1. Helmets and hand shields should be made of a material that is an insulator for heat and electricity. Helmets, shields, and goggles must be fire retardant and must be capable of withstanding sterilization.

2. Helmets and hand shields of federal specification GGG-H-21 1 should be arranged to accommodate and securely hold window lenses having the specified dimensions, with cover glass, and designed to permit easy removal of lenses. Absorptive lenses must be mounted in helmets so they are not less than 2 inches from the eyes.

3. Goggles designated as style 1 have a rigid nonadjustable bridge (or adjustable metallic bridge) without side shields.

4. Goggles designated as style 2 have a rigid nonadjustable bridge (or adjustable metallic bridge) with side shields.

5. Goggles designated as style 3 have flexibly connected lens containers shaped to conform to the configuration of the face.

6. Lens containers must be suitable to firmly hold lenses of the correct dimensions.

7. Goggles of style 2 should be provided with side shields of metal, leather, or other durable asbestos-free material. The material should also be pliable to permit adjusting the shield to the contour of the face. If side shields are of metal, they should be of wire mesh or of perforated sheet having openings not larger than 0.394 inch.

8. Goggles of style 3 should consist of eyecups and should be shaped to fit the configuration of the face. They must have adequate ventilation to prevent fogging.

9. Lenses for helmet and hand shield windows should have a height of 2 inches (50.8 mm) and a width of 4.25 inches (108 mm) where one window is provided.

10. Lenses for goggles should have dimensions not less than 1.5 inches (38 mm) in the vertical direction and 1.75 inches (44.5 mm) in the horizontal direction. It is recommended that circular lenses not involving optical correction be a uniform diameter of 1.97 inches (50 mm). Cover glasses should be provided to protect each helmet, hand shield, or goggle lens.

11. Table 7-1 is a guide for the selection of the proper shade number. These recommendations may be varied to suit the individual's needs. The shade numbers in the following list will help you select the proper lens to use.

a. Shade No. 4, in any type goggle, may be used for stray light from nearby cutting and welding operations and for light electric spot welding.

b. Shade No. 5 filter lenses are usually sufficient for light gas cutting and welding.

c. Shade No. 6 filter lenses are usually sufficient for gas cutting, medium gas welding, and arc welding up to 30 amperes.

d. Shade No. 8 filter lenses are usually sufficient for heavy gas welding and for arc welding and cutting exceeding 30 but not exceeding 75 amperes.

e. Shade No. 10 filter lenses should be used for arc cutting and welding exceeding 75 but not exceeding 200 amperes.

f. Shade No. 12 filter lenses should be used for arc cutting and welding exceeding 200 but not exceeding 400 amperes.

g. Shade No. 14 filter lenses should be used for arc cutting and welding exceeding 400 amperes.

A variety of special clothing is available to protect the body during cutting and welding operations. The protective clothing to be worn will vary with the size, location, and nature of the work to be performed. During ANY welding or cutting operation, you should wear flameproof gauntlets at all times. For gas welding and cutting, a five-finger glove is generally used. For electric-arc welding, a gauntlet-type mitt is recommended. Gauntlets protect the hands from both heat and metal spatter. The one-finger mitt designed for electric-arcwelding has an advantage over the glove because it reduces the danger of weld spatter and sparks lodging between the fingers. It also reduces the chafing of fingers, which sometimes occurs when five-finger gloves are used for electric-arc welding.

Table 7-1.—Eye Protection Shade Guidelines

Welding Operations	Shade Numbers
Shielded Metal-Arc Welding—l/16, 3/32, 1/8, 5/32-inch	10
Inert-Gas Metal-Arc Welding—(Nonferrous) 1/16, 3/32, 1/8, 5/32-inch electrodes	11
Inert-Gas Metal-Arc Welding—(Ferrous) 1/16, 3/32, 1/8, 5/32-inch electrodes	12
Shielded Metal-Arc Welding—3/16, 7/32, 1/4-inch electrodes	12
Shielded Metal-Arc Welding—5/16, 3/8-inch electrodes	14
Arc-Air Cutting and Gouging	12-14
Soldering	2
Torch Brazing	3-4
Light Cutting, up to 1 inch	3-4
Medium Cutting, 1 inch to 6 inches	4-5
Heavy Cutting, 6 inches and over	5-6
Gas Welding (Light), up to 1/8-inch	4-5
Gas Welding (Medium), 1/8-inch to 1/2-inch	5-6
Gas Welding (Heavy), 1/2-inch and over	6-8

Some light gas welding and cutting jobs require no special protective clothing other than gauntlets and goggles if the regular work clothing is worn correctly. Sleeves must be rolled down, collar and cuffs buttoned, and pockets that are not protected by button-down flaps must be eliminated from the front of work clothing. Trouser cuffs must not be turned up on the outside. All other clothing must be free of oil and grease. High-top or safety shoes should be worn, and low-cut shoes with unprotected tops should NOT be worn. Wearing clothing in the manner described decreases the probability that sparks will lodge in folds of cloth such as rolled-up sleeves and cuffs, pockets, or the shirt collar.

During medium and heavy welding, specially designed flameproof clothing made of leather, or other suitable material, may be required. A wide choice of protective clothing is available so that you can select the type required for any particular welding or cutting job.

This clothing consists of aprons, sleeves, a combination of sleeves and bib, jackets, and overalls. Sleeves provide satisfactory protection for light welding operations at floor or bench level. Capes and sleeves are particularly suitable for overhead welding because the cape protects the back of the neck, top of the shoulders, and upper part of the back and chest. Use of the bib in combination with the cape and sleeves gives added protection to the chest and abdomen in jobs where protection for the lower part of the back is not required. The jacket should be worn only when complete all-around protection for the upper part of the body is needed, such as when several welders are working near each other. Aprons and overalls provide protection to the legs and therefore are suitable for welding operations on the deck or floor.

During overhead welding operations, leather caps should be worn under helmets to prevent head burns. Where the welder may be exposed to sharp or heavy falling objects, hard hats or head protectors should be attached in such a way as to form a part of the welding helmet. For very heavy work, fire-resistant leggings or high boots should be worn. Shoes or boots having exposed nail heads or rivets should not be worn. Oilskins or plastic clothing must not be worn while welding or cutting.

If leather protective clothing is not available, woolen garments rather than cotton garments should be worn. Wood does not ignite as readily as cotton, and it affords greater protection from changes in temperature. Cotton clothing, if it must be used, should be chemically treated to reduce its flammability. Synthetic fabrics should not be worn.

Report all injuries to the medical department as soon as possible. Even a slight burn or scratch should be treated promptly to prevent infection. Eye burns should be treated IMMEDIATELY. All eye burns should be seen as soon as possible by medical personnel.

SOURCES OF INFORMATION

To keep abreast of changes in the field of welding, it is essential that you be familiar with a number of sources of information. There are numerous Navy and commercial publications pertaining to welding. Some of these publications have already been mentioned earlier in this chapter. In the field of welding, as in so many other fields, official publications are constantly under revision; therefore, it is important to make an effort to keep up with the latest changes as they are issued.

The basic naval reference on welding and allied processes is *NSTM,* chapter 074, volume 1.

HYDROSTATIC TESTS

All welded piping must be subjected to hydrostatic tests to prove the tightness and the strength of the joints. Test pressures are usually included in the instructions or specifications for the welding. If test pressures are not specified, the hydrostatic test is normally performed at 135 percent of the maximum working pressure.

NONDESTRUCTIVE TESTS AND INSPECTIONS

A number of nondestructive techniques are used to determine the quality of welds and welded structures. Nondestructive tests and inspections include visual examination, magnetic particle inspection, liquid penetrant inspection, radiographic inspection, and ultrasonic tests. Some of these techniques are widely used throughout the Navy, and others are used only at large production or repair activities. These tests will be described in chapter 11 of this training manual.

VISUAL EXAMINATION

Prior to being tested by any other nondestructive test, all welds must pass a visual examination. Visual inspection of welds is useful for detecting undercutting, large cracks, inaccurate dimensions, and other obvious defects. However, there are many serious defects that cannot be detected by visual inspection, even by an experienced inspector. Visual examination of welds is NOT adequate for determining the internal soundness of welds or for detecting very small surface defects.

SUMMARY

This chapter has covered several areas of basic welding. You now have the basic knowledge of the welding processes, basic sequences, and the positions of welding. You were given the basic information on joints, welds, weld symbols, welding symbols, weld defects, and filler metals. With the knowledge gained from this chapter, you are on your way to learning to become a good, safe, and conscientious welder. Safety can never be stressed enough.

CHAPTER 8

OXYACETYLENE CUTTING AND WELDING

LEARNING OBJECTIVES

Upon completion of this chapter; you will be able to perform the following:

- *Describe the equipment used in oxyacetylene welding and the proper procedures for setup and safe operation of the equipment.*
- *State the principles of oxyacetylene cutting.*
- *Identify the parts of a cutting torch and the function of each part, and describe some of the special cutting techniques.*
- *Identify the safety precautions you should follow when performing cutting operations.*
- *Describe the different techniques of oxyacetylene welding and the safety precautions you should follow.*

INTRODUCTION

This chapter deals with oxyacetylene cutting and welding processes, and identifies the equipment and the operation of the equipment used in oxyacetylene operations.

Oxyacetylene cutting is a method of cutting metal by using heat and a jet of pure oxygen to produce a chemical reaction known as oxidation. The results obtained by using the oxyacetylene cutting method will range from a ragged, inaccurate edge to a smooth edge. The material being cut, the cutting method used, and the skill of the operator are among the factors that determine the final results.

Oxyacetylene welding is a nonpressure process in which coalescence is produced by heat from an oxyacetylene flame formed by the combustion of oxygen and acetylene. The two gases are mixed to correct proportions in a torch. The torch can be adjusted to give various types of flame.

OXYACETYLENE EQUIPMENT

Oxyacetylene equipment consists of a cylinder of acetylene, a cylinder of oxygen, two regulators, two lengths of hose with fittings, a welding torch with tips, and either a cutting attachment or a separate cutting torch. Accessories include a friction igniter to light the torch, an apparatus wrench to fit the various connections on the regulators, the cylinders, and the torches; goggles with filter lenses for eye protection; and gloves for protection of the hands. Flame-resistant clothing is worn when necessary.

The major components of a typical portable oxyacetylene outfit are shown in figure 8-1. Figure 8-2 illustrates a stationary acetylene cylinder bank of a type used at some activities.

ACETYLENE

Acetylene (chemical formula C_2H_2) is a fuel gas made up of carbon and hydrogen. When burned with oxygen, acetylene produces a very hot flame, having a temperature between 5700°F and 6300°F. Acetylene gas is colorless, but has a distinct, easily recognized odor. The acetylene used on board ship is taken from compressed gas cylinders. The cylinder is filled with balsa wood, charcoal, finely shredded asbestos, corn pith, portland cement, or infusorial earth (an absorbent material composed of decayed organic matter). These porous filler materials are used to decrease the size of

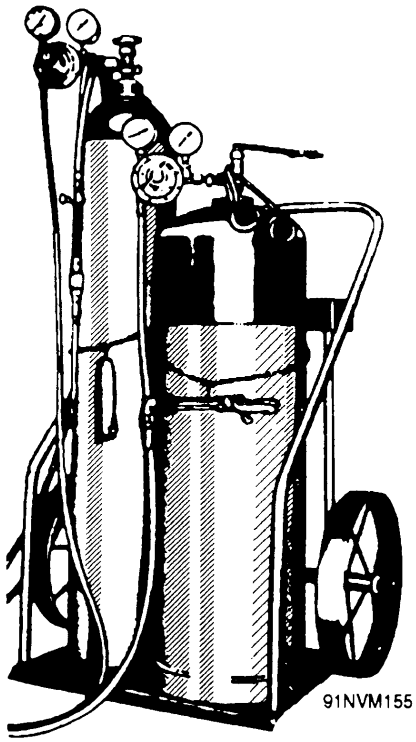
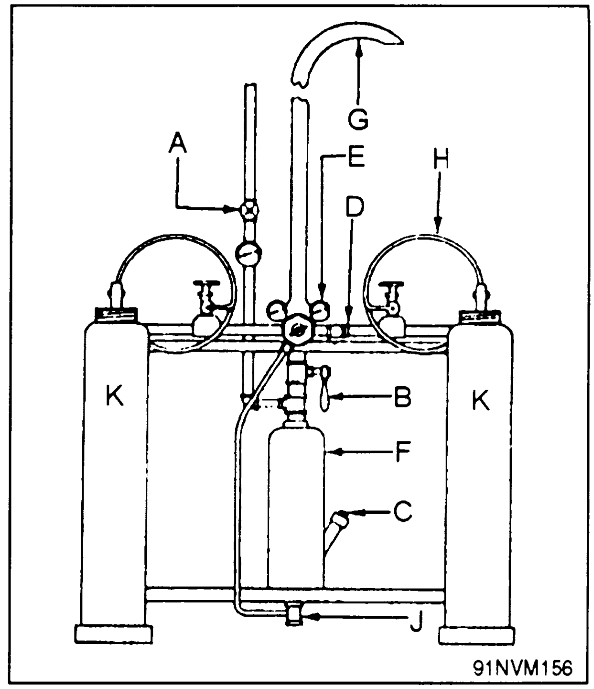


Figure 8-1.—A portable oxyacetylene outfit.



A. Line valve
B. Release valve
C. Filler plug
D. Header pipe
E. Regulator
F. Flash arrester chamber
G. Escape pipe
H. Cylinder connection pipe
J. Check valve and drain plug
K. Acetylene cylinders

Figure 8-2.—Stationary acetylene cylinder bank.

the open spaces in the cylinder and thus reduce the danger of explosion. At approximately 29 psi (pounds per square inch), pure acetylene can be exploded by nothing more than a slight shock; dissolved in acetone, however, and stored in cylinders that are filled with porous material, acetylene can be compressed safely into cylinders at pressures up to 250 psi. An acetylene cylinder is shown in figure 8-3. The acetylene cylinder must be in the vertical position a minimum of 2 hours before use to allow the porous filler material to settle and to prevent it from being drawn into the hose, gauges, and torch.

MAPP GAS

MAPP (methylacetylene-propadiene) gas is an all-purpose industrial fuel that has the high flame temperature of acetylene and the handling characteristics of propane. Being a liquid, MAPP gas is obtained by the pound rather than by the cubic foot, as with acetylene. One 70-pound (31.5-kg) cylinder of MAPP gas will do the work of more than 6 1/2, 225-cubic foot acetylene cylinders. This is a ratio of 70 pounds of MAPP gas to 1,500 cubic feet of acetylene.

The total weight for the 70-pound (31.5-kg) MAPP cylinder, which is the same physical size as a

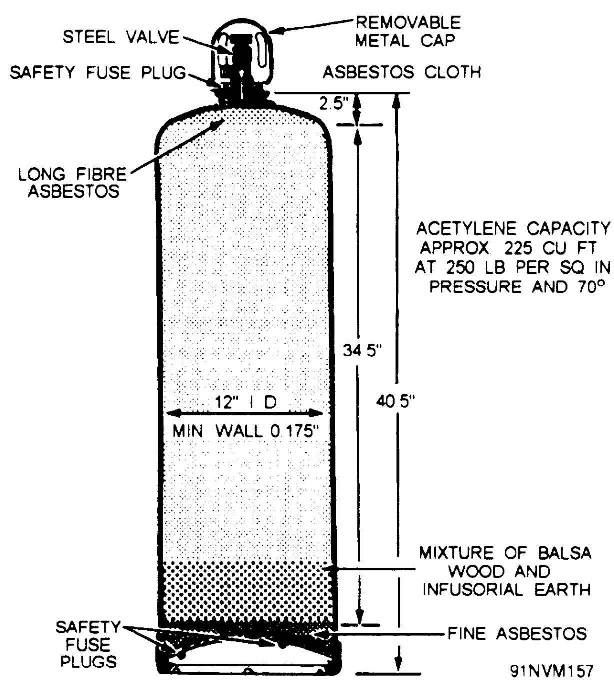


Figure 8-3.—Acetylene cylinder.

225-cubic foot acetylene cylinder, is 120 pounds (54.0 kg) when full.

MAPP cylinders contain only liquid fuel. There is no cylinder packing of acetone to impair fuel withdrawal. For heavy-use situations, a MAPP cylinder will deliver more than twice as much gas as an acetylene cylinder and for longer periods of time. The entire contents of a MAPP cylinder can be used, as there is no acetone that could be drawn into the regulators or torch. As the gas bums with oxygen, it produces a flame temperature of 5300°F (2950°C) and will equal or exceed the performance of acetylene for cutting, heating, and brazing due to its superior heat transfer characteristics.

MAPP is nonsensitive to shock and nonflammable in the absence of oxygen. There is no chance of an explosion if a cylinder is bumped, jarred, or dropped. The cylinders may be stored or transported in any position with no danger of an explosive air pocket being formed.

The characteristic odor, while harmless, gives warnings of fuel leaks in the equipment long before a dangerous condition can occur.

MAPP gas is not restricted to a maximum working pressure of 15 psig, as is acetylene. In jobs requiring higher pressures and gas flows, MAPP at the full cylinder pressure of 95 psig at 70°F (21 °C) can be used safely.

MAPP Gas Safety

Liquified MAPP gas is insensitive to shock. A MAPP gas cylinder will not detonate when dented, dropped, hammered, or even incinerated. It may also be safely used up to full cylinder pressures. The gas vapors, up to 419°F and 285 psig, will not decompose when subjected to an energy source in the absence of oxygen. The vapor also is stable up to 600°F and 1,100 psig when exposed to an 825°F probe. The explosive limits of MAPP gas are 3.4 percent to 10.8 percent in air, or 2.5 percent to 80 percent in oxygen. As you can see, these limits are very narrow in comparison with that of acetylene.

MAPP gas has a highly detectable odor. The smell is detectable at 100 ppm, or at a concentration 1/340th of its lower explosive limit.

Small fuel-gas systems may leak 1 or 1 1/2 pounds of fuel or more in an 8-hour shift. Fuel-gas leaks are often difficult to find, and many times go unnoticed. However, a MAPP gas leak is easy to detect and can be repaired before it becomes dangerous.

MAPP toxicity is rated “very slight,” but high concentrations (5,000 ppm) may have an anesthetic effect. Local eye or skin contact with MAPP gas vapor causes no adverse effect. However, the liquid fuel will cause dangerous frostlike burns due to the temperature at which MAPP gas must be stored.

OXYGEN

Oxygen is a colorless, tasteless, odorless gas that is slightly heavier than air. Oxygen will not bum by itself, but it will support combustion when combined with other gases. Extreme care must be taken to ensure that compressed oxygen does not become contaminated with hydrogen or hydrocarbon gases or liquids, unless the oxygen is controlled by such means as the mixing chamber of a torch. A highly explosive mixture will be formed if uncontrolled compressed oxygen becomes contaminated. Oxygen should NEVER come in contact with oil or grease.

Oxygen cylinders are supplied in several sizes. The size most commonly used aboard ship is 9 1/8 inches in diameter, weighs about 145 pounds, and has a capacity of 200 cubic feet. At 70°F, the gas is under a pressure of 1800 psi.

REGULATORS

The gas pressure in a cylinder must be reduced to a suitable working pressure before it can be used. This is done by a regulator or reducing valve. Regulators are either the single-stage or the double-stage type. Single-stage regulators reduce the pressure of the gas in one step; two-stage regulators do the same job in two steps or stages. Less adjustment is generally necessary when two-stage regulators are used.

Figure 8-4 shows a typical single-stage regulator. The regulator mechanism consists of a nozzle through

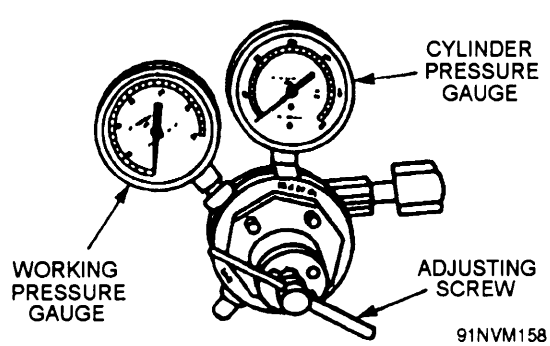


Figure 8-4.—Single-stage regulator.

which the high-pressure gases pass, a valve seat to close off the nozzle, a diaphragm, and balancing springs. These are all enclosed in a suitable housing. Pressure gauges are provided to indicate the pressure in the cylinder or pipeline (inlet), as well as the working pressure (outlet). The inlet pressure gauge, used to record cylinder pressures, is a high-pressure gauge; the outlet pressure gauge, used to record working pressures, is a low-pressure gauge. Acetylene regulators and oxygen regulators are of the same general type, although those designed for acetylene are not made to withstand such high pressures as are those designed for use with oxygen cylinders.

