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FUNDAMENTALS OF MANUAL WELDING

Main Category:	Materials Engineering
Sub Category:	Welding
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OFFICIAL COURSE/EXAM
(SEE INSTRUCTIONS ON NEXT PAGE)

MAT-114 EXAM PREVIEW

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Exam Preview:

1. One of the most popular welding methods uses a gas flame as a source of heat. In the oxyfuel ____ process (fig. 3-2), heat is produced by burning a combustible gas, such as MAPP (methylacetylene-propadiene) or acetylene, mixed with oxygen.
   a. Arc Welding
   b. Brazing
   c. Sub-Arc Welding
   d. Gas welding

2. Arc welding is a process that uses an electric arc to join the metals being welded. A distinct advantage of arc welding over gas welding is the concentration of heat, because less heat spread reduces buckling and warping.
   a. True
   b. False

3. To prevent head burns during overhead welding operations, you should wear leather or flameproof caps under the helmet. Earplugs also should be worn to keep sparks or splatter from entering and burning the ears.
   a. True
   b. False

4. Welding cables carry the current to and from the workpiece. One of the cables runs from the welding machine to the electrode holder and the other cable connects the workpiece to the welding machine. The cable that connects the workpiece to the welding machine is called the ground.
   a. True
   b. False

5. You use the FILLET-WELDED JOINT TEST to check the _____ of a fillet weld. _____ refers to the degree of freedom a weld has from defects found by visual inspection of any exposed welding surface.
    a. Stress
    b. Strength
    c. Toughness
    d. Soundness

6. When welding material solidly, you may use _____ to hold it in place temporarily. _____ is one of the most important steps in pipe welding or any other type of welding.
    a. Fillet weld
    b. Wearfacing
    c. Weld gapping
    d. Tack Welds

7. To produce good quality welds, a welder must learn to recognize and correct possible welding defects. ____ usually results from pulling the torch and gas shield away before the crater has solidified. To correct this problem, you should reduce the travel speed at the end of the joint. You also may try reducing the tip-to-work distance.
    a. Lack of Penetration
    b. Crater porosity
    c. Burn-Through
    d. Cold Lap

8. Special filler rods are available for GTA welding; therefore, but you can also use welding rods designed for oxyfuel welding because they can contaminate the tungsten electrode
    a. True
    b. False

9. For GMA Welding of Aluminum, the joint design for aluminum is similar to that of steel; however, aluminum requires a narrower joint spacing and lower welding current setting.
    a. True
    b. False

10. For GMA Welding of Stainless Steel, DCRP with a 1- or 2-percen_____ oxygen with argon mixture is recommended for most stainless steel welding.
    a. 1-2%
    b. 2-3%
    c. 4-5%
    d. 5-10%

INTRODUCTION TO WELDING

In the Navy as well as private industry, welding is widely used by metalworkers in the fabrication, maintenance, and repair of parts and structures. While there are many methods for joining metals, welding is one of the most convenient and rapid methods available. The term welding refers to the process of joining metals by heating them to their melting temperature and causing the molten metal to flow together. These range from simple steel brackets to nuclear reactors.

Welding, like any skilled trade, is broad in scope and you cannot become a welder simply by reading a book. You need practice and experience as well as patience; however, much can be gained through study. For instance, by learning the correct method or procedure for accomplishing a job from a book, you may eliminate many mistakes that otherwise would occur through trial and error.

This chapter is designed to equip you with a background of basic information applicable to welding in general. If you take time to study this material carefully, it will provide you with the foundation needed to become a skilled welder.

WELDING PROCESSES

Welding is not new. The earliest known form of welding, called forge welding, dates back to the year 2000 B.C. Forge welding is a primitive process of joining metals by heating and hammering until the metals are fused (mixed) together. Although forge welding still exists, it is mainly limited to the blacksmith trade.

Today, there are many welding processes available. Figure 3-1 provides a list of processes used in modern metal fabrication and repair. This list, published by the American Welding Society (AWS), shows the official abbreviations for each process. For example, RSW stands for **resistance spot welding. Shielded metal arc welding** (SMAW) is an arc-welding process that fuses (melts) metal by heating it with an electric arc created between a covered metal electrode and the metals being joined. Of the welding processes listed in figure 3-1, shielded metal arc welding, called stick welding, is the

most common welding process. The primary differences between the various welding processes are the methods by which heat is generated to melt the metal. Once you understand the theory of welding, you can apply it to most welding processes.

The most common types of welding are oxyfuel gas welding (OFW), arc welding (AW), and resistance welding (RW). As a Steelworker, your primary concern is gas and arc welding. The primary difference between these two processes is the method used to generate the heat.

GAS WELDING

One of the most popular welding methods uses a gas flame as a source of heat. In the oxyfuel gas welding process (fig. 3-2), heat is produced by burning a combustible gas, such as MAPP (methylacetylene-propadiene) or acetylene, mixed with oxygen. Gas welding is widely used in maintenance and repair work because of the ease in transporting oxygen and fuel cylinders. Once you learn the basics of gas welding, you will find the oxyfuel process adaptable to brazing, cutting, and heat treating all types of metals. You will learn more about gas welding in chapter 5.

ARC WELDING

Arc welding is a process that uses an electric arc to join the metals being welded. A distinct advantage of arc welding over gas welding is the concentration of heat. In gas welding the flame spreads over a large area, sometimes causing heat distortion. The concentration of heat, characteristic of arc welding, is an advantage because less heat spread reduces buckling and warping. This heat concentration also increases the depth of penetration and speeds up the welding operation; therefore, you will find that arc welding is often more practical and economical than gas welding.

All arc-welding processes have three things in common: a heat source, filler metal, and shielding. The source of heat in arc welding is produced by the arcing of an electrical current between two contacts. The power

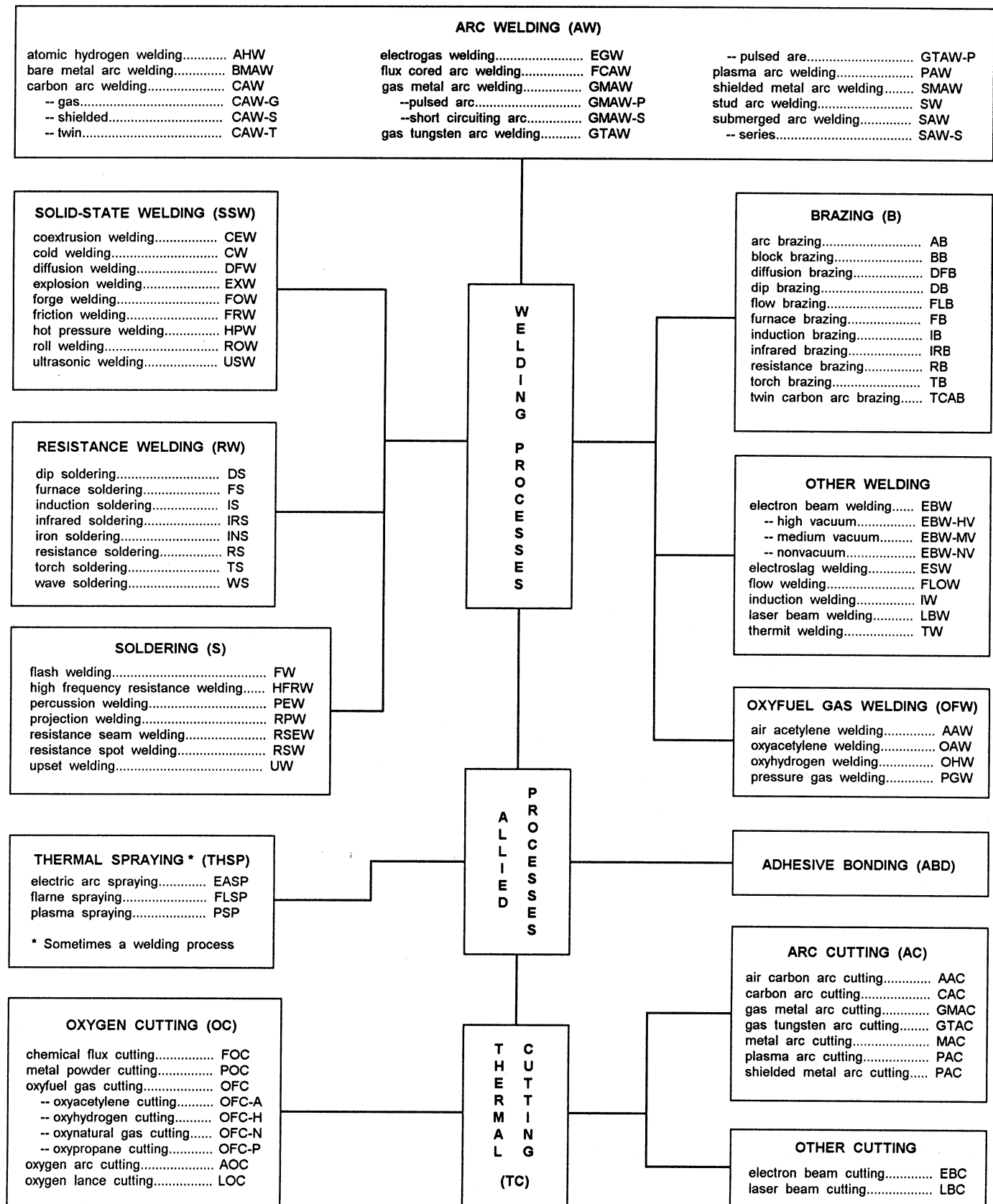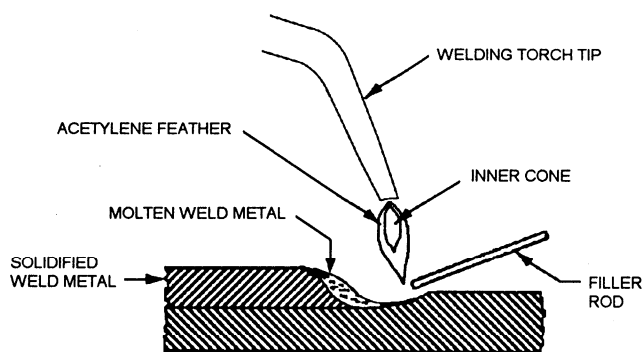# MASTER CHART OF WELDING AND ALLIED PROCESSES

ARC WELDING (AW)

atomic hydrogen welding	AHW	electrogas welding	EGW	-- pulsed arc	GTAW-P
bare metal arc welding	BMAW	flux cored arc welding	FCAW	plasma arc welding	PAW
carbon arc welding	CAW	gas metal arc welding	GMAW	shielded metal arc welding	SMAW
-- gas	CAW-G	--pulsed arc	GMAW-P	stud arc welding	SW
-- shielded	CAW-S	--short circuiting arc	GMAW-S	submerged arc welding	SAW
-- twin	CAW-T	gas tungsten arc welding	GTAW	-- series	SAW-S

SOLID-STATE WELDING (SSW)

coextrusion welding	CEW
cold welding	CW
diffusion welding	DFW
explosion welding	EXW
forge welding	FOW
friction welding	FRW
hot pressure welding	HPW
roll welding	ROW
ultrasonic welding	USW

RESISTANCE WELDING (RW)

dip soldering	DS
furnace soldering	FS
induction soldering	IS
infrared soldering	IRS
iron soldering	INS
resistance soldering	RS
torch soldering	TS
wave soldering	WS

SOLDERING (S)

flash welding	FW
high frequency resistance welding	HFRW
percussion welding	PEW
projection welding	RPW
resistance seam welding	RSEW
resistance spot welding	RSW
upset welding	UW

THERMAL SPRAYING * (THSP)

electric arc spraying	EASP
flame spraying	FLSP
plasma spraying	PSP

* Sometimes a welding process

OXYGEN CUTTING (OC)

chemical flux cutting	FOC
metal powder cutting	POC
oxyfuel gas cutting	OFC
-- oxyacetylene cutting	OFC-A
-- oxyhydrogen cutting	OFC-H
-- oxynatural gas cutting	OFC-N
-- oxypropane cutting	OFC-P
oxygen arc cutting	AOC
oxygen lance cutting	LOC

BRAZING (B)

arc brazing	AB
block brazing	BB
diffusion brazing	DFB
dip brazing	DB
flow brazing	FLB
furnace brazing	FB
induction brazing	IB
infrared brazing	IRB
resistance brazing	RB
torch brazing	TB
twin carbon arc brazing	TCAB

OTHER WELDING

electron beam welding	EBW
-- high vacuum	EBW-HV
-- medium vacuum	EBW-MV
-- nonvacuum	EBW-NV
electroslag welding	ESW
flow welding	FLOW
induction welding	IW
laser beam welding	LBW
thermit welding	TW

OXYFUEL GAS WELDING (OFW)

air acetylene welding	AAW
oxyacetylene welding	OAW
oxyhydrogen welding	OHW
pressure gas welding	PGW

ADHESIVE BONDING (ABD)

ARC CUTTING (AC)

air carbon arc cutting	AAC
carbon arc cutting	CAC
gas metal arc cutting	GMAC
gas tungsten arc cutting	GTAC
metal arc cutting	MAC
plasma arc cutting	PAC
shielded metal arc cutting	PAC

OTHER CUTTING

electron beam cutting	EBC
laser beam cutting	LBC

Center columns: WELDING PROCESSES / ALLIED PROCESSES / THERMAL CUTTING (TC)

Figure 3-1.—Welding processes.
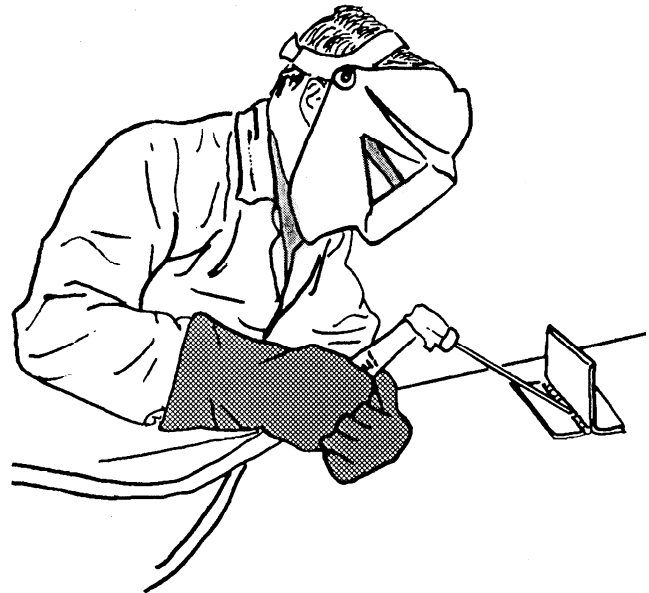
Figure 3-2.—Oxyfuel gas welding (OFW).

Figure 3-3.—Shielded metal arc welding (SMAW).

source is called a welding machine or simply, a **welder.** This should not be confined with the same term that is also used to describe the person who is performing the welding operation. The welder (welding machine) is either electric- or motor-powered. In the Naval Con-struction Force (NCF), there are two main types of arc-welding processes with which you should become familiar. They are shielded metal arc welding and gas shielded arc welding.

Shielded Metal Arc Welding (SMAW)

Shielded metal arc welding (fig. 3-3) is performed by striking an arc between a coated-metal electrode and the base metal. Once the arc has been established, the molten metal from the tip of the electrode flows together with the molten metal from the edges of the base metal to forma sound joint. This process is known as **fusion.** The coating from the electrode forms a covering over the weld deposit, shielding it from contamination;

therefore the process is called **shielded metal arc welding.** The main advantages of shielded metal arc welding are that high-quality welds are made rapidly at a low cost. You will learn more about shielded metal arc welding in chapter 7.

Gas Shielded Arc Welding

The primary difference between shielded metal arc welding and gas shielded arc welding is the type of shielding used. In gas shielded arc welding, both the arc and the molten puddle are covered by a shield of inert gas. The shield of inert gas prevents atmospheric con-tamination, thereby producing a better weld. The pri-mary gases used for this process are helium, argon, or carbon dioxide. In some instances, a mixture of these gases is used. The processes used in gas shielded arc welding are known as **gas tungsten arc welding**
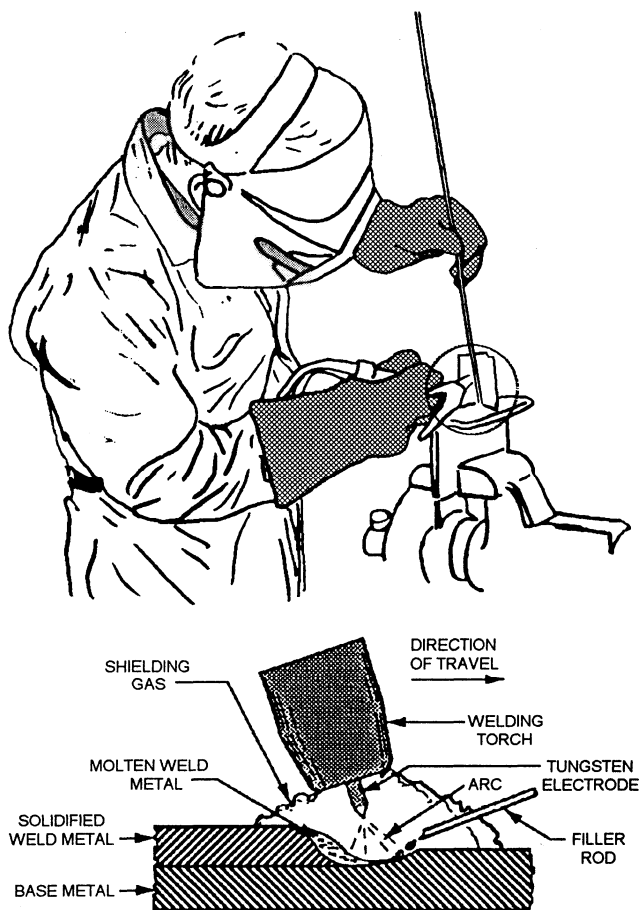
Figure 3-4.—Gas tungsten arc welding (GTAW).

Figure 3-5.—Gas metal arc welding (GMAW).

(GTAW) (fig. 3-4) and gas metal arc welding (GMAW) (fig. 3-5). You will also hear these called "TIG" and "MIG." Gas shielded arc welding is extremely useful because it can be used to weld all types of ferrous and nonferrous metals of all thicknesses.

Now that we have discussed a few of the welding processes available, which one should you choose? There are no hard-and-fast rules. In general, the controlling factors are the types of metal you are joining, cost involved, nature of the products you are fabricating, and the techniques you use to fabricate them. Because of its flexibility and mobility, gas welding is widely used for maintenance and repair work in the field. On the other hand, you should probably choose gas shielded metal arc welding to repair a critical piece of equipment made from aluminum or stainless steel.

No matter what welding process you use, there is some basic information you need to know. The remainder of this chapter is devoted to this type of information. Study this information carefully because it allows you to follow welding instructions, read welding symbols, and weld various types of joints using the proper welding techniques.

WELDING TERMINOLOGY

To become a skilled welder, you first need to learn the technical vocabulary '(language) of welding. The sections in this chapter introduce you to some of the basic terms of the welding language. Once you understand the language of welding, you will be prepared to interpret and communicate welding information accurately.

FILLER METALS

When welding two pieces of metal together, you often have to leave a space between the joint. The material that you add to fill this space during the welding process is known as the filler metal, or material. Two types of filler metals commonly used in welding are welding rods and welding electrodes.

The term *welding rod* refers to a form of filler metal that does not conduct an electric current during the welding process. The only purpose of a welding rod is to supply filler metal to the joint. This type of filler metal is often used for gas welding.

In electric-arc welding, the term *electrode* refers to the component that conducts the current from the electrode holder to the metal being welded. Electrodes are

classified into two groups: consumable and nonconsumable. Consumable electrodes not only provide a path for the current but they also supply fuller metal to the joint. An example is the electrode used in shielded metal-arc welding. Nonconsumable electrodes are only used as a conductor for the electrical current, such as in gas tungsten arc welding. The filler metal for gas tungsten arc welding is a hand fed consumable welding rod.

Additional information about filler rods and electrodes is covered in other chapters of this TRAMAN that deal with specific welding processes.

FLUXES

Before performing any welding process, you must ensure the base metal is clean. No matter how much the base metal is physically cleaned, it still contains impurities. These impurities, called oxides, result from oxygen combining with the metal and other contaminants in the base metal. Unless these oxides are removed by using a proper **flux,** a faulty weld may result. The term *flux* refers to a material used to dissolve oxides and release trapped gases and slag (impurities) from the base metal; thus the flux can be thought of as a cleaning agent. In performing this function, the flux allows the filler metal and the base metal to be fused.

Different types of fluxes are used with different types of metals; therefore, you should choose a flux formulated for a specific base metal. Beyond that, you can select a flux based on the expected soldering, brazing, or welding temperature; for example, when brazing, you should select a flux that becomes liquid at the correct brazing temperature. When it melts, you will know it is time to add the filler metal. The ideal flux has the right fluidity at the welding temperature and thus blankets the molten metal from oxidation.

Fluxes are available in many different forms. There are fluxes for oxyfuel gas applications, such as brazing and soldering. These fluxes usually come in the form of a paste, powder, or liquid. Powders can be sprinkled on the base metal, or the fuller rod can be heated and dipped into the powder. Liquid and paste fluxes can be applied to the filler rod and to the base metal with a brush. For shielded metal arc welding, the flux is on the electrode. In this case, the flux combines with impurities in the base metal, floating them away in the form of a heavy slag which shields the weld from the atmosphere.

You should realize that no single flux is satisfactory for universal use; however, there are a lot of good general-purpose fluxes for use with common metals. In general, a good flux has the following characteristics:

- It is fluid and active at the melting point of the fuller metal.

- It remains stable and does not change to a vapor rapidly within the temperature range of the welding procedure.

- It dissolves all oxides and removes them from the joint surfaces.

- It adheres to the metal surfaces while they are being heated and does not ball up or blow away.

- It does not cause a glare that makes it difficult to see the progress of welding or brazing.

- It is easy to remove after the joint is welded.

- It is available in an easily applied form.

CAUTION

Nearly all fluxes give off fumes that may be toxic. Use ONLY in well-ventilated spaces. It is also good to remember that **ALL** welding operations require adequate ventilation whether a flux is used or not.

WELD JOINTS

The **weld joint** is where two or more metal parts are joined by welding. The five basic types of weld joints are the butt, corner, tee, lap, and edge, as shown in figure 3-6.
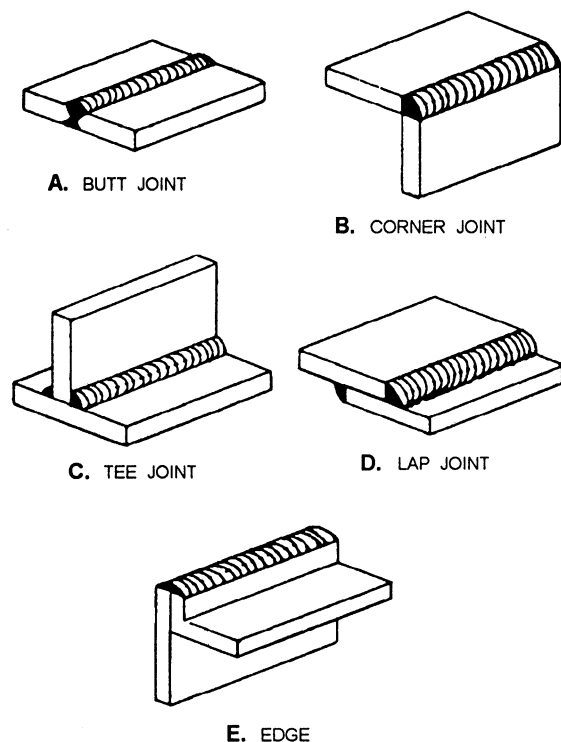

A. BUTT JOINT

B. CORNER JOINT

C. TEE JOINT

D. LAP JOINT

E. EDGE

Figure 3-6.—Basic weld joints.

ROOT OF JOINT

Figure 3-7.—Root of joint.

ROOT FACE AND GROOVE FACE

GROOVE FACE

ROOT FACE AND GROOVE FACE

GROOVE FACE

A

ROOT EDGE

GROOVE FACE

B

GROOVE AND ROOT FACE

C

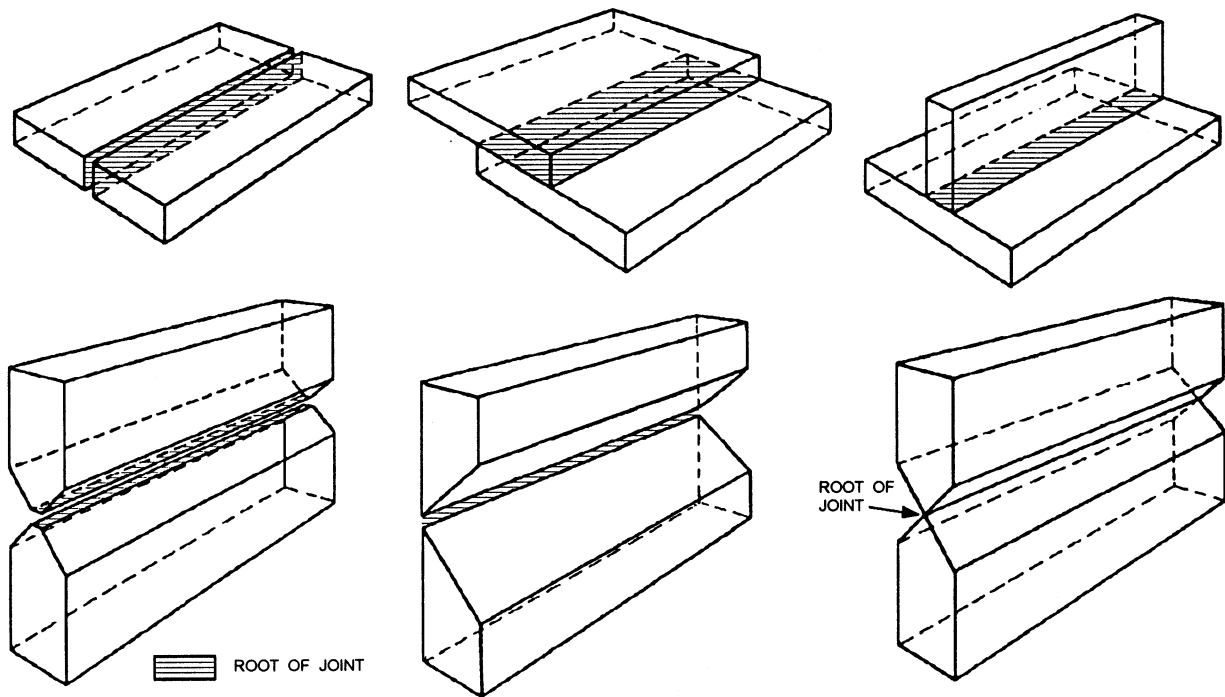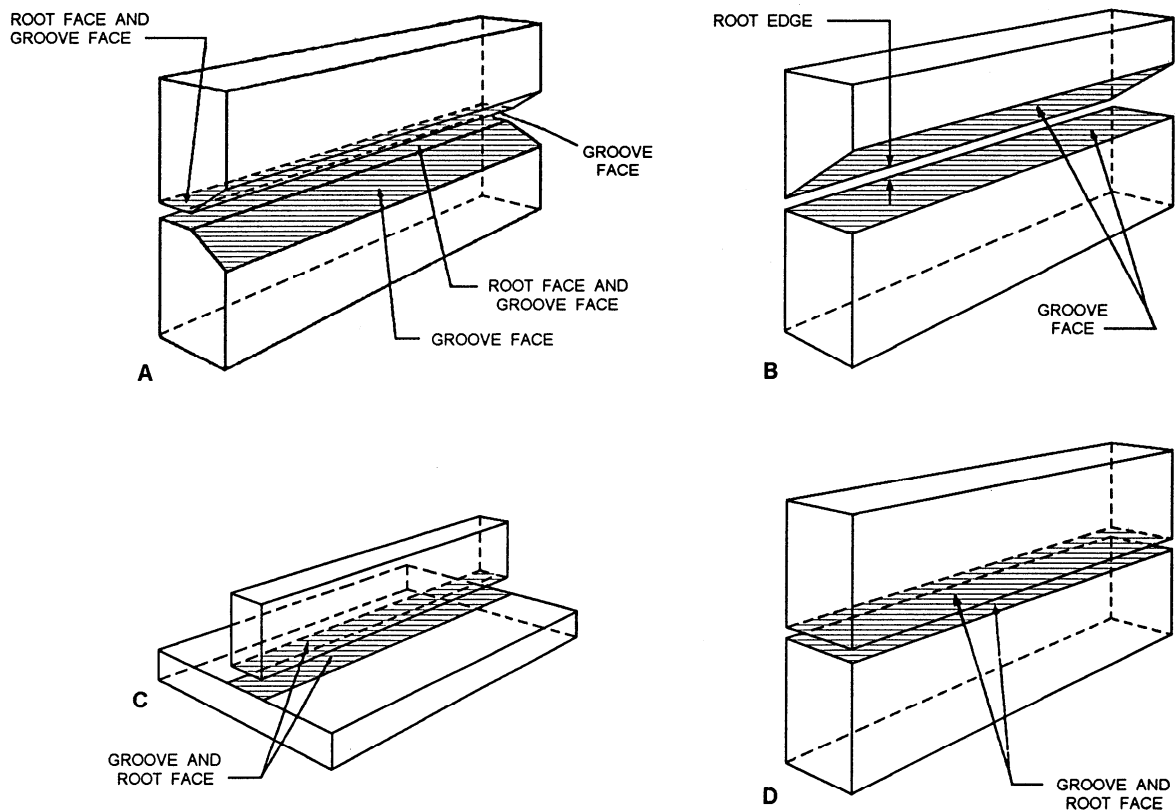GROOVE AND ROOT FACE

D

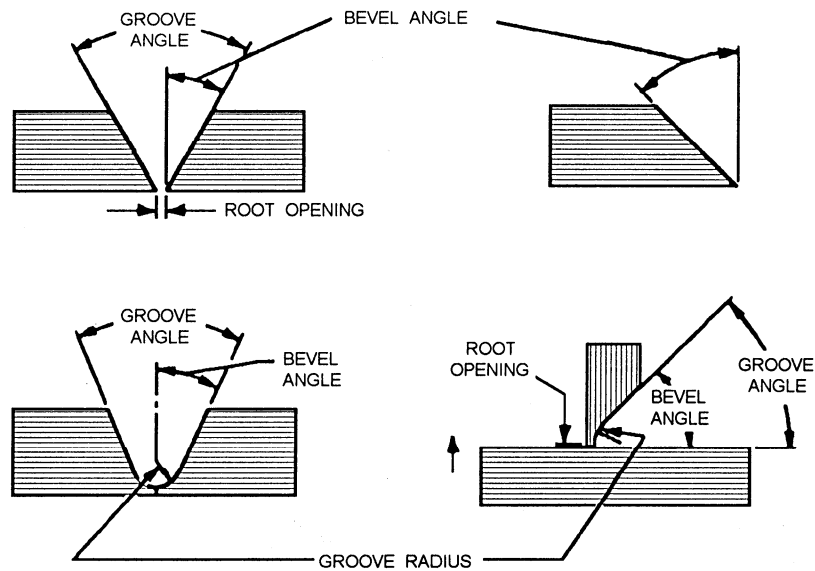Figure 3-8.—The groove face, root face, and root edge of joints.

Figure 3-9.—Bevel angle, groove angle, groove radius, and root opening of joints for welding.

A **butt** joint is used to join two members aligned in the same plane (fig. 3-6, view A). This joint is frequently used in plate, sheet metal, and pipe work. A joint of this type may be either square or grooved. Some of the variations of this joint are discussed later in this chapter.

Corner and **tee** joints are used to join two members located at right angles to each other (fig. 3-6, views B and C). In cross section, the corner joint forms an L-shape, and the tee joint has the shape of the letter *T*. Various joint designs of both types have uses in many types of metal structures.

A **lap** joint, as the name implies, is made by lapping one piece of metal over another (fig. 3-6, view D). This is one of the strongest types of joints available; however, for maximum joint efficiency, you should overlap the metals a minimum of three times the thickness of the thinnest member you are joining. Lap joints are commonly used with torch brazing and spot welding applications.

An **edge** joint is used to join the edges of two or more members lying in the same plane. Inmost cases, one of the members is flanged, as shown in figure 3-6, view E. While this type of joint has some applications in platework, it is more fixquently used in sheet metal work An edge joint should only be used for joining metals 1/4 inch or less in thickness that are not subjected to heavy loads.

The above paragraphs discussed only the five basic types of joints; however, there are many possible variations. Later in this chapter, we discuss some of these variations.

PARTS OF JOINTS

While there are many variations of joints, the parts of the joint are described by standard terms. The **root** of a joint is that portion of the joint where the metals are closest to each other. As shown in figure 3-7, the root may be a point, a line, or an area, when viewed in cross section. A **groove** (fig. 3-8) is an opening or space provided between the edges of the metal parts to be welded. The **groove face** is that surface of a metal part included in the groove, as shown in figure 3-8, view A. A given joint may have a root face or a root edge. The **root face,** also shown in view A, is the portion of the prepared edge of a part to be joined by a groove weld that has not been grooved. As you can see, the root face has relatively small dimensions. The **root edge** is basically a root face of zero width, as shown in view B. As you can see in views C and D of the illustration, the groove face and the root face are the same metal surfaces in some joints.

The specified requirements for a particular joint are expressed in such terms as *bevel angle, groove angle, groove radius,* and *root opening.* A brief description of each term is shown in figure 3-9.

The **bevel angle** is the angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member.

The **groove angle** is the total angle of the groove between the parts to be joined. For example, if the edge of each of two plates were beveled to an angle of 30 degrees, the groove angle would be 60 degrees. This is
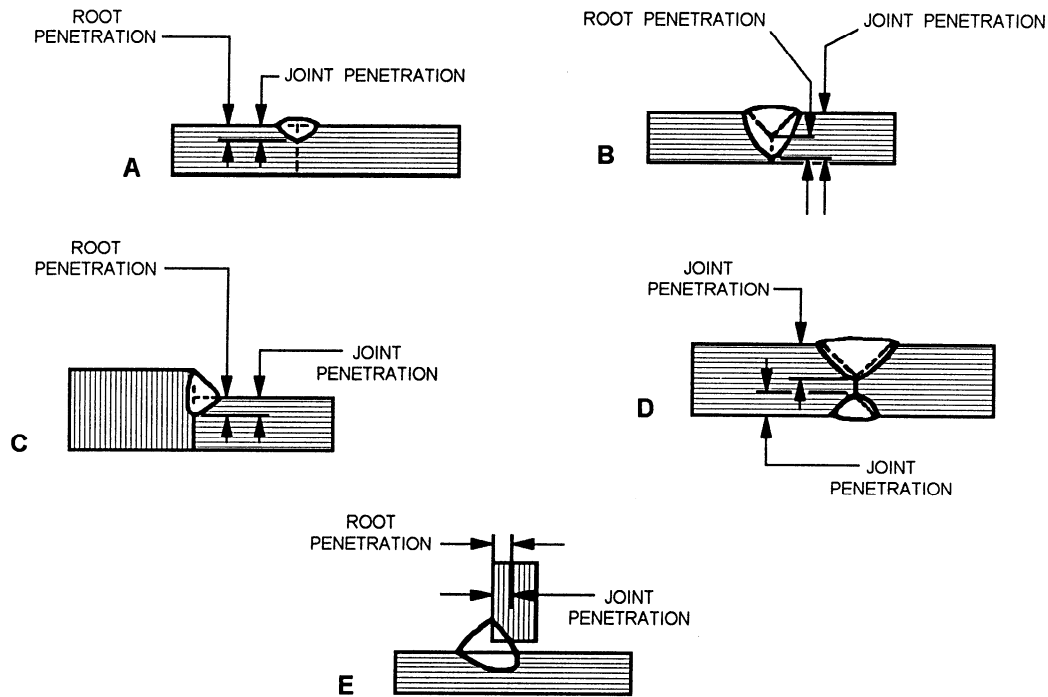
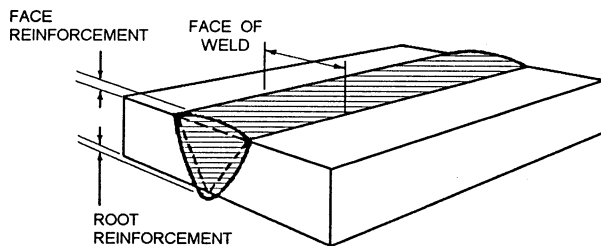Figure3-10.—Root penetration and joint penetration of welds.
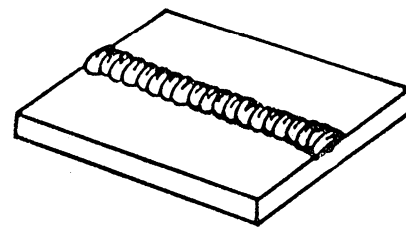

Figure 3-11.—Weld reinforcement.

Figure 3-12.—Simple weld bead.

often referred to as the "included angle" between the parts to be joined by agroove weld.

The **groove radius** is the radius used to form the shape of a J- or U-groove weld joint. It is used only for special groove joint designs.

The **root opening** refers to the separation between the parts to be joined at the root of the joint. It is sometimes called the "root gap."

To determine the bevel angle, groove angle, and root opening for a joint, you must consider the thickness of the weld material, the type of joint to be made, and the welding process to be used. As a general rule, gas welding requires a larger groove angle than manual metal-arc welding.

The root opening is usually governed by the diameter of the filler material. This, in turn, depends on the thickness of the base metal and the welding position.

Having an adequate root opening is essential for root penetration.

Root penetration and joint penetration of welds are shown in figure 3-10. **Root penetration** refers to the depth that a weld extends into the root of the joint. Root penetration is measured on the center line of the root cross section. **Joint penetration** refers to the minimum depth that a groove (or a flange) weld extends from its face into a joint, exclusive of weld reinforcement. As you can see in the figure, the terms, *root penetration* and *joint penetration,* often refer to the same dimension. This is the case in views A, C, and E of the illustration. View B, however, shows the difference between root penetration and joint penetration. View D shows joint penetration only. *Weld reinforcement* is a term used to describe weld metal in excess of the metal necessary to fill a joint. (See fig. 3-11.)
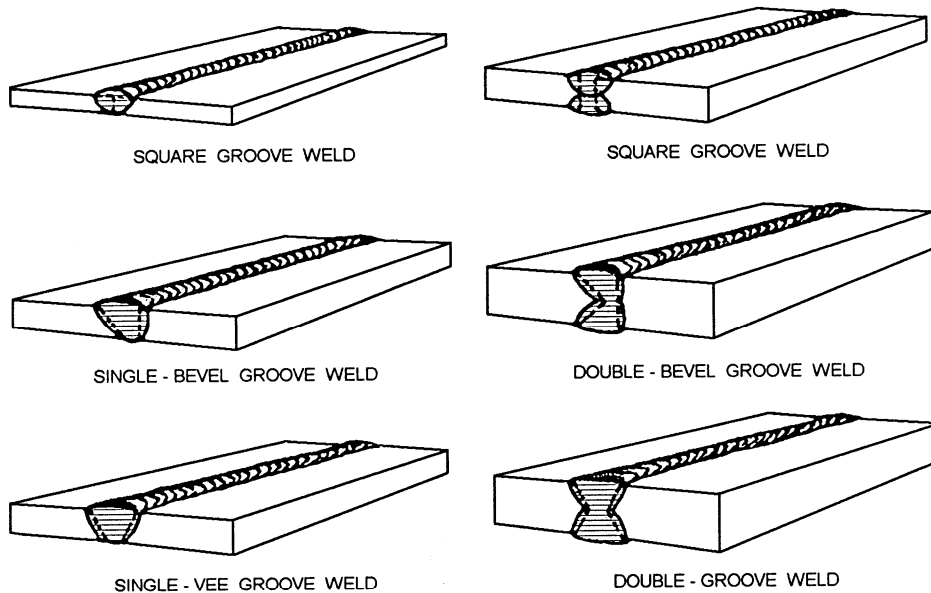
Figure 3-13.—Standard groove welds.

TYPES OF WELDS

There are many types of welds. Some of the common types you will work with are the bead, groove, fillet, surfacing, tack, plug, slot, and resistance.

As a beginner, the first type of weld that you learn to produce is called a **weld bead** (referred to simply as a bead). A weld bead is a weld deposit produced by a single pass with one of the welding processes. An example of a weld bead is shown in figure 3-12. A weld bead may be either narrow or wide, depending on the amount of transverse oscillation (side-to-side movement) used by the welder. When there is a great deal of oscillation, the bead is wide; when there is little or no oscillation, the bead is narrow. A weld bead made without much weaving motion is often referred to as a **stringer bead.** On the other hand, a weld bead made with side-to-side oscillation is called a **weave bead.**

Groove welds are simply welds made in the groove between two members to be joined. The weld is adaptable to a variety of butt joints, as shown in figure 3-13. Groove welds may be joined with one or more weld beads, depending on the thickness of the metal. If two or more beads are deposited in the groove, the weld is made with multiple-pass **layers,** as shown in figure 3-14. As a rule, a multiple-pass layer is made with stringer beads in manual operations. As a Steelworker, you will use groove welds frequently in your work.

Another term you should be familiar with, when making a multiple-pass weld, is the **buildup sequence,** as shown in figure 3-15. Buildup sequence refers to the
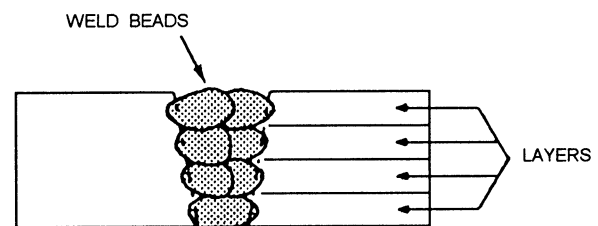
Figure 3-14.—Multiple-pass layers.
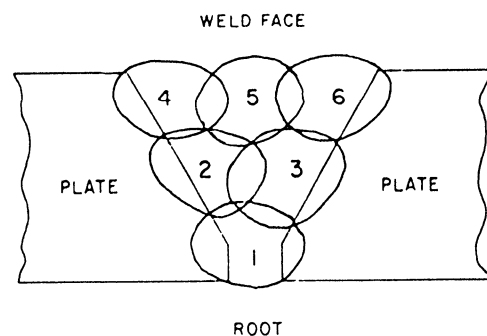
Figure 3-15.—Weld layer sequence.

order in which the beads of a multiple-pass weld are deposited in the joint.

NOTE: Often welding instructions specify an interpass temperature. The interpass **temperature** refers to the temperature below which the previously deposited weld metal must be before the next pass may be started.

LAP FILLET   TEE FILLET   CORNER FILLET
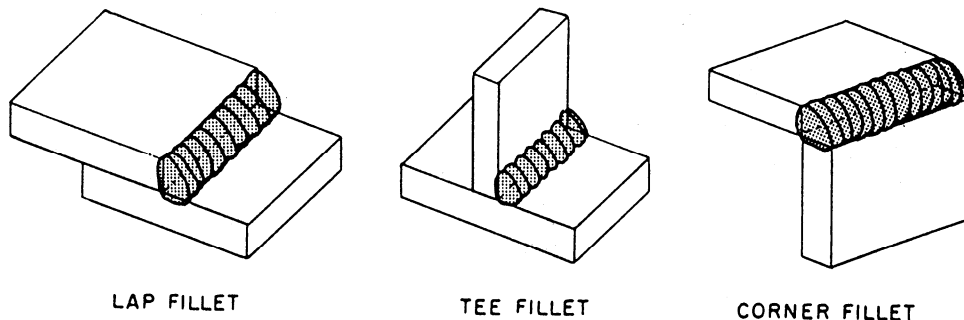
Figure 3-16.—Fillet welds.
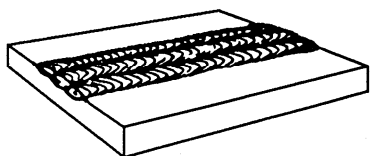
Figure 3-17.—Surfacing welds.

PLUG WELDS

SLOT WELDS

Figure 3-18.—Plug and slot welds.

After the effects of heat on metal are discussed, later in the chapter, you will understand the significance of the buildup sequence and the importance of controlling the interpass temperature.

Across-sectional view of a **fillet weld** (fig. 3-16) is triangular in shape. This weld is used to join two surfaces that are at approximately right angles to each other in a lap, tee, or comer joint.

Surfacing is a welding process used to apply a hard, wear-resistant layer of metal to surfaces or edges of worn-out parts. It is one of the most economical methods of conserving and extending the life of machines, tools, and construction equipment. As you can see in figure 3-17, a surfacing weld is composed of one or more stringer or weave beads. Surfacing, sometimes known as **hardfacing** or **wearfacing,** is often used to build up worn shafts, gears, or cutting edges. You will learn more about this type of welding in chapter 6 of this training manual.

A **tack weld** is a weld made to hold parts of an assembly in proper alignment temporarily until the final welds are made. Although the sizes of tack welds are not specified, they are normally between 1/2 inch to 3/4 inch in length, but never more than 1 inch in length. In determining the size and number of tack welds for a specific job, you should consider thicknesses of the metals being joined and the complexity of the object being assembled.

Plug and **slot welds** (fig. 3-18) are welds made through holes or slots in one member of a lap joint. These welds are used to join that member to the surface of another member that has been exposed through the hole. The hole may or may not be completely filled with weld metal. These types of welds are often used to join face-hardened plates from the backer soft side, to install liner metals inside tanks, or to fill up holes in a plate.

Resistance welding is a metal fabricating process in which the fusing temperature is generated at the joint by the resistance to the flow of an electrical current. This is accomplished by clamping two or more sheets of metal between copper electrodes and then passing an electrical current through them. When the metals are heated to a melting temperature, forging pressure is applied through either a manual or automatic means to weld the pieces together. **Spot** and **seam** welding (fig. 3-19) are two common types of resistance welding processes.

Spot welding is probably the most commonly used type of resistance welding. The material to be joined is placed between two electrodes and pressure is applied. Next, a charge of electricity is sent from one electrode through the material to the other electrode. Spot welding is especially useful in fabricating sheet metal parts.

Seam welding is like spot welding except that the spots overlap each other, making a continuous weld
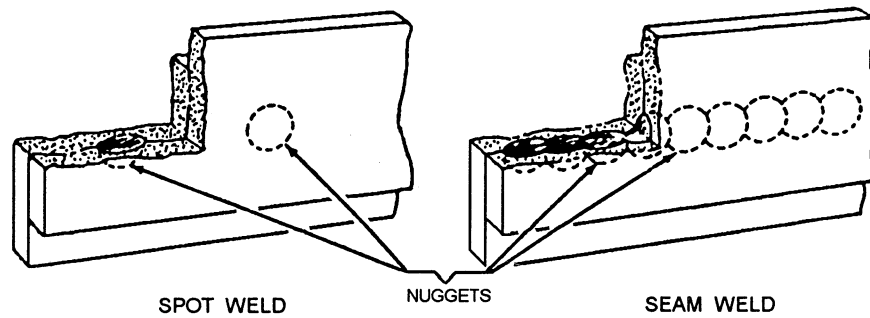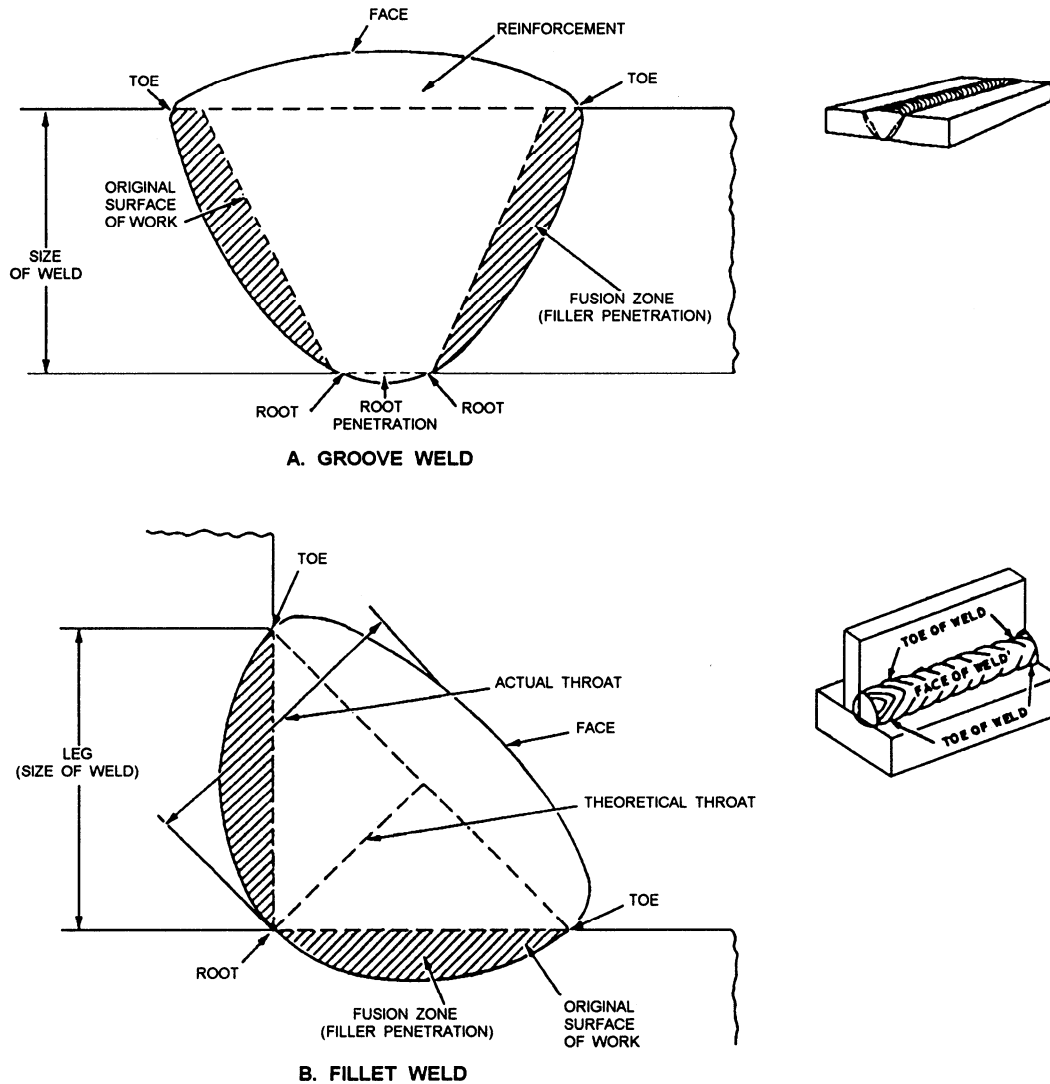
SPOT WELD   NUGGETS   SEAM WELD

Figure 3-19.—Spot and seam welds.

FACE   REINFORCEMENT

TOE   TOE

ORIGINAL
SURFACE
OF WORK

SIZE
OF WELD

FUSION ZONE
(FILLER PENETRATION)

ROOT   ROOT   ROOT
          PENETRATION

A. GROOVE WELD

TOE

ACTUAL THROAT

FACE

LEG
(SIZE OF WELD)

THEORETICAL THROAT

TOE

ROOT

FUSION ZONE
(FILLER PENETRATION)

ORIGINAL
SURFACE
OF WORK

B. FILLET WELD

Figure 3-20.—Parts of a groove weld and fillet weld.

seam. In this process, the metal pieces pass between roller type of electrodes. As the electrodes revolve, the current is automatically turned on and off at the speed at which the parts are set to move. Seabees do not normally use seam welding, because this type of welding is most often used in industrial manufacturing.

PARTS OF WELDS

For you to produce welds that meet the job requirements, it is important that you become familiar with the terms used to describe a weld. Figure 3-20 shows a groove weld and a fillet weld. 'he face is the exposed

SIZE OF CONVEX FILLET

SIZE OF CONCAVE FILLET

BUTT WELD REINFORCEMANT
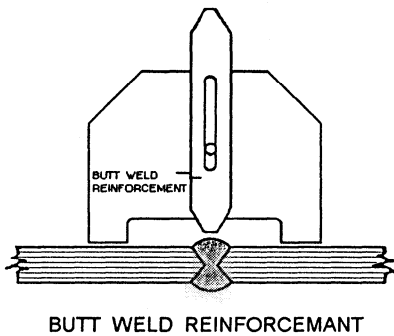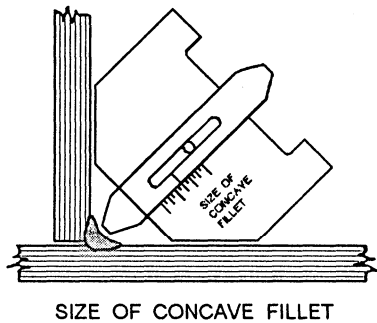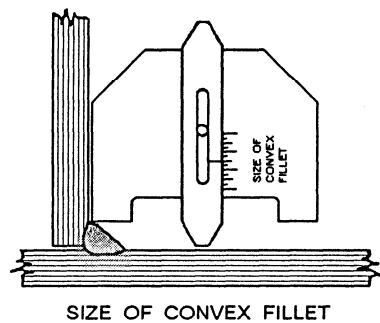
Figure 3-21.—Using a welding micrometer.

surface of a weld on the side from which the weld was made. The **toe** is the junction between the face of the weld and the base metal. The **root** of a weld includes the points at which the back of the weld intersects the base metal surfaces. When we look at a triangular cross section of a fillet weld, as shown in view B, the **leg** is the portion of the weld from the toe to the root. The **throat** is the distance from the root to a point on the face of the weld along a line perpendicular to the face of the weld. Theoretically, the face forms a straight line between the toes.

NOTE: The terms *leg* and *throat* apply only to fillet welds.

In determining the size of a groove weld (fig. 3-20, view A), such factors as the depth of the groove, root opening, and groove angle must be taken into consideration. The size of a fillet weld (view B) refers to the
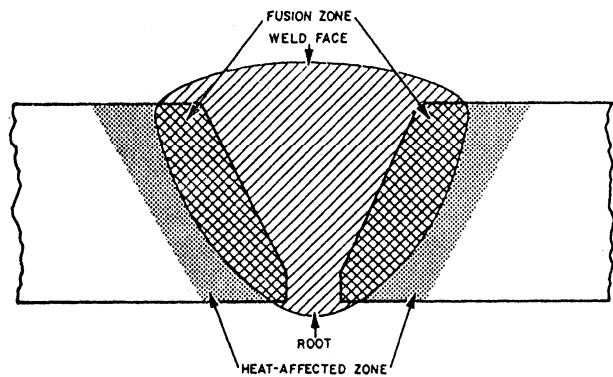
Figure 3-22.—Zones in a weld.

length of the legs of the weld. The two legs are assumed to be equal in size unless otherwise specified.

A gauge used for determining the size of a weld is known as a **welding micrometer.** Figure 3-21 shows how the welding micrometer is used to determine the various dimensions of a weld.

Some other terms you should be familiar with are used to describe areas or zones of welds. As we discussed earlier in the chapter, fusion is the melting together of base and/or fuller metal. The **fusion zone,** as shown in figure 3-22, is the region of the base metal that is actually melted. The depth of fusion is the distance that fusion extends into the base metal or previous welding pass.

Another zone of interest to the welder is the **heat-affected zone,** as shown in figure 3-22. This zone includes that portion of the base metal that has not been melted; however, the structural or mechanical properties of the metal have been altered by the welding heat. Because the mechanical properties of the base metal are affected by the welding heat, it is important that you learn techniques to control the heat input. One technique often used to minimize heat input is the intermittent weld. We discuss this and other techniques as we progress through this chapter; but, first we will discuss some of the considerations that affect the welded joint design.

