardened by normalizing or heating it to its upper critical point and letting it cool in still air. The base metal quenching effect produced next to a weld in heavy armor plate under normal welding conditions is about halfway between the effects of air cooling and oil quenching it. During the welding of armor plate the temperature of the weld metal ranges upwards of 3000° F from the original temperature of the base metal. Therefore, a narrow zone on each side of the deposited weld metal is heated above its critical temperature. This narrow zone is then quenched by the relatively cold base metal and becomes a hard brittle zone known as martensite. It is in this zone that cracks are most likely to occur upon the application of a load. For this reason, special precautions must be taken in all welding operations to minimize the formation of hard zones. In addition, care must be taken to prevent rapid cooling of the armor plate after welding in order to avoid the formation of cracks in hard zones.

b. *Types of Armor Plate*.

(1) *General*. There are two types of armor that are used on combat vehicles: homogeneous, which can be cast or rolled, and face hardened, which is rolled. It is essential that the armor plate be specifically identified before any welding or cutting operations are performed. This is important because the welding procedures for each type of armor are distinctly different and are not interchangeable.

(2) *Homogeneous Armor Plate*. Homogeneous armor is heat treated through its entire thickness to develop good shock or impact resisting properties. This type of armor is uniform in hardness, composition, and structure throughout and can be welded on either side. Aluminum armor plate is in the homogeneous class. Welding procedures for aluminum armor plate are the same as for gas metal-arc welding, which are discussed in the inert gas welding operation subcourse.

(3) *Face Hardened Armor Plate*. Face hardened armor plate has an extremely hard surface layer which is obtained by carburizing. (Carburizing is the process of combining carbon with another alloy

or impregnating a metal with carbon to strengthen it). This hard surface extends to a depth of 1/5 to 1/4 of the outward facing thickness of the armor on the tank or armored vehicle. The primary purpose of face hardened armor is to provide good resistance against penetration from enemy projectiles. The inner side is comparatively soft and has properties similar to those of homogeneous armor. As a matter of fact, the inside and outside of face hardened armor plate has two different kinds of steel. Face hardened steel up to 1/2 inch in thickness should be welded from the soft side only.

c. *Identification of Armor Plate*. A very important part of welding lies in the welder having the ability to identify metal products to be welded. The following paragraphs describe two simple but accurate tests that may be made in a field shop for identifying armor plate.

(1) *File Test*. This type test is performed with the use of an ordinary file found in the mechanics and welders tool sets.

(a) *Homogeneous Armor*. A file will bite into homogeneous armor on both the outside and inside of the plate. As the file is drawn across either surface of the armor plate, the teeth on the file will bite into the metal, making it necessary to apply force to draw the file across the metal. This type test is performed by applying the file only once or twice across the surface. The armor protection qualities of the armor plate can be impaired by repeated applications of the file; therefore, the number of applications should be limited.

(b) *Face Hardened Armor*. In this type armor the file will bite only into the soft side of face hardened armor plate. When applied across the face side (outside) of the armor plate, the file will slip instead of biting into the metal. But when the file is applied to the reverse side (inside), the file will bite as in homogeneous metal.

(2) *Fracture Test*. Some metals can be quickly identified by looking at the surface of the broken part or by studying the chips produced with a hammer and chisel.

(a) *Homogeneous Armor*. The metal edges of holes or cracks made by an anti-tank projectile in homogeneous armor plate are ragged and bent, with the metal drifted in the direction of penetration. Cracks in homogeneous armor are usually caused by stresses in the metal. These cracks are present at severe bulges or bends in the damaged armor plate.

(b) *Face Hardened Armor*. The metal edges of holes and cracks in face hardened armor are relatively clean cut and sharp. The plates do not bulge to any great extent before cracking. By examining the edges of freshly broken face hardened armor, it can be noted that the metal at the face side is brighter and of a finer structure than the metal at the soft side. The brighter metal extends to a depth of approximately 1/5 to 1/4 inch in thickness from the outside surface.

4. Cutting Armor Plate

a. *Homogeneous Armor Plate*. Either the oxygen cutting torch or the electric arc can be used to cut homogeneous armor plate. The oxygen cutting torch, however, is preferable. The carbon arc can be used to cut out welds and to cut castings and plates, but the shielded metal-arc is preferred when oxygen and acetylene are not available.

b. *Face Hardened Armor Plate*.

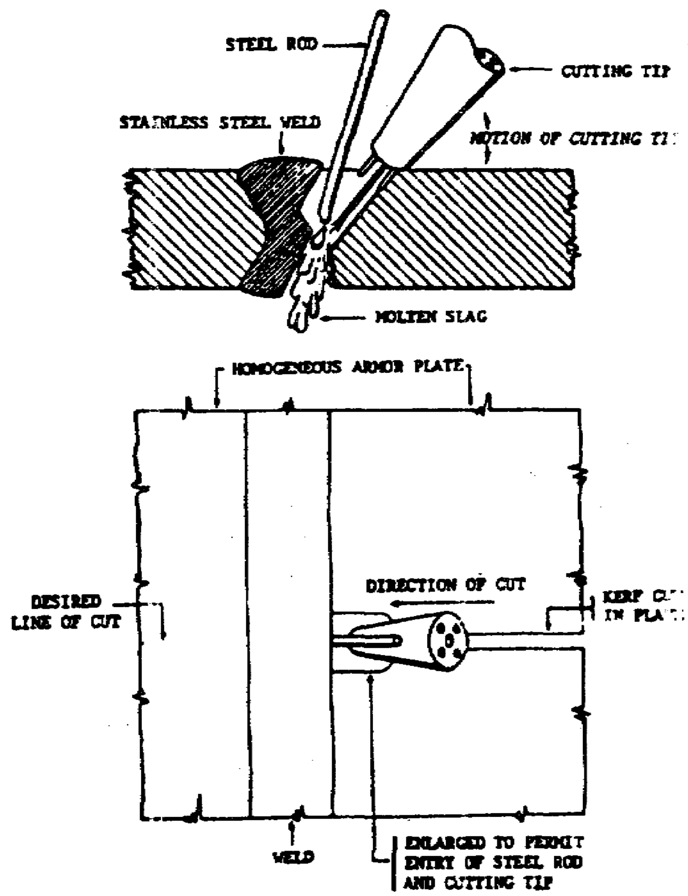
(1) *General*. The procedure for cutting this type of armor is essentially the same as that required for homogeneous armor. However, every precaution should be taken to keep as much heat as possible away from the hard face side of the plate. This is done by cutting from the soft side of the armor plate. Cutting from the soft side limits the extent of heating and consequent softening of the hard face side.

(2) *Cutting with the Oxygen Torch*.

(a) The general practice used for oxygen torch cutting can be applied for cutting armor plate, but the tip size, cutting oxygen, and preheating gas temperatures should be kept at the minimum, consistent with good quality cuts, to prevent overheating.

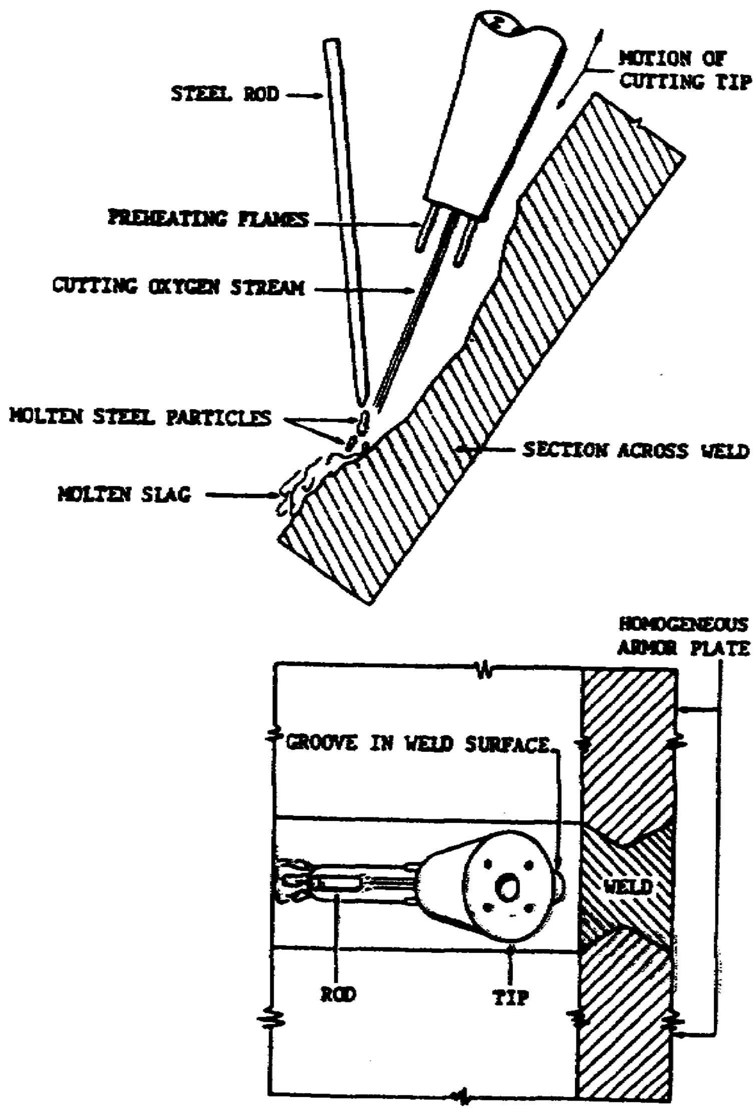
(b) Stainless steel is a nonoxidizing metal. Therefore, when cutting stainless steel type welds with an oxygen cutting torch, it is necessary to use an oxidizable steel rod. The oxygen combines with metal from the steel rod creating high temperature drops of molten steel. These drops of molten steel wash off onto the weld and help melt the stainless steel weld. This washing action is accomplished by an oscillating motion of the torch tip which causes the molten weld metal to wash away in thin layers. When thick stainless steel welds are cut, the steel rod should be held against the side of the weld and fed downward slowly to generate the high temperature required to create the molten steel into drops. The cutting process using a steel rod is illustrated in figure 25.

FIGURE 25. CUTTING STAINLESS STEEL WELDS.



(c) Cracks or other defects on the face of stainless steel welds can be removed by holding the cutting tip at a slight angle away from the face of the weld as shown in figure 26. The reaction between the cutting oxygen and the steel rod develops sufficient heat to melt the weld metal and is then washed away. Afterwards, the joint surface can be rewelded.

FIGURE 26. REMOVING SURFACE DEFECTS FROM STAINLESS STEEL WELDS.



(3) *Cutting with the Electric Arc*.

(a) Electric arc cutting is a procedure whereby metal is cut using the heat of an arc maintained between the electrode and the base metal. Three procedures described in the following subparagraphs are used in cutting with the electric arc.

(b) Carbon-arc cutting is a process whereby the cutting of metals is accomplished by progressive melting with the heat of an electric arc between a metal electrode and the base metal. Direct current straight polarity (electrode negative) is preferred. The carbon arc is used under some conditions in conjunction with a jet of compressed air for the removal of defective austenitic (corrosion resistant) weld metal. Cutting with the carbon arc is used for cutting both ferrous and nonferrous metal, but does not produce a cut of particularly good appearance. The electrodes are either carbon or graphite, preferably with a pointed end to reduce arc wandering, and thus produce less erratic cuts.

(c) Metal-arc cutting is a process whereby the cut is produced by progressively melting the metal. Direct current straight polarity is preferred for this process. Coated electrodes ranging in diameter from 1/8 to 1/4 inch are used; larger diameters are not satisfactory because of excessive spatter. The thickness of the metal that can be cut by the metal-arc process is limited only by the length of the electrode. The coating on the electrode serves as an insulator between the core of the electrode and the side wall of the cut, resulting in less short-circuiting against the kerf. Cuts made by the metal-arc process are less ragged than those produced with carbon-arc, but they must still be prepared by grinding or chiseling before rewelding is accomplished.