In the regulator, the gas enters the regulator through the high-pressure inlet connection and passes through a glass wool filter that removes dust and dirt. Turning the adjusting screw in, to the right, allows the gas to pass from the high-pressure chamber to the low-pressure chamber of the regulator, through the regulator outlet, and through the hose to the torch. Turning the adjusting screw to the right INCREASES the working pressure; turning it to the left DECREASES the working pressure. The high-pressure gauge is graduated in pounds per square inch from 0 to 3,000 for oxygen and 0 to 400 for acetylene. This permits reading of the gauge to determine cylinder pressure. The gauges are graduated to read correctly at 70°F. The working pressure gauge is graduated in pounds per square inch from 0 to 30 for acetylene and from 0 to 50, 0 to 100, 0 to 200, or 0 to 400 for oxygen, depending upon the purpose for which the regulator is designed. For example, on regulators designed for heavy cutting, the working pressure gauge is graduated in pounds per square inch from 0 to 400.

The two-stage regulator is similar in principle to the one-stage regulator, the chief difference being that the total pressure drop takes place in two steps instead of one. In the high-pressure stage, the cylinder pressure is reduced to an intermediate pressure. In the low-pressure stage, the pressure is reduced from the intermediate pressure to a working pressure. A two-stage regulator is shown in figure 8-5.

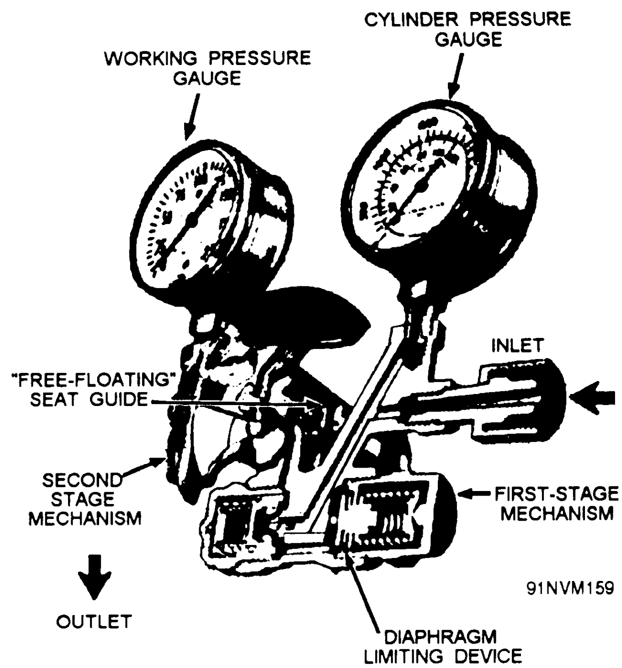


Figure 8-5.—Two-stage regulator.

WELDING TORCHES

The oxyacetylene welding torch is used to mix oxygen and acetylene gas in the proper proportions and to control the volume of these gases burned at the welding tip. Torches have two needle valves, one for adjusting the flow of oxygen and the other for adjusting the flow of acetylene. In addition, they have a handle (body), two tubes (one for oxygen and one for acetylene), a mixing head, and a tip. Welding tips are made from a special copper alloy, which dissipates heat (less than 60 percent copper), and are available in different sizes to handle a wide range of plate thicknesses.

There are two types of welding torches, the low-pressure type and the medium-pressure type. In the low-pressure type, the acetylene pressure is 1 psi or less. A jet of high-pressure oxygen is necessary to produce a suction effect, which draws in the required amount of acetylene. This is accomplished by the design of the mixer in the torch, which operates on the injector principle. The welding tips may or may not have separate injectors designed into the tip. A typical mixing head for the low-pressure or injector type of torch is shown in figure 8-6.

In the medium-pressure torches, the acetylene is burned at pressures from 1 to 15 psi. These torches are made to operate at equal pressures for acetylene and oxygen. They are sometimes called equal-pressure or balanced-pressure torches. The medium-pressure torch is easier to adjust than the low-pressure torch and, because equal pressures are used, you are less likely to get a flashback. This means that the flame is less likely to catch in or back of the mixing chamber. A typical equal-pressure torch is shown in figure 8-7.

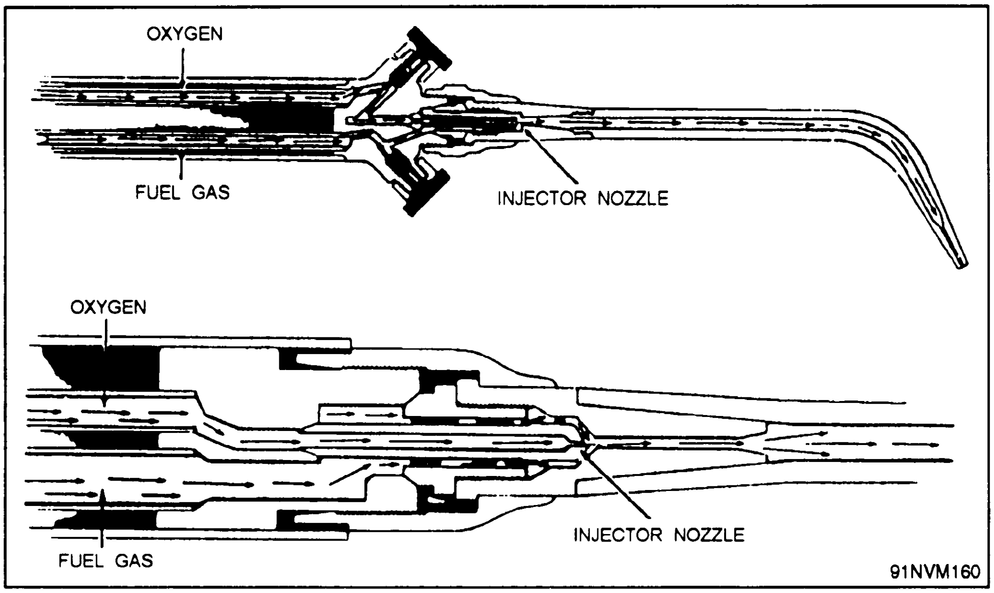


Figure 8-6.—Mixing head for a low-pressure torch..

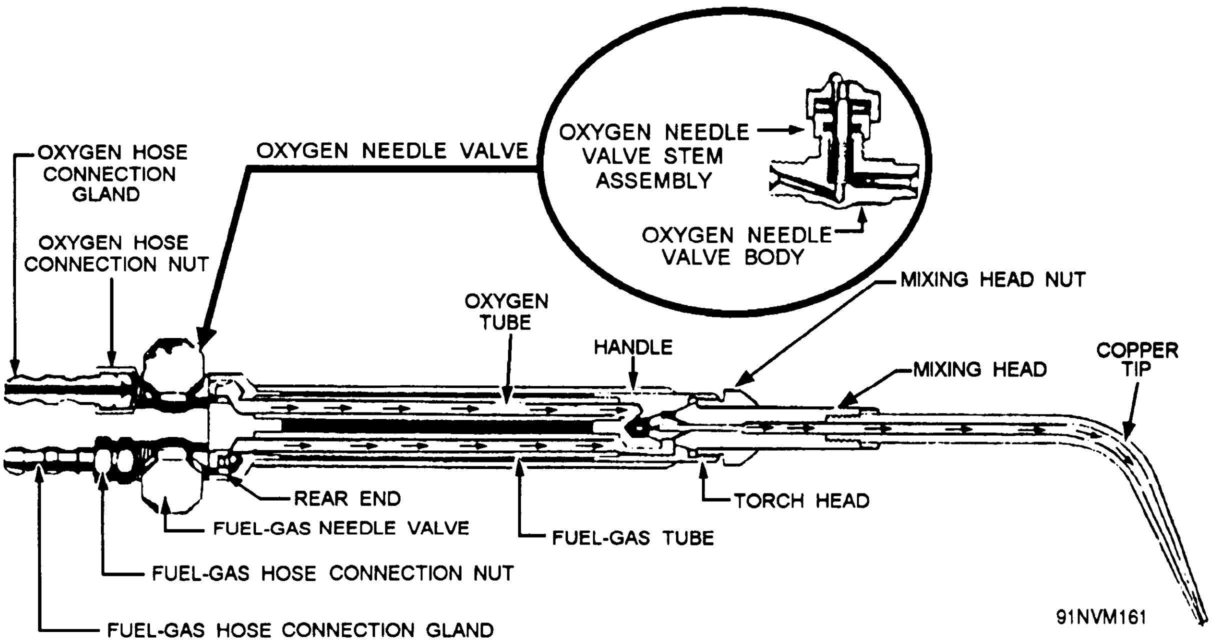


Figure 8-7.—Equal-pressure welding torch.

Welding tips and mixers made by different manufacturers differ in design. Some makes of torches are provided with an individual mixing head or mixer for each size of tip. Other makes have only one mixer for several tip sizes. Tips come in various types. Some are one-piece, hard copper tips. Others are two-piece tips that include an extension tube to make 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 its own arrangement for classifying them. Tips have different hole diameters.

No matter what type or size tip you select, the tip must be kept clean. Quite often the orifice becomes clogged with slag. When this happens, the flame will not bum properly. Inspect the tip before you use it. If the passage is obstructed, you can clear it with wire tip cleaners of the proper diameter or with soft copper wire. Tips should not be cleaned with machinists' drills or other sharp instruments. These devices may enlarge or scratch the tip opening and greatly reduce the efficiency of the torch tip.

HOSE

The hose used to make the connection between the torch and the regulators is strong, nonporous, and flexible and light enough to make torch movements easy. It is made to withstand high internal pressures, and the rubber used in its manufacture is specially treated to remove sulfur to avoid the danger of spontaneous combustion. Welding hose is available in various sizes, depending upon the size of work for which it is intended. Hose used for light work is 3/16 or 1/4 inch in diameter and has one or two plies of fabric. For heavy-duty welding and cutting operations, the hose will have an inside diameter of 1/4 or 5/16 inch and three to five plies of fabric. Single hose may be ordered in various lengths up to 600 feet on a spool. Some manufacturers make a double hose that conforms to the same general specifications. The hoses used for acetylene and oxygen are the same in grade, but they differ in color and have different types of threads on the hose fittings. The oxygen hose is GREEN and the acetylene hose is RED. For added protection against mixing of the hoses during connection, the oxygen hose has right-hand threads and the acetylene hose has left-hand threads. The acetylene fittings also have a notch that goes around the circumference of the fittings for an additional identification factor.

WELDING RODS

The term *welding rod* refers to a filler metal, in wire or rod form, used in gas welding and brazing processes and in certain electric welding processes (tungsten inert-gas) in which the filler metal is not a part of the electric circuit. A welding rod serves only one purpose—it supplies filler metal to the joint.

As a rule, rods are uncoated except for a thin film resulting from the manufacturing process. Welding rods for 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 in cross section. The rod diameter selected for a given job is governed by the thickness of the metals being joined.

Except for rod diameter, the welding rod selected is determined by specification on the basis of the metals being joined. These specifications may be either federal or military. This means that they apply to all federal agencies and the military establishment. Filler metals are presently covered by one or both of these specifications.

Many different types of rods are manufactured for welding ferrous and nonferrous metals. In general, shipboard 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. One such general-purpose rod that will be found in any Navy welding shop is a rod suitable for oxyacetylene welding of low-carbon steel. Such a rod is class 1, type A, as specified in AWS-A5.2-88. The same specification covers welding rods (class II) for use on cast iron.

Rods for gas welding on other common materials are covered by other specifications. At the time this manual was written, the following specifications applied: copper-base alloys, MIL-R-19631B; corrosion-resisting and heat-resisting steel, MIL-R-5031B, class 5; nickel-base alloys, including Monel, QQ-R-571C; and nickel-chromium-iron alloys, MIL-T-23227.

SETTING UP THE EQUIPMENT

The procedure for setting up oxyacetylene equipment is as follows:

1. Secure the cylinders so that they cannot be upset. Ensure that the acetylene cylinders have been in the vertical position a minimum of 2 hours before removing the protective caps.

2. Crack the cylinder valves slightly to blow out any dirt that may be in the valves. Close the valves. Check for grease and oil on or near the valves and fittings of the cylinders. Wipe the connections with a clean cloth.

CAUTION

Never crack gas cylinder valves toward an individual and always wear safety glasses.

3. Connect the acetylene pressure regulator to the acetylene cylinder and the oxygen pressure regulator to the oxygen cylinder. Using the appropriate wrench provided with the equipment, tighten the connecting

nuts enough to prevent leakage. Never use vice grips, pliers, adjustable wrenches, and so on to open or close gas cylinder valves or to tighten equipment fittings. You will only ruin the valve stem and damage equipment, making it impossible to open or close the equipment in an emergency.

4. Connect the red hose to the acetylene regulator and the green hose to the oxygen regulator. Tighten the connecting nuts enough to prevent leakage.

5. Back off on the regulator screws, and then open the cylinder valves slowly. Open the acetylene valve one-fourth to one-half turn. This will allow an adequate flow of acetylene, and the valve can be turned off quickly in an emergency. (NEVER open the acetylene cylinder valve more than 1 1/2 turns.) The oxygen cylinder valve should be opened all the way to eliminate leakage around the stem. (Oxygen valves are double-seated or have diaphragms to prevent leakage when they are open.) Read the high-pressure gauge to check the pressure of each cylinder.

6. Blow out the oxygen hose by turning the regulator screw in and then back out again. If it is necessary to blow out the acetylene hose, do it ONLY in a well-ventilated place that is free from sparks, flames, or other possible sources of ignition.

7. Connect the hose to the torch. The torch hose connections should be marked with a small "ac" or "acet" for acetylene or "ox" for oxygen stamped on the connection or the needle valve. Also, to prevent you from cross-connecting hoses or equipment, all acetylene connections have left-hand threads and all oxygen connections have right-hand threads.

8. Test all oxyaceteylene connections for leaks. There are several ways to test oxyacetylene connections for leaks after the system has been pressurized. The preferred method is to coat all connections with a soapy water solution and check for the formation of small bubbles. The formation of small bubbles at the connection indicates leaking gas and you should retighten the connection as needed. Another way to check fittings for leakage is to secure the system at the cylinder by closing the cylinder valve and check for a pressure drop on the regulator gauges. Any drop in pressure, on the gauges, indicates a loose connection and you should retighten all connections.

9. Adjust the tip. Screw the tip into the mixing head and assemble in the torch body. Tighten by hand and adjust to the proper angle. Secure this adjustment by tightening with the wrench provided with the torch.

10. Adjust the working pressures. A standard, working pressure of 20 to 25 psi oxygen and 5 to 7 psi acetylene is recommended. The acetylene pressure is adjusted by turning the regulator screw to the right until the desired pressure is attained. (Due to the instability of acetylene at high pressures, you should never exceed 15 psig on the regulator gauge.)

11. Light and adjust the welding flame. Open the oxygen needle valve a very slight amount and then the acetylene needle valve considerably more than the oxygen needle valve. Light the flame with a friction igniter. Make sure that the flame path is pointed in a safe direction and that your hands are not in front of the torch tip. Adjust the oxygen and acetylene needle valves as necessary to get a proper flame.

ADJUSTING THE FLAME

A pure acetylene flame is long and bushy and has a yellowish color, as shown in figure 8-8. It is burned by the oxygen in the air, which is not sufficient to bum the acetylene completely; therefore, the flame is smoky, producing a soot of fine, unburned carbon. The pure acetylene flame is unsuitable for welding. When the oxygen valve is opened, the mixed gases burn in contact with the tip face. The flame changes to a bluish-white color and forms a bright inner cone surrounded by an outer flame envelope. The inner cone develops the high temperature required for welding.

There are three types of flame commonly used for welding. These are neutral, reducing or carburizing, and oxidizing flames. (See fig. 8-8.) The NEUTRAL flame is produced by burning one part of oxygen to one part of acetylene. Together with the oxygen in the air, it produces complete combustion of the acetylene. The luminous white cone is well defined and there is no greenish tinge of acetylene at its tip, nor is there an excess of oxygen. The welding flame should always be adjusted to neutral before either the oxidizing or carburizing flame mixture is set. A neutral flame is obtained by gradually opening the oxygen valve to shorten the acetylene flame until a clearly defined inner luminous cone is visible. The neutral flame is used for most welding and for the preheating flames during cutting operations. The temperature at the tip of the inner cone is about 5900°F, while at the extreme-end of the outer cone it is only about 2300°F. This gives you a chance to exercise some temperature control by moving the torch closer or farther from the work. When steel is welded with this flame, the puddle

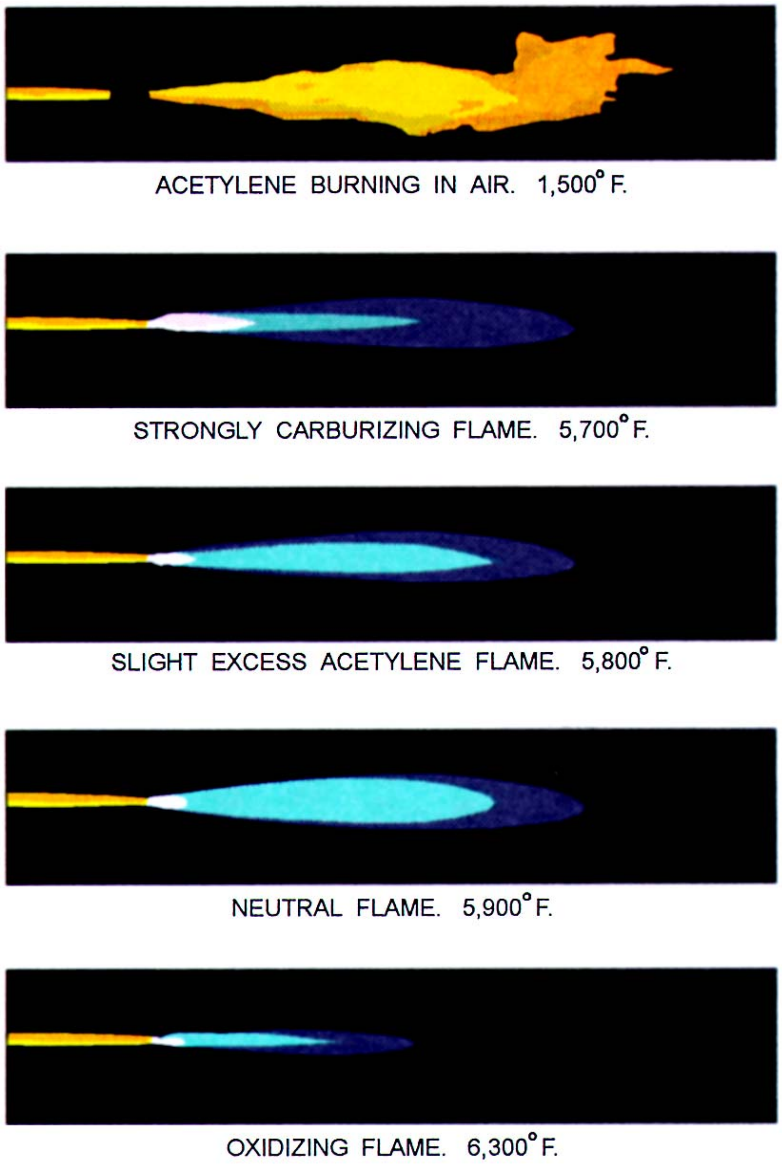


Figure 8-8.—Characteristics of the oxyacetylene flame.

of molten metal is quiet and clear, and the metal flows without boiling, foaming, or sparking.

The REDUCING (or CARBURIZING) flame is produced by burning an excess of acetylene. You will be able to recognize it by the feather at the tip of the inner cone. At the end of the inner cone, this feathery tip has a greenish color. The degree of carburization can be judged from the length of the feather. For most welding operations, the length of the feather should be about twice the length of the inner cone. You can always recognize the carburizing flame by its three distinct colors. These are the bluish-white inner cone, a white intermediate cone, and the light-blue outer flame. The carburizing flame bums with a temperature of about 5700°F at the tip of the inner cone. When it is used for welding steel, the metal boils and is not clear. A carburizing flame is best for welding high-carbon steels, for hard-surfacing, and for welding nonferrous alloys such as Monel.

The OXIDIZING flame is produced by burning an excess of oxygen. The oxidizing flame bums with a temperature of about 6300°F at the tip of the inner cone. You can identify this flame by the short outer flame and the small, white, inner cone. It takes about two parts of oxygen to one part of acetylene to produce this flame, and you will find that the adjustment for the oxidizing flame is a bit more difficult to make than the adjustment for other flames. To adjust for the oxidizing flame, first adjust to a neutral flame and then open the oxygen valve until the inner cone is about one-tenth of its original length. An oxidizing flame makes a hissing sound, and the inner cone is somewhat pointed and purplish in color at the tip. The oxidizing flame has a limited use and is harmful to many metals. When it is applied to steel, the oxidizing flame causes the molten metal to foam and give off sparks. This means that the extra amount of oxygen is combining with the steel, causing the metal to burn. However, the oxidizing flame does have its uses. A slightly oxidizing flame is used to braze weld steel and cast iron, and a stronger oxidizing flame is used for fusion welding of brass and bronze. You will have to determine the amount of excess oxygen to use in this type of flame adjustment by watching the molten metal.