WELDED JOINT DESIGN

The details of a joint, which includes both the geometry and the required dimensions, are called the joint **design.** Just what type of joint design is best suited for a particular job depends on many factors. Although welded joints are designed primarily to meet strength and safety requirements, there are other factors that must be considered. A few of these factors areas follows:
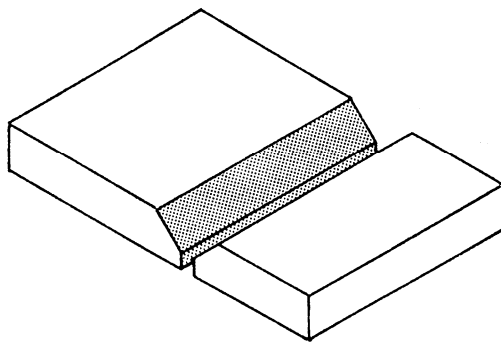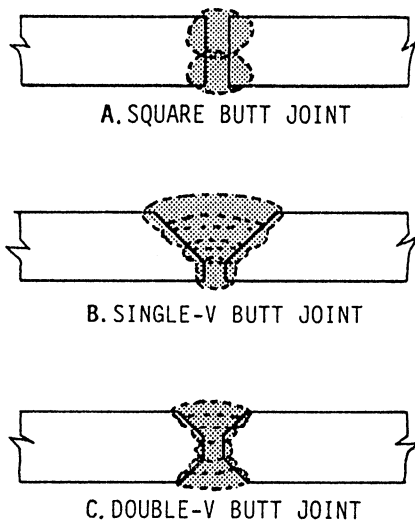
Figure 3-23.—Butt joints.

Whether the load will be in tension or compression and whether bending, fatigue, or impact stresses will be applied

- How a load will be applied; that is, whether the load will be steady, sudden, or variable

- The direction of the load as applied to the joint

- The cost of preparing the joint

Another consideration that must be made is the ratio of the strength of the joint compared to the strength of the base metal. This ratio is called **joint efficiency.** An efficient joint is one that is just as strong as the base metal.

Normally, the joint design is determined by a designer or engineer and is included in the project plans and specifications. Even so, understanding the joint design for a weld enables you to produce better welds.

Earlier in this chapter, we discussed the five basic types of welded joints—butt, corner, tee, lap, and edge. While there are many variations, every joint you weld will be one of these basic types. Now, we will consider

some of the variations of the welded joint designs and the efficiency of the joints.

BUTT JOINTS

The **square butt joint** is used primarily for metals that are 3/16 inch or less in thickness. The joint is reasonably strong, but its use is not recommended when the metals are subject to fatigue or impact loads. Preparation of the joint is simple, since it only requires matching the edges of the plates together; however, as with any other joint, it is important that it is fitted together correctly for the entire length of the joint. It is also important that you allow enough root opening for the joint. Figure 3-23 shows an example of this type of joint.

When you are welding metals greater than 3/16 inch in thickness, it is often necessary to use a grooved butt joint. The purpose of grooving is to give the joint the required strength. When you are using a grooved joint, it is important that the groove angle is sufficient to allow the electrode into the joint; otherwise, the weld will lack penetration and may crack. However, you also should avoid excess beveling because this wastes both weld metal and time. Depending on the thickness of the base metal, the joint is either single-grooved (grooved on one side only) or double-grooved (grooved on both sides). As a welder, you primarily use the single-V and double-V grooved joints.

The **single-V butt joint** (fig. 3-23, view B) is for use on plates 1/4 inch through 3/4 inch in thickness. Each member should be beveled so the included angle for the joint is approximately 60 degrees for plate and 75 degrees for pipe. Preparation of the joint requires a special beveling machine (or cutting torch), which makes it more costly than a square butt joint. It also requires more filler material than the square joint; however, the joint is stronger than the square butt joint. But, as with the square joint, it is not recommended when subjected to bending at the root of the weld.

The **double-V butt joint** (fig. 3-23, view C) is an excellent joint for all load conditions. Its primary use is on metals thicker than 3/4 inch but can be used on thinner plate where strength is critical. Compared to the single-V joint, preparation time is greater, but you use less filler metal because of the narrower included angle. Because of the heat produced by welding, you should alternate weld deposits, welding first on one side and then on the other side. This practice produces a more symmetrical weld and minimizes warpage.

Remember, to produce good quality welds using the groove joint, you should ensure the fit-up is consistent for the entire length of the joint, use the correct groove
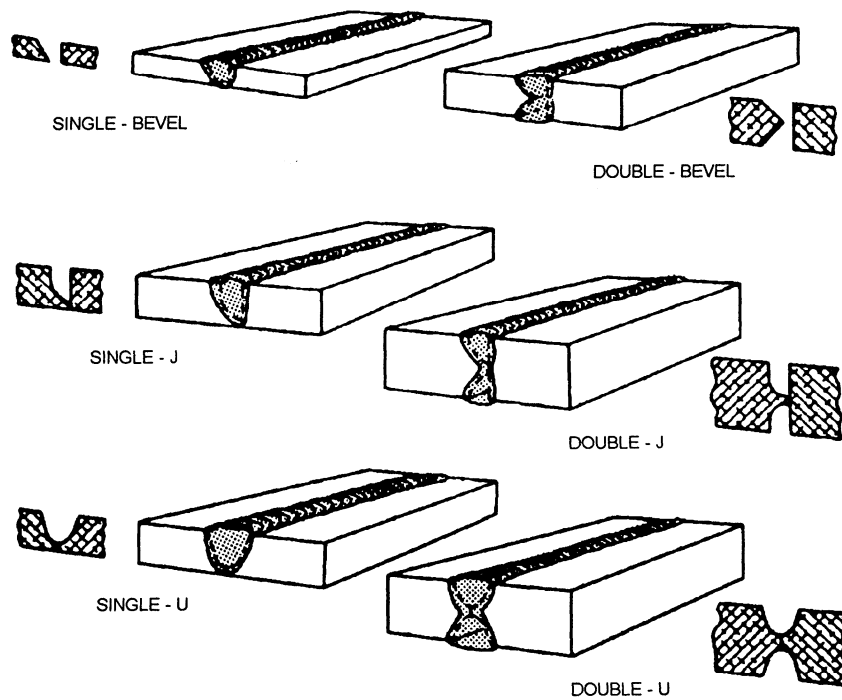
Figure 3-24.—Additional types of groove welds.

angle, use the correct root opening, and use the correct root face for the joint. When you follow these principles, you produce better welds every time. Other standard grooved butt joint designs include the bevel groove, J-groove, and U-groove, as shown in figure 3-24.

CORNER JOINTS

The **flush corner joint** (fig. 3-25, view A) is designed primarily for welding sheet metal that is 12 gauge or thinner. It is restricted to lighter materials, because deep penetration is sometimes difficult and the design can support only moderate loads.

The **half-open corner joint** (fig. 3-25, view B) is used for welding materials heavier than 12 gauge. Penetration is better than in the flush corner joint, but its use is only recommended for moderate loads.

The **full-open corner joint** (fig. 3-25, view C) produces a strong joint, especially when welded on both sides. It is useful for welding plates of all thicknesses.

TEE JOINTS

The **square tee joint** (fig. 3-26, view A) requires a fillet weld that can be made on one or both sides. It can be used for light or fairly thick materials. For maximum strength, considerable weld metal should be placed on each side of the vertical plate.
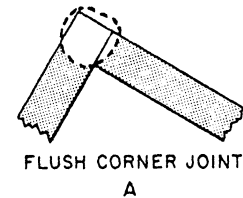

FLUSH CORNER JOINT
A

HALF-OPEN CORNER JOINT
B

FULL-OPEN CORNER JOINT
C
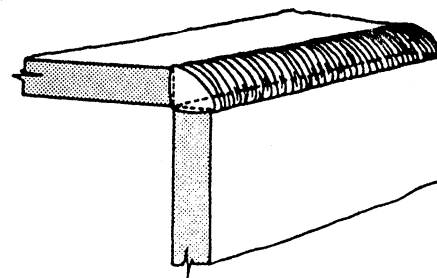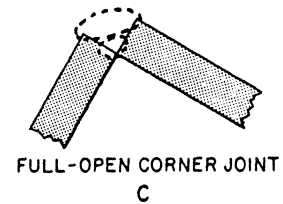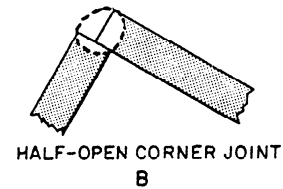
Figure 3-25.—Corner joints.

3-14

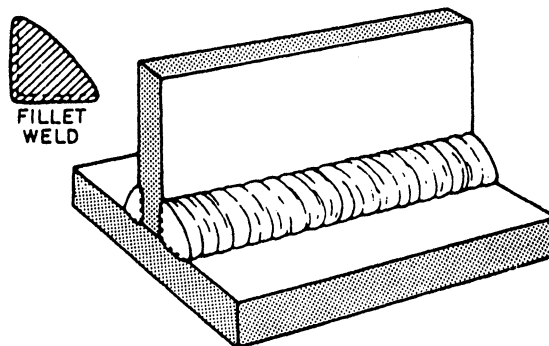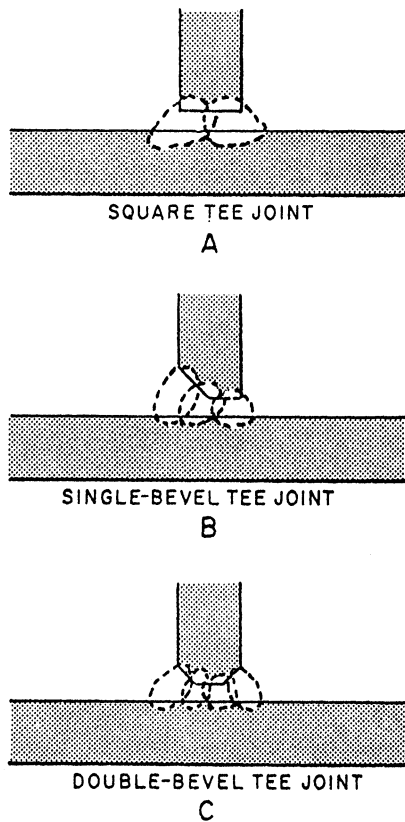Figure 3-26.—Tee joints.

Figure 3-27.—Lap joints,

Figure 3-28.—Flanged edge Joints.

The **single-bevel tee joint** (fig. 3-26, view B) can withstand more severe loadings than the square tee joint, because of better distribution of stresses. It is generally used on plates of 1/2 inch or less in thickness and where welding can only be done from one side.

The **double-bevel tee joint** (fig. 3-26, view C) is for use where heavy loads are applied and the welding can be done on both sides of the vertical plate.

LAP JOINTS

The **single-fillet lap joint** (fig. 3-27, view A) is easy to weld, since the filler metal is simply deposited along the seam. The strength of the weld depends on the size of the fillet. Metal up to 1/2 inch in thickness and not subject to heavy loads can be welded using this joint.

When the joint will be subjected to heavy loads, you should use the **double-fillet lap joint** (fig. 3-27, view B). When welded properly, the strength of this joint is very close to the strength of the base metal.

EDGE JOINTS

The **flanged edge joint** (fig. 3-28, view A) is suitable for plate 1/4 inch or less in thickness and can only

FLAT POSITION

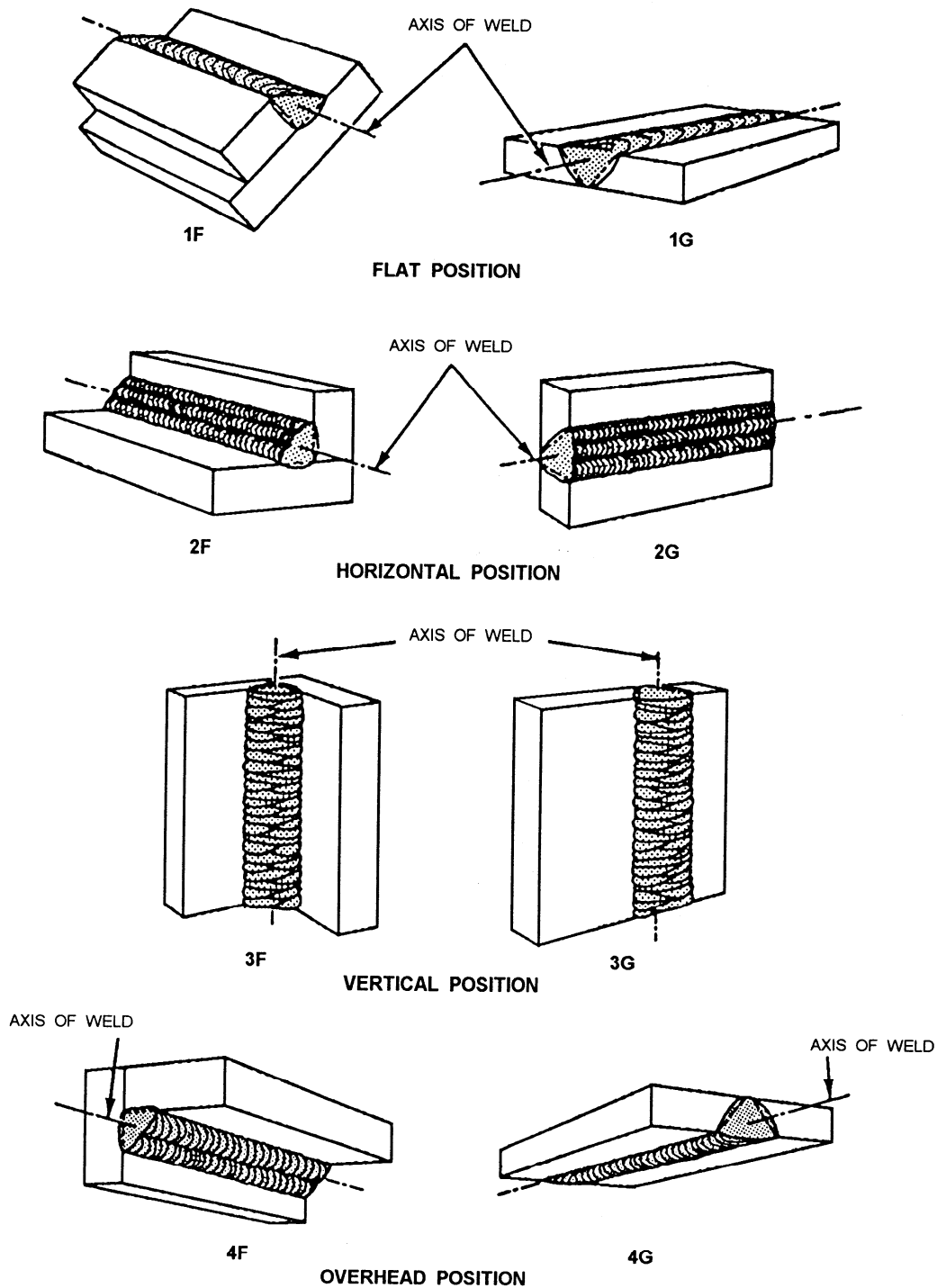HORIZONTAL POSITION

VERTICAL POSITION

OVERHEAD POSITION

Figure 3-29.—Welding positions—plate.

sustain light loads. Edge preparation for this joint may be done, as shown in either views B or C.

WELDING POSITIONS

All welding is done in one of four positions: (1) flat, (2) horizontal, (3) vertical, or (4) overhead. Fillet or groove welds can be made in all of these positions. Figure 3-29 shows the various positions used in plate welding. The American Welding Society (AWS) identifies these positions by a number/letter designation; for instance, the 1G position refers to a groove weld that is to be made in the flat position. Here the 1 is used to
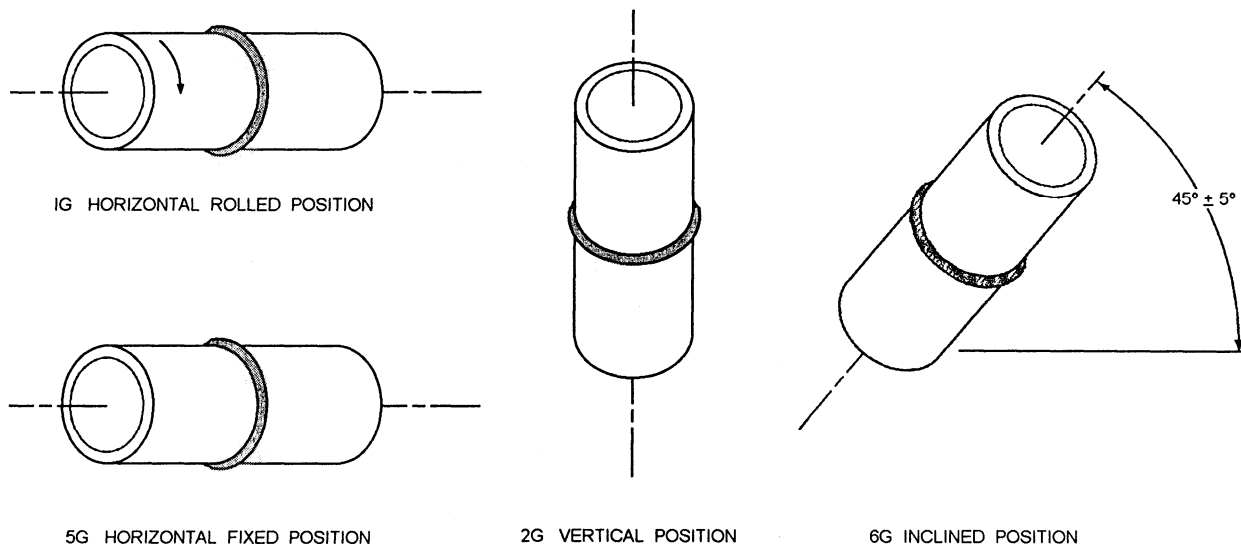
IG HORIZONTAL ROLLED POSITION

5G HORIZONTAL FIXED POSITION

2G VERTICAL POSITION

6G INCLINED POSITION

45° ± 5°

Figure 3-30.—Welding position-pipe.

indicate the flat position and the G indicates a groove weld. For a fillet weld made in the flat position, the number/letter designation is 1F (F for fillet). These number/letter designations refer to test positions. These are positions a welder would be required to use during a welding qualification test. As a Steelworker, there is a good possibility that someday you will be required to certify or perform a welding qualification test; therefore, it is important that you have a good understanding and can apply the techniques for welding in each of the test positions.

Because of gravity, the position in which you are welding affects the flow of molten filler metal. Use the flat position, if at all possible, because gravity draws the molten metal downward into the joint making the welding faster and easier. Horizontal welding is a little more difficult, because the molten metal tends to sag or flow downhill onto the lower plate. Vertical welding is done in a vertical line, usually from bottom to top; however, on thin material downhill or downhand welding may be easier. The overhead position is the most difficult position. Because the weld metal flows downward, this position requires considerable practice on your part to produce good quality welds.

Although the terms *flat, horizontal, vertical,* and *overhead* sufficiently describe the positions for plate welding, they do not adequately describe pipe welding positions. In pipe welding, there are four basic test positions used (fig. 3-30). Notice that the position refers to the position of the pipe, not the position of welding.

Test position 1G is made with the pipe in the horizontal position. In this position, the pipe is rolled so that the welding is done in the flat position with the pipe rotating under the arc. This position is the most advantageous of all the pipe welding positions. When you are welding in the 2G position, the pipe is placed in the vertical position so the welding can be done in the horizontal position. The 5G position is similar to the 1G position in that the axis of the pipe is horizontal. But, when you are using the 5G position, the pipe is not turned or rolled during the welding operation; therefore, the welding is more difficult in this position. When you are using the 6G position for pipe welding, the axis of the pipe is at a 45-degree angle with the horizontal and the pipe is not rolled. Since the pipe is not rolled, welding has to be done in all the positions— flat, vertical, horizontal, and overhead. If you can weld pipe in this position, you can handle all the other welding positions.

NOTE: There is no 3G or 4G test position in pipe welding. Also, since most pipe welds are groove welds, they are identified by the letter G.

We will discuss more about the techniques used for welding in the various positions later in this training manual, but for now, let's talk about the effects of heat on metal.

EXPANSION AND CONTRACTION

When apiece of metal is heated, the metal expands. Upon cooling, the metal contracts and tries to resume its original shape. The effects of this expansion and
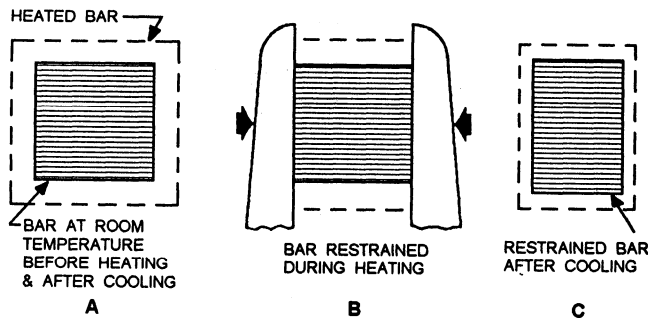
Figure 3-31.—Effects of expansion and contraction.

HEATED BAR

BAR AT ROOM TEMPERATURE BEFORE HEATING & AFTER COOLING
A

BAR RESTRAINED DURING HEATING
B

RESTRAINED BAR AFTER COOLING
C

contraction are shown in figure 3-31. View A shows a bar that is not restricted in any way. When the bar is heated, it is free to expand in all directions. If the bar is allowed to cool without restraint, it contracts to its original dimensions.

When the bar is clamped in a vise (view B) and heated, expansion is limited to the unrestricted sides of the bar. As the bar begins to cool, it still contracts uniformly in all directions. As a result, the bar is now deformed. It has become narrower and thicker, as shown in view C.

These same expansion and contraction forces act on the weld metal and base metal of a welded joint; however, when two pieces of metal are welded together, expansion and contraction may not be uniform throughout all parts of the metal. This is due to the difference in the temperature from the actual weld joint out to the edges of the joint. This difference in temperature leads

to internal stresses, distortion, and warpage. Figure 3-32 shows some of the most common difficulties that you are likely to encounter.

When you are welding a single-V butt joint (fig. 3-32, view A), the highest temperature is at the surface of the molten puddle. The temperature decreases as you move toward the root of the weld and away from the weld. Because of the high temperature of the molten metal, this is where expansion and contraction are greatest. When the weld begins to cool, the surface of the weld joint contracts (or shrinks) the most, thus causing warpage or distortion. View B shows how the same principles apply to a tee joint. Views C and D show the distortions caused by welding a bead on one side of a plate and welding two plates together without proper tack welds.

All metals, when exposed to heat buildup during welding, expand in the direction of least resistance. Conversely, when the metal cools, it contracts by the same amount; therefore, if you want to prevent or reduce the distortion of the weldment, you have to use some method to overcome the effects of heating and cooling.

CONTROLLING DISTORTION

You can control the distortion caused by expansion and contraction during welding by following the simple procedures listed below.

A. FLAT WORK PULLED OUT OF LINE

B. VERTICAL WORK PULLED OFF CENTER

C. FLAT WORK IS DRAWN INTO CURVE
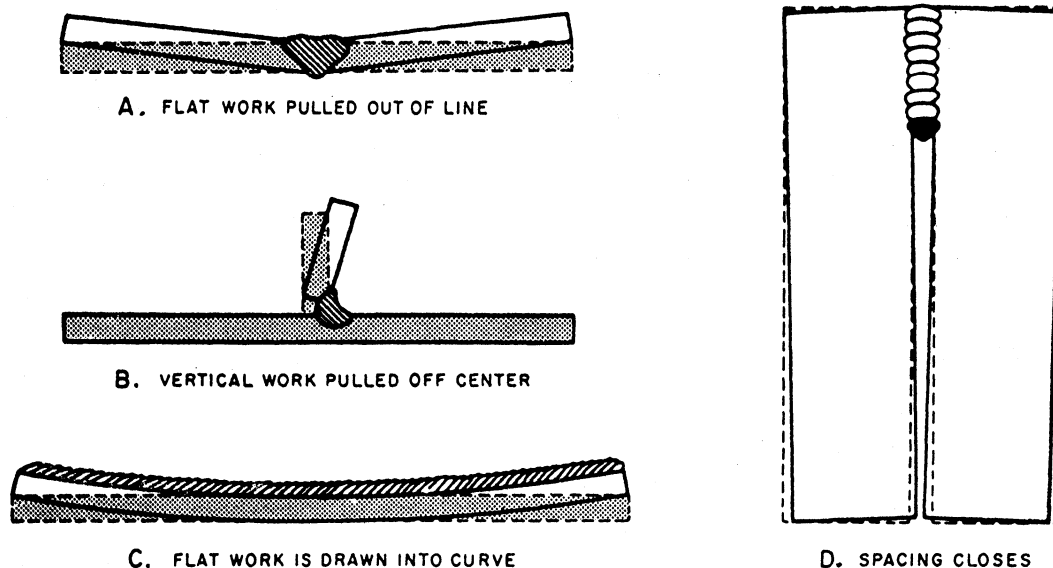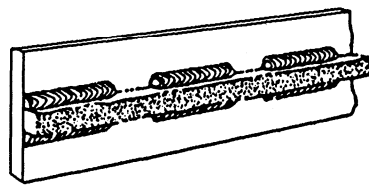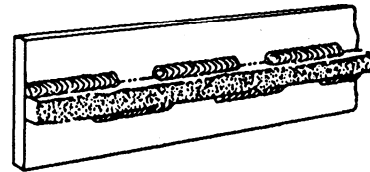
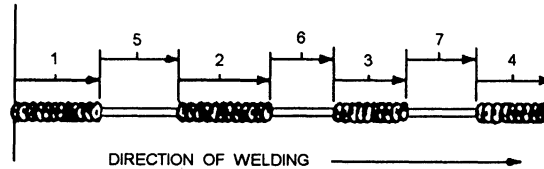D. SPACING CLOSES

Figure 3-32.—Distortion caused by welding.

CHAIN INTERMITTENT FILLET WELD   STAGGERED INTERMITTENT FILLET WELD

INTERMITTENT FILLET WELDS

DIRECTION OF WELDING

INTERMITTENT BUTT WELD

Figure 3-33.—Intermittent welds.
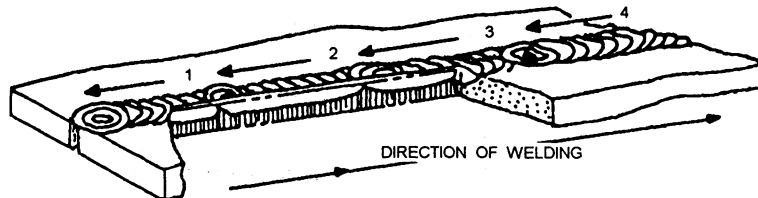

DIRECTION OF WELDING

Figure 3-34.—Back-step welding.

Proper Edge Preparation and Fit-up

As discussed earlier in this chapter, proper edge preparation and fit-up are essential to good quality welds. By making certain the edges are properly beveled and spacing is adequate, you can restrict the effects of distortion. Additionally, you should use tack welds, especially on long joints. Tack welds should be spaced at least 12 inches apart and run approximately twice as long as the thickness of the weld.

Control the Heat Input

You should understand that the faster a weld is made, the less heat is absorbed by the base metal. As you gain welding experience, it will become easier for you to weld a seam with the minimum amount of heat by simply speeding up the welding process.

Regardless of your experience, it is often necessary to use a welding technique designed to control heat input. An intermittent weld (sometimes called a skip weld) is often used instead of one continuous weld. When you are using an intermittent weld, a short weld is made at the beginning of the joint. Next, you skip to the center of the seam and weld a few inches. Then, you weld at the other end of the joint. Finally, you return to the end of the first weld and repeat the cycle until the weld is finished. Figure 3-33 shows the intermittent weld.

Another technique to control the heat input is the back-step method (fig. 3-34). When using this technique, you deposit short weld beads from right to left along the seam.

Preheat the Metal

As discussed earlier, expansion and contraction rates are not uniform in a structure during welding due to the differences in temperature throughout the metal.
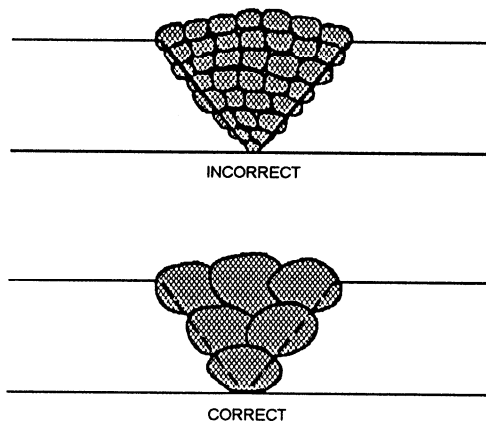
3-19

Figure 3-35.—Weld passes.

Figure 3-36.—Allowing for distortion.

To control the forces of expansion and contraction, you preheat the entire structure before welding. After the welding is complete, you allow the structure to cool slowly. More about preheating and postheating is discussed later in this training manual.

Limit the Number of Weld Passes

You can keep distortion to a minimum by using as few weld passes as possible. You should limit the number of weld passes to the number necessary to meet the requirements of the job. (See fig. 3-35.)

Use Jigs and Fixtures

Since holding the metal in a fixed position prevents excessive movements, the use of jigs and fixtures can help prevent distortion. A jig or fixture is simply a device used to hold the metal rigidly in position during the welding operation.

Allow for Distortion

A simple remedy for the distortion caused by expansion and contraction is to allow for it during fit-up. To reduce distortion, you angle the parts to be welded slightly in the opposite direction in which the contraction takes place. When the metal cools, contraction forces pull the pieces back into position. Figure 3-36 shows how distortion can be overcome in both the butt and tee joints.

There is more to being a good welder than just being able to lay a good bead. There are many factors that must
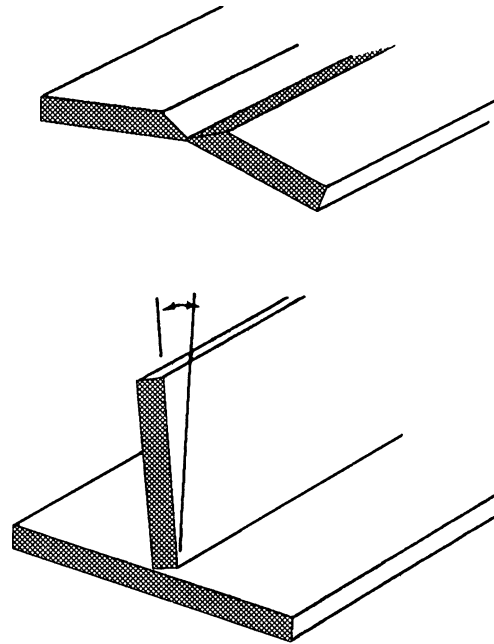
be considered. Later, we discuss additional techniques that you can apply to specific welding situations.

WELDING PROCEDURES

There are many factors involved in the preparation of any welded joint. The detailed methods and practices used to prepare a particular weldment are called the **welding procedure.** A welding procedure identifies all the welding variables pertinent to a particular job or project. Generally, these variables include the welding process, type of base metal, joint design, welding position, type of shielding, preheating and postheating requirements, welding machine setting, and testing requirements.

Welding procedures are used to produce welds that will meet the requirements of commonly used codes. The American Welding Society (AWS) produces the *Structural Welding Code* that is used for the design and construction of steel structures. Another code that is used for the construction of steam boilers and pressure vessels is published by the American Society of Mechanical Engineers (ASME). These codes provide a standardized guide of proven welding practices and procedures.

While you are not directly responsible for developing welding procedures, you could be assigned to a

welding job that requires you to follow them. For example, when a job is assigned to a Naval Construction Force unit, it is accompanied by a set of drawings and specifications. When there is welding required for the job, the specifications normally require it to be accomplished according to a specific code requirement. For instance, if your unit is tasked to fabricate a welded steel structure, the specifications may require that all welding be accomplished according to AWS D1.1 *(Structural Welding Code).* The unit is then responsible for ensuring that the welders assigned to the job are qualified to produce the welds according to this welding procedure specification. As shown in figure 3-37, a welding procedure specification is simply a document that provides details of the required variables for a specific welding application.

For an NMCB, the welding procedure specification is normally prepared by the certified welding inspector at the local Naval Construction Training Center. Using the *Structural Welding Code,* along with the project drawings and specifications, the welding inspector develops a welding procedure specification that meets the requirements of the job. The importance of this document is that it assures that each of the variables can be repeated by qualified welders.

Once a welding procedure specification has been developed and qualified, welders are then required to perform a Welding Performance Qualification test. After the test is complete, the weld specimens are tested according to the requirements of the Welding Procedure Specification. You may use either destructive or nondestructive tests. One example of a destructive test is the *guided-bend* test. An X-ray test is considered nondestructive. Testing is discussed in greater detail later in this training manual.

NOTE: When you are assigned to do a welding job, make a thorough examination of the drawings and specifications. Look carefully at the notes on the drawings and Section 5 (metals) of the specifications. If specific codes are cited, inform the project supervisor so that you can receive the training needed to perform the required welds.

DRAWINGS

Drawings or sketches are used to convey the ideas of an engineer to the skilled craftsman working in the shop. As a welder, you must be able to work from a drawing in order to fabricate metal parts exactly as the engineer has designed them.

READING DRAWINGS

To read a drawing, you must know how engineers use lines, dimensions, and notes to communicate their ideas on paper. In this section, we briefly discuss each of these drawing elements. For a more thorough discussion, refer to publications, such as *Blueprint Reading and Sketching,* NAVEDTRA 10077-F1, or to *Engineering Aid 3,* NAVEDTRA 10696.

Lines

Figure 3-38 shows many of the different types of lines that are used in drawings. You can see that each line has a specific meaning you must understand to interpret a drawing correctly. Let's discuss a few of the most important types. A **visible line** (sometimes called object line) is used to show the edges of an object that are visible to the viewer. For example, if you look at one of the walls of the room you are in, you can see the outline of the walls and (depending on the wall you are looking at) the outline of doors and windows. On a drawing, these visible outlines or edges can be shown using visible lines that are drawn as described in figure 3-38.

Now look at the wall again. Assuming that the wall is wood frame, you know that there are studs or framing members inside the wall that you cannot see. Also, the wall may contain other items, such as water pipes and electrical conduit, that you also cannot see. On a drawing, the edges of those concealed studs and other items can be shown using **hidden lines** (fig. 3-38). These lines are commonly used in drawings. As you can imagine, the more hidden lines there are, the more difficult it becomes to decipher what is what; however, there is another way these studs and other items can be "seen." Imagine that you "cut away" the wallboard that covers the wall and replace it with a sheet of clear plastic. That clear plastic can be thought of as a **cutting** or **viewing plane** (fig. 3-38) through which the previously concealed studs, piping, and conduit are now visible. Now those items can be drawn using visible lines, rather than hidden lines. A view of this type is called a sectional view, and a drawing of the view is called a **section drawing.** Section drawings are commonly used to show the internal components of a complicated object.

Many times, you will see lines drawn on the visible surfaces of a section drawing. These lines, called **section lines,** are used to show different types of materials.

Company Name_____USNAVY_____ By: __M. KONSCAK_____

Welding Procedure Specification No._1111_____ Date_4/26/90_____ Supporting PQR No.(s)__1111-A1_____

Revision No.__N/A_____ Date__N/A_____

Welding Process(es)_S.M.A.W._____ Type(s)___MANUAL_____
(Automatic, Manual, Machine, or Semi-Auto.)

JOINTS (QW-402)   Details

Joint Design__BU-1_____

Backing (Yes)_____ (No)__X_____

Backing Material (Type)_____N/A_____
(Refer to both backing and retainers.)

☐ Metal   ☐ Nonfusing Metal

☐ Nonmetallic   ☐ Other

Sketches, Production Drawings, Weld Symbols or Written Description
should show the general arrangement of the parts to be welded. Where
applicable, the root spacing and the details of weld groove may be
specified.

(At the option of the Mfgr., sketches may be attached to illustrate joint
design, weld layers and bead sequence, e.g. for notch toughness proce-
dures, for multiple process procedures, etc.)

BASE METALS (QW-403)

P-No.___1____Group No.____1____to P-No.___1____,Group No.___1___

OR

Specification type and grade_SA-285-C_____

to Specification type and grade_SA-285-C_____

OR

Chem. Analysis and Mech. Prop.__A-1_____

to Chem. Analysis and Mech. Prop.__A-1_____

Thickness Range:

Base Metal: Groove_3G_____ Fillet_N/A_____

Pipe Dia. Range: Groove_24"+DIA_____ Fillet_N/A_____

Other_____

FILLER METALS (QW-404)	1/8" E-6011	1/8" E-7018
Spec. No. (SFA)	SFA 5.1	SFA 5.5
AWS No. (Class)	E-6011	E-7018
F-No.	F-3	F-4
A-No.	A-1	A-1
Size of Filler Metals	1/8"	1/8"
Deposited Weld Metal	6"-12"	6"-12"
Thickness Range:	1/8"	1/8"
Groove	OPEN V GROOVE	OPEN V GROOVE
Fillet	-----	-----
Electrode-Flux (Class)	N/A	N/A
Flux Trade Name	N/A	N/A
Consumable Insert	N/A	N/A
Other	N/A	N/A

*Each base metal-filler metal combination should be recorded individually.

This form (E00006) may be obtained from the Order Dept., ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300

Figure 3-37.—Welding procedure specification.

QW-482 (Back)

WPS No. __1111__ Rev. _____

POSITIONS (QW-405)
Position(s) of Groove __3G__
Welding Progression: Up __X__ Down _____
Position(s) of Fillet __N/A__

PREHEAT (QW-406)
Preheat Temp. Min. __200°__
Interpass Temp. Max. __500°__
Preheat Maintenance __CHECK EACH LAYER__
(Continuous or special heating where applicable should be recorded)

POSTWELD HEAT TREATMENT (QW-407)
Temperature Range __WRAP W/ INSULATION__
Time Range __WARM TO TOUCH__

GAS (QW-408)

	Gas(es)	Percent Composition (Mixture)	Flow Rate
Shielding	N/A		
Trailing	N/A		
Backing	N/A		

ELECTRICAL CHARACTERISTICS (QW-409)
Current AC or DC __DC__ Polarity __RP__
Amps (Range) __85-120__ Volts (Range) __19-22__

(Amps and volts range should be recorded for each electrode size, position, and thickness, etc. This information may be listed in a tabular form similar to that shown below.)

Tungsten Electrode Size and Type __N/A__
(Pure Tungsten, 2% Thoriated, etc.)

Mode of Metal Transfer for GMAW __N/A__
(Spray arc, short circuiting arc, etc.)

Electrode Wire feed speed range __N/A__

TECHNIQUE (QW-410)
String or Weave Bead __STRINGER AND WEAVE__
Orifice or Gas Cup Size __N/A__
Initial and Interpass Cleaning (Brushing, Grinding, etc.) __CLEAN EACH PASS WITH WIRE BRUSH OR BUFFER__
Method of Back Gouging __N/A__
Oscillation __N/A__
Contact Tube to Work Distance __N/A__
Multiple or Single Pass (per side) __MULTIPASS__
Multiple or Single Electrodes __SINGLE__
Travel Speed (Range) __6"-12"__
Peening __N/A__
Other __N/A__

Weld Layer(s)	Process	Filler Metal Class	Filler Metal Dia.	Current Type Polar.	Current Amp. Range	Volt Range	Travel Speed Range	Other (e.g. Remarks, Comments, Hot Wire Addition, Technique, Torch Angle, Etc.)
1	SMAW	E-6011	1/8"	DCRP	85-120	19-22	6"-10"	N/A
2	SMAW	E-7018	3/32"	DCRP	85-120	19-22	6"-10"	N/A
3	SMAW	E-7018	1/8"	DCRP	85-120	19-22	6"-10"	N/A
4	SMAW	E-7018	1/8"	DCRP	85-120	19-22	8"-12"	N/A
5	SMAW	E-7018	1/8"	DCRP	85-120	19-22	8"-12"	N/A

Figure 3-37.—Welding procedure specification-Continued.

3-23

Figure 3-38.—Line characters and uses.

LINE STANDARDS

NAME	CONVENTION	DESCRIPTION AND APPLICATION	EXAMPLE
VISIBLE LINES	———	HEAVY UNBROKEN LINES / USED TO INDICATE VISIBLE EDGES OF AN OBJECT	
HIDDEN LINES	– – – –	MEDIUM LINES WITH SHORT EVENLY SPACED DASHES / USED TO INDICATE CONCEALED EDGES	
CENTER LINES	–·–·–	THIN LINES MADE UP OF LONG AND SHORT DASHES ALTERNATELY SPACED AND CONSISTENT IN LENGTH / USED TO INDICATE SYMMETRY ABOUT AN AXIS AND LOCATION OF CENTERS	
DIMENSION LINES	←——→	THIN LINES TERMINATED WITH ARROW HEADS AT EACH END / USED TO INDICATE DISTANCE MEASURED	
EXTENSION LINES	———	THIN UNBROKEN LINES / USED TO INDICATE EXTENT OF DIMENSIONS	
LEADER	←———	THIN LINE TERMINATED WITH ARROW HEAD OR DOT AT ONE END / USED TO INDICATE A PART, DIMENSION OR OTHER REFERENCE	¼ X 20 THD.
PHANTOM OR DATUM LINE	–··–··–	MEDIUM SERIES OF ONE LONG DASH AND TWO SHORT DASHES EVENLY SPACED ENDING WITH LONG DASH / USED TO INDICATE ALTERNATE POSITION OF PARTS, REPEATED DETAIL OR TO INDICATE A DATUM PLANE	
STITCH LINE	– – – – –	MEDIUM LINE OF SHORT DASHES EVENLY SPACED AND LABELED / USED TO INDICATE STITCHING OR SEWING	STITCH
BREAK (LONG)	⌇	THIN SOLID RULED LINES WITH FREEHAND ZIG-ZAGS / USED TO REDUCE SIZE OF DRAWING REQUIRED TO DELINEATE OBJECT AND REDUCE DETAIL	
BREAK (SHORT)	∿∿∿	THICK SOLID FREE HAND LINES / USED TO INDICATE A SHORT BREAK	
CUTTING OR VIEWING PLANE / VIEWING PLANE OPTIONAL		THICK SOLID LINES WITH ARROWHEAD TO INDICATE DIRECTION IN WHICH SECTION OR PLANE IS VIEWED OR TAKEN	
CUTTING PLANE FOR COMPLEX OR OFFSET VIEWS		THICK SHORT DASHES / USED TO SHOW OFFSET WITH ARROW HEADS TO SHOW DIRECTION VIEWED	

STEEL

COPPER, BRASS,
BRONZE, AND
COMPOSITIONS

CAST IRON,
MALLEABLE IRON.
GENERAL USE FOR
ALL MATERIALS

ZINC, LEAD, WHITE
METAL, BABBITT,
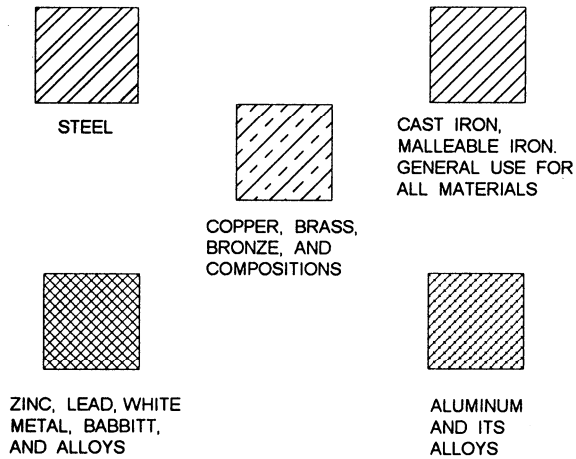AND ALLOYS

ALUMINUM
AND ITS
ALLOYS

Figure 3-39.—Section lines for various metals.

Some of the types of section lines you are likely to encounter as a welder are shown in figure 3-39.

Another use of lines is to form symbols, such as welding symbols, that are discussed later in this chapter.

Dimensions

While engineers use lines to describe the shape or form of an object, they use dimensions to provide a complete size description. Dimensions used on drawings are of two types: size and location. As implied by their names, a size dimension shows the size of an object or parts of an object and a location dimension is used to describe the location of features. Examples of both size and location dimensions are shown in figure 3-40.
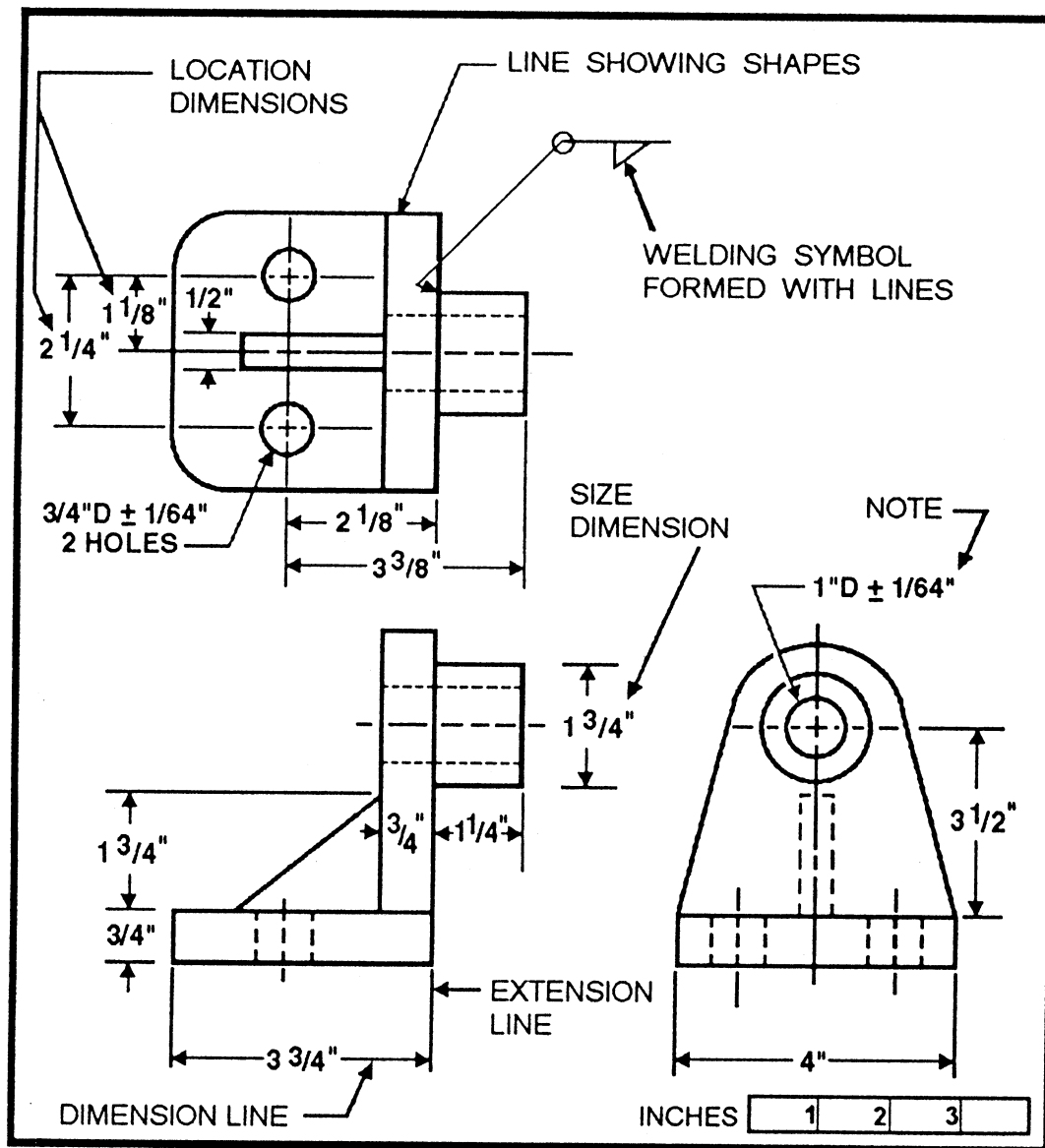

Figure 3-40.—Elements of an orthographic drawing.

While on the subject of dimensions, it should be noted that large objects are seldom drawn to their true size. Instead, the engineer or draftsman reduces the size of the object "to scale." For example, when drawing a 40-foot tower, the drawing may be prepared using a scale of 1/2"= 1'-0". In this case, the height of the tower, on paper, is 20 inches. The scale used to prepare working drawings is always noted on the drawing. It maybe a fractional scale, such as discussed here, or a graphic scale, such as the one shown in figure 3-40. In the Navy, both numerical and graphic scales are usually shown on construction drawings.

When you are using a drawing, the dimensions of an object should never be measured (scaled) directly from the drawing. These measurements are frequently inaccurate, since a change in atmospheric conditions causes drawing paper to shrink or expand. To ensure accuracy, always use the size and location dimensions shown on the drawing. If a needed dimension is not shown on the drawing, you should check the graphic scale, since it will always shrink or expand at the same rate as the drawing paper.

Notes

Drawing notes are used for different purposes and are either general or specific in nature. One example of how notes are used are the two notes shown in figure 3-40 that give the inside diameters of the holes. As you can see, these notes are used for size dimensioning. They are specific notes in that, by using a leader line, each note is referred to a specific hole or set of holes.

A general note is used to provide additional information that does not apply to any one particular part or feature of the drawing. For example, the drawing shown in figure 3-40 could contain a general note saying: "All holes shall be reamed using a tolerance of ± 1/64 inch."

Drawing Views

Look at the drawing shown in figure 3-41. This type of drawing is called a pictorial drawing. These drawings are frequently used to show how an object should appear after it is manufactured. Pictorial drawings are used as working drawings for a simple item, such as a metal washer. For a more complex object, as shown in figure 3-41, it becomes too difficult to provide a complete description in a pictorial drawing. In this case, it is common practice to prepare orthographic drawings to describe the object fully.
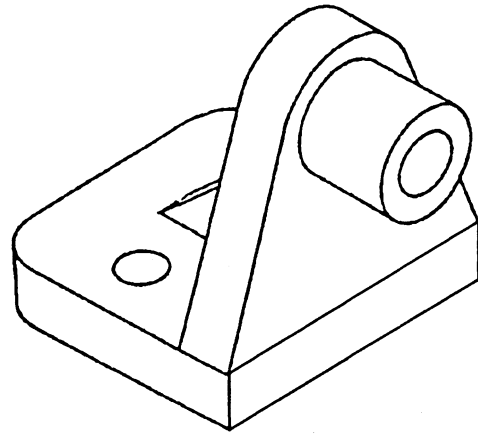

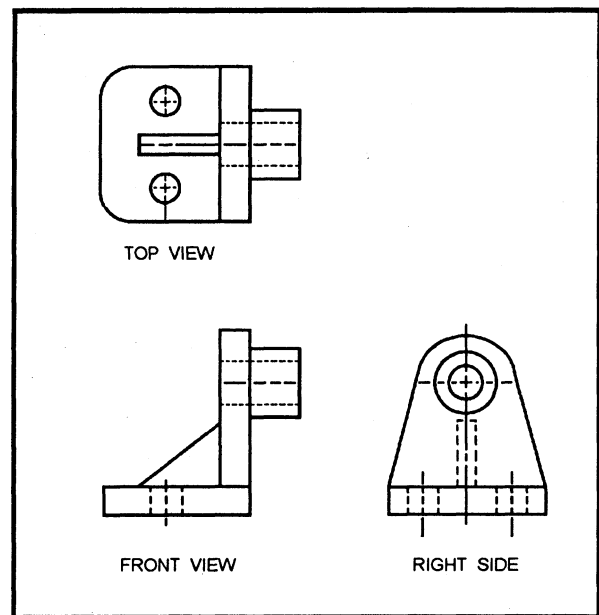Figure 3-41.—Pictorial drawing of a steel part.

Figure 3-42.—Three-view orthographic drawing of the steel part shown in figure 3-41.

Assume you are holding the object shown in figure 3-41 in your hands. When you hold the object so you are looking directly at the top face of the object, the view you see is the top view. A drawing of that view is called an orthographic drawing.

Obviously, an orthographic drawing of only the top view of the object is insufficient to describe the entire object; therefore, additional orthographic drawings of one or more of the other faces of the object are necessary. The number of orthographic views needed to describe an object fully depends upon the complexity of the object. For example, a simple metal washer can be fully described using only one orthographic view; however, an extremely complex object may require as many as

Figure 3-43.—Standard welding symbol.

six views (top, front, left side, right side, back, and bottom). Most objects, such as the steel part shown in figure 3-41, can be sufficiently described using three views: top, front, and right side. For the object shown in figure 3-41, orthographic drawings of the top, front, and right-side views are shown in figure 3-42.

Notice the placement of the views shown in figure 3-42. This is a standard practice that you should be aware of when reading orthographic drawings. By this standard practice, the top view is always placed above the front view and the right-side view is placed to the right of the front view. When additional views are needed, the left side is always drawn to the left of the front view and the bottom is drawn below the front view. Placement of the back view is somewhat flexible; however, it is usually drawn to the left of the left-side view. When reading and understanding the different orthographic views, you find it is sometimes helpful to prepare a pictorial sketch. You can find a discussion of sketching in *Blueprint Reading and Sketching,* NAVEDTRA 10077-F1 .

Think of drawings as a form of communication. They are intended to help you understand all the necessary information you need to fabricate and assemble an object regardless of the complexity. It is important that you learn to read drawings.

Handling and Care of Drawings

Special care should be exercised in the handling of drawings. When they are not being used, keep them on a rack or in another assigned place of storage. Drawings are valuable, and they may be difficult or impossible to replace if they are lost or damaged.

Now, we will discuss some special symbols. These are symbols a welder must be able to read and to understand how they are used to convey information.
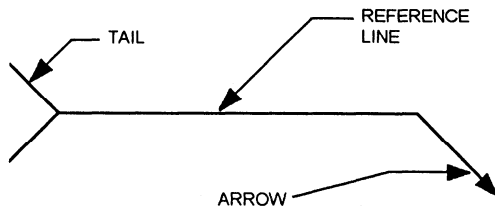
WELDING SYMBOLS

Special symbols are used on a drawing to specify where welds are to be located, the type of joint to be used, as well as the size and amount of weld metal to be deposited in the joint. These symbols have been standardized by the American Welding Society (AWS). You will come into contact with these symbols anytime you do a welding job from a set of blueprints. You need to have a working knowledge of the basic weld symbols and the standard location of all the elements of a welding symbol.

A standard welding symbol (fig. 3-43) consists of a reference line, an arrow, and a tail. The reference line becomes the foundation of the welding symbol. It is used to apply weld symbols, dimensions, and other data to the weld. The arrow simply connects the reference line to the joint or area to be welded. The direction of the arrow has no bearing on the significance of the reference line. The tail of the welding symbol is used only when necessary to include a specification, process, or other reference information.

Weld Symbols

The term *weld symbol* refers to the symbol for a specific type of weld. As discussed earlier, fillet, groove, surfacing, plug, and slot are all types of welds. Basic weld symbols are shown in figure 3-44. The weld

BASIC WELD SYMBOLS									
BEAD	FILLET	PLUG OR SLOT	GROOVE OR BUTT						
			SQUARE	V	BEVEL	U	J	FLARE V	FLARE BEVEL
⌒	◺	▭	‖	∨	⩒	⩗	⩞	⫫	⫭

Figure 3-44.—Basic weld symbols.

FILLET

BEVEL

J-GROOVE

FLARE-BEVEL

CORNER FLANGE
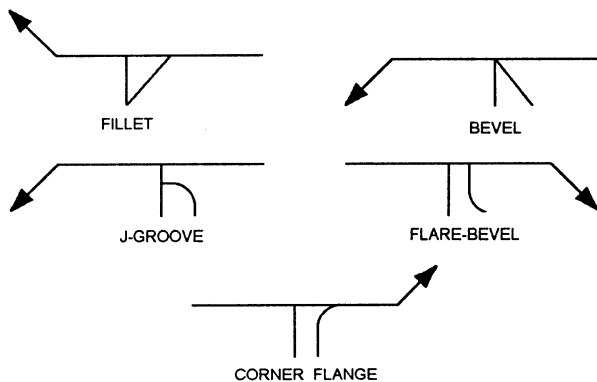
Figure 3-45.—Weld symbols applied to reference line.