(d) Oxy-arc cutting is accomplished by directing a stream of oxygen into the molten pool of metal. The pool is kept molten by the arc struck between the base metal and the coated tubular cutting rod. The rod is consumed during the cutting operation. The tubular rod also provides an oxidizing flux and a means of converging oxygen onto the surface being cut. The tubular cutting electrode is made of mild steel. Contamination of the metal is eliminated by the extremely high heat and oxygen emitted by this process. This high heat and oxygen also oxidize the rod and coating thereby preventing the rod metal from fusing with the base metal.

(e) After completing the cut with an arc cutting process, the rough edges and slag should be removed by hammering, chipping, or grinding prior to welding.

5. Welding Homogeneous Armor Plate

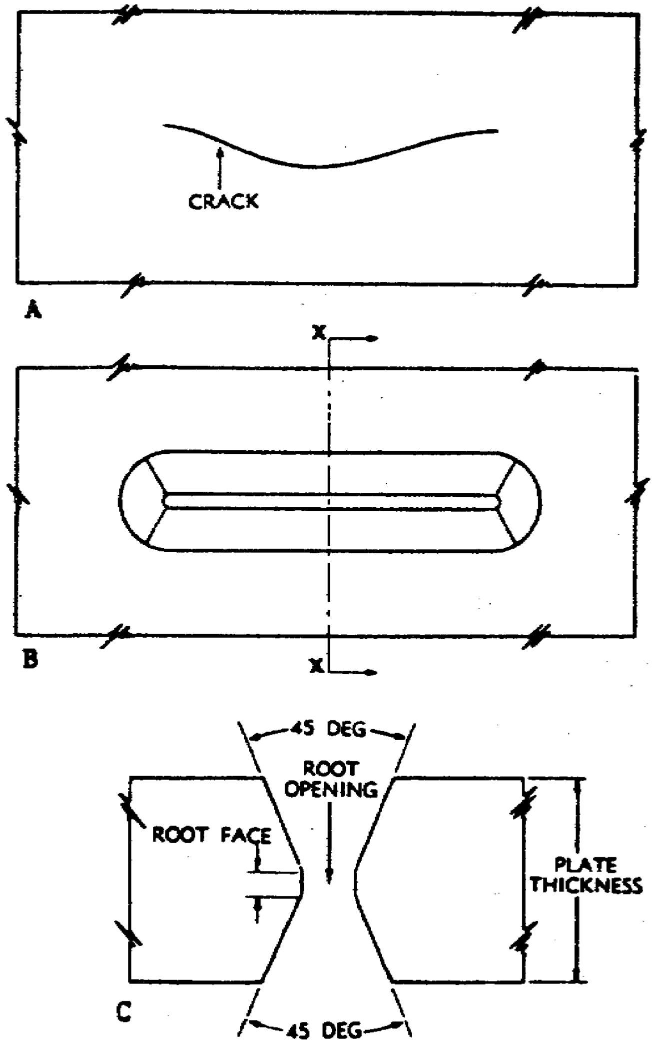
a. *General*. Before welding damaged armor plate, the type of armor must first be identified. This identification can be accomplished in the field by one of the methods described in paragraph 2c on page 63. Homogeneous armor plate can be satisfactorily welded using the electric arc welding process and 18-8 stainless steel heavy coated electrodes with reverse polarity. Armored vehicles that have been exposed to conditions of extreme cold should not be welded until the base metal has been preheated sufficiently to bring the temperature of the base metal in the zone of welding up to no less than 100° F. At this temperature, the metal will be noticeably warm to the touch. If this preheat is not applied, cracking will occur in the deposited weld metal.

b. *Procedure*.

(1) Simple cracks as shown in figure 27, view A, on the following page, should be flame cut into a beveled V joint as shown in figure 27, view B, before welding. Care should be taken to round off the corners at the toe and root of the joint. This is necessary in order to eliminate excessive weld metal dilution. The included angle of bevel, as shown in figure 27, view C, should be approximately 45 degrees to provide electrode clearance for making the root welding beads. The root opening, as shown in figure 27, view D, should be from 3/16 to 5/16 inch, depending on plate thickness.

(2) The weld beads deposited at the root of the weld must be good quality. It is essential that care be taken to prevent cracks, oxide and slag inclusions, incomplete penetration, or excessive weld metal dilution in this area. Some of the methods recommended as preparatory steps for root

FIGURE 27. WELDING CRACKS IN HOMOGENEOUS ARMOR.



SECTION X-X

D

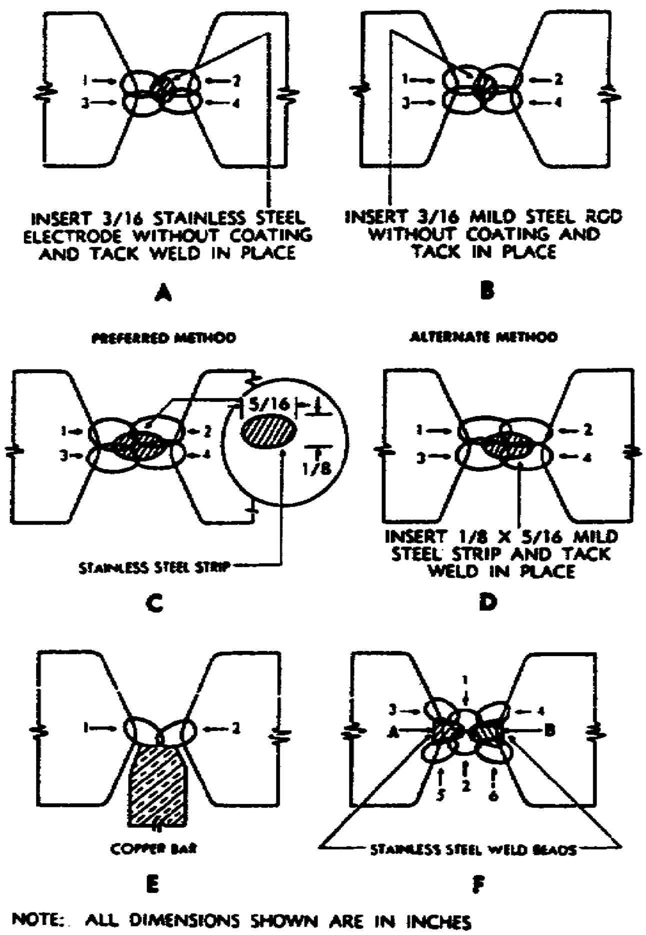
PLATE THICKNESS	ROOT OPENING	ROOT FACE
3/8 TO 7/8	3/16	√0
1 TO 1-1/2	1/4	√0
GREATER THAN 1-1/2	5/16	√1/16

√ TOLERANCE, PLUS 3/16, MINUS 0

√ TOLERANCE, PLUS 1/16 MINUS 0

NOTE: ALL DIMENSIONS SHOWN ARE IN INCHES bead welding are shown on figure 28. For narrow root openings, a 3/16 inch stainless steel electrode without coating can be tack welded in place as shown in figure 28, view A. Welding bead numbers 1 through 4 are then deposited sequentially. To ensure a sound weld, remove all slag and oxides from the joint before depositing beads 3 and 4. If a mild steel rod or strip, as shown in figure 28, view B, the back side of the backing rod or strip should be chipped out after beads 1 and 2 are deposited to minimize dilution in beads 3 and 4. The use of a stainless steel strip as a backing for root beads in a wide root opening is shown as view C of figure 28. An alternate

FIGURE 28. ROOT BEAD WELD.



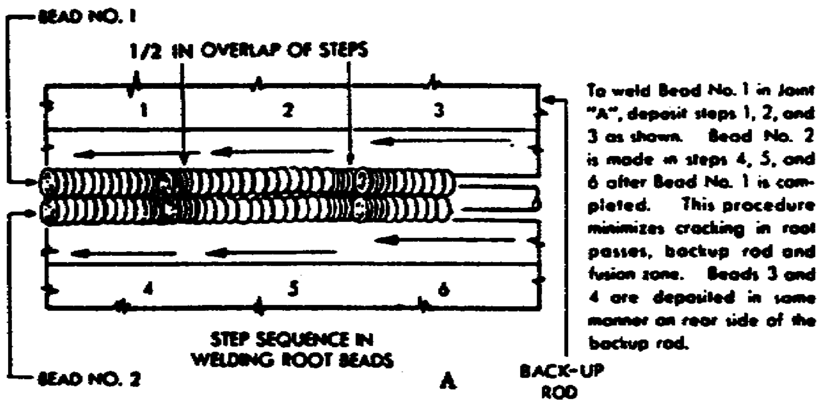
method, shown in figure 28, view D, on the previous page, uses a mild steel strip. When this method is used, the backing rod or strip should be chipped out before depositing beads 3 and 4.

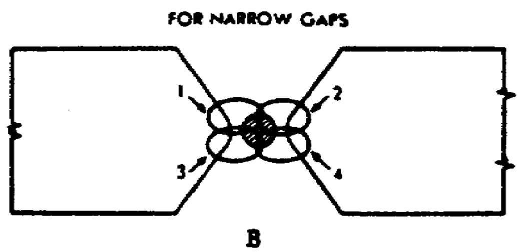
Another procedure, as shown in figure 28, view E, uses a copper backing bar. The copper bar is removed after beads 1 and 2 are deposited. (The beads will not weld to the copper bar.) Beads 3 and 4 are deposited after removal of the copper bar. In certain cases, where plates of homogeneous armor are cracked along their entire cross section of the plate, another method of joint preparation, as shown at figure 28, view F, can be used. In this other method, root beads A and B are deposited opposite from each other at the base of the bevel. These root beads act as backing for beads 1 through 6, which are deposited afterwards.

(3) Weld crater and fusion zone cracking, especially in the root beads, is a major factor involved in welding cracks in armor that terminate within the plates. To prevent this cracking, an intermittent backstep and overlap procedure, as shown in figure 29, view A, on the following page, is recommended. It should be noted that all of the welding steps necessary for bead number 1 must be completed before depositing bead number 2. By back stepping, the craters at the end of each previous pass are located and filled. All craters on subsequent passes, that do not terminate on previous deposited metal, should be filled by a hesitation and drawback technique. The filling up of weld craters avoids the formation of star cracks which are caused by the solidification of shallow deposits of molten weld metal.

(4) Each pass in beads 1 through 4, shown in figure 29, views B and C, is limited from 1 to 2 inches in length and should be peened while the weld metal is still hot to help overcome the cooling stresses. No electrode weaving motion should be used when the root beads are deposited. The welding should be performed preferably with a 5/32 inch electrode. Peening also tends to eliminate or minimize warpage in the section being welded. Arc blow should be controlled by properly adjusting the method of welding. Some of the more common defects encountered when welding root beads on homogeneous armor plate and the proper remedial procedures are shown in figure 30, on page 74.

FIGURE 29. WELD BEADS ON HOMOGENEOUS ARMOR PLATE.