EXTINGUISHING THE FLAME

To extinguish the oxyacetylene flame and to secure equipment after completing a job, or when work is to be interrupted temporarily, the following steps should be taken:

1. Close the acetylene needle valve first; this extinguishes the flame and prevents a flashback. (Flashback is discussed later in this chapter.) Then close the oxygen needle valve.

2. Close both oxygen and acetylene cylinder valves. Leave the oxygen and acetylene regulators open temporarily.

3. Open the acetylene needle valve on the torch and allow gas in the hose to escape for 5 to 15 seconds. Do not allow gas to escape into a small or closed compartment. Close the acetylene needle valve.

4. Open the oxygen needle valve on the torch. Allow gas in the hose to escape for 5 to 15 seconds. Close the valve.

5. Close both oxygen and acetylene cylinder regulators by backing out the adjusting screws until they are loose.

The foregoing procedure should be followed whenever work is interrupted for an indefinite period. If work is to stop for only a few minutes, securing cylinder valves and draining the hose is not necessary. However, for any indefinite work stoppage, the entire extinguishing and securing procedure should be followed. For overnight work stoppage in areas other than the shop, you should always remove the pressure regulators and the torch from the system, double check the cylinder valves to make sure they are closed securely, and reinstall the cylinder valve protection cap.

OXYACETYLENE CUTTING

Oxyacetylene cutting is the most commonly used method of cutting ferrous metals by the application of heat. The principle of oxyacetylene cutting is simple. The metal is heated to its ignition temperature by oxyacetylene flames. Then a jet of pure oxygen is directed at the hot metal, and a chemical reaction known as OXIDATION takes place. Oxidation is a familiar chemical reaction. When it occurs rapidly, it is called COMBUSTION or BURNING; when it occurs slowly, it is called RUSTING. When metal is being cut by the oxyacetylene torch method, the oxidation of the metal is extremely rapid-in short, the metal actually burns. The heat liberated by the burning of the iron or steel melts the iron oxide formed by the chemical reaction, and it also heats the pure iron or steel. The molten material runs off as slag, exposing more iron or steel to the oxygen jet.

In oxyacetylene cutting, only that portion of the metal that is in the direct path of the oxygen jet is oxidized. Thus, a narrow slit (called a kerf) is formed in the metal as the cutting progresses. Most of the material removed from the kerf is in the form of oxides (products of the oxidation reaction). The remainder of the material removed from the kerf is pure metal, which is blown or washed out of the kerf by the force of the oxygen jet.

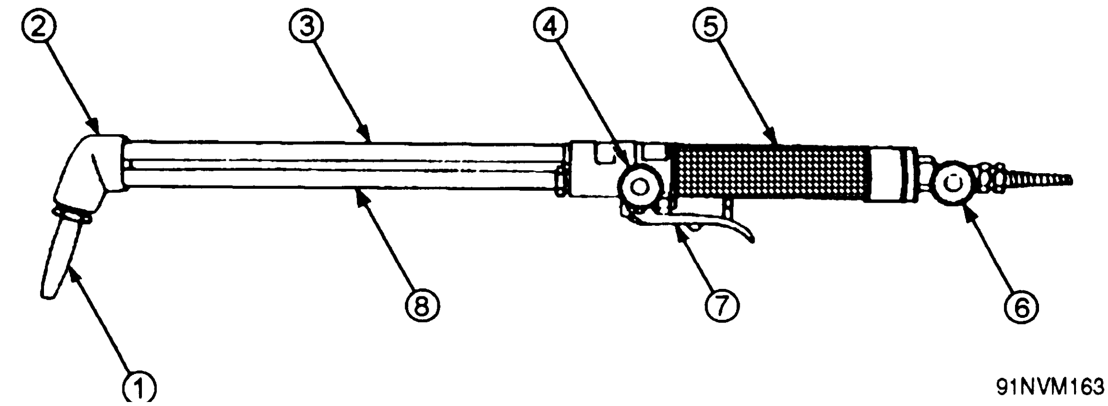
Since oxidation of the metal is a vital part of the oxyacetylene cutting process, this process is not suitable for metals that do not oxidize readily, such as copper, brass, stainless steel, and so on. Low-carbon steels are easily cut by the oxyacetylene cutting process, but special techniques (described later in this chapter) are required for the oxyacetylene cutting of many other metals.

The walls of the kerf formed by oxyacetylene cutting should be fairly smooth and parallel. When you develop skill in handling the torch, you will be able to hold the cut to within reasonably close tolerances. Also, you will be able to guide the cut along straight, curved, or irregular lines, and to cut bevels or other shapes that require holding the torch at an angle.

CUTTING TORCHES

The standard cutting torch looks very much like the oxyacetylene welding torch. The main difference in the two torches is that the cutting torch has an extra tube for high-pressure (cutting) oxygen. The flow of high-pressure oxygen is controlled by a lever valve assembly on the handle of the cutting torch. A standard cutting torch is shown in figure 8-9. This torch is of rugged, trouble-free construction; and it is designed for operator comfort, and ease and economy of maintenance and repair if it is damaged. This torch is available with either a 75-degree or 90-degree cutting head. The spiral mixer chamber provides excellent mixing of the oxygen and acetylene to the preheating flame.

Some welding torches are furnished with a cutting attachment that may be fitted to the torch in place of the welding head (tip). With this type of attachment (shown in fig. 8-10), the welding torch may be used as a cutting torch. This type of torch is generally called a combination torch. High-pressure oxygen is controlled by a lever on the torch handle.



1. Tip | **3. Cutting Oxygen Tube** | **5. Handle** | **7. Cutting Oxygen Lever**
2. 90° Head | **4. Oxygen Valve Assembly** | **6. Acetylene Valve Assembly** | **8. Acetylene Tube**

Figure 8-9.—Standard oxyacetylene cutting torch.

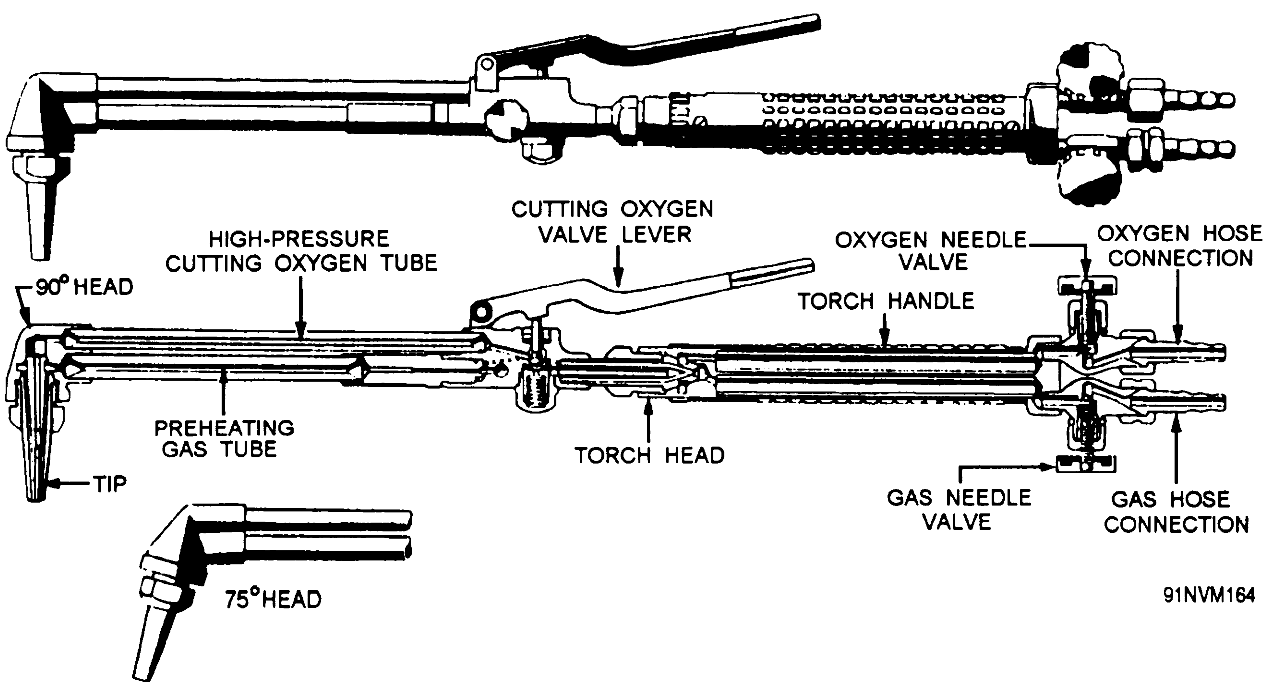
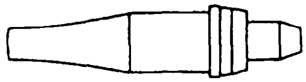
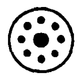
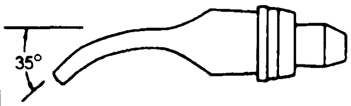
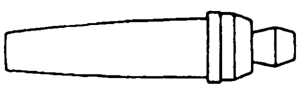
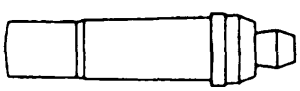
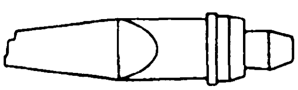
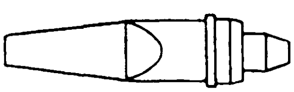
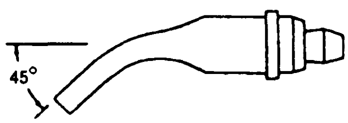
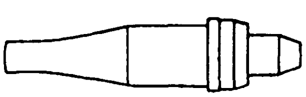
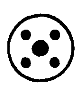
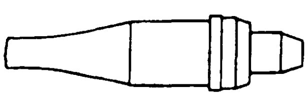
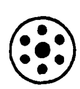


Figure 8-10.—Cutting attachment for an oxyacetylene cutting torch.

CUTTING TIPS

Just as in welding, you must use the proper size cutting tip if quality work is to be done. The preheat flames must furnish just the right amount of heat, and the oxygen jet orifice must deliver the correct amount of oxygen at just the right pressure and velocity to produce a clean cut (kerf). All of this must be done with a minimum consumption of oxygen and fuel gases. All too often, careless workers or ones not acquainted with the correct procedures waste both oxygen and fuel gas.

Cutting tips are made of copper or of tellurium-copper alloy. Each manufacturer has cutting tips of different designs. The orifice arrangements and tip material are much the same among various manufacturers; however, the part of the tip that fits into the torch head often differs in design. Figure 8-11 shows several different orifice arrangements and their uses.

STYLE	PRE-HEAT	DESCRIPTION	SIZE	TYPE
	 Medium	**MAPP* GAS—One-Piece** Preheat: Medium Typical use: Hand and machine cutting.	00-6	1-303M
	 Medium	**MAPP* GAS—One-Piece** Preheat: Medium. Typical use: Cutting close to bulkheads, hand cutting of rivet heads, machine cutting 35° with torch perpendicular.	1, 2, 3	1-312M
	 Medium	**MAPP* GAS—Two-Piece** Preheat: Medium. Typical use: General-purpose cutting hand and machine thru 4".	000-4	2-210M
	 Heavy	**MAPP* GAS—Two-Piece** Preheat: Heavy. Typical use: General-purpose cutting hand and machine 4" and over.	5-8, 10	2-210M
	 Light	**ACETYLENE** Preheat: Very light. Typical use: Clean metal. Plate cutting and trimming.	00-2	1-110
	 Medium	**ACETYLENE** Preheat: Medium. Typical use: Clean plate, straight line or circle machine cutting and trimming. Special lengths available on request.	00-4	1-111
	 Medium	**ACETYLENE** Preheat: Medium. Typical use: Cutting close to bulkheads, hand cutting of rivet heads. Machine cutting 45° with torch perpendicular.	00-4	1-112
	 Light	**ACETYLENE** Preheat: Light. Typical use: Hand & machine cutting. Clean plate.	0, 1, 2	1-100
	 Medium	**ACETYLENE** Preheat: Medium. Typical use: General hand & machine cutting	000-8	1-101

91NVM165

Figure 8-11.—Common cutting torch tips and their uses.

Table 8-1.—Ranges of Oxyacetylene Cutting Tips

TIP IDENTIFICATION	CUTTING OXYGEN ORIFICE (DRILL SIZE)	PREHEAT ORIFICES		APPROXIMATE CUTTING RANGE, STRAIGHT EDGE CUTTING OF MEDIUM STEEL (INCHES)
		DRILL SIZE	HOW MANY	
1–62–64	62	64	4	1/8 to 1/2
2–56–62	56	62	4	1/4 to 1 1/4
3–52–59	52	59	4	1 to 2 1/2
4–43–57	43	57	6	2 to 6
5–30–56	30	56	6	6 to 12

The central opening or orifice in the tip is for the jet or stream of high-pressure oxygen that does the cutting. The smaller orifices are for oxyacetylene flames used for preheating the metal to its ignition temperature. There are usually four or six of these preheat orifices in each oxyacetylene cutting tip; however, some heavy-duty tips have many more preheat orifices.

Cutting tips are furnished in various sizes. In general, the smaller sizes are used for cutting thin metal and the larger sizes are used for cutting heavy metal. Tip sizes are identified by numbers. When numbers such as 000, 00, 0, 1, 2, 3, 4, and 5 are used to identify tip sizes, the lower numbers indicate the smaller tips; for example, a 000 tip is smaller than a number 1 tip, and a number 1 tip is smaller than a number 5 tip. Some manufacturers identify cutting tips by giving the drill size number of the orifices. Large drill size numbers indicate small orifices; for example, drill size 64 is smaller than drill size 56. In military

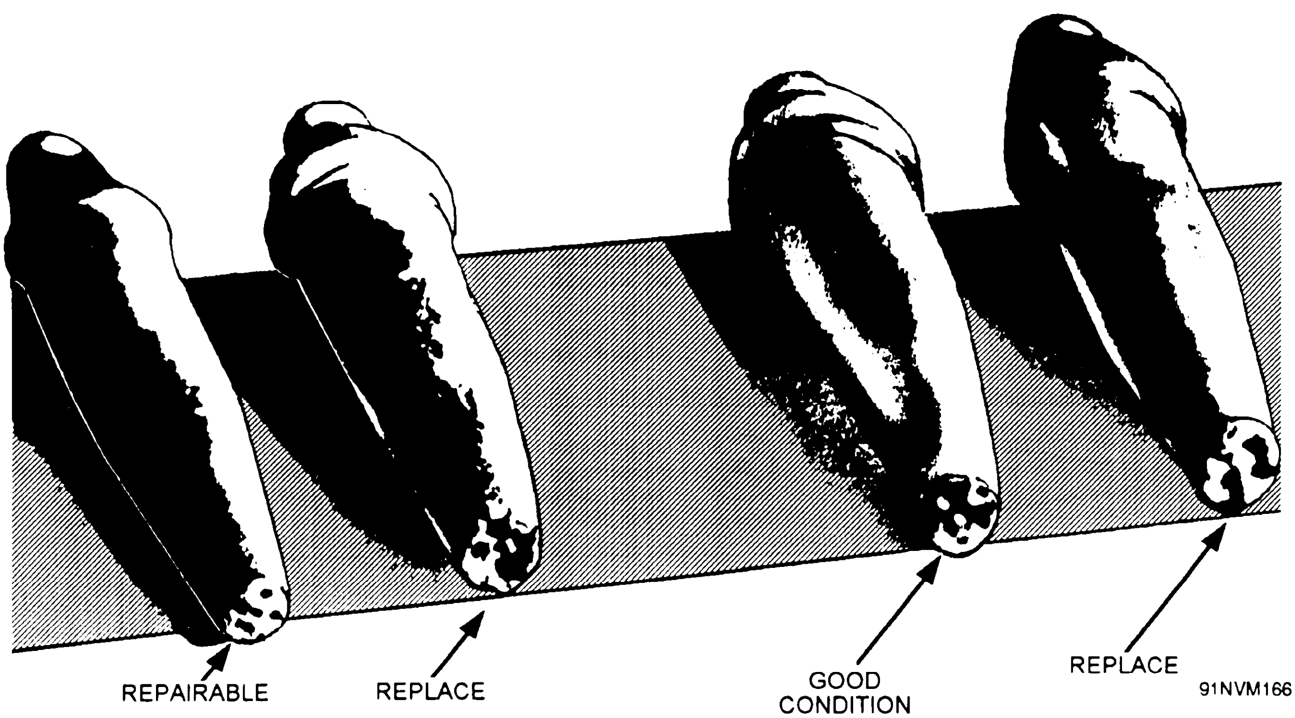


Figure 8-12.—Cutting tips in various conditions.

specifications and standards, oxyacetylene cutting tips are identified by three-part numbers. The first part is the tip size (0, 1, 2, 3, and so on). The second part is the drill size number of the orifice for the cutting oxygen. The third part is the drill size number of the preheat orifices. For example, the number l-62-64 identifies a number 1 tip with a cutting oxygen orifice of drill size 62 and preheat orifices of drill size 64.

Table 8-1 gives tip numbers, orifice sizes, and approximate cutting ranges of various sizes of oxyacetylene cutting tips. Cutting tips from different manufacturers are not interchangeable; when changing tips, you must match the right tip with the right torch.

The tips and seats are designed and constructed to produce a good flow of gases, to keep the tips as cool as possible, and to produce leakproof joints. If the joints leak, the preheat gases may mix with the cutting oxygen or they may escape to the atmosphere.

It is very important that the orifices and passages be kept clean and free of burrs to permit a free gas flow and a well-shaped flame. Figure 8-12 shows four tips: one that is repairable, two that need replacing, and one in good condition. Since it is extremely important that the sealing surfaces be kept clean and free of scratches or burrs, the tips should be stored in a container that cannot scratch the seats, preferably an aluminum or wood rack.

MAPP Gas Cutting Tips

There are four basic types of MAPP gas cutting tips; two are designed for use with standard pressures and normal cutting speeds, and two for use with high pressures and high cutting speeds. Only the standard pressure tips, types SP (standard pressure) and FS (fine standard), will be covered here since they are the ones that HTs will most likely use.

SP TIP.—The SP tip (fig. 8-13, view A) is a one-piece standard-pressure tip. It is used for cutting by hand, especially by welders who are accustomed to one-piece tips. SP tips are also likely to be used in situations where MAPP gas is replacing acetylene as the fuel gas.

FS TIP.—The FS tip (fig. 8-13, view B) is a two-piece, fine-spline, standard-pressure tip. It is used for cutting by hand as well as by machine. Welders accustomed to two-piece cutting tips will use them in hand cutting, especially in cases where MAPP gas is replacing natural gas or propane as the fuel gas. The FS tips will produce heavier preheating flames and faster starts than the SP tips. However, two-piece tips will not take as much thermal abuse or physical abuse as will one-piece tips. But in the hands of skilled welders, they should last just as long as one-piece tips.

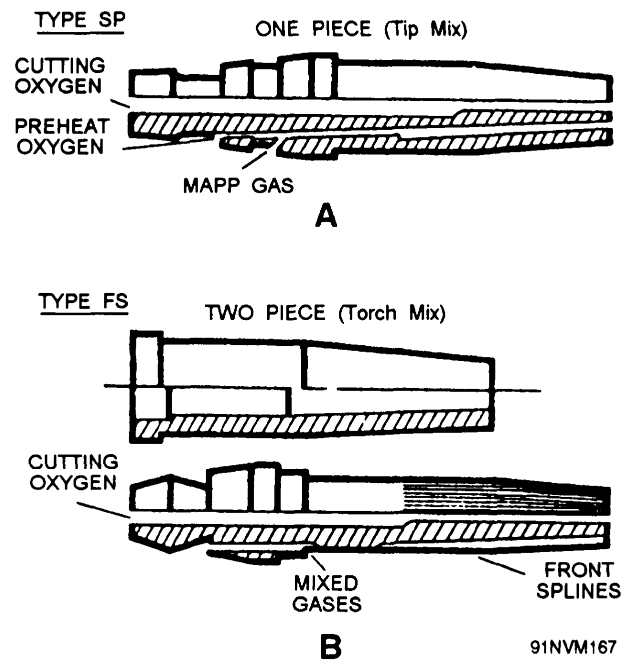


Figure 8-13.—MAPP gas cutting tips.

Care of Tips

In cutting operations, the stream of cutting oxygen sometimes will blow slag and molten metal into the orifices and cause them to become partly clogged. When this happens, you should clean the orifices thoroughly before you use the tip again; even a very small amount of slag or metal in an orifice will seriously interfere with the cutting operation. The recommendations of the torch manufacturer should be followed as to the size of drill or tip cleaner to use for cleaning the orifices. If you do not have a tip cleaner or a drill, then you may use a piece of soft copper wire. Do not use twist drills, nails, or welding rods for cleaning tips, as these items are likely to enlarge and distort the orifices.