SYMBOL

MEANING

A. FILLET WELD, ARROW SIDE

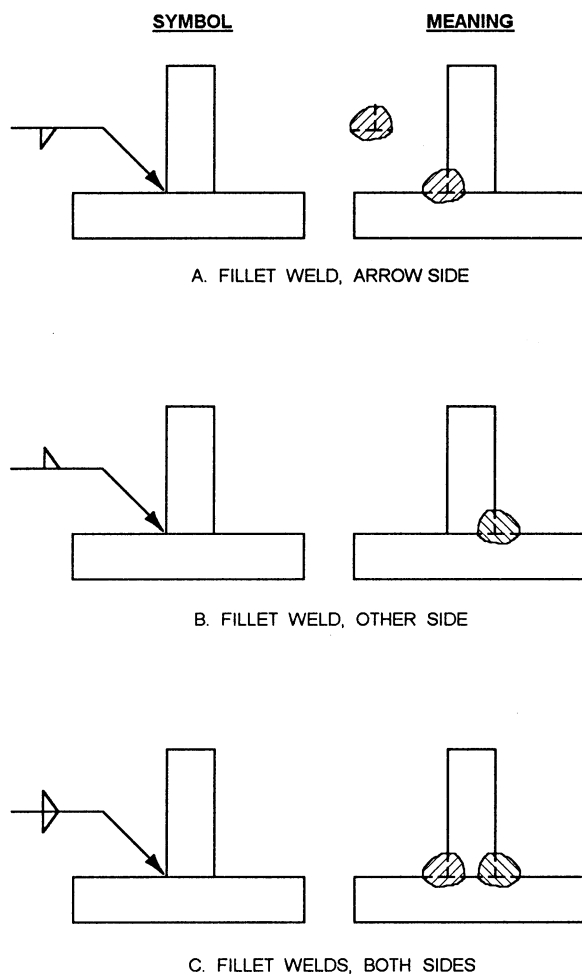B. FILLET WELD, OTHER SIDE

C. FILLET WELDS, BOTH SIDES

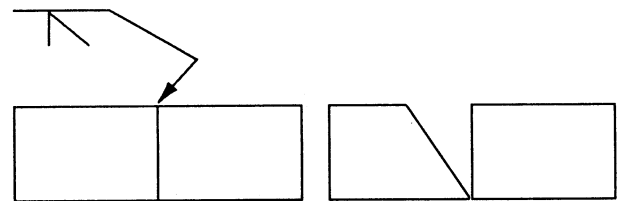**Figure 3-46.—Specifying weld locations.**

Figure 3-47.—Arrowhead indicates beveled plate.

symbol is only part of the information required in the welding symbol. The term *welding symbol* refers to the total symbol, which includes all information needed to specify the weld(s) required.

Figure 3-45 shows how a weld symbol is applied to the reference line. Notice that the vertical leg of the weld symbol is shown drawn to the left of the slanted leg. Regardless of whether the symbol is for a fillet, bevel, J-groove, or flare-bevel weld, the vertical leg is always drawn to the left.

Figure 3-46 shows the significance of the positions of the weld symbols position on the reference line. In view A the weld symbol is on the lower side of the reference line that is termed the *arrow side. View* B shows a weld symbol on the upper side of the reference line that is termed the *other side.* When weld symbols are placed on both sides of the reference line, welds must be made on both sides of the joint (view C).

When only one edge of a joint is to be beveled, it is necessary to show which member is to be beveled. When such a joint is specified, the arrow of the welding symbol points with a definite break toward the member to be beveled. This is shown in figure 3-47.

Figure 3-48 shows other elements that may be added to a welding symbol. The information applied to the reference line on a welding symbol is read from left to right regardless of the direction of the arrow.

Dimensioning

In figure 3-48, notice there are designated locations for the size, length, pitch (center-to-center spacing), groove angle, and root opening of a weld. These locations are determined by the side of the reference line on which the weld symbol is placed. Figure 3-49 shows how dimensions are applied to symbols.
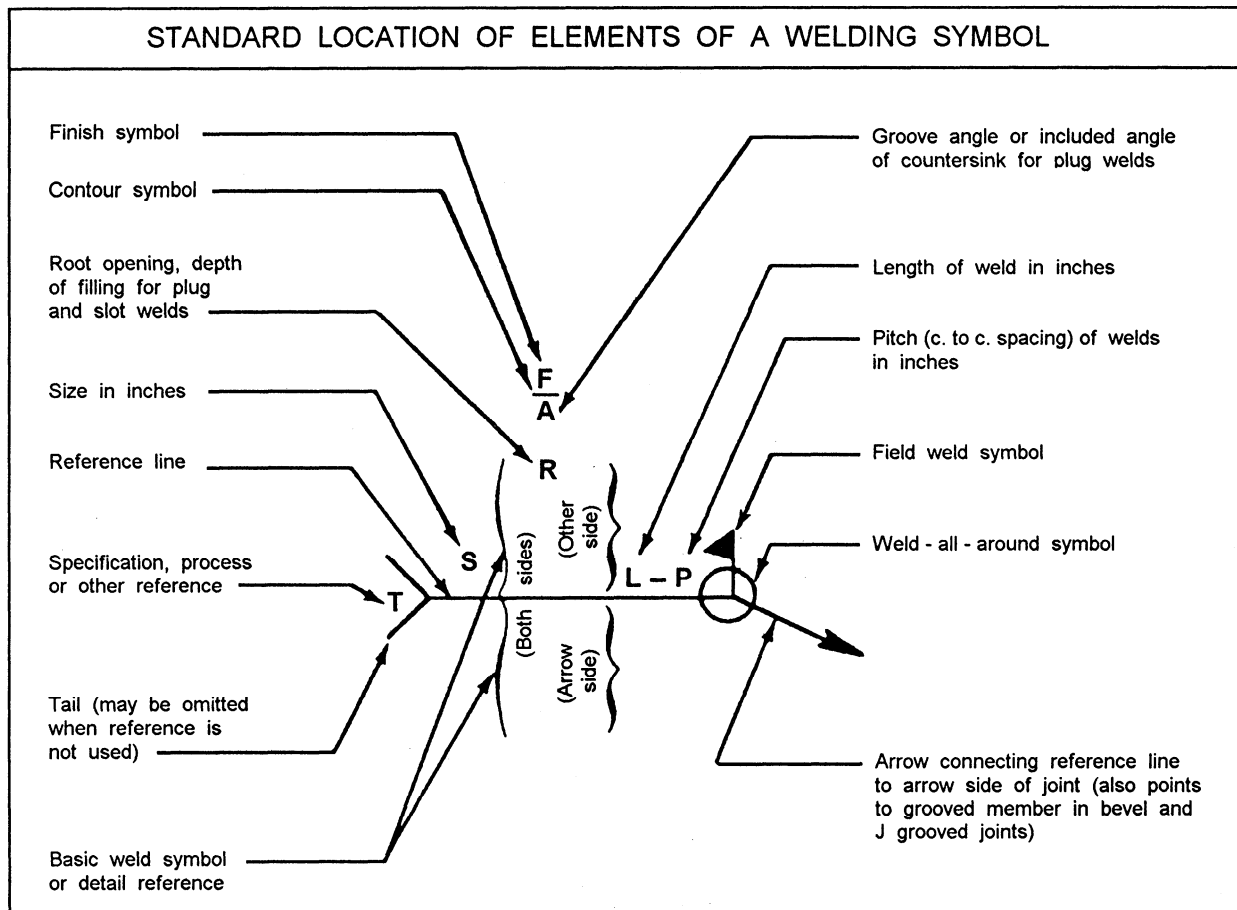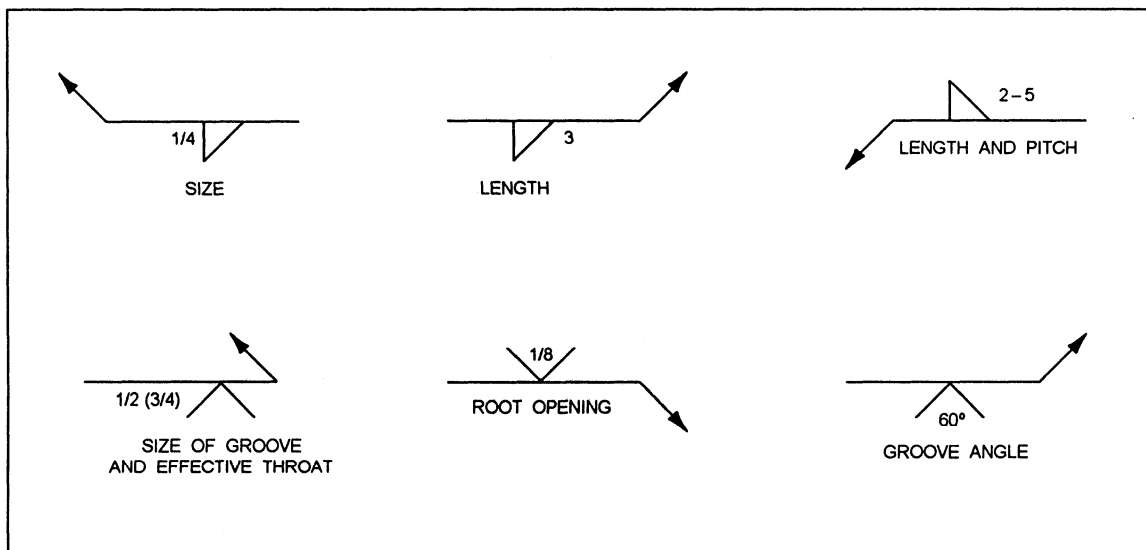
STANDARD LOCATION OF ELEMENTS OF A WELDING SYMBOL

Finish symbol

Contour symbol

Root opening, depth of filling for plug and slot welds

Size in inches

Reference line

Specification, process or other reference

Tail (may be omitted when reference is not used)

Basic weld symbol or detail reference

F / A

R

S

T

(Other side)

(Both sides)

(Arrow side)

L – P

Groove angle or included angle of countersink for plug welds

Length of weld in inches

Pitch (c. to c. spacing) of welds in inches

Field weld symbol

Weld - all - around symbol

Arrow connecting reference line to arrow side of joint (also points to grooved member in bevel and J grooved joints)

Figure 3-48.—Elements of a welding symbol.

1/4 — SIZE

3 — LENGTH

2 – 5 — LENGTH AND PITCH

1/2 (3/4) — SIZE OF GROOVE AND EFFECTIVE THROAT

1/8 — ROOT OPENING

60° — GROOVE ANGLE

Figure 3-49.—Dimensions applied to weld symbols.

SYMBOL

MEANING

A

B

C
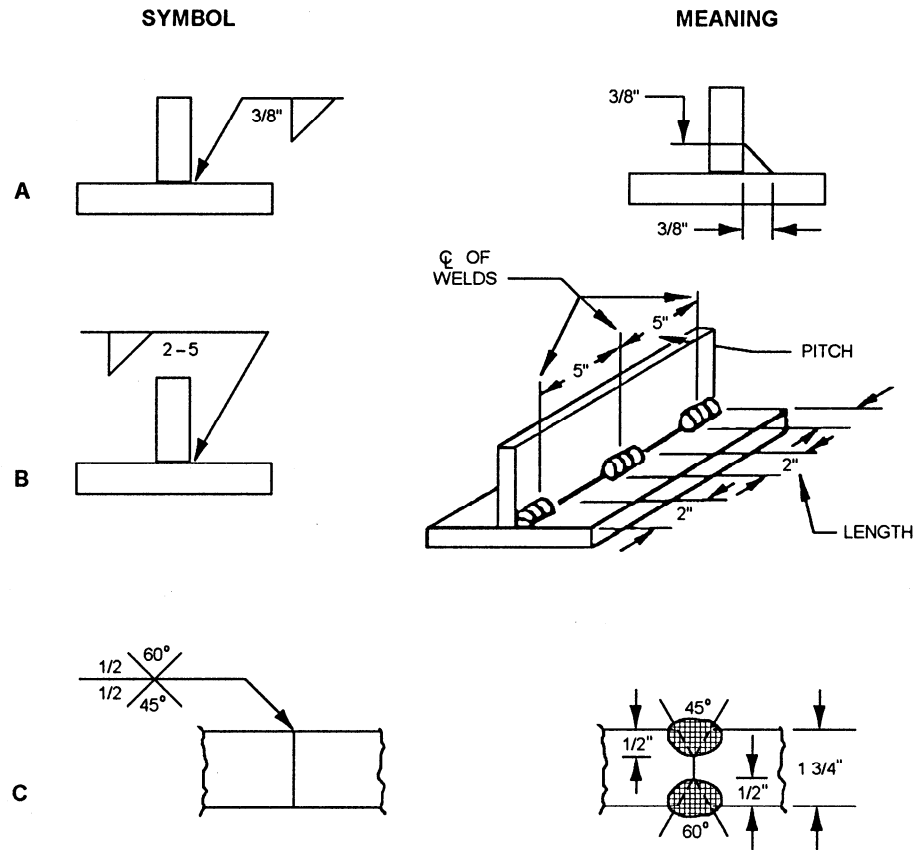
Figure 3-50.—Dimensioning of welds.

Figure 3-51.—Supplementary symbols.

Figure 3-50 shows the meaning of various welding dimension symbols. Notice that the size of a weld is shown on the left side of the weld symbol (fig. 3-50, view A). The length and pitch of a fillet weld are indicated on the right side of the weld symbol. View B

shows a tee joint with 2-inch intermittent fillet welds that are 5 inches apart, on center. The size of a groove weld is shown in view C. Both sides are 1/2 inch, but note that the 60-degree groove is on the other side of the joint and the 45-degree groove is on the arrow side.

Supplementary Symbols

In addition to basic weld symbols, a set of supplementary symbols may be added to a welding symbol. Some of the most common supplementary symbols are shown in figure 3-51.

Contour symbols are used with weld symbols to show how the face of the weld is to be formed. In addition to contour symbols, finish symbols are used to indicate the method to use for forming the contour of the weld.

When a finish symbol is used, it shows the method of finish, not the degree of finish; for example, a C is used to indicate finish by chipping, an M means machining, and a G indicates grinding. Figure 3-52 shows how contour and finish symbols are applied to a weldng symbol. This figure shows that the weld is to be ground flush. Also, notice that the symbols are placed on the same side of the reference line as the weld symbol.
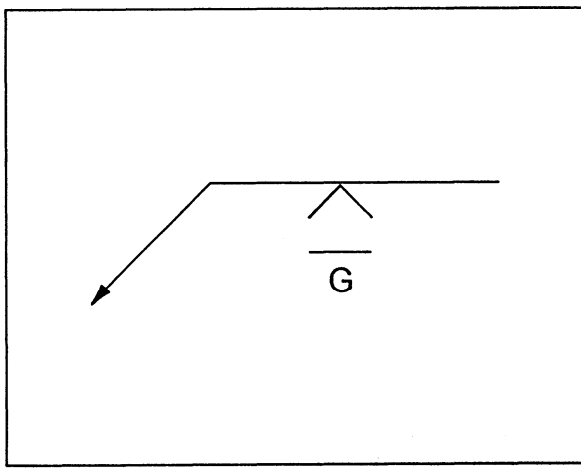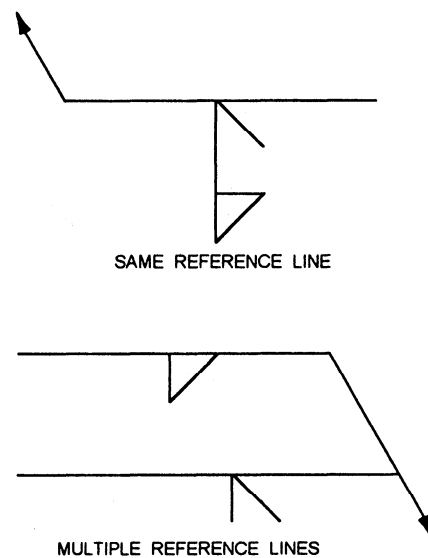
Figure 3-52.—Finish and contour symbols.

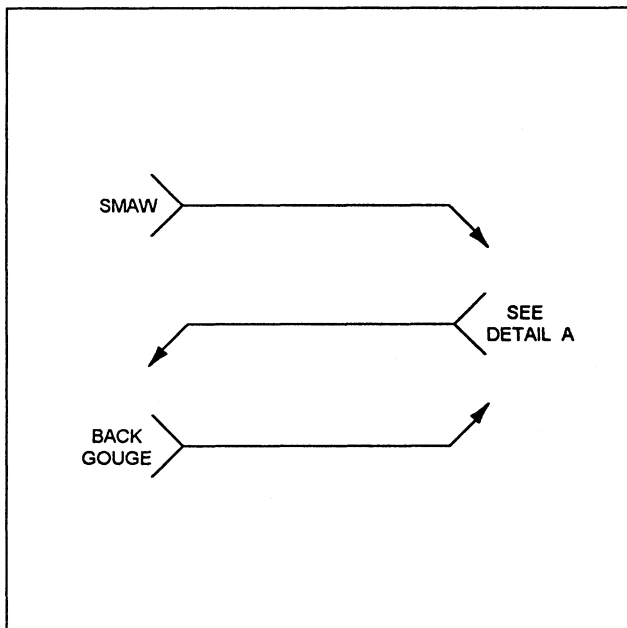Figure 3-54.—Representing multiple welds.

Figure 3-53.—Specifying additional welding information.

Figure 3-55.—Example of welding symbol in use.

Another supplementary symbol shown in figure 3-51 is the weld-all-around symbol. When this symbol is placed on a welding symbol, welds are to continue all around the joint.

Welds that cannot be made in the shop are identified as field welds. Afield weld symbol is shown in figure 3-51. This symbol is a black flag that points toward the tail of the welding symbol.

Specifying Additional Information

It is sometimes necessary to specify a certain welding process, a type of electrode, or some type of reference necessary to complete a weld. In this case, a note can be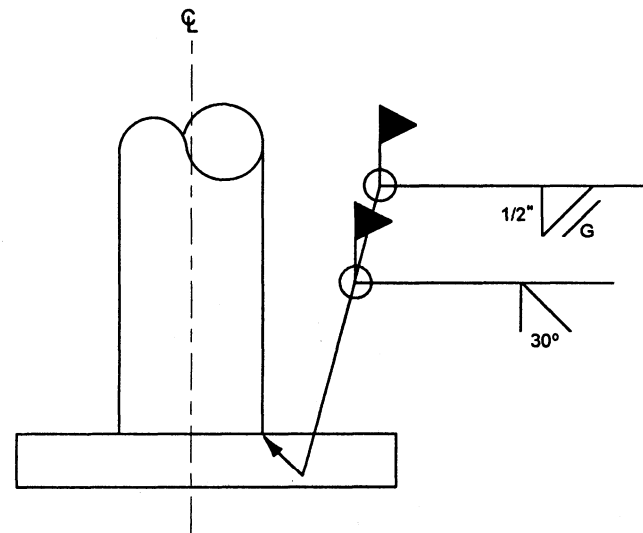 placed in the tail of the reference line. (See fig. 3-53.) If additional information is not needed, then the tail is omitted.

Multiple-Weld Symbols

When you are fabricating a metal part, there are times when more than one type of weld is needed on the same joint; for example, a joint may require both a bevel groove weld and a fillet weld. Two methods of illustrating these weld symbols are shown in figure 3-54. Note that in each welding symbol, the bevel groove weld is to be completed first, followed by the fillet weld.

Applying a Welding Symbol

Figure 3-55 shows an example of how a welding symbol may appear on a drawing. This figure shows a
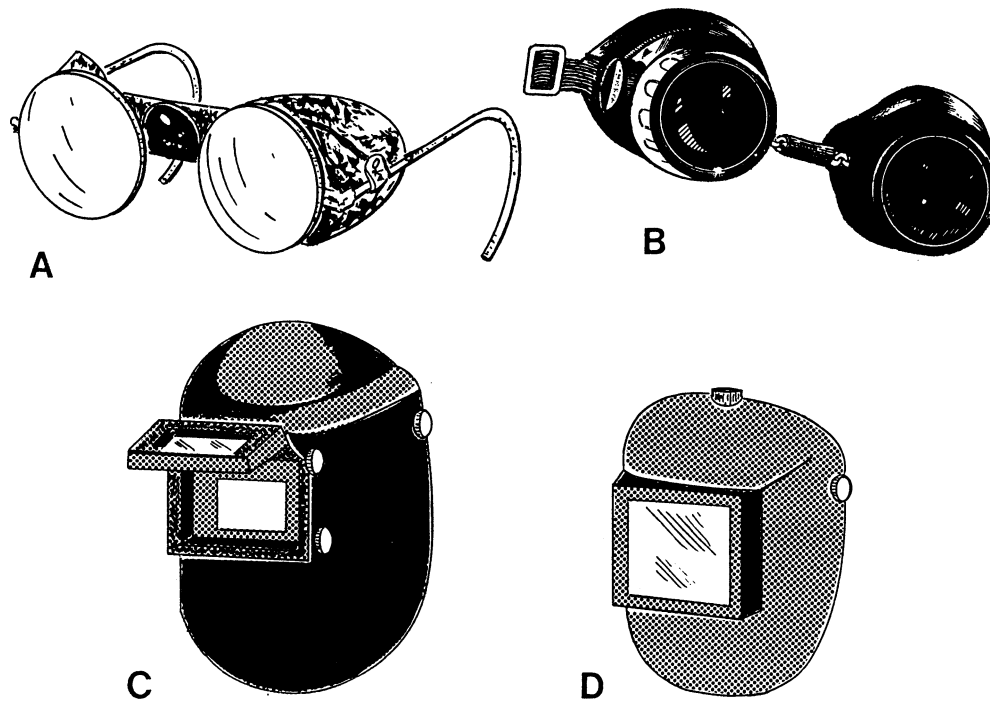
Figure 3-56.—Eye protection devices.

steel pipe column that is to be welded to a baseplate. The symbol tells the welder that the pipe is to be beveled at a 30-degree angle followed by a bevel groove weld all around the joint. This is followed by a 1/2-inch fillet weld that is also welded all around the joint. Finally, finish the fillet weld by grinding it to a flush contour. As the field weld symbol indicates, all welds are to be accomplished in the field.

For additional information about welding symbols, refer to *Symbols for Welding and Nondestructive Testing,* ANSI/AWS A2.4-86.

SAFETY

Mishaps frequently occur in welding operations. In many instances, they result in serious injury to the welder or other personnel working in the immediate area. In most cases, mishaps occur because of carelessness, lack of knowledge, and the misuse of available equipment. Precautions that apply to specific welding equipment are pointed out in the chapters that cover that equipment. In this section we are particularly interested in such topics as protective clothing, eye protection devices, and practices applicable to the personal safety of the operator and personnel working nearby.

Proper eye protection is of the utmost importance. This covers the welding operator and the other personnel, such as helpers, chippers, or inspectors, who are in the vicinity of the welding and cutting operations. Eye protection is necessary because of the hazards posed by stray flashes, reflected glare, flying sparks, and globules of molten metal. Devices used for eye protection include helmets and goggles.

NOTE: In addition to providing eye protection, helmets also provide a shield against flying metal and ultraviolet rays for the entire face and neck. Figure 3-56 shows several types of eye protection devices in common use.

Flash goggles (view A) are worn under the welder's helmet and by persons working around the area where welding operations are taking place. This spectacle type of goggles has side shields and may have either an adjustable or nonadjustable nose bridge.

Eyecup or **cover** type of goggles (view B) are for use in fuel-gas welding or cutting operations. They are contoured to fit the configuration of the face. These goggles must be fitted with a shade of filter lens that is suitable for the type of work being done.

NOTE: The eyecup or cover type of goggles are NOT to be used as a substitute for an arc-welding helmet.

For electric arc-welding and arc-cutting operations, a helmet having a suitable filter lens is necessary. The helmet shown in view C has an opening, called a

Table 3-1.—Recommended Filter Lenses for Various Welding Operations

Shade No.	Operation
Up to 4	Light electric spot welding or for protection from stray light from nearby welding.
5	Light gas cutting and welding.
6-7	Gas cutting, medium gas welding, and arc welding up to 30 amperes.
8-9	Heavy gas welding and arc welding and cutting, 30-75 amperes.
10-11	Arc welding and cutting, 76-200 amperes.
12	Arc welding and cutting, 201-400 amperes.
13-14	Arc welding and cutting exceeding 400 amperes.

window, for a flip-up filter lens 2 inches by 4 1/4 inches in size. The helmet shown in view D has a 4 1/2-inch by 5 1/4-inch window. The larger window affords the welder a wider view and is especially useful when the welder is working in a confined place where head and body movement is restricted. When welding in locations where other welders are working, the welder should wear flash goggles beneath his helmet to provide protection from the flashes caused by the other welders' arcs. The flash goggles will also serve as eye protection when chipping the slag from a previous weld deposit.

Helmets and welding goggles used for eye protection are made from a nonflammable insulating material. They are fitted with a removable protective colored filter and a clear cover lens.

NOTE: The purpose of the clear cover lens is to protect the filter lens against pitting caused by sparks and hot metal spatter. The clear lens must be placed on the outside of the filter lens. The clear lens should be replaced when it impairs vision.

Filter lenses are furnished in a variety of shades, which are designated by number. The lower the number, the lighter the shade; the higher the number, the darker the shade. Table 3-1 shows you the recommended filter lens shade for various welding operations. The filter lens shade number selected depends on the type of work and somewhat on the preference of the user. Remember, a filter lens serves two purposes. The first is to diminish the intensity of the visible light to a point where there is no glare and the welding area can be clearly seen. The

second is to eliminate the harmful infrared and ultraviolet radiations coming from the arc or flame; consequently, the filter lens shade number you select must not vary more than two shades from the numbers recommended in table 3-1.

Rule of thumb: When selecting the proper shade of filter lens for electric-arc welding helmets, place the lens in the helmet and look through the lens as if you were welding. Look at an exposed bare light bulb and see if you can distinguish its outline. If you can, then use the next darker shade lens. Repeat the test again. When you no longer see the outline of the bulb, then the lens is of the proper shade. Remember that this test should be performed in the same lighting conditions as the welding operation is to be performed. Welding in a shop may require a shade lighter lens than if the same job were being performed in bright daylight. For field operations, this test may be performed by looking at a bright reflective object.

WARNING

Never look at the welding arc without proper eye protection. Looking at the arc with the naked eye could lead to permanent eye damage. If you receive flash burns, they should be treated by medical personnel.

A variety of special welder's clothing is used to protect parts of the body. The clothing selected varies
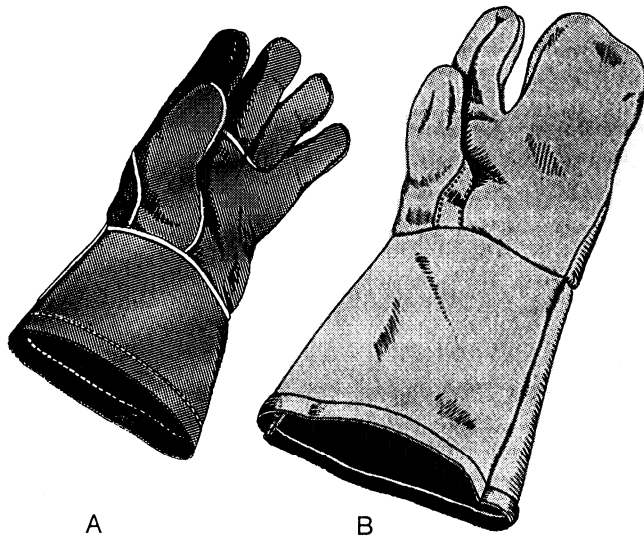
Figure 3-57.—Welding gloves and mitts.

with the size, location, and nature of the work to be performed. During any welding or cutting operation, you should always wear flameproof gauntlets. (See fig. 3-57.) For gas welding and cutting, five-finger gloves like those shown in view A should be used. For electric-arc welding, use the two-finger gloves (or mitts) shown in view B.

Both types of gloves protect the hands from heat and metal spatter. The two-finger gloves have an advantage over the five-finger gloves in that they reduce the danger of weld spatter and sparks lodging between the fingers. They also reduce finger chafing which sometimes occurs when five-finger gloves are worn for electric-arc welding.

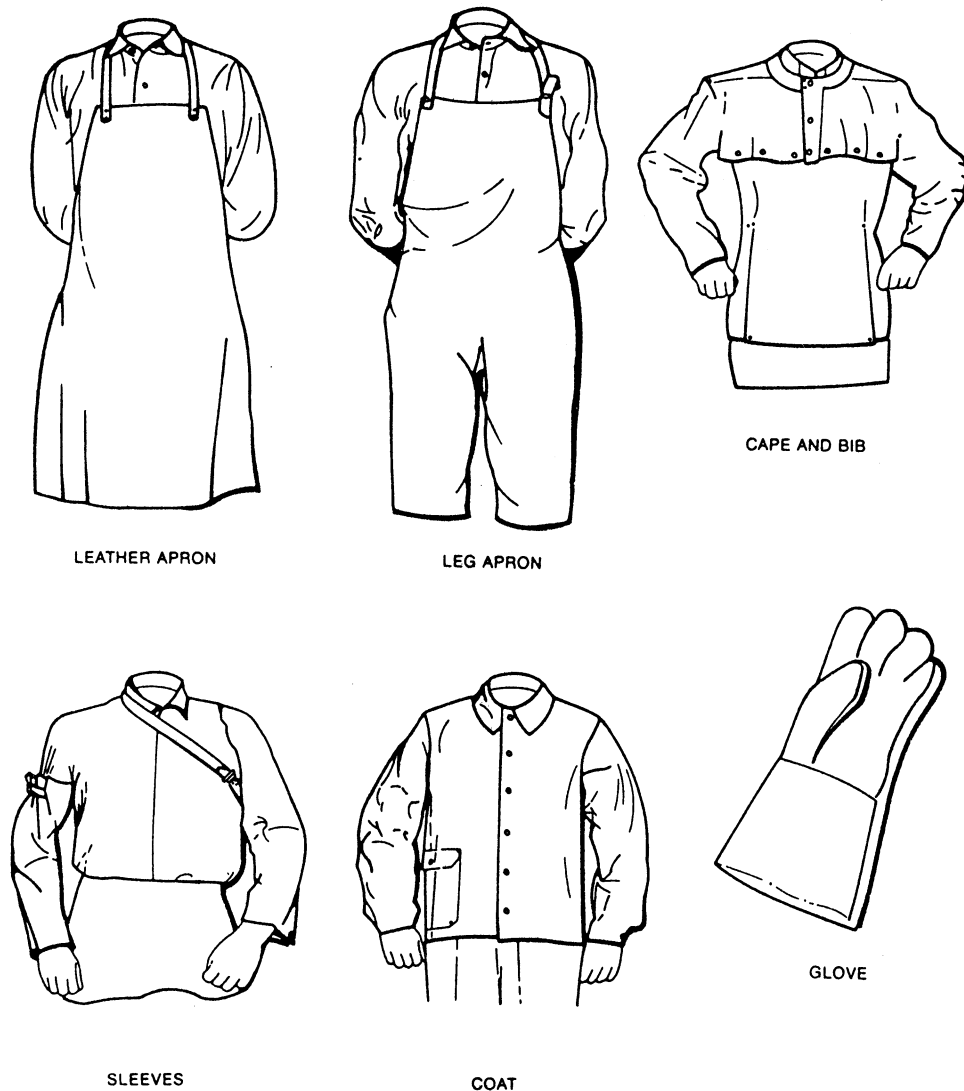Many light-gas welding and brazing jobs require no special protective clothing other than gloves and

LEATHER APRON

LEG APRON

CAPE AND BIB

SLEEVES

COAT

GLOVE

Figure 3-58.—Welder's protective clothing.

goggles. Even here, it is essential that you wear your work clothes properly. Sparks are very likely to lodge in rolled-up sleeves, pockets of clothing, or cuffs of trousers or overalls. Sleeves should be rolled down and the cuffs buttoned. The shirt collar, also, should be fully buttoned. Trousers should not be cuffed on the outside, and pockets not protected by button-down flaps should be eliminated from the front of overalls and aprons. All other clothing must be free of oil and grease. Wear high top-safety shoes; low-cut shoes are a hazard because sparks and molten metal could lodge in them, especially when you are sitting down.

Medium- and heavy-gas welding, all-electric welding, and welding in the vertical or overhead welding position require special flameproof clothing made of leather or other suitable material. This clothing is designed to protect you against radiated heat, splashes of hot metal, or sparks. This clothing consists of aprons, sleeves, combination sleeves and bib, jackets, and overalls. They afford a choice of protection depending upon the specific nature of the particular welding or cutting job. Sleeves provide satisfactory protection for welding operations at floor or bench level.

The cape and sleeves are particularly suited for overhead welding, because it protects the back of the neck, top of the shoulders, and the upperpart of the back and chest. Use of the bib, in combination with the cape and sleeves, gives added protection to the chest and abdomen. The jacket should be worn when there is a need for complete all-around protection to the upperpart of the body. This is especially true when several welders are working in close proximity to one another. Aprons and overalls provide protection to the legs and are suited for welding operations on the floor. Figure 3-58 shows some of the protective clothing available to welders.

To prevent head burns during overhead welding operations, you should wear leather or flameproof caps under the helmet. Earplugs also should be worn to keep sparks or splatter from entering and burning the ears. Where the welder is exposed to falling or sharp objects, combination welding helmet/hard hats should be used. For very heavy work, fire-resistant leggings or high boots should be worn. Shoes or boots having exposed nailheads or rivets should NOT be worn. Oilskins or plastic clothing must NOT be worn in any welding operation.

NOTE: If leather protective clothing is not available, then woolen clothing is preferable to cotton. Woolen clothing is not as flammable as cotton and helps protect the operator from the changes in temperature caused by welding. Cotton clothing, if used, should be chemically treated to reduce its flammability.

CHAPTER 5

GAS WELDING

This chapter discusses equipment and materials used in gas welding. Information is provided on the operation and maintenance of oxyacetylene and oxy-MAPP equipment. Included are welding techniques and safety precautions associated with gas welding.

Oxyacetylene and oxy-MAPP (methylacetylene-propadiene) welding are two types of gas-welding processes. They require a gas-fueled torch to raise the temperature of two similar pieces of metal to their fusion point that allows them to flow together. A filler rod is used to deposit additional metal. The gas and oxygen are mixed to correct proportions in the torch, and you can adjust the torch to produce various types of flames.

A properly made gas weld is consistent in appearance, showing a uniform deposit of weld metal. Complete fusion of the sidewalls is necessary to forma good joint. Some of the factors you must consider when making a gas weld are as follows: edge preparation, spacing and alignment of the parts, temperature control (before, during, and after the welding process), size of the torch tip, size and type of the filler rod, flame adjustment, and rod and torch manipulation. In some cases, fluxes are needed to remove oxides and slag from the molten metal and to protect the puddle from atmospheric contamination.

When you join sections of plate by gas welding, the edges of the plate at the joint are uniformly melted by the heat from the torch. When welding heavier sheets and plates, you have to use filler metals. The edges of the heavier plate are beveled to permit penetration to the base of the joint. Both the filler metal and the base metal are melted, and as they solidify, they form one continuous piece. For welding light sheet metal, filler metal is usually not necessary. The edges of light sheet metal are flanged at the joint so they flow together to form one solid piece when you melt them.

OXYGAS WELDING EQUIPMENT

An oxygas welding outfit is basically the same as an oxygas cutting outfit with the exception of the torch. The welding outfit usually consists of a cylinder of acetylene or MAPP gas, a cylinder of oxygen, two regulators, two lengths of hose with fittings, and a welding torch with tips (fig. 5-1). An oxygas welding outfit also is called a welding rig.

In addition to the basic equipment mentioned, you also use the same auxiliary equipment that was discussed in chapter 4. This equipment consists of tip cleaners, cylinder trucks, clamps, and holding jigs. Safety apparel, which includes goggles, hand shields, gloves, leather aprons, sleeves and leggings, is essential and should be worn as required. Information on safety apparel is contained in chapter 3.

Oxygas welding equipment, like cutting equipment, may be stationary or portable. A portable oxygas outfit, as shown in figure 5-2, is an advantage when it becomes necessary to move the equipment.

To perform your welding duties, you must be able to set up the welding equipment and make the adjustments required to perform the welding operation. Thus it is important that you understand the purpose and function of the basic pieces of equipment that makeup the welding outfit. The gases, cylinders, regulators, hoses, and safety equipment are covered in chapter 4. If you have any questions, you should review chapter 4 before continuing.

WELDING TORCHES

The oxygas welding torch mixes oxygen and fuel gas in the proper proportions and controls the amount of the mixture burned at the welding tip. Torches have two needle valves: one for adjusting the oxygen flow and the other for adjusting the fuel gas flow. Other basic parts include a handle (body), two tubes (one for oxygen and another for fuel), a mixing head, and a tip. On some models the tubes are silver-brazed to the head and the rear end forgings, which are, in turn, fitted into the handle. Welding tips are made from a special copper alloy and are available indifferent sizes to handle a wide range of uses and plate thicknesses.

Two general types of welding torches are used:
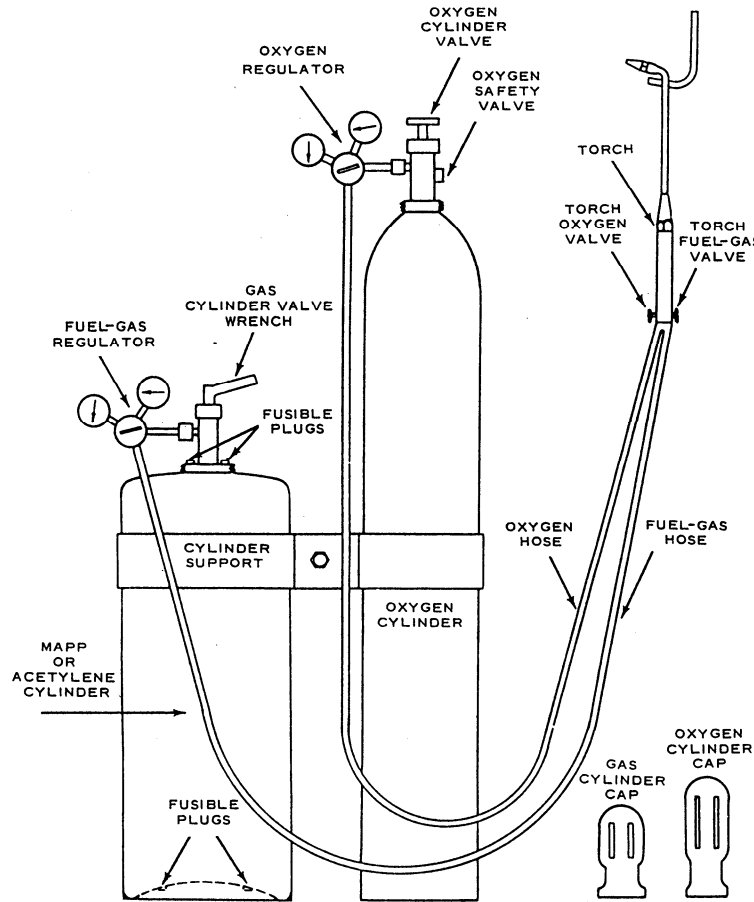
- Low pressure

- Medium pressure

Figure 5-1.—An oxygas welding outfit.

The low-pressure torch is also known as an injector torch. The fuel-gas pressure is 1 psi (pound per square inch) or less. The oxygen pressure ranges between 10 to 40 pounds, depending on the size of the torch tip. A jet of relatively high-pressure oxygen produces the suction necessary to draw the fuel gas into the mixing head. The welding tips may or may not have separate injectors in the tip. Atypical mixing head for the low-pressure (or injector) torch is shown in figure 5-3.

Medium-pressure torches are often called balanced-pressure or equal-pressure torches because the fuel gas and the oxygen pressure are kept equal. Operating pressures vary, depending on the type of tip used.

DANGER

If acetylene is used as the fuel gas, the pressure must never be allowed to exceed 15 psi because acetylene becomes very dangerous at 15 psi and self-explosive at 29.4 psi.
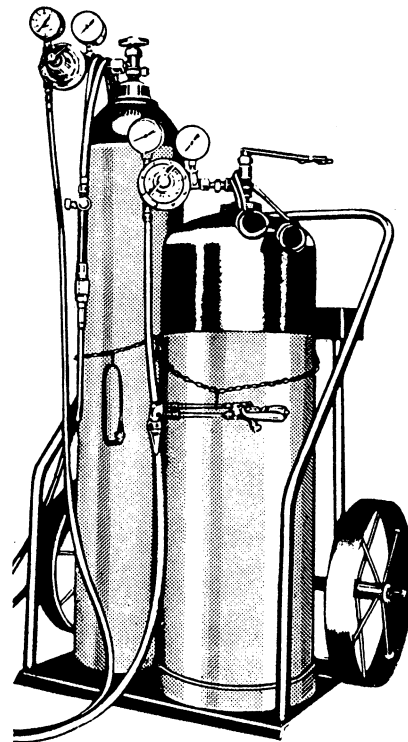

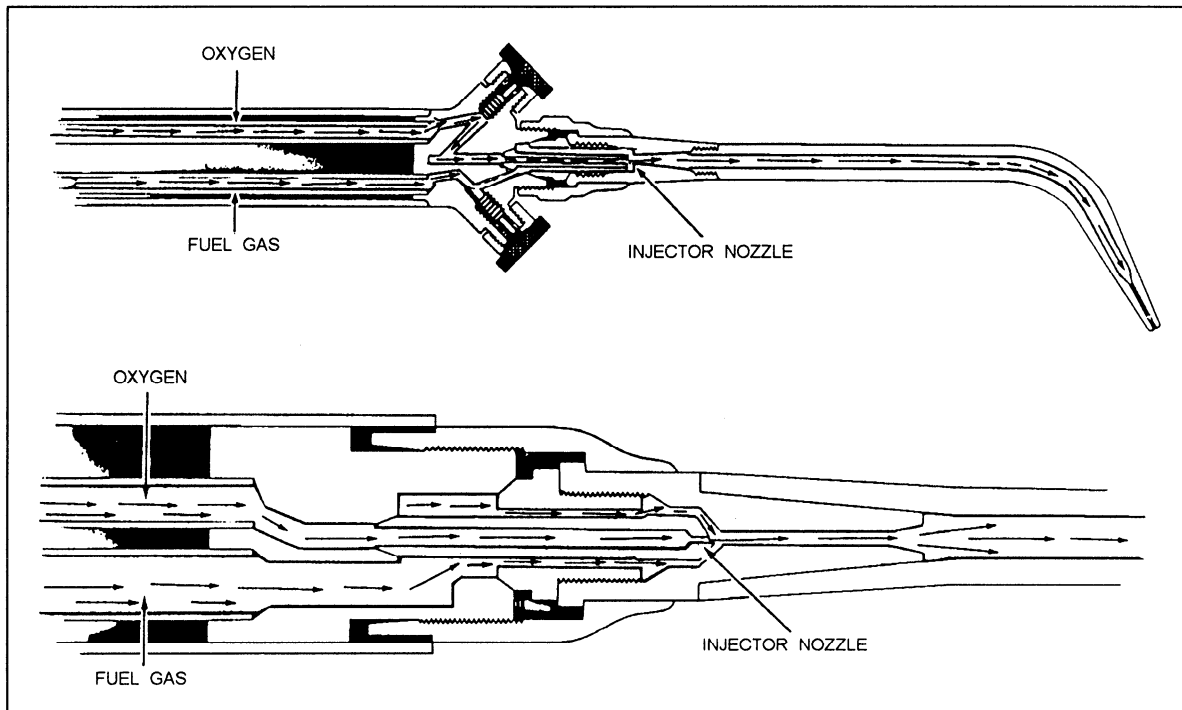**Figure 5-2.—A portable oxygas welding and cutting outfit,**

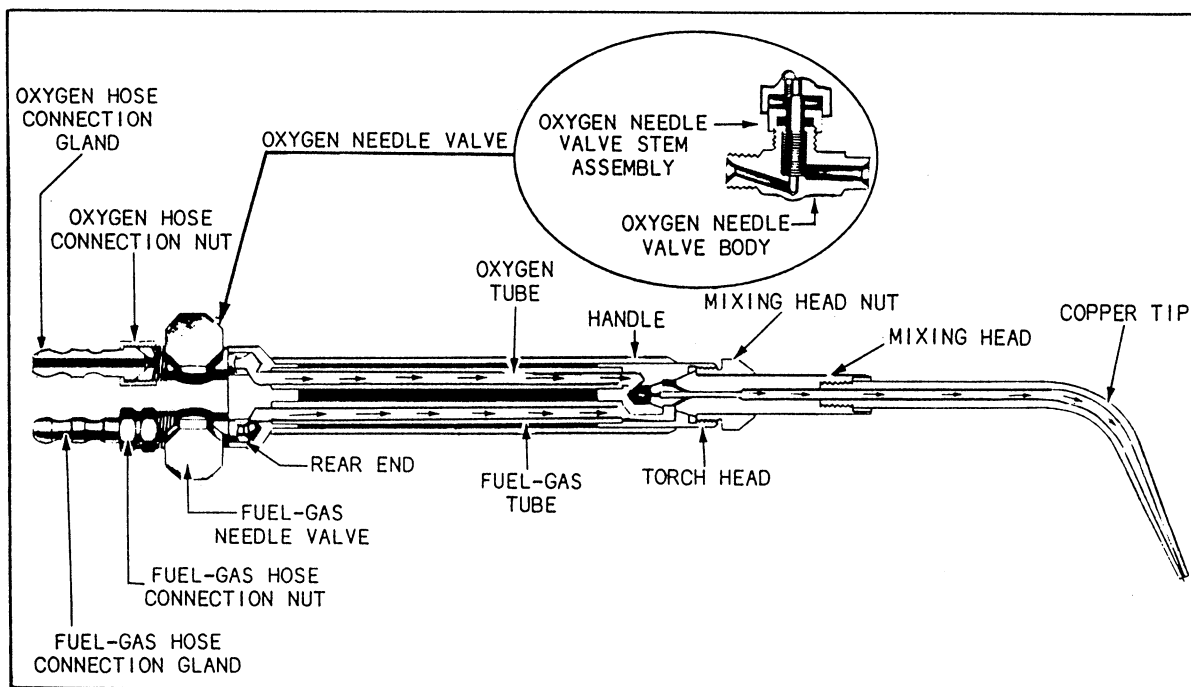Figure 5-3.—Mixing head for the low-pressure torch.

Figure 5-4.—Equal-pressure welding torch.

A typical equal-pressure welding torch, also called a general-purpose torch, is shown in figure 5-4. The medium-pressure torch is easier to adjust than the low-pressure torch and, since equal gas pressures are used, you are less likely to get a flashback. (Flashbacks are covered in chapter 4.)

Welding TIPS and MIXERS are designed in several ways, depending on the manufacturer. Some torch designs have a separate mixing head or mixer for each tip size. Other designs have only one mixer for several tip sizes. Tips come in various types; some are one-piece hard-copper tips and others are two-piece tips that

include an extension tube to make the connection between the tip and the mixing head. When used with an extension tube, removable tips are made of hard copper, brass, or bronze. Tip sizes are designated by numbers, and each manufacturer has his own arrangement for classifying them. Tip sizes differ in the diameter of the hole.

FILLER RODS

The term *filler rod* refers to a filler metal used in gas welding, brazing, and certain electric welding processes in which the filler metal is not a part of the electrical circuit. The only function of the filler rod is to supply filler metal to the joint. Filler rod comes in wire or rod form that is often referred to as "welding rod."

As a rule, filler rods are uncoated except for a thin film resulting from the manufacturing process. Filler rods for welding steel are often copper-coated to protect them from corrosion during storage. Most rods are furnished in 36-inch lengths and a wide variety of diameters, ranging from 1/32 to 3/8 inch. Rods for welding cast iron vary from 12 to 24 inches in length and are frequently square, rather than round. You determine the rod diameter for a given job by the thickness of the metal you are joining.

Except for rod diameter, you select the filler rod based on the specifications of the metals being joined. These specifications may be federal, military, or Navy specifications. This means that they apply to all federal agencies, the Military Establishment, or the Navy, respectively. Filler metals are presently covered by one or more of these three types of specifications. Eventually, all Navy specifications will be rewritten as military (MIL) specifications. For that reason, some of the specifications for welding materials presented in this section may subsequently be published as military, rather than Navy specifications.

Many different types of rods are manufactured for welding ferrous and nonferrous metals. In general, welding shops stock only a few basic types that are suitable for use in all welding positions. These basic types are known as general-purpose rods.

OPERATION AND MAINTENANCE OF OXYGAS EQUIPMENT

This section discusses basic procedures involved in setting up oxygas equipment, lighting off, adjusting the flame, and securing the equipment. Information also is provided on the maintenance of oxygas welding equipment.

SELECTING THE WELDING TORCH TIP SIZE

Welding torch tip size is designated by a number stamped on the tip. The tip size is determined by the size of the orifice. There is no standard system of numbering welding torch tip sizes; each manufacturer has his own numbering system. In this manual, the tip size is given in the number drill orifice size. Number drills consist of a series of 80 drills, number 1 through 80. The diameter of a number 1 drill is 0.2280 of an inch and the diameter of a number 80 drill is 0.0135 of an inch.

NOTE: As the drill size number increases, the size of the drill decreases.

Once you become familiar with the use of a specific manufacturer's torch and numbering system, it becomes unnecessary to refer to orifice number drill size. The orifice size determines the amount of fuel gas and oxygen fed to the flame; therefore, it determines the amount of heat produced by the torch. The larger the orifice, the greater the amount of heat generated.

If the torch tip orifice is too small, not enough heat will be available to bring the metal to its fusion temperature. If the torch tip is too large, poor welds result from the following: the weld is made too fast, control of the welding rod melting is difficult, and the appearance and quality of the weld is unsatisfactory.

For practice purposes, using an equal-pressure torch, the welding rod sizes and the tip sizes shown in table 5-1 should give satisfactory results.

EQUIPMENT SETUP

Setting up the oxygas equipment and preparing for welding is identical to setting up for oxygas cutting (chapter 4) except for the selection of the torch tip. Select the correct tip and mixing head (depending on torch manufacturer), and connect them to the torch body. Tighten the assembly by hand, and then adjust to the proper angle. After the desired adjustment has been made, tighten the tip. On some types of equipment, the tip is tightened with a wrench, while on other types, only hand tightening is required.

TORCH LIGHTING AND FLAME ADJUSTMENT

When lighting the torch and adjusting the flame, you should always follow the manufacturer's directions for the particular model of torch being used. This is necessary because the procedure varies somewhat with

Table 5-1.—Welding Rod Sizes and Tip Sizes Used to Weld Various Thicknesses of Metal

Metal Thickness	Diameter Welding Rod *	Tip Drill Size	Pressures Oxygen-Fuel Gas	
1/16	1/16-3/32	60-69	4	4
1/8	3/32-1/8	54-57	5	5
1/4	5/32-3/16	44-52	8	8
3/8	3/16-1/4	40-50	9	9

* Sizes listed in this table are approximate and will give satisfactory results. The size of the piece welded will govern the choice. When welding small pieces, use the smaller tip and welding rod. When welding larger pieces, use the larger size tip and welding rod.

different types of torches and, in some cases, even with different models made by the same manufacturer.

After lighting the torch, you adjust the flame according to the type of metal being welded. In-depth coverage of the different types of flames is covered in chapter 4.

The carburizing flame is best used for welding high-carbon steels, for hardfacing, and for welding non-ferrous alloys, such as Monel. A neutral flame is the correct flame to use for welding most metals. When steel is welded with this flame, the puddle of molten metal is quiet and clear, and the metal flows without boiling, foaming, or sparking. The welding flame should always be adjusted to neutral before either the oxidizing or carburizing flame mixture is set.

The oxidizing flame has a limited use and is harmful to many metals. When applied to steel, the oxidizing flame causes the molten metal to foam and produce sparks. The major use of the flame is that of the slightly oxidizing flame used to braze steel and cast iron. A stronger oxidizing flame is used for fusion welding brass and bronze. You determine the amount of excess oxygen to use by watching the molten metal.

MAINTAINING THE EQUIPMENT

For welding equipment to operate at peak efficiency and give useful service, you must perform the proper maintenance and upkeep on it. Your responsibilities involve the maintenance and care of oxygas welding equipment. You will not be required to make major repairs to welding equipment; but when major repairs are needed, it is your responsibility to see that the equipment is removed from service and turned in for repair. This section briefs you on some of the common types of maintenance duties that you will be required to perform,

Torch Gas Leaks

At times the needle valves may fail to shut off when hand tightened in the usual manner. When this happens, do not use a wrench to tighten the valve stem. Instead, open the valve and try to blow the foreign matter off the valve seat, using the working gas pressure in the hose. If this fails, it will be necessary to remove the stem assembly and wipe the seat clean. Reassemble the valve and try closing it tightly by hand several times. If these measures fail to stop the leak, you should have the parts replaced or the valve body reseated. These repairs should be made only by qualified personnel.

When there is leakage around the torch valve stem, you should tighten the packing nut or repack it if necessary. For repacking, you should use only the packing recommended by the manufacturer of the torch. **DO NOT USE ANY OIL.** If the valve stem is bent or badly worn, replace it with a new stem.

Before you use a new torch for the first time, it is a good idea to check the packing nut on the valves to make sure it is tight. The reason is that some manufacturers ship torches with these nuts loose.

Leaks in the mixing-head seat of the torch causes oxygen and fuel-gas leaks between the inlet orifices leading to the mixing head. This problem causes improper gas mixing and results in flashbacks. The problem can be corrected by having the seat in the torch head reamed and by truing the mixing-head seat. Usually, you must send the equipment to the manufacturer for these repairs.
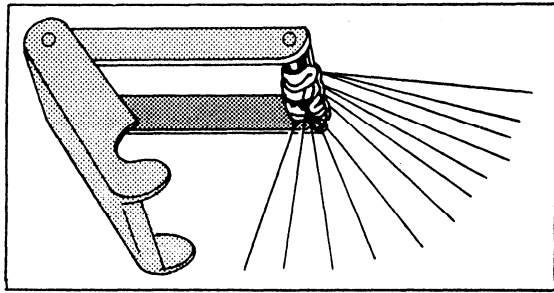
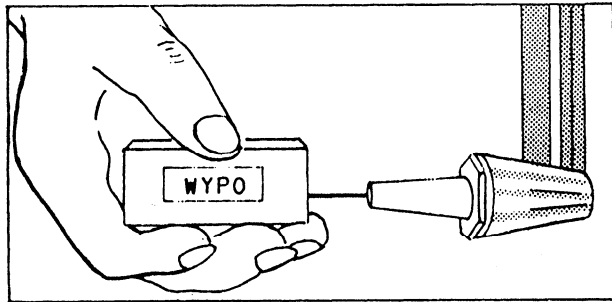Figure 5-5.—Welding tip orifice cleaner.

Figure 5-6.—A welding tip cleaner in use.

Welding Torch Tips

Welding tips are subject to considerable abuse and you must keep the orifice smooth and clean if the tip is to perform satisfactorily. When cleaning a welding tip, you must be careful and ensure you do not enlarge or scar the orifice. Carbon deposits and slag must be removed regularly to ensure good performance.

Avoid dropping a tip because the seat that seals the joint may be damaged. Also, the flame end of the tip also may receive damage if it is allowed to come in contact with the welding work, bench, or firebricks. This damage roughens the end of the tip and causes the flame to burn with a "fishtail."

Special welding tip cleaners have been developed to remove the carbon or slag from the tip orifice. The cleaner consists of a series of broachlike wires that correspond in diameter to the diameter of the tip orifices (fig. 5-5). These wires are packaged in a holder, which makes their use safe and convenient. Figure 5-6 shows a tip cleaner in use. Some welders prefer to use a number drill the size of the tip orifice to clean welding tip orifices. A number drill must be used carefully so the orifice is not enlarged, bell-mouthed, reamed out of round, or otherwise deformed.
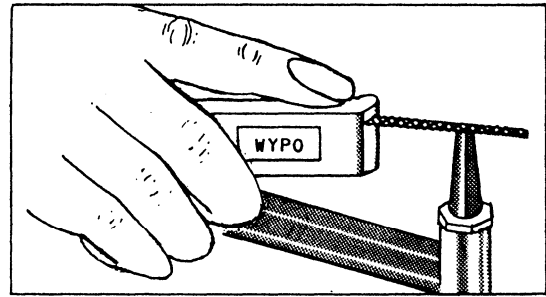

Figure 5-7.—Reconditioning the orifice end of a torch tip.