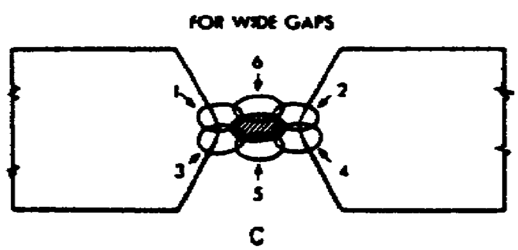
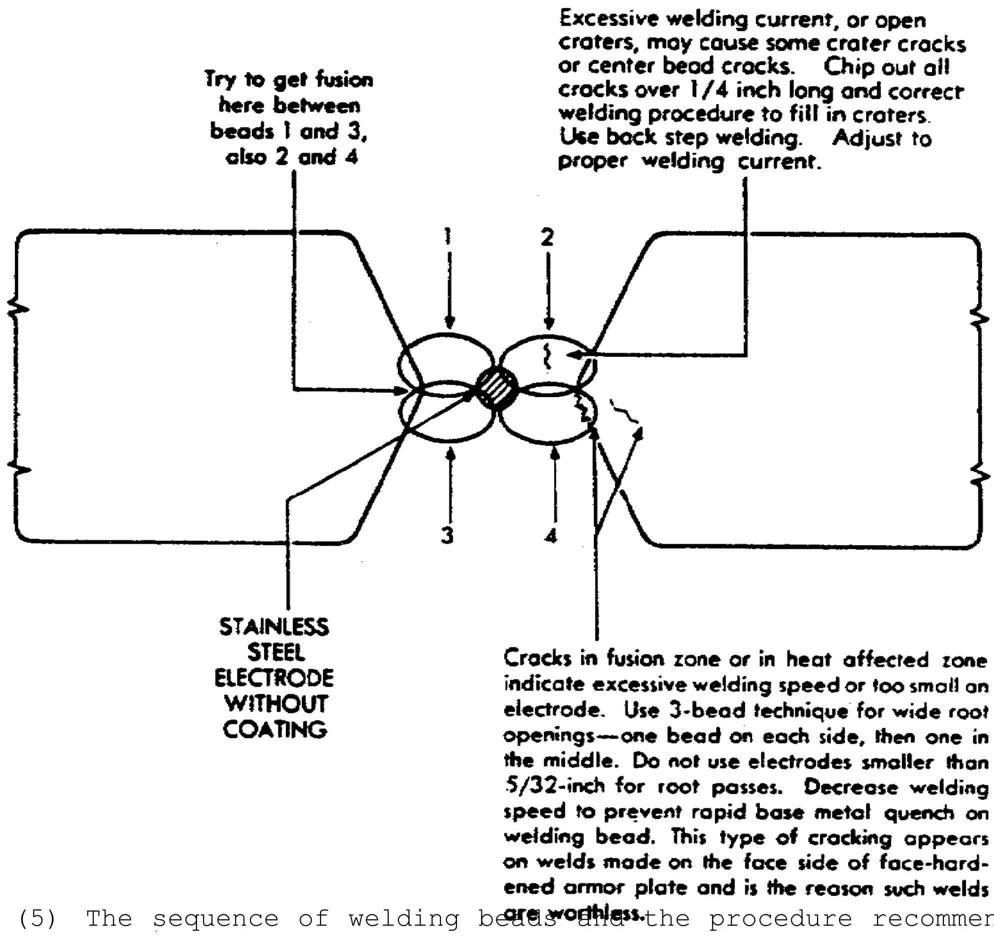
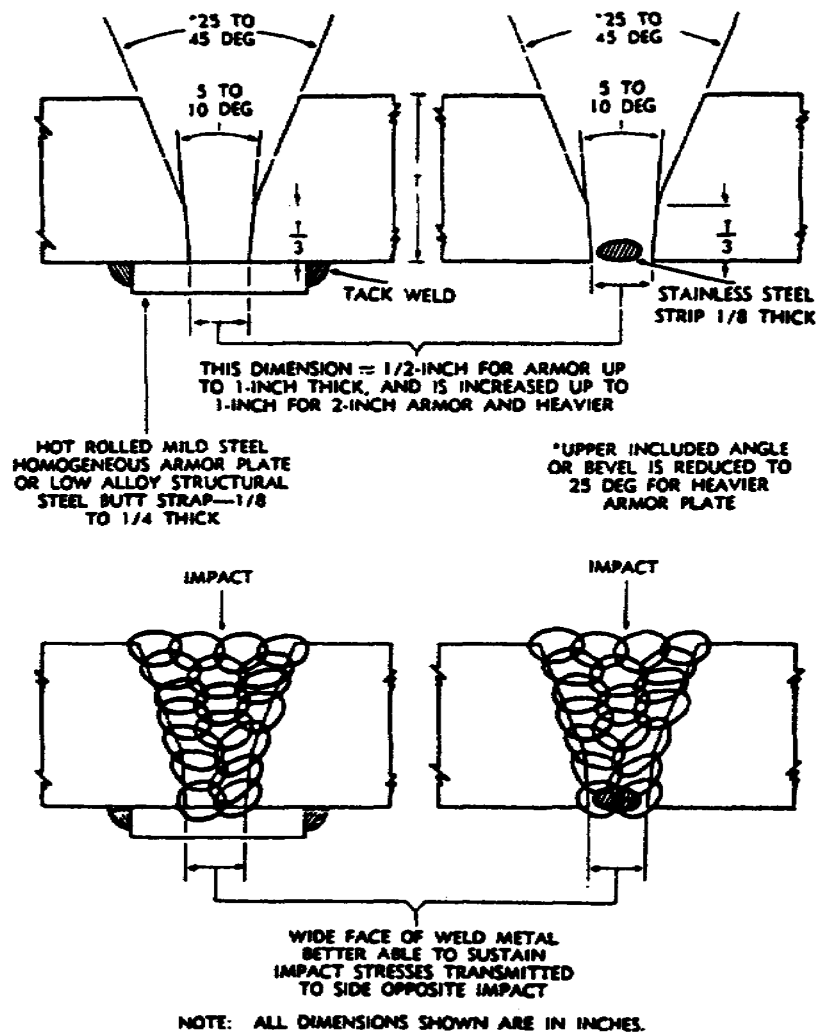


FIGURE 30. HOMOGENEOUS ARMOR COMMON DEFECTS AND REMEDIAL PROCEDURES.



(5) The sequence of welding beads and the procedure recommended to completely weld the single V joint are shown in figure 31, on the following page. Welding should be performed with a 5/32 or 3/16 inch electrode. The electrode is directed against the side wall 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 procedure, the side wall penetration can be effectively controlled. The electrode weaving motion should not exceed 2 1/2 electrode core wire diameters. This is important because stainless steel has a coefficient of expansion approximately 1 1/2 times that of mild steel; if a weaving motion

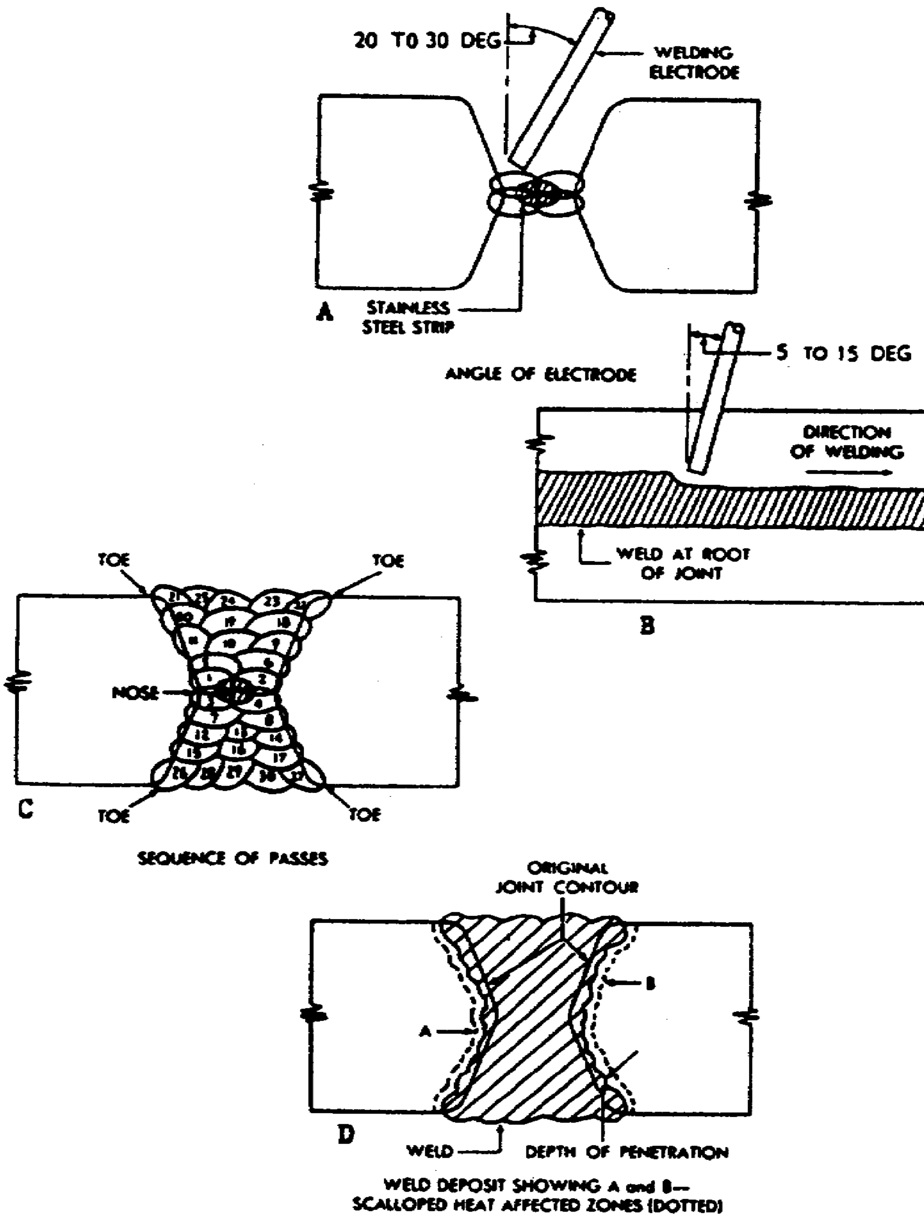
FIGURE 31. WELDING SINGLE V JOINTS ON HOMOGENEOUS ARMOR PLATE.



greater than that recommended is used, longitudinal shrinkage cracks in the weld or fusion zone may develop.

(6) The sequence of passes used for completely filling a double joint is shown in figure 32, views A through C, on the following page. The depth of penetration of weld metal into the base metal should be controlled in order to obtain good fusion without excessive dilution of the weld.

FIGURE 32. WELDING DOUBLE V JOINTS ON HOMOGENEOUS ARMOR PLATE.



Excessive dilution will cause the weld to be non-stainless, brittle, and subject to cracking. Proper penetration will give a long scalloped heat affected zone on each side of the weld as shown in figure 32, view D, on the previous page. Insufficient penetration (surface fusion) will produce a fairly straight edged heat affected zone on each side of the weld. This condition is undesirable from the standpoint of good ballistic properties.

(7) Better control can be maintained of the heat input at the joint and of the shape of the joint, by alternately depositing the weld metal on one side of the joint and then the other. Each layer of metal deposited serves to stress relieve the weld metal immediately beneath it, and to partially temper the heat affected zone produced in the base metal by the previous welding bead. The passes at the toe of the weld joint, as shown in figure 32, view C, also serve to anneal the base metal and are deposited before the intermediate passes are added to fill the weld joint. The annealing passes at the toe of the weld joint are an important factor in the elimination of fusion zone cracks which might start at the surface of the weld. Through careful control of the depth of penetration, a heat affected zone with a scalloped effect is produced.

c. *Emergency Repairs*. Two methods of emergency repairs on cracked armor plate that can be made by using butt straps are shown in figure 33, views E and F, on the following page. These straps are welded to the back of the cracked armor plate. The primary purpose of these butt straps is to strengthen the section weakened by the crack.

d. *Repairing Penetrations*. Complete penetrations in homogeneous armor plate are repaired by using the procedures shown in figures 34 through 36, on pages 79 through 81. Figure 35, view A, on page 80, shows that considerable structural damage has been done to the metal immediately adjacent to the shell penetration. Shell penetration holes smaller than the thickness of the armor plate can be repaired by the butt strap method. To effect repairs, all torn and irregular edges of the damaged metal should be removed to permit good contact between the butt strap and the base armor

FIGURE 33. BUTT STRAP WELDS ON CRACKED ARMOR PLATE.