The orifices of the cutting torch tip are cleaned in the same manner as the single orifice of the welding torch tip. Remember that the proper technique for cleaning the tips is to push the cleaner straight in and out of the orifice; be careful not to turn or twist it.

Occasionally the cleaning of the tips will cause enlargement and distortion of the orifices even if the proper tip cleaners are used. If the orifices become enlarged, you will get shorter and thicker preheating flames; in addition, the jet of cutting oxygen will spread rather than leave the torch in the form of a long thin stream. If the orifices become belled for a very short distance at the end, it is sometimes possible to correct this condition by rubbing the tip back and forth against emery cloth on a flat surface. This wears down the end of the tip where the orifices have been beveled, thus bringing the orifices back to their original size. Obviously, this procedure would not work if the enlargement is very great or if the belling extends more than a slight distance into the orifice.

After reconditioning a tip, you may test it by lighting the torch and observing the preheating flames. If the flames are too short, the orifices are still partially blocked. If the flames snap out when the valves are closed, the orifices are still distorted.

If the tip seat is dirty or scaled so that it does not fit properly into the torch head, you should heat the tip to a dull red and quench it in water. This will loosen the sale and dirt enough so that they can be rubbed off with a cloth.

OXYACETYLENE CUTTING OPERATIONS

Before beginning any oxyacetylene cutting operation, be sure you have selected the right size tip for the job. Follow the manufacturer's recommendations concerning tip sizes to use for different kinds of work. The oxygen and acetylene pressures to be used with various sizes of tips are also given by the manufacturer. Before fitting a cutting tip into the torch head, inspect the tip carefully to be sure that it is clean and not distorted, and that the orifices are not clogged with slag.

Cutting Low-Carbon Steel

To cut low-carbon steel with the oxyacetylene cutting torch, adjust the preheating flames to neutral. Hold the torch perpendicular to the work, with the inner cones of the preheating flames about one-sixteenth inch above the end of the line to be cut, as shown in figure 8-14. Hold the torch in this position until the spot you are heating is a bright red. Introduce the cutting oxygen by depressing the oxygen lever slowly but steadily.

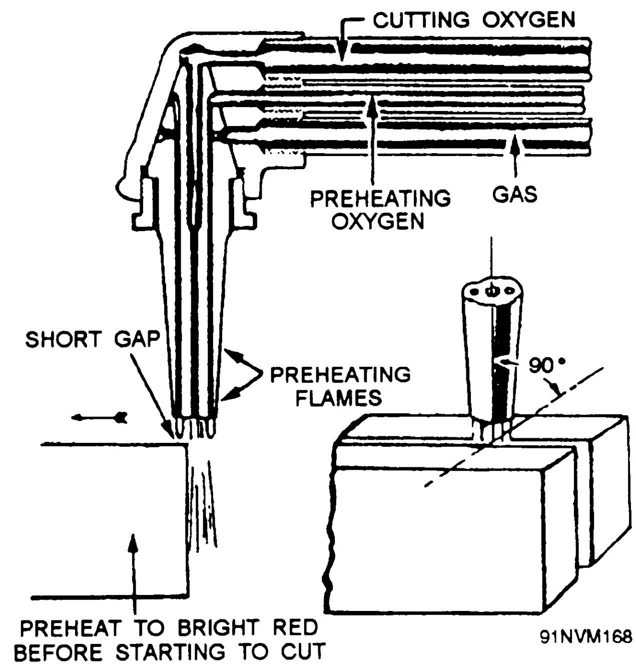


Figure 8-14.—Position of torch tip for starting a cut.

If the cut is being started correctly, a shower of sparks will fall from the opposite side of the work, indicating that the cut is going all the way through. Move the cutting torch forward along the line just fast enough for the cut to continue to penetrate the work completely. If you have made the cut properly, you will get a clean, narrow cut that looks somewhat like one made by sawing. When cutting round bars or heavy sections, you can save time and gas if you raise a small burr with a chisel where the cut is to start. This small raised portion will heat quickly, and cutting can be started sooner. If you have a cut to start from the center on some portion of metal other than the edge, use the following method for starting the cut. Preheat to a bright red the spot on the surface where the cut is to start. Tilt the torch at an angle of about 45° from the perpendicular, in line with the direction of the cut. Press the cutting oxygen lever very slowly. As the torch begins to cut, start righting it to a perpendicular position to the surface of the plate. Continue to right the position of the torch gradually as it cuts until it is at 90° to the surface of the plate and is cutting all the way through. Move it forward along the line of cut as fast as complete penetration can be accomplished. If you do not follow this procedure, you are likely to blow the slag back on the cutting tip, clogging the orifices or otherwise damaging the equipment. When you have started a cut, move the torch slowly along the cutting mark or guide. As you move the torch along, watch the

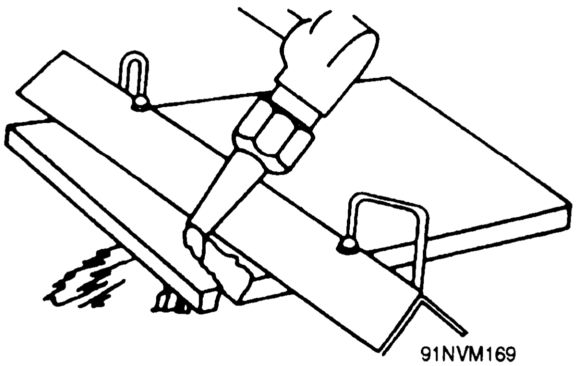


Figure 8-15.—Bevel cutting with an oxyacetylene torch.

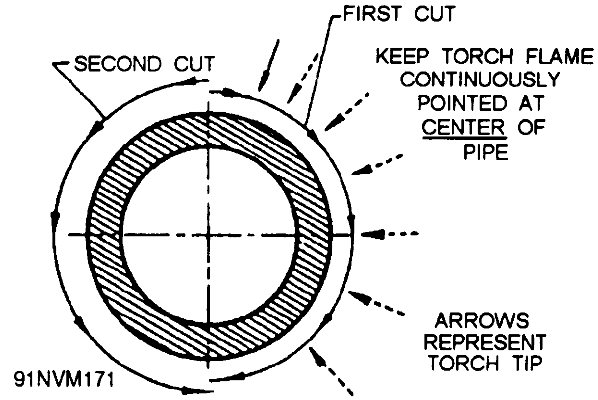


Figure 8-17.—Cutting pipe with a cutting torch.

cut so you can tell how it is progressing. Make torch adjustments if necessary. You must move the torch along at the right speed. If you go too slowly, the preheating flame will melt the edges along the cut and may even weld them back together at the top surface. If you go too fast, the oxygen will not penetrate completely through the metal, and the cut will be incomplete. If you must restart or recut your work, do so on the waste side of your metal. This serves three purposes. First, it is easier to restart your cut on the edge of the kerf than in the center. Second, you don't leave an unsightly gouge or nick in your finished work where you restarted your cut. And finally, you don't cut your metal too short by recutting the edge.

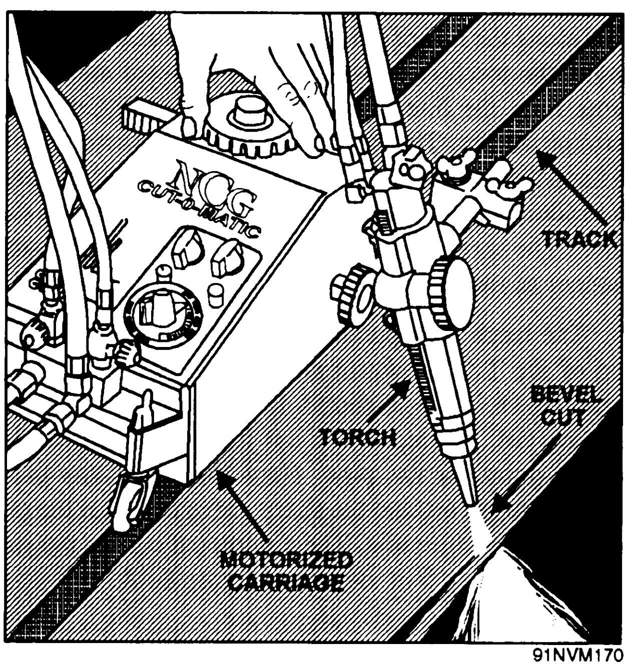


Figure 8-16.—Bevel cutting on a circular path with a radiograph automatic cutting machine.

Beveling Plate

You will frequently have to cut bevels to form joints for welding. To make a bevel cut of 45° in 1-inch steel, the flame must actually cut through 1.4 inches of metal. Consider this when selecting the tip size and gas working pressures. You will have to use more pressure and less speed for a bevel cut than for a straight cut. When you are bevel cutting, adjust the tip so that the preheating orifices are lined up for efficient preheating. A piece of 1 -inch angle iron, clamped with the angle up, makes an excellent guide for beveling straight edges. Pull the torch along the guide as shown in figure 8-15.

If you are aboard a repair ship or a tender, you may have a radiograph automatic cutting machine similar to the one in figure 8-16. This is a motor-driven cutting machine designed to support the cutting torch and guide it along the line of cut. It can be set to make uniformly clean cuts or bevels on steel plate. Straight-line cutting or beveling is done by guiding the machine along a straight line on steel tracks. Arcs and circles are cut by guiding the machine with a radius rod pivoted about a center point.

Cutting and Beveling Pipe

When you are cutting off a piece of pipe, keep the torch pointed toward the center line of the pipe. Start the cut at the top and cut down one side. Then begin at the top again and cut down the other side, finishing at the bottom of the pipe. The procedure is shown in figure 8-17.

Sometimes it is necessary to take T and Y fittings from pipe. Here the cutting torch is a most valuable tool. The usual procedure for fabricating pipe fittings is to develop a pattern like that shown in figure 8-18, view A, step 1. After the pattern is developed, it is wrapped around the pipe as shown in figure 8-18, view A, step 2. Be sure to leave enough stock so that the ends will overlap. Trace around the pattern with soapstone or a scriber. It is a good idea to mark the outline with a prick punch at about one-fourth-inch intervals. When the metal is heated during the cutting procedure, the punch marks will stand out, making it easier to follow the line of cut. Place the punch marks so that they will be removed during cutting. If punch marks are not removed, they provide notches from which cracking may start.

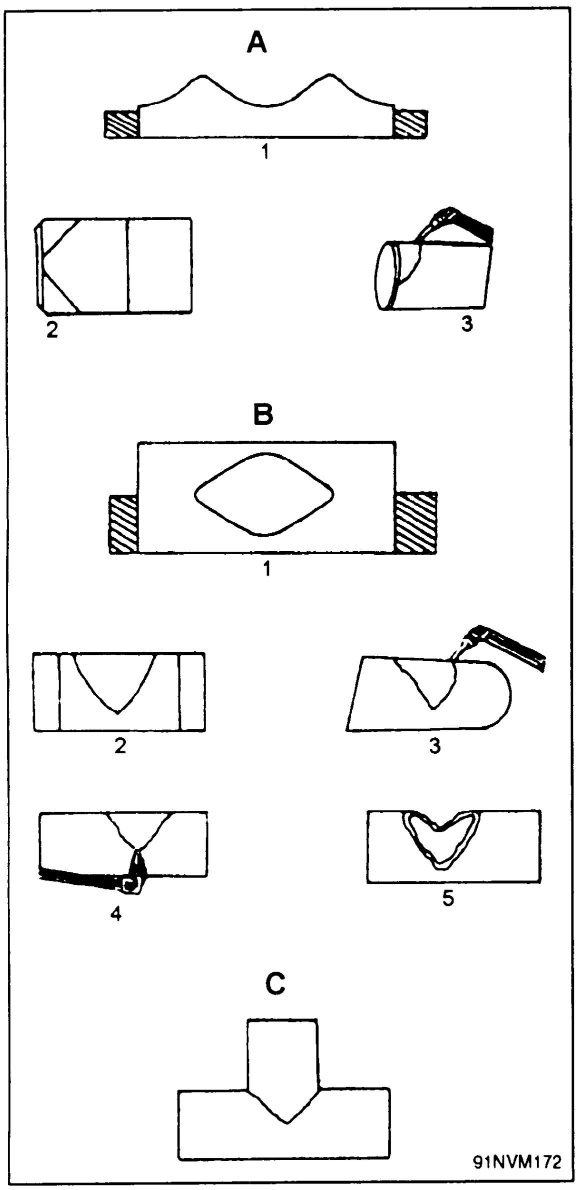


Figure 8-18.—Fabricating a T fitting.

An experienced burner can cut and bevel pipe at a 45-degree angle in one operation; however, a person with little experience may have to do the job in two steps. The first step is to cut the desired part at a 90-degree angle. The second step is to bevel the edge of the cut to a 45-degree angle. When employing the two-step procedure, another line must be marked on the pipe. This second line follows the contour of the line traced around the pattern, but it is drawn away from the original pattern line at a distance equal to the pipe wall thickness. The first (or 90°) cut in the two-step procedure is made along the second line. The second (or 45°) cut is made along the original pattern line. The two-step procedure is time consuming and uneconomical in terms of oxygen and acetylene consumption.

When you are experienced enough to use the one-step cutting and beveling procedure, you will find that it is not complicated. However, both a steady hand and a great deal of practice are necessary to turn out a first-class job. The one-step procedure for cutting and fabricating a T is shown in figure 8-18. View A of figure 8-18 outlines the step-by-step procedure for producing the branch; view B shows the steps for preparing the other section of the T; and view C shows the assembled T, tack welded and ready for welding. Figure 8-18, view A, step 3, shows the procedure for cutting the miter on the branch. The cut is started at the end of the pipe and worked around until one-half of one side is cut. The torch is manipulated so that at all times the tip is at an angle of 45° to the surface of the pipe along the line of cut. While the tip is at a 45-degree angle, the torch is moved steadily forward and at the same time the butt of the torch is swinging upward through an arc. This torch manipulation is necessary to keep the cut progressing in the proper direction and to produce a bevel that will be 45° at all points on the miter. The second portion of the miter is cut in the same manner as the first.

The torch manipulation necessary for cutting the run of the T is shown in steps 3 and 4 in view B of figure 8-18. Step 3 shows the torch angle for the starting cut. At step 4, the cut has progressed to the lowest point on the pipe. Here the angle has been changed to get around the sharp curve and start the cut in an upward direction. The completed cut for the run is shown in step 5 in view B of figure 8-18.

Before the parts of any fabricated fitting are assembled and tack welded, be sure to clean the fit of the joint. The bevels must be smooth to allow complete fusion when the joint is welded.

Piercing Holes

The cutting torch is also a valuable tool for piercing holes in steel plate. The steps are illustrated in figure 8-19. Lay the plate out on two firebricks so that the flame will not hit something else when it bums through the plate. Hold the torch over the hole location with the tips of the inner cone of the preheating flames about one-fourth inch above the surface of the plate. Continue to hold the torch in this position until a small round spot has been heated to a bright red. Introduce the cutting oxygen by gradually depressing the oxygen lever, and at the same time slightly raise the tip away from the work to keep from blowing slag back onto the cutting tip. As you start raising the torch and introducing the cutting oxygen, start rotating the torch with a spiral motion. This will cause the molten slag to be blown out of the hole. The hot slag may fly around, so BE SURE your goggles are well fitted to your eyes and face, and avoid having your head directly above the cut.

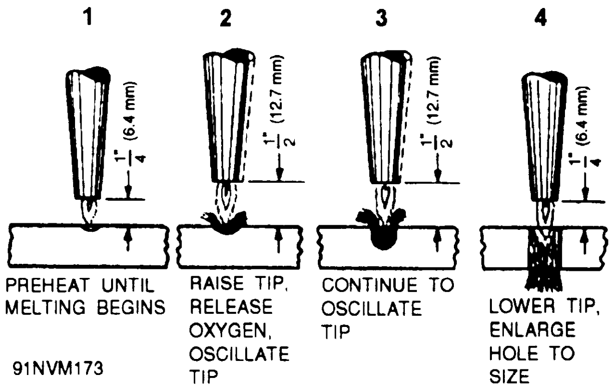


Figure 8-19.—Piercing a hole with an oxyacetylene cutting torch.

If you need a larger hole, outline the edge of the hole with a piece of chalk, and follow the procedure given in the previous paragraph. Start the cut from the hole that you have pierced by moving the preheating flames to the normal distance and by working to and following the line that has been drawn on the plate. Round holes can be made by using a cutting torch with a radius bar attachment.

Cutting Rivets

When you are required to remove rivets from plates that are to be disassembled, you will find the cutting torch a good tool. The cutting procedure is shown in figure 8-20. Use the preheating flames of the

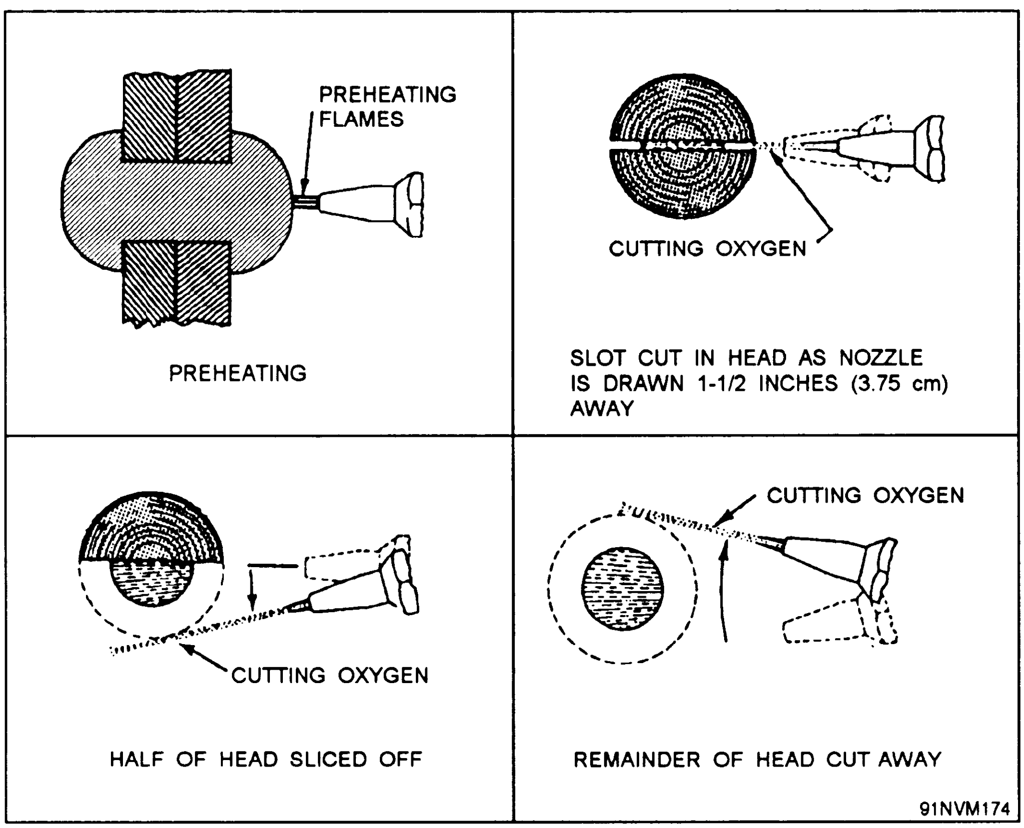


Figure 8-20.—Using a cutting torch to remove the head of a rivet.

cutting torch to bring the head of the rivet up to the proper temperature; then introduce the cutting oxygen by gradually depressing the oxygen lever, and wash off the rivet head. The remaining portion of the rivet can then be punched out with a light hammer blow. The step-by-step procedure follows:

1. Use the size of tip and the oxygen pressure required for the size and type of rivet you are going to cut.

2. Heat a spot on the head until it is bright red.

3. Move the tip to a position parallel with the surface of the plate and slowly turn on the cutting oxygen.

4. Cut a slot in the rivet head like the screwdriver slot in a roundhead screw. When the cut nears the plate, draw the nozzle back at least 1 1/2 inches from the rivet so that you will not cut through the plate.

5. When you have cut the slot through to the plate, swing the tip through a small arc. This slices off half of the rivet head.

6. Then swing the tip in an arc in the other direction to slice off the other half of the rivet head.

By the time the slot has been cut, the rest of the rivet head has usually been heated to cutting temperature. Just before you get through the slot, draw the torch tip back 1 1/2 inches to allow the cutting oxygen to scatter slightly. This keeps the torch from breaking through the layer of scale that is always present between the rivet head and the plate. It allows the head of the rivet to be cut off without damaging the surface of the plate. If you do not draw the tip away, you may cut through the film of scale and into the plate.