The flame end of the tip must be clean and smooth. The surface must beat right angles to the centerline of the tip orifice to ensure a proper shaped flame. A 4-inch mill file or the file in the tip cleaner can be used to recondition the surface, as shown in figure 5-7.

Recondition the tip if it becomes rough and pitted or the orifice is bell-mouthed. An easy method to use involves placing apiece of emery cloth, grit side up, on a flat surface; hold the tip perpendicular to the emery cloth, and rub the tip back and forth just enough to true the surface and to bring the orifice back to its original diameter.

Regulator Leaks

With regulators, gas leakage between the regulator seat and nozzle is the most common type of trouble. You often hear this problem referred to as *regulator creep.* This problem can be detected by the gradual rise in pressure on the working-pressure gauge without moving the adjusting screw. Frequently, this trouble is caused by worn or cracked seats. It also can be caused by foreign matter lodged between the seat and the nozzle. It is important that you have leaking regulators repaired at once; otherwise, injury to personnel or equipment damage could result. This is particular y dangerous with fuel-gas regulators because fuel gas at a high pressure in a hose becomes an explosive hazard. To ensure the safety of personnel and equipment, ensure that regulators with such leaks are removed from service and turned in for repair.

OXYGAS WELDING TECHNIQUES

Oxygas welding maybe done using either the forehand or the backhand method. Each of these techniques has special advantages and you should become skillful with both. The deciding factor that determines whether a technique is considered forehand or backhand is the relative position of the torch and rod during welding, not
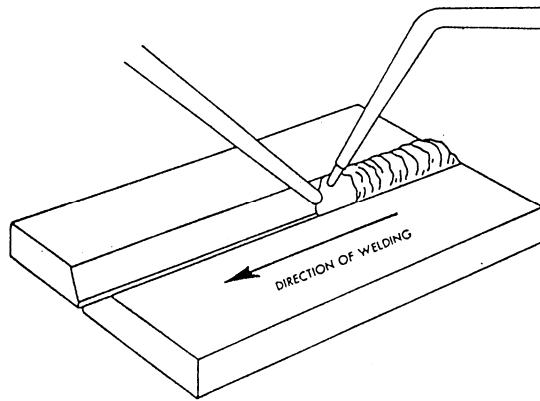
Figure 5-8.—Forehand welding.

Figure 5-9.—Backhand welding.

the direction of welding. The best method to use depends upon the type of joint, joint position, and the need for heat control on the parts to be welded.

FOREHAND WELDING

Forehand welding (fig. 5-8) is often called PUD-DLE or RIPPLE WELDING. In this method of welding, the rod is kept ahead of the flame in the direction in which the weld is being made. You point the flame in the direction of travel and hold the tip at an angle of about 45 degrees to the working surfaces. This flame position preheats the edges you are welding just ahead of the molten puddle. Move the rod in the same direction as the tip, and by moving the torch tip and the welding rod back and forth in opposite, semicircular paths, you can distribute the heat evenly. As the flame passes the welding rod, it melts a short length of the rod and adds it to the puddle. The motion of the torch distributes the molten metal evenly to both edges of the joint and to the molten puddle.

The forehand method is used in all positions for welding sheet and light plate up to 1/8 of an inch thick. This method is ideal because it permits better control of a small puddle and results in a smoother weld. The forehand technique is not recommended for welding heavy plate due to its lack of base metal penetration.

BACKHAND WELDING

In backhand welding (fig. 5-9), the torch tip pre-cedes the rod in the direction of welding and the flame points back at the molten puddle and completed weld. The welding tip should make an angle of about 60 degrees with the plates or joint being welded. The end of the welding rod is placed between the torch tip and the molten puddle.
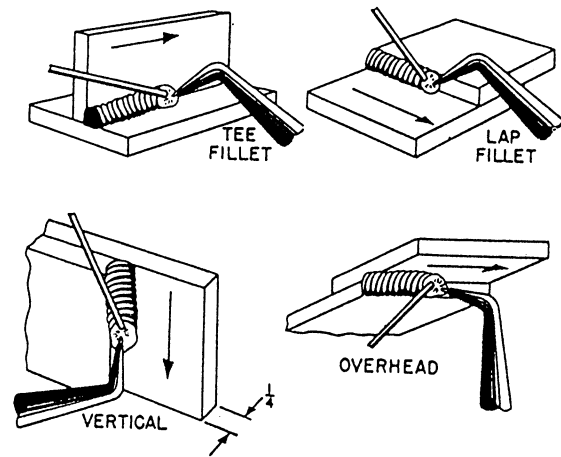
Less motion is used in the backhand method than in the forehand method. If you use a straight welding rod, you should rotate it so the end rolls from side to side and melts off evenly. You might have to bend the rod when working in confined spaces. If you do, it becomes diffi-cult to roll a bent rod, and to compensate, you have to move the rod and torch back and forth at a rather rapid rate. When making a large weld, you should move the rod so it makes complete circles in the molten puddle. The torch is moved back and forth across the weld while it is advanced slowly and uniformly in the direction of the welding.

The backhand method is best for welding material more than 1/8 of an inch thick. You can use a narrower vee at the joint than is possible in forehand welding. An included angle of 60 degrees is a sufficient angle of bevel to get a good joint. The backhand method requires less welding rod or puddling as the forehand method.

By using the backhand technique on heavier mate-rial, you can increase your welding speed, better your control of the larger puddle, and have more complete fusion at the weld root. If you use a slightly reducing flame with the backhand technique, a smaller amount of base metal is melted while welding the joint. When you are welding steel with a backhand technique and a slightly reducing flame, the absorption of carbon by a thin surface layer of metal reduces the melting point of the steel. This speeds up the welding operation, This technique is also used in surfacing with chromium-co-balt alloys.

MULTILAYER WELDING is used in order to avoid carrying too large a puddle of molten metal when welding thick plate and pipe. Large puddles are difficult to control. Concentrate on getting a good weld at the bottom of the vee in the first pass. Then, in the next

layers, concentrate on getting good fusion with the sides of the vee and the previous layer. The final layer is easily controlled to get a smooth surface. This method of welding has an added advantage in that it refines the previous layer as the succeeding layer is made. In effect, it heat-treats the weld metal by allowing one layer to cool to a black heat before it is reheated This improves the ductility of the weld metal. If this added quality is desired in the last layer, an additional or succeeding layer is deposited and then machined off.

JOINT EDGE PREPARATION

Sheet metal is easily melted and does not require special edge preparation. In welding operations involving plate, joint edge preparation and proper spacing between edges are important factors. The thickness of the plates determines the amount of edge preparation required. The faces of square edges can be butted together and welded You can use this type of joint on plate up to 3/16 of an inch thick. For plate 3/16 to 1/4 of an inch thick, a slight root opening between the parts is necessary to get complete penetration. Plate more than 1/4 of an inch thick requires beveled edges and a root opening of 1/16 of an inch. For oxygas welding on plate more than 1/4 of an inch thick, bevel the edges at an angle of 30 degrees to 45 degrees, making the groove included angle from 60 degrees to 90 degrees. You can prepare the edges by flame cutting, shearing, flame grooving, machining, chipping, or grinding. In any case, the edge surfaces should be free of oxides, scale, dirt, grease, or other foreign matter.

Plate from 3/8 to 1/2 of an inch thick can be welded from one side only, but thicker sections should be welded by preparing the edges on both sides. Generally, butt joints prepared on both sides permit easier welding, produce less distortion, and ensure better weld qualities.

Heavy steel plate is rarely welded with oxygas unless other types of welding equipment are not available. The welding of heavy plate is just not cost effective because of the amount of gas consumed and time used to complete a weld. If at all possible, use a form of electric arc welding because the joint can be welded faster, cheaper, and there is less heat distortion

OXYGAS WELDING OF
FERROUS METALS

Low-carbon steel, low-alloy steel, cast steel, and wrought iron are easily welded by the oxygas process. A flux is not necessary with these metals because their oxides melt at a lower temperature than the base metal.

During the welding process, you should enclose the molten puddle with the flame envelope to ensure the molten metal does not contact the air. If the metal is exposed to the air, it will oxidize rapidly. You also should avoid overheating the metal.

The proper flame adjustment is required to make a good weld Adjust the flame to a neutral or slightly reducing (carburizing) flame. Do not use an oxidizing flame. Manipulate the torch and rod so the tip of the oxygas cone is about 1/16 to 1/8 of an inch from the surface of the metal. Melt the end of the filler rod in the puddle, not with the flame. The welding of low-carbon steels and cast steels presents no special problems other than the selection of the proper filler rod Low-alloy steels usually require prewelding and postwelding heat treatment. This heat treatment relieves the stresses developed during the welding phase and produces the desired physical properties of the metal.

As the carbon content of a steel increases, welding becomes more difficult. Steels whose carbon content is within the 0.3-percent to 0.5-percent range are welded with a slightly carburizing flame. These low-carbon steels require postwelding heat treatment to develop their best physical properties.

High-carbon steel and tool steel require a slightly different technique. While protecting the parts from drafts, slowly preheat them to about 1000°F. Complete the weld as rapidly as possible using a carburizing flame and no flux. Do not manipulate either rod or torch and add the filler metal in small amounts, as it is needed. You should use a smaller flame and lower gas pressure than that used for low-carbon steel. This is to ensure you do not overheat the steel. You must heat-treat high-carbon steels and tool steels after welding to develop the physical properties required.

The procedure for oxygas welding of WROUGHT IRON is the same as that for low-carbon or mild steel; however, you should keep several points in mind. Wrought iron contains a slag that was incorporated in it during the manufacturing stage. This slag gives the surface of the molten puddle a greasy appearance. Do not confuse this greasy appearance with the appearance of actual fusion. Continue heating until the sidewalls of the joint break down into the puddle. Best results with wrought iron are obtained when the filler metal (usually mild steel) and base metal are mixed in the molten puddle with a minimum of agitation

Oxygas welding of CAST IRON is not difficult, but does require a modification of the procedure used with steel. For material that does not exceed 3/16 of an inch

in thickness, you do not need to make a V-groove. Metal that is between 3/16 of an inch and 3/8 of an inch should have a single V-butt joint with an included angle of 60 degrees. For metal over 3/8 of an inch, use a double V-butt joint with 60-degree included angles.

Before you begin welding, preheat the entire weldment to a temperature between 750°F and 900°F The welding should be done with a neutral flame using the backhand method. Use a cast-iron filler metal and the appropriate flux. The flux is necessary, but use it sparingly as needed Add filler metal by directing the inner cone of the flame against the rod instead of dipping the tip of the rod into the puddle. The filler metal should be deposited inlayers not exceeding 1/8 of an inch thick. Upon completion of the weld, you must stress relieve the weldment by heating it to a temperature between 1100°F and 1150°F and then cool it slowly. Oxygas welding cast iron gives a good color match and good machinability; however, if color match is not essential, a cast-iron repair can be made more easily and economically by braze welding.

Oxygas welding can be used with some CHRO-MIUM-NICKEL STEELS (STAINLESS STEELS). As a rule, oxygas welding is used only for light sheet; heavier pieces of these steels are usually joined by one of the electric arc welding processes. On material 20 gauge (0.040 of an inch) or less in thickness, a flange equal to the thickness of the metal is turned up and the weld is made without filler metal. Before welding, you should clean the joint surfaces of the metal with sandpaper or other abrasives and then apply a stainless steel flux. The torch tip used for welding stainless steel is usually one or two sizes smaller than the tip used to weld mild steel of the same thickness. Adjust the torch so you have a carburizing flame, as seen through your goggles, with an excess fuel-gas feather extending about 1/16 of an inch beyond the tip of the inner cone. Hold the torch so the flame makes an angle of 80 degrees to the surface of the sheet. The tip of the cone should almost, but not quite touch the molten metal. Make the weld in one pass, using a forehand technique. Do not puddle or retrace the weld. A uniform speed of welding is essential. If it is necessary to stop the welding process or reweld a section, wait until the entire weld has cooled.

OXYGAS WELDING OF NONFERROUS METALS

Although brazing and braze welding are used extensively to make joints in nonferrous metals, there are many situations in which oxygas welding is just as suitable. The joint designs are the same for nonferrous metals as for ferrous metals in most cases. Oxygas welding of nonferrous metals usually requires mechanical cleaning of the surfaces before welding and the use of flux during welding. Filler metals must be suitable for the base metal being welded A separate section on aluminum and aluminum alloys is included as part of this chapter since you may need more detailed instructions in welding these materials.

Copper

Pure copper can be welded using the oxygas torch. Where high-joint strength is required you should use DEOXIDIZED copper (copper that contains no oxygen). A neutral flame is used and flux is required when welding copper alloys. Because of the high thermal conductivity of copper, you should preheat the joint area to a temperature ranging between 500°F to 800°F and use a larger size torch tip for welding. The larger size tip supplies more heat to the joint and thus makes it possible to maintain the required temperature at the joint. After welding is completed, cool the part slowly. Other than the extra volume of heat required, the technique for welding copper is the same as for steel.

Copper-Zinc Alloy (Brasses)

Copper-zinc alloys (brasses) can be welded using the same methods as deoxidized copper; however, a silicon-copper rod is used for welding brasses. The rods are usually flux-coated so the use of additional flux is not required. Preheat temperatures for these metals range between 200°F to 300°F.

Copper-Silicon Alloy (Silicon Bronze)

Copper-silicon alloy (silicon bronze) requires a different oxygas welding technique from that used for copper and copper-zinc. You weld this material with a slightly oxidizing flame and use a flux having a high boric acid content. Add filler metal of the same composition as the base metal; as the weld progresses, dip the tip of the rod under the viscous film that covers the puddle. Keep the puddle small so the weld solidifies quickly. A word of caution: when welding copper-zinc, you should safeguard against zinc poisoning by either doing all the welding outdoors or by wearing a respirator or by both, depending on the situation

Copper-Nickel Alloy

Oxygas welding of copper-nickel alloys requires surface preparation and preheating. The flux used for

this welding is a thin paste and is applied by brush to all parts of the joint and to the welding rod. Adjust the torch to give a slightly carburizing flame; the tip of the inner cone should just touch the base metal. Do not melt the base metal any more than necessary to ensure good fusion. Keep the end of the filler rod within the protective envelope of the flame, adding the filler metal without disturbing the molten pool of weld metal. If possible, run the weld from one end of the joint to the other without stopping. After you complete the weld, cool the part slowly and remove the remaining traces of flux with warm water.

Nickel and High-Nickel Alloys

Oxygas welding of nickel and high-nickel alloys is similar to that for copper-nickel alloys. Good mechanical cleaning of the joint surfaces is essential. The joint designs are basically the same as steel of equivalent thickness. The included angle for V-butt welds is approximately 75 degrees. You may weld plain nickel without a flux, but high-nickel alloys require a special boron-free and borax-free flux. The flux is in the form of a thin paste and should be applied with a small brush. You should flux both sides of the seam, the top and bottom, and the filler rod. Adjust the torch to give a very slightly carburizing flame; the tip selected should be the same size or one size larger than for steel of the same thickness. The flame should be soft and the tip of the cone kept in contact with the molten pool. Use a rod suitable for the base metal, and always keep the rod well within the protective envelope of the flame. After the weld is completed, postheat the part and cool it slowly. Then remove the flux with warm water.

Lead

Oxygas welding of lead requires special tools and special techniques. Although you do not require a flux, you must ensure that the metal in the joint area is scrupulously clean. You may accomplish this by shaving the joint surfaces with a scraper and wire brushing them to remove oxides and foreign matter. In the flat-welding position, a square butt joint is satisfactory. In other positions, a lap joint is used almost exclusively. When you use a lap joint, the edges should overlap each other from 1/2 of an inch to 2 inches, depending upon the thickness of the lead.

To weld lead, use a special, lightweight, fingertip torch, with tips ranging from 68 to 78 in drill size. Adjust your torch to a neutral flame with the gas pressure ranging from 1 1/2 psig to 5 psig, depending on the

thickness of the lead. The length of the flame varies from about 1 1/2 inches to 4 inches, depending upon the gas pressures used. When you are welding in the horizontal and flat positions, a soft, bushy flame is most desirable. But, when you are welding in the vertical and overhead positions, better results are obtained with a more pointed flame.

For oxygas welding of lead, you should ensure that the filler metal has the same composition as the base metal. The molten puddle is controlled and distributed by manipulating the torch so the flame moves in a semicircular or V-shaped pattern. Each tiny segment of the weld is made separately, and the torch is flicked away at the completion of each semicircular or V-shaped movement. Joints are made in thin layers. Filler metal is not added during the first pass, but it is added on subsequent passes.

When welding lead or lead alloys, you should wear a respirator of a type approved for protection against lead fumes.

WARNING

LEAD FUMES ARE POISONOUS.

Aluminum and Aluminum Alloys

When assigned to work with nonferrous metals, you can expect jobs that involve the welding of aluminum and aluminum alloys. Pure aluminum has a specific gravity of 2.70 and a melting point of 1210°F. Pure aluminum is soft and seldom used in its pure form because it is not hard or strong enough for structural purposes; however, the strength of aluminum can be improved by the addition of other elements to form aluminum alloys.

Aluminum alloys are usually 90-percent pure. When elements, such as silicon, magnesium, copper, nickel, and manganese, are added to aluminum, an alloy stronger than mild steel results; whereas pure aluminum is only about one fourth as strong as steel.

A considerable number of aluminum alloys are available. You may use some of the aluminum alloys in sheet form to make and repair lockers, shelves, boxes, trays, and other containers. You also may have to repair chairs, tables, and other items of furniture that are made of aluminum alloys.

Oxygas welding of aluminum alloys is usually confined to materials from 0.031 of an inch to 0.125 of an inch in thickness. Also, thicker material can be welded

by the oxygas process if necessary; however, thinner material is usually spot or seam welded.

MELTING CHARACTERISTICS.— Before attempting to weld aluminum alloy for the first time, you should become familiar with how the metal reacts when under the welding flame.

A good example of how aluminum reacts when heated can be seen if you place a small piece of sheet aluminum on a welding table and heat it with a neutral flame. Hold the flame perpendicular to the surface of the sheet and bring the tip of the inner cone almost in contact with the metal. Observe that almost without warning the metal suddenly melts and runs away, leaving a hole in the sheet. Now repeat the operation with the torch held at an angle of about 30 degrees to the plane of the surface. With a little practice, you will be able to melt the surface metal without forming a hole. Now try moving the flame slowly along the surface of the sheet, melting a small puddle. Observe how quickly the puddle solidifies when the flame is removed. Continue this practice until you are able to control the melting. When you have mastered this, proceed by practicing actual welding. Start with simple flanged and notched butt joints that do not require a welding rod. Next, you should try using a welding rod with thin sheet and then with castings.

WELDING RODS.— Two types of welding rods available for gas welding aluminum alloys are the 1100 and 4043 rods. The 1100 rod is used when maximum resistance to corrosion and high ductility are of primary importance. The 1100 rod is used for welding 1100 and 3003 type aluminum alloys only. The 4043 rod is used for greater strength and minimizes the tendency for cracking. It also is used for all other wrought aluminum alloys and castings.

WELDING FLUXES.— The use of the proper flux in welding aluminum is extremely important. Aluminum welding flux is designed to remove the aluminum oxide by chemically combining with it. In gas welding, the oxide forms rapidly in the molten metal. It must be removed or a defective weld will result. To ensure proper distribution, you should paint flux on the welding rod and the surface to be welded.

Aluminum flux is usually in powder form and is prepared for use by mixing with water to form a paste. The paste should be kept in an aluminum, glass, or earthenware container because steel or copper containers tend to contaminate the mixture.

It is essential that plenty of flux be applied to the edges of flanged joints because no filler rod is used in
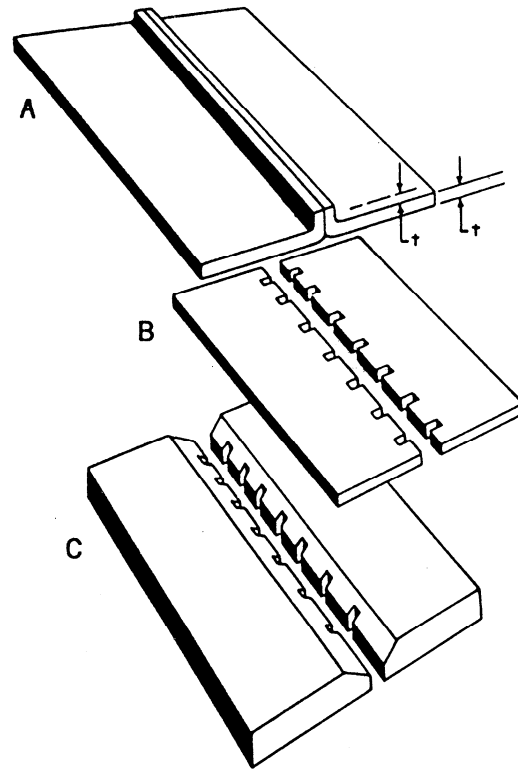

Figure 5-10.—Edge preparation for gas-welding aluminum.

these joints. In all cases, the flux should be applied to both the bottom and top sides of the sheet in the area of the weld. After you finish welding, it is important that you remove all traces of flux. You can do this by using a brush and hot water. If aluminum flux is left on the weld, it will corrode the metal.

WELDING PREPARATION.— The thickness of the aluminum determines the method of edge preparation. On material up to 0.062 of an inch, the edges should be formed to a 90-degree flange. The height of the flange should be about the same height, or a little higher, as the thickness of the material (fig. 5-10, view A). The only requirement for the flanges is that their edges be straight and square. If desired, material up to 0.125 of an inch can be welded with a flange joint. No filler rod is necessary if you flange the edges.

Unbeveled butt welds can be made on thicknesses from 0.062 of an inch to 0.188 of an inch; but in these applications, it is necessary to notch the edges with a saw or cold chisel in a manner similar to that shown in view B of figure 5-10. Edge notching is recommended in aluminum welding because it aids in getting full penetration and prevents local distortion. All butt welds made in material over 0.125 of an inch thick are usually notched in some manner.

In welding aluminum more than 0.188 of an inch thick, bevel the edges and notch them, as shown in view C of figure 5-10. The included angle of bevel maybe from 90 to 120 degrees.

After you have prepared the edges of the pieces properly, you should then clean the surfaces to be welded. If heavy oxide is present on the metal surface, you may have to use a stainless-steel wire brush to remove it. Dirt, grease, or oil can be removed by wiping the weld area with a solvent-soaked rag.

Aluminum plate 1/4 of an inch thick or greater should be preheated to a temperature ranging between 500°F to 700°F. This aids in avoiding heat stresses. Preheating also reduces fuel and oxygen requirements for the actual welding. It is important that the preheating temperature does exceed 700°F. If the temperature does go above 700°F, the alloy maybe severely weakened. High temperatures also could cause large aluminum parts to collapse under their own weight. Thin material should be warmed with the torch before welding. This slight preheat helps to prevent cracks.

WELDING TECHNIQUES.— After preparing and fluxing the pieces for welding, you should pass the flame, in small circles, over the starting point until the flux melts. Keep the inner cone of the flame off the flux to avoid burning it. If the inner cone of the flame should burn the flux, it will be necessary to clean the joint and apply new flux. Next, scrape the rod over the surface at about 3- or 4-second intervals, permitting the rod to come clear of the flame each time. If you leave the rod in the flame too long, it melts before the parent metal does. The scraping action indicates when you can start welding without overheating the metal. Maintain this cycle throughout the course of welding except for allowing the rod to remain under the flame long enough to melt the amount of metal needed. With practice, the movement of the rod can be easily mastered.

Forehand welding is usually preferred for welding aluminum alloys because the flame points away from the completed weld, and this preheats the edges to be welded that prevents too rapid melting. Hold the torch at a low angle when you are welding thin material. For thicknesses 0.188 of an inch and above, you should increase the angle of the torch to a near vertical position. Changing the angle of the torch according to the thickness of the metal minimizes the possibility of burning through the sheet during welding.

When welding aluminum alloys up to 0.188 of an inch thick, you have little need to impart any motion to the torch other than moving it forward. On flanged material, care must be taken to break the oxide film as the flange melts down. This may be done by stirring the melted flange with a puddling rod. A puddling rod is essentially a paddle flattened and shaped from a 1/4-inch stainless steel welding rod.

With aluminum alloys above 0.188 of an inch in thickness, you should give the torch a more uniform lateral motion to distribute the weld metal over the entire width of the weld. A slight back-and-forth motion assists the flux in its removal of oxides. Dip the filler rod in the weld puddle with a forward motion.

The angle of the torch is directly related to the welding speed. Instead of lifting the flame from time to time to avoid melting holes in the metal, you will find it advantageous to hold the torch at a flatter angle to the work The welding speed should be increased as the edge of the sheet is approached. The inner cone of the flame should never be permitted to come in contact with the molten metal, but should beheld about 1/8 of an inch away from the metal.

In the vertical position, the torch is given an up-and-down motion, rather than a rotating one. In the overhead position, alight back-and-forth motion is used the same as in flat welding.

Heat-treatable alloys should be held in a jig for welding, whenever possible. This helps to eliminate the possibility of cracking. The likelihood of cracking can also be reduced by the use of a 4043 filler rod. This rod has a lower melting range than the alloy being joined which permits the base metal to solidify before the weld puddle freezes. As the weld is the last area to solidify, all of the contraction strains are in the weld bead, rather than throughout the base metal. You may reduce weld cracking by tack welding the parts while they are in the jig and then loosening the clamps before completing the seam.

As soon as the weld is completed and the work has had time to cool, you should thoroughly wash the weld. This can be done by vigorously scrubbing it with a stiff brush while hot water runs over it until all traces of the flux are removed. This is important, because if any flux is left on the weld, it can corrode the metal. If hot water is not available, you may use a diluted solution of 10 percent sulfuric acid. The acid solution should then be washed off with cold, fresh water after using.
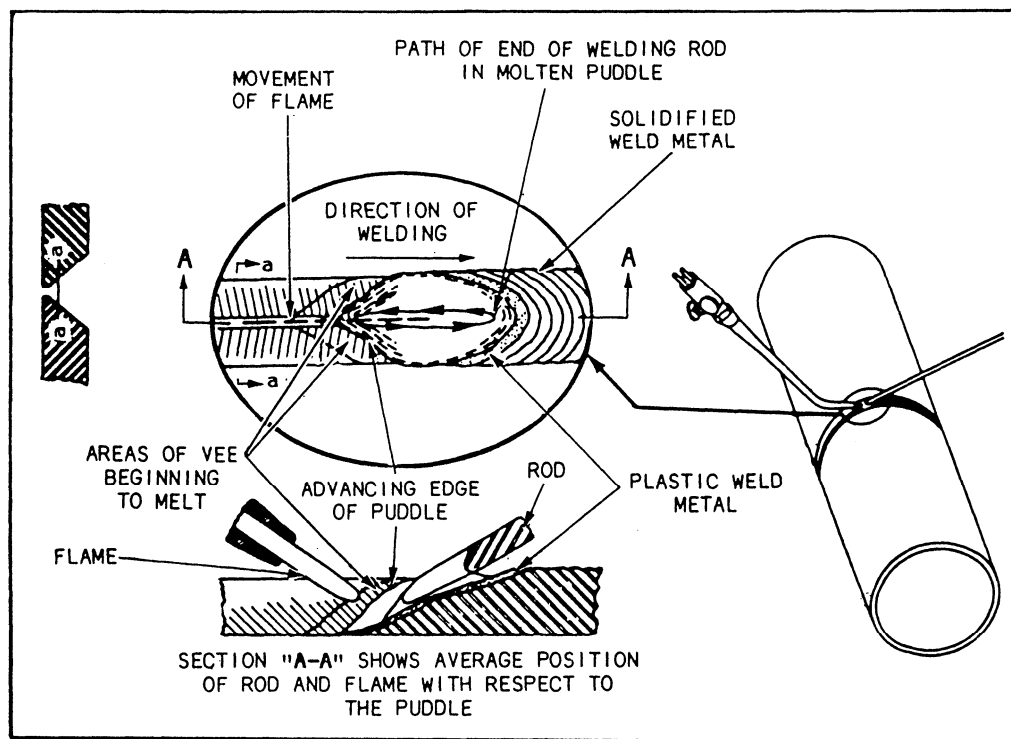
Figure 5-11.—Welding operation with backhand technique.

FUSION WELDING PIPE

In oxygas welding of pipe, many tests have proved that fusion welded pipe joints, when properly made, are as strong as the pipe itself.

For success in oxygas welding of pipe, three essential requirements must be met: there must be a convenient source of controlled heat available to produce rapid localized melting of the metal, the oxides present on the surface or edges of the joints must be removed, and a metal-to-metal union between the edges or surfaces to be joined must be made by means of molten metal.

One method used for welding steel and wrought iron pipe is known as *FUSION WELDING. This* method involves melting the pipe metal and adding metal from a rod of similar composition. The welding operation performed at the top of a joint in a horizontal pipe is shown diagrammatically in figure 5-11. This shows the BACKHAND welding technique. The rod and flame are moved alternately toward and away from each other, as shown in figure 5-12. Full strength oxygas welds can be made in any welding position.

The cohesiveness of the molten metal, the pressure of the flame, the support of the weld metal already deposited, and the manipulation of the rod all combine
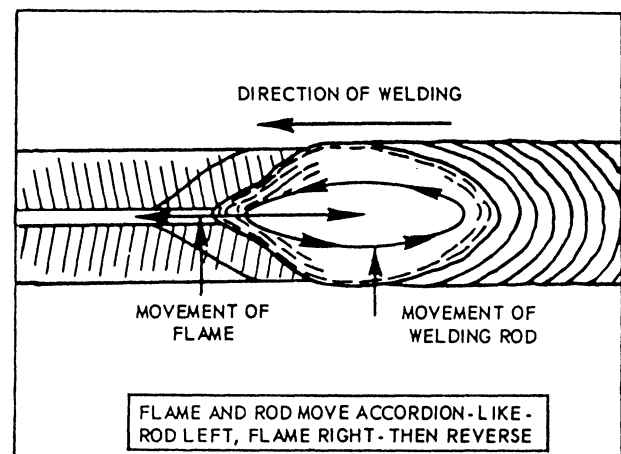
Figure 5-12.—Flame and rod motion with backhand technique.

to keep the molten metal in the puddle from running or falling.

The soundness and strength of welds depend on the quality of the welding rod used. If you have any doubt about the quality of the rods or are not sure of the type to use, then it would be to your advantage to contact the manufacturer or one of his distributors. If the rod is supplied through the federal stock system, supply personnel should be able to look up the information based on the federal stock number of the rod.

A. PIPE CLAMP

C. ELBOW CLAMP

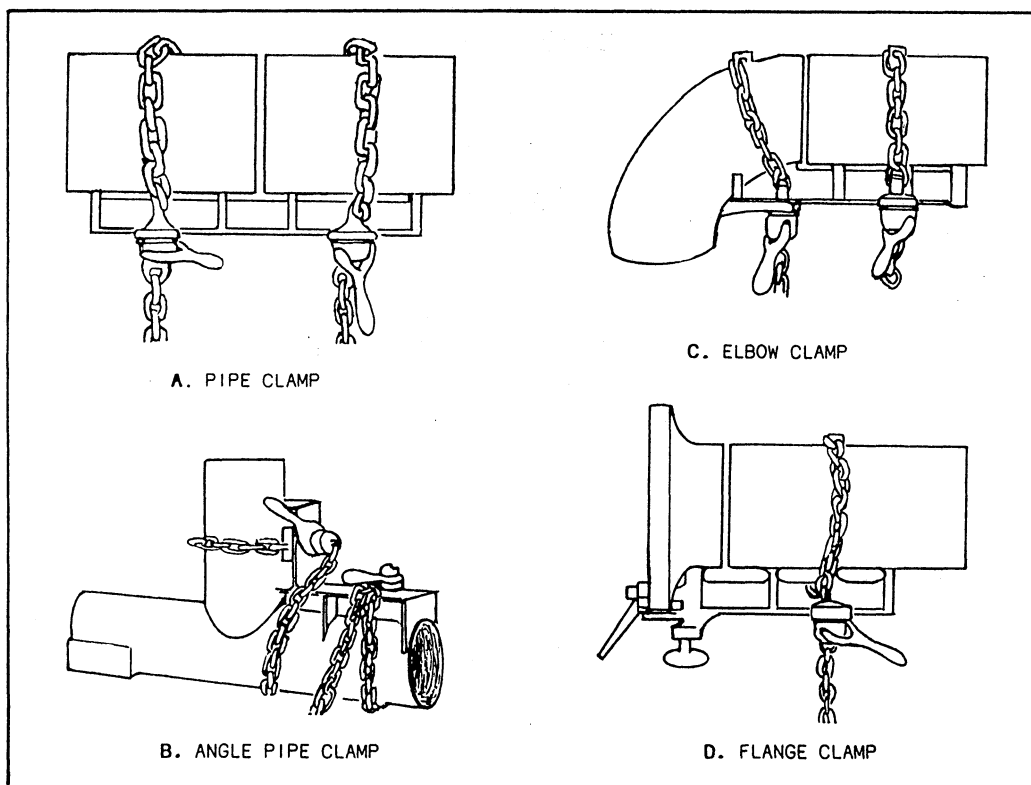**B. ANGLE PIPE CLAMP**

D. FLANGE CLAMP

Figure 5-13.—Chain clamps quickly align pipe fittings of any description.

The Linde Company has a method of fusion welding that is remarkably fast and produces welds of high quality. Anyone can use this process for welding pipe if they adhere to the following conditions:

1. Use an excess fuel-gas flame.

2. Use a welding rod containing deoxidizing agents.

3. Use the backhand welding technique.

The following is a brief explanation of the previously mentioned conditions:

1. EXCESS FUEL-GAS FLAME. The base metal surface, as it reaches white heat, absorbs carbon from the excess fuel-gas flame. The absorption of carbon lowers the melting point of steel, thereby the surface melts faster and speeds up the welding action.

2. SPECIAL WELDING ROD. The deoxidizing agents in the recommended rod eliminates the impurities and prevents excess oxidation of carbon. Were it not for this action, considerable carbon, the most valuable strengthening element of steel, would be lost.

Thus, even in high-carbon, high-strength pipe, the weld metal is as strong as, or stronger than the pipe material.

3. BACKHAND TECHNIQUE. This technique produces faster melting of the base metal surfaces. Also, a smaller bevel can be used which results in a savings of 20 to 30 percent in welding time, rods, and gases.

One of the most valuable tools you can use when welding pipe is the pipe clamp. Pipe clamps hold the pipe in perfect alignment until tack welds are placed. They are quick opening and you can move or attach a clamp quickly.

Figure 5-13 shows four different types of chain clamps that are used for pipe welding. If these clamps are not available, you can fabricate your own by welding two C-clamps to a piece of heavy angle iron. A piece of 3/8-inch angle iron that is 4 inches by 4 inches by 12 inches is usually suitable. When working with small-diameter pipe, you can lay it in apiece of channel iron to obtain true alignment for butt welding. When the pipe you are working on has a large diameter, you can use a wide flange beam for alignment purposes.

CHAPTER 7

SHIELDED METAL-ARC WELDING AND WEARFACING

The shielded metal-arc welding process, referred to as metallic-arc welding, arc welding, or stick welding, is extensively used in welding ferrous and nonferrous metals. It has many applications for producing a vast assortment of metal products. Shielded metal-arc welding is found in the ship building industry and in the construction industry for fabricating girders, beams, and columns. Because it is easy to use and portable, shielded metal-arc welding is universally used in the repair and servicing of equipment, machinery, and a host of other items.

MANUAL SHIELDED METAL-ARC WELDING

Arc welding provides you the ability to join two metals by melting them with an arc generated between a coated-metal electrode and the base metal. The temperatures developed by the arc can reach as high as 10000°F. The arc energy is provided by a power source that generates either direct or alternating current. The electrodes that carry the current produce a gas that shields the arc from the atmosphere and supplies filler metal to develop the weld shape.

ARC-WELDING EQUIPMENT

A wide variety of welding equipment is available, and there are many differences between the makes and models of the equipment produced by the manufacturers. However, all types of arc-welding equipment are similar in their basic function of producing the high-amperage, low-voltage electric power required for the welding arc. In this discussion, we are primarily concerned with the typical items of arc-welding equipment, rather than the specific types. For specific information about the equipment your battalion or duty station has available, consult the manufacturer's instruction manual. For additional operational information and safety instruction, have your leading welding petty officer explain the operation to you.

The basic parts of a typical shielded metal-arc welding outfit include a welding machine, cables, electrode holder (stinger), and electrodes. The Steelworker also requires a number of accessories that include a combination chipping hammer and wire brush, welding table (for shopwork), C-clamps, and protective apparel.

Before we discuss the different types of welding machines, you must first have a basic knowledge of the electrical terms used with welding.

Electrical Terms

Many terms are associated with arc welding. The following basic terms are especially important.

ALTERNATING CURRENT.— Alternating current is an electrical current that has alternating negative and positive values. In the first half-cycle, the current flows in one direction and then reverses itself for the next half-cycle. In one complete cycle, the current spends 50 percent of the time flowing one way and the other 50 percent flowing the other way. The rate of change in direction is called frequency, and it is indicated by cycles per second. In the United States, the alternating current is set at 60 cycles per second.

AMPERE.— Amperes, sometimes called "amps," refers to the amount of current that flows through a circuit. It is measured by an "amp" meter.

**CONDUCTOR.—** Conductor means any material that allows the passage of an electrical current.

CURRENT.— Current is the movement or flow of an electrical charge through a conductor.

DIRECT CURRENT.— Direct current is an electrical current that flows in one direction only.

ELECTRICAL CIRCUIT.— Electrical circuit is the path taken by an electrical current flowing through a conductor from one terminal of the source to the load and returning to the other terminal of the source.

POLARITY.— Polarity is the direction of the flow of current in a circuit. Since current flows in one direction only in a dc welder, the polarity becomes an important factor in welding operations.

RESISTANCE.— Resistance is the opposition of the conductor to the flow of current. Resistance causes electrical energy to be changed into heat.
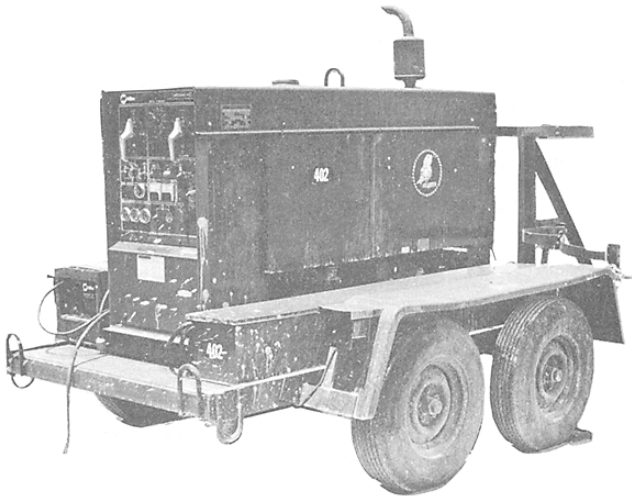
127.517
Figure 7-1.—A 300 amp ac/dc portable welding machine.

Figure 7-2.—An ac arc-welding transformer.

VOLT.— A volt is the force required to make the current flow in an electrical circuit. It can be compared to pressure in a hydraulic system. Volts are measured with a volt meter.

Power Source

The power source used in arc welding is called a welding machine or a welder. Three basic types of welding machines are presently in use: motor-generators, transformers, and rectifiers.

MOTOR-GENERATOR WELDING MACHINES.— These types of welding machines are powered by electrical, gasoline, or diesel motors. The diesel and gasoline motors are ideal for use in areas where electricity is not available. Portable gas/diesel welding machines are part of the equipment allowance for Naval Mobile Construction Battalions. These machines usually have the capability of generating alternating or direct current. On the newer machines, when you are welding in the direct-current mode, the polarity can be changed by turning a switch. Some of the older machines require reversing the cable connections. One of the advantages of a direct-current (dc) welding generator is that you have the choice of welding with either straight or reverse polarity. The welding machine, as shown in figure 7-1, consists of a heavy-duty, ac/dc 300 amp generator powered by a diesel engine. The generator is also capable of producing 3 kilowatts of 60 cycle ac power.

Welding machines are made in six standardized ratings for general purposes and are listed as follows:

1. Machines rated 150 and 200 amperes—30 volts are for light-shielded metal-arc welding and for inert-gas arc welding. They are also for general-purpose jobs or shopwork.

2. Machines rated 200,300, and 400 amperes—40 volts are for general welding purposes by machine or manual application.

3. Machines rated 600 amperes—40 volts are for submerged-arc welding or carbon-arc cutting.

ALTERNATING-CURRENT TRANSFORMER WELDING MACHINES.— Practically all the alternating current (at) arc-welding machines in use are the static-transformer type, as shown in figure 7-2. These types of machines are the smallest, least expensive, and the lightest type of welders made. Industrial applications for manual operation use machines having 200, 300, and 400 ampere ratings. Machines with a 150-ampere rating are used in light industrial, garage, and job/shop welding.

The transformers are usually equipped with arc-stabilizing capacitors. Current control is provided in several ways by the welding transformer manufacturers. One such method is an adjustable reactor that is set by turning a crank until the appropriate setting is found. Another method is by plugging the electrode cable into different sockets located on the front of the machine.

One major advantage of ac transformers is the freedom from arc blow, which often occurs when welding with direct-current (dc) machines. Arc blow causes the arc to wander while you are welding in corners on heavy metal or using large coated electrodes.

7-2

Table 7-1.—Cable Size Selection Guide

| Current | Distance from welder (Total length of electrode and ground cables divided by two) | | | | | | | | | | | |
Amp	50′	75′	100′	125′	150′	175′	200′	225′	250′	300′	350′	400′
100	4	4	2	2	1	1/0	1/0	2/0	2/0	3/0	4/0	4/0
150	4	2	1	1/0	2/0	3/0	3/0	4/0	4/0			
200	2	1	1/0	2/0	3/0	4/0	4/0					
250	1	1/0	2/0	3/0	4/0							
300	1/0	2/0	3/0	4/0								
350	1/0	2/0	4/0									
400	1/0	3/0	4/0			Based on a 4-Volt Drop						
450	2/0	3/0										
500	2/0	4/0										
550	3/0											
600	3/0											

Figure 7-3.—Combination ac, dc transformer-rectifier arc welder.

RECTIFIER WELDING MACHINES.— Rectifier welders are single-phase or three-phase transformers that have selenium or silicon rectifiers added to rectify (change) the output current from alternating to direct current. Most of these machines have the capability of producing either ac or dc straight or reverse polarity current. By flicking a switch, the welder can select the current that best suits the job. Figure 7-3 shows an example of a combination ac/dc rectifier.

Cables

Welding cables carry the current to and from the workpiece. One of the cables runs from the welding machine to the electrode holder and the other cable connects the workpiece to the welding machine. The cable that connects the workpiece to the welding machine is called the ground. When the machine is turned on and the operator touches the electrode to the workpiece, the circuit is completed, current begins to flow, and the welding process commences.

The welding cables must be flexible, durable, well insulated, and large enough to carry the required current. Only cable that is specifically designed for welding should be used. A highly flexible cable must be used for the electrode holder connection. This is necessary so the operator can easily maneuver the electrode holder during the welding process. The ground cable need not be so flexible because once it is connected, it does not move.

Two factors determine the size of welding cable to use: the amperage rating of the machine and the distance between the work and the machine. If either amperage or distance increases, the cable size also must increase. (See table 7-1.) A cable that is too small for the amperage or the distance between the machine and the work will overheat. On the other hand, larger size cables are more

difficult to handle, especially if you are working on a structure that requires a lot of moving around. The best size cable is one that meets the amperage demand but is small enough to manipulate with ease.

As a rule, the cable between the machine and the work should be as short as possible. Use one continuous length of cable if the distance is less than 35 feet. If you must use more than one length of cable, join the sections with insulated lock-type cable connectors. Joints in the cable should be at least 10 feet away from the operator.

Electrode Holder

An electrode holder, commonly called a stinger, is a clamping device for holding the electrode securely in any position. The welding cable attaches to the holder through the hollow insulated handle. The design of the electrode holder permits quick and easy electrode exchange. Two general types of electrode holders are in use: insulated and noninsulated. The noninsulated holders are not recommended because they are subject to accidental short circuiting if bumped against the workpiece during welding. For safety reasons, try to ensure the use of only insulated stingers on the jobsite.

Electrode holders are made in different sizes, and manufacturers have their own system of designation. Each holder is designed for use within a specified range of electrode diameters and welding current. You require a larger holder when welding with a machine having a 300-ampere rating than when welding with a 100-ampere machine. If the holder is too small, it will overheat.

Ground Clamps

The use of a good ground clamp is essential to producing quality welds. Without proper grounding, the circuit voltage fails to produce enough heat for proper welding, and there is the possibility of damage to the welding machine and cables. Three basic methods are used to ground a welding machine. You can fasten the ground cable to the workbench with a C-clamp (fig. 7-4), attach a spring-loaded clamp (fig. 7-5) directly onto the workpiece, or bolt or tack-weld the end of the ground cable to the welding bench (fig. 7-6). The third way creates a permanent common ground.

Cleaning Equipment

Strong welds require good preparation and procedure. The surface area of the workpiece must be free of all foreign material, such as rust, paint, and oil. A steel brush is an excellent cleaning tool and is an essential
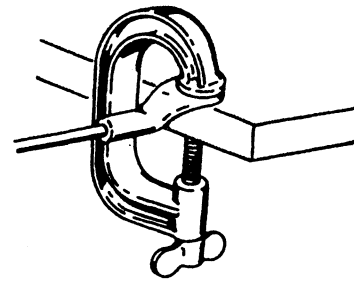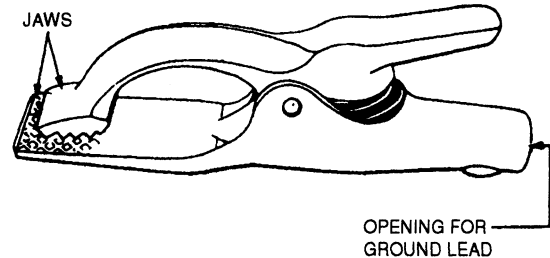

Figure 7-4.—C-clamped ground cable.

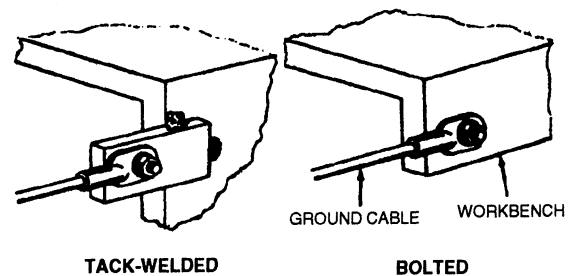**Figure 7-5.—A spring-loaded ground clamp for the ground lead.**

Figure 7-6.—Bolted and tack-welded ground clamps.

part of the welder's equipment. After initial cleaning and a weld bead has been deposited, the slag cover must be removed before additional beads are added. The chipping hammer was specifically designed for this task. The chipping operation is then followed by more brushing, and this cycle is repeated until the slag has been removed. When the slag is not removed, the result is porosity in the weld that weakens the weld joint.

Cleaning can also be accomplished by the use of power tools or chemical agents. If these items are used, it is essential that all safety precautions are followed.

Safety Equipment

Arc welding not only produces a brilliant light, but it also emits ultraviolet and infrared rays that are very

dangerous to your eyes and skin. In chapter 3, personal safety items, such as helmets, lenses, and gloves, were covered. An important item that needs to be covered here is welding screens. The welder not only has to protect himself but he also must take precautions to protect other people who may be working close by. When you are welding in the field, you must install a welding screen around your work area. It can be an elaborate factory-manufactured screen or as simple as one constructed on site from heavy fire-resistant canvas.

WARNING

Never look at thes welding arc without proper eye protection. Looking at the arc with the naked eye could result in permanent eye damage. If you receive flash burns, they should be treated by medical personnel.

Another area often overlooked is ventilation. Welding produces a lot of smoke and fumes that can be injurious to the welder if they are allowed to accumulate. This is especially true if you are welding in a tank or other inclosed area. Permanent welding booths should be equipped with a exhaust hood and fan system for removal of smoke and fumes.

EQUIPMENT OPERATION AND MAINTENANCE

Learning to arc weld requires you to possess many skills. Among these skills are the abilities to set up, operate, and maintain your welding equipment.

WELDING AREA REQUIREMENTS

In most factory environments, the work is brought to the welder. In the Seabees, the majority of the time the opposite is true. You will be called to the field for welding on buildings, earthmoving equipment, well drilling pipe, ship to shore fuel lines, pontoon causeways, and the list goes on. To accomplish these tasks, you have to become familiar with your equipment and be able to maintain it in the field. It would be impossible to give detailed maintenance information here because of the many different types of equipment found in the field; therefore, only the highlights will be covered.

WELDING MACHINE OPERATION AND MAINTENANCE

You should become familiar with the welding machine that you will be using. Study the manufacturer's literature and check with your senior petty officer or chief on the items that you do not understand. Machine setup involves selecting current type, polarity, and current settings. The current selection depends on the size and type of electrode used, position of the weld, and the properties of the base metal.

Cable size and connections are determined by the distance required to reach the work the size of the machine, and the amperage needed for the weld.

Operator maintenance depends on the type of welding machine used. Transformers and rectifiers require little maintenance compared to engine-driven welding machines. Transformer welders require only to be kept dry and a minimal amount of cleaning. Internal maintenance should only be done by electricians due to the possibilities of electrical shock Engine-driven machines require daily maintenance of the motors. Inmost places you will be required to fill out and turn in a daily inspection form called a "hard card" before starting the engine. This form is a list of items, such as oil level, water level, visible leaks, and other things, that affect the operation of the machine. Transportation departments are the ones who usually handle these forms.

After all of the above items have been checked, you are now ready to start welding.

SHIELDED-METAL ARC WELDING

Before you start to weld, ensure that you have all the required equipment and accessories. Listed below are some additional welding rules that should be followed.

- Clear the welding area of all debris and clutter.

- Do not use gloves or clothing that contains oil or grease.

- Check that all wiring and cables are installed properly.

- Ensure that the machine is grounded and dry.

- Follow all manufacturer's directions on operating the welding machine.

- Have on hand a protective screen to protect others in the welding area from FLASH bums.

- Always keep fire-fighting equipment on hand.

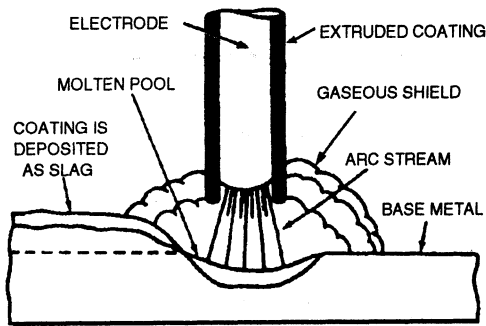- Clean rust, scale, paint, or dirt from the joints that are to be welded.

Figure 7-7.—Electrode covering and gaseous shield that protects weld metal from the atmosphere.

ELECTRODES

In general, all electrodes are classified into five main groups:

1. Mild steel

2. High-carbon steel

3. Special alloy steel

4. Cast iron

5. Nonferrous

The widest range of arc welding is done with electrodes in the mild steel group.

Electrodes are manufactured for use in specific positions and for many different types of metal. They also are specially designed to use with ac or dc welding machines. Some manufacturer's electrodes work identically on either ac or dc, while others are best suited for flat-position welding. Another type is made primarily for vertical and overhead welding, and some can be used in any position. As you can see, electrode selection depends on many variables.

Types of Electrodes

Electrodes are classified as either bare or shielded. The original bare electrodes were exactly as their name implied—bare. Today, they have a light covering, but even with this improvement they are rarely used because of their limitations. They are difficult to weld with, produce brittle welds, and have low strength. Just about all welding is done with shielded electrodes.

The shielded electrode has a heavy coating of several chemicals, such as cellulose, titania sodium, low-hydrogen sodium, or iron powder. Each of the chemicals in the coating serves a particular function in the welding process. In general, their main purposes are to induce easier arc starting, stabilize the arc, improve weld appearance and penetration, reduce spatter, and protect

All mild steel and low-alloy electrodes are classified with a 4 or 5 digit number prefixed by "E."
Prefix "E" = Electrode
First two (or three) digits = Tensile strength (psi) (stress relieved or as welded)
Third (or fourth) digit = Position of welding
  1 = all positions (flat, horizontal, vertical, overhead)
  2 = horizontal and flat positions only

FOURTH DIGIT	TYPE OF COATING	WELDING CURRENT
1	cellulose potassium	ac or dc Reverse or Straight
2	titania sodium	ac or dc Straight
3	titania potassium	ac or dc Straight or Reverse
4	iron powder titania	ac or dc Straight or Reverse
5	low hydrogen sodium	dc Reverse
6	low hydrogen potassium	dc or dc Reverse
7	iron powder iron oxide	ac or dc
8	iron powder low hydrogen	dc Reverse or Straight or ac
0*	see reference below	

EXAMPLE
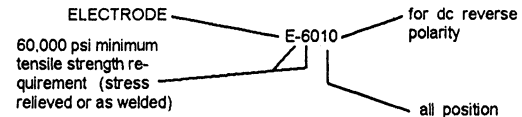
*When the fourth digit is 0, the type of coating and current to use are determined by the third digit. For example, E-6010 indicates a cellulose sodium coating and operates on dc reverse, while E-6020 has an iron oxide coating and operates on ac or dc.

Figure 7-8.—Explanation of AWS classification numbers.

the molten metal from oxidation or contamination by the surrounding atmosphere.

As molten metal is deposited in the welding process, it attracts oxygen and nitrogen. Since the arc stream takes place in the atmosphere, oxidation occurs while the metal passes from the electrode to the work. When this happens, the strength and ductility of the weld are reduced as well as the resistance to corrosion. The coating on the electrode prevents oxidation from taking place. As the electrode melts, the heavy coating releases an inert gas around the molten metal that excludes the atmosphere from the weld (fig. 7-7).

The burning residue of the coating forms a slag over the deposited metal that slows down the cooling rate and produces a more ductile weld. Some coatings include powdered iron that is converted to steel by the intense heat of the arc as it flows into the weld deposit.

Electrode Identification

Electrodes are often referred to by a manufacturer's trade name. The American Welding Society (AWS) and the American Society foresting and Materials (ASTM) have set up certain requirements for electrodes to assure some degree of uniformity in manufacturing electrodes. Thus different manufacturer's electrodes that are within the classification established by the AWS and ASTM should have the same welding characteristics. (See fig. 7-8.)