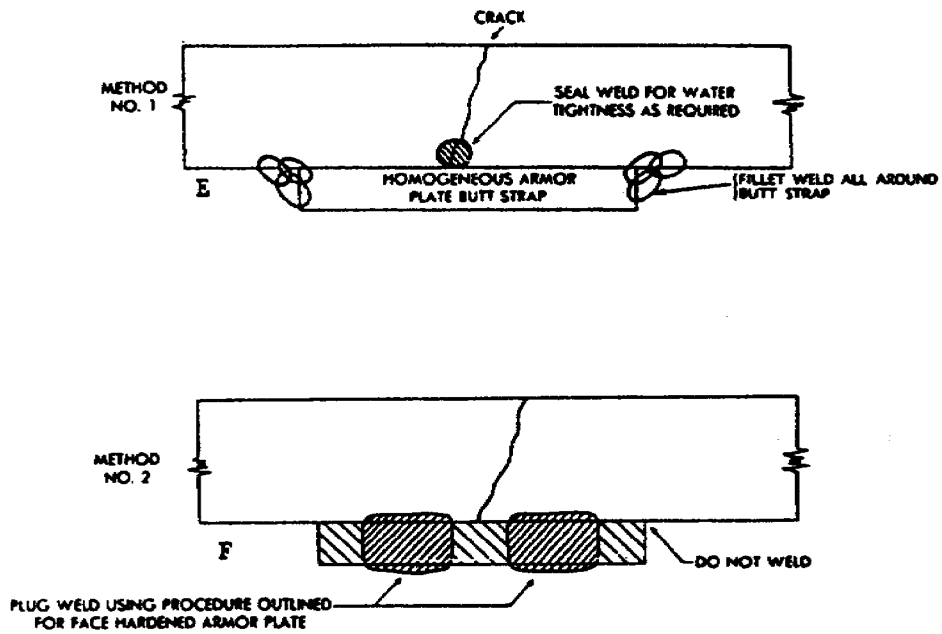


plate as shown in figure 34, on the following page. For holes that are larger than the thickness of the armor plate, a plug patch of homogeneous metal of the same thickness as the base metal should be used as shown in figure 35, view B, on page 80. The correct and incorrect method of preparing and welding the plug patch is shown in figure 36, views A and B, on page 81. Small diameter penetrations can be repaired by plug welding without the use of a patch.

e. *Repairing Bulges*. Bulges in armor that are also cracked, but do not interfere with the operation of internal mechanisms in the vehicle, can be repaired by welding the cracked section using the procedure described in paragraph c above. For best results, the bulge should be cut out and a patch inserted. Bulges in the armor that interfere with the operation of internal mechanisms may be removed by grinding or chipping them away. In all cases, the welds should be made to the full thickness of the plate and all cracks over 1/4 inch in width should be chipped out before rewelding.

f. *Repairs Made from One Side*. Where it is not feasible to make the welding repair from both sides of the armor, the joint must then be made from one side as shown in figure 31 on page 75. Note that either a butt strap or stainless steel strip can be used as a backup for the root beads of the weld.

FIGURE 34. EMERGENCY REPAIRS.

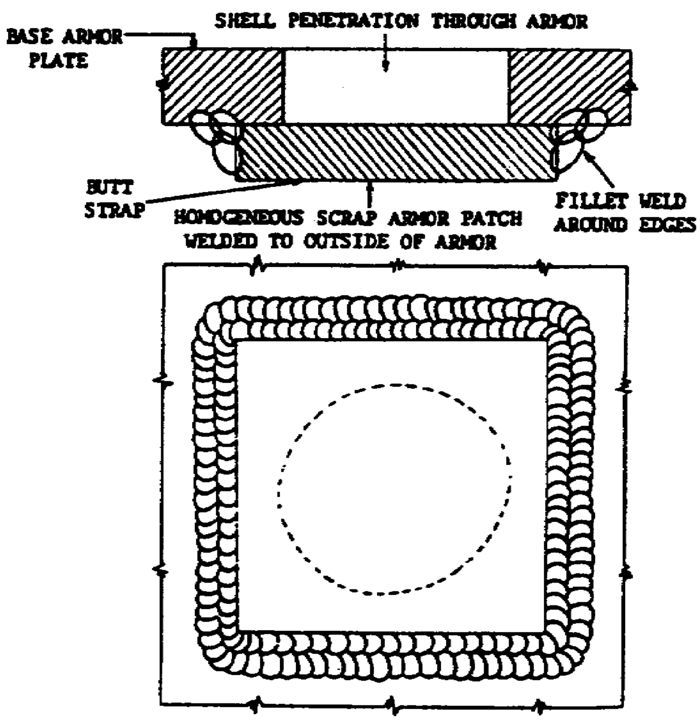
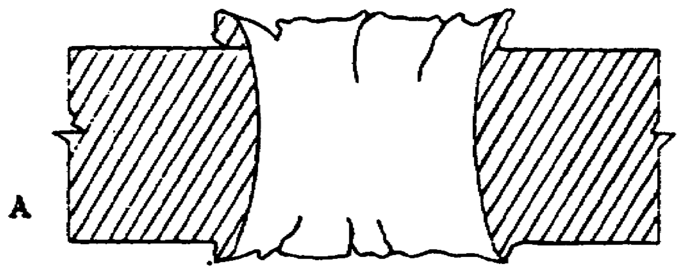
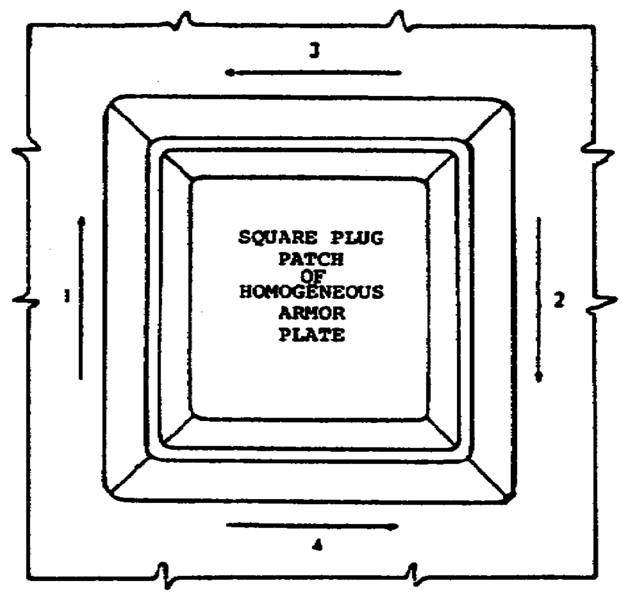


FIGURE 35. DOUBLE V PLUG WELDING.

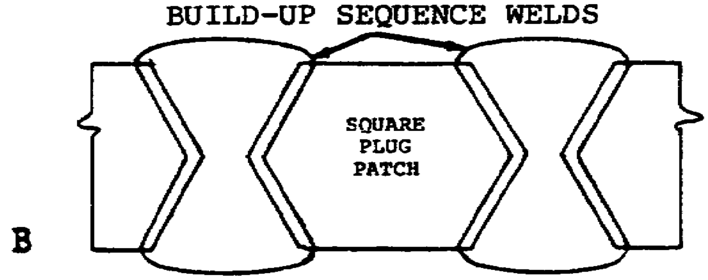


SHELL PENETRATION IN HOMOGENEOUS ARMOR PLATE. ALL TORN AND IRREGULAR EDGES SHOULD BE FLAME CUT BEFORE BEVELING SIDEWALLS FOR WELDING



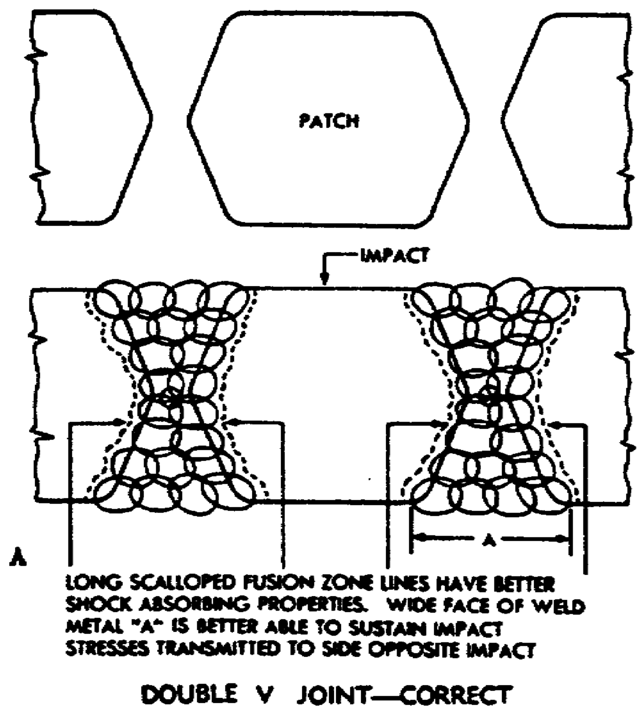
SQUARE PLUG DESIGN HAS DISTINCT ADVANTAGES OVER ROUND PLUG IN THAT STRAIGHT LINE WELDS CAN BE MADE. ROUND PLUGS REQUIRE CONSTANT VARIATION IN ANGLE OF ELECTRODE TO MAKE CURVED WELDS. THIS PROCEDURE PROMOTES ERRATIC PENETRATION AND IRREGULAR WELDS. NUMBERS INDICATE SEQUENCE TO BE USED IN WELDING

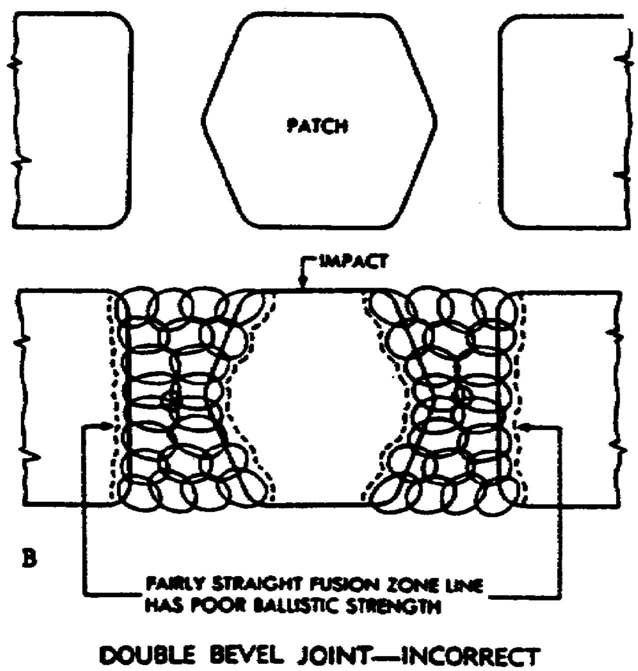
BUILD-UP SEQUENCE WELDS



DOUBLE BEVEL, PATCH AND SIDEWALLS OF HOLE

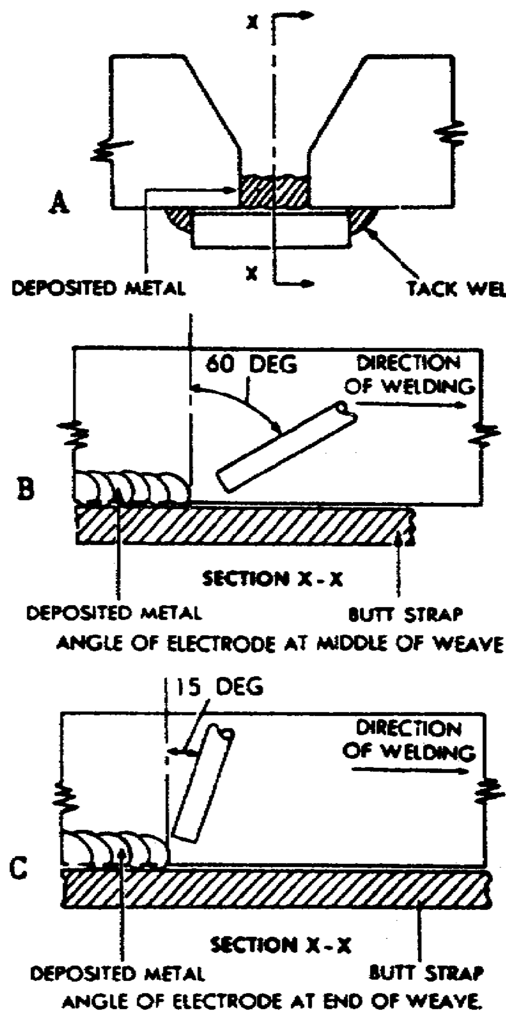
FIGURE 36. CORRECT AND INCORRECT PLUG WELD PREPARATION.