A low-velocity cutting tip is best for cutting buttonhead rivets and for removing countersunk rivets. A low-velocity cutting tip has a cutting oxygen orifice with a large diameter. Above this orifice are three heating orifices. Always place a low-velocity cutting tip in the torch so that the heating orifices are above the cutting orifice when the torch is held in the rivet cutting position. To remove countersunk rivets from a vertical sheet or plate, use the method shown in figure 8-21 and follow these instructions:

1. Hold the torch horizontally and turn it so that the tip also points horizontally.

2. Tilt the tip upward about 15° and hold the preheating flames on a point slightly below the center of the rivet head.

3. When you get the area heated to a dull red, move the torch upward, still keeping the upward tilt, and press the cutting oxygen lever.

4. Hold the torch steady with the cutting stream directed at the center of the rivet. As the rivet is cut away, the angle of the torch should be decreased until the tip is perpendicular to the sheet or plate and the cutting stream is directed at the center of the rivet.

5. When you have cut through the head to the shank of the rivet, wash away the remainder of the head with one circular wiping motion. Always move the torch so that the cutting stream will follow the preheat.

6. The shank may then be removed by a light tap with a hammer and punch.

Buttonhead rivets may be removed in the same manner as countersunk rivets with the low-velocity cutting tip. The process is illustrated step by step in figure 8-22. Remember that it is important to start below the center of the rivet head so that molten metal and slag will not be deposited on the plate.

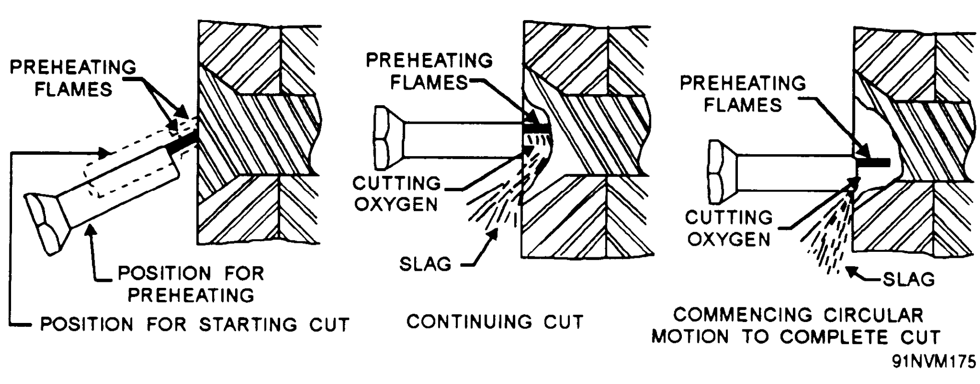


Figure 8-21.—Cutting a countersunk rivet with a low-velocity cutting tip.

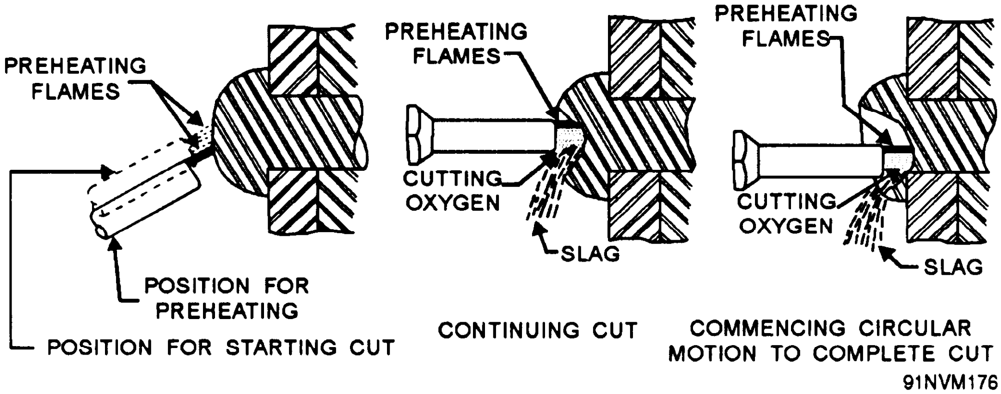


Figure 8-22.—Cutting buttonhead rivets with a low-velocity cutting tip.

Special Cutting Techniques

Carbon steels containing up to 1.0 percent carbon are easily cut with the oxyacetylene cutting torch. Nonferrous metals, however, and ferrous metals such as cast iron, carbon steels containing more than 1.0 percent carbon, and many alloy steels can be successfully flame cut only if special techniques are used. These special techniques include using more intense and more widely distributed preheat; using different flame adjustments; introducing iron or low-carbon steel into the cutting area; varying the torch movements; and using fluxes.

PREHEAT.—Preheating the metal before cutting reduces the amount of oxygen and fuel gas required to make the cut. It also tends to prevent or minimize distortion and to prevent surface hardness of the piece after the cut has been made. While preheating is helpful in any cutting operation, it is essential for some of the metals and alloys that are not easily cut. The preheating temperatures generally used for oxyacetylene cutting range from 200° to about 600°F, although considerably higher temperatures are occasionally used.

Preheating is usually accomplished by using the preheating orifices in the cutting tip. Special tips having larger and more numerous preheating orifices are available for cutting cast iron and other materials that require intense and widely distributed preheat. Preheating furnaces are sometimes used to bring heavy sections to a uniform preheat temperature.

FLAME ADJUSTMENT.—A neutral preheating flame is used for most oxyacetylene cutting. For some metals, however, other flame adjustments give better results. For example, a highly carburizing flame is used for preheating cast iron. The excess acetylene in the carburizing flame ignites when it combines with the cutting oxygen deep in the kerf, thus increasing both the intensity and the distribution of the preheat. For cutting cast iron, the length of the feather on the preheating flame should be approximately equal to the thickness of the cast iron. A slightly less carburizing flame is used for cutting stainless steel.

INTRODUCTION OF IRON OR LOW-CARBON STEEL.—Introducing iron or low-carbon steel into the cutting area greatly simplifies the cutting of some metals. When the oxides of a metal have a higher melting point than the metal itself, the oxides protect the base metal from the cutting action of the oxygen. In such a metal, introducing iron or low-carbon steel into the cutting area solves the problem because the rapid oxidation of the iron or steel liberates enough heat to melt the oxides that would otherwise interfere with the cutting. When alloying elements are responsible for the difficulty of cutting the metal, the introduction of iron or low-carbon steel reduces the percentage of these alloying elements and so makes the metal easier to cut.

Several techniques are used to introduce iron or low-carbon steel into the cutting area. An easily cut steel waster plate may be clamped firmly to the surface of the metal to be cut; a steel welding rod may be fed into the kerf as the cutting proceeds; a bead of low-carbon steel may be deposited along the line of cut before the cut is made; or finely divided iron powder may be blown into the stream of cutting oxygen through special orifices in the cutting tip.

Cast iron, chromium irons, stainless steels, and various alloys having small ferrous content can be successfully cut with the oxyacetylene torch when iron or low-carbon steel is introduced into the cutting area.

TORCH MOVEMENTS.—For most oxyacetylene cutting, the torch is moved steadily forward along the line of cut, as shown in view A of figure 8-23. Metals that are difficult to cut often require special torch movements. For example, the oscillating movement, shown in view B of figure 8-23, is suitable for cutting thin sections of cast iron; view C shows the oscillating movement that is best for cutting heavier sections of cast iron. View D shows the reciprocating (or back and forth) torch movement that is most effective for cutting stainless steels.

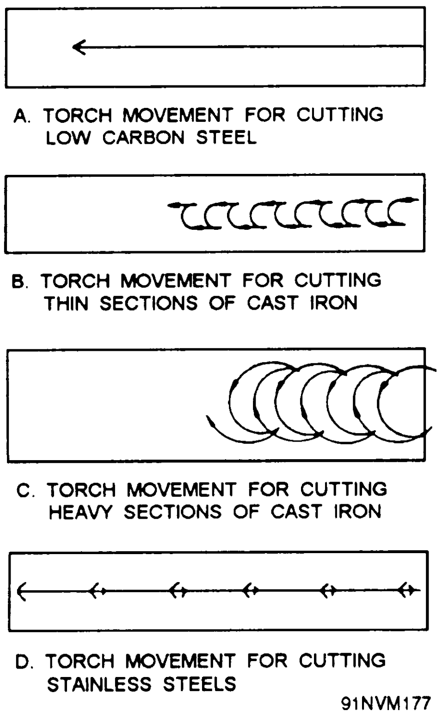


Figure 8-23.—Manipulation of the oxyacetylene cutting torch.

FLUXES.—Although fluxes are not used for most oxyacetylene cutting, they are used for cutting stainless steels, chromium irons, and other metals that are hard to cut. Fluxes used for cutting are nonmetallic compounds in powder form. As the powdered flux is injected into the kerf, it reacts chemically with the oxides, which have a higher melting point than the base metal. The result of this chemical reaction is a slag that melts at a lower temperature. The stream of cutting oxygen washes the molten slag out of the cut and exposes the base metal to the cutting action of the oxygen.

Fluxes are introduced into the cut by means of an attachment to the standard cutting torch. The attachment, shown in figure 8-24, consists of a canister for holding the flux, a length of air hose, and a copper tube that is secured to the cutting torch with clamps. Air pressure forces the powdered flux into the kerf; the stream of cutting oxygen carries the flux deeper into the kerf.

Judging the Quality of Oxyacetylene Cuts

To know how good a job of cutting you are doing, you must know what constitutes a good oxyacetylene torch cut. In general, the quality of an oxyacetylene cut is judged by (1) the shape and length of the drag lines, (2) the smoothness of the sides, (3) the sharpness of

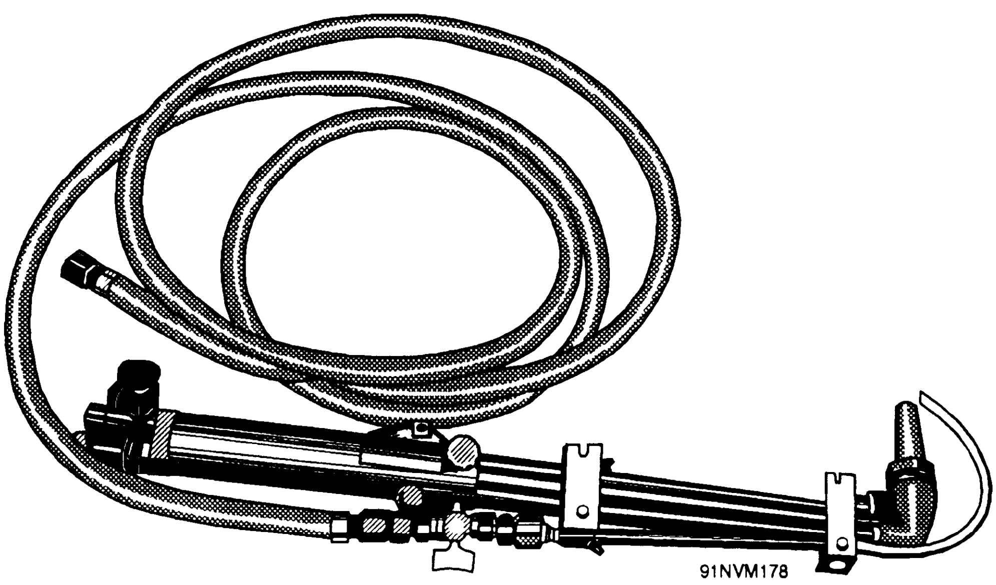


Figure 8-24.—Flux cutting attachment.

the top edges, and (4) the amount of slag adhering to the metal.

DRAG LINES.—Drag lines are the line markings that show on the cut surfaces. Good drag lines are almost straight up and down, as shown in view A of figure 8-25. Poor drag lines are long and irregular or excessively curved, as shown in view B of figure 8-25; drag lines of this type indicate poor cutting procedure which may also result in loss of the cut (views B and C of fig. 8-25).

Drag lines are probably the best single indication of the quality of an oxyacetylene cut. If the drag lines are short and almost vertical, the smoothness of the sides, the sharpness of the top edges, and the slag conditions are almost sure to be satisfactory.

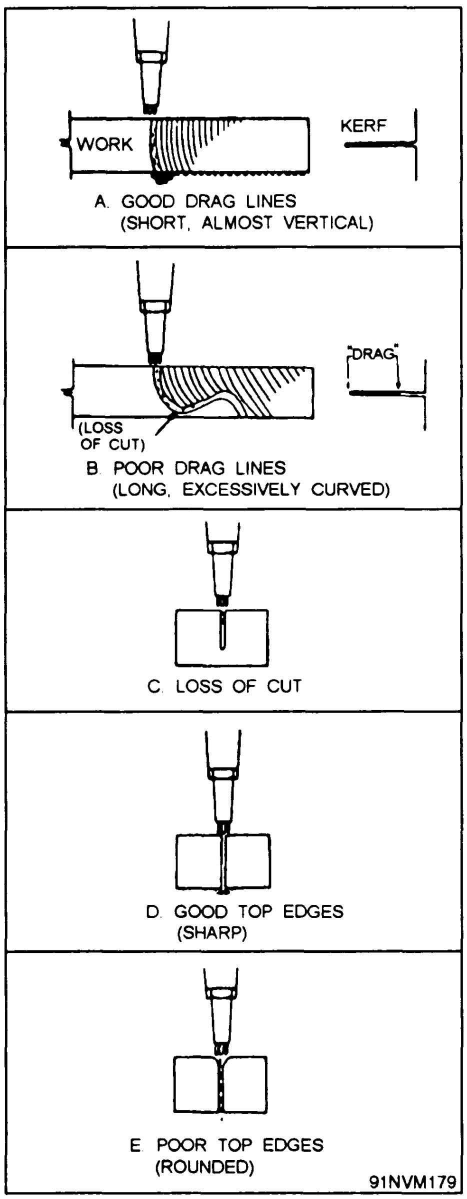


Figure 8-25.—Effects of correct and incorrect cutting procedures.

SMOOTHNESS OF SIDES.—A satisfactory oxyacetylene cut shows smooth sides. A grooved, fluted, or ragged cut surface indicates a cut of poor quality.

SHARPNESS OF TOP EDGES.—The top edges resulting from an oxyacetylene cut should be sharp and square (view D, fig. 8-25). Rounded top edges, such as those shown in view E of figure 8-25, are not considered satisfactory. Melting down of the top edges may result from incorrect preheating procedures or from moving the torch too slowly.

SLAG CONDITIONS.—An oxyacetylene cut is not considered satisfactory if slag adheres so tightly to the metal that it is difficult to remove.

SAFETY PRECAUTIONS

In all cutting operations, be careful to see that hot slag does not come in contact with any combustible material. Globules of hot slag can roll along a deck for quite a distance. Do not cut within 30 or 40 feet of unprotected combustible materials. If combustible materials cannot be removed, cover them with sheet metal or noncombustible materials. Keep the acetylene and oxygen cylinders far enough away from the work so that hot slag will not fall on the cylinders.

Many of the safety precautions discussed in chapter 1 of this training manual apply to cutting as well as to welding. Be sure that you are entirely familiar with all appropriate safety precautions before attempting any oxyacetylene cutting operation.

OXYACETYLENE WELDING TECHNIQUES

Oxyacetylene welding may be accomplished by either the forehand or the backhand method. Each of these techniques has special advantages; you should be skillful with both. Whether a technique is considered to be forehand or backhand depends on the relative position of the torch tip and filler rod in relationship to the direction of welding. The best technique to use depends upon the type of joint, its position, and the necessity for controlling the heat on the parts to be welded.

FOREHAND WELDING (also called puddle welding or ripple welding) is the oldest method of welding.

The filler rod is kept ahead of the torch tip in the direction in which the weld is being made. Point the flame in the direction of the welding and hold the torch tip at an angle of about 45° to 60° to the plates. (See fig. 8-26.) This position of the flame preheats the edges you are welding just ahead of the molten puddle. By moving the torch tip and filler rod back and forth in opposite, semicircular paths, you balance the heat to melt the end of the filler rod and the side walls of the joint into a uniformly distributed molten puddle. As the flame passes the filler rod, it melts off a short length of the filler rod and adds it to the puddle. The motion of the torch tip distributes the molten metal evenly to both edges of the joint and to the molten puddle. This method is used in all positions for welding sheets and light plates up to one-eighth inch thick because it permits better control of a small puddle and results in a smoother weld. The forehand technique is not the best method for welding heavy plate.

BACKHAND WELDING is a newer method of welding. In this method, the torch tip precedes the filler rod in the direction of welding, and the flame is pointed back at the molten puddle and the completed weld. The end of the filler rod is placed between the torch tip and the molten puddle, and the welding torch tip should make an angle of about 45° to 60° with the plates or joint being welded. (See fig. 8-27.)

Less motion is required in the backhand method than in the forehand method. If you use a straight filler rod, it should be rotated so that the end will roll from side to side and melt off evenly. You may also bend the filler rod and, when welding, move the filler rod and torch tip back and forth at a rather rapid rate. If you are making a large weld, you should move the filler rod so as to make complete circles in the molten puddle. The torch tip is moved back and forth across the weld while it is advanced slowly and uniformly in the direction of the welding. You'll find the backhand method best for welding material more than one-eighth inch thick. You can use a narrower V at the joint than is possible in forehand welding. An included angle of 60° is a sufficient angle of bevel to get a good joint. It doesn't take as much filler rod or puddling for the backhand method as it does for the forehand method.

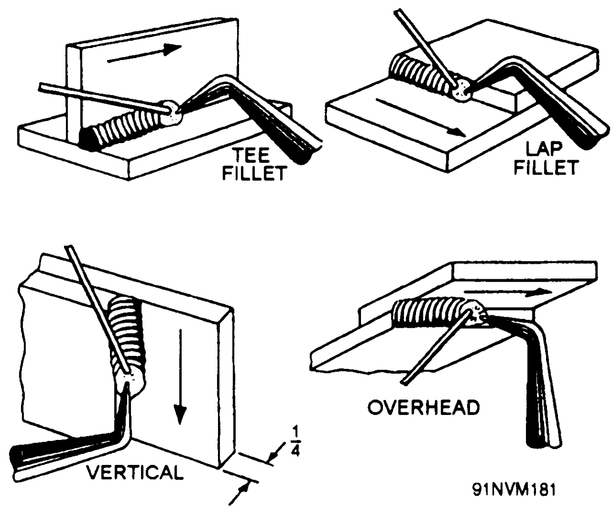


Figure 8-27.—Backhand welding.

By using the backhand technique on heavier material, you can obtain increased welding speeds, better control of the larger puddle, and more complete fusion at the root of the weld. Further, by using a reducing flame with the backhand technique, a smaller amount of base metal is melted while welding the joint. When welding steel with a backhand technique and a 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.

MULTILAYER WELDING is used in welding thick plate and pipe to avoid carrying too large a puddle of molten metal, which is difficult to control. Concentrate on getting a good weld at the bottom of the V in the first pass. Then in the next layers, concentrate on getting good fusion with the sides of the V 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 one 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.

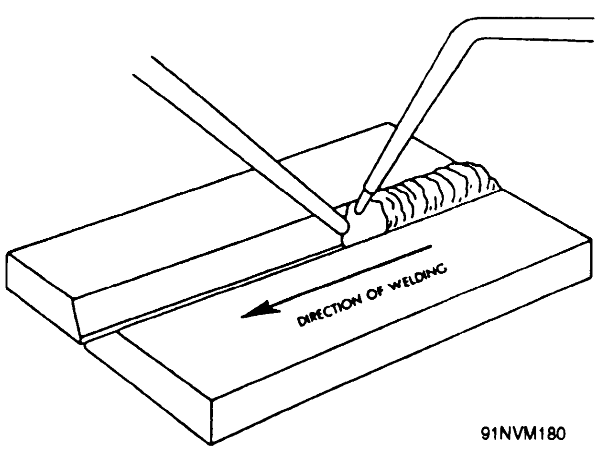


Figure 8-26.—Forehand welding.

PRACTICE PROJECTS

A great deal of practice is required to master the techniques of welding. A good way to acquire skill in oxyacetylene welding is to practice on scrap pieces of mild steel (sheet of plate). Try your hand at the various problems described in the following section. Oxyacetylene welding may be done in any position. In the examples given here, we will start with the flat position, since this is usually the easiest, and go on to the more difficult positions. Before trying any of these projects, be sure that the equipment is set up properly and that all safety precautions are being observed. Until you have gained considerable skill in welding, your practice should be done under the supervision of an experienced welder.

Running a Bead Without Filler (Flat Position)

For this project, you are not welding two pieces together but are merely running a bead. Select a piece of plate about 2 inches by 4 inches by 1/8 inch thick. Place the two firebricks as shown in figure 8-28.

If you are right handed, start at the right and work to the left. If you are left handed, start at the left and work to the right. Hold the torch so that the tip forms a 45-degree angle with the plate along the line of weld. Direct the inner cone of the flame at a point near the right edge of the metal and hold it there until a molten puddle forms. Keep the tip of the cone from one-sixteenth to one-eighth inch away from the surface of the molten metal. As soon as the puddle is formed, move the torch tip slowly forward with a slight weaving or oscillating motion, as indicated in figure 8-28. Both the forward motion and the weaving motion must be uniform to produce a smooth, regular bead.