In this classification, each type of electrode is assigned a specific symbol, such as E-6010, E-7010, and E-8010. The prefix E identifies the electrode for

Table 7-2.—Electrode Selection Guide

Type	AWS Class	Current Type	Welding Position	Weld Results
Mild Steel	E6010 E6011	DCR DCR, AC	F, V, OH, H F, V, OH, H	Fast freeze, deep penetrating, flat beads, all-purpose welding
	E6012 E6013 E6014	DCS, AC DCR, DCS, AC DCS, AC	F, V, OH, H F, V, OH, H F, V, OH, H	Fill-freeze, low penetration, for poor fit-up, good bead contour, minimum spatter
	E6020 E6024	DCR, DCS, AC DCR, DCS, AC	F, H F, H	Fast-fill, high deposition, deep groove welds, single pass
	E6027	DCR, DCS, AC	F, H	Iron powder, high deposition, deep penetration
	57014	DCR, DCS, AC	F, V, OH, H	Iron powder, low penetration, high speed
	E7024	DCR, DCS, AC	F, H	Iron powder, high deposition, single and multiple pass
Low Hydrogen	E6015 E6016 E6018 E7016 E7018 E7028	DCR DCR, AC DCR, AC DCR, AC DCR, AC DCR, AC	F, V, OH, H F, V, OH, H F, V, OH, H F, V, OH, H F, V, OH, H F, H	Welding of high-sulphur and high-carbon steels that tend to develop porosity and crack under weld deposit
Stainless Steel	E308-15, 16	DC, AC	F, V, OH, H	Welding stainless steel 301, 302, 303 304, 308
	E309-15, 16	DC, AC	F, V, OH, H	Welding 309 alloy at elevated temperature application and dissimilar metals
	E310-15, 16	DC, AC	F, V, OH, H	Welding type 310 and 314 stainless steel where high corrosion and elevated temperatures are required
	E316-15, 16	DC, AC	F, V, OH, H	Welding type 316 stainless steel and welds of highest quality. Contains less carbon to minimize carbon transfer in the weld. Type 316 reduces pitting corrosion
	E347-15, 16	DC, AC	F, V, OH, H	For welding all grades of stainless steels
Low Alloy	E7011-A1 E7020-A1	DCR, AC DCR, DCS, AC	F, V, OH, H F 2	For welding carbon moly steels
	E8018-C3	DCR, AC	F, V, OH, H	For low alloy, high-tensile strength
	E10013-G	DCS, AC	F, V, OH, H	For low alloy, high-tensile steels

DCR—Direct Current Reverse Polarity   AC—Alternating Current
DCS—Direct Current Straight Polarity   F—flat, V—vertical, OH—overhead, H—horizontal

electric-arc welding. The first two digits in the symbol designate the minimum allowable tensile strength in thousands of pounds per square inch of the deposited weld metal. For example, the 60-series electrodes have a minimum tensile strength of 60,000 pounds per square inch, while the 70-series electrodes have a strength of 70,000 pounds per square inch.

The third digit of the symbol indicates the joint position for which the electrode is designed. Two numbers are used for this purpose: 1 and 2. Number 1 designates an electrode that can be used for welding in any position. Number 2 represents an electrode restricted for welding in the horizontal and flat positions only.

The fourth digit of the symbol represents special characteristics of the electrode, such as weld quality, type of current, and amount of penetration. The numbers range from 0 through 8. Since the welding position is dependent on the manufacturer's characteristics of the coating, the third and fourth numbers are often identified together.

Electrode Selection

Several factors are critical when you choose an electrode for welding. The welding position is particularly significant. Table 7-2 shows the recommended

current types and welding positions for the most common electrodes.

As a rule of thumb, you should never use an electrode that has a diameter larger than the thickness of the metal that you are welding. Some operators prefer larger electrodes because they permit faster travel, but this takes a lot of expedience to produce certified welds.

Position and the type of joint are also factors in determining the size of the electrode. For example, in a thick-metal section with a narrow vee, a small-diameter electrode is always used to run the frost weld or root pass. This is done to ensure full penetration at the root of the weld. Successive passes are then made with larger electrodes.

For vertical and overhead welding, 3/16 inch is the largest diameter electrode that you should use regardless of plate thickness. Larger electrodes make it too difficult to control the deposited metal. For economy, you should always use the largest electrode that is practical for the work It takes about one half of the time to deposit an equal quantity of weld metal from 1/4-inch electrodes as it does from 3/16-inch electrodes of the same type. The larger sizes not only allow the use of higher currents but also require fewer stops to change electrodes.

Deposit rate and joint preparation are also important in the selection of an electrode. Electrodes for welding mild steel can be classified as fast freeze, fill freeze, and fast fill. FAST-FREEZE electrodes produce a snappy, deep penetrating arc and fast-freezing deposits. They are commonly called reverse-polarity electrodes, even though some can be used on ac. These electrodes have little slag and produce flat beads. They are widely used for all-position welding for both fabrication and repair work

FILL-FREEZE electrodes have a moderately forceful arc and a deposit rate between those of the fast-freeze and fast-fill electrodes. They are commonly called the straight-polarity electrodes, even though they may be used on ac. These electrodes have complete slag coverage and weld deposits with distinct, even ripples. They are the general-purpose electrode for a production shop and are also widely used for repair work They can be used in all positions, but fast-freeze electrodes are still preferred for vertical and overhead welding.

Among the FAST-FILL electrodes are the heavy-coated, iron powder electrodes with a soft arc and fast deposit rate. These electrodes have a heavy slag and produce exceptionally smooth weld deposits. They are generally used for production welding where the work is positioned for flat welding.

Another group of electrodes are the low-hydrogen type that were developed for welding high-sulfur and high-carbon steel. These electrodes produce X-ray quality deposits by reducing the absorption of hydrogen that causes porosity and cracks under the weld bead.

Welding stainless steel requires an electrode containing chromium and nickel. All stainless steels have low-thermal conductivity that causes electrode overheating and improper arc action when high currents are used. In the base metal, it causes large temperature differentials between the weld and the rest of the work, which warps the plate. A basic rule in welding stainless steel is to avoid high currents and high heat. Another reason for keeping the weld cool is to avoid carbon corrosion.

There are also many special-purpose electrodes for surfacing and welding copper and copper alloys, aluminum, cast iron, manganese, nickel alloys, and nickel-manganese steels. The composition of these electrodes is designed to match the base metal. The basic rule in selecting electrodes is to pick one that is similar in composition to the base metal.

Electrode Storage

Electrodes are expensive; therefore, the loss or deterioration through improper handling or storage can become very costly. Always store them in a dry place at room temperature with 50-percent maximum relative humidity. Moisture causes the coating on electrodes to disintegrate and fall off. Low-hydrogen rods are especially sensitive to moisture. After removing these rods from their original packaging, you should store them in a storage space maintained at a temperature between 250°F to 400°F. Portable or stationary drying ovens are used to store and preserve electrodes at specified temperatures. Care should be taken when handling electrodes because bumping or dropping them can cause the coatings to fall off, rendering the rod useless.

Polarity

Earlier in this chapter, ac and dc current was briefly covered. With ac welding machines, polarity is not a problem. When using dc welding machines, you can weld with either straight polarity or reverse polarity.

Polarity is the direction of the current flow in a circuit, as shown in figure 7-9. In straight polarity, the electrode is negative and the workpiece positive; the electrons flow from the electrode to the workpiece. In reverse polarity, the electrode is positive and the workpiece negative; the electrons flow from the workpiece to the electrode. To help you remember the difference, think of straight polarity as a SENator and reverse polarity as a REPresentative. Use only the first three letters of each key word. SEN stands for Straight Electrode Negative; REP for Reverse Electrode Positive.
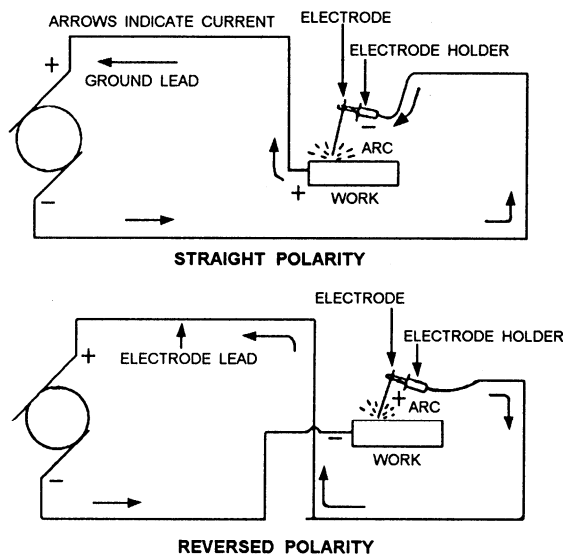
Figure 7-9.—Straight and reverse polarity in electric welding.

Figure 7-10.—Striking or brushing method of starting the arc.

On some of the older machines, polarity is changed by switching cables. On many of the newer machines, the polarity can be changed by turning a switch on the machine.

Polarity affects the amount of heat going into the base metal. By changing polarity, you can direct the amount of heat to where it is needed. When you use straight polarity, the majority of the heat is directed toward the workpiece. When you use reverse polarity, the heat is concentrated on the electrode. In some welding situations, it is desirable to have more heat on the workpiece because of its size and the need for more heat to melt the base metal than the electrode; therefore, when making large heavy deposits, you should use STRAIGHT POLARITY.

On the other hand, in overhead welding it is necessary to rapidly freeze the filler metal so the force of gravity will not cause it to fall. When you use REVERSE POLARITY, less heat is concentrated at the workpiece. This allows the filler metal to cool faster, giving it greater holding power. Cast-iron arc welding is another good example of the need to keep the workpiece cool; reverse polarity permits the deposits from the electrode to be applied rapidly while preventing overheating in the base metal.

In general, straight polarity is used for all mild steel, bare, or lightly coated electrodes. With these types of electrodes, the majority of heat is developed at the positive side of the current, the workpiece. However, when heavy-coated electrodes are used, the gases given off in the arc may alter the heat conditions so the

opposite is true and the greatest heat is produced on the negative side. Electrode coatings affect the heat conditions differently. 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.

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.

You can recognize the proper polarity for a given electrode by the sharp, crackling sound of the arc. The wrong polarity causes the arc to emit a hissing sound, and the welding bead is difficult to control.

One disadvantage of direct-current welding is "arc blow." As stated earlier, arc blow causes the arc to wander while you are welding in corners on heavy metal or when using large-coated electrodes. Direct current flowing through the electrode, workpiece, and ground clamp generates a magnetic field around each of these units. This field can cause the arc to deviate from the intended path. The arc is usually deflected forward or backward along the line of travel and may cause excessive spatter and incomplete fusion. It also has the tendency to pull atmospheric gases into the arc, resulting in porosity.

Arc blow can often be corrected by one of the following methods: by changing the position of the ground clamp, by welding away from the ground clamp, or by changing the position of the workpiece.

STARTING THE ARC

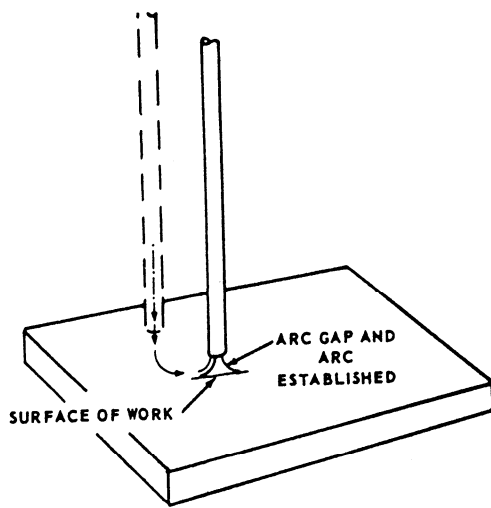Two basic methods are used for starting the arc: the STRIKING or BRUSHING method (fig. 7-10) and the

Figure 7-11.—Tapping method of starting the arc.

TAPPING method (fig. 7-11). In either method, the arc is started by short circuiting the welding current between the electrode and the work surface. The surge of high current causes the end of the electrode and a small spot on the base metal beneath the electrode to melt instantly. In the STRIKING or BRUSHING method, the electrode is brought down to the work with a lateral motion similar to striking a match. As soon as the electrode touches the work surface, it must be raised to establish the arc (fig. 7-10). The arc length or gap between the end of the electrode and the work should be equal to the diameter of the electrode. When the proper arc length is obtained, it produces a sharp, crackling sound.

In the TAPPING method, you hold the electrode in a vertical position to the surface of the work. The arc is started by tapping or bouncing it on the work surface and then raising it to a distance equal to the diameter of the electrode (fig. 7-11). When the proper length of arc is established, a sharp, crackling sound is heard.

When the electrode is withdrawn too slowly with either of the starting methods described above, it will stick or freeze to the plate or base metal. If this occurs, you can usually free the electrode by a quick sideways wrist motion to snap the end of the electrode from the plate. If this method fails, immediately release the electrode from the holder or shutoff the welding machine. Use alight blow with a chipping hammer or a chisel to free the electrode from the base metal.

CAUTION

NEVER remove your helmet or the shield from your eyes as long as there is any possibility that the electrode could produce an arc.

After you strike the arc, the end of the electrode melts and flows into the molten crater of the base metal. To compensate for this loss of metal, you must adjust the length of the arc. Unless you keep moving the electrode closer to the base metal, the length of the arc will increase. An arc that is too long will have a humming type of sound. One that is too short makes a popping noise. When the electrode is fed down to the plate and along the surface at a constant rate, a bead of metal is deposited or welded onto the surface of the base metal. After striking the arc, hold it for a short time at the starting point to ensure good fusion and crater deposition. Good arc welding depends upon the control of the motion of the electrode along the surface of the base metal.

Setting the Current

The amount of current used during a welding operation depends primarily upon the diameter of the electrode. As a rule, higher currents and larger diameter electrodes are better for welding in the flat position than the vertical or overhead position. Manufacturers of electrodes usually specify a current range for each type and size of electrode; this information is normally found on the face of the electrode container.

Since most recommended current settings are only approximate, final current settings and adjustments need to be made during the welding operation. For example, when the recommended current range for an electrode is 90-100 amperes, the usual practice is to set the controls midway between the two limits, or at 95 amperes. After starting the weld, make your final adjustments by either increasing or decreasing the current.

When the current is too high, the electrode melts faster and the molten puddle will be excessively large and irregular. High current also leaves a groove in the base metal along both sides of the weld. This is called undercutting, and an example is shown in figure 7-12, view C.

With current that is too low, there is not enough heat to melt the base metal and the molten pool will be too small. The result is poor fusion and a irregular shaped deposit that piles up, as shown in figure 7-12, view B. This piling up of molten metal is called overlap. The molten metal from the electrode lays on the work without penetrating the base metal. Both undercutting and overlapping result in poor welds, as shown in figure 7-13.

When the electrode, current, and polarity are correct, a good arc produces a sharp, crackling sound. When any of these conditions are incorrect, the arc produces a steady, hissing sound, such as steam escaping.
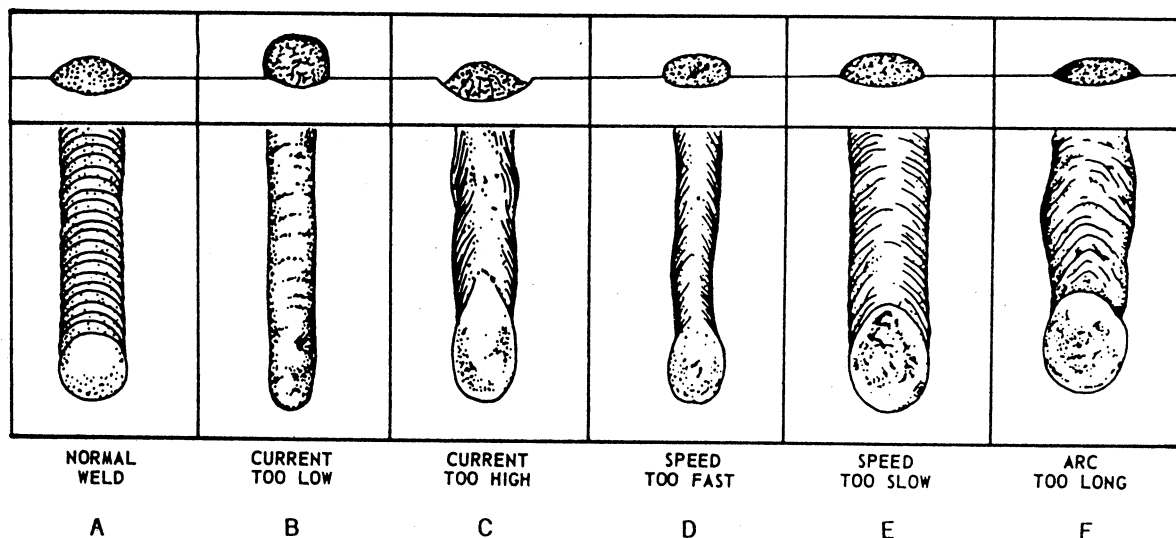
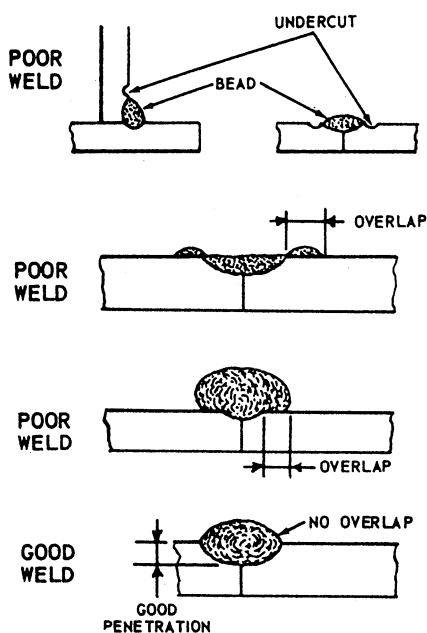| NORMAL WELD	CURRENT TOO LOW	CURRENT TOO HIGH	SPEED TOO FAST	SPEED TOO SLOW	ARC TOO LONG
A	B	C	D	E	F

Figure 7-12.—Comparison chart of welds.

Figure 7-13.—Undercuts and overlaps in welding.

SHORT ARC
Sharp Crackling Sound.
Best for Most Welding.

LONG ARC
Steady Hiss Allows
Oxidation and Spatter.

Figure 7-14.—Setting the length of an arc.

Length of Arc

When an arc is too long, the metal melts off the electrode in large globules and the arc may break frequently. This produces a wide, spattered, and irregular deposit with insufficient fusion between the base metal and the weld (fig. 7-12, view F).

When an arc is too short, it fails to generate enough heat to melt the base metal properly, causes the electrode to stick frequently to the base metal, and produces uneven deposits with irregular ripples. The recommended length of the arc is equal to the diameter of the bare end of the electrode, as shown in figure 7-14.

The length of the arc depends upon the type of electrode and the type of welding being done; therefore, for smaller diameter electrodes, a shorter arc is necessary than for larger electrodes. Remember: the length of the arc should be about equal to the diameter of the bare electrode except when welding in the vertical or overhead position. In either position, a shorter arc is desirable because it gives better control of the molten puddle and prevents atmospherical impurities from entering the weld.

7-11
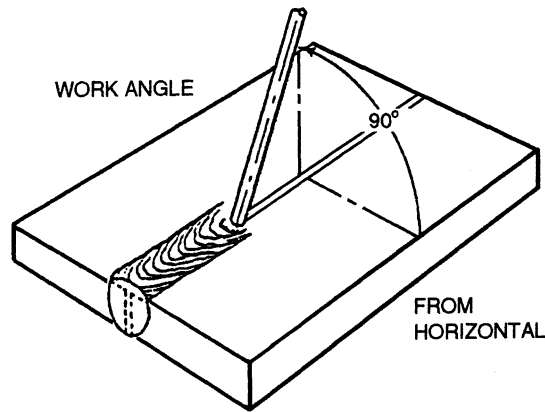
Figure 7-15.—Work angle.
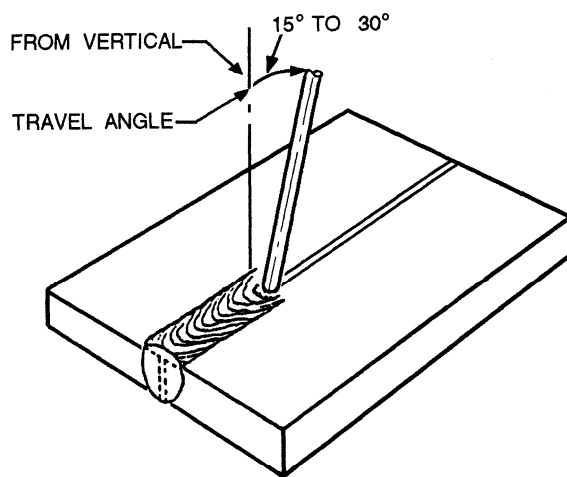
Figure 7-16.—Travel angle.

Electrode Angle

The angle at which you hold the electrode greatly affects the shape of the weld bead which is very important in fillet and deep groove welding. The electrode angle consists of two positions: work angle and travel angle. Work angle is the angle from the horizontal measured at right angles to the direction of welding (fig, 7-15). Travel angle is the angle in the direction of welding and may vary from 5 to 30 degrees, depending on the welder's choice and conditions (fig. 7-16).

Work angle is especially important in multiple-pass fillet welding. Normally, a small variance of the work angle will not affect the appearance or quality of a weld; however, when undercuts occur in the vertical section of a fillet weld, the angle of the arc should be lowered and the electrode directed more toward the vertical section.

Travel Speed

Travel speed is the rate at which the electrode travels along a weld seam. The maximum speed of welding depends on the skill of the operator, the position of the weld, the type of electrode, and the required joint penetration.

Normally, when the travel speed is too fast, the molten pool cools too quickly, locking in impurities and causing the weld bead to be narrow with pointed ripples, as shown in figure 7-12, view D. On the other hand, if the travel speed is too slow, the metal deposit piles up excessively and the weld is high and wide, as shown in figure 7-12, view E. In most cases, the limiting factor is the highest speed that produces a satisfactory surface appearance of a normal weld, as shown in figure 7-12, view A.

Breaking the Arc

The most commonly used method to break the arc is to hold the electrode stationary until the crater is filled and then slowly withdraw the electrode. This method reduces the possibilities of crater cracks.

Reestablishing the Arc

When it becomes necessary to reestablish the arc (as in a long weld that requires the use of more than one electrode), the crater must first be cleaned before striking the arc. Strike the tip of the new electrode at the forward (cold) end of the crater and establish an arc. Move the arc backward over the crater, and then move forward again and continue the weld. This procedure fills the crater and prevents porosity and slag inclusions.

Peening

Peening is a procedure that involves lightly hammering a weld as it cools. This process aids in relieving built-up stresses and preventing surface cracking in the joint area; however, peening should be done with care because excess hammering can work harden and increase stresses in the weld. This condition leads to weld embrittlement and early failure. Some welds are covered by specific codes that prohibit peening so you should check the weld specification before peening.

ARC WELDING POSITIONS

The types of welds, joints, and welding positions used in manual-shielded metal arc welding are very similar to those used in oxygas welding. Naturally, the techniques are somewhat different because of the equipment involved is different.
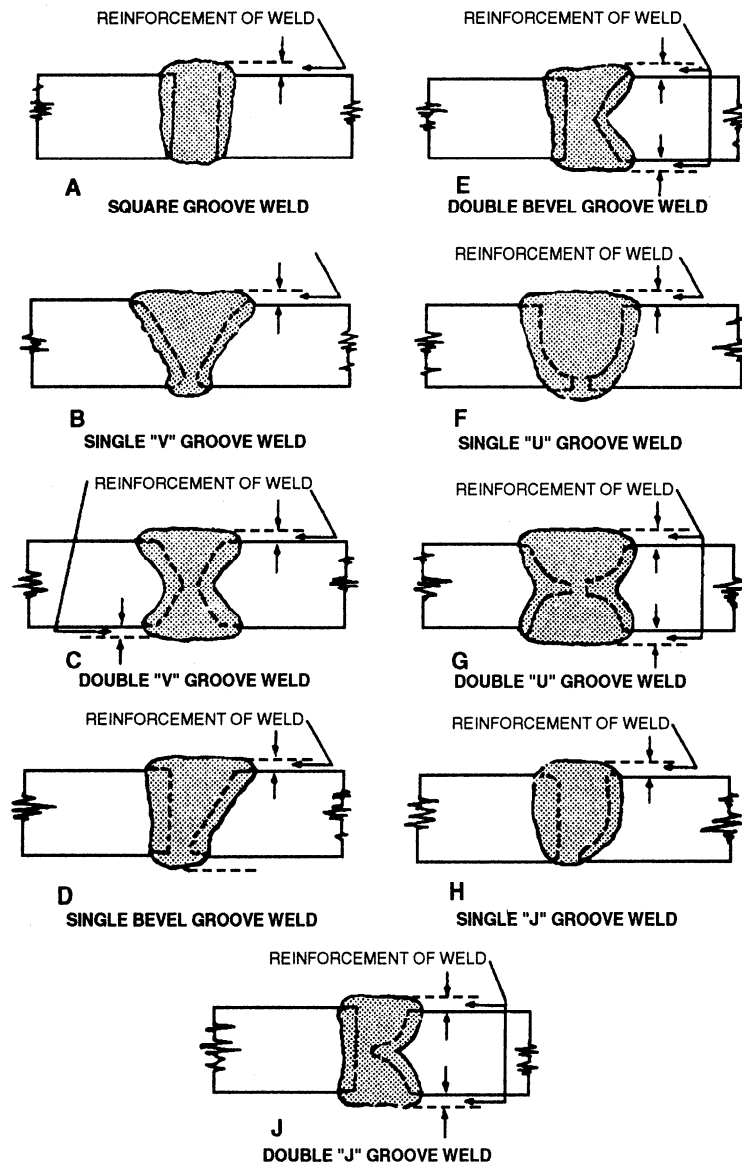
Figure 7-17.—Butt joints in the flat position.

FLAT-POSITION WELDING

Earlier reexplained that welding can be done in any position, but it is much simpler when done in the flat position. In this position, the work is less tiring, welding speed is faster, the molten puddle is not as likely to run, and better penetration can be achieved. Whenever possible, try to position the work so you can weld in the flat position. In the flat position, the face of the weld is approximately horizontal.

Joint Type

Butt joints are the primary type of joints used in the flat position of welding; however, flat-position welding can be made on just about any type of joint providing you can rotate the section you are welding on to the appropriate position. Techniques that are useful in making butt joints in the flat position, with and without the use of backing strips, are described below.

BUTT JOINTS WITHOUT BACKING STRIPS.— A butt joint is used to join two plates having surfaces in about the same plane. Several forms of butt joints are shown in figure 7-17.

Plates up to 1/8 inch thick can be welded in one pass with no special edge preparation. Plates from 1/8 to 3/16 inch in thickness also can be welded with no special edge preparation by welding on both sides of the joint.

7-13
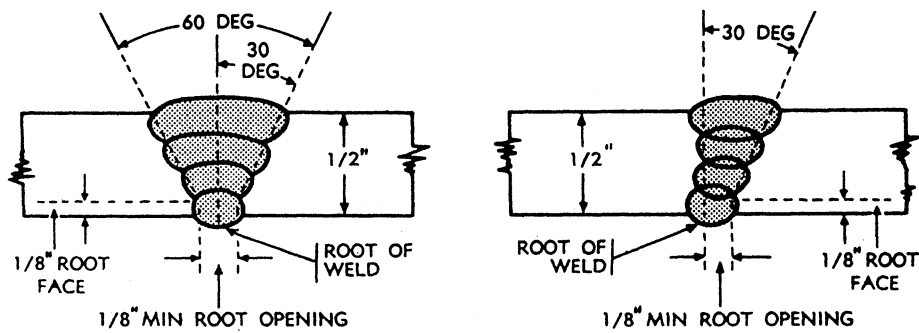
Figure 7-18.—Butt welds with multipass beads.
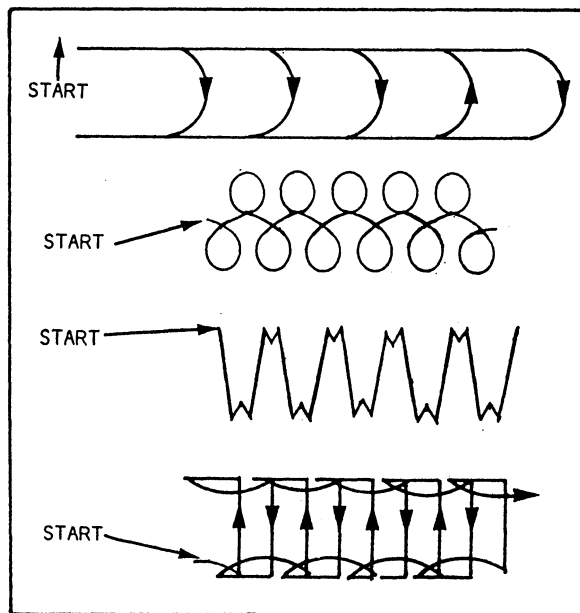
Figure 7-19.—Weave motions used in manual shielded arc welding.

Figure 7-20.—Undercutting in butt joint welds.

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.

In welding 1/4-inch plate or heavier, you should prepare the edges of the plates by beveling or by J-, U-, or V-grooving, whichever is the most applicable. You should use single or double bevels or grooves when the specifications and/or the plate thickness requires it. The first bead is deposited to seal the space between the two plates and to weld the root of the joint. This bead or layer of weld metal must be thoroughly cleaned to remove all slag and dirt before the second layer of metal is deposited.

In making multipass welds, as shown in figure 7-18, the second, third, and fourth layers of weld metal are made with a weaving motion of the electrode. Clean each layer of metal before laying additional beads. You may use one of the weaving motions shown in figure 7-19, depending upon the type of joint and size of electrode.

In the weaving motion, oscillate or move the electrode uniformly from side to side, with a slight hesitation at the end of each oscillation. Incline the electrode 5 to 15 degrees in the direction of welding as in bead welding. When the weaving motion is not done properly, undercutting could occur at the joint, as shown in figure 7-20. Excessive welding speed also can cause undercutting and poor fusion at the edges of the weld bead.

BUTT JOINTS WITH BACKING STRIPS.— Welding 3/16-inch plate or thicker requires backing strips to ensure complete fusion in the weld root pass and to provide better control of the arc and the weld metal. Prepare the edges of the plates in the same manner as required for welding without backing strips.

7-14
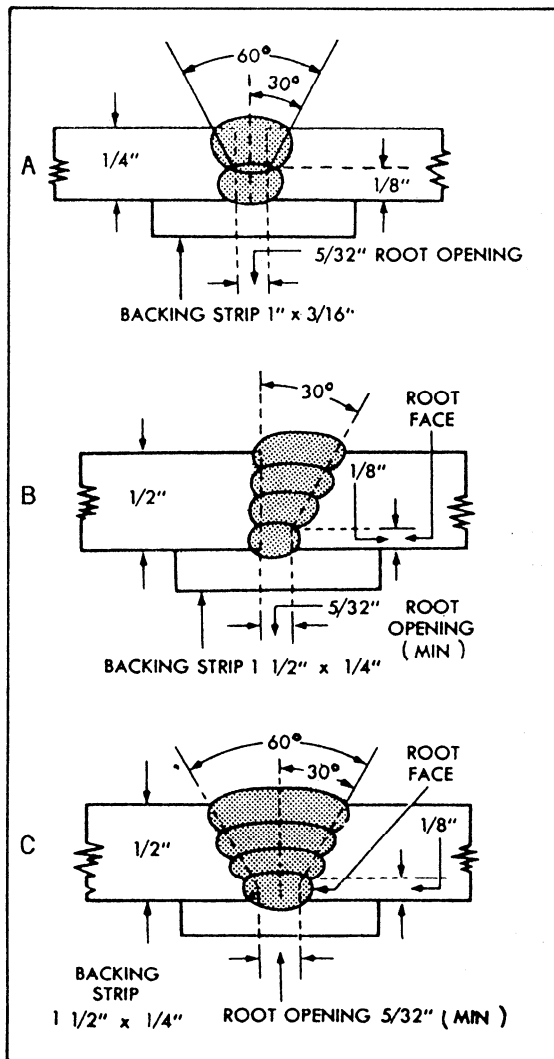
Figure 7-21.—Use of backing strips in welding butt joints.

Figure 7-22.—Horizontal groove weld.
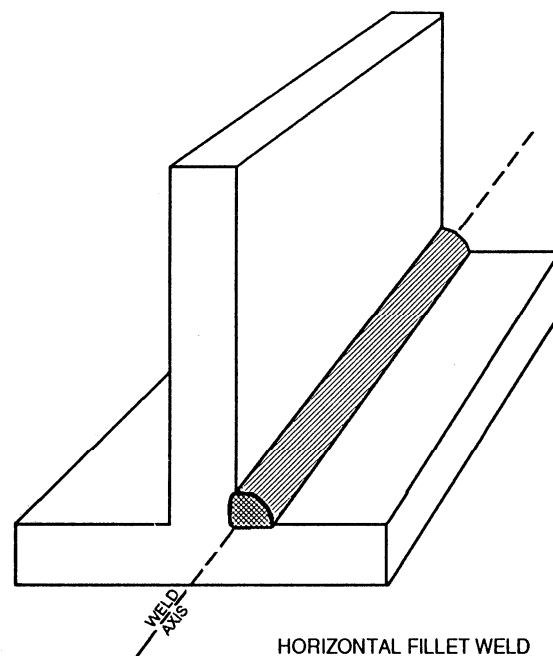
Figure 7-23.—Horizontal fillet weld,

For plates up to 3/8 inch thick, the backing strips should be approximately 1 inch wide and 3/16 inch thick. For plates more than 1/2inch thick, the backing strips should be 1 1/2 inches wide and 1/4 inch thick Tack-weld the backing strip to the base of the joint, as shown in figure 7-21. The backing strip acts as a cushion for the root pass. Complete the joint by welding additional layers of metal. After you complete the joint, the backing strip may be "washed" off or cut away with a cutting torch. When specified, place a seal bead along the root of the joint.

Bear in mind that many times it will not always be possible to use a backing strip; therefore, the welder must be able to run the root pass and get good penetration without the formation of icicles.

HORIZONTAL-POSITION WELDING

You will discover that it is impossible to weld all pieces in the flat position. Often the work must be done in the horizontal position. The horizontal position has two basic forms, depending upon whether it is used with a groove weld or a fillet weld. In a groove weld, the axis of the weld lies in a relative horizontal plane and the face of the weld is in a vertical plane (fig. 7-22). In a fillet weld, the welding is performed on the upper side of a relatively horizontal surface and against an approximately vertical plane (fig. 7-23).

7-15
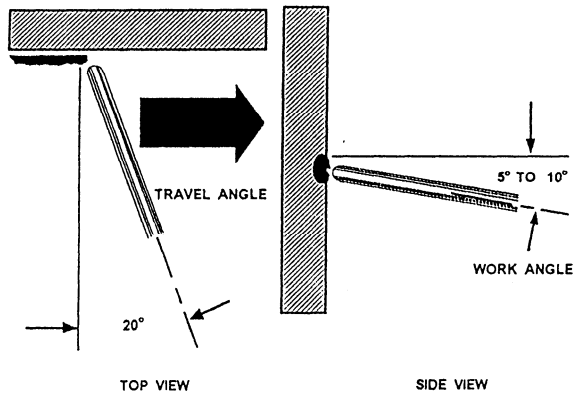
Figure 7-24.—Horizontal welding angles.

Figure 7-26.—Position of electrode and fusion area of fillet weld on a tee joint.

Figure 7-25.—Tack-weld to hold the tee joint elements in place.

An inexperienced welder usually finds the horizontal position of arc welding difficult, at least until he has developed a fair degree of skill in applying the proper technique. The primary difficulty is that in this position you have no "shoulder" of previously deposited weld metal to hold the molten metal.

Electrode Movement

In horizontal welding, position the electrode so that it points upward at a 5- to 10-degree angle in conjunction with a 20-degree travel angle (fig. 7-24). Use a narrow weaving motion in laying the bead. This weaving motion distributes the heat evenly, reducing the tendency of the molten puddle to sag. You should use the shortest arc length possible, and when the force of the arc undercuts the plate at the top of the bead, lower the electrode holder a little to increase the upward angle.

As you move in and out of the crater, pause slightly each time you return. This keeps the crater small and the bead has less tendency to sag.

Joint Type

Horizontal-position welding can be used on most types of joints. The most common types of joints it is used on are tee joints, lap joints, and butt joints.

TEE JOINTS.— When you make tee joints in the horizontal position, the two plates are 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, as shown in figure 7-25.

A fillet weld is used in making the tee joint, and a short arc is necessary to provide good fusion at the root and along the legs of the weld (fig. 7-26, view A). Hold the electrode at an angle of 45 degrees to the two plate surfaces (fig. 7-26, view B) with an incline of approximately 15 degrees in the direction of welding.

When practical, weld light plates with a fillet weld in one pass with little or no weaving of the electrode. Welding of heavier plates may require two or more passes in which the second pass or layer is made with a semicircular weaving motion, as shown in figure 7-27. To ensure good fusion and the prevention of undercutting, you should make a slight pause at the end of each weave or oscillation.

For fillet-welded tee joints on 1/2-inch plate or heavier, deposit stringer beads in the sequence shown in figure 7-28.
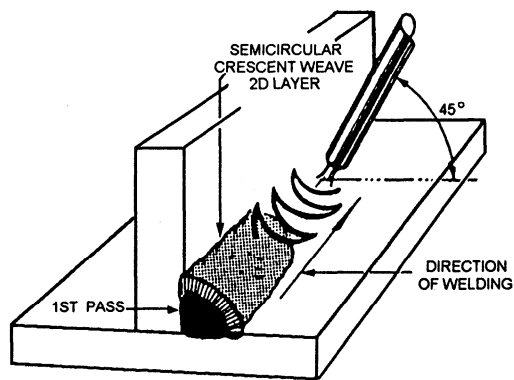
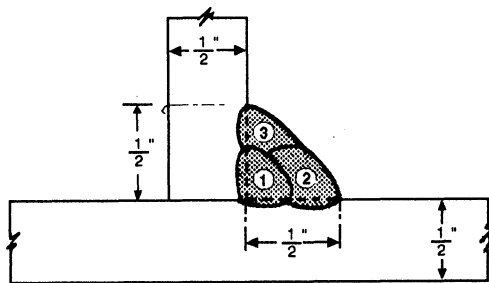**7-16**

Figure 7-27.—Weave motion for multipass fillet weld.

Figure 7-30.—Tack welding a lap joint.

Figure 7-28.—Order of making string beads for a tee joint in heavy plate.

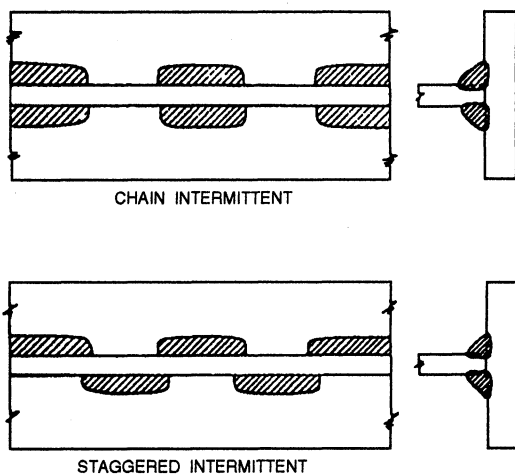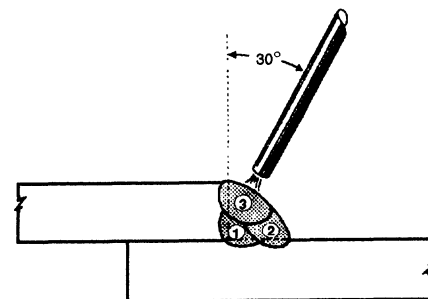Figure 7-31.—Position of electrode on a lap joint.

Figure 7-29.—Intermittent fillet welds.

Chain-intermittent or staggered-intermittent fillet welds, as shown in figure 7-29, are used on long tee joints. Fillet welds of these types are for joints where high weld strength is not required; however, the short welds are arranged so the finished joint is equal in strength to that of a joint that has a fillet weld along the entire length of one side. Intermittent welds also have the advantage of reduced warpage and distortion.

LAP JOINTS.— When you make a lap joint, two overlapping plates are tack-welded in place (fig. 7-30), and a fillet weld is deposited along the joint.

The procedure for making this fillet weld is similar to that used for making fillet welds in tee joints. You should hold the electrode so it forms an angle of about 30 degrees from the vertical and is inclined 15 degrees in the direction of welding. The position of the electrode in relation to the plates is shown in figure 7-31. The weaving motion is the same as that used for tee joints, except that the pause at the edge of the top plate is long enough to ensure good fusion without undercut. Lap joints on 1/2-inch plate or heavier are made by depositing a sequence of stringer beads, as shown in figure 7-31,

In making lap joints on plates of different thickness, you should hold the electrode so that it forms an angle of between 20 and 30 degrees from the vertical
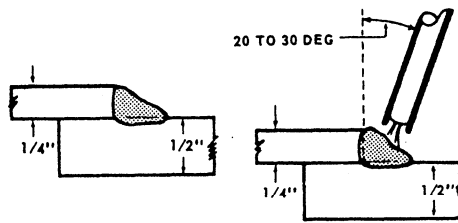
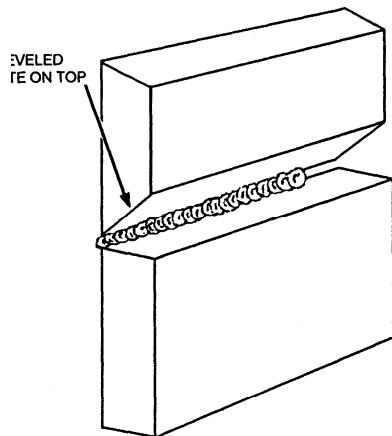**Figure 7-32.—Lap joints on plates of different thickness.**

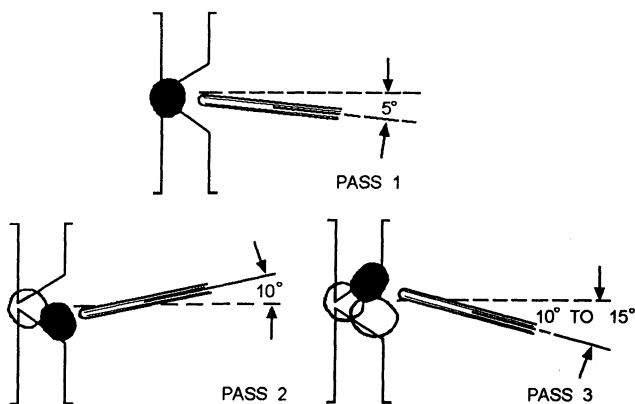**Figure 7-33.—Horizontal butt joint.**
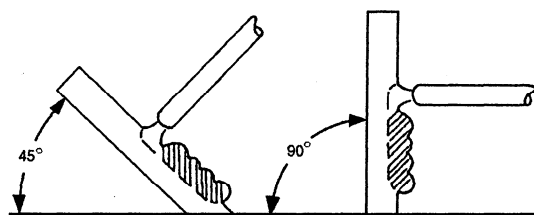

Figure 7-34.—Multiple passes.

Figure 7-35.—Vertical weld plate positions.

(fig. 7-32). Be careful not to overheat or undercut the thinner plate edge.

BUTT JOINTS.— Most butt joints, designed for horizontal welding, have the beveled plate positioned on the top. The plate that is not beveled is on the bottom and the flat edge of this plate provides a shelf for the molten metal so that it does not run out of the joint (fig. 7-33). Often both edges are beveled to forma 60-degree included angle. When this type of joint is used, more skill is required because you do not have the retaining shelf to hold the molten puddle.

The number of passes required for a joint depends on the diameter of the electrode and the thickness of the metal. When multiple passes are required (fig. 7-34), place the first bead deep in the root of the joint. The electrode holder should be inclined about 5 degrees downward. Clean and remove all slag before applying each following bead. The second bead should be placed with the electrode holder held about 10 degrees upward. For the third pass, hold the electrode holder 10 to 15 degrees downward from the horizontal. Use a slight weaving motion and ensure that each bead penetrates the base metal.

VERTICAL-POSITION WELDING

A "vertical weld" is defined as a weld that is applied to a vertical surface or one that is inclined 45 degrees or less (fig. 7-35). Erecting structures, such as buildings, pontoons, tanks, and pipelines, require welding in this position. Welding on a vertical surface is much more difficult than welding in the flat or horizontal position due to the force of gravity. Gravity pulls the molten metal down. To counteract this force, you should use fast-freeze or fill-freeze electrodes.

Vertical welding is done in either an upward or downward position. The terms used for the direction of welding are *vertical up* or *vertical down. Vertical down welding* is suited for welding light gauge metal because the penetration is shallow and diminishes the possibility of burning through the metal. Furthermore, vertical down welding is faster which is very important in production work.

Current Settings and Electrode Movement

In vertical arc welding, the current settings should be less than those used for the same electrode in the flat position. Another difference is that the current used for welding upward on a vertical plate is slightly higher than the current used for welding downward on the same plate.

VERTICAL BEAD WELD, WELDING UP

A

VERTICAL WEAVE BEAD WELD, WELDING UP

B

VERTICAL BEAD WELD, WELDING DOWN

C

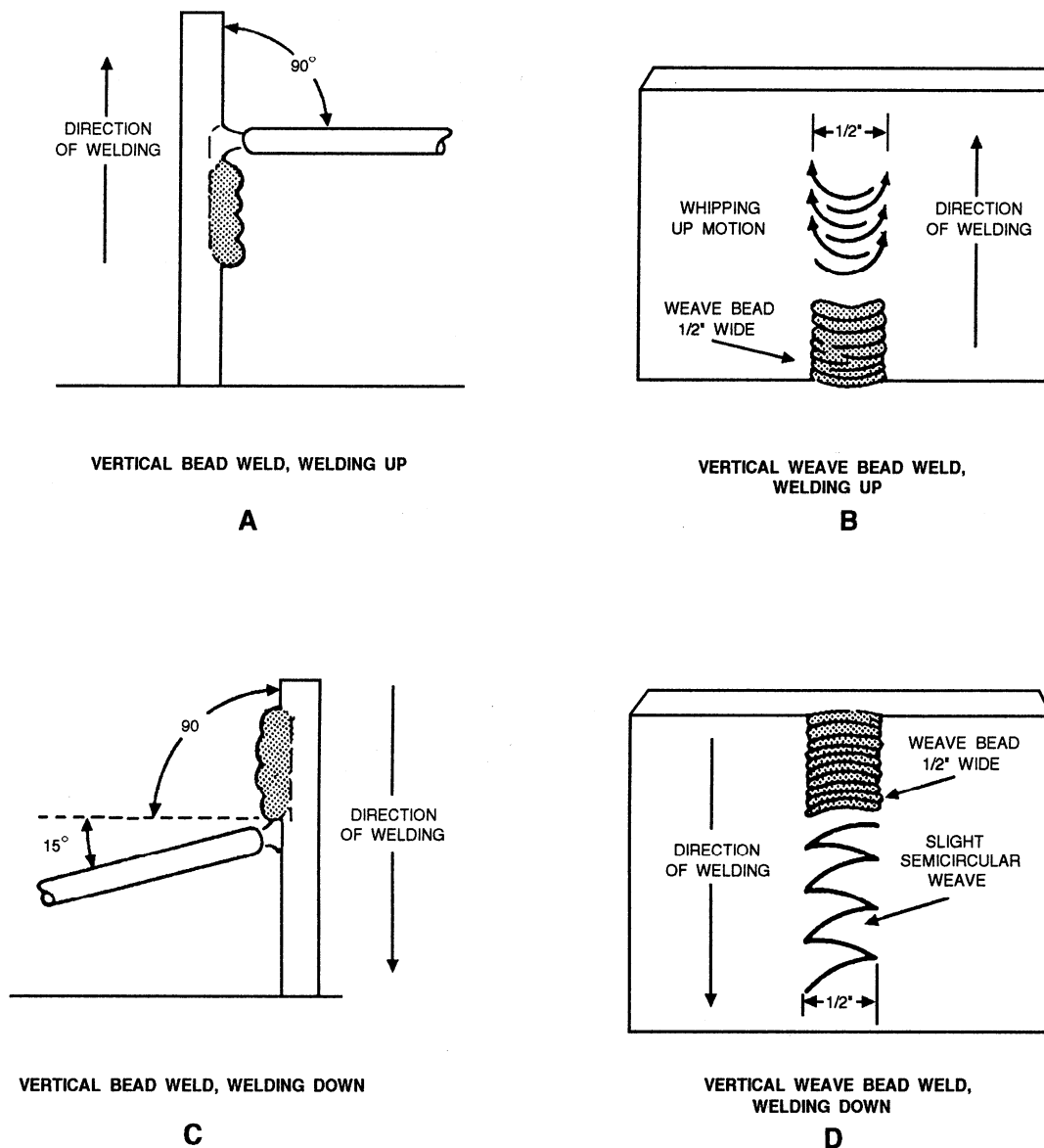**VERTICAL WEAVE BEAD WELD, WELDING DOWN**

D

Figure 7-36.—Bead welding in the vertical position.

To produce good welds, you must maintain the proper angle between the electrode and the base metal. In welding upward, you should hold the electrode at 90 degrees to the vertical, as shown in figure 7-36, view A. When weaving is necessary, oscillate the electrode, as shown in figure 7-36, view B.

In vertical down welding, incline the outer end of the electrode downward about 15 degrees from the horizontal while keeping the arc pointing upward toward the deposited molten metal (figure 7-36, view C). When vertical down welding requires a weave bead, you should oscillate the electrode, as shown in figure 7-36, view D.

Joint Type

Vertical welding is used on most types of joints. The types of joints you will most often use it on are tee joints, lap joints, and butt joints.

When making fillet welds in either tee or lap joints in the vertical position, hold the electrode at 90 degrees to the plates or not more than 15 degrees off the horizontal for proper molten metal control. Keep the arc short to obtain good fusion and penetration.

TEE JOINTS.— To weld tee joints in the vertical position, start the joint at the bottom and weld upward.
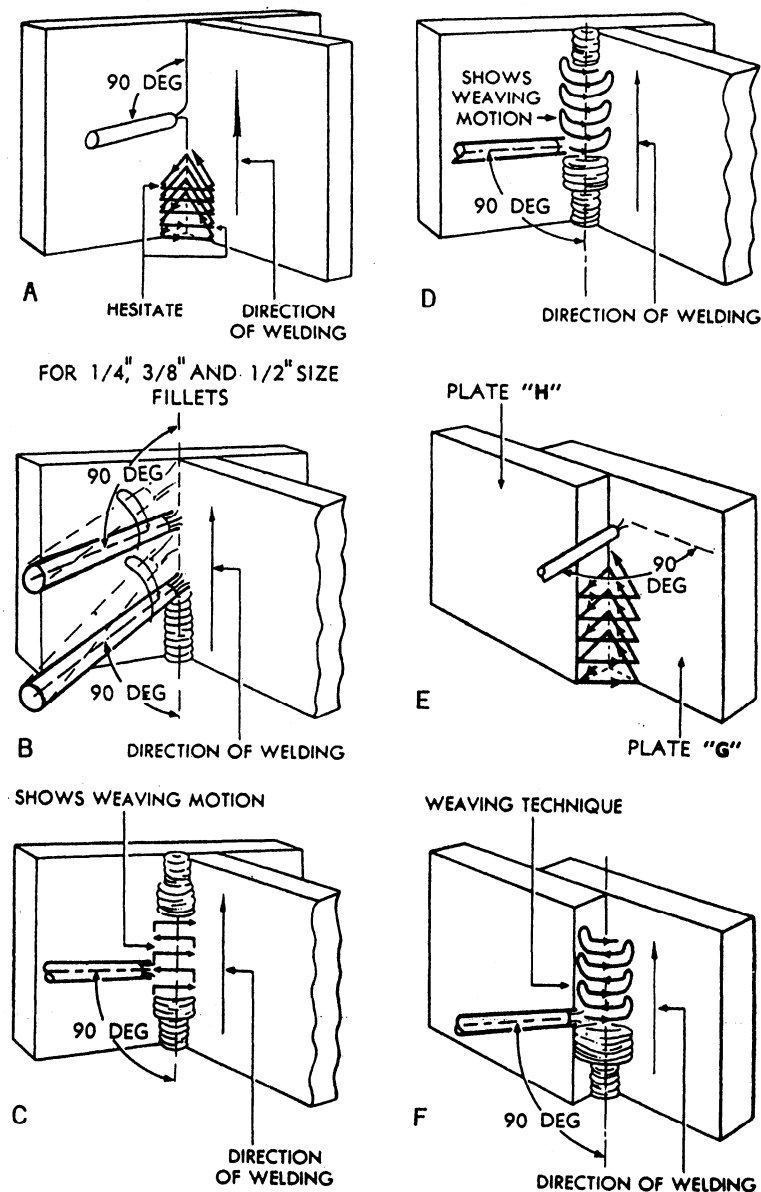
7-19

Figure 7-37.—Fillet welds in the vertical position.

Move the electrode in a triangular weaving motion, as shown in figure 7-37, view A. A slight pause in the weave, at the points indicated, improves the sidewall penetration and provides good fusion at the root of the joint.

When the weld metal overheats, you should quickly shift the electrode away from the crater without breaking the arc, as shown in figure 7-37, view B. This permits the molten metal to solidify without running downward. Return the electrode immediately to the crater of the weld in order to maintain the desired size of the weld.

When more than one pass is necessary to make a tee weld, you may use either of the weaving motions shown in figure 7-37, views C and D. A slight pause at the end of the weave will ensure fusion without undercutting the edges of the plates.

LAP JOINTS.— To make welds on lap joints in the vertical position, you should move the electrode in a triangular weaving motion, as shown in figure 7-37, view E. Use the same procedure, as outlined above for the tee joint, except direct the electrode more toward the vertical plate marked "G." Hold the arc short, and pause
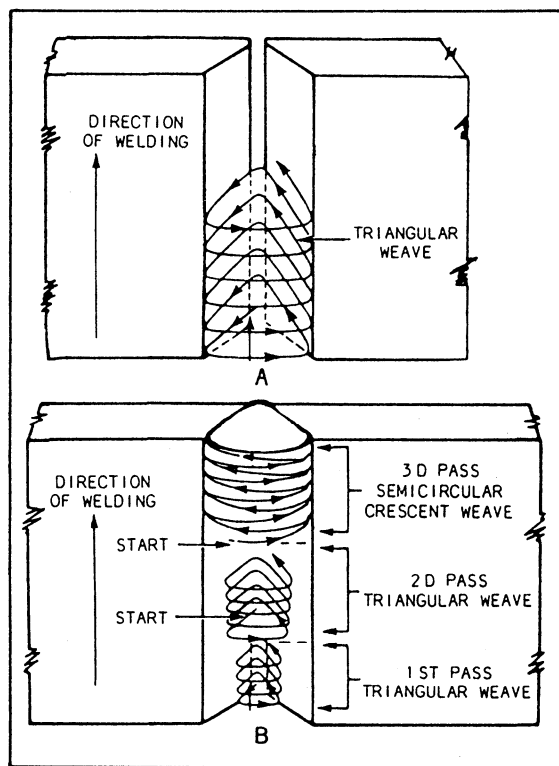
7-20

Figure 7-38.—Butt joint welding in the vertical position.

slightly at the surface of plate G. Try not to undercut either of the plates or to allow the molten metal to overlap at the edges of the weave.

Lap joints on heavier plate may require more than one bead. If it does, clean the initial bead thoroughly and place all subsequent beads as shown in figure 7-37, view F. The precautions to ensure good fusion and uniform weld deposits that was previously outlined for tee joints also apply to lap joints.

BUTT JOINTS.— Prepare the plates used in vertical welding identically to those prepared for welding in the flat position. To obtain good fusion and penetration with no undercutting, you should hold a short arc and the motion of the arc should be carefully controlled.

Butt joints on beveled plates 1/4 inch thick can be welded in one pass by using a triangular weave motion, as shown in figure 7-38, view A.

Welds made on 1/2-inch plate or heavier should be done in several passes, as shown in figure 7-38, view B. Deposit the last pass with a semicircular weaving motion with a slight "whip-up" and pause of the electrode at the edge of the bead. This produces a good cover pass

with no undercutting. Welds made on plates with a backup strip should be done in the same manner.

E-7018 Electrode Welding Technique

The previously described vertical welding techniques generally cover all types of electrodes; however, you should modify the procedure slightly when using E-7018 electrodes.

When vertical down welding, you should drag the electrode lightly using a very short arc. Refrain from using a long arc since the weld depends on the molten slag for shielding. Small weaves and stringer beads are preferred to wide weave passes. Use higher amperage with ac than with dc. Point the electrode straight into the joint and tip it forward only a few degrees in the direction of travel.