g. *Repairs with Nonwelded Butt Strap*. A technique that permits removal of the butt strap after welding is shown in figure 37, view A. This technique is used for applications where a butt strap would interfere with the operation of internal mechanisms. It permits welding a single V joint in homogeneous armor plate without welding the butt strap to the weld metal. This technique

FIGURE 37. WELDING WITHOUT A BUTT STRAP.



requires increasing the angle of the electrode to 60 degrees, as shown in figure 37, view B, on the previous page, at the middle of the weave while simultaneously increasing the weaving speed. As a result, the weld metal is deposited to the base metal and to previously deposited metal instead of adhering to the butt strap. At the end of each weave, the angle of the electrode is decreased to 15 degrees, as shown in figure 37, view C, simultaneous with the weaving speed, and the electrode is held momentarily adjacent to the side wall to ensure good side wall penetration. After depositing the root pass, the butt strap can be removed by breaking the tack welds which secure it to the armor plate. A final pass can be applied to the root of the weld after removing the butt strap.

h. *Repairing Gouges*. Occasionally, a projectile will impact on the armor plate at an angle and only gouge it without penetrating. To effect repairs, the gouge should be prepared into a double V joint, as shown in figure 38, view A, on the following page, to allow welding from both sides. Merely filling the gouge with weld metal, as shown in figure 38, view B, is not satisfactory, since it does not remove any subsurface cracks that may have been caused by the shell impact. Also, the heat zone produced at the base of the filled-in gouge has poor ballistic strength.

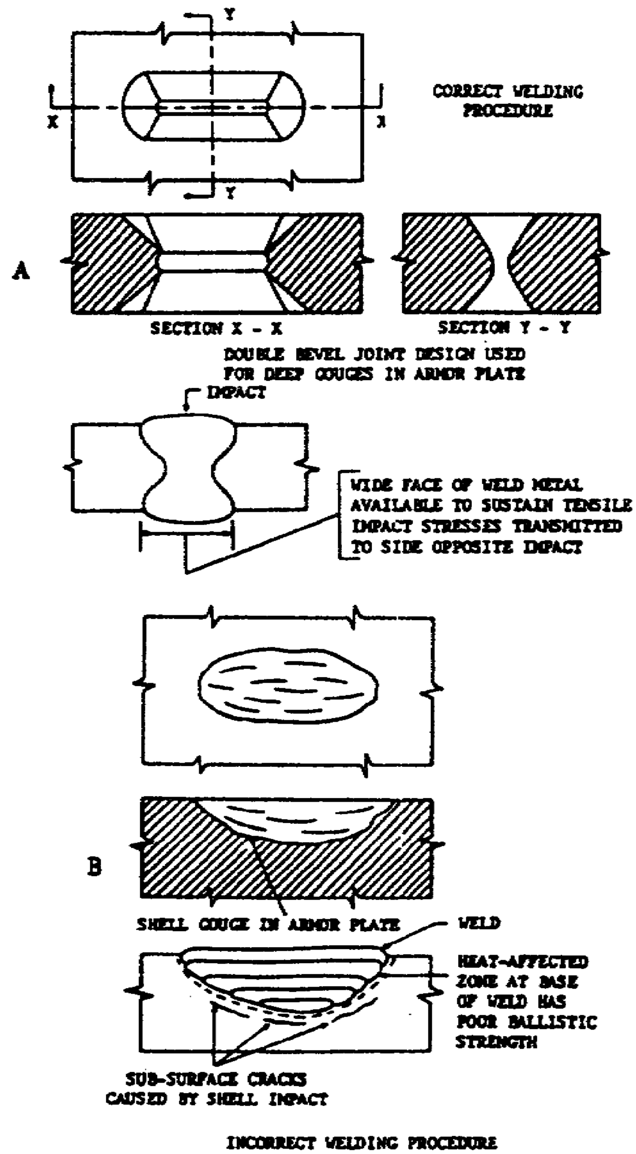
6. Welding Face Hardened Armor Plate

a. *General*.

(1) The face side of face hardened armor is extremely hard and brittle. Cracks on this type armor plate can be welded satisfactorily from the soft side. These cracks can be repaired by using 18-8 stainless steel reverse polarity heavy coated electrodes. Special precautions, however, must be taken to avoid distorting and excessively heating the armor plate. Distortion and excessive heat place stress on the base metal causing the plate face to crack.

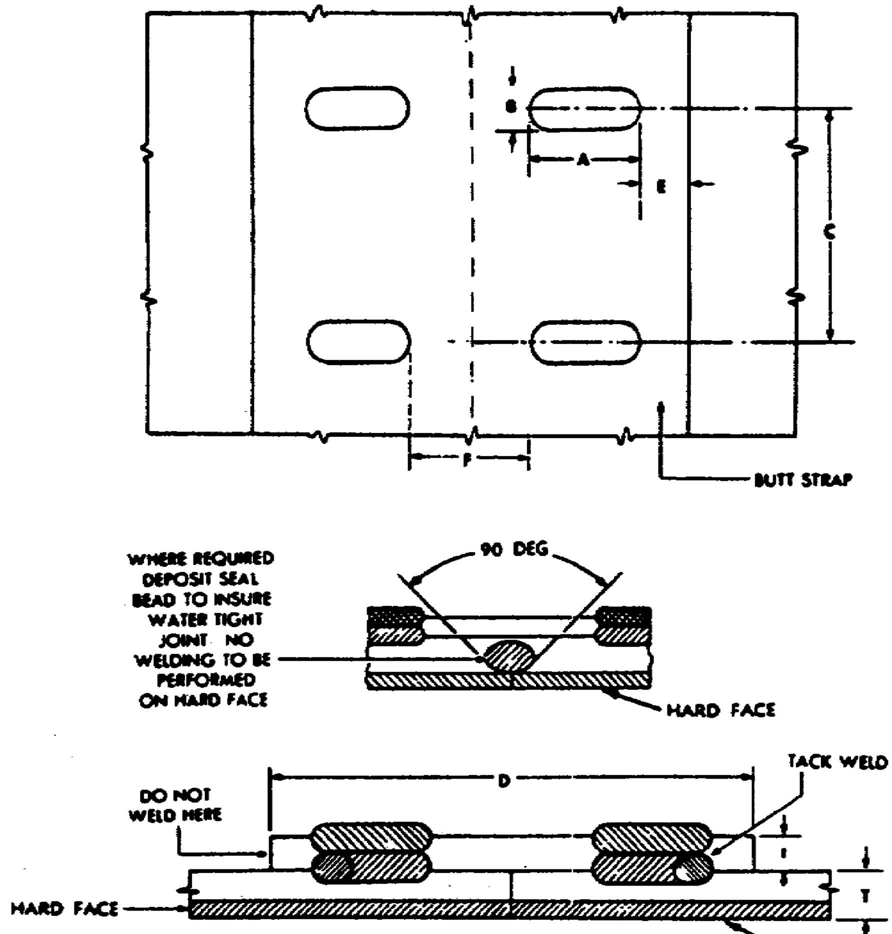
(2) Satisfactory methods for welding this type of armor makes use of the butt strap and butt welding techniques, shown in figures 39 and 40 on pages 85 and 86. The dimensions of the butt strap depend on the thickness of the armor. Butt strap dimensions for armor up to one inch thick are

FIGURE 38. REPAIRING GOUGES IN HOMOGENEOUS ARMOR PLATE.



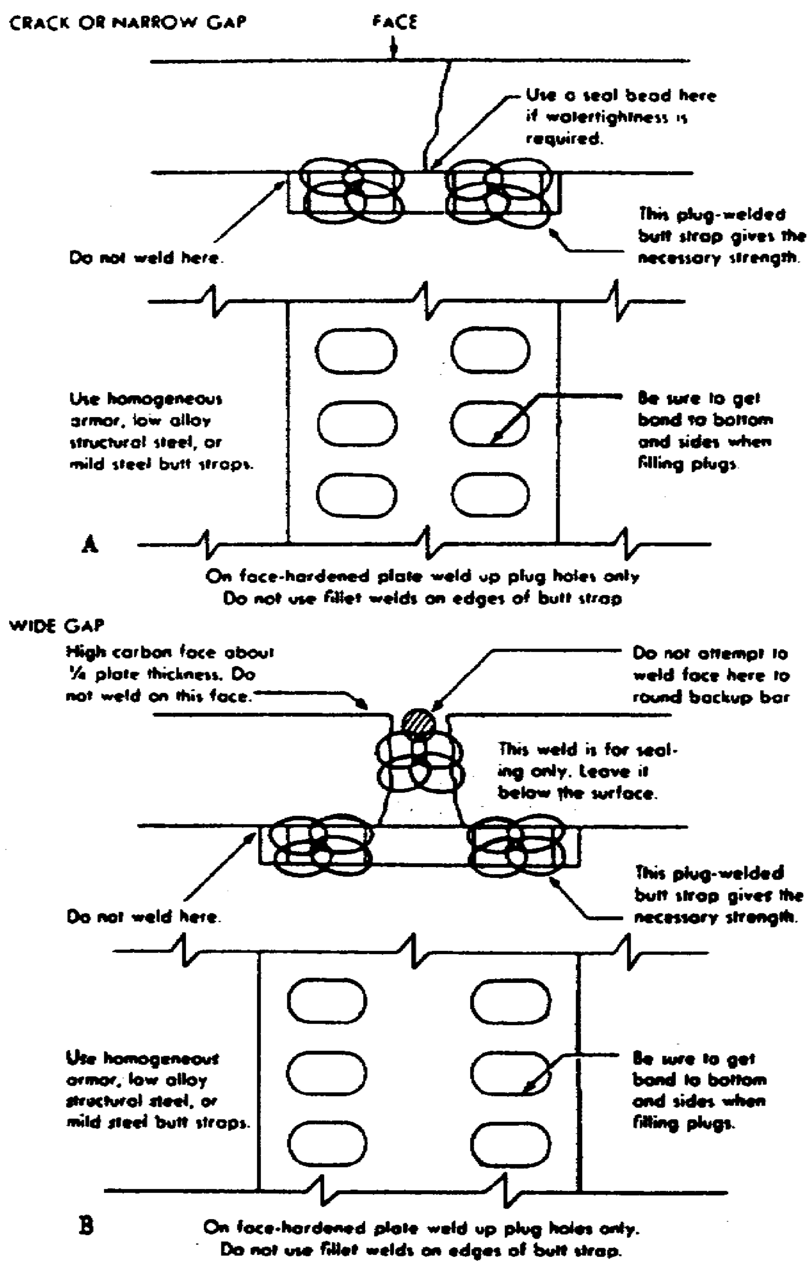
provided in TM 9-237, if desired. The butt strap is tack welded to the soft side of the armor through elongated slots cut into the strap. The slots are then completely filled by plug welding them. Do not use excessive weld reinforcement or undercutting at the surface of the plug.

FIGURE 39. BUTT STRAP WELDS FOR FACE HARDENED ARMOR PLATE.



(3) To seal a crack in face hardened armor, as shown in figure 40, view A, on the following page, against spatter and to make it watertight, weld a seal bead on the soft side and grind it flush before applying the butt strap. All welding should be performed on clean, scale free surfaces. Previously deposited weld metal should be thoroughly cleaned by chipping and wire brushing to remove slag and oxides to ensure sound welds.

FIGURE 40. SEALING CRACK IN FACE HARDENED ARMOR.