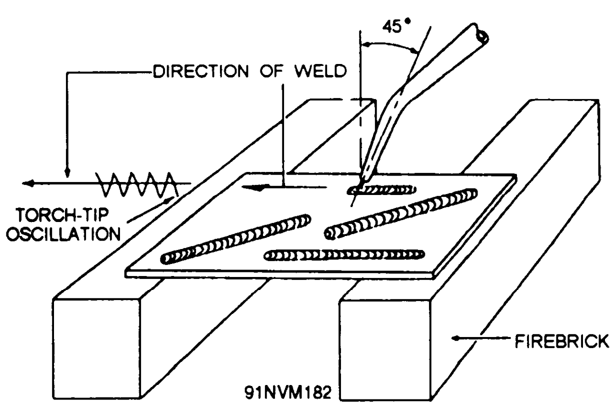


Figure 8-28.—Running a bead without using filler rod (flat position).

A good weld bead must be of uniform width at the weld face and must have a weld surface that is slightly below the surface of the base metal. The surface of the weld should be covered with a thin film of oxides. The speed with which the flame is carried along the plate should be regulated to obtain good fusion without burning through the metal.

When you have developed skill in running a bead without filler on a piece of one-eighth inch mild steel, try the same thing on a piece of thinner stock. A bead without filler can be used to join two pieces along an edge, in the manner shown in figure 8-29. To do this, tack weld the ends by fusing them together; then start a puddle and run a bead along the edges.

Running a Bead With Filler (Flat Position)

The next step in learning to perform oxyacetylene welding is to run a bead in the flat position, using filler metal. This job is very similar to the first one, but requires manipulation of a filler rod as well as of the torch tip. The bead is built up by the filler metal, as shown in figure 8-30; it should be built up about 25

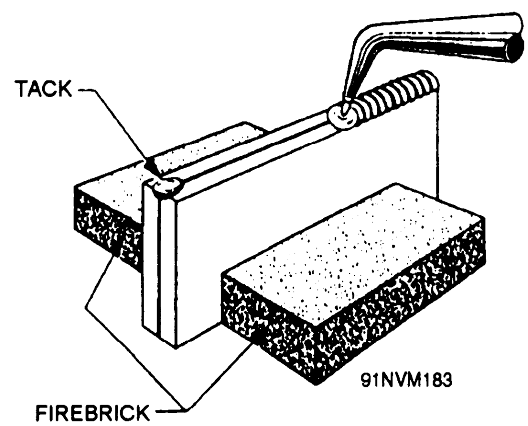


Figure 8-29.—Bead weld without filler, used to join two pieces along an edge.

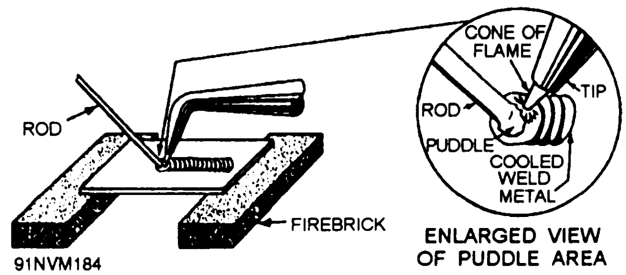


Figure 8-30.—Bead weld with filler (flat position).

percent, or an amount equal to one-fourth the thickness of the stock.

Start the puddle in the usual way. As soon as the puddle is formed, dip the filler rod into the middle of the puddle. Oscillate both the filler rod and the torch tip. The filler rod should be moved in a direction OPPOSITE to the direction of movement of the flame. When the flame is on one side of the puddle, the rod should be on the other side. Stir the end of the rod in the puddle, not above it. Do not direct the flame at the end of the filler rod; the filler rod should be melted by the puddle, not by the flame. Direct the flame so that it preheats the weld area uniformly. The direction of the flame is very important from the point of view of obtaining good fusion and avoiding undercutting or overlapping.

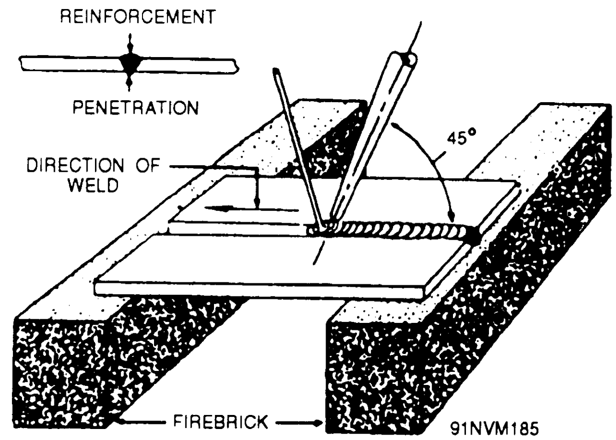


Figure 8-31.—Welding a butt joint in the flat position.

Making a Butt Joint (Flat Position)

Butt welding in the flat position is often used to join sheet metal. First tack the two pieces of sheet together, leaving a slight gap for a root opening. Be sure the flame is correctly adjusted to a neutral or slightly carburizing flame. Let the tacks cool, and then start a puddle at one end.

The position of the torch tip and the filler rod must be just right to achieve the fusion and penetration required for a good weld of this type. Hold the torch tip at an angle of 45° to the base metal, as shown in figure 8-31. Apply the flame at the root of the joint, first to one part of the joint and then to the other until the side walls melt or break down to form a pool of molten metal that bridges the gap between the plates at the root. Add filler metal to the molten pool until the pool is sufficiently large. Carry the puddle forward by manipulating the torch with an oscillating motion. If you weave the torch tip and the filler rod correctly, you can carry along a molten puddle that will give complete penetration and also provide enough filler metal to reinforce the weld. Avoid overheating the puddle; overheating can actually bum the metal and thus greatly impair the strength of the finished weld.

Making a Butt Joint (Vertical Position)

When welding in the vertical position, you have the problem of keeping the molten metal from running down and accumulating at the bottom of the joint. To control the flow of molten metal, hold the flame below the filler rod. The flame should point upward at an angle of 45° to the base metal. The gas pressure from the torch tip will support the molten metal and distribute it evenly along the joint. Bending the filler rod to an angle of 90°, a short distance from the end, makes it easier to get the end of the filler rod into the puddle. Figure 8-32 shows the positions of the torch tip and the filler rod with respect to the base metal.

Making a Butt Joint (Overhead Position)

When welding in the overhead position, you will have to overcome the tendency of the molten metal to drop down or to sag on the plate. Keeping the puddle small helps to control the molten metal. If the molten puddle gets too large, remove the flame for an instant to allow the metal to freeze; then resume the welding.

Figure 8-33 illustrates the welding of a butt joint in the overhead position. Direct the flame so that it will melt both edges. Add enough filler to keep the puddle the right size and to provide some metal for

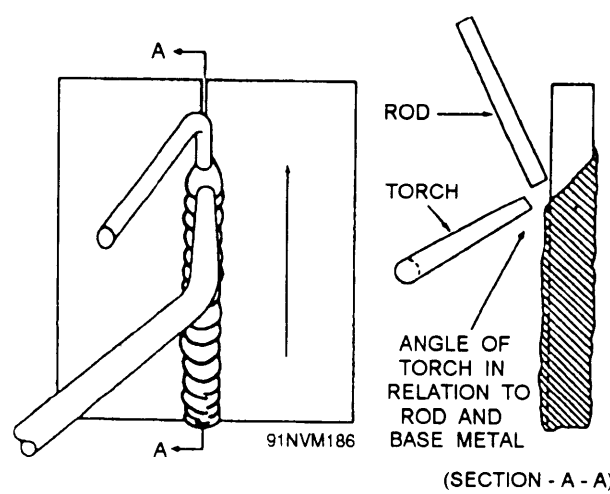


Figure 8-32.—Welding a butt joint in the vertical position.

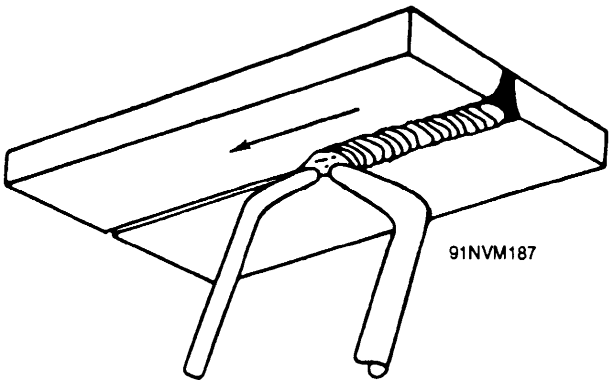


Figure 8-33.—Welding a butt joint in the overhead position.

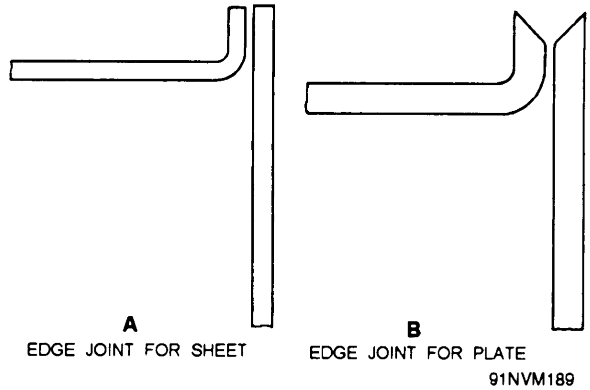


Figure 8-35.—Edge joints for sheet and plate.

reinforcement of the weld. Keep the flame in such a position that it will support the molten metal and distribute it along the joint. Use a small filler rod; this will help you to keep the puddle small. In many overhead welding jobs, it is possible to weld from one side only. In such cases, particular care is required to make sure the heat is evenly distributed, so that one plate will not be burned through.

Making a Corner Joint

The comer joint is used to join the edges of two plates when the surfaces of the plates make a 90-degree angle with each other. Figure 8-34 shows three designs that are commonly used for corner joints. The CLOSED comer joint (view A) is used on lighter sheets and plates where strength requirements for the joint are not a factor. In making this joint, melt the overlapping edge with the torch and add only a small amount of filler metal. When using this joint design for heavier sections, V-bevel or U-groove the lapped plate to permit penetration to the root of the joint.

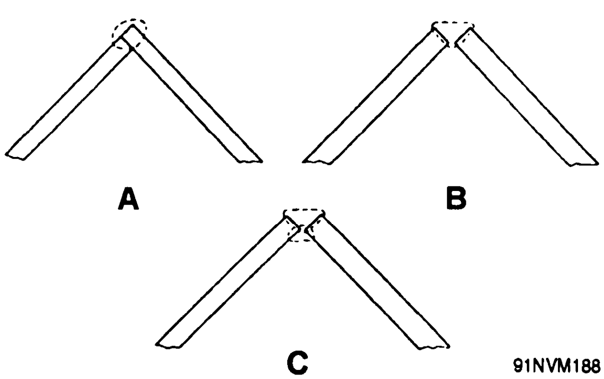


Figure 8-34.—Corner joints. A. Closed joint. B. Open joint, welded from one side. C. Open joint, welded from both sides.

View B of figure 8-34 shows an OPEN corner joint that is often used on heavy sheets and plates. To make this joint, melt down the edges of the plate and add enough filler metal to build up the comer from one side.

View C shows an open corner joint that is welded from both sides. First weld the joint from the outside, then reinforce the joint and seal it (as for use in drip pans) from the inside with a seal bead weld.

Making an Edge Joint

Edge joints are used mainly to join the edges of sheet metal and to weld reinforcing plates on flanges of I-beams or edges of angles. Figure 8-35 shows two common types of edge joints. The joint shown in view A is used for welding thin sheets; this joint requires no edge preparation other than cleaning the edges and tacking them together. The joint shown in view B is used for heavier plate. To make this joint, bevel the edges to allow good penetration and fusion of the side walls. In making both of these joints, use enough filler metal to fuse both edges and to reinforce the joint.

Making a Lap Joint

The lap joint is the simplest of all weld joints and is formed by overlapping two plates of metal. Lap joints may be welded from one side or from two sides. They are stronger when welded from both sides, but even a lap joint that is welded from only one side is stronger than a butt joint in some applications.

Making a Joint

The T joint is another simple joint that is formed by butting the edge of a piece of plate up to the face of another plate to form the letter T. A plain T joint in thin material requires little preparation. For thicker plate, the edges should be prepared as shown in figure 8-36.

GUIDE FOR OXYACETYLENE WELDING OF FERROUS METALS

Low-carbon steel, low-alloy steel, cast steel, and wrought iron are easily welded by the oxyacetylene process. A flux is not necessary with these materials, since the oxides melt at a lower temperature than the base metal. You must keep the molten puddle of metal enclosed by an envelope of flame at all times during the welding process. If the metal is permitted to come in contact with the air while it is in a molten condition, it will oxidize rapidly. Care should be taken to prevent overheating the metal. Use a neutral or slightly reducing (carburizing) flame. Do NOT use an oxidizing flame. Manipulate the torch and the filler rod so that the top of the oxyacetylene cone is about one-sixteenth to one-eighth 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 welding rod. Low-alloy steels usually require preheating and postheating.

As the carbon content increases, steels become more difficult to weld. Steels with a carbon content of 0.30 to 0.50 percent should be welded with a slightly reducing (carburizing) flame, and should be postheated to develop the best physical properties and to reduce internal stress.

High-carbon steels and tool steels require somewhat special techniques if they are to be successfully welded. Slow preheating to about 1000°F is required; the metal should be protected from drafts during the preheating. No flux is required. The welding should be completed as rapidly as possible with a carburizing flame. The filler rod and the torch tip should not be manipulated for the welding of high-carbon steels and tool steels. Filler metal should be added in small amounts, just as it is needed. A smaller flame and a lower gas pressure should be used for these materials than for low-carbon steel since there is even more danger of overheating the high-carbon steels and the tool steels. High-carbon steels and tool steels must be heat treated after welding.

The procedure for oxyacetylene welding of wrought iron is the same as for low-carbon steel. However, certain special considerations should be

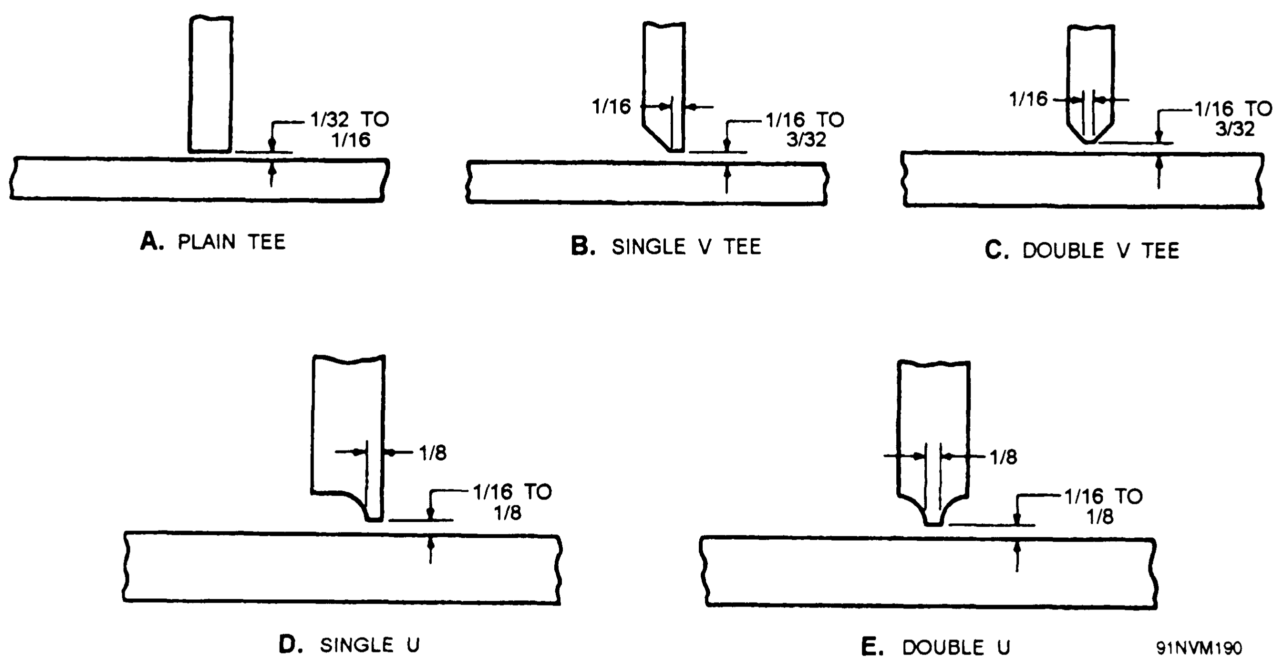


Figure 8-36.—Edge preparation required for various types of T joints.

kept in mind. Wrought iron contains a slag that is incorporated in it during the manufacturing process. This slag gives the surface of the molten puddle of weld metal a greasy appearance. Do not confuse this greasy appearance with the appearance of actual fusion. Continue heating the metal until the side walls of the joint break down into the puddle. Best results with wrought iron are obtained when the filler metal (usually mild steel) and the base metal are mixed in the molten puddle with as little agitation as possible.

Oxyacetylene welding of cast iron requires different procedures than those used for welding steels. Special edge preparation is usually required. The entire weldment should be preheated to between 750° and 900°F before the welding is begun. The welding should be done with a neutral flame, by a backhand technique. Use a cast iron filler metal. Flux is required but should be used sparingly, as needed, to overcome temporary difficulties. The filler metal is added by directing the inner cone of the flame against the rod into the puddle. The filler metal should be deposited in layers that are no more than one-eighth inch thick. The weldment must be stress relieved after welding; heat it to a temperature of between 1100° and 1150°F and then cool it slowly.

Oxyacetylene welding is successful with some chromium-nickel steels (stainless steels). As a rule, oxyacetylene welding is used only for light gauge sheet metal. Heavier pieces of these steels are usually joined by one of the electric arc welding processes, which will be discussed in chapter 10. On material 0.040 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 being welded, the joint surfaces of the metal should be cleaned with sandpaper or other abrasive and then coated with stainless steel flux. The torch tip used for welding stainless steel should be one or two sizes smaller than the tip used to weld mild steel of the same thickness. The torch should be adjusted to produce a carburizing flame that has an excess acetylene feather extending about one-sixteenth inch beyond the tip of the inner cone, as seen through the goggles. The torch should be held so that the flame makes an angle of 80° with 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. Uniform speed is essential in welding stainless steels. If it is necessary to stop the welding before it is completed, or to reweld a section, wait until the entire weld has cooled before beginning to weld again.

GUIDE FOR OXYACETYLENE WELDING OF NONFERROUS METALS

Although brazing is used extensively to make joints in nonferrous metals, there are many situations in which oxyacetylene welding is suitable for this purpose. In general, joint designs are the same for nonferrous metals as for ferrous metals. Oxyacetylene welding of nonferrous metals may require mechanical cleaning of the surfaces before welding and the use of a flux during welding. Filler metal must be suitable for the base metal being welded.

Copper

Where high joint strength is required, the only kind of copper that can be successfully welded by oxyacetylene welding is DEOXIDIZED copper (copper that contains no oxygen). Either a neutral or a slightly oxidizing flame adjustment may be used. With a neutral flame, a flux is necessary; with an oxidizing flame, no flux is needed because the oxide formed on the surface protects the molten metal. Because of the high thermal conductivity of copper, it is necessary to preheat the joint area to between 500° and 800°F and to use a large 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 has been completed, the part should be cooled slowly.

Copper-Zinc Alloys

Copper-zinc alloys (brasses) may be welded in the same way as deoxidized copper. However, a silicon-copper rod is used for welding brasses. Preheat temperature is from 200° to 300°F. Copper-silicon alloy (silicon bronze) requires a different oxyacetylene welding technique. This material should be welded with a slightly oxidizing flame. A flux with a high boric acid content should be used. 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 that the weld will solidify rapidly.

Copper-Nickel Alloys

Oxyacetylene welding of copper-nickel alloys requires surface preparation and preheating. The flux used for this welding is in the form of a thin paste; it is applied by brush to all parts of the joint and to the welding rod. The torch should be adjusted 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 is required to give good fusion. Keep the end of the welding rod within the protective envelope of the flame, adding the filler metal without agitating the molten puddle. Run the weld from one end of the joint to the other without stopping. After welding is completed, cool the part slowly and then remove the remaining traces of flux with warm water.

Nickel and High-Nickel Alloys

Oxyacetylene welding of nickel and high-nickel alloys is similar to that for copper-nickel alloys. Good mechanical cleaning of the joint surfaces is essential. Plain nickel is welded without a flux, but high-nickel alloys require a special boron-free and borax-free flux in the form of a thin paste. The flux is applied by brush to both sides of the seam, to the top and bottom, and to the welding rod. The torch should be adjusted to give a slightly carburizing flame; the tip selected should be the same size as (or one size larger than) for steel of the same thickness. Keep the tip of the cone in contact with the molten puddle, and keep the welding rod well within the protective envelope of the flame at all times. After the weld is completed, postheat the part and cool it slowly. Then remove the flux with warm water.