On vertical up welding, a triangular weave motion produces the best results. Do not use a whipping motion or remove the electrode from the molten puddle. Point the electrode straight into the joint and slightly upward in order to allow the arc force to help control the puddle. Adjust the amperage in the lower level of the recommended range.

OVERHEAD-POSITION WELDING

Overhead welding is the most difficult position in welding. Not only do you have to contend with the force of gravity but the majority of the time you also have to assume an awkward stance. Nevertheless, with practice it is possible to make welds equal to those made in the other positions.

Current Settings and Electrode Movement

To retain complete control of the molten puddle, use a very short arc and reduce the amperage as recommended. As in the vertical position of welding, gravity causes the molten metal to drop or sag from the plate. When too long an arc is held, the transfer of metal from the electrode to the base metal becomes increasingly difficult, and the chances of large globules of molten metal dropping from the electrode increase. When you routinely shorten and lengthen the arc, the dropping of molten metal can be prevented; however, you will defeat your purpose should you carry too large a pool of molten metal in the weld.

One of the problems encountered in overhead welding is the weight of the cable. To reduce arm and wrist fatigue, drape the cable over your shoulder when welding in the standing position. When sitting, place the
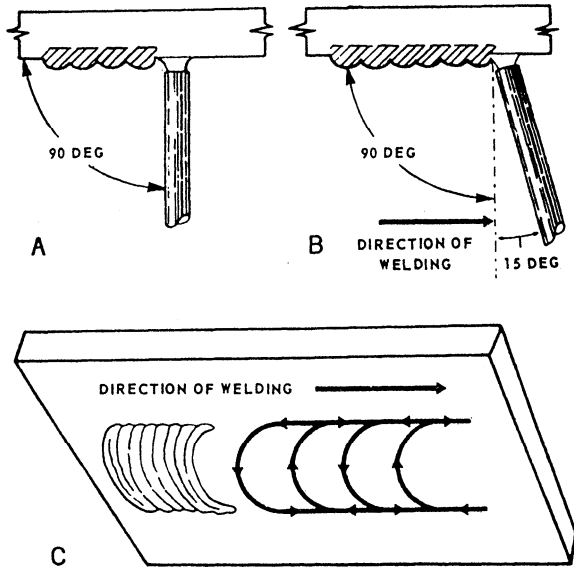
Figure 7-39.—Position of electrode and weave motion in the overhead position.

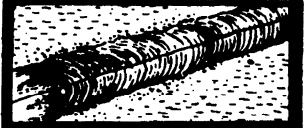Figure 7-40.—Multipass butt joint in the overhead position.

cable over your knee. With experience, cable placement will become second nature.

WARNING

Because of the possibility of falling molten metal, use a protective garment that has a tight fitting collar that buttons or zips up to the neck. Roll down your sleeves and wear a cap and appropriate shoes.

Type of Welds

Techniques used in making bead welds, butt joints, and fillet welds in the overhead position are discussed in the following paragraphs.

BEAD WELDS.— For bead welds, the work angle of the electrode is 90 degrees to the base metal (fig. 7-39, view A). The travel angle should be 10 to 15 degrees in the direction of welding (fig. 7-39, view B).

Weave beads can be made by using the motion shown in figure 7-39, view C. A rather rapid motion is necessary at the end of each semicircular weave to control the molten metal deposit. Avoid excessive weaving because this can cause overheating of the weld deposit and the formation of a large, uncontrollable pool.

BUTT JOINTS.— Prepare the plates for overhead butt welding in the same manner as required for the flat position. The best results are obtained when backing strips are used; however, you must remember that you will not always be able to use a backing strip. When you bevel the plates with a featheredge and do not use a backing strip, the weld will repeatedly burn through unless extreme care is taken by the operator.

For overhead butt welding, bead welds are preferred over weave welds. Clean each bead and chip out the rough areas before placing the next pass. The electrode position and the order of deposition of the weld beads when welding on 1/4- or 1/2-inch plate are shown in figure 7-40, views B and C. Make the first pass with the electrode held at 90 degrees to the plate, as shown in figure 7-40, view A. When you use an electrode that is too large, you can not hold a short arc in the root area. This results in insufficient root penetration and inferior joints.

FILLET WELDS.— In making fillet welds in either tee or lap joints in the overhead position, maintain a short arc and refrain from weaving of the electrode.
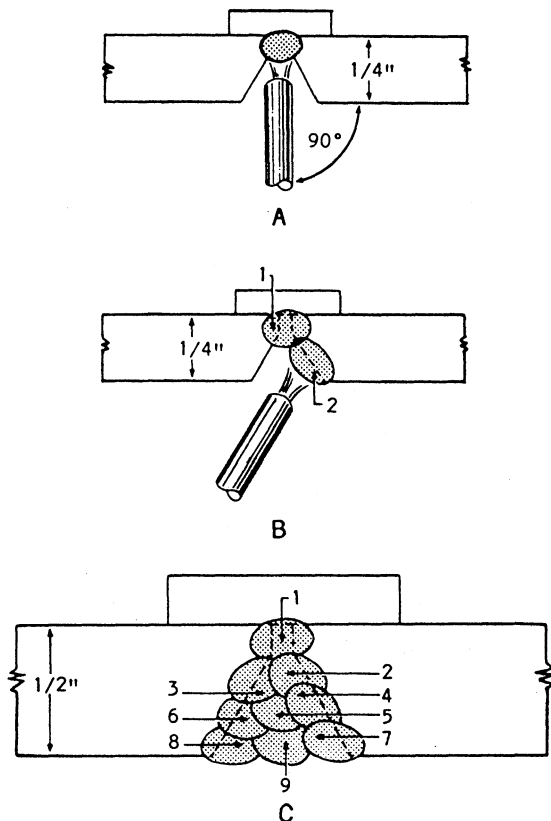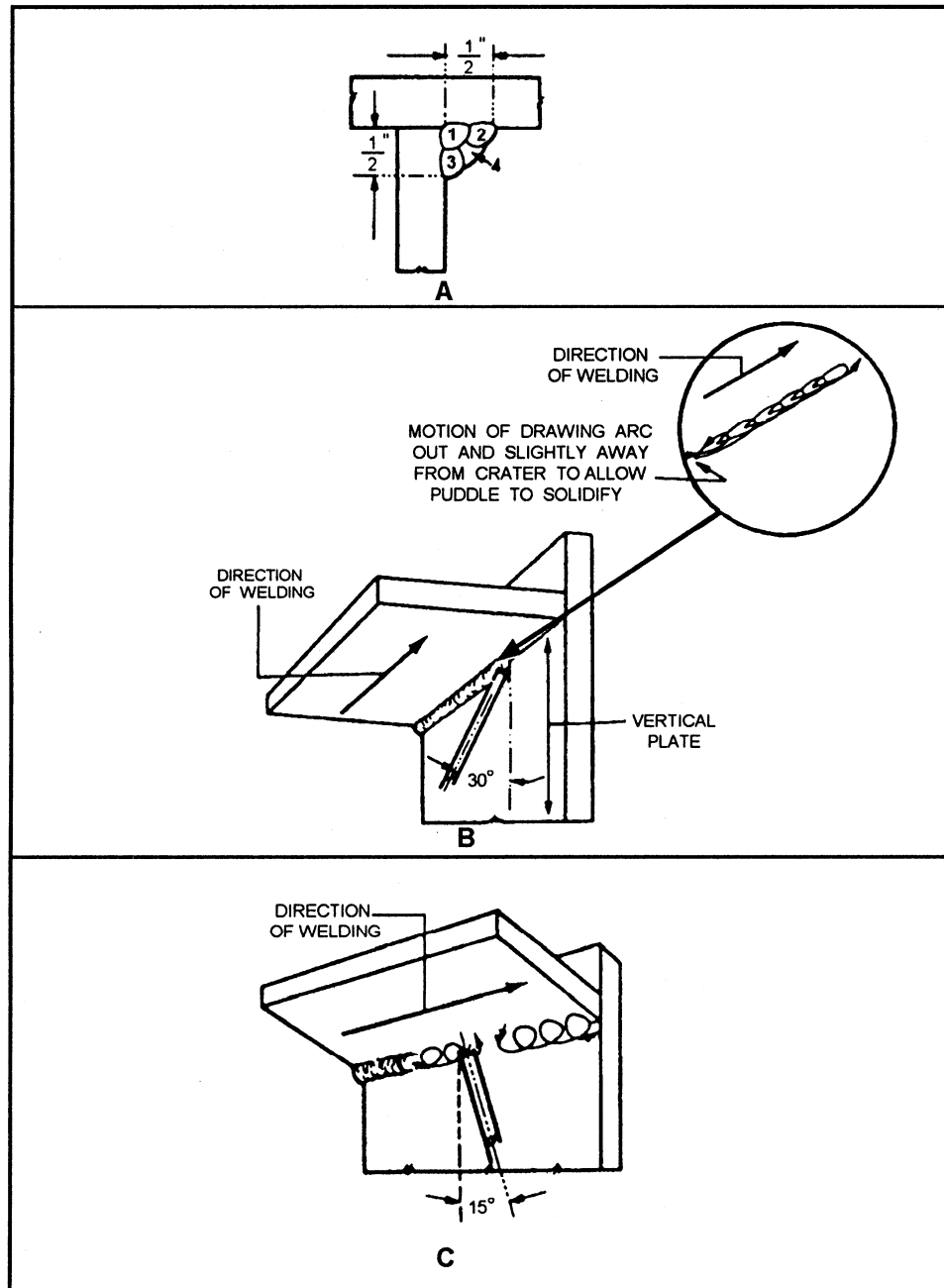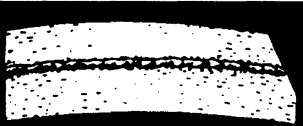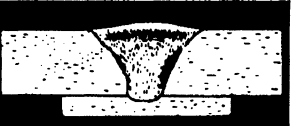
Figure 7-41.—Fillet welding in the overhead position.

Hold the electrode at approximately 30 degrees to the vertical plate and move it uniformly in the direction of welding, as shown in figure 7-41, view B. Control the arc motion to secure good penetration in the root of the weld and good fusion with the sidewalls of the vertical and horizontal plates. When the molten metal becomes too fluid and tends to sag, whip the electrode quickly away from the crater and ahead of the weld to lengthen the arc and allow the metal to solidify. Immediately return the electrode to the crater and continue welding.

Overhead fillet welds for either tee or lap joints on heavy plate require several passes or beads to complete the joint. One example of an order of bead deposition is shown in figure 7-41, view A. The root pass is a string bead made with no weaving motion of the electrode. Tilt the electrode about 15 degrees in the direction of welding, as shown in figure 7-41, view C, and with a

7-23

Table 7-3—Causes and Cures of Common Welding Problems

porous welds
WHY
1. Short arc with exception of low hydrogen and stainless
2. Insufficient puddling time
3. Impaired base metal
4. Poor electrode
5. Improper shield coverage

WHAT TO DO
1. Check impurities in base metal
2. Allow sufficient puddling time for gases to escape
3. Use proper current
4. Weave your weld to eliminate pin holes
5. Use proper electrode for job
6. Hold longer arc
7. Check shield gas

cracked welds
WHY
1. Wrong electrode
2. Weld and parts sizes unbalanced
3. Faulty welds
4. Faulty preparation
5. Rigid joint

WHAT TO DO
1. Design structure to eliminate rigid joints
2. Heat parts before welding
3. Avoid welds in string beads
4. Keep ends free to move as long as possible
5. Make sound welds of good fusion
6. Adjust weld size to parts size
7. Allow joints a proper and uniform gap
8. Work with amperage as low as possible

poor penetration
WHY
1. Speed too fast
2. Electrode too large
3. Current too low
4. Faulty preparation

WHAT TO DO
1. Use enough current to obtain desired penetration—weld slowly
2. Select electrode according to welding groove size
3. Leave proper gap at bottom of weld

poor appearance
WHY
1. Faulty electrode
2. Overhang
3. Improper use of electrode
4. Wrong arc voltage and current

WHAT TO DO
1. Use a proper welding technique
2. Avoid overheating
3. Use a uniform weave
4. Avoid overly high current

warping
WHY
1. Shrinkage of weld metal
2. Faulty clamping of parts
3. Faulty preparation
4. Overheating at joint

WHAT TO DO
1. Peen joint edges before welding
2. Weld more rapidly
3. Avoid excessive space between parts
4. Preform parts before welding
5. Use proper sequence
6. Clamp or tack parts properly —back-up to cool
7. Adopt a proper welding procedure
8. Use high speed, moderate penetration process

poor fusion
WHY
1. Wrong speed
2. Current improperly adjusted
3. Faulty preparation
4. Improper electrode size

WHAT TO DO
1. Adjust electrode to match joint
2. Weave must be sufficient to melt sides of joint
3. Select proper current and voltage
4. Keep weld metal from flowing away from plates

undercutting
WHY
1. Faulty electrode or gun manipulation
2. Faulty electrode usage
3. Current too high

WHAT TO DO
1. Use a uniform weave in butt welding
2. Avoid using an overly large electrode
3. Avoid excessive weaving
4. Use moderate current, weld slowly
5. Hold electrode at safe distance from vertical plane in making horizontal fillet weld

brittle welds
WHY
1. Wrong electrode
2. Faulty preheating
3. Metal hardened by air

WHAT TO DO
1. Preheat at 300° to 500° F. if welding on medium carbon steel or certain alloy steels
2. Make multiple layer welds
3. Stress relieving after welding
4. Use low hydrogen processes for increased weld ductility

spatter
WHY
1. Arc blow
2. Current too high
3. Arc too long
4. Faulty electrodes

WHAT TO DO
1. Clean parts in weld area
2. Adjust current properly
3. Adjust voltage
4. Pick suitable electrode

magnetic blow
WHY
1. Magnetic fields cause the arc to deviate from its intended course

WHAT TO DO
1. Use steel blocks to alter magnetic path around arc
2. Divide the ground into parts
3. Weld in same direction the arc blows
4. Use a short arc length
5. Locate the ground properly on the work
6. Use A-C welding

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slight circular motion make the second, third, and fourth passes. This motion of the electrode permits greater control and better distribution of the weld metal. Remove all slag and oxides from the surface of each pass by chipping or wire brushing before applying additional beads to the joint.

WELDING DIFFICULTIES

Many of the welding difficulties in metal-arc welding are the same as in oxygas welding. A few such problems include undercut, cracked welds, poor fusion, and incomplete penetration.

Table 7-3 provides an illustration of the most common welding problems encountered during the arc-welding process and methods to correct them.

Every welder has the responsibility of making each weld the best one possible. You can produce quality welds by adhering to the rules that follow.

1. Use only high-quality welding machines, electrodes, and welding accessories.

2. Know the base material that you are working on.

3. Select the proper welding process that gives the highest quality welds for the base material used.

4. Select the proper welding procedure that meets the service requirement of the finished weldment.

5. Select the correct electrode for the job in question.

6. When preheating is specified or required make sure you meet the temperature requirements. In any case, do not weld on material that is below 32°F without first preheating.

7. Clean the base metal of all slag, paint, grease, oil, moisture, or any other foreign materials.

8. Remove weld slag and thoroughly clean each bead before making the next bead or pass.

9. Do not weld over cracks or porous tack welds. Remove defective tack welds before welding.

10. Be particularly alert to obtain root fusion on the first pass of fillet and groove welds.

11. When groove weld root gaps are excessive, build up one side of the joint before welding the pieces together.

12. When fillet weld root gaps are excessive, be sure you increase the size of the fillet weld to the size of the root gap to maintain the strength requirement. In some cases, it is advantageous to make a groove weld l to avoid extremely large fillet welds.

13. Inspect your work after completion and immediately remove and replace any defective weld.

14. Observe the size requirement for each weld and make sure that you meet or slightly exceed the specified size.

15. Make sure that the finished appearance of the weld is smooth and that overlaps and undercuts have been repaired.

PIPE WELDING

Welding is the simplest and easiest way to join sections of pipe. The need for complicated joint designs and special threading equipment is eliminated. Welded pipe has reduced flow restrictions compared to mechanical connections and the overall installation costs are less. The most popular method for welding pipe is the shielded metal-arc process; however, gas shielded arc methods have made big inroads as a result of new advances in welding technology.

Pipe welding has become recognized as a profession in itself. Even though many of the skills are comparable to other types of welding, pipe welders develop skills that are unique only to pipe welding. Because of the hazardous materials that most pipelines carry, pipe welders are required to pass specific tests before they can be certified

In the following paragraphs, pipe welding positions, pipe welding procedures, definitions, and related information are discussed.

PIPE WELDING POSITIONS

You may recall from chapter 3 of this manual that there are four positions used in pipe welding (fig. 3-30). They are known as the *horizontal rolled position* (1G), the *horizontal fixed position* (5G), *pipe inclined fixed* (6G), and the *vertical position* (2G). Remember: these terms refer to the position of the pipe and not to the weld

PIPE WELDING PROCEDURES

Welds that you cannot make in a single pass should be made in interlocked multiple layers, not less than one layer for each 1/8 inch of pipe thickness. Deposit each layer with a weaving or oscillating motion. To prevent entrapping slag in the weld metal, you should clean each layer thoroughly before depositing the next layer.
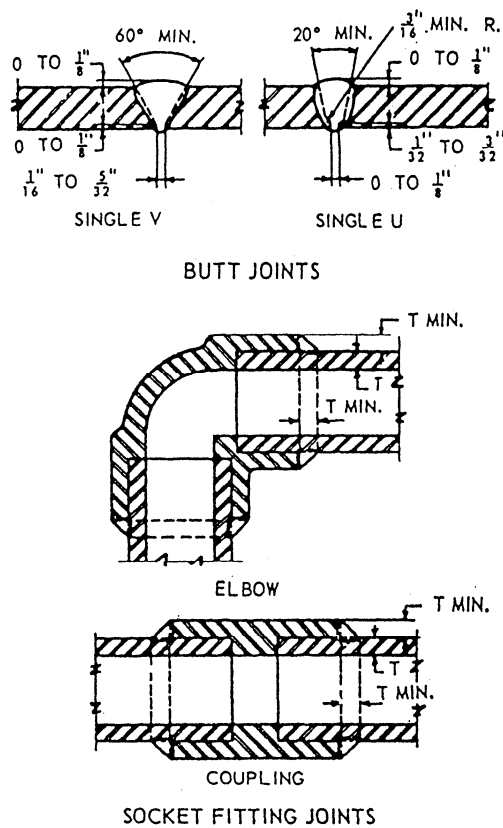
BUTT JOINTS

SOCKET FITTING JOINTS

Figure 7-42.—Butt joints and socket fitting joints.

Figure 7-43.—Flange connections.

Figure 7-44.—Flange alignment.

Butt joints are commonly used between pipes and between pipes and welded fittings. They are also used for butt welding of flanges and welding stubs. In making a butt joint, place two pieces of pipe end to end, align them, and then weld them. (See fig. 7-42.)

When the wall thickness of the pipe is 3/4 inch or less, you can use either the single V or single U type of butt joint; however, when the wall thickness is more than 3/4 inch, only the single U type should be used.

Fillet welds are used for welding slip-on and threaded flanges to pipe. Depending on the flange and type of service, fillet welds may be required on both sides of the flange or in combination with a bevel weld (fig. 7-43). Fillet welds are also used in welding screw or socket couplings to pipe, using a single fillet weld (fig. 7-42). Sometimes flanges require alignment. Figure 7-44 shows one type of flange square and its use in vertical and horizontal alignment.

Another form of fillet weld used in pipe fitting is a *seal weld* A seal weld is used primarily to obtain tightness and prevent leakage. Seal welds should not be considered as adding strength to the joint.
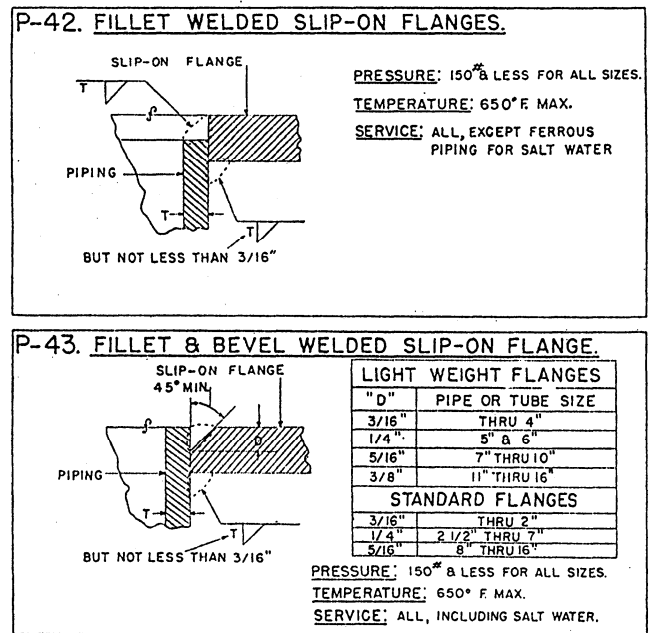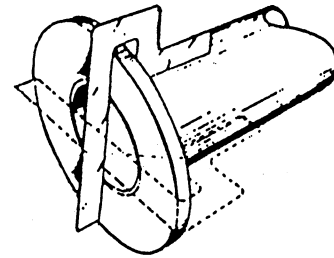
JOINT PREPARATION AND FIT-UP

You must carefully prepare pipe joints for welding if you want good results. Clean the weld edges or surfaces of all loose scale, slag, rust, paint, oil, and other foreign matter. Ensure that the joint surfaces are smooth and uniform. Remove the slag from flame-cut edges; however, it is not necessary to remove the temper color.

When you prepare joints for welding, remember that bevels must be cut accurately. Bevels can be made by machining, grinding, or using a gas cutting torch. In fieldwork, the welding operator usually must make the bevel cuts with a gas torch. When you are beveling, cut away as little metal as possible to allow for complete fusion and penetration. Proper beveling reduces the amount of filler metal required which, in turn, reduces time and expense. In addition, it also means less strain in the weld and a better job of design and welding.
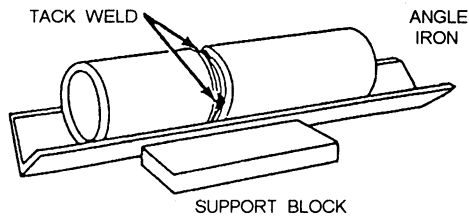
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Figure 7-45.—Angle iron jig.

Align the piping before welding and maintain it in alignment during the welding operation. The maximum alignment tolerance is 20 percent of the pipe thickness. To ensure proper initial alignment, you should use clamps or jigs as holding devices. Apiece of angle iron makes a good jig for a small-diameter pipe (fig. 7-45), while a section of channel or I-beam is more suitable for larger diameter pipe.

TACK WELDING

When welding material solidly, you may use tack welds to hold it in place temporarily. Tack welding is one of the most important steps in pipe welding or any other type of welding. The number of tack welds required depends upon the diameter of the pipe. For 1/2-inch pipe, you need two tacks; place them directly opposite each other. As a rule, four tacks are adequate for standard size of pipe. The size of a tack weld is determined by the wall thickness of the pipe. Be sure that a tack weld is not more than twice the pipe thickness in length or two thirds of the pipe thickness in depth. Tack welds should be the same quality as the final weld. Ensure that the tack welds have good fusion and are thoroughly cleaned before proceeding with the weld.

SPACERS

In addition to tack welds, spacers sometimes are required to maintain proper joint alignment. Spacers are accurately machined pieces of metal that conform to the dimensions of the joint design used. Spacers are sometimes referred to as chill rings or backing rings, and they serve a number of purposes. They provide a means for maintaining the specified root opening, provide a convenient location for tack welds, and aid in the pipe alignment. In addition, spacers can prevent weld spatter and the formation of slag or icicles inside the pipe.

ELECTRODE SELECTION

Select the electrode that is best suited for the position and type of welding to be done. For the root pass of a multilayer weld, you need an electrode large enough,

yet not exceeding 3/16 inch, that ensures complete fusion and penetration without undercutting and slag inclusions.

Make certain the welding current is within the range recommended by the manufacturers of the welding machines and electrodes.

WEATHER CONDITIONS

Do not assign a welder to a job under any of the following conditions listed below unless the welder and the work area are properly protected:

- When the atmospheric temperature is less than 0°F

- When the surfaces are wet

- When rain or snow is falling, or moisture is condensing on the weld surfaces

- During periods of high wind

At temperatures between 0°F and 32°F, heat the weld area within 3 inches of the joint with a torch to a temperature warm to the hand before beginning to weld.

WEARFACING

The Seabee welder can greatly extend the life of construction equipment by the use of wearfacing procedures. Wearfacing is the process of applying a layer of special composition metal onto the surface of another type of metal for the purpose of reducing wear. The selection of a wearfacing alloy for application is based on the ability of the alloy to withstand impact or abrasion. Impact refers to a blow or series of blows to a surface that results in fracture or gradual deterioration. Abrasion is the grinding action that results when one surface slides, rolls, or rubs against another. Under high-compressive loads, this action can result in gouging.

Alloys that are abrasion resistant are poor in withstanding impact. Conversely, those that withstand impact well are poor in resisting abrasion; however, there are many alloys whose wearfacing properties fall between the two extremes. These alloys offer some protection against abrasion and withstand impact well.

WORKPIECE PREPARATION

Before you wear-face a workpiece, all dirt, oil, rust, grease, and other foreign matter must be removed. If you do not, your finished product will be porous and subject to spalling. You also need a solid foundation; therefore, repair all cracks and remove any metal that is fatigued or rolled over.
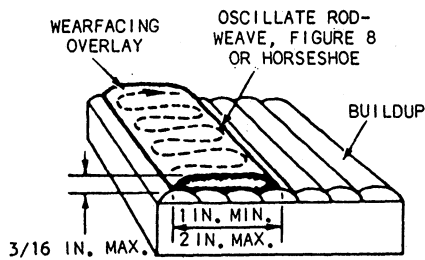
Figure 7-46.—Wearfacing techniques.

PREHEATING

Depending on the type of metal, sometimes it is necessary to preheat the base metal to lessen distortion, to prevent spalling or cracking, and to avoid thermal shock The preheating temperature depends on the carbon and alloy content of the base metal. In general, as carbon content increases so does the preheating temperature. Improper heating can adversely affect a metal by reducing its resistance to wear, by making it hard and brittle, or by making it more prone to oxidation and scaling.

To preheat properly, you must know the composition of the base metal. A magnet can be used to determine if you are working with carbon steel or austenitic manganese steel. Carbon steel is magnetic, but be careful because work-hardened austenitic manganese steel is also magnetic. Make sure that you check for magnetism in a nonworked part of the austenitic manganese steel. There are other ways to tell the difference between metals, such as cast iron and cast steel. Cast iron chips or cracks, while cast steel shaves. Also, some metals give off telltale sparks when struck by a chisel.

In preheating, you should raise the surface temperature of the workpiece to the desired point and then soak it until the heat reaches its core. After wearfacing, cool the work places slowly.
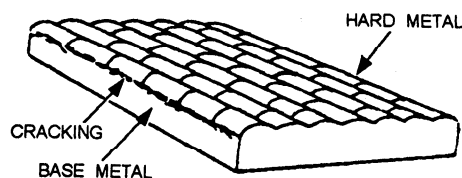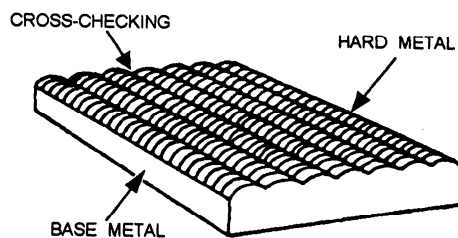
TECHNIQUES

Where possible, position the workpiece for down-hand welding. This allows you to finish the job quicker and at less cost.

The building up and wearfacing of cast iron is not generally recommended because cast iron tends to crack. However, some cast-iron parts that are subject to straight abrasion can be wearfaced successfully. You must preheat these parts to temperatures of 1000°F to 1200°F and then allow them to cool slowly after wearfacing. Peening deposits on cast iron helps to relieve stresses after welding.

Welding materials for building up worn parts differ from those used in wearfacing the same parts. Before wearfacing a badly worn part, you must first build it up to 3/16 to 3/8 of an inch of its finished size. The buildup material must be compatible with both the base metal and the wearfacing overlay as well as being strong enough to meet the structural requirements. Also, they must have the properties that enable them to resist cold flowing, mushing under high-compressive loads, and plastic deformation under heavy impact. Without these properties, the buildup materials cannot support the wearfacing overlay. When the overlay is not properly supported, it will span.

Many times high-alloy wearfacing materials are deposited on the parts before they are placed in service. The maximum allowable wear is usually no more than two layers deep (1/4 inch) before wearfacing. Try to deposit the wearfacing alloy in layers that are not too thick. Thick layers creates more problems than no overlay at all. Usually you only need two layers. The frost layer produces an admixture with the base metal; the second forms a wear-resistant surface.

In wearfacing built-up carbon-steel parts, maintain high interpass temperatures and use a weaving bead, rather than a stringer bead. (See fig. 7-46.) Limit the thickness of a single pass bead to 3/16 inch. Use the same technique for each layer and avoid severe quenching.

Deposits made with high-alloy electrodes should check on the surface. Checking reduces residual

Figure 7-47.—Comparison between cross-checking and cracking.
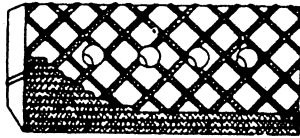
7-28

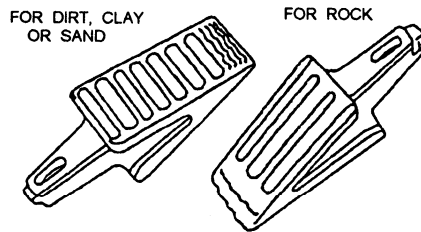Figure 7-48.—Wearfacing bulldozer end bits.

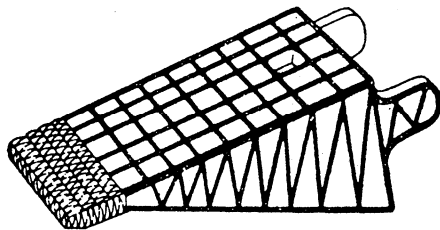Figure 7-49.—Wearfacing shovel teeth.

Figure 7-50.—Waffle or crosshatching.

(locked-in) stresses. Without checking, the combination of residual stresses and service stresses may exceed tensile strength and cause deep cracks or spalling (fig. 7-47). Be sure to induce checking if it does not occur naturally or if it is unlikely to occur, as in large parts where heat builds up. You can bring on checking by sponging the deposit with a wet cloth or by spraying it with a fine mist of water. Also you can speed up checking by occasionally striking it with a hammer while it is cooling. When a check-free deposit is required, use a softer alloy and adjust preheating and postheating requirements.

Bulldozer Blades

Bulldozer blades are wear-faced by placing the end bits in the flat position and welding beads across the outer corners and along the edges. Be sure to preheat the high-carbon blades before wearfacing. On worn end bits, weld new corners and then wear-face (fig. 7-48).

Shovel teeth

Wear-face shovel teeth when they are new and before being placed into service. The weld bead pattern used in wearfacing can have a marked effect on the service life of the teeth. Wear-face shovel teeth that work mainly in rock with beads running the length of each tooth (fig. 7-49). This allows the rock to ride on the hard metal beads. Teeth that are primarily used to work in dirt, clay, or sand should be wear-faced with beads running across the width of each tooth, perpendicular to the direction of the material that flows past the teeth. (See fig. 7-49.) This allows the material to fill the spaces between the beads and provide more protection to the base metal. Another effective pattern is the waffle or crosshatch (fig. 7-50). The wearfacing is laid on the top and sides of each tooth, 2 inches from its point. Stringer beads behind a solid deposit reduce wash (fig. 7-51).
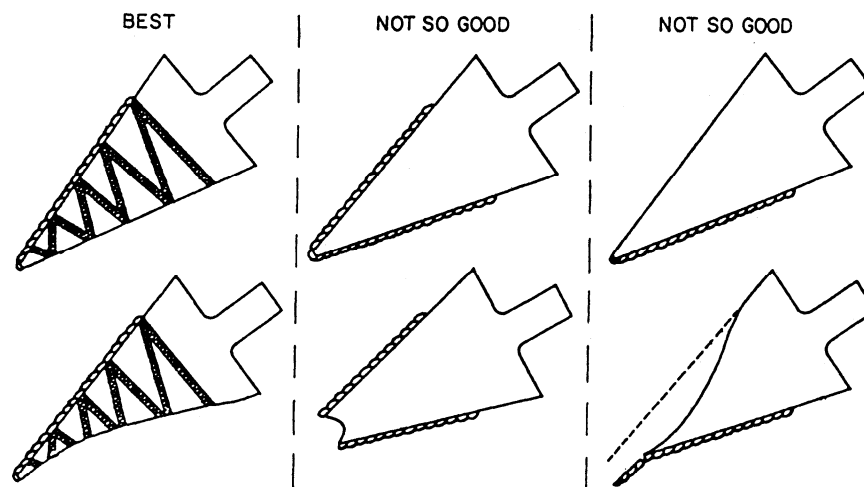

Figure 7-51.—Comparison of wearfacing patterns for shovel teeth.

THICKNESS OF PLATE INCHES	CURRENT SETTING AND CARBON DIA.			
	300 AMPS. 1/2 IN. DIA.	500 AMPS. 5/8 IN. DIA.	700 AMPS. 3/4 IN. DIA.	1000 AMPS. 1 IN. DIA.
	SPEED OF CUTTING IN MINUTE PER FOOT			
1/2	3.5	2.0	1.5	1.0
3/4	4/7	3.0	2.0	1.4
1	6.8	4.1	2.9	2.0
1-1/4	9.8	5.6	4.0	2.9
1-1/2	...	8.0	5.8	4.0
1-3/4	...	...	8.0	5.3
2	...	...	...	7.0

More information on wearfacing applications may be obtained from the *NCF Welding Materials Handbook,* NAVFAC P-433.

CARBON-ARC CUTTING

Metals can be cut cleanly with a carbon electrode arc because no foreign metals are introduced at the arc. The cutting current should be 25 to 50 amps above the welding current for the same thickness of metal.

The carbon electrode point should be ground so that it is very sharp. During the actual cutting, move the carbon electrode in a vertical elliptical movement to undercut the metal; this aids in the removal of the molten metal. As in oxygen cutting, a crescent motion is preferred. Figure 7-52 shows the relative positions of the electrode and the work in the cutting of cast iron.
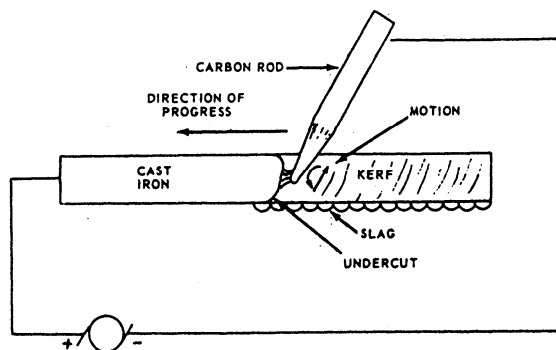

Figure 7-52.—Carbon-arc cutting on cast iron.

The carbon-arc method of cutting is successful on cast iron because the arc temperature is high enough to melt the oxides formed. It is especially important to undercut the cast-iron kerf to produce an even cut. Position the electrode so the molten metal flows away from the gouge or cutting areas. Table 7-4 is a list of cutting speeds, plate thicknesses, and current settings for carbon-arc cutting.

Because of the high currents required, the graphite form of carbon electrode is better. To reduce the heating effect on the electrode, you should not let it extend more than 6 inches beyond the holder when cutting. If the carbon burns away too fast, shorten the length that it extends out of the electrode holder to as little as 3 inches. Operating a carbon electrode at extremely high temperatures causes its surface to oxidize and burn away, resulting in a rapid reduction in the electrode diameter.

Carbon-arc cutting does not require special generators. Standard arc-welding generators and other items of arc-welding station equipment are suitable for use. Straight polarity direct current (DCSP) is always used.

Because of the high temperature and the intensity of the arc, choose a shade of helmet lens that is darker than the normal shade you would use for welding on the same thickness of metal. A number 12 or 14 lens shade is recommended for carbon-arc welding or cutting.

AIR CARBON-ARC CUTTING

Air carbon-arc cutting (ACC) is a process of cutting, piercing, or gouging metal by heating it to a molten state and then using compressed air to blow away the molten
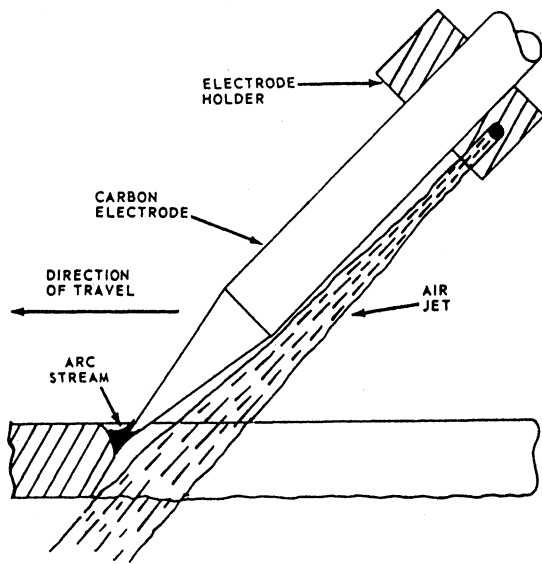
Figure 7-53.—Air carbon-arc cutting.

metal. Figure 7-53 shows the process. The equipment consists of a special holder, as shown in figure 7-54, that uses carbon or graphite electrodes and compressed air fed through jets built into the electrode holder. A push button or a hand valve on the electrode holder controls the air jet.

The air jet blows the molten metal away and usually leaves a surface that needs no further preparation for welding. The electrode holder operates at air pressures varying between 60 and 100 psig.

During use, bare carbon or graphite electrodes become smaller due to oxidation caused by heat buildup. Copper coating these electrodes reduces the heat buildup and prolong their use.

The operating procedures for *air carbon-arc cutting* and *gouging* are basically the same. The procedures are as follows:

- Adjust the machine to the correct current for electrode diameter.

- Start the air compressor and adjust the regulator to the correct air pressure. Use the lowest air pressure possible-just enough pressure to blow away the molten metal.

- Insert the electrode in the holder. Extend the carbon electrode 6 inches beyond the holder. Ensure that the electrode point is properly shaped.

- Strike the arc; then open the air-jet valve. The air-jet disc can swivel, and the V-groove in the disc automatically aligns the air jets along the electrode. The electrode is adjusted relative to the holder.

- Control the arc and the speed of travel according to the shape and the condition of the cut desired.
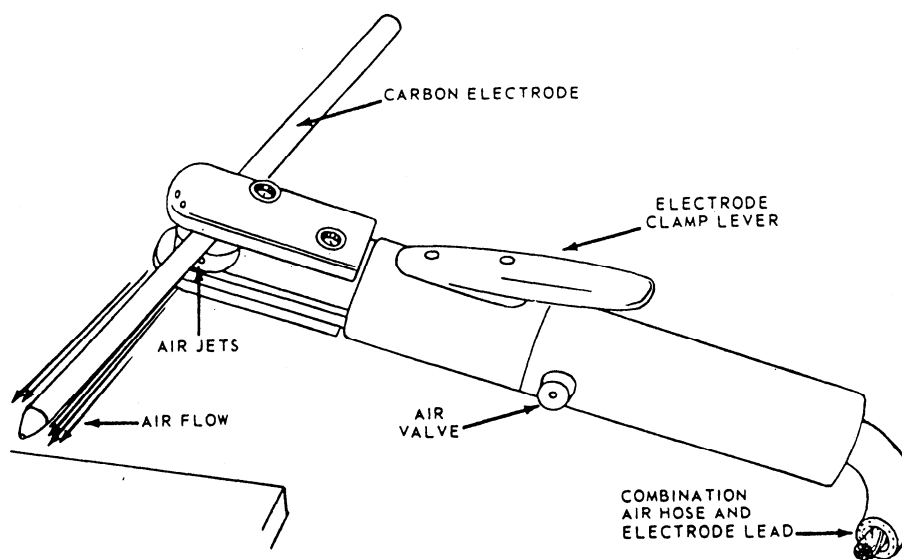

Figure 7-54.—Air carbon-arc electrode holder with carbon electrode installed.
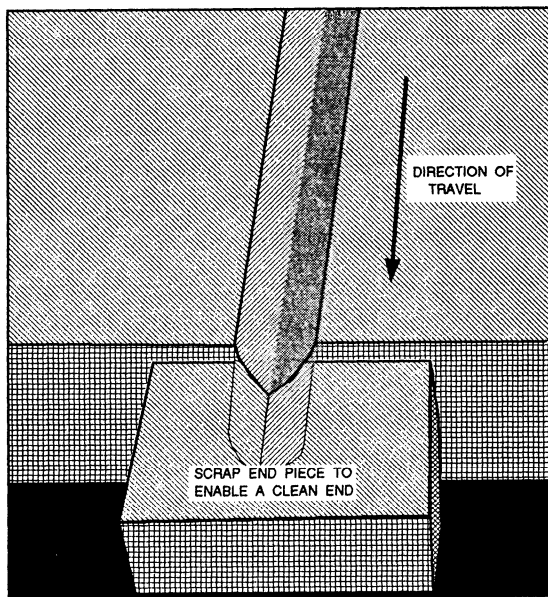
Figure 7-55.—V-groove gouged in 2-inch-thick carbon steel.

Figure 7-56.—Steel electrode being used to cut plate.

● Always cut away from the operator as molten metal sprays some distance from the cutting action. You may use this process to cut or gouge metal in the flat, horizontal, vertical, or overhead positions.

AIR CARBON-ARC GOUGING

Air carbon-arc gouging is useful in many various metalworking applications, such as metal shaping and other welding preparations. For gouging, hold the electrode holder so the electrode slopes back from the direction of travel. The air blast is directed along the electrode toward the arc. The depth and contour of the groove are controlled by the electrode angle and travel speed. The width of the groove is governed by the diameter of the electrode.

When cutting or gouging a shallow groove on the surface of a piece of metal, you should position the electrode holder at a very flat angle in relation to the work. The speed of travel and the current setting also affect the depth of the groove. The slower the movement and the higher the current, the deeper the groove. An example of a V-groove cut made in a 2-inch-thick mild steel plate by a machine guided carbon-arc air-jet is shown in figure 7-55.

METAL ELECTRODE ARC CUTTING

Metal can be removed with the standard electric arc, but for good gouging or cutting results, you should use special metal electrodes that have been designed for this type of work, Manufacturers have developed electrodes with special coatings that intensify the arc stream for rapid cutting. The covering disintegrates at a slower rate than the metallic center. This creates a deep recess that produces a jet action that blows the molten metal away (fig. 7-56). The main disadvantage of these electrodes is that the additional metal produced must be removed.

These electrodes are designed for cutting stainless steel, copper, aluminum, bronze, nickel, cast iron, manganese, steel, or alloy steels.

Atypical gouge-cutting operation is shown in figure 7-57. Notice that the angle between the electrode and plate is small (5 degrees or less). This makes it easy to remove the extra metal produced by the electrode.

The recommended current setting is as high as the electrode will take without becoming overheated to the point of cracking the covering. For 1/8-inch electrodes, the setting ranges between 125 and 300 amperes; for 5/32-inch electrodes, the setting ranges between 250 and 375 amperes; and for 3/16-inch electrodes, the setting ranges between 300 and 450 amperes. Use a very short arc, and when cutting takes place underwater, the coating must be waterproof.

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Figure 7-57.—Gouge-cutting operation using a solid core arc-cutting electrode.

Figure 7-58.—Circular magnetization (prod method).
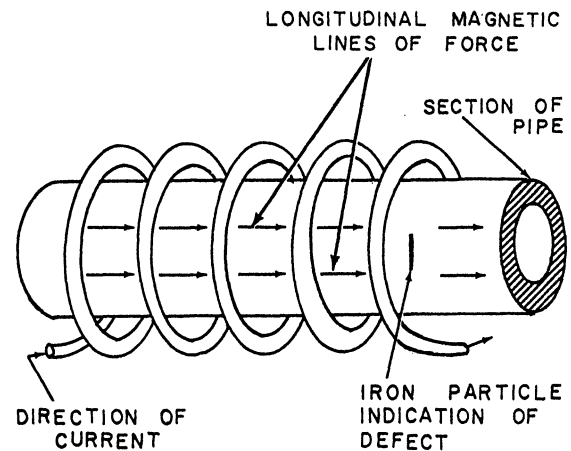
Figure 7-59.—Longitudinal magnetization (coil method).

WELDING QUALITY CONTROL

In the fabrication or repair of equipment, tests are used to determine the quality and soundness of the welds. Many different tests have been designed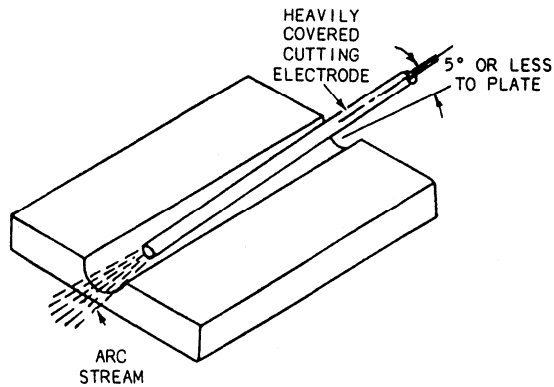 for specific faults. The type of test used depends upon the requirements of the welds and the availability of testing equipment. In this section, nondestructive and destructive testing are briefly discussed.

NONDESTRUCTIVE TESTING

Nondestructive testing is a method of testing that does not destroy or impair the usefulness of a welded item. These tests disclose all of the common internal and surface defects that can occur when improper welding procedures are used. A large choice of testing devices is available and most of them are easier to use than the destructive methods, especially when working on large and expensive items.

Visual Inspection

Visual inspection is usually done automatically by the welder as he completes his welds. This is strictly a subjective type of inspection and usually there are no definite or rigid limits of acceptability. The welder may use templates for weld bead contour checks. Visual inspections are basically a comparison of finished welds with an accepted standard. This test is effective only when the visual qualities of a weld are the most important.

Magnetic Particle Inspection

Magnetic particle inspection is most effective for the detection of surface or near surface flaws in welds.

It is used in metals or alloys in which you can induce magnetism. While the test piece is magnetized, a liquid containing finely ground iron powder is applied. As long as the magnetic field is not disturbed, the iron particles will form a regular pattern on the surface of the test piece. When the magnetic field is interrupted by a crack or some other defect in the metal, the pattern of the suspended ground metal also is interrupted. The particles of metal cluster around the defect, making it easy to locate.

You can magnetize the test piece by either having an electric current pass through it, as shown in figure 7-58, or by having an electric current pass through a coil of wire that surrounds the test piece, as shown in figure 7-59. When an electric current flows in a straight line from one contact point to the other, magnetic lines of

7-33

force are in a circular direction, as shown in figure 7-58. When the current flow is through a coil around the test piece, as shown in figure 7-59, the magnetic lines of force are longitudinal through the test piece.

When a defect is to show up as a disturbance in the pattern of the iron particles, the direction of the magnetic field must be at right angles to the major axis of the defect. A magnetic field having the necessary direction is established when the current flow is parallel to the major axis of the defect. Since the orientation of the defect is unknown, different current directions must be used during the test. As shown in figure 7-58, circular magnetism is induced in the test piece so you can inspect the piece for lengthwise cracks, while longitudinal magnetism, as shown in figure 7-59, is induced so you can inspect the piece for transverse cracks. In general, magnetic particle inspection is satisfactory for detecting surface cracks and subsurface cracks that are not more than 1/4 inch below the surface.

The type of magnetic particle inspection unit commonly used in the Navy is a portable low-voltage unit having a maximum magnetizing output of 1,000 amperes, either alternating or direct current. It is ready to operate when plugged into the voltage supply specified by the manufacturer. The unit consists of a magnetizing current source, controls, metering, three 10-foot lengths of flexible cable, and a prod kit. The prod kit includes an insulated prod grip fitted with an **ON**-**OFF** relay or current control switch, a pair of heavy copper contact prods, and two 5-foot lengths of flexible cable. Cable fittings are designed so that either end of the cable can be connected to the unit, to the prods, or to any other cable. The three outlets on the front of the unit make changing from alternating to direct current or vice versa very easy. The outlets are labeled as follows: left is ac, the center is **COMMON,** and the right is dc. One cable will always be plugged into the **COMMON** outlet, while the other cable is plugged into either the ac or dc outlet, depending upon what type of current the test requires. For most work, alternating current magnetization effectively locates fatigue cracks and similar defects extending through to the surface. When you require a more sensitive inspection to detect defects below the surface, use direct current.

You can use the unit with alternating or direct current in either of two ways: (1) with prods attached to the flexible cable and used as contacts for the current to pass into and out of a portion of the test piece, setting up circular magnetization in the area between the prods contact points, as shown in figure 7-58; or (2) with the flexible cable wrapped around the work to form a coil

that induces longitudinal magnetism in the part of the workpiece that is surrounded by the coiled cable (fig. 7-59).

Although you can use either of these two methods, the prod method is probably the easier to apply. Inmost instances, it effectively serves to detect surface defects. With the prods, however, only a small area of the test piece can be magnetized at any one time. This magnetized area is limited to the distance between prod contact points and a few inches on each side of the current path. To check the entire surface, you must test each adjacent area by changing the location of the prod contact points. Each area of the test piece must be inspected twice—once with the current passing through the metal in one direction and then with the current passing through the metal in a direction at right angles to the direction of the first test. One of the advantages of the prod method is that the current can be easily passed through the metal in any desired direction. Thus, when a given area is suspect, magnetic fields of different directions can be induced during the test.

The prod method is accomplished by adjusting the unit for a current output suitable for the magnetizing and testing of any particular kind of metal. The current setting required depends on the distance between prod contact points. With the prod kit that is supplied with the unit, the space between prod contact points is 4 to 6 inches. A current setting between 300 and 400 amperes is satisfactory when the material thickness is less than 3/4 inch. When the material thickness is over 3/4 inch, use 400 to 600 amperes. When the prod contact points are closer together, the same magnetic field force can be obtained with less current. With prods constantly at the same spacing, more current will induce a greater field strength.

After adjusting the unit, place the prods in position. Hold them infirm contact with the metal and turn on the current. Then apply magnetic particles to the test area with the duster bulb and look for any indicator patterns. With the current still on, remove the excess particles from the test area with a blower bulb and complete the inspection. Do not move the prods until after the current has been turned off. To do so could cause the current to arc, resulting in a flash similar to that occurring in arc welding.

When you use magnetic particle inspection, hairline cracks that are otherwise invisible are readily indicated by an unmistakable outline of the defect. Large voids beneath the surface are easier to detect than small voids, but any defect below the surface is more difficult to detect than one that extends through to the surface. Since

false indications frequently occur, you must be able to interpret the particle indications accurately.

The factors that help you interpret the test results include the amount of magnetizing current applied, the shape of the indication, the sharpness of the outline, the width of the pattern, and the height or buildup of the particles. Although these characteristics do not determine the seriousness of the fault, they do serve to identify the kind of defect.

The indication of a crack is a sharp, well-defined pattern of magnetic particles having a definite buildup. This indication is produced by a relatively low-magnetizing current. Seams are revealed by a straight, sharp, fine indication. The buildup of particles is relatively weak, and the magnetizing current must be higher than that required to detect cracks. Small porosity and rounded indentations or similar defects are difficult to detect for inexperienced inspectors. A high-magnetizing current continuously applied is usually required. The particle patterns for these defects are fuzzy in outline and have a medium buildup.

The specifications governing the job determine whether or not an indicated defect is to be chipped or ground out and repaired by welding. Surface cracks are always removed and repaired. Indications of subsurface defects detected by magnetic particle inspection are evaluated by the inspector. When the indication is positive, the standard policy is to grind or chip down to solid metal and make the repair. Unless the inspector can differentiate accurately between true and false indications, the use of magnetic particle inspection should be restricted to the detection of surface defects, for which this application is almost foolproof.

After the indicated defects have been repaired, you should reinspect the areas to ensure that the repair is sound. The final step in magnetic particle inspection, is to demagnetize the workpiece. This is especially important when the workpiece is made of high-carbon steel. Demagnetization is essential when you use direct current to induce the magnetic field; however, it is not as necessary when alternating current was used in the test. In fact, the usual demagnetization procedure involves placing the workpiece in an ac coil or solenoid and slowly withdrawing it while current passes through the coil.

Demagnetization can be accomplished with the portable unit if a special demagnetizer is not available. To demagnetize with the portable unit, form a coil of flexible cable around the workpiece. Ensure that the cable is plugged into the unit for the delivery of alternating current. Set the current regulator to deliver a current identical to that used for the inspection and turn on the unit. Gradually decrease the current until the ammeter indicates zero. On large pieces, it may be necessary to demagnetize a small portion of the work at a time.

A check for the presence of a magnetic field may be made by using a small compass. A deviation of the needle from the normal position, when the compass is held near the workpiece, is an indication that a magnetic field is present. Also you can use an instrument called a field indicator to check for the presence of a magnetic field. This instrument usually comes with the magnetic particle inspection unit.

Liquid Penetrant Inspection

Liquid penetrant methods are used to inspect metals for surface defects that are similar to those revealed by magnetic particle inspection. Unlike magnetic particle inspection, which can reveal subsurface defects, liquid penetrant inspection reveals only those defects that are open to the surface.

Four groups of liquid penetrants are presently in use. Group I is a dye penetrant that is nonwater washable. Group II is a water washable dye penetrant. Group III and Group IV are fluorescent penetrants. Carefully follow the instructions given for each type of penetrant since there are some differences in the procedures and safety precautions required for the various penetrants.

Before using a liquid penetrant to inspect a weld, remove all slag, rust, paint, and moisture from the surface. Except where a specific finish is required, it is not necessary to grind the weld surface as long as the weld surface meets applicable specifications. Ensure the weld contour blends into the base metal without undercutting. When a specific finish is required, perform the liquid penetrant inspection before the finish is made. This enables you to detect defects that extend beyond the final dimensions, but you must make a final liquid penetrant inspection after the specified finish has been given.

Before using a liquid penetrant, clean the surface of the material very carefully, including the areas next to the inspection area. You can clean the surface by swabbing it with a clean, lint-free cloth saturated in a nonvolatile solvent or by dipping the entire piece into a solvent. After the surface has been cleaned, remove all traces of the cleaning material. It is extremely important to remove all dirt, grease, scale, lint, salts, or other

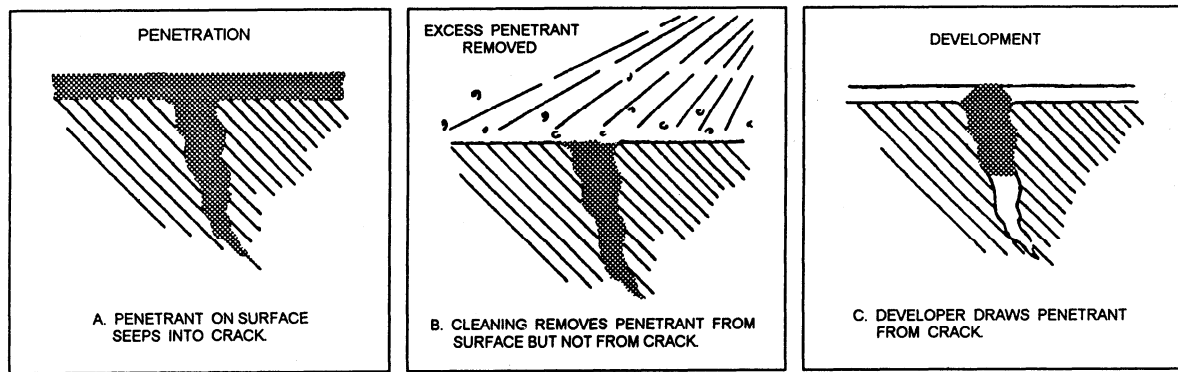| PENETRATION	EXCESS PENETRANT REMOVED	DEVELOPMENT
A. PENETRANT ON SURFACE SEEPS INTO CRACK.	B. CLEANING REMOVES PENETRANT FROM SURFACE BUT NOT FROM CRACK.	C. DEVELOPER DRAWS PENETRANT FROM CRACK.