(4) Crater cracks can be eliminated by the backstep and overlap procedures or by using the electrode hesitation and drawback technique. Crater cracks formed in the initial weld passes should be chipped out before additional weld metal is applied. Then they can be welded out successfully by the subsequent passes. As a precaution, string beads should be used on the initial passes. On subsequent passes, do not weave the electrode more than 2 1/2 electrode core wire diameters. The efficiency of the joint welded by this method depends upon good fusion to the base metal and side walls of the slots in the butt strap.

(5) If straightening is necessary, use a hammer only on the soft side of face hardened armor, on the butt strap, or on the plug welds. Do not hammer on the face hardened side. As a rule, force should not be applied to straighten face hardened armor if the applied force will produce tension on the face hardened side.

(6) When two or more butt straps are used to repair irregular cracks or to make patch welds, the butt straps are welded together for additional strength as shown in figure 41.

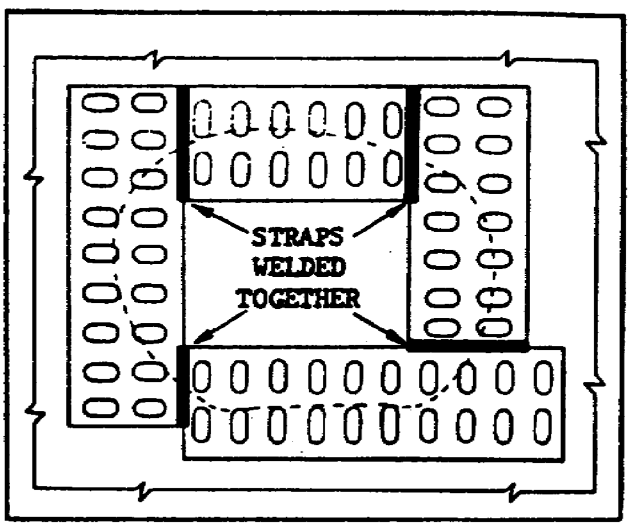
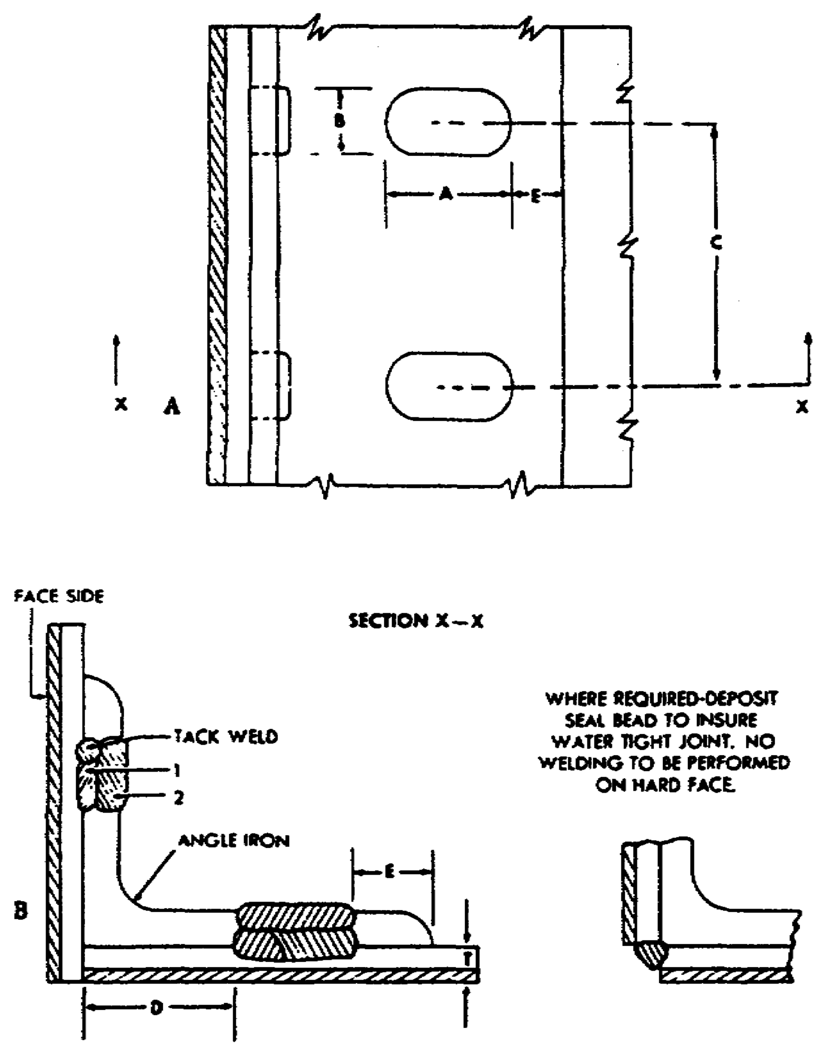


FIGURE 41. BUTT STRAP.

b. *Armor Plate Repair Methods*.

(1) Corner joints can be repaired by using angle iron for butt straps as shown in figure 42. The procedures used to effect this type of repair are the same as those used in making plug welds for repairing cracks in face hardened armor and described in paragraph 6a(2) beginning on page 83.

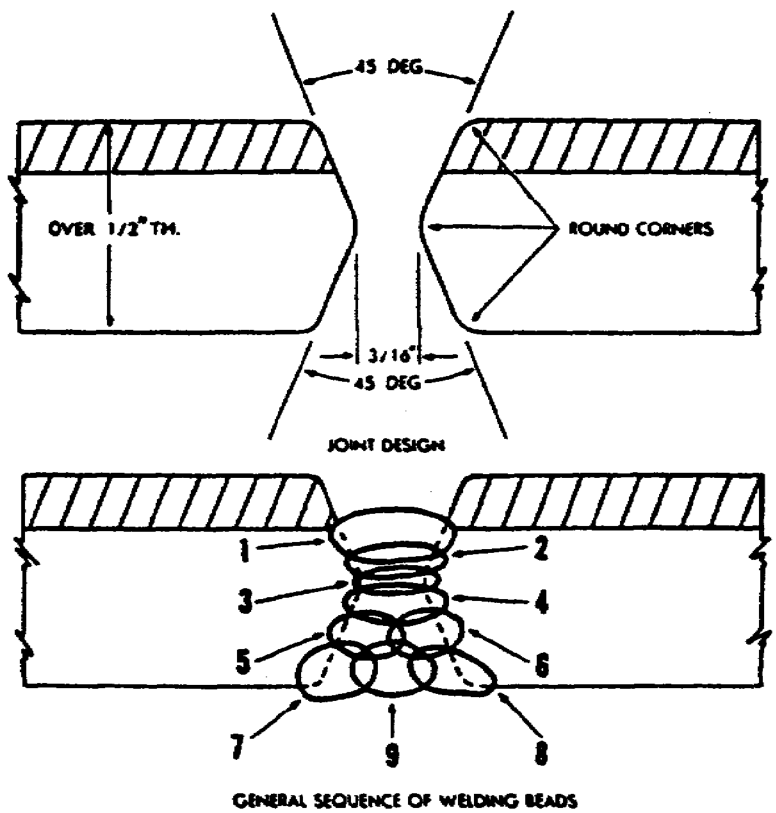
FIGURE 42. CORNER JOINT IN ARMOR PLATE.



(2) Generally, the butt strap method is satisfactory for repairing up to one inch or thicker of face hardened armor. However, it is usually only used on thicknesses up to and including 1/2 inch plate.

(3) Another accepted procedure for welding face hardened armor above 1/2 inch in thickness is the double V joint method, as shown in figure 43. This method requires that the soft side of the plate be

FIGURE 43. V JOINT WELDING FACE HARDENED ARMOR PLATE.

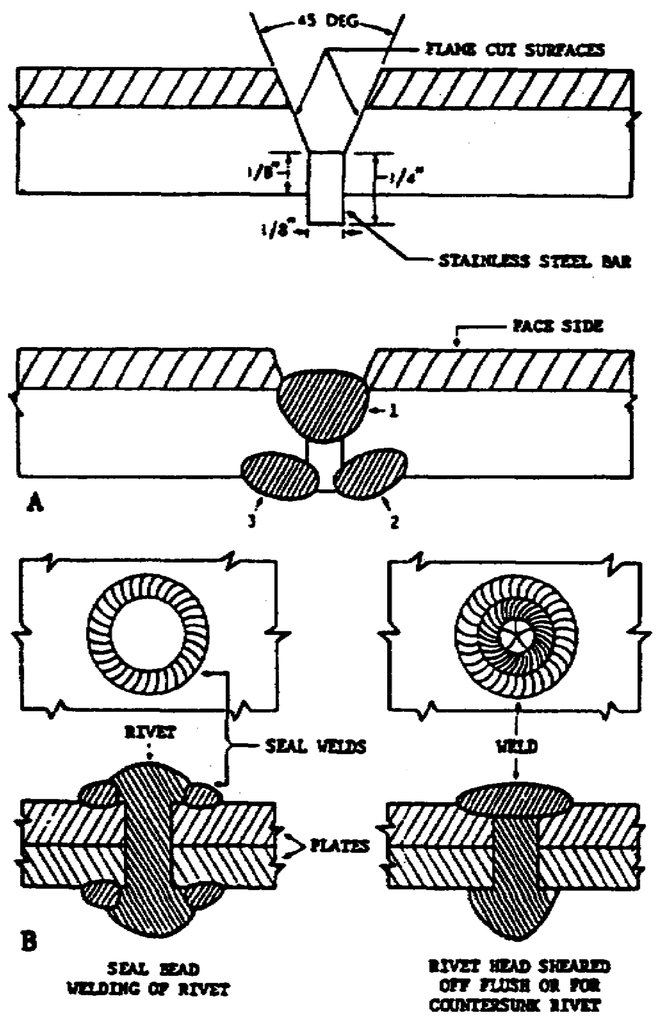


Completely weld soft side with Beads No. 1-9. For Bead No. 1 use 1/8 inch electrodes. For all other Beads use 5/32 and 3/16 inch electrodes. Use string bead technique throughout.

completely welded before welding on the face side. Using string bead welds, and the backstep and overlap procedures for the root passes, reduces the danger of cracks developing in the weld. To keep the structure free of warpage, no weaving motion of the welding rod should be used on this type joint.

(4) A modified procedure, known as the depressed joint method, shown in figure 44, view A, is used for welding up to and including 1/2 inch thick face hardened armor plate. This method uses a 1/8 inch

FIGURE 44. DEPRESSED JOINT ON FACE HARDENED ARMOR PLATE AND SEAL BEAD WELD.



by 1/4 inch stainless steel bar which is placed in the damaged portion of the armor plate. It is then bead welded in place. The principal advantages of this joint are its simplicity, and good structural and ballistic properties. Care should be taken that no welding is done on the hard face side of the armor plate.

c. *Armor Plate Welding Electrodes.*

(1) The most satisfactory method for the repair of homogeneous and face hardened armor plate is the arc welding process with stainless steel electrodes.

(2) In the oxyacetylene welding process, a large section of base metal must be heated to maintain a welding puddle to weld satisfactorily. This heating destroys the heat treatment of the base metal, causing large areas to become structurally and ballistically weak. In addition, this process is slow and produces considerable warpage of the base metal.

(3) Initially, developments in armor plate welding required the use of stainless steel electrodes containing 25 percent chromium and 20 percent nickel. Further developments served to produce electrodes with a core of 18 percent chromium and 8 percent nickel, and a coating of manganese or molybdenum, or both, which produce excellent results. These electrodes are known as manganese modified 18-8, and molybdenum modified 18-8 stainless steel electrodes. They can be used for welding all types of armor plate by the electric arc process without preheating or postheating the base metal structure.

(4) *Current and Polarity*. The exact current required for arc welding with the electrodes previously discussed depend to some extent on the joint type, electrode design, and position of welding. Listed below are the recommended welding current settings listed for direct current reverse polarity, all position, heavy coated, modified 18-8 stainless steel electrodes.