Lead

Oxyacetylene welding of lead requires special tools and special techniques. A flux is not required. The metal in the joint area must be thoroughly cleaned before welding. This cleaning is accomplished by shaving the joint surfaces with a scraper and then wire-brushing the metal with a clean stainless steel wire brush to remove oxides and foreign matter. The lap joint is used for practically all oxyacetylene welding of lead, except that a square butt joint may be used when the welding is done in the flat position. When the lap joint is used, the edges should overlap each other from 1/2 inch to 2 inches, depending upon the thickness of the lead.

A special lightweight torch is used for the oxyacetylene welding of lead. The gas pressures range from 1 1/2 to 5 psi. A completely neutral flame must be used; the length of the flame should be somewhere between 1 1/2 to 4 inches, depending upon the gas pressures that are used. A soft, bushy flame is best for welding lead in the horizontal position and in the flat position. A more pointed flame gives better results in the vertical position and in the overhead position.

For oxyacetylene welding of lead, the filler metal should be of the same composition as the base metal. The molten puddle is controlled and distributed by manipulating the torch so that 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 on the first pass, but is added on subsequent passes. When welding lead or lead alloys, wear a respirator of a type approved for protection against lead fumes. LEAD FUMES ARE POISONOUS.

SAFETY PRECAUTIONS

Whether you are welding, torch brazing, flame cutting, or heating with oxyacetylene equipment, certain precautions must be observed to protect personnel and the structure from injury by fire or explosion. The precautions that follow apply specifically to oxyacetylene work. Other safety precautions are listed in chapter 1 of this manual and in OPNAVINST 5 100.19.

1. CLOTHING: You should use goggles, a faceplate, respirators, flameproof gloves, jackets, leggings, and boots, as appropriate. Do not keep any type of lighter on your person and do not wear synthetic clothing.

2. CYLINDER SAFETY: You should follow these safety precautions when working with compressed gas cylinders during cutting or welding operations:

— Place cylinders a safe distance away from the actual welding or cutting operations so that sparks, hot slag, or flame will not touch them.

— Do not tamper with, or attempt to repair, cylinder valves.

— Always place fuel-gas cylinders with the valve end up. Acetylene cylinders should be stored in the vertical position for a minimum of 2 hours before use to stabilize the gas.

— Handle cylinders carefully; avoid rough handling that could damage cylinders.

— Close cylinder valve and release gas from the regulator before attempting to remove the regulator from the cylinder valve.

— Do not place anything on top of an acetylene cylinder that may interfere with the quick closing of the cylinder valve.

— Always use regulators to reduce compressed gases to a suitable working pressure.

— Copper tubing should not be used with acetylene gas because of the potential of an explosive chemical reaction.

3. OPERATIONS: The improper operation of oxyacetylene equipment is the major cause of accidents. Follow these basic safety precautions when operating oxyacetylene equipment:

— Check all gas connections for leakage.

— Do not use defective or damaged equipment.

— Never use petroleum-based products (oil or grease) to lubricate oxyacetylene equipment. Oil or grease in the presence of oxygen under pressure will ignite violently.

NOTE: Glycerin is a suitable lubricant for oxyacetylene equipment.

— Do not use vice grips, adjustable wrenches, pliers, or other similar tools to tighten connections or to open gas cylinder valves. You will only damage the connections rendering them unusable in an emergency.

— Always leave the apparatus wrench on the acetylene cylinder valve so the cylinder can be secured quickly in an emergency.

— Never open an acetylene cylinder valve more than 1/4 to 1/2 of a turn.

— Fully back out the adjusting screw on a regulator and stand to one side when pressurizing a compressed gas system. Regulators have been known to explode if pressurized improperly.

— Never run oxyacetylene hoses on the deck. The hoses should always be run in the overhead. When running hoses through hatches, doors, or scuttles, locate the connection near the access and block open the door to prevent the hose from being cut.

— Never use matches, lighters, or any open flame to light your torch; use a friction lighter only. Butane lighters have been known to explode if exposed to excessive heat or if the casing melts.

— When lighting the torch, open the acetylene valve first and ignite the gas before introducing oxygen to the flame.

— Never allow unburned acetylene to escape into small or closed spaces.

— Report any safety discrepancy or unsafe act to your immediate supervisor.

4. BACKFIRE AND FLASHBACK: Unless the system is thoroughly purged of air and all connections in the system are tight before the torch is ignited, the flame is likely to bum inside the torch instead of outside the tip. The difference between the two terms *backfire* and *flashback* is this: in a backfire, there is a momentary burning back of the flame into the torch tip; in a flashback, the flame bums in or beyond the torch mixing chamber. A backfire is characterized by a loud snap or pop as the flame goes out. A flashback is usually accompanied by a hissing or squealing sound. At the same time, the flame at the tip becomes smoky and sharp pointed. When a flashback occurs, immediately shut off the torch oxygen valve, then close the acetylene valve. By closing the oxygen valve, the flashback is stopped at once. The occurrence of a flashback indicates that something is radically wrong either with the torch or with the manner of handling it. A backfire is less serious. Usually the flame can be relighted without difficulty. If backfiring continues whenever the torch is relighted, check for these causes: overheated tip, gas working pressures greater than that recommended for the tip size being used, loose tip, or dirt on the torch tip seat. These same difficulties may be the cause of a flashback, except that the difficulty is present to a greater degree. For example, the torch head may be distorted or cracked.

In most instances, backfires and flashbacks result from carelessness. These difficulties can be avoided by making certain that (1) all connections in the system are clean and tight; (2) torch valves are closed (not open or merely loosely closed) when the equipment is stowed; (3) the oxygen and acetylene working pressures used are those recommended for the torch employed; and (4) the system is purged of air before the apparatus is used. Purging the system of air is especially necessary when the hose and torch have been newly connected or a new cylinder is incorporated into the system. Purging a system is accomplished as follows: Close torch valves tightly, then slowly open the cylinder valves. Next, open the regulator slightly. Open the torch acetylene valve and allow acetylene to escape for 5 to 15 seconds, depending on the length of the hose. Close the acetylene valve. Repeat the procedure on the oxygen side of the system. After purging air from the system, light the torch as described previously.

SUMMARY

As you look back at this chapterr, you will find that you now have a knowledge of the components of oxyacetylene equipment and the use of the equipment. You also have the information required to perform certain welding techniques and oxyacetylene cutting operations. Review of the safety precautions is highly recommended. Failure to obey some of the precautions could cause a fire, personnel injury, or equipment damage. However, failure to follow other precautions may just cost you your life.

CHAPTER 9

BRAZING AND BRAZE WELDING

LEARNING OBJECTIVES

Upon completion of this chapter; you should be able to do the following:

- *Identify the tools and equipment used in silver brazing.*
- *Describe the techniques used in braze welding and silver brazing, and define the different types of filler metals available.*
- *Explain the necessity of using fluxes, the different types of flux available, and the correct procedures to use in applying fluxes.*
- *Describe the procedures for hydrostatically testing silver-brazed joints.*
- *Describe hard surfacing and identify the materials and techniques used in hard surfacing.*
- *Describe the uses of powdered metals and the correct procedures in the application of powdered metals.*
- *Describe the technique used in soldering.*

INTRODUCTION

This chapter will cover silver brazing, braze welding, surfacing, powdered metal flame spraying, and soldering processes. The various associated equipment will also be discussed along with its safe operation. You will find that silver brazing and braze welding are two welding processes that you will use quite often. There are a number of ways to silver braze, but it is done most often with an oxyacetylene torch.

Braze welding and silver brazing are similar in many ways, but they are two different welding processes. In silver brazing, a silver-base alloy is used as a filler metal and the base metal is NEVER melted. The filler metal is distributed throughout the joint by capillary attraction. In braze welding, a copper-base alloy is used as a filler metal and it is deposited in groove and fillet welds exactly at the points where it is to be used. Limited base metal fusion may also occur in braze welding; capillary attraction is not a factor.

You will often see the word tinning used in connection with silver brazing and braze welding. The surface of the base metal is said to be tinned when a very thin continuous film of tiller metal precedes the main part of the filler metal. Tinning can only occur on metal that has been cleaned, fluxed, and heated to the correct temperature. If tinning does not occur, the main part of the filler metal will not adhere to the base metal. Tinning will be discussed later in this chapter.

SILVER BRAZING

Silver brazing is a process where coalescence is produced by heating with a gas flame. It uses a silver alloy filler metal with a melting point above 800°F, but below the melting point of the base metal. The filler metal is distributed in the joint by capillary attraction.

Let’s consider some everyday examples of the process used in silver brazing. When you use a blotter, the ink is drawn up into the blotter by capillary attraction. The wick on an oil lamp can be lit because the oil rises in the wick by capillary attraction. In each of these examples, we have a liquid that moves into an opening in a solid by the process called capillary attraction. A basic rule of the process is that the distance the liquid will be drawn into the opening in the solid depends on the size of the opening in the solid. The smaller the opening, the farther the liquid will be drawn in.

This same capillary attraction causes the melted filler metal used in silver brazing to be drawn into the narrow clearance between the joining members. Capillary attraction will not work unless the tiller metal is in a fluid state and the size of the opening is quite small (usually 0 to 0.012 depending on pipe or tube size). Therefore, the application of heat and the use of a very small clearance between joining members are essential to silver brazing. The heat is necessary to melt the filler metal and to keep it molten. The small clearance is necessary to allow capillary attraction to draw the molten metal into the space between the joint members.

You will often hear silver brazing called SILVER SOLDERING or HARD SOLDERING. Silver brazing is similar in many respects to soldering. The basic distinction between a welding process and a soldering process is that the metals or alloys used for a welding process have melting points above 800°F, while those used for a true (or SOFT) soldering process have melting points below 800°F.

TORCHES

Silver brazing depends largely upon the operator's manipulation of the torch to control the application of heat. A lightweight torch with or without a flexible extension tube (fig. 9-1) simplifies the silver brazing procedure and helps reduce operator fatigue. The flexible extension tube is made of soft copper. It can be bent as needed to heat the surfaces to be joined.

Since one tip size cannot be used for making joints on all thicknesses of metal, torches are provided with various sizes of tips. Tips are designed to heat a large area and still allow little or no "bounce" (reflected heat). Figure 9-2 shows the shapes of the flame at the ends of different kinds of tips.

The tip shown in view A of figure 9-2 has the lowest velocity and heats the largest area. This tip should be used in joining with silver alloys.

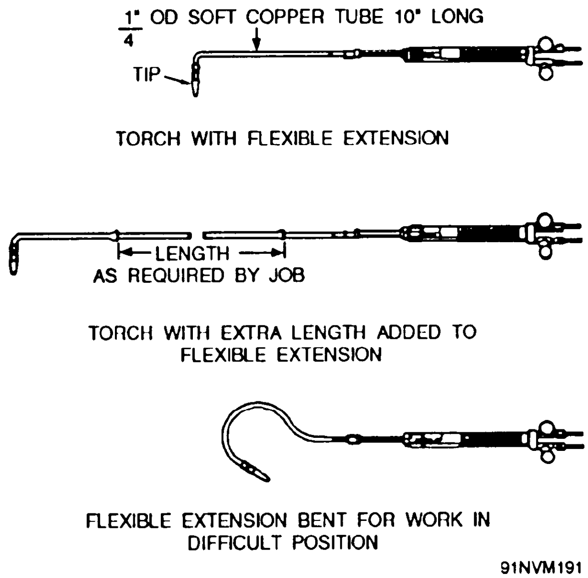


Figure 9-1.—Lightweight oxyacetylene torches with flexible extension tubes.

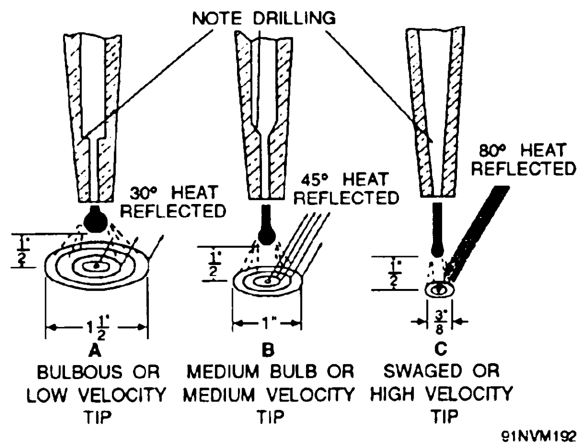


Figure 9-2.—Tip designs.

The size of tip selected for the torch should be determined by the size and type of work to be done. For silver brazing sheet stock, for instance, you would ordinarily use size 4, 5, or 6. Table 9-1 may be used as a general guide.

SILVER BRAZING FILLER METALS

Silver brazing filler metals are nonferrous metals or alloys that have a melting temperature above 800°F, but below the melting point of the base metal being joined. You may have heard these silver brazing filler metals referred to as silver solder, hard solder, or brazing alloys, but the correct term is *silver brazing filler metals.*

Table 9-1.—Tip Sizes and Gas Pressures for Silver Brazing Various Thicknesses of Metal

Tip No. (Bulbous-type tips)	Drill size	Metal thickness (inches)	Oxygen pressure (psi)	Acetylene pressure (psi)
1	68	1/16	1.0	1.0
2	62	3/32	2.0	2.0
3	56	1/8	3.0	3.0
4	54	3/16	4.0	4.0
5	51	1/4	5.0	5.0
6	48	5/16	6.0	6.0
7	44	3/8	7.0	7.0
8	40	1/2	7.0	7.0
9	35	5/8	7.5	7.5
10	30	3/4 & over	9.0	9.0

Silver brazing filler metals covered in Navy specifications have the following major characteristics:

- Low melting point
- High tensile strength
- High resistance to corrosion
- Flows readily at the lower brazing temperatures
- Brazes readily to copper and to copper alloys

The metals commonly used for silver brazing filler metals include silver, copper, zinc, phosphorus, cadmium, and nickel. The percentage of the various metals determines the color, strength, melting point, and flow point of the filler metal. All grades of silver brazing alloy can be obtained in strips, wires, pigs, shot, or chips, as required.

Table 9-2 lists the silver brazing filler metals commonly used in the Navy. There are six different filler metals: grades 0, I, II, III, IV, and V.

Grades 0, I, and II are suitable for joining ferrous metals. They cost less and are often used for large quantities of work.

Grade III is used for brazing copper and copper-base alloys. It is not intended for use with ferrous metals.

Grade IV is used for joining ferrous and nonferrous metals, except those having melting points lower than the filler metal.

Grade V is used when the characteristics of grade IV are required, but where close tolerances cannot be maintained or when the addition of a filler is desired. Grade V should be used for brazing hard materials.

FLUXES

All silver brazing operations require the use of a flux. The flux prevents the oxidation of the metal surfaces and removes oxides already present. Flux also increases the flow of the brazing filler metal and increases its ability to adhere to the base metal. It brings the brazing filler metal into immediate contact with the metals being joined and permits the tiller to penetrate the pores of the metal. Silver brazing flux (as specified in table 9-3) must be applied evenly to each brazing surface.

For best results, a flux must become active at a temperature slightly below the melting point of the filler metal, and must remain fluid at the brazing temperature. Regardless of the type of flux you select, you need to apply it in such a manner that all oxide film is removed.

You can get flux in three forms: liquid, paste, and powder. When used either in paste form or in liquid form, the flux is applied with a brush to both parts of the joint and to the filler metal. Use a circular motion to brush it on, and let the flux extend outside the joint or fitting. For best results, flux should be applied after cleaning and before heating. Brush the flux on with a circular motion to give a uniform coating and lessen the

Table 9-2.—Silver Brazing Metals Commonly Used in the Navy

Brazing Filler Metal	Grade No.	Composition (%)	Melting and Flow Point[1]	Shape	Color	Suggested Use
Copper-silver	0	Silver . . . . . . 20 Copper . . . . . 45 Zinc 35	1430°F 1500°F	Strip	Yellow	Seal joints operating up to 1230°F. Suitable for joining ferrous metals.
Copper-silver	I	Silver . . . . . . 45 Copper . . . . . 30 Zinc 25	1250°F 1370°F	Strip or wire.	Nearly white.	Seal joints operating up to 1050°F. Suitable for joining ferrous metals.
Copper-silver	II	Silver . . . . . . 65 Copper . . . . . 20 Zinc 15	1280°F 1325°F	strip	White	High silver content primarily for color match. Suitable for joining ferrous metals.
Copper-silver	III	Silver . . . . . . 15 Copper . . . . . 80 Phosphorous . . 5	1200°F 1300°F	Strip or wire.	Gray-white.	For brazing copper and copper-base alloys.
Copper-silver	IV	Silver . . . . . . 50 Copper . . . . . 15 Zinc . . . . 17 Cadmium 18	1160°F 1175°F	Strip or wire.	Yellow-white.	For brazing all ferrous and nonferrous metals except those having lower melting points. Use only where proper tolerances can be maintained.
Copper-silver	V	Silver . . . . . . 50 Copper . . . . . 15 Zinc . . . . 15 Cadmium . . . . 17 Nickel 3	1195°F 1270°F	Strip or wire.	Yellow-white.	For same applications as grade IV but where close tolerances cannot be maintained. For brazing hard metals.

[1]In all instances, the lesser temperature indicates melting point and the higher temperature indicates flow point of the brazing filler metal.

possibility of bare spots that will oxidize during heating. Flux the filler metal by heating the filler rod and dipping it into the flux. Enough flux to do the job will stick to the hot rod.

Borax or a mixture of borax and other chemicals is most often used as a flux. Up to a certain point, heat causes borax to swell and bubble. Common crystalline borax contains approximately 47 percent water of crystallization (water that is chemically combined in a crystallized substance). When the borax is heated, this water is driven off, and the borax appears to boil. Borax may be mixed with water to form a paste. However, borax can hold water, and it will quickly take up the water and become crystalline borax again. If

Table 9-3.—Types of Silver Brazing Fluxes

Metals	Fluxes
Brass, copper, tin . . .	Rosin
Lead	Tallow, rosin
Iron, steel	Borax sal ammoniac
Galvanized iron	Zinc chloride
Zinc	Zinc chloride
Aluminum	Stearine, special flux

commercial powdered borax is used, see that it is kept in sealed glass jars.

If a prepared flux is not available, a mixture of 12 parts of borax and 1 part boric acid may be used as a flux for brazing.

When you apply flux or assemble the parts, avoid handling the polished parts of the joint or you will defeat the purpose of cleaning. If the parts are not assembled immediately, the fluxed surfaces should be protected so that the flux will not be contaminated by dirt or washed or brushed off. If the coating of flux dries before the parts are assembled, remove the old flux and apply a fresh coat of flux. It should always be applied as soon as a joint area is cleaned, even though it will not be brazed immediately. Joints that have been assembled but not brazed within 24 hours must be disassembled, recleaned, and refluxed before brazing. After you finish the brazing, allow the work to cool below 200°F before cleaning the joint with warm water to remove the residue left by the flux.

TYPES OF JOINTS

The filler metal used in silver brazing must be distributed by capillary action. Therefore, the joints must be of a type that requires closeness of fit. In silver brazing there are three basic joint designs: lap, butt, and scarf. The joint members in which these designs are used may be flat, round, tubular, or irregular in cross section.

The lap joint design is used most frequently in silver brazing, especially in pipe work. Good practice requires a length of lap at least three times the thickness of the metal being joined. The maximum permissible diametrical clearances used in silver brazing range from 0.001 to 0.012 depending on the pipe or tube size and the classification of the brazed piping system. (See table 9-4.)

Table 9-4.—Maximum Permissible Diametrical Clearances

MAXIMUM PERMISSIBLE DIAMETRICAL CLEARANCES[1]

Pipe or Tube Size (Inches)	Maximum Clearances (Inches) at Ambient Temperature	
	Class P-3a	Class P-3b
1/4 to 1/2 Inclusive	0.005	0.010
Over 1/2 to 1 Inclusive	0.006	0.010
Over 1	0.008	0.012

[1]In fitting up joints for brazing, it is the responsibility of the fabricator to use a clearance within the limits established by this table, which assures conformity to inspection or test requirements set forth in this document or in other specifications or standards governing brazed piping systems.

High-strength butt joints can be made if a joint clearance between 0.001 and 0.003 inch can be maintained in the finished braze. The edges of the joint must be perfectly square so that you have a uniform clearance between all portions of the joint surfaces. Butt joints are usually used where you do not want the double thickness of a lap joint. In these situations, the scarfjoint is probably better.

A scarf joint provides an increased area of bond without increasing the thickness of the joint. The area of bond, however, depends on the angle at which the edges of the joint are scarfed. Usually, you will want an area of bond two to three times that of a butt joint in the same thickness of material. A 30-degree scarf angle gives a bond area twice that of a 90-degree butt joint, and a 19 1/2-degree scarf angle gives a bond area three times that of a butt joint.