Figure 7-60.—Liquid penetrant inspection.

materials and to make sure that the surface is entirely dry before using the liquid penetrant.

Maintain the temperature of the inspection piece and the liquid penetrant in the range of 50°F to 100°F. Do not attempt to use the liquid penetrant when this temperature range cannot be maintained. Do not use an open flame to increase the temperature because some of the liquid penetrant materials are flammable.

After thoroughly cleaning and drying the surface, coat the surface with the liquid penetrant. Spray or brush on the penetrant or dip the entire piece into the penetrant. To allow time for the penetrant to soak into all the cracks, crevices, or other defects that are open to the surface, keep the surface of the piece wet with the penetrant for a minimum of 15 or 30 minutes, depending upon the penetrant being used.

After keeping the surface wet with the penetrant for the required length of time, remove any excess penetrant from the surface with a clean, dry cloth, or absorbent paper towel. Then dampen a clean, lint-free material with penetrant remover and wipe the remaining excess penetrant from the test surface. Next, allow the test surface to dry by normal evaporation or wipe it dry with a clean, lint-free absorbent material. In drying the surface, avoid contaminating it with oil, lint, dust, or other materials that would interfere with the inspection.

After the surface has dried, apply another substance, called a developer. Allow the developer (powder or liquid) to stay on the surface for a minimum of 7 minutes before starting the inspection. Leave it on no longer than 30 minutes, thus allowing a total of 23 minutes to evaluate the results.

The following actions take place when using dye penetrants. First, the penetrant that is applied to the surface of the material will seep into any passageway open to the surface, as shown in figure 7-60, view A. The penetrant is normally red in color, and like penetrating oil, it seeps into any crack or crevice that is open to the surface. Next, the excess penetrant is removed from the surface of the metal with the penetrant remover and a lint-free absorbent material. Only the penetrant on top of the metal surface is removed (fig. 7-60, view B), leaving the penetrant that has seeped into the defect.

Finally, the white developer is applied to the surface of the metal, as shown in figure 7-60, view C. The developer is an absorbing material that actually draws the penetrant from the defect. Therefore, the red penetrant indications in the white developer represent the defective areas. The amount of red penetrant drawn from the defective areas indicates the size and sometimes the type of defect. When you use dye penetrants, the lighting in the test area must be bright enough to enable you to see any indications of defects on the test surface.

The indications you see during a liquid penetrant inspection must be carefully interpreted and evaluated. In almost every inspection, some insignificant indications are present. Most of these are the result of the failure to remove all the excess penetrant from the surface. At least 10 percent of all indications must be removed from the surface to determine whether defects are actually present or whether the indications are the result of excess penetrant. When a second inspection does not reveal indications in the same locations, it is usually safe to assume that the first indications were false.

Remove all penetrant inspection materials as soon as possible after the final inspection has been made. Use water or solvents, as appropriate. Since some of the liquid penetrant materials are flammable, do not use them near open flames, and do not apply them to any surface that is at a temperature higher than 100°F. In addition to being flammable, many solvents are poisonous in the vapor form and highly imitating to the skin in the liquid form.

Radiographic Inspection

Radiographic inspection is a method of inspecting weldments by the use of rays that penetrate through the welds. X rays or gamma rays are the two types of waves used for this process. The rays pass through the weld and onto a sensitized film that is in direct contact with the back of the weld. When the film is developed, gas pockets, slag inclusions, cracks, or poor penetration will be visible on the film.

Because of the danger of these rays, only qualified personnel are authorized to perform these tests. As Seabees, you will rarely come in contact with these procedures.

Ultrasonic Inspection

Ultrasonic inspection of testing uses high-frequency vibrations or waves to locate and measure defects in welds. It can be used in both ferrous and nonferrous materials. This is an extremely sensitive system and can locate very fine surface and subsurface cracks as well as other types of defects. All types of joints can be tested.

This process uses high-frequency impulses to check the soundness of the weld. In a good weld, the signal travels through the weld to the other side and is then reflected back and shown on a calibrated screen. Irregularities, such as gas pockets or slag inclusions, cause the signal to reflect back sooner and will be displayed on the screen as a change in depth. When you use this system, most all types of materials can be checked for defects. Another advantage of this system is that only one side of the weld needs to be exposed for testing.

Eddy Current Testing

Eddy current is another type of testing that uses electromagnetic energy to detect faults in weld deposits and is effective for both ferrous and nonferrous materials. As a Seabee, you will rarely use this type of testing in the field.

Eddy current testing operates on the principle that whenever a coil carrying a high-frequency alternating current is placed next to a metal, an electrical current is produced in the metal by induction. This induced current is called an *eddy current.*

The test piece is exposed to electromagnetic energy by being placed in or near high-frequency ac current coils. The differences in the weld cause changes in the impedance of the coil, and this is indicated on electronic instruments. When there are defects, they show up as a change in impedance, and the size of the defect is shown by the amount of this change.

DESTRUCTIVE TESTING

In destructive testing, sample portions of the welded structures are required. These samples are subjected to loads until they actually fail. The failed pieces are then studied and compared to known standards to determine the quality of the weld. The most common types of destructive testing are known as *free bend, guided bend, nick-break, impact, fillet welded joint, etching,* and *tensile* testing. The primary disadvantage of destructive testing is that an actual section of a weldment must be destroyed to evaluate the weld. This type of testing is usually used in the certification process of the welder.

Some of the testing requires elaborate equipment that is not available for use in the field. Three tests that may be performed in the field without elaborate equipment are the free-bend test, the guided-bend test, and the nick-break test.

Free-Bend Test

The FREE-BEND TEST is designed to measure the ductility of the weld deposit and the heat-affected area adjacent to the weld. Also it is used to determine the percentage of elongation of the weld metal. Ductility, you should recall, is that property of a metal that allows it to be drawn out or hammered thin.

The first step in preparing a welded specimen for the free-bend test is to machine the welded reinforcement crown flush with the surface of the test plate. When the weld area of a test plate is machined, as is the case of the guided-bend as well as in the free-bend test, perform the machining operation in the opposite direction that the weld was deposited.

The next step in the free-bend testis to scribe two lines on the face of the filler deposit. Locate these lines
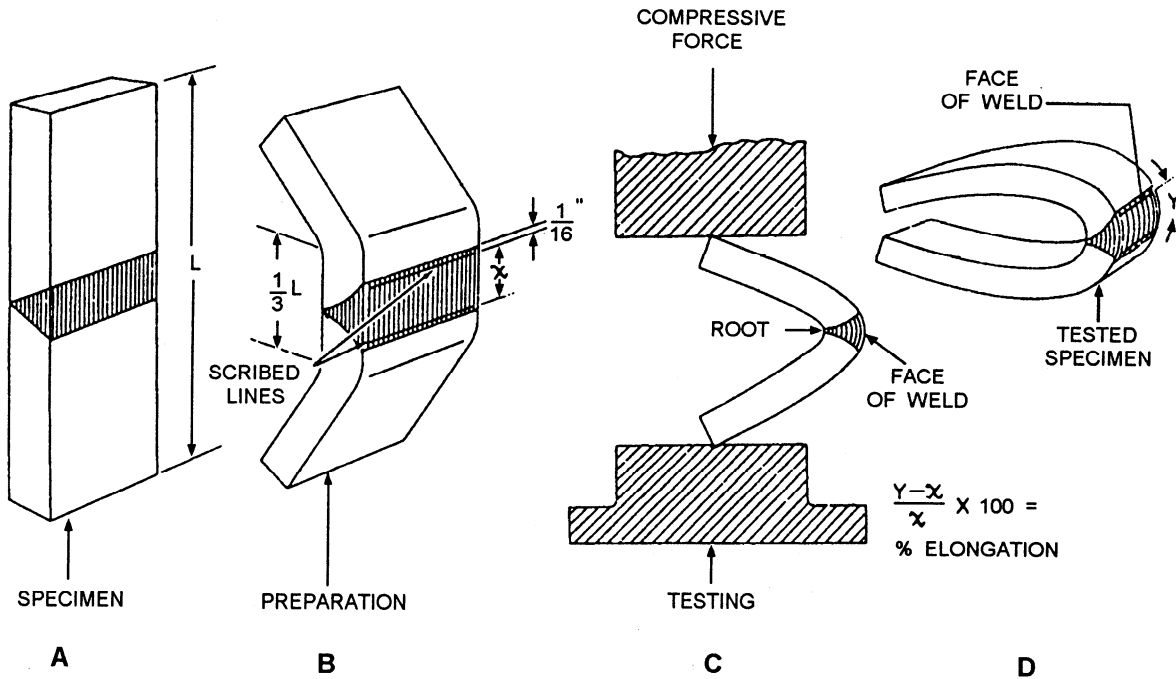
Figure 7-61.—Free-bend test
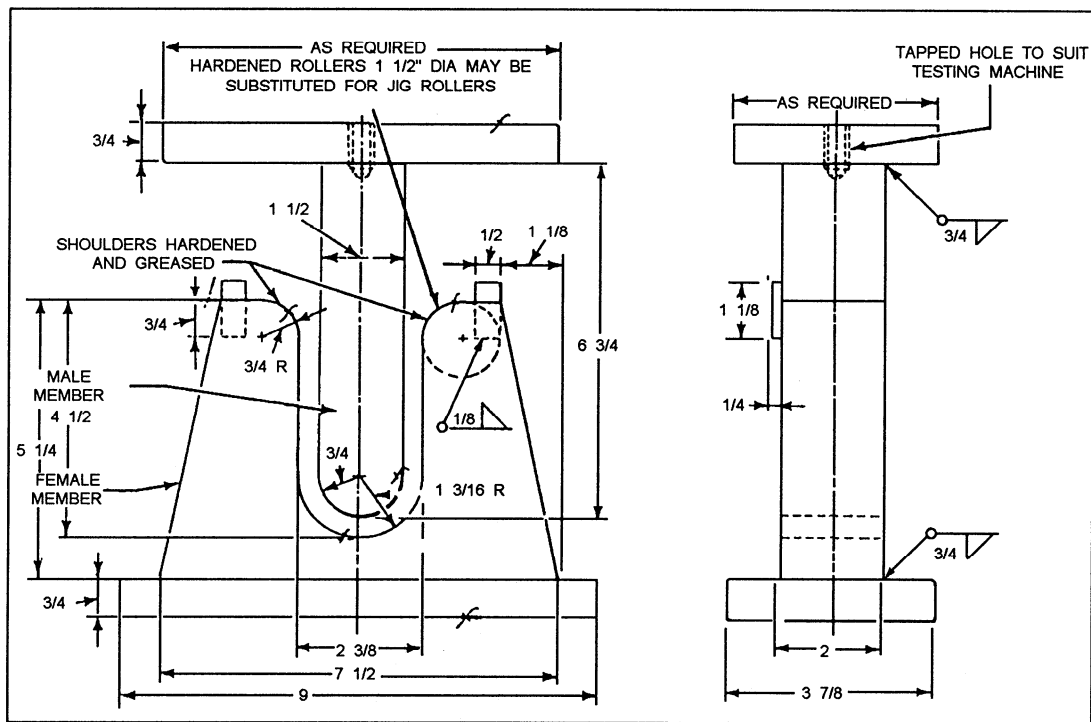
Figure 7-62.—Guided-bend test jig.

1/16 inch from each edge of the weld metal, as shown in figure 7-61, view B. Measure the distance, in inches, between the lines to the nearest 0.01 inch and let the resulting measurement equal (x). Then bend the ends of

the test specimen until each leg forms an angle of 30 degrees to the original centerline.

With the scribed lines on the outside and the piece placed so all the bending occurs in the weld, bend the

7-38

Figure 7-63.—Guided-bend test specimens.

test piece by using a hydraulic press or similar machine. When the proper precautions are taken, a blacksmith's forging press or hammer can be used to complete the bending operation. If a crack more than 1/16 inch develops during the test, stop the bending because the weld has failed; otherwise, bend the specimen flat. After completing the test, measure the 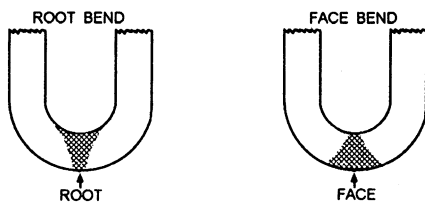distance between the scribed lines and call that measurement (y). The percentage of elongation is then determined by the formula:

$$\frac{Y-X}{X} \times 100 = \% \ elongation$$

Requirements for a satisfactory test area minimum elongation of 15 percent and no cracks greater than 1/16 inch on the face of the weld.

Guided-Bend Test

You use the GUIDED-BEND TEST to determine the quality of weld metal at the face and root of a welded joint. This test is made in a specially designed jig. An example of one type of jig is shown in figure 7-62.

The test specimen is placed across the supports of the die. A plunger, operated from above by hydraulic pressure, forces the specimen into the die. To fulfill the requirements of this test, you must bend the specimen 180 degrees—the capacity of the jig. No cracks should appear on the surface greater than 1/8 inch. The face-bend tests are made in this jig with the face of the weld in tension (outside), as shown in figure 7-63. The root-bend tests are made with the root of the weld in tension (outside), as shown in figure 7-63.

Figure 7-64 shows a machine used for making the guided-bend test. It is used in many welding schools and
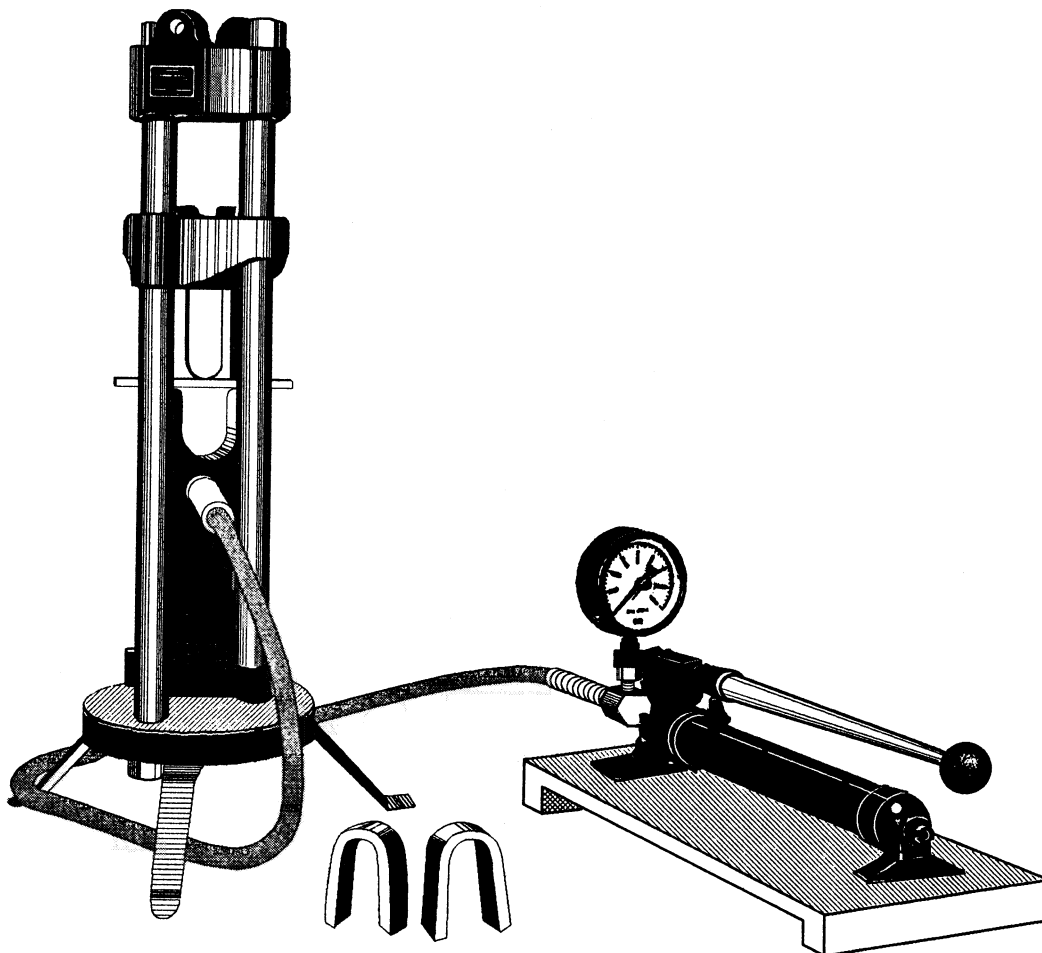

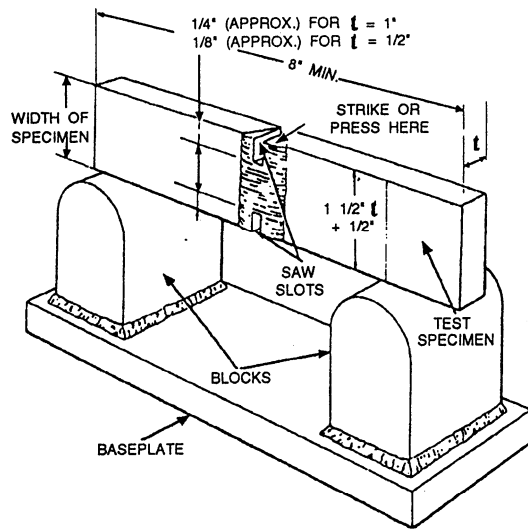**Figure 7-64.—Testing machine for making guided-bend tests.**

Figure 7-65.—Nick-break test of a butt weld.

which the test piece bends by the position of an auxiliary hand that is carried along by the gauge pointer. The hand remains at the point of maximum load after the pointer returns to zero.

Nick-Break Test

The NICK-BREAK TEST is useful for determining the internal quality of the weld metal. This test reveals various internal defects (if present), such as slag inclusions, gas pockets, lack of fusion, and oxidized or burned metal. To accomplish the nick-break test for checking a butt weld, you must first flame-cut the test specimens from a sample weld (fig. 7-65). Make a saw cut at each edge through the center of the weld. The depth of cut should be about 1/4 inch.

Next, place the saw-nicked specimen on two steel supports, as shown in figure 7-65. Using a heave hammer, break the specimen by striking it in the zone where you made the saw cuts. The weld metal exposed in the break should be completely fused, free from slag inclusions, and contain no gas pockets greater than 1/16 inch across their greatest dimension. There should not be more than six pores or gas pockets per square inch of exposed broken surface of the weld.

Impact Test

You use the IMPACT TEST to check the ability of a weld to absorb energy under impact without

testing laboratories for the daily testing of specimens. Simple in construction and easy to use, it works by hydraulic pressure and can apply a direct load up to 40,000 pounds, and even more on small specimens. When you make the test, position the specimen in the machine as previously indicated and start pumping the actuator. Keep your eye on the large gauge and watch the load increase. You will know the actual load under

Figure 7-66.—Test pieces for impact testing.
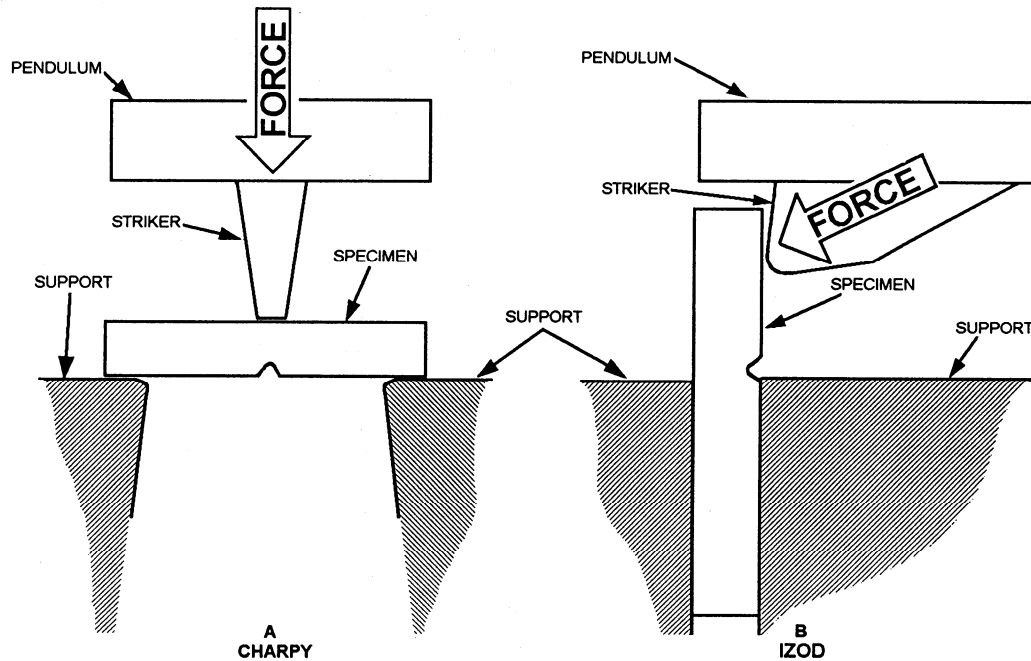
Figure 7-67.—Performing impact test.

fracturing. This is a dynamic test in which a test specimen is broken by a single blow, and the energy used in breaking the piece is measured in foot-pounds. This test compares the toughness of the weld metal with the base metal. It is useful in finding if any of the mechanical properties of the base metal were destroyed by the welding process.

The two kinds of specimens used for impact testing are known as *Charpy* and *Izod (fig.* 7-66). Both test pieces are broken in an impact testing machine. The only difference is in the manner that they are anchored. The Charpy piece is supported horizontally between two anvils and the pendulum strikes opposite the notch, as shown in figure 7-67, view A. The Izod piece is supported as a vertical cantilever beam and is struck on the free end projecting over the holding vise (fig. 7-67, view B).

Fillet-Welded Joint Test

You use the FILLET-WELDED JOINT TEST to check the soundness of a fillet weld. *Soundness* refers to the degree of freedom a weld has from defects found by visual inspection of any exposed welding surface. These defects include penetrations, gas pockets, and inclusions. Prepare the test specimen, as shown in figure 7-68. Now apply force at Point A

Figure 7-68.—Test plate for fillet weld test.

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Figure 7-69.—Rupturing fillet weld test plate.

(fig. 7-69) until a break occurs in the joint. This force may be applied by hydraulics or hammer blows.

In addition to checking the fractured weld for soundness, now is a good time to etch the weld to check for cracks.
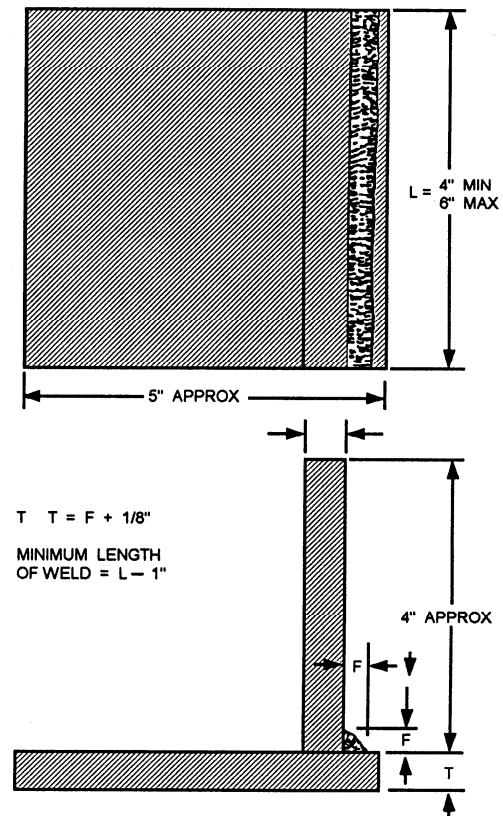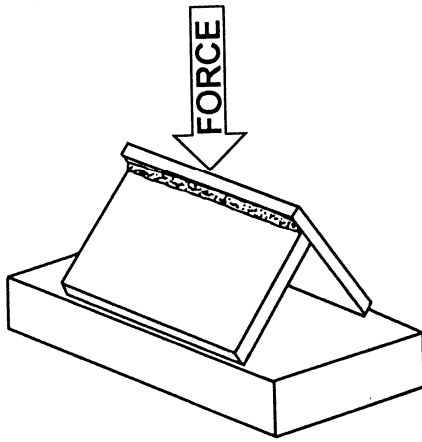
Etching Test

The ETCHING TEST is used to determine the soundness of a weld and also make visible the boundary between the base metal and the weld metal.

To accomplish the test, you must cut a test piece from the welded joint so it shows a complete transverse section of the weld. You can make the cut by either sawing or flame cutting. File the face of the cut and then polish it with grade 00 abrasive cloth. Now place the test piece in the etching solution.

The etching solutions generally used are hydrochloric acid, ammonium persulfate, iodine and potassium iodide, or nitric acid. Each solution highlights different defects and areas of the weld. The hydrochloric acid dissolves slag inclusions and enlarges gas pockets, while nitric acid is used to show the refined zone as well as the metal zone.

Tensile Strength Test

The term *TENSILE STRENGTH* may be defined as the resistance to longitudinal stress or pull and is measured in pounds per square inch of cross section. Testing for tensile strength involves placing a weld sample in a tensile testing machine and pulling on the test sample until it breaks.
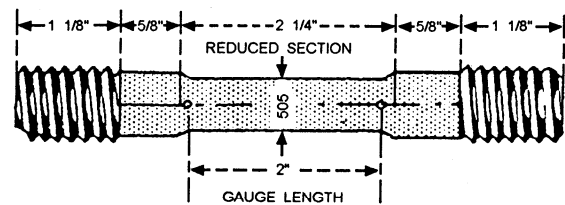

Figure 7-70.—Standard tensile test specimen.

The essential features of a tensile testing machine are the parts that pull the test specimen and the devices that measure the resistance of the test specimen. Another instrument, known as an extensometer or strain gauge, is also used to measure the strain in the test piece. Some equipment comes with a device that records and plots the stress-strain curve for a permanent record.

The tensile test is classified as a destructive test because the test specimen must be loaded or stressed until it fails. Because of the design of the test machine, weld samples must be machined to specific dimensions. This explains why the test is made on a standard specimen, rather than on the part itself. It is important that the test specimen represents the part. Not only must the specimen be given the same heat treatment as the part but it also must be heat-treated at the same time.

There are many standard types of tensile test specimens, and figure 7-70 shows one standard type of specimen commonly used. The standard test piece is an accurately machined specimen. Overall length is not a critical item, but the diameter and gauge length are. The 0.505-inch-diameter (0.2 square inch area) cross section of the reduced portion provides an easy factor to manipulate arithmetically. The 2-inch gauge length is the distance between strain-measuring points. This is the portion of the specimen where you attach the extensometer. In addition, you can use the gauge length to determine percent elongation.

The tensile test amounts to applying a smooth, steadily increasing load (or pull) on a test specimen and measuring the resistance of the specimen until it breaks. Even if recording equipment is not available, the testis not difficult to perform. During the test, you observe the behavior of the specimen and record the extensometer and gauge readings at regular intervals. After the specimen breaks and the fracturing load is recorded, you measure the specimen with calipers to determine the percent of elongation and the percent reduction in area. In addition, you should plot a stress-strain curve. From the data obtained, you can determine tensile strength,

yield point, elastic limit, modulus of elasticity, and other properties of the material.

SAFETY REGULATIONS

You, as the welder, must have a thorough KNOWLEDGE of the safety precautions relating to the job. That is not all; you should also consider it your responsibility to observe all of the applicable safety precautions. When welding, carelessness can cause serious injury to yourself as well as others.

Bear in mind the safety precautions for operating welding equipment can vary considerably because of the different types of equipment involved; therefore, only general precautions on operating metal arc-welding equipment are presented here. For specific instructions on the operation and maintenance of your individual equipment, consult the equipment manufacturer's instruction manual. In regards to general precautions, know your equipment and how to operate it. Use only approved welding equipment, and ensure that it is maintained properly.

l Before you start welding, ensure that the welding machine frame is grounded, that neither terminal of the welding generator is bonded to the frame, and that all electrical connections are secure. The ground connection must be attached firmly to the work, not merely laid loosely upon it.

● Keep welding cables dry and free of oil or grease. Keep the cables in good condition and always take appropriate steps to protect them from damage. When it is necessary to run cables some distance from the machine, lay them overhead, if at all possible, using adequate support devices.

● When you are using portable machines, make sure that the primary power cable is separate from the welding cables so they do not become entangled. Any portable equipment mounted on wheels should be securely blocked to prevent accidental movement during welding operations.

● When stopping work for any appreciable length of time, be sure to de-energize the equipment. When the equipment is not in use, you should completely disconnect it from its source of power.

● Keep the work area neat and clean. If at all possible, make it a practice to dispose the hot electrode stubs in a metal container.

Chapter 3 contains information on protective clothing, eye protection, and safe practices applicable to the personal safety of the operator and other persons who may be working nearby so that information will not be repeated here. If necessary, go back and review the section entitled "Safety" in chapter 3 before proceeding to the next chapter.

CHAPTER 8

GAS SHIELDED-ARC WELDING

The primary goal of any welding operation is to make a weld that has the same properties as the base metal. The only way to produce such-a weld is to protect the molten puddle from the atmosphere. In gas shielded-arc welding, briefly discussed in chapter 3,

you use a gas as a covering shield around the arc to prevent the atmosphere from contaminating the weld. Gas shielding makes it possible to weld metals that are otherwise impractical or difficult to weld by eliminating atmospheric contamination from the molten puddle. Figure 8-1 shows the basic principle of gas shielded-arc welding.

The two general types of gas shielded-arc welding processes are gas tungsten-arc welding (GTA) and gas metal-arc welding (GMA). GTA is often tilled *TIG* (tungsten inert gas) and GMA is referred to as *MIG* (metal inert gas). The term *inert* refers to a gas that will not combine chemically with other elements.

GAS TUNGSTEN-ARC WELDING—GTAW

Gas tungsten-arc welding is basically a form of arc welding; however, in gas tungsten-arc welding, the electrode is used only to create the arc. The electrode is not consumed in the weld as in the shielded metal-arc process. The gas tungsten-arc welding process generally produces welds that are far superior to those produced by metallic arc welding electrodes. Especially useful for welding aluminum, it also may be used for welding many other types of metals. The GTA process is most effective for joining metals up to 1/8 inch thick, although you can use it to weld thicker material.

As shown in figure 8-2, the basic GTA process involves an intense arc between the base metal and a

Figure 8-1.—Gas shielded-arc welding principle.

Figure 8-2.—GTA welding process.

Figure 8-3.—Power supply unit specifically designed for gas tungsten-arc welding.

tungsten electrode. The arc, the electrode, and the weld zone are surrounded by an inert gas (usually either helium or argon or a mixture of the two) that displaces the air and eliminates the possibility of weld contamination by the oxygen and nitrogen present in the atmosphere. The tungsten electrode has a high melting point that makes it virtually nonconsumable.

Specific advantages of gas tungsten-arc welding include the following:
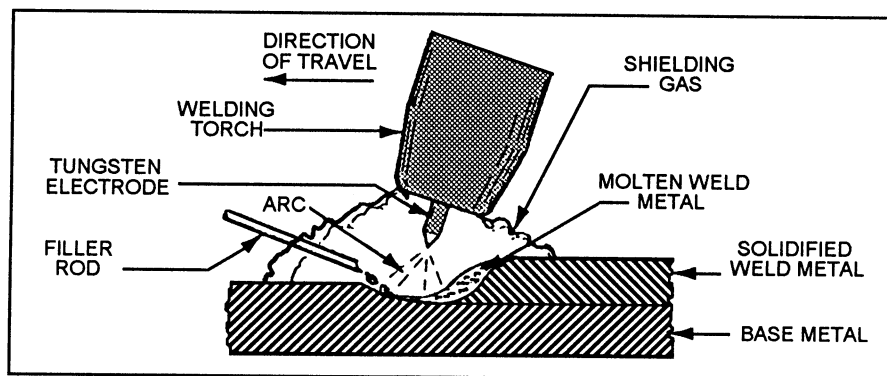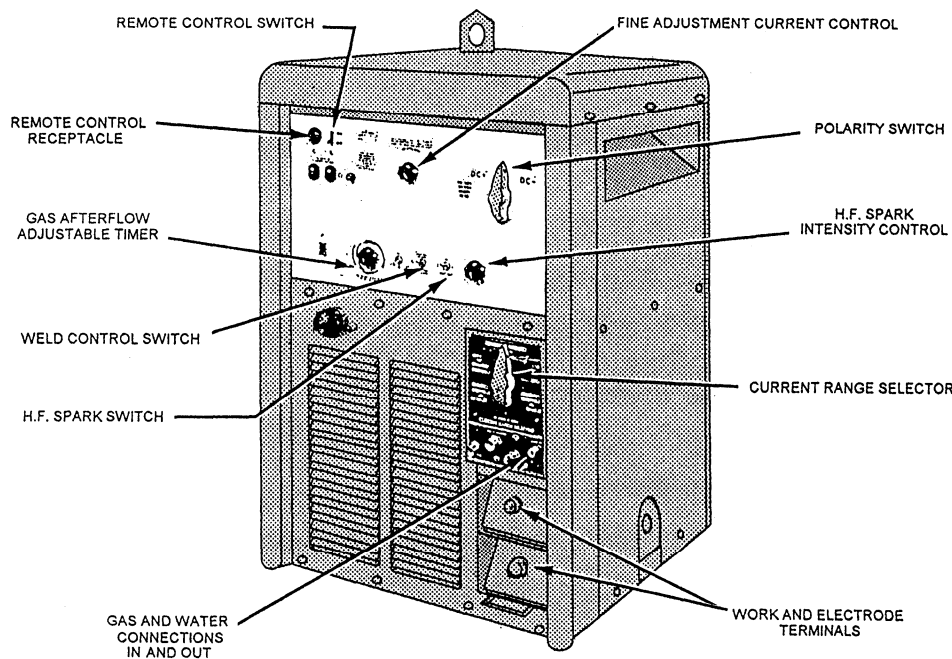
- Welding can be done in all positions.

- The weld is usually equal to the base metal in composition.

- Flux is not used; therefore, finished welds do not require cleaning of corrosive residue.

- Smoke or fumes are not present to obscure vision; therefore, you can easily see the welding process.

- Distortion of the base metal is minimal because the heat is concentrated in a small area.

- No splatter is produced because metal is not transferred across the arc.

GTA WELDING EQUIPMENT AND SUPPLIES

The equipment and supplies required for gas tungsten-arc welding consist of an electric power unit, shielding gas, a pressure-reducing regulator and flowmeter, an electrode holder (commonly called a torch), nonconsumable tungsten electrodes, filler rods, a supply of cooling water (when required), and personal protective gear.

Electric Power Unit

Most welding power sources can provide the current needed for GTA welding. The common welding machines, whether alternating current (at) or direct current (de), have their advantages in certain welding applications; however, they can be cumbersome and their hose and cable connections can create difficulties. Because of this, specially designed machines with all the necessary controls are available for gas tungsten-arc welding (fig. 8-3).

GTA power units are equipped with solenoid valves that turn the flow of shielding gas and cooling water on and off. They are also equipped with a hand- or foot-operated remote-control switch that turns the water and gas on and off. Some of these remote-control devices
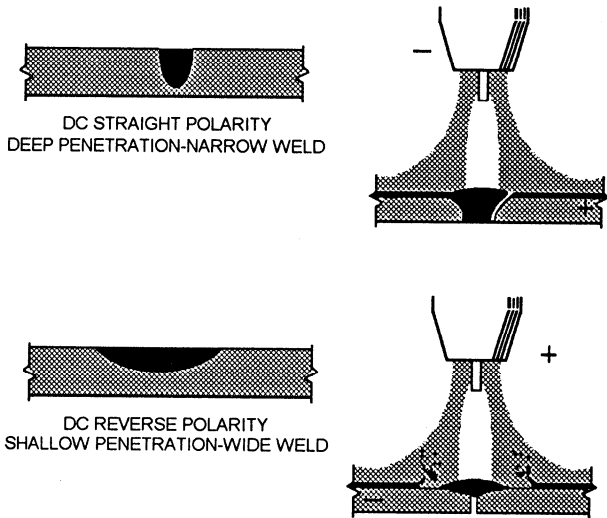
8-2

DC STRAIGHT POLARITY
DEEP PENETRATION-NARROW WELD

DC REVERSE POLARITY
SHALLOW PENETRATION-WIDE WELD

Figure 8-4.—Effects of polarity on the weld.

WORK (AND OPPOSITELY THE ELECTRODE)
ALTERNATELY POSITIVE AND NEGATIVE A C

DIRECT CURRENT
REVERSE POLARITY
A

DIRECT CURRENT
STRAIGHT POLARITY
B

ONE COMPLETE
CYCLE OF A C
C

Figure 8-5.—The ac welding cycle.

also turn the main welding current on and off at the same time. This not only allows the operator to start and stop without leaving the work but also to adjust the current while welding.

Most of these welding machines can produce both ac and dc current. The choice of ac or dc depends on the welding characteristics required.

DIRECT CURRENT.— As you learned in chapter 7, a direct-current welding circuit maybe either straight or reverse polarity. When the machine is set on straight polarity, the electrons flow from the electrode to the plate, concentrating most of the heat on the work With reverse polarity, the flow of electrons is from the plate to the electrode, thus causing a greater concentration of heat at the electrode. Because of this intense heat, the electrode tends to melt off; therefore, direct-current reverse polarity (DCRP) requires a larger diameter electrode than direct-current straight polarity (DCSP).

The effects of polarity on the weld are shown in figure 8-4. Notice that DCSP produces a narrow, deep weld. Since the heat is concentrated on the work, the welding process is more rapid and there is less distortion of the base metal. Overall, straight polarity is preferred over reverse polarity because you can achieve better welds.

DCRP forms a wide and shallow weld and is rarely used in the GTAW process. The exception to this is when it is used to weld sections of aluminum or magnesium. DCRP has excellent cleaning power that results from the

ACHF
DEEP PENETRATION-WIDE WELD

Figure 8-6.—ACHF combines the desired cleaning action of DCRP with the good penetration of DCSP.

action of positive-charged gas ions. When these gas ions strike the metal, they pierce the oxide film and form a path for the welding current to follow. This same cleaning action occurs in the reverse polarity half of an alternating-current welding cycle.

ALTERNATING CURRENT.— AS shown in figure 8-5, ac welding is actually a combination of DCSP and DCRP; however, the electrical characteristics of the oxides on the metal often prevent the current from flowing smoothly in the reverse polarity half of the cycle. This partial or complete stoppage of current flow *(rectification)* causes the arc to be unstable and sometimes go out. Ac welding machines were developed with a high-frequency current flow unit to prevent this rectification. The high-frequency current pierces the oxide film and forms a path for the welding current to follow. The effects of alternating current high-frequency *(ACHF)* are shown in figure 8-6. Notice that ACHF offers both the advantages of DCRP and DCSP. ACHF is excellent for welding aluminum.

Table 8-1.—Current Selection Guide for GTA Welding of Common Metals

Material	Alternating Current With High-Frequency Stabilization	With High-Frequency Starting Current	
		Straight Polarity	Reverse Polarity
Aluminum-up to 3/32 inch thick	1	2	N.R.
Aluminum-over 3/32 inch thick	1	N.R.	N.R.
Aluminum castings	1	N.R.	N.R.
Brass alloys	2	1	N.R.
Silcon copper	N.R.	1	N.R.
Monel	2	1	N.R.
Stainless steel	2	1	N.R.
Hard-surfacing alloys	2	1	N.R

Key: 1. Excellent Results
2. Good Results
N.R. Not Recommended

You can use table 8-1 as a guide for selecting the current for welding some of the more common metals. For more specific information, refer to the operator's manual for the specific machine you are using.

Torches

GTA welding torches are designed to conduct both welding current and inert gas to the weld zone. The torches can be either air or water cooled, depending on the welding current. Air-cooled torches are used for welding light-gauge materials at relatively low-current settings. Water-cooled torches are recommended for currents above 200 amperes. A sectional view of a GTA water-cooled torch is shown in figure 8-7. When you are using this type of torch, a circulating stream of water flows around the torch to keep it from overheating.
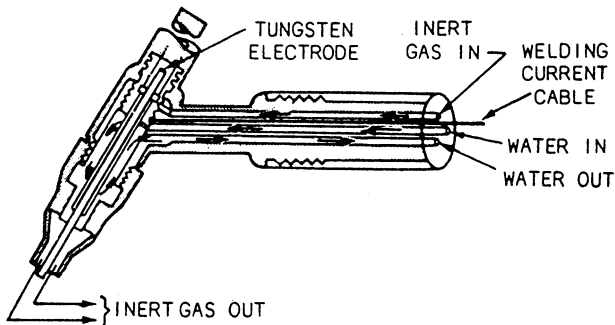
NOTE: To avoid torch overheating caused by clogging and flow restrictions, you must keep the water clean.

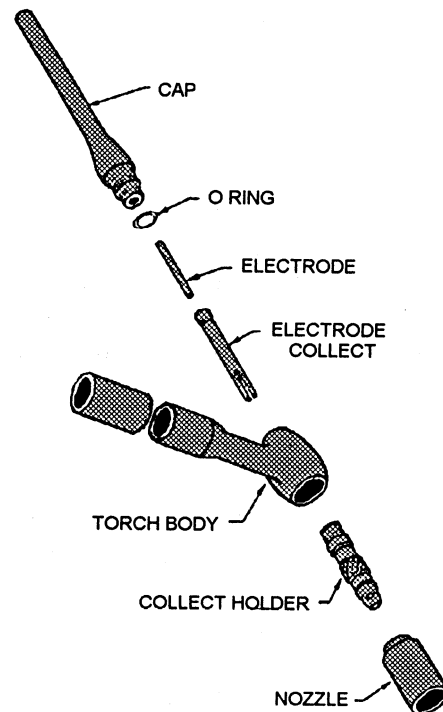The GTA welding torch carries the welding current and directs the gas to the weld area. The torch must have

Figure 8-7.—GTA water-cooled torch.

Figure 8-8.—GTA torch parts.

Table 8-2.—Approximate Cup Size for GTA Welding

TUNGSTEN ELECTRODE diameter (inches)	CUP ORIFICE diameter (inches)
1/16	1/4-3/8
3/32	3/8-7/16
1/8	7/16-1/2
3/16	1/2-3/4

Table 8-3.—Approximate Current Ranges for Tungsten Electrodes

Electrode Diameter Inches	Current, Amperes	
	Standard Tungsten Electrodes	Thoriated Tungsten Electrodes
0.04	10-60	15-80
1/16	40-120	60-150
3/32	100-160	140-250
1/8	150-210	225-350
5/32	190-275	300-450
3/16	250-350	400-550
1/4	300-490	500-800
5/16	450-600	

the proper insulation for the maximum current ranges to ensure 'operational safety. Current is transmitted-from the weld-rig machine through the power cable to a collet holding the tungsten electrode. A variety of collet sizes are available, depending on the diameter of the electrode. Figure 8-8 shows the various parts of a typical GTA torch.

Gas is fed to the welding zone through the torch nozzle that consists of a ceramic cup. Nozzles also are made of steel (chrome plated), plastic, and glass (Pyrex) materials. These nozzles (gas cups) vary in size, depending upon the type and size of torch and the diameter of the electrode. See table 8-2 for sizes.

Electrodes

The electrode should extend beyond the end of the gas cup a distance equal to its diameter for butt welding and slightly further for fillet welding. Selecting the right size electrode for each job is important to prevent electrode damage and poor welds caused by too high or too low a current. Excessive current causes tungsten particles to transfer to the weld, while not enough current allows the arc to wander emetically over the end of the electrode.

The diameter of the electrode selected for GTA welding is governed by the amount of welding current used. Remember: DCRP requires larger electrodes than DCSP. Recommended electrode sizes for various ranges of welding current are shown in table 8-3. These current ranges are broad. You should refer to the manufacturer's recommendations for specific current ranges and electrode sizes based on the type of material you are welding.

Basic diameters of nonconsumable electrodes are .040, 1/16, 3/32, and 1/8 of an inch. They are either pure tungsten or alloyed tungsten. The alloyed electrodes are of three types: 1% thorium alloy, 2% thorium alley, and zirconium alloy. Pure tungsten is routinely used with ac welding and is sufficient for most GTA welding operations. The thoriated types are normally used for DCSP welding. These electrodes give slightly better penetration and arc-starting characteristics over a wider range of current settings. The zirconium alloy is excellent for ac welding and has high resistance to contamination. The electrodes alloyed with thorium and zirconium are primarily used for critical weldments in the aircraft and missile industries.
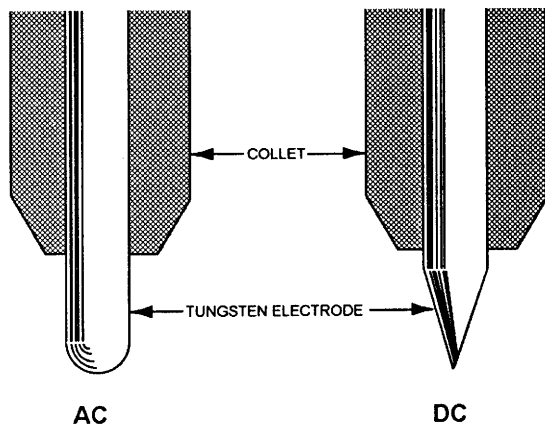
Figure 8-9.—Tungsten electrode shapes for ac and dc welding.

127.286

Figure 8-10.—Combination regulator and flowmeter.

Tungsten electrodes are usually color-coded at one end. A green color indicates that the rod is pure tungsten; yellow indicates a 1-percent thoriated tungsten rod; red indicates a 2-percent thoriated tungsten rod; and brown indicates that the rod is alloyed with zirconium.
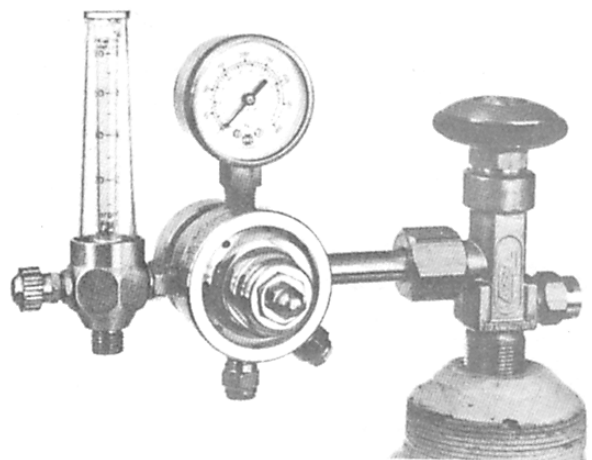
To produce good quality welds with the GTA process, you must shape the electrode properly. The general practice is to use a pointed electrode with dc welding and a spherical end with ac welding (fig. 8-9).

Shielding Gas

Shielding gas for GTA welding can be argon, he-lium, or a mixture of argon and helium. Argon is by far the most popular. When compared to helium, argon has greater cleaning action and provides a more stable arc. Argon is heavier than air; therefore, it provides a blanket over the weld that protects it from contaminants. Helium, being lighter than air, requires a higher gas flow than argon and is therefore more expensive to use. However, as a shielding gas, helium - allows greater penetration and faster welding speeds because the arc is hotter in the helium atmosphere than in the argon atmosphere. The opposite is true for GMA welding; therefore, a mixture of argon and helium is sometimes used in welding metals that require a higher heat input. Table 8-4 lists a selection of shielding gases recommended for various metals for both the GTA and GMA welding processes. Notice that for most GTA welding operations, you use pure argon.

Regulators

The primary difference between the regulators used for oxyfuel welding and for GTA/GMA welding is that the working pressure on the oxyfuel regulators is shown in pounds per square inch (psi) while the regulators used

Figure 8-11.—Cross section of flowmeter.

for GMA/GTA show the flow of shielding gas in cubic feet per hour (cfh) or liters per minute (lpm). Regulators used for GMA/GTA welding have a flowmeter instead of a working pressure gauge along with the cylinder pressure gauge. See figure 8-10.

The flowmeter consists of a plastic or glass tube that contains a loosely fitting ball. As the gas flows up the tube, it passes around the ball and lifts it up. The more

8-6

Table 8-4.—Selection of Shielding Gases for Various GMAW and GTAW Applications

METALS	ARGON	HELIUM	CO₂	O₂	H₂	N₂	METHOD (GTAW)	METHOD (GMAW)	POLARITY
Aluminum Alloys	100							*	DCRP
	100						*		ACHF
		100					*		DCSP
	25	75						*	DCSP
Aluminum Bronze	100							*	*	DCSP
Copper	25	75						*	*	DCSP
	100							*	DCSP
		100					*		DCSP
	95					5			DCSP
Magnesium	100								*	DCRP
	100						*		ACHF
Nickel	100							*	*	ACHF
	20	80							ACHF
		100					*A		DCSP
Silicon Bronze	100							*	*	ACHF
	100							*	ACHF
Steel mild	100							*		DCSP
	75		25					*	DCRP
		100					*A		DCRP
			100					*	DCRP
	98			2				*	DCRP
Low alloy	97			3					*	DCRP
	95			5					*	DCRP
	80				20				DCRP
	80		20						DCRP
Stainless	99			1					*	DCRP
	95			5					*	DCSP
	80				20		*		DCSP
	100						*		DCSP
		100					*A		DCSP
Titanium	100								*	DCSP
	100						*		DCSP
		100					*A		DCSP
Dissimilar Metals Backup Gas	100							*		DCSP
					5	80			DCSP

gas that moves up the tube, the higher the ball is lifted. Figure 8-11 shows a cross section of the flowmeter.

The shielding gas regulator has a constant outlet pressure to the flowmeter of about 50 psig. This is important because the flowmeter scales are accurate only if the gas entering them is at that approximate pressure. If you use higher inlet pressures, the gas flow rate will be higher than the actual reading. The reverse is true if the inlet pressure is lower than 50 psig; therefore, it is important to use accurately adjusted regulators. With an accurate flowmeter, these regulators can deliver inert gas flows up to 60 cfh. You should read the scale by aligning the top of the ball with the cfh desired.

Table 8-5.—Suggested Inert Gas Flow Rates for Various Metals

METAL		GAS FLOW CU. FT./HR. (CFH)		
KIND	THICKNESS	ARGON	HELIUM	*CO_2
Steel	.035-3/32	8-10	20-30	8-10
Cast Iron	1/4	16	40	– – –
Stainless Steel	1/16-1/8	11	30	– – –
Stainless Steel	3/16-1/4	13	32	– – –
Copper	1/16-1/4	15	38	– – –
Magnesium	1/16-1/8	10	25	– – –
* Pure CO_2 is currently used exclusively on steel.				

To obtain an accurate reading, you must mount the meter in a vertical position. Any slant will create an off-center gas flow and result in an inaccurate reading. Also, because gas densities vary, you should use different flowmeters for different gases.

The flow of gas necessary for good GTA welding depends primarily on the thickness of the material. Other factors include the following: welding current, size of nozzle, joint design, speed of welding, and a draft-free area in the location the welding is done. This last factor can affect gas coverage and use considerably. Table 8-5 shows the approximate gas flow rates for various types of metals.

Filler Rods

Normally you do not require filler metal when GTA welding light-gauge materials since they tend to flow together easily. Thick material and thin material that needs reinforcing should be welded using a filler metal.

Special filler rods are available for GTA welding; therefore, you should not use welding rods designed for oxyfuel welding because they can contaminate the tungsten electrode. You should use filler rods that have the same composition as the base metal; for example, use mild steel rods to weld low-carbon steel and aluminum rods for welding aluminum. Additionally, there are many different compositions of the same metal; therefore, you should select a filler metal of the same composition as the metal you are welding.

Personal Protective Equipment

A welding hood like the one used in shielded metal-arc welding should be used for gas tungsten-arc welding. The correct shade of lens depends on the intensity of the arc. Chapter 3 provides a chart of recommended lens shades based on the current setting of the machine. For normal GTA welding at current ranges of 76 to 200 amperes, a shade No. 10 lens is satisfactory. Eye fatigue indicates you should use a different shade of lens or there is leakage around the protective filter glass.

In addition to the welding hood, protective clothing, such as gloves and an apron, should be worn. Bare skin should never be exposed to the rays of the welding arc because painful burns may result.

GTA WELDING PREPARATION

Although it can produce outstanding results, GTA welding can be expensive. The equipment, electrodes, and shielding gas are costly and the material you weld is usually much more expensive than the material welded by other welding processes. To avoid costly mistakes, you should take the time to prepare for each welding operation fully. Preparation is the key to producing quality weldments.

Specific information on the different manufacturers of GTA welding equipment is not provided in this training manual. You should read the manufacturer's instructional pamphlets for specific information on your machine. The following suggestions are considered general and you can apply them to any GTA welding operation:

● Prepare the joint according to the welding procedure you are performing. Refer to chapter 3 of this training manual for specific information about joint preparation.

- Clean the metal of all oxidation, scale, oil, dirt, or other foreign matter. Regardless of the type of joint used, proper cleaning of the metal is essential. For best results, use a stainless steel wire brush.

- Check all electrical circuit connections to make sure they are properly connected and all fittings are tight.

- Be sure the torch is the right type and capacity for the current at which most of the welding will be done. Some manufacturers offer different torches for different ranges of welding current.

- Check the size, appearance, and position of the tungsten electrode in the torch. Ensure that the electrode diameter and nozzle size meet the manufacturer's recommendations. The tip should be properly shaped as discussed earlier (refer to figure 8-9). The electrode should extend beyond the end of the gas cup a distance ranging from 1/8 to 3/16 of an inch for butt welding and 1/4 to 3/8 of an inch for fillet welding. Check the electrode for positioning and good electrical contact. The electrode should be clean and silvery. A dirty tungsten electrode can usually be cleaned satisfactorily with a fine emery cloth. If severely contaminated, the electrode should be replaced or the tip broken off and dressed on a grinding wheel. A contaminated tungsten electrode and a good tungsten electrode are shown in figure 8-12.

- Check the ground cable connections to the workpiece. The connections should be periodically checked after welding begins because they tend to work loose. When this happens, the welding current varies.

- Set the machine for the correct welding amperage. (Follow manufacturer's recommendations.)

- Open the cylinder valve and adjust the gas flow. Before welding, check the connections on the gas supply for leaks with soapy water.

- If using a water-cooled torch, turn on the water. Be sure the water pressure is not higher than recommended by the torch manufacturer.

GTA WELDING PROCEDURES

As we discussed in chapter 3, the detailed methods and practices used to prepare a particular weldment are called the *welding procedure.* We also said that the
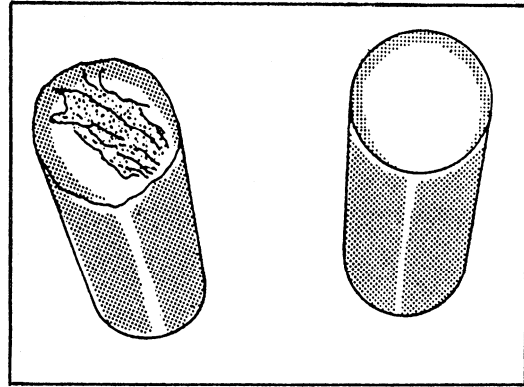

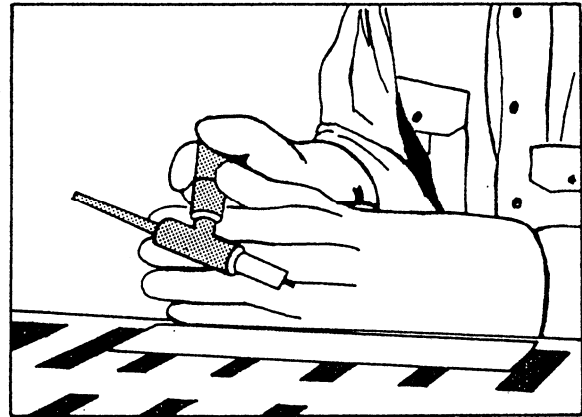Figure 8-12.—Contaminated and good tungsten electrode.