Electrode Diameter (inch)	***Current Range (ampere)***
1/8	**90 to 100**
5/32	**110 to 130**

7. Strengthening Riveted Joints in Armor Plate

a. *Buttonhead Riveted Joints*. To strengthen buttonhead riveted joints in armor plate, a seal bead weld is recommended as shown in figure 44, view B, on page 90. To apply the bead, the arc is struck at the top of the rivet using a stainless steel electrode. The electrode is held above the top of the rivet long enough to melt approximately 1/2 inch of the electrode. The electrode is then moved along the curved surface of the rivet down to the armor plate and around the edge of the rivet until the rivet is completely welded to the armor plate. Rivet joints in homogeneous armor plate can be seal welded on both sides. Rivet joints in face hardened armor, however, should be seal welded only on the soft side of the plate.

b. *Countersunk Rivet Joints*. Countersunk rivet joints are sealed in the same manner as buttonhead rivet joints.

c. *Advantage of Welding Rivet Joints*. Seal bead welding rivet joints prevents the rivet head from shearing off, and the rivet shank from punching through the plate upon a projectile impacting on the armor plate.

8. Testing of Welds

a. *General*. To ensure the satisfactory performance of a welded structure, the quality of the welds must be determined by adequate testing procedures. The welded structure, therefore, must be proof tested under conditions that are the same or more severe than those found in the field. Tests also serve to determine the proper welding design; and forestall injury, inconvenience, and untimely failure of materiel. Generally, there are two types of tests that can be performed to ensure the satisfactory performance of the welded structure. They are, the performance and the physical types of tests.

b. *Performance Tests*.

Materiel repaired by standard welding procedures may be tested by operating it to perform the functions for which it was designed. For example, a weapon can be tested by firing an extra heavy charge to determine the safety of the weld; a wheel vehicle can be tested at high speeds over rough terrain; and welded armor plate and other heavy structural members can be tested by gunfire. But, test firing of weapons and testing of armor plate by gunfire is not feasible for maintenance units in the field. The succeeding paragraphs, therefore, describe only those physical type tests that can be conducted in intermediate direct and general support maintenance units, in field depot maintenance operations, and in CONUS (continental United States) depot maintenance operations.

c. *Physical Tests*.

(1) *General*. These types of tests are designed to check the skill of the welder, the quality of the weld metal, and the strength of the welded joint. Some of these tests, such as the free bend and nick break tests, are destructive. In these tests, the specimen is tested until it fails in order that the desired information can be gained. Other physical tests, such as the hydrostatic and magnetic particle tests, are not destructive. Then there are simple physical tests, such as the appearance, fracture, and grinding tests, that can be performed with tools found in a field maintenance company shop. These simple physical tests are described in the following subparagraph. The destructive and nondestructive type tests are described in the succeeding subparagraphs.

(2) *Simple Physical Tests*.

(a) *Appearance Test*. This is a nondestructive test. In this type test, a visual examination is made of the weld to check for such defects as brittleness, cracks, craters, undercut, overlap and slag inclusions. All these defects are unacceptable and the joint must be reconstructed and rewelded.

(b) *Fracture Test*. This is a destructive test. To perform this test, a cross section specimen must be cut off from the welded metal. The specimen is then fractured to expose the weld. The welded zone is then visually examined to check for unevenness of the weld metal grain, cracks, craters, and inadequate penetration of the weld into the base metal.

(c) *Grinding Test*. This is a nondestructive test. It is particularly applicable to seal bead welds made for waterproofing and sealing cracks in face hardened metal. This type weld must be ground down flush with the base metal before welding of the strap to reinforce the damaged area. After grinding, the weld is then visually examined to check for proper penetration, craters, cracks, and evenness in the weld metal grain.

(3) *Destructive and Nondestructive Tests*. In the following subparagraphs, we will describe a total of six tests, three destructive and three nondestructive. These six test are the ones most likely to be performed in maintenance units in the field and depot maintenance operations. If more information on other tests is desired, it is provided in TM 9-237.

(a) *Destructive Tests*.

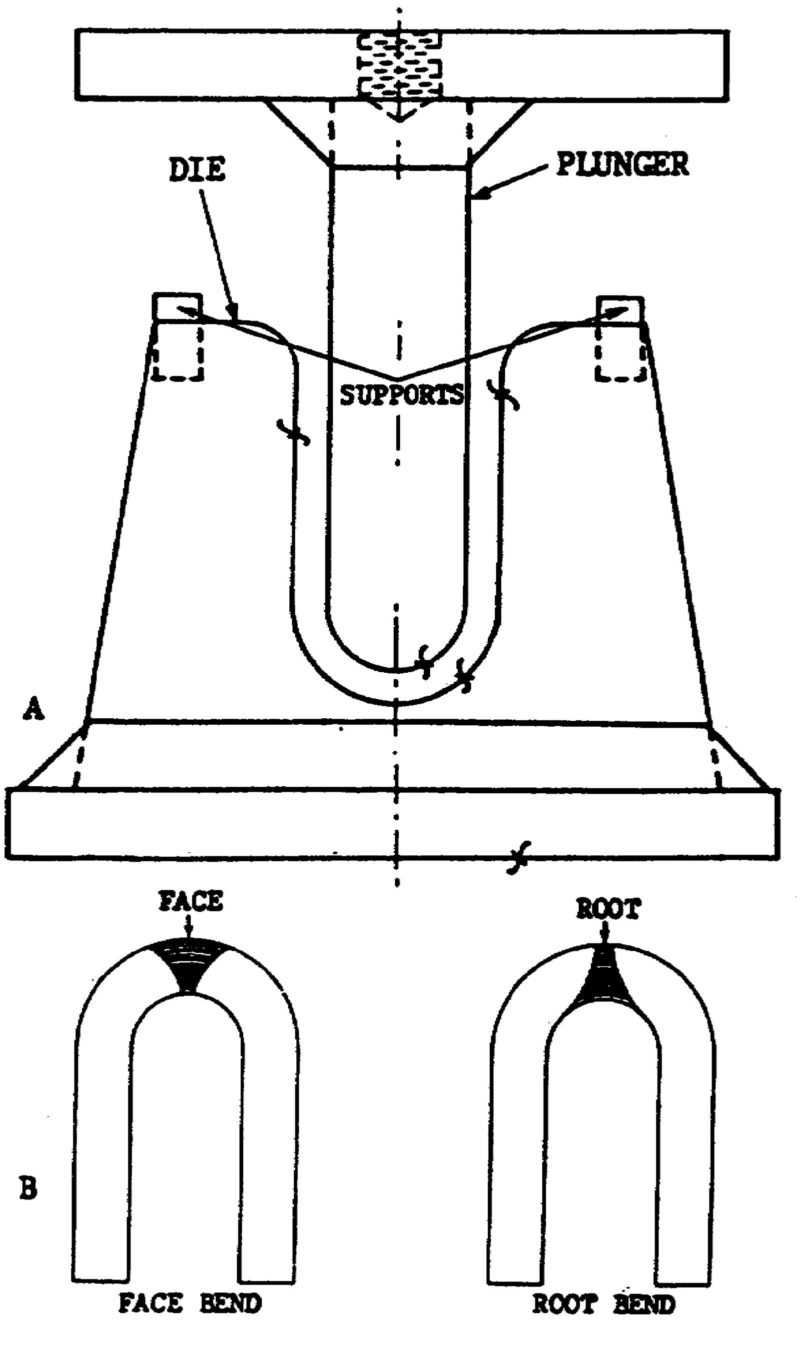
1 *Guided Bend Test*.

a This type test serves to determine the quality of the weld metal at the face, the root of the welded joint, and the degree of penetration and fusion to the base metal. These tests are made on a jig as shown in figure 45, view A, on the following page. This jig can be fabricated to any size desired in a field maintenance company machine shop.

b To perform this test, the test specimens must be machined from welded plates to a thickness within the capacity of the bending jig. The specimen is then placed across die supports. The weld on the specimen must be centered on the U portion of the die. The plunger is then lowered onto the specimen from above by a hydraulic jack or other device to force the specimen into the U portion of the die. To fulfill the requirements of this test, the specimen must bend 180 degrees and have no cracks greater than 1/8 inch on its surface.

c Both a face bend and a root bend test of weld, as shown in figure 45, view B, can be performed on this jig. To perform the face bend test, place the face of the weld facing down on the jig. The root bend test is performed by placing the specimen on the die with the face of the weld facing up.

FIGURE 45. GUIDED BEND TEST JIG.



2 *Free Bend Test*.

a The free bend test has been devised to measure the ductility of the weld metal deposited in a weld joint. A test specimen is machined from the welded plate with the weld located in the center as shown in figure 46, view A, on the following page. Each lengthwise edge of the specimen should be rounded off to a radius not to exceed one-tenth of the thickness of the specimen. Any tool marks should be made lengthwise of the specimen. And two lines, opposite each other, are scribed on the face of the weld at a distance of 1/16 inch inward from the edges of the weld as shown in figure 46, view B. The distance between these two lines is measured in inches and recorded as the initial distance X. The ends of the specimen are then bent to form two 30 degree angles at approximately one-third of the length inward from the ends. The weld is thus centrally located to ensure that all bending occurs in the weld.

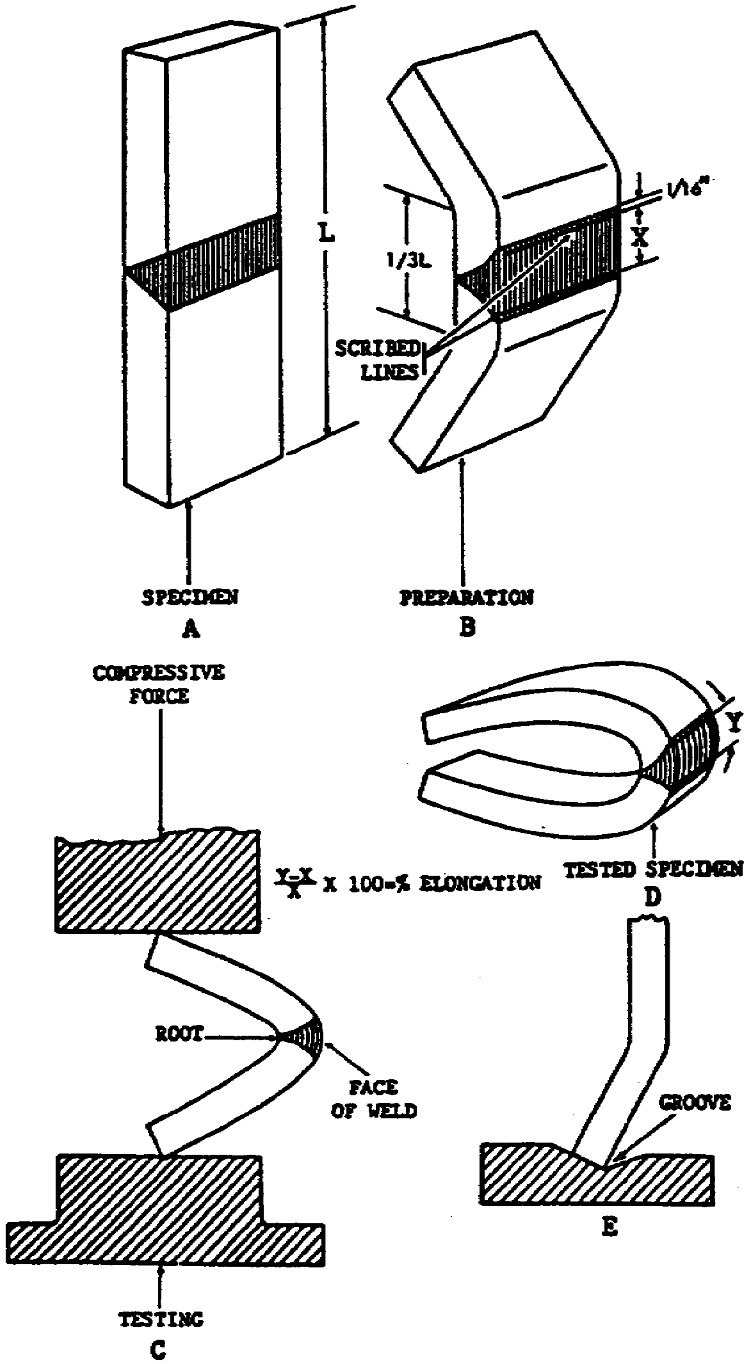
b The bent specimen is then placed in a hydraulic or mechanical machine as shown in figure 46, view C, and bent until a crack greater than 1/16 inch appears on the face of the weld. If no cracks appear on thin armor plate, continue bending until the specimen can be bent in a vise. Heavier plate specimens are usually tested in a hydraulic press or bending jig. To prevent slipping of the specimen, a groove should be machined in the upper and lower contact plates of the bending equipment, as shown in figure 46, view E.

c After being bent to the specifications prescribed in the preceding subparagraph, the distance between the scribed lines is again measured and recorded as the distance Y. Find the percentage of elongation by using the formula shown in figure 46. The tested specimen must have a minimum elongation of 15 percent with no cracks greater than 1/16 inch at the weld to pass this test.