Figure 8-13.—Torch position for the starting swing to strike the arc.

procedure for a particular welded joint includes many variables. The same variables that must be considered for other welding processes also must be considered for gas shielded-arc welding. Some of the variables that you must consider include the following: type of base metal, the joint design, the welding position, the type of shielding gas, and the welding machine setting.

Starting the Arc

Before starting the arc, you should form a ball on the end of the electrode for ac welding. To do this, simply set the current to DCRP and strike an arc for a moment on a piece of carbon or a piece of copper. The ball diameter should be only slightly larger than the original diameter of the tungsten electrode.

When starting the arc with an ac high-frequency current, you do not have to bring the electrode into contact with the workpiece. To strike the arc, you must hold the torch in a horizontal position about 2 inches above the work surface, as shown in figure 8-13. Then
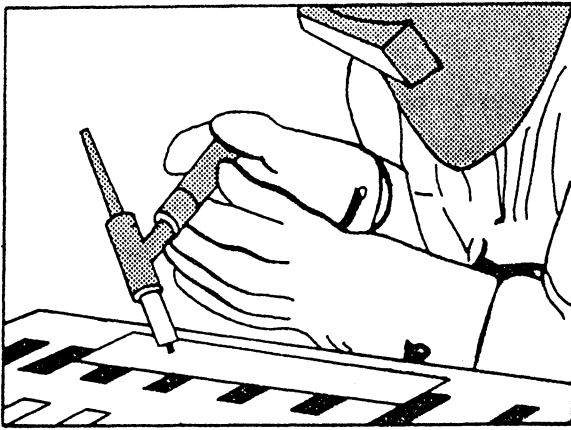
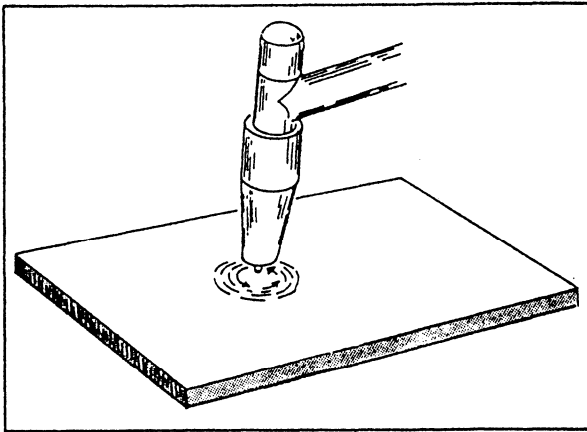Figure 8-14.—Torch position at the end of the swing when the arc strikes.

Figure 8-15.—Forming a molten puddle with a GTA torch.

Figure 8-16.—Addition of filler metal in the flat position.

rapidly swing the electrode end of the torch down to within 1/8 of an inch of the work surface. The high-frequency arc will then jump the gap between the electrode and the plate, establishing the arc. Figure 8-14 shows the torch position at the time the arc strikes.

If you are using a dc machine, hold the torch in the same position, but touch the plate to start the arc. When the arc is struck withdraw the electrode so it is about 1/8 of an inch above the plate.

To stop the arc, quickly swing the electrode back to the horizontal position. If the machine has a foot pedal, gradually decrease the current before stopping the arc.

Welded Joints

In the following paragraphs the different types of joints and the procedures used to weld them is discussed.

BUTT JOINTS.— After you strike the arc, hold the torch at a 90-degree angle to the workpiece surface, and

with small circular motions, as shown in figure 8-15, form a molten puddle. After you form the molten puddle, hold the torch at a 75-degree angle to the work surface and move it slowly and steadily along the joint at a speed that produces a bead of uniform width. Move the torch slowly enough to keep the puddle bright and fluid. No oscillating or other movement of the torch is necessary except the steady forward movement.

When you must use a filler metal, form the molten puddle as described previously. When the puddle becomes bright and fluid, you should move the arc to the rear of the puddle and add the filler metal by quickly touching the rod to the front edge of the puddle. Hold the rod at about a 15-degree angle from the work. Because the electrode is pointing toward the filler metal or pushing it, it is known as the *push angle.* Remove the

Figure 8-17.—GTA welding a tee joint.

Figure 8-18.—GTA welding a lap joint.

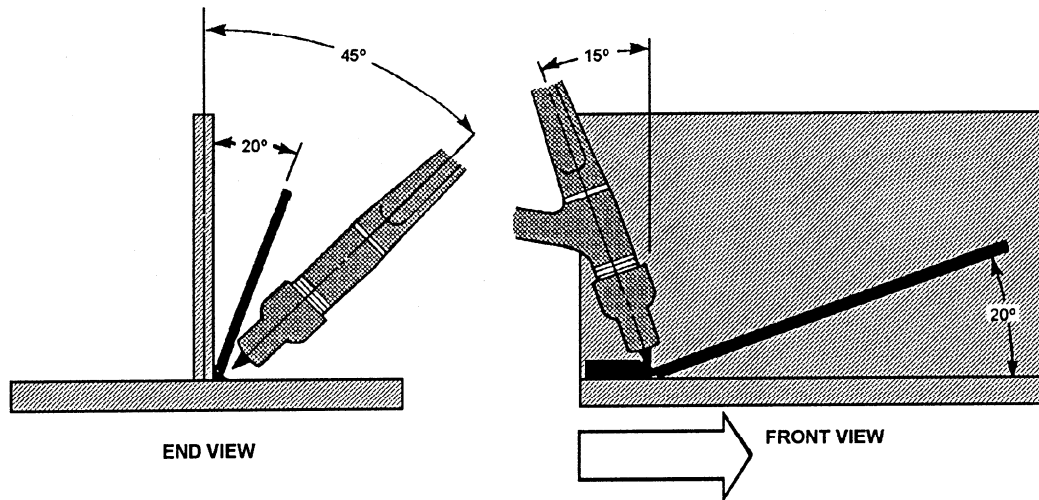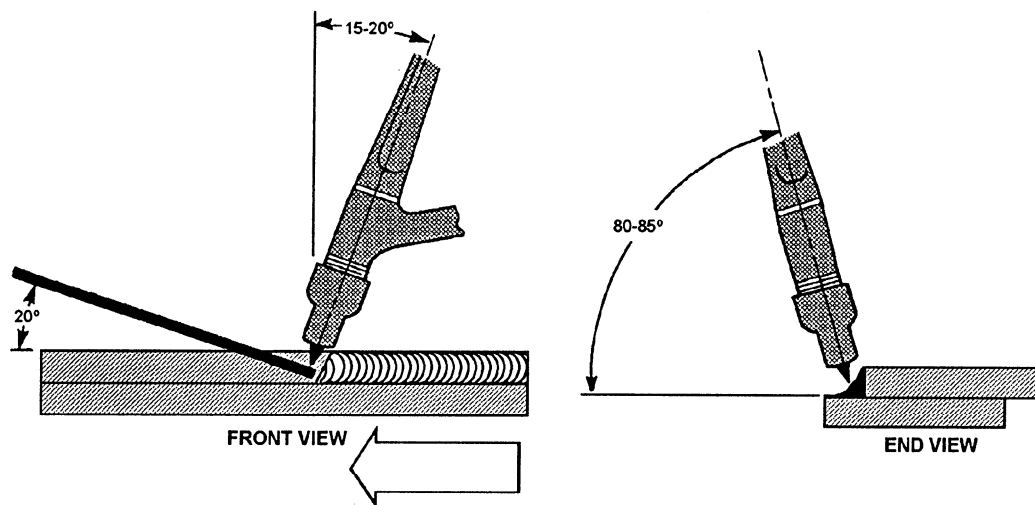filler rod and bring the arc back to the front edge of the puddle. When the puddle becomes bright and fluid again, you should repeat the steps as described before. Figure 8-16 shows the correct procedures for adding filler metal. Continue this sequence until the weld joint has been completed. The width and height of the weld bead is determined by the speed of travel, by the movement of the torch, and by the amount of filler metal added.

In welding practice, it is again stressed that good (GTA welding depends on following this definite procedure—form the molten pool and then feed filler rod intermittently to the leading edge of the pool as you move the torch forward. DO NOT feed the filler rod into

the arc. You should practice making single-pass butt welds until you can produce satisfactory welds.

LAP AND TEE JOINTS.— In chapter 3, we said that lap and tee joints are welded using the fillet weld. Fillet welds are slightly awkward to make using the GTA welding process because of the gas nozzle. Once you establish the arc, you should pay close attention to the molten puddle. Figures 8-17 and 8-18 show the correct torch and rod angles for the tee and lap joints.

In welding a tee or lap joint, the puddle forms a V-shape. The center of the V is called a *notch,* and the speed at which you fill the notch governs how fast you should move the torch. Do NOT get ahead of the notch. If you do, the joint will have insufficient fusion and penetration. As you weld along the joint, dip the rod in
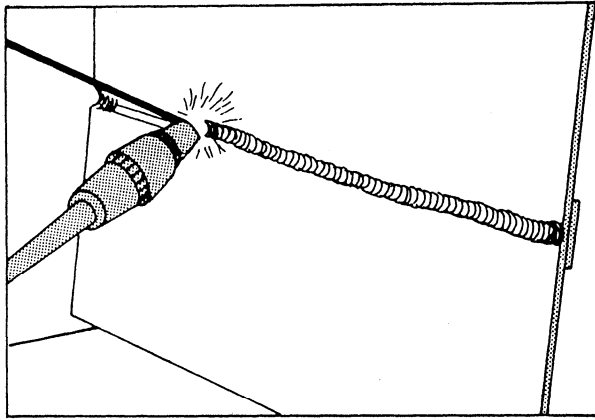
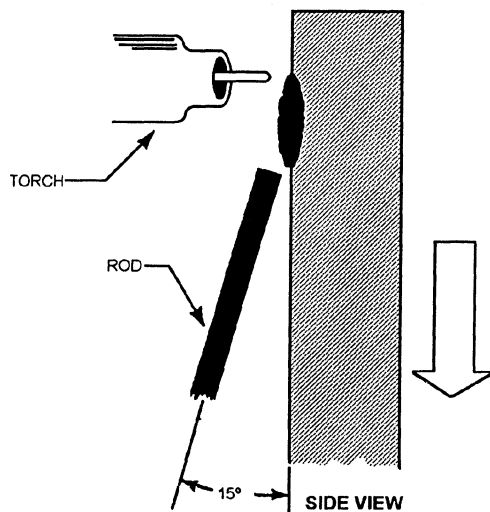Figure 8-19.—GTA welding in the horizontal position.
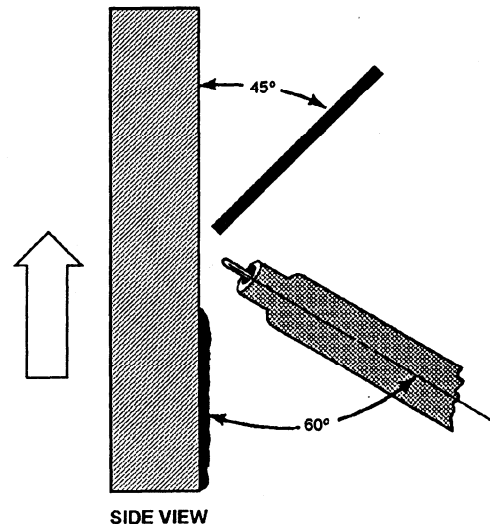

Figure 8-21.—GTA welding vertical upward.

Figure 8-20.—GTA welding vertical downward.
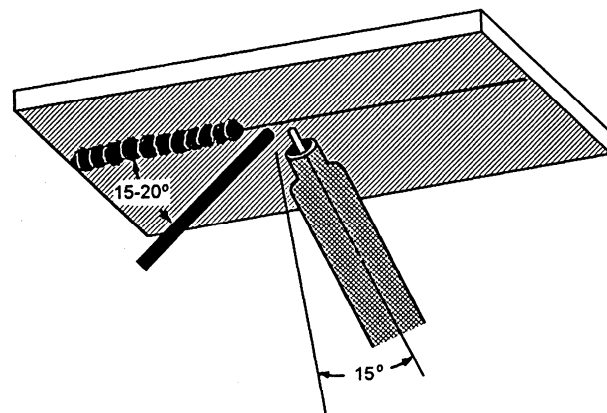
Figure 8-22.—GTA welding overhead.

and out of the puddle about every 1/4 of an inch of travel. If you add the filler rod to the molten puddle at just the right time uniform welds result every time.

Out-of-Position Welding

Rules for quality welding in the flat position also must be followed for out-of-position GTA welding. Cleanliness, good joint fit-up, preheat, sufficient shielding gas, and correct welding current are important. In addition, you should not use high welding current or deposit large weld beads. Direct the arc so there is no overheating at anyone area that could cause sagging or undercutting. The adding of filler metal, bead size, and sequence must be done correctly to ensure complete fusion between passes.

HORIZONTAL WELDING.— When welding in the horizontal position, start the arc on the edge of the joint. Then hold the torch at a work angle of 15 degrees and a push angle of 15 degrees. After you establish the puddle, dip the rod into the front edge of the puddle on the high side as you move the torch along the joint (fig. 8-19). Maintain an arc length as close as possible to the diameter of the electrode. Correct arc length coupled with the correct speed of travel helps prevent undercutting and permits complete penetration.

VERTICAL WELDING.— When welding thin material with the GTA welding process, you should weld from the top, moving downward (fig. 8-20). This helps you produce an adequate weld without burning through the metal. Filler material is not normally needed for welding downward.

On heavier materials, you should weld from the bottom, upwards (fig. 8-21). This enables you to achieve adequate penetration. When welding upward, you normally need to use a filler rod.

OVERHEAD WELDING.— When GTA welding in the overhead position, you should lower the welding current by 5 to 10 percent of what normally is used for flat welding. This reduced welding current enables you to maintain better control of the welding puddle. Conversely, you need a higher flow of shielding gas. Hold the torch and the rod as you do for flat welding (fig. 8-22). You should try to maintain a small weld puddle to avoid the effects of gravity. Most inexperienced welders find overhead welding awkward; therefore, try to get in as comfortable and relaxed a position as possible when welding. This helps you to maintain steady, even torch and filler rod manipulation.

GTA WELDING COMMON METALS

The actual welding technique for gas tungsten-arc welding common metals is virtually the same; however, each of the metals that we discuss has its own unique welding characteristics. In this section we discuss some of those characteristics. It is not the scope of this training manual to provide you with an in depth study of the welding procedures required to weld all types of metals. This chapter is merely an introduction to gas shielded-arc welding. For more information, refer to the manufacturer's literature for the specific welding equipment you use or any of the references listed in this book.

Aluminum

Steelworkers use the gas tungsten-arc welding procedure more for aluminum than for any other metal. Aluminum is available in a variety of compositions. Series 1000, 3000, and 5000 aluminum alloys are considered nonheat-treatable and are easily weldable. The heat-treatable alloys in the series 2000, 6000, and 7000 also can be welded; however, higher welding temperatures and speed are needed.

You can weld aluminum in all positions, but better welds are normally produced in the flat position. You should also use copper backup blocks whenever possible, especially on thin material. For best results use ACHF current and argon for shielding gas.

Stainless Steel

In GTA welding of stainless steel, the welding techniques used are similar to those used with aluminum. The major differences are in the selection of the welding current and the type of tungsten electrode used. To get the best results in welding stainless steel, you should use DCSP welding current; however, ACHF can be used. The forehand welding technique should be used.

The amperage settings for GTA welding stainless steel are higher than for aluminum. The amperage used for different thicknesses of stainless should be according to the recommended settings that you can find in the manufacturer's technical manual or the information pamphlets provided with the equipment.

Copper and Its Alloys

Pure copper is easily welded; however, as with any of the other metals we have discussed, it must be thoroughly cleaned before to welding. The GTA weldability of each copper-alloy group depends largely upon the alloying elements. Copper-silicon and copper-nickel alloys are weldable using the GTA process. Copper-zinc, copper-tin, and copper-lead alloys are difficult or impossible to weld by the GTA process. Plates up to 1/4 of an inch thick are generally prepared with a square edge. The forehand welding technique with DCSP is recommended for materials thicker than 0.050 of an inch. On lighter material, ACHF also can be used.

Cast Iron

You can make sound welds using the GTA welding process in three principal grades of cast iron: gray, white, and malleable. Cast-iron parts must always be preheated before to welding. Gray cast iron should be preheated to a temperature ranging between 500°F to 1250°F. The required temperature depends on the size and shape of the workpiece.

In either GTA or GMA welding, you should allow the workpiece to cool slowly after welding. You can accomplish this by covering the workpiece in a bed of lime or ashes. This slow cooling prevents cracking and residual stresses.

Magnesium

The welding characteristics of magnesium are comparable to those of aluminum. Both have high-heat conductivity, a low-melting point, high-thermal expansion, and both oxidize rapidly. Both DCRP and ac provide excellent cleaning action to the weld metal. DCRP can be used with helium gas to produce wide weld deposits, high heat, and shallow penetration. ACHF with helium, argon, or a mixture of the gases can be used to join metals ranging from 0.20 to over 0.25 of an inch. DCSP with helium produces deep penetration but no surface cleaning.

Most satisfactory results on magnesium are obtained by using the electrode in as nearly a vertical
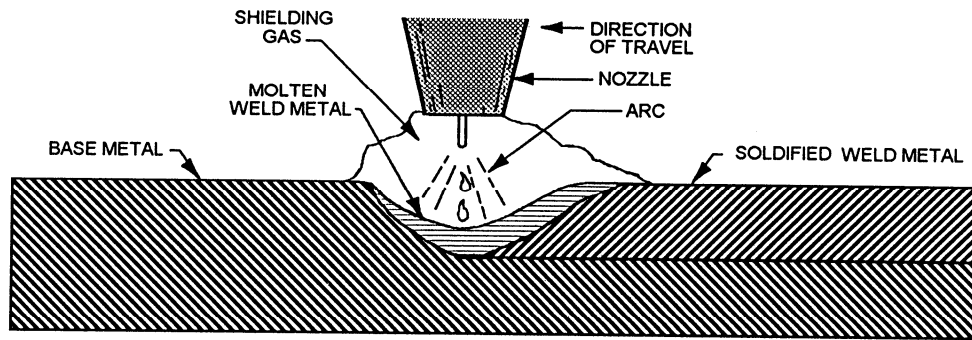
Figure 8-23.—GMA welding process.
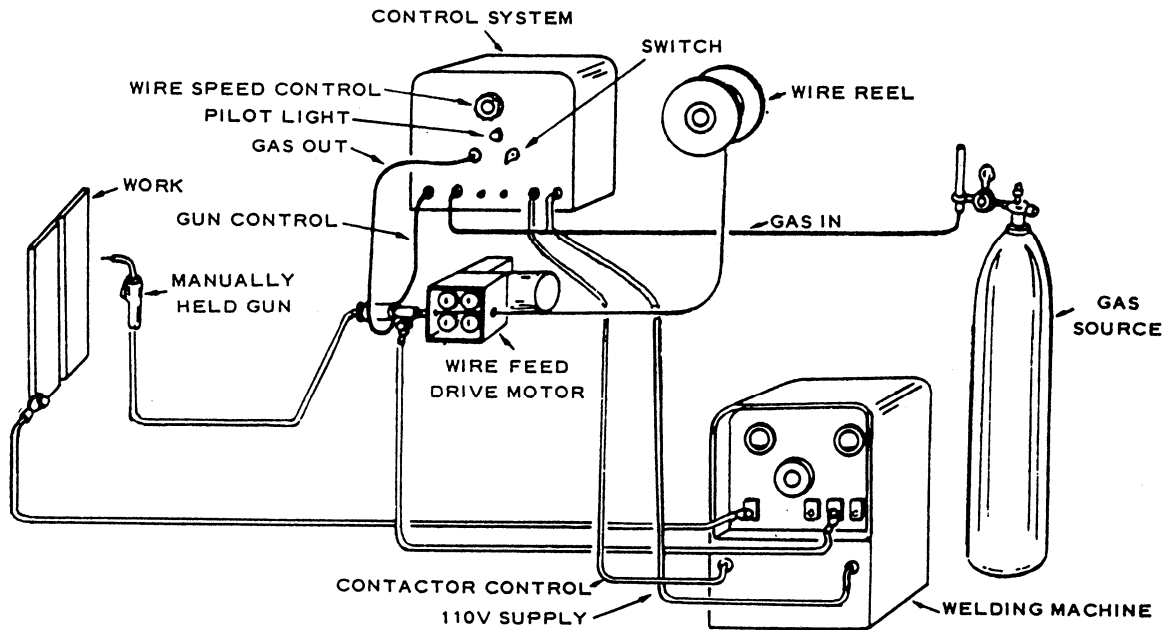
Figure 8-24.—Diagram of GMA welding equipment.

position as possible. The electrode is advanced along the line of weld, using the forehand technique.

CAUTION

Always be sure there is good ventilation when welding. The fumes from some of these metals are highly toxic; therefore, a good ventilating system is essential.

GAS METAL-ARC WELDING-GMAW

The gas metal-arc welding process (GMAW), often called *MIG,* has revolutionized arc welding. In this process, a consumable electrode (in the form of wire) is fed from a spool through the torch (welding gun) at a preset controlled speed. As the wire passes through the contact tube of the gun, it picks up the welding current. The consumable wire electrode serves two functions: it maintains the arc and provides filler metal to the joint. The method of delivery of the filler metal allows GMAW welding to be basically a one-handed operation which does not require the same degree of skill as GTAW. Figure 8-23 shows the basic principle of gas metal-arc welding.

An important factor in the GMA welding process is the high rate at which metal can be deposited. This high rate of metal deposition and high speed of welding results in minimum distortion and a narrow heat-affected zone. When you are deciding whether to use GTA or GMA welding, the thickness of the material should

8-14

be a deciding factor. GMAW is often chosen for welding thicker material.

Like GTA welding, gas metal-arc welding also uses a shielding gas to protect the weld zone during welding. The inert gas is fed through the gun into the weld zone and prevents atmospheric contamination.

GMAW offers many of the advantages of GTAW. Since there is no flux, GMA welds are clean and there is no slag to remove. GMAW enables you to produce sound welds in all positions quickly. Now let's take a look at the equipment you will use for GMA welding.

GMA WELDING EQUIPMENT AND SUPPLIES

Gas metal-arc welding equipment basically consists of four units: the power supply, the wire feeding mechanism, the welding gun (also referred to as the torch), and the gas supply. Figure 8-24 shows atypical GMA welding outfit.

Welding Machine

When you use a conventional type of welding machine for GMA welding, the voltage varies depending on the length of the arc. Whenever the nozzle-to-work distance changes, the arc length and the voltage changes. The only way to produce uniform welds with this type of power source is to maintain the arc length and voltage at a constant value. Besides producing nonuniform welds, this inconsistent voltage can cause the wire to burn back to the nozzle.

A *constant voltage* (CV) power source was developed to overcome the inconsistent voltage characteristics of a conventional welding machine, (See fig. 8-25). It can be either a dc rectifier or motor generator that supplies current with normal limits of 200 to 250 amperes.

The CV type power source has a nearly flat voltampere characteristic. This means that the machine maintains the same voltage regardless of the amount of current used. With this type of power source, you can change the wire-feed speed over a considerable range without causing the wire to burn back to the nozzle. When the wire-feed speed is set at a specific rate, a proportionate amount of current is automatically drawn. In other words, the current selection is based on the wire-feed speed. When the wire is fed faster, the current increases; when it is fed slower, the current decreases. With this type of power supply, variations in
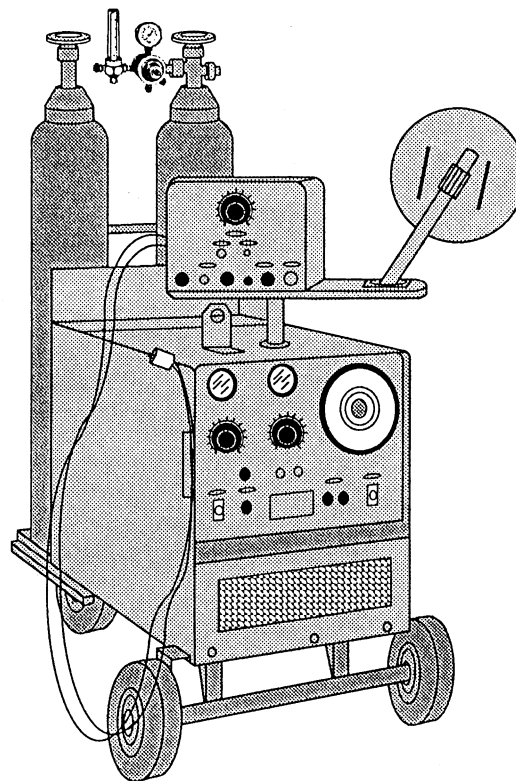
Figure 8-25.—Constant voltage (CV) power unit.

the nozzle-to-work distance will not change the arc length and burn back is virtually eliminated.

In gas metal-arc welding, direct-current reverse polarity (DCRP) is recommended. You should recall from the previous section that DCRP produces excellent cleaning action and allows for deeper penetration.

Wire Feed Drive Motor

The wire feed drive motor is used to automatically drive the electrode wire from the wire spool through the gun up to the arc point. You can vary the speed of the wire feed by adjusting the controls on the wire-feed control panel. The wire feeder can be mounted on the power unit or it can be separate from the welding machine.

Welding Gun

The function of the welding gun is to carry the electrode wire, the welding current, and the shielding gas to the arc area. The gun has a trigger switch that controls the wire feed and arc as well as the shielding gas. The welding operator directs the arc and controls the weld with the welding gun. GMA welding guns are available in many different styles, some of which are

Figure 8-26.—GMA welding guns.

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Figure 8-27.—GMA welding torch with wire feed motor and wire spool inside.

shown in figure 8-26. When using these guns, the wire is fed to the torch by an automatic wire feeding machine which pushes the wire through a flexible tube to the arc point.

Figure 8-27 shows another type of GMA welding gun that Steelworkers could use. This model incorporates the drive motor and a small spool of wire 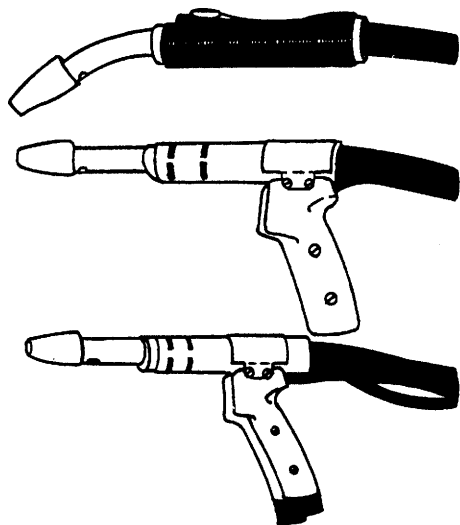inside the gun. This type of gun is attached directly to the welding unit and gas supply, eliminating the need for a separate control unit and wire drive assembly.

As with the GTA welding torch, the torch nozzle must be kept clean at all times. Also, you should clean the tube through which the electrode wire passes each time the electrode reel is changed.

Shielding Gas

In gas metal-arc welding, as with gas tungsten-arc welding, the shielding gas can have a major effect on the properties of the base metal. Some of the shielding gases commonly used with the GMA process are pure argon, argon-helium, argon-oxygen, argon-carbon dioxide, and carbon dioxide. Refer to table 8-4 for a selection of shielding gases recommended for various metals for both the GMA and GTA welding processes. The smoothness of operation, weld appearance, weld quality, and welding speeds are affected indifferent ways with each type of metal, thickness, and gas mixture.

ARGON.— Earlier in this chapter, we said that argon provides greater cleaning action than other gases. Because it is heavier than air, argon blankets the weld from contamination. Also, when you are using argon as a shielding gas, the welding arc tends to be more stable. For this reason, argon is often used in combination with

other gases for arc shielding. Argon reduces spatter by producing a quiet arc and reducing arc voltage that results in lower power in the arc and thus lower penetration. The combination of lower penetration and reduced spatter makes argon desirable when welding sheet metal.

Pure argon is seldom used for arc shielding except in welding such metals as aluminum, copper, nickel, and titanium. The use of pure argon to weld steel usually results in undercutting, poor bead contour, and the penetration is somewhat shallow.

ARGON-OXYGEN.— Small amounts of oxygen added to argon can produce excellent results. Normally oxygen is added in amounts of 1, 2, or 5 percent. When oxygen is added to argon, it improves the penetration pattern. It also improves the bead contour and eliminates the undercut at the edge of the weld. You use argon-oxygen mixtures in welding alloy steels, carbon steels, and stainless steel.

HELIUM.— Helium, like argon, is an inert gas. But there are few similarities between the two gases. Argon is heavier than air and helium is lighter than air. Helium has a high-voltage change as the arc length changes. When you use helium for GMA welding, more arc energy is lost in the arc itself and is not transmitted to the work In the section on GTA welding, we said that helium produces good penetration and fast welding speeds. For GMA welding, the opposite is true. In GMA welding, helium produces a broader weld bead, but shallower penetration.

Because of its high cost, helium is primarily used for special welding tasks and for welding nonferrous metals, such as aluminum, magnesium, and copper. It is also used in combination with other gases.

CARBON DIOXIDE (CO_2).— Argon and helium gases are composed of single atoms. Carbon dioxide, on the other hand, consists of molecules. Each molecule contains one carbon atom and two oxygen atoms. At

8-16

Table 8-6.—Recommended Wire Diameters for GMA Welding Using Welding Grade CO_2 and a Wire Stick-out of 1/4 to 3/8 of an Inch

(Manual travel, single pass, flat fillet welds)					
MATERIAL THICKNESS (inches)	ELECTRODE SIZE	WELDING DCRO (arc volts)	CONDITIONS (amperes)	GAS FLOW (cfh)	TRAVEL SPEED (ipm)
0.025	0.030	15-17	30-50	15-20	15-20
.031	.030	15-17	40-60	15-20	18-22
.037	.035	15-17	65-85	15-20	35-40
.050	.035	17-19	80-100	15-20	35-40
.062	.035	17-19	90-110	20-25	30-35
.078	.035	18-20	110-130	20-25	25-30
.125	.035	19-21	140-160	20-25	20-25
.125	.045	20-23	180-200	20-25	27-32
.187	.035	19-21	140-160	20-25	14-19
.187	.045	20-23	180-200	20-25	18-22
.250	.035	19-21	140-160	20-25	10-15
.250	.045	20-23	180-200	20-25	12-18

normal temperatures carbon dioxide is essentially an inert gas; however, at high temperatures it decomposes into carbon monoxide (CO) and oxygen (O_2). Because the excess oxygen atoms can combine with carbon or iron in the weld metal, wires used with this gas must contain *deoxidizing* elements. A deoxidizing element has a great affinity for the oxygen and readily combines with it. Some of the more common deoxidizers used in wire electrodes are manganese, silicon, and aluminum.

Carbon dioxide is used primarily for the GMA welding of mild steel. Because of its low cost, CO_2 is often used in combination with other shielding gases for welding different types of metals. Direct-current reverse polarity (DCRP) is generally used with CO_2. The current setting is about 25 percent higher with CO_2 than with other shielding gases.

Carbon dioxide produces abroad, deep penetration pattern. It also produces good bead contour and there is no tendency toward undercutting. The only problem with CO_2 gas is the tendency for the arc to be violent. This can lead to spatter problems; however, for most applications this is not a problem and the advantages of CO_2 far outweigh the disadvantages.

Regulators

You should use the same type of regulator and flowmeter for gas metal-arc welding that you use for gas tungsten-arc welding. The gas flow rates vary, depending on the types and thicknesses of the material and the joint design. At times it is necessary to connect two or more gas cylinders (manifold) together to maintain higher gas flow.

For most welding conditions, the gas flow rate is approximately 35 cubic feet per hour (cfh). This flow rate may be increased or decreased, depending upon the particular welding application. Final adjustments usually are made on a trial-and-error basis. The proper amount of gas shielding results in a rapidly crackling or sizzling arc sound. Inadequate gas shielding produces a popping arc sound and results in weld discoloration, porosity, and spatter.

Filler Wires

The composition of the filler wire used for GMA welding must match the base metal. For mild steel, you should select mild steel wire; for aluminum, you should select aluminum wire. Additionally, you should try to select electrode wire that matches the composition of the various metals you are welding. For instance, when you are welding Type 308 aluminum, you should use an ER-308L filler wire.

Wires are available in spools of several different sizes. The wire varies in diameter from .020 to 1/8 of an inch. You should select the proper diameter of wire based on the thickness of the metal you are welding as well as the position in which you are welding. Wires of 0.020, 0.030, and 0.035 of an inch are generally used for welding thin materials. You also can use them for welding low- and medium-carbon steels and low-alloy/high-strength steels of medium thicknesses. (See table 8-6.) Medium thicknesses of metals are normally welded with
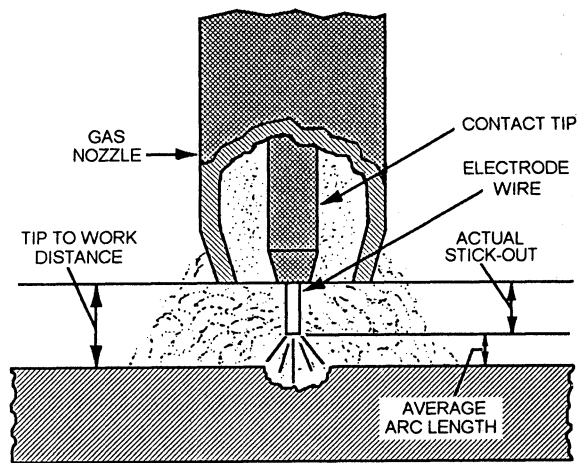
Figure 8-28.—Correct wire stick-out.

0.045-inch or 1/16-inch diameter wires. For thicker metals, larger diameter electrodes may be required.

As you learned earlier, the position of welding is a factor that must be considered. For instance, when you are welding in the vertical or overhead positions, you normally use smaller diameter electrodes.

Special attention must be given to ensure the wire is clean. Unsound welds result from the use of wire that is contaminated by oil, grease, dust, or shop fumes. You can obtain the best welding results with wire that has just been taken out of its carton. Wire should be stored in a hot locker or in a warm dry area, and should be kept covered. If welding is stopped for a long period of time, you should remove the wire and place it in its original carton to prevent contamination.

WIRE STICK-OUT.— In gas metal-arc welding, *wire stick-out* refers to the distance the wire extends from the nozzle of the gun (fig. 8-28). The correct amount of wire stick-out is important because it influences the welding current of the power source. Since the power source is self-regulating, the current output is automatically decreased when the wire stick-out increases. Conversely, when the stick-out decreases, the power source is forced to furnish more current. Too little stickout causes the wire to fuse to the nozzle tip, which decreases the tip life.

For most GMA welding, the wire stickout should measure from 3/8 to 3/4 of an inch. For smaller (micro) wires, the stick-out should be between 1/4 and 3/8 of an inch.

WIRE-FEED SPEED.— As we stated earlier, you can adjust the wire-feed drive motor to vary the wire-feed speed. This adjustment is limited to a definite range, depending on the welding current used. (See table 8-6). The wire-feed speed is measured in inches per minute (ipm). For a specific amperage setting, a high wire-feed speed results in a short arc, whereas a low speed produces a long arc. You use higher speeds for overhead welding than with flat-position welding.

Personal Protective Equipment

As with any other welding process, SAFETY is extremely important. A welding hood like the one used in shielded metal-arc welding should be used for gas metal-arc welding. The correct shade of lens depends on the intensity of the arc. Chapter 3 provides a chart of recommended lens shades based on the current setting of the machine. Eye fatigue indicates you should use a different shade of lens or there is leakage around the protective filter glass.

In addition to the welding hood, protective clothing, such as gloves and an apron, should be worn. Bare skin should never be exposed to the rays of the welding arc because it could result in painful burns.

TYPES OF GMA WELDING

When using the GMA welding process, metal is transferred by one of three methods: spray transfer, globular transfer, or short-circuiting transfer. The type of metal transfer depends on the arc voltage, current setting, electrode wire size, and shielding gas.

Spray-Arc Welding

Spray-arc transfer is a high-current range method that produces a rapid disposition of weld metal. This type of transfer is effective for welding heavy-gauge metals because it produces deep weld penetration. The use of argon or a mixture of argon and oxygen are necessary for spray transfer. Argon produces a pinching effect on the molten tip of the electrode, permitting only small droplets to form and transfer during the welding process. Spray transfer is useful when welding aluminum; however, it is not practical for welding light-gauge metal.

Globular Transfer

Globular transfer occurs when the welding current is low. Because of the low current, only a few drops are

transferred per second, whereas many small drops are transferred with a higher current setting. In this type of transfer, the ball at the tip of the electrode grows in size before it is transferred to the workpiece. This globule tends to reconnect with the electrode and the workpiece, causing the arc to go out periodically. This results in poor arc stability, poor penetration, and excessive spatter.

Globular transfer is not effective for GMA welding. When it is used, it is generally restricted to thin materials where low heat input is desired.

Short-Circuiting Arc Transfer

Short-circuiting arc transfer is also known as *short arc.* Short arc was developed to eliminate distortion, burn-through, and spatter when welding thin-gauge metals. It can be used for welding in all positions, especially vertical and overhead where puddle control is more difficult. In most cases, it is used with current levels below 200 amperes and wire of 0.045 of an inch or less in diameter. Small wire produces weld puddles that are small and easily manageable.

The shielding gas mixture for short-arc welding is 75% carbon dioxide and 25% argon. The carbon dioxide provides for increased heat and higher speeds, while the argon controls the spatter. Straight CO_2 is now being used for short-arc welding; however, it does not produce the excellent bead contour that the argon mixture does.

GMA WELDING PREPARATION

Preparation is the key to producing quality weldments with the gas metal-arc welding process. As in GTA welding, the equipment is expensive; therefore, you should make every effort to follow the manufacturer's instruction manuals when preparing to use GMA welding equipment.

Joints

For the most part, the same joint designs recommended for other arc welding processes can be used for gas metal-arc welding (refer to chapter 3). There are some minor modifications that should be considered due to the welding characteristics of the GMA process. Since the arc in GMA welding is more penetrating and narrower than the arc for shielded metal-arc welding, groove joints can have smaller root faces and root openings. Also, since the nozzle does not have to be placed within the groove, less beveling of the plates is required.

GMA welding can actually lower material costs, since you use less weld metal in the joint.

Equipment

The following suggestions are general and can be applied to any GMA welding operation:

- Check all hose and cable connections to make sure they are in good condition and are properly connected.

- Check to see that the nozzle is clean and the correct size for the particular wire diameter used.

- Make sure that the guide tube is clean and that the wire is properly threaded through the gun.

- Determine the correct wire-feed speed and adjust the feeder control accordingly. During welding, the wire-speed rate may have to be varied to correct for too little or too much heat input.

- Make sure the shielding gas and water coolant sources are on and adjusted properly.

- Check the wire stick-out.

GMA WELDING PROCEDURES

As with any other type of welding, the GMA welding procedure consists of certain variables that you must understand and follow. Many of the variables have already been discussed. This section applies some of these variables to the actual welding procedure.

Starting the Arc

For a good arc start, the electrode must make good electrical contact with the work For the best results, you should clean the metal of all impurities. The wire stick-out must be set correctly because as the wire stick-out increases, the arc initiation becomes increasingly difficult.

When preparing to start the arc, hold the torch at an angle between 5 and 20 degrees. Support the weight of the welding cable and gas hose across your shoulder to ensure free movement of the welding torch. Hold the torch close to, but not touching, the workpiece. Lower your helmet and squeeze the torch trigger. Squeezing the trigger starts the flow of shielding gas and energizes the welding circuit. The wire-feed motor does not energize until the wire electrode comes in contact with the workpiece. Move the torch toward the work, touching the wire electrode to the work with a sideways scratching
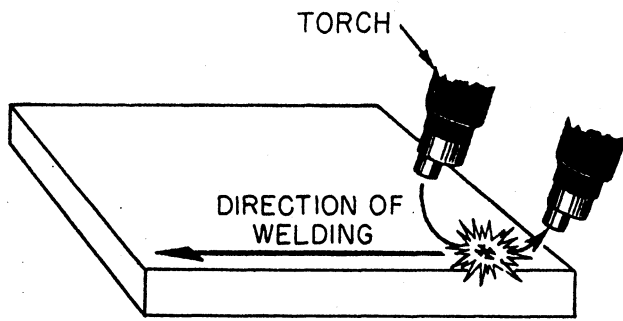
Figure 8-29.—Striking the arc (GMAW).

wire-feed dial slightly counterclockwise. This decreases the wire-feed speed and increases the arc length. A clockwise movement of the dial has the opposite effect. With experience, you can recognize the sound of the proper length of arc to use.

To break the arc, you simply release the trigger. This breaks the welding circuit and de-energizes the wire-feed motor. Should the wire electrode stick to the work when striking the arc or during welding, release the trigger and clip the wire with a pair of side cutters.

Welding Positions

In gas metal-arc welding, the proper position of the welding torch and weldment are important. The position of the torch in relation to the plate is called the work and travel angle. Work and travel angles are shown in figure 8-30. If the parts are equal in thickness, the work angle should normally be on the center line of the joint; however, if the pieces are unequal in thickness, the torch should angle toward the thicker piece.

The travel angle refers to the angle in which welding takes place. This angle should be between 5 and 25 degrees. The travel angle may be either a push angle or a drag angle, depending on the position of the torch.

motion, as shown in figure 8-29. To prevent sticking, you should pull the torch back quickly, about 1/2 of an inch—the instant contact is made between the wire electrode and the workpiece. The arc strikes as soon as contact is made and the wire-feed motor feeds the wire automatically as long as the trigger is held.

A properly established arc has a soft, sizzling sound. Adjustment of the wire-feed control dial or the welding machine itself is necessary when the arc does not sound right. For example, a loud, crackling sound indicates that the arc is too short and that the wire-feed speed is too fast. You may correct this problem by moving the
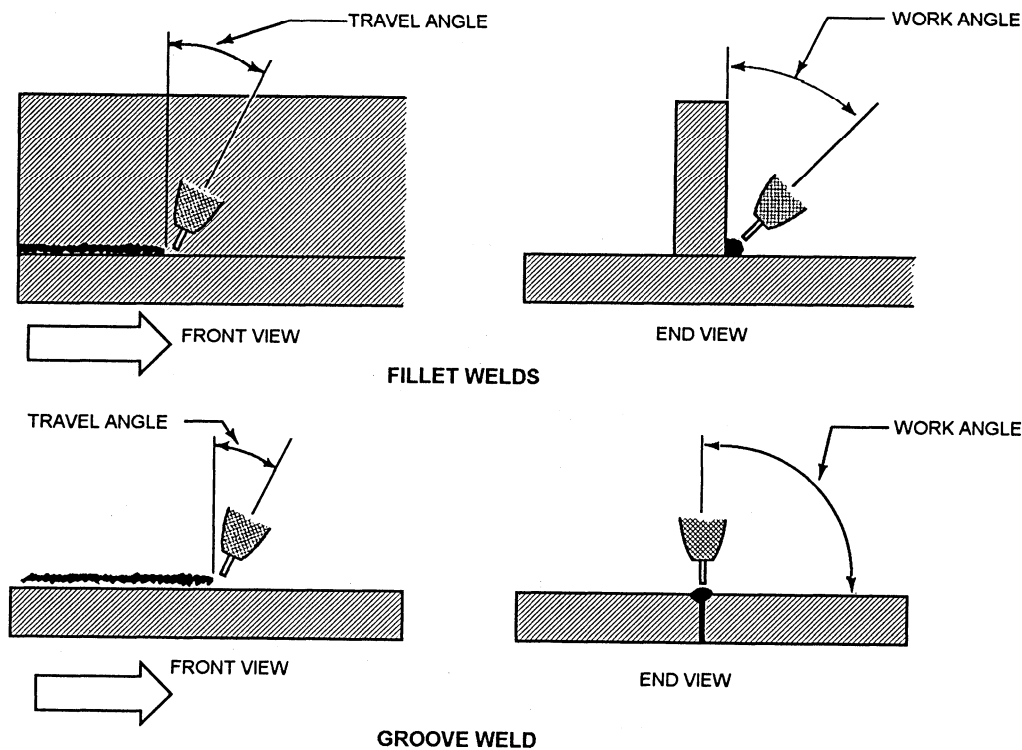

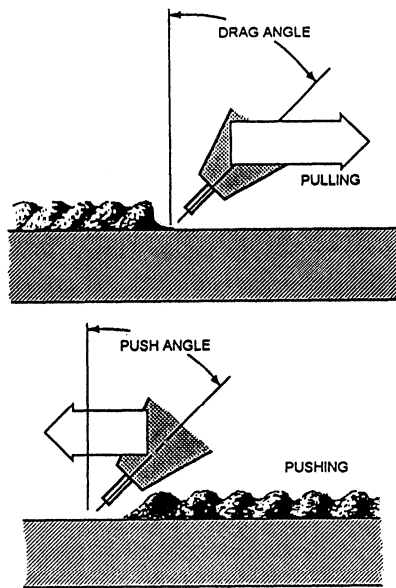Figure 8-30.—Travel and work angle for GMA welding.

Figure 8-31.—Pulling and pushing travel angle techniques.

When the torch is ahead of the weld, it is known as pulling (or dragging) the weld. When the torch is behind the weld, it is referred to as pushing the metal (fig. 8-31).

The pulling or drag technique is for heavy-gauge metals. Usually the drag technique produces greater penetration than the pushing technique. Also, since the welder can see the weld crater more easily, better quality welds can consistently be made. The pushing technique is normally used for light-gauge metals. Welds made with this technique are less penetrating and wider because the welding speed is faster.

For the best results, you should position the weldment in the flat position. 'This position improves the molten metal flow, bead contour, and gives better shielding gas protection.

After you have learned to weld in the flat position, you should be able to use your acquired skill and knowledge to weld out of position. These positions include horizontal, vertical-up, vertical-down, and overhead welds. The only difference in welding out of position from the fiat position is a 10-percent reduction in amperage.

When welding heavier thicknesses of metal with the GMA welding process, you should use the multipass technique (discussed in chapter 3). This is accomplished by overlapping single small beads or making larger beads, using the weaving technique. Various multipass welding sequences are shown in figure 8-32. The numbers refer to the sequences in which you make the passes.

Common Weld Defects

Once you get the feel of welding with GMA equipment, you will probably find that the techniques are less difficult to master than many of the other welding processes; however, as with any other welding process, GMA welding does have some pitfalls. To produce good quality welds, you must learn to recognize and correct possible welding defects. The following are a few of the more common defects you may encounter along with corrective actions that you can take.
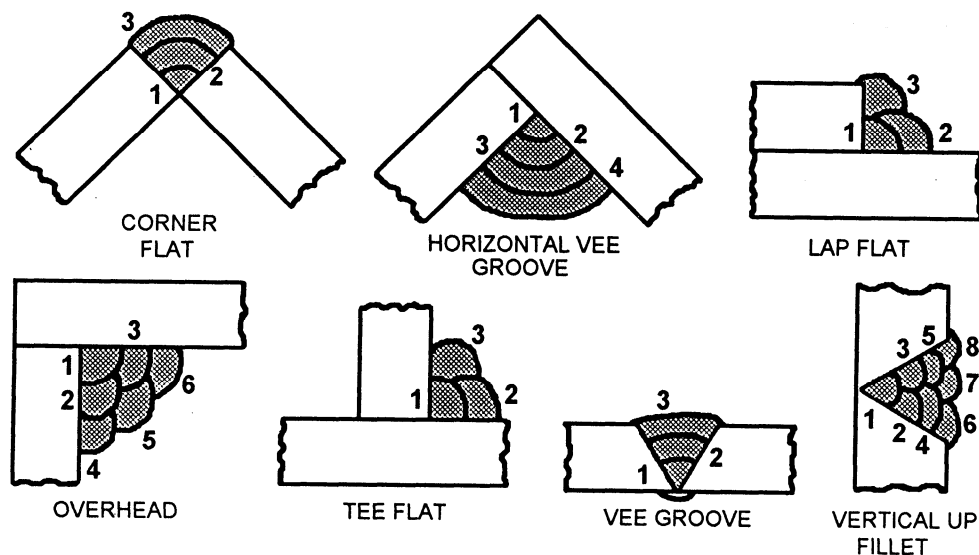

Figure 8-32.—Multipass welding.

SURFACE POROSITY.— Surface porosity usually results from atmospheric contamination. It can be caused by a clogged nozzle, shielding gas set too low or too high, or welding in a windy area. To avoid surface porosity, you should keep the nozzle clean of spatter, use the correct gas pressure, and use a protective wind shield when welding in a windy area.

CRATER POROSITY.— Crater porosity usually results from pulling the torch and gas shield away before the crater has solidified. To correct this problem, you should reduce the travel speed at the end of the joint. You also may try reducing the tip-to-work distance.

COLD LAP.— Cold laps often result when the arc does not melt the base metal sufficiently. When cold lap occurs, the molten puddle flows into an unwelded base metal. Often this results when the puddle is allowed to become too large. To correct this problem, you should keep the arc at the leading edge of the puddle. Also, reduce the size of the puddle by increasing the travel speed or reducing the wire-feed speed. You also may use a slight whip motion.

LACK OF PENETRATION.— Lack of penetration usually results from too little heat input in the weld zone. If the heat input is too low, increase the wire-feed speed to get a higher amperage. Also, you may try reducing the wire stick-out.

BURN-THROUGH.— Burn-through (too much penetration) is caused by having too much heat input in the weld zone. You can correct this problem by reducing the wire-feed speed, which, in turn lowers the welding amperage. Also you can increase the travel speed. Burn-through can also result from having an excessive amount of root opening. To correct this problem, you increase the wire stick-out and oscillate the torch slightly.

WHISKERS.— Whiskers are short pieces of electrode wire sticking through the root side of the weld joint. This is caused by pushing the wire past the leading edge of the weld puddle. To prevent this problem, you should cut off the ball on the end of the wire with side cutters before pulling the trigger. Also, reduce the travel speed and, if necessary, use a whipping motion.

GMA WELDING COMMON METALS

You can use the welding equipment and techniques for gas metal-arc welding to join all types of metals; however, as we discussed in the GTAWprocess, each of the metals requires a unique welding method. In this

section, we discuss some of the welding methods associated with a few of the more commonly welded metals.

Carbon Steels

The majority of welding by all methods is done on carbon steels. When you are using GMA to weld carbon steels, both the spray-arc and short-arc methods may be applied. For spray-arc welding, a mixture of 5-percent oxygen with argon is recommended. As we mentioned earlier, this mixture provides a more stable arc. Also you may use a mixture of argon and CO_2 or straight CO_2. Straight CO_2 is often used for high-speed production welding; however, with CO_2 the arc is not a true spray arc. For short-arc welding, a 25-percent CO_2 and 75-percent argon mixture is preferred.

For GMA welding of thin materials (0.035 inch to 1/8 inch), no edge preparation is needed and a root opening of 1/16 of an inch or less is recommended. For production of adequate welds on thicker material, some beveling is normally required. When welding plates 1/4 of an inch or greater in thickness, you should prepare a single or double-V groove with 50- to 60-degree included angle(s).

Aluminum

The joint design for aluminum is similar to that of steel; however, aluminum requires a narrower joint spacing and lower welding current setting.

The short-arc welding method is normally used for out-of-position welding or when welding thin materials because short-arc produces a cooler arc than the spray type arc. When welding thinner material (up to 1 inch in thickness), you should use pure argon.

The spray-arc welding method is recommended for welding thicker materials. With spray arc, more heat is produced to melt the wire and base metal. When you are welding thicker material (between 1 and 2 inches) a mixture of 90-percent argon and 10-percent helium is recommended. The helium provides more heat input and the argon provides good cleaning action.

Stainless Steel

DCRP with a 1- or 2-percent oxygen with argon mixture is recommended for most stainless steel welding. In general, you weld stainless steel with the spray-arc welding method and a pushing technique. When welding stainless steel up to 1/1 6 of an inch in thickness, you should use a copper backup strip. For welding thin materials in the overhead or vertical positions, the short-arc method produces better results.

APPENDIX I

GLOSSARY

ACC— Air carbon arc cutting.

ARC BLOW— The tendency for an arc to wander or whip from its normal course during arc welding.

ASME— American Society of Mechanical Engineers.

AWS— American Welding Society.

BACKFIRE— Momentary burning back of the flame into the torch tip during welding or cutting.

BACKHAND WELDING— Welding in the direction opposite the direction the gas flame is pointing.

BURR— The sharp edge remaining on metal after cutting.

CARBURIZING FLAME— Produced by burning an excess of fuel gas.

CHAMFER— Bevel angling the metal edge where welding is to take place.

COMPRESSION STRESSES— The stresses developed within a material when forces tend to compress or crush the material.

DCRP— Direct current reverse polarity.

DCSP— Direct current straight polarity.

DISTORTION— The warping of a structure.

DUCTILITY— The property that enables a material to withstand extensive permanent deformation due to tension.

ELASTICITY— The ability of a material to return to its original form after deformation.

FATIGUE—- The tendency of a material to fail after repeated stressing at the same point.

FATIGUE STRENGTH— The ability of a material to resist various kinds of rapidly alternating stresses.

FERROUS— Denotes the family of metals in which iron is the major ingredient.

FLASHBACK— The flame burning in or beyond the torch mixing chamber during welding or cutting.

FLUX— A chemical used to promote fusion of metals during the welding process.

FOREHAND WELDING— Welding in the same direction as the torch flame points.

FUSION— The melting together of metals.

GMAW— Gas metal arc welding.

GTAW— Gas tungsten arc welding.

IMPACT STRENGTH— The ability of a metal to resist suddenly applied loads; measured in foot-pounds of force.

KERF— The narrow slit formed in metal as cutting progresses.

LAYOUT— The process of measuring and marking materials for cutting, bending, drilling, or welding.

MALLEABILITY— The property that enables a material to withstand permanent deformation caused by compression.

MAPP— A stabilized methyl acetylene-propadiene fuel gas. A Dow Chemical Company product.

METALLOID— A nonmetal that can combine with a metal to form an alloy.

METALLURGY— The science and technology of metals.

MIG— A term used to describe gas metal arc welding (metal inert gas).

NEUTRAL FLAME— Produced when equal amounts of oxygen and fuel gas are burned.

NORMALIZING— A heat-treating operation involving the heating of an iron-base alloy above its critical temperature range and cooling it in still air for the purpose of removing stresses.

NONFERROUS— Metals containing no iron.

OFW— Oxyfuel welding.

OXIDIZING FLAME— Produced by burning about twice as much oxygen as fuel gas.

PASS— A single progression of a welding operation along a joint or weld deposit. The result of a pass is a weld bead.

PLASTICITY— The ability of a material to permanently deform without breaking or rupturing.

POROSITY— The presence of gas pockets or voids in metal.

QUENCHING— The process of rapid cooling from an elevated temperature by contact with fluids or gases.

QUENCHING MEDIUM— The oil, water, brine, or other medium used for rapid cooling.

RSW— Resistance spot welding.

RW— Resistance welding.

SEIZE— To bind securely the end of a wire rope or strand with seizing wire.

SHEARING STRESSES— The stresses developed within a material when external forces are applied along parallel lines in opposite directions.

SMAW— Shielded metal arc welding.

SOAKING— Holding a metal at a required temperature for a specified time to obtain even temperature throughout the section.

STINGER— An electrode holder; a clamping device for holding the electrode securely in any position.

STRESS— External or internal force applied to an object.

TENSILE STRENGTH— The resistance to being pulled apart.

TENSION STRESSES— The stresses developed when a material is subjected to a pulling load.

TIG— A term used to describe gas tungsten arc welding (tungsten inert gas).

TINNING— A term applied to soldering where the metals to be soldered together are first given a coat of the soldering metal.

WELD— To join metals by heating them to a melting temperature and causing the molten metal to flow together.

WELDMENT— An assembly whose parts are joined by welding.

ULTIMATE STRENGTH— The maximum strain that a material is capable of withstanding.

APPENDIX II

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THE TRAMAN

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