3 *Nick Break Test*.

a The nick break test has been devised to determine if the weld metal of a welded butt joint has any internal defects, such as slag inclusions, gas pockets, poor fusion, and/or oxidized or burnt metal. The specimen is obtained from a welded butt joint either by machining or by cutting with an

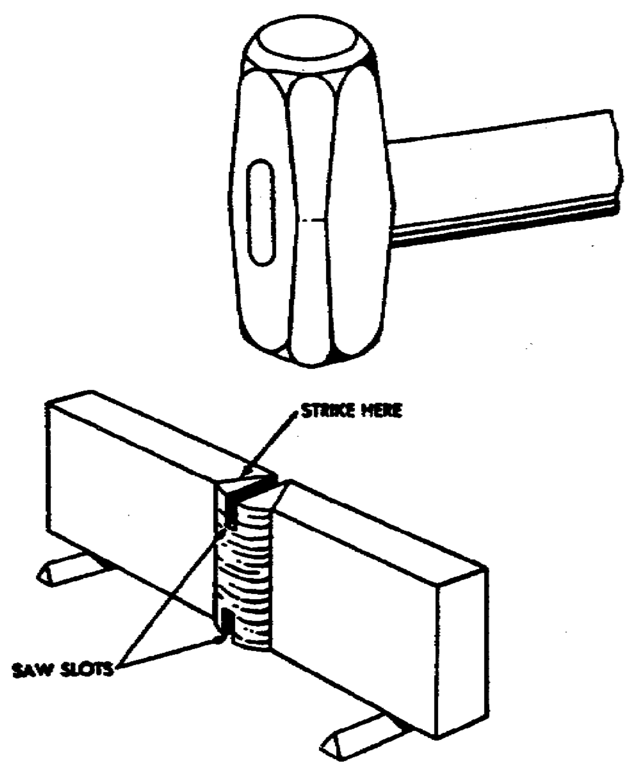
FIGURE 46. FREE BEND TEST.



oxyacetylene torch. Each end of the weld at the joint is slotted with a hacksaw or band saw as shown in figure 47. The specimen is then bridged across two steel blocks, and struck with a heavy hammer until the section of the weld between the slots fractures. The metal thus exposed should be completely fused and free from slag inclusions. The size of any gas pocket must not be greater than 1/16 inch at its widest point. The number of gas pockets or pores should not exceed six per square inch.

b Another break test method is used to determine the soundness of fillet welds. This is known as the fillet weld break test. This test is performed by applying force on the apex of the V shaped specimen with a hydraulic press or by striking it with a hammer until the fillet weld ruptures. The surfaces of the fracture are then examined for the same defects mentioned in the preceding paragraph.

FIGURE 47. NICK BREAK TEST.



(b) *Nondestructive Tests*.

1 *Hydrostatic Test*.

a This nondestructive test is used to check the quality of welds on closed containers such as pressure vessels and liquid tanks.

b One method of performing this test is to fill the vessel with water and apply a pressure greater than the working pressure of the vessel. The outside surface of the vessel is then observed for leaks through the welds. To check welds in nonpressurized tanks, they may be filled with water and observed for seepage or leaks through the welds.

2 *Magnetic Particle Test*. This method of testing is used on welds and parts made of magnetic alloy steels. It is applicable only to ferromagnetic materials in which the deposited weld is also ferromagnetic. A strong magnetic field is set up in the ferromagnetic specimen by an electric current. Any discontinuity in the metal will set up a leakage field with local magnetic poles of its own. These poles then attract the magnetic particles sprinkled on the surface of the specimen indicating a discontinuity in the overall pattern of the magnetized specimen. This discontinuity indicates that a defect, such as a crack, exists on or close to the surface of the specimen.

3 *Fluorescent Penetrant Test*. Fluorescent penetrant inspection is a nondestructive test whereby cracks, pores, leaks, and other discontinuities can be located in solid materials. It is particularly useful for locating surface defects in nonmagnetic materials such as aluminum, magnesium and austenitic steel welds and for locating leaks in all types of welds. This test makes use of a water-washable and highly fluorescent material. This material is applied to the clean, dry surface of the specimen by brushing, spraying, or dipping. The excess material is removed by rinsing, wiping with clean water-soaked cloths, or by sandblasting. A wet or dry type developer is then applied. Afterwards, a black light is used to reveal discontinuities in the weld specimen. The discontinuities will show up as brilliant fluorescent spots on the surface of the specimen.

9. Troubleshooting Welds.

a. Thus far, this lesson has described the processes for identifying electrodes, the automotive welding processes, the types and techniques of joint design, the procedures for welding armor plate, and the methods of destructive and nondestructive testing of welds. This material provided the basis for the troubleshooting of welds to be discussed in the succeeding paragraphs. Each of the troubleshooting procedures discussed are based on specific malfunctions detected as a result of visually examining welds. The troubleshooting procedures discussed below, therefore, are based on a total of five specific malfunctions most likely to be encountered in a maintenance unit in the field. For further information on other troubleshooting procedures refer to TM 9-237.

b. *Procedure*. Listed below are the procedures that the welder would follow in troubleshooting a weld upon detecting the malfunction indicated.

(1) *Poor Fusion*.

Step 1. Check the diameter and the length of the electrode. The electrode selected should be of a size that will permit its reaching the bottom of the joint to obtain adequate penetration and good fusion.

Step 2. Check the welding current setting. Use sufficient welding current to permit adequate deposit and penetration of the weld. Heavier plates require higher current for a given electrode than light plates.

Step 3. Check the welding technique used. Be sure that the weave is wide enough to thoroughly melt the sidewalls of the joint.

Step 4. Check the preparation of the joint. The deposited metal should fuse with the base metal and not curl away from it or merely stick to it.

(2) *Poor Penetration*.

Step 1. Check to see if the electrode is designed for the welding position being used. Electrodes should be used for welding in the position for which they were designed. Be sure to allow the proper root openings at the bottom of a weld. Use a backup bar if possible. Chip or cut out the back of the joint and deposit a bead of weld metal at this point.

Step 2. Check the size of the electrode being used. Do not expect excessive penetration from an electrode. Use small diameter electrodes in a narrow welding groove to permit reaching the bottom of the groove.

Step 3. Check the welding current setting. Use sufficient welding current to obtain proper penetration.

Step 4. Check the welding speed. Do not weld too rapidly. Control the welding speed to permit penetration to the bottom of the welded joint.

(3) *Undercut.*

Step 1. Check the welding current setting. Use moderate welding current and do not try to weld at too high a speed.

Step 2. Check for proper manipulation of the electrode. Do not use too large an electrode. If the puddle of molten metal becomes too large, undercut may result. Excessive width of weave will cause undercut and should not be used. A uniform weave, not over three times the electrode diameter, will aid greatly in preventing undercut in butt welds. If an electrode is held too near the vertical plate in making a horizontal fillet weld, undercut on the vertical plate will result.

(4) *Poor Weld Appearance.*

Step 1. Check welding technique for proper current and electrode manipulation technique. Ensure the use of the proper welding technique for the electrode used. Do not use excessive welding current. Use a uniform weave or rate of travel at all times.

Step 2. Check the characteristics of type electrode used. Use an electrode designed for the type of weld, base metal, and the position in which the weld is to be made.

Step 3. Check the welding position for which the electrode is designed. Do not make fillet welds with downhand (flat position) electrodes unless the parts are positioned properly.

Step 4. Check for the proper joint preparation. Make sure all joints are properly prepared.

(5) *Warping of Thin Plates*.

Step 1. Check for shrinkage of the deposited weld metal. Select an electrode with high welding speed and moderate penetrating properties.

Step 2. Check for excessive local heating at the joint. Weld rapidly to prevent excessive local heating of the plates adjacent to the weld.

Step 3. Check for proper preparation of the weld joint. Avoid an excessive root opening in the joint between the parts to be welded. Hammer the joint edges thinner than the rest of the plates before welding. Hammering elongates the edges and the weld shrinkage causes them to pull back to the original shape.

Step 4. Check the welding procedure. Use either the special intermittent or alternating welding sequence, or backstep or skip welding procedure.

Step 5. Check the clamping of parts. Properly clamp parts adjacent to the joint. Use backup fixtures to cool parts rapidly.

10. Conclusion

This task served to describe the theory, principles, and procedures of welding armor plate; the methods of destructive and nondestructive testing of welds, and the troubleshooting of welds pertaining to electric arc welding. This task completes the text material of this lesson. The next task consists of a practical exercise which you are required to complete by providing the answers to the questions.

PRACTICAL EXERCISE

Instructions

This exercise is provided to test your progress in learning the materials in the subcourse. Please answer the questions that follow. You may check your answers from the page that follows the questions.

1. List two of the seven factors that must be considered in selecting electrodes.

2. What are the three groups into which metal-arc electrodes may be grouped and classified?

3. The American Welding Society has formulated a number series for the identification of electrodes.

a. What does the letter E at the beginning of this number signify?

b. What two digits of this number series indicate the position of the weld and the type of electrical current required?

4. What is one of the functions performed by the coating on thinly-coated electrodes?

5. What two types of electric current are used for electric arc welding?

6. What two methods of welding may be used to repair cracks in cast iron engine blocks?

7. By what commonly used method are broken or weakened vehicle frames crossmembers repaired or strengthened?

8. Name two of the five type welding joints used in metal-arc welding.

9. What is the preferred arc lengths for obtaining better control of the filler metal deposited during welding?

10. Of the four general positions used for welding, which is most difficult to weld in?

11. What are the two types of armor plate used on Army combat vehicles?

12. What type of armor plate may be repaired from both sides?

13. What is one of the three simple tests that can be performed in a maintenance company shop for testing welds?

14. What is one of the three nondestructive tests that is used for testing welds?

15. What is the first step in troubleshooting a weld with poor fusion?

LESSON 1. PRACTICAL EXERCISE - ANSWERS

1. a. Specific properties
   b. Type of base metal
   c. Position of the weld
   d. Type of current available
   e. Current polarity available
   f. Dimensions of the section to be welded
   g. The type of fit permitted by the work

2. a. Bare
   b. Thinly coated
   c. Shielded-arc or heavy coated

3. a. The letter in the number series indicates that the welding rod is intended for use in metal-arc welding
   b. The third and fourth numbers respectively

4. a. It dissolves or reduces impurities on the weld metal deposited
   b. It reduces the adhesive force between the molten metal and the end of the electrode
   c. It increases the stability of the arc

5. Alternating and direct current.

6. Metal-arc welding and brazing with oxyacetylene.

7. By the use of reinforcing plates.

8. a. Butt joint
   b. Corner joint
   c. Edge joint
   d. Lap joint
   e. Tee joint

9. Short arc length.

10. The overhead position.

11. Homogeneous and face hardened armor plate.

12. Homogeneous plate.

13. a. Appearance test
    b. Fracture test
    c. Grinding test

14. a. Guided bend test
    b. Free bend test
    c. Nick break test

15. Check the diameter of the electrode.

REFERENCES

REFERENCES

The following documents were used as resource materials in developing this subcourse:

TM 9-237