You will use modifications of these basic joint designs. In some instances, you will add the silver brazing filler metal when the proper temperature has been attained. In other instances, you will preplace the filler metal in the joint before heat is applied. This technique is common in pipe work where special fittings containing preinserted rings of silver brazing. filler metal are used. The technique is also used in sheet metal work involving locked scams. Here, you will place the silver brazing filler metal in the seam before it is locked. The preplaced insert method produces a strong leaktight joint in both sheet metal and pipe work.

SILVER BRAZING TECHNIQUES

You will need some knowledge of the principles of heat flow through metals to understand silver brazing techniques.

The following points are particularly important:

1. Heat always flows from a hotter area to a colder area.

2. The process by which heat flows from molecule to molecule through a metal (fig. 9-3) is called conduction. Conduction takes place quite rapidly in most metals, but air is a very poor conductor of heat. Therefore, if two pieces of metal that are to be joined by silver brazing are not in contact with each other, each piece must be heated separately. If the two pieces are in contact with each other, you can heat both by applying heat to one of them. The second piece will be heated by conduction from the first piece. These principles are shown in figure 9-4.

3. In the molten state, filler metal flows from the colder toward the hotter areas on a heated surface. Therefore, you might say that the filler metal flows in a direction OPPOSITE to the direction of flow of the heat. This principle is shown in figure 9-5.

4. The filler metal and the flux used in silver brazing cannot occupy the same space at the same time. Therefore, a clearance must be provided in the setup of the joint so that the filler metal can flow in and the flux can flow out. Heat should be applied in the manner shown in figure 9-6 so that the flux will flow out when the filler metal reaches the bonding temperature.

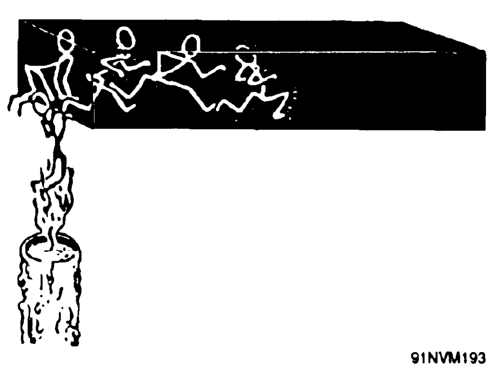


Figure 9-3.—Conduction of heat.

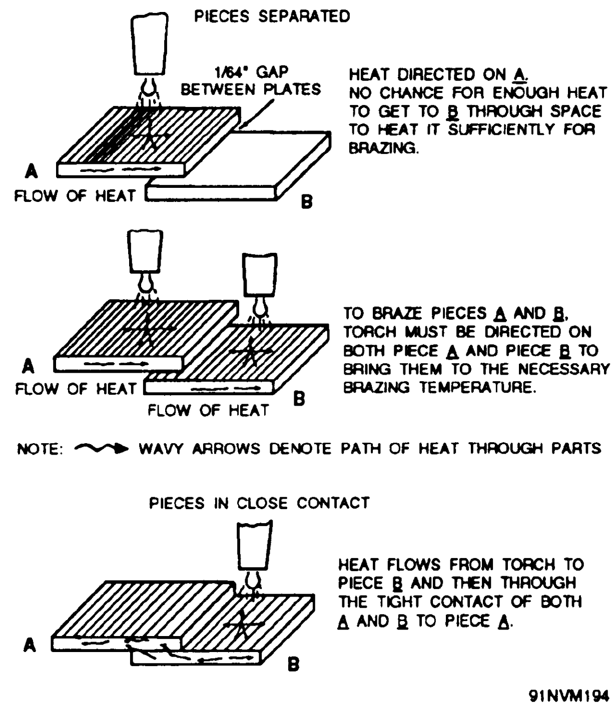


Figure 9-4.—Flow of heat.

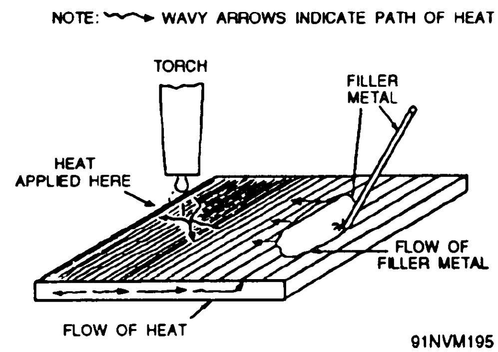


Figure 9-5.—Flow of molten filler metal.

5. Heat travels faster through some metals than through others (fig. 9-7). All metals and alloys have high conductivity as compared with most other substances, but there is a good deal of variation in the speed with which various metals and alloys will conduct heat. Copper, for example, is a very rapid conductor of heat. When two pieces of different metals are to be joined by silver brazing, the difference in heat conductivity of the two metals causes some problems in heating. For example, if you are trying to join a steel part and a copper part by silver brazing, you will find that the steel part reaches the joining temperature more rapidly and has a tendency to overheat because the heat

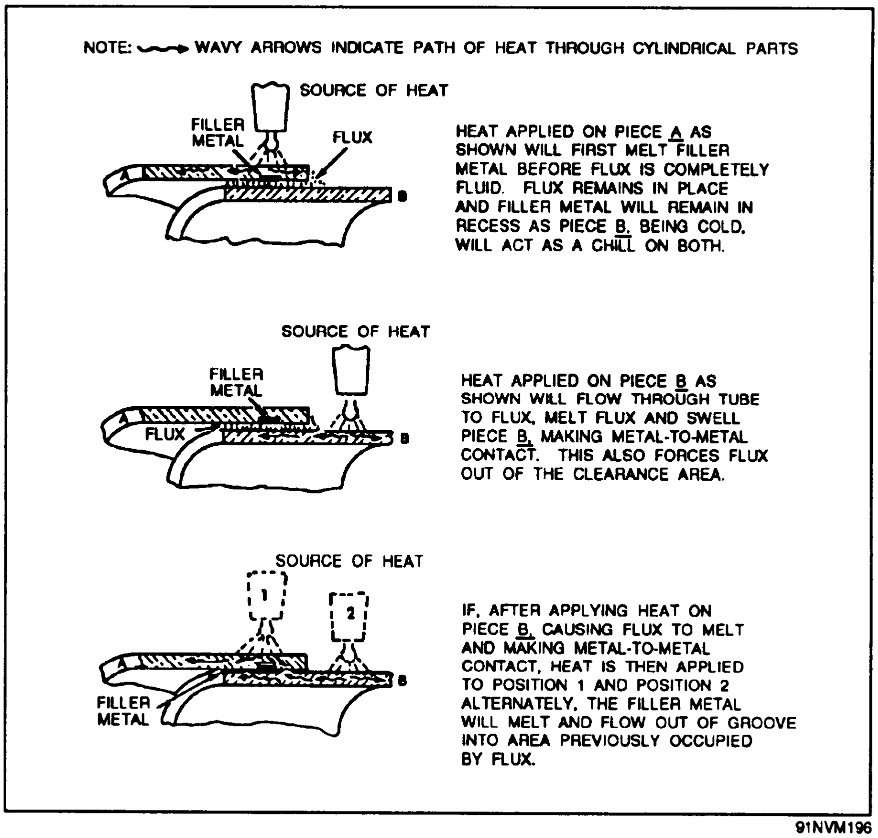


Figure 9-6.—Flow of flux and filler metal.

is carried away from it more slowly. The copper part, on the other hand, conducts heat away from the brazing area more rapidly than does the steel part. Therefore, more heat is required to bring the copper part to the brazing temperature.

Control of heat is one of the most difficult parts of silver brazing. To do it properly, you must manipulate the torch correctly, and you must remember the points just discussed concerning the flow of heat through metals. Basically, the problem of heat control in silver brazing is one of bringing BOTH parts to the correct temperature at the same time. If one piece is hot enough but the other is not, the filler metal will flow onto the hot piece, but it will not bond to the cooler piece.

If you have heavy and thin metal sections that must be silver brazed, be careful to avoid overheating the thin part. A good example is the silver brazing of thin copper tubing to a heavy cast fitting. If the same amount of heat were applied to the tubing as to the casting, the tubing would be overheated and probably burned. Therefore, most of the heat must be directed toward the heavier part. Frequently, heavy parts and large areas must be

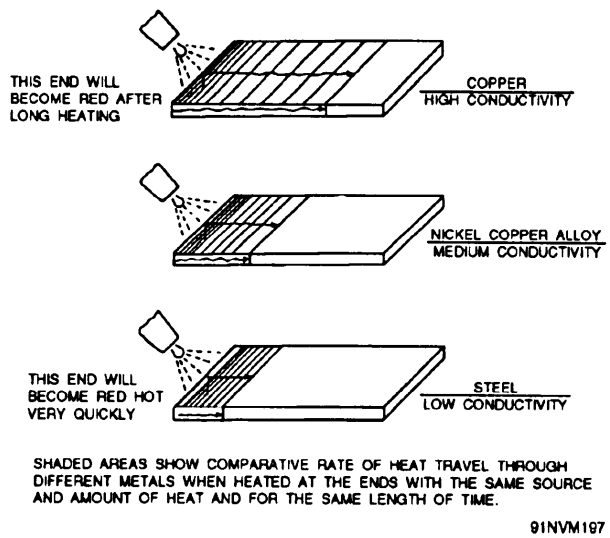


Figure 9-7.—Relative rate of heat flow through copper, nickel-copper alloy, and steel.

preheated for best brazing results. Preheating may be done with a forge, a furnace, or a welding torch.

Joints must be clean and properly fitted for satisfactory silver brazing. All parts to be brazed must be thoroughly cleaned to remove surface scale, oxide,

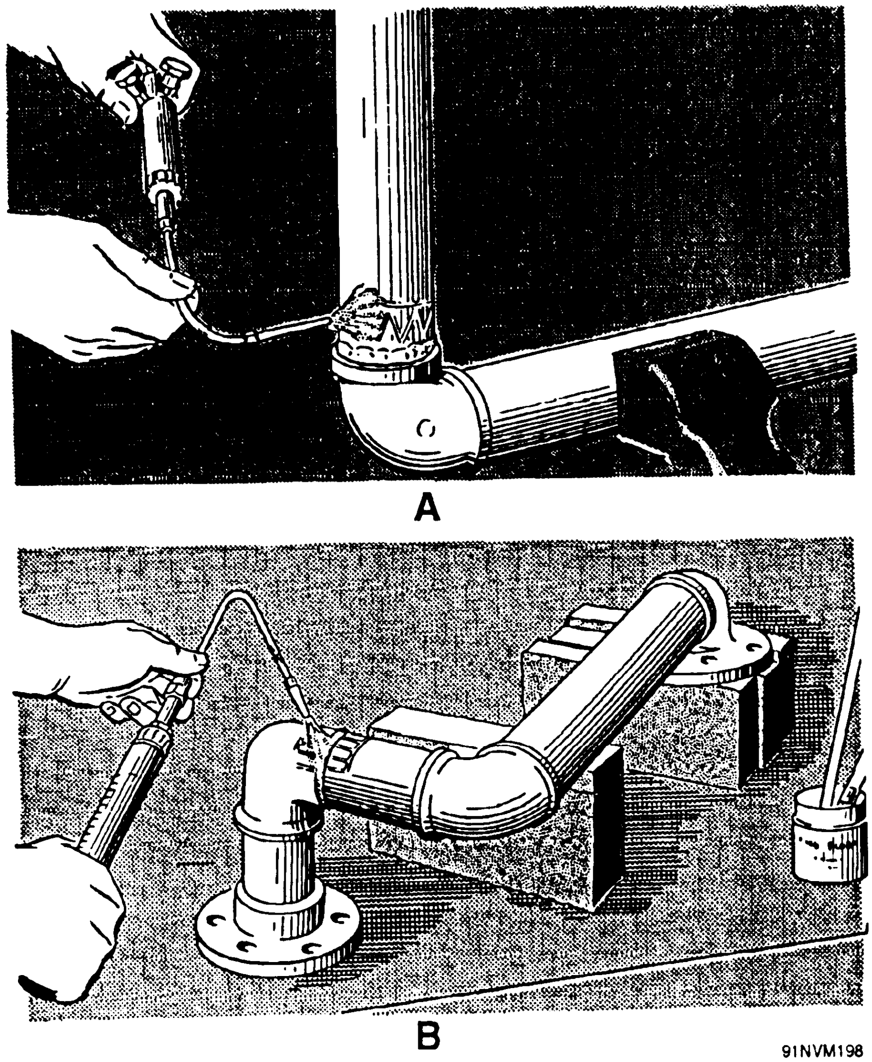


Figure 9-8.—Applying heat for silver brazing a tube and fitting.

oil, and grease. Any one or a combination of the following methods must be used for the cleaning of scale and oxides or other foreign substances:

- Abrasive cloth, followed by wiping with an acetone-, alcohol-, or water-damp clean cloth.
- Stainless steel wire brush, hand or rotary, followed by wiping with an acetone-, alcohol-, or waterdamp clean cloth.
- Metallic stainless steel wool followed by wiping with an acetone-, alcohol-, or water-damp clean cloth.
- Commercial cleaning solutions or degreasing baths may be used when included in an approved brazing procedure or specification.

Rust and corrosion should be removed by sanding, grinding, sandblasting, wire brushing, or filing. Oil and grease should be removed with solutions of trichloroethylene or trisodium phosphate, not by heat. The cleaned surfaces should not be handled unnecessarily. When parts have been cleaned and the elapsed time before fluxing is more than 8 hours, the parts should be recleaned. Brazing alloy should be free of all visible oxides, grease, oil, or other foreign substances when assembled or fed into the joint. Never try to braze dirty metal.

Use a slightly carburizing flame to apply heat with the oxyacetylene torch for brazing with a silver-base filler metal. Select a torch tip to suit the type of work you are doing. Ordinarily a size 4, 5, or 6 tip is suitable for silver brazing. Keep the inner cone of the flame from one-fourth to one-half inch away from the metal. Play the flame over the surface with a circular, sweeping motion so that you obtain uniform heating of the parts to be joined. The flame should be soft so that it will not blow or boil the molten filler metal.

Bring up the temperature of the parts until the flux on them is melted. Continue heating the parts to be joined until they are hot enough to melt the tiller rod. The filler should be melted by the heat of the joint, not by the flame. It should flow like water wherever the flux has been applied. Avoid overheating. Use just enough heat to get the parts of the joint hot enough to melt the filler metal so that it can flow.

Two methods are used to make joints with silver-base brazing filler metal: the insert method and the feed-in method (more commonly referred to as face feeding). With either method, the parts must be adequately supported during heating to maintain alignment and tolerances or fit. The work must be held firmly in positionuntil the silver brazing tiller metal has completely solidified.

When you use the insert method, insert a strip of the silver-base filler metal in the joint before assembly. Before brazing the parts, clean them with emery cloth, sandpaper, or some other abrasive, and apply flux with a brush. Next, fit the two parts together and align them. Then, light-off the torch and direct the heat on the tube or thinner portion, as shown in figure 9-8. The lines drawn on the tube indicate the path of the torch while the tube is being heated.

Heat applied to the tubing causes it to swell. This brings the surface of the tube into contact with the inside surface of the fitting. The clearance area is closed, forcing the flux from either end of the joint. Be sure to heat the entire circumference of the tube until the flux begins to flow. Flux flow tells you that the tube has expanded sufficiently, and signals you to proceed to the second phase of heating. The flux flows freely shortly after fluidity becomes apparent. At that time, direct the flame to that portion of the fitting hub farthest from the junction of the tube and the fitting. Sweep the flame over the joint segment in a circular motion until the brazing filler metal appears at the junction of the pipe and fitting. At that moment, flick the torch away so that the flame wipes toward the pipe. This completes one segment of the joint. Repeat the procedure until all segments are completed. A satisfactory joint shows a continuous ring of filler metal at the end of the fitting. The ring must be smooth and concave.

In the insert method, the filler metal will not leave the recess unless both parts are at the proper bonding temperature. One of the parts may be up to temperature while the other is not. At that point, the filler metal will not flow because it will be cooled or quenched by the surface not yet up to temperature. Play the torch over a 2- or 3-inch section of the fitting. That will cause the fitting to stretch or open up and let whatever remaining flux is present run out. Hold the torch off the work and the fitting will return to normal size and force the filler metal to the edge of the fitting. You may be sure that a good joint is formed when you can see the filler metal at one or both edges of the joined area. Figure 9-9 shows the step-by-step process of brazing by the insert method.

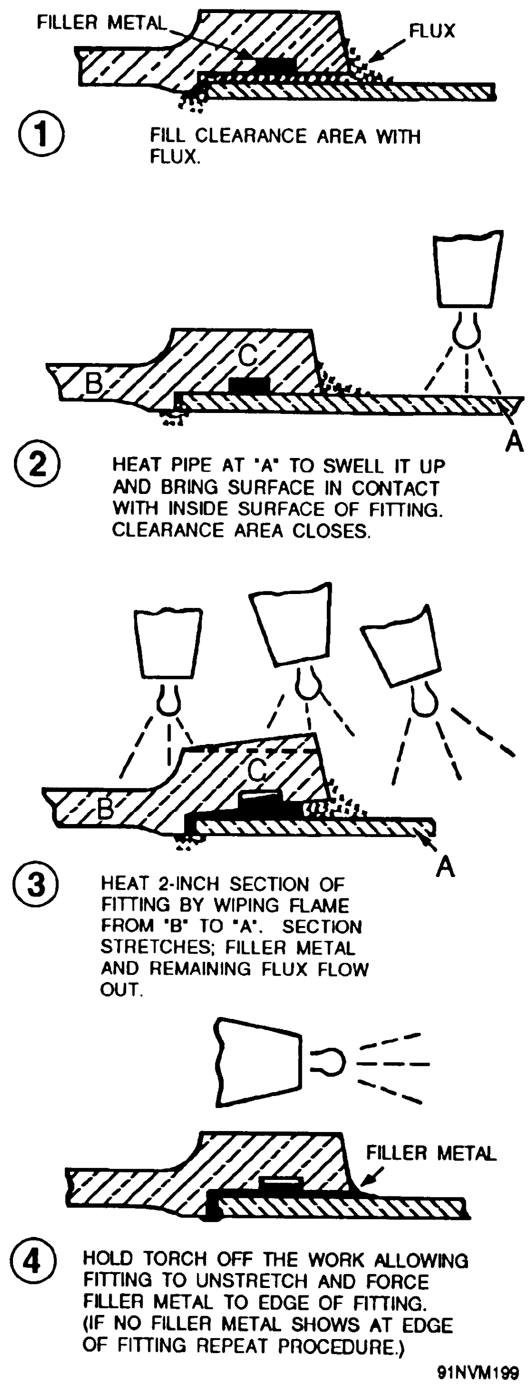


Figure 9-9.—Insert method of silver brazing.

The feed-in method, sometimes called the face-feed method, is accomplished by feeding the filler metal by hand into the area to be joined. Remember that the filler metal always flows along a heated surface from the cooler to the hotter section. In other words, the filler metal flows toward the source of heat or to the point where the heat is being applied. Feed the tiller metal to the outer edge of the joint while you direct heat to the inner edge of the joint. Figure 9-10 illustrates the stepby-step technique for brazing a joint by the feed-in method.

The parts to be joined are cleaned and fluxed in the same manner as in the insert method. When the parts are fitted together, the clearance area is tilled with flux. After aligning the parts, apply heat as previously described. Then apply heat to the fitting or the inner edge of the joint at the same time that the filler metal is fed at the outer edge of the joint. The filler metal will flow toward the hottest section. This means it will flow through the joint toward the point at which heat is being applied. It is left entirely to your judgment to decide when both parts are properly heated and when to feed the filler metal. It is also left to your judgment to decide when enough filler metal has been fed into the joint to completely fill the space between the two parts being joined. Skillful torch manipulation is necessary to apply heat to the proper point to cause the filler metal to flow from the cooler to the hotter section. Filler metal visible at the edge of the joint does not necessarily indicate that the entire joint is filled.

The difference, then, between making a joint by the insert method and by the feed-in method is in procedure. When using the insert method, you heat a section and remove the torch with a wiping motion, which causes the filler metal to flow from the insert. In the feed-in method, after you heat a section, you must direct the flame to the inside edge of the joint while the filler metal is being fed in at the outside edge of the fitting.

After the joint has cooled, clean the joint area with a wire brush and warm water to remove flux, scale, and discoloration. If flux is allowed to remain on the joint area, it will cause corrosion and future failure of the joint. After cooling and prior to performance of pressure or leak testing, completed piping systems should be cleaned and flushed to the extent necessary to ensure satisfactory operation of the system and components in service. Special cleaning, when required, will be according to the specified requirements in the shipbuilding, overhaul, or component specification. Unless otherwise specified, all P-3a special category systems (often referred to as P-3a critical systems) in submarines, as shown in table 9-5, will be flushed according to one of the following procedures:

—Hot flush with fresh water for 1 hour while ensuring that the temperature at any part of the system does not go below 110°F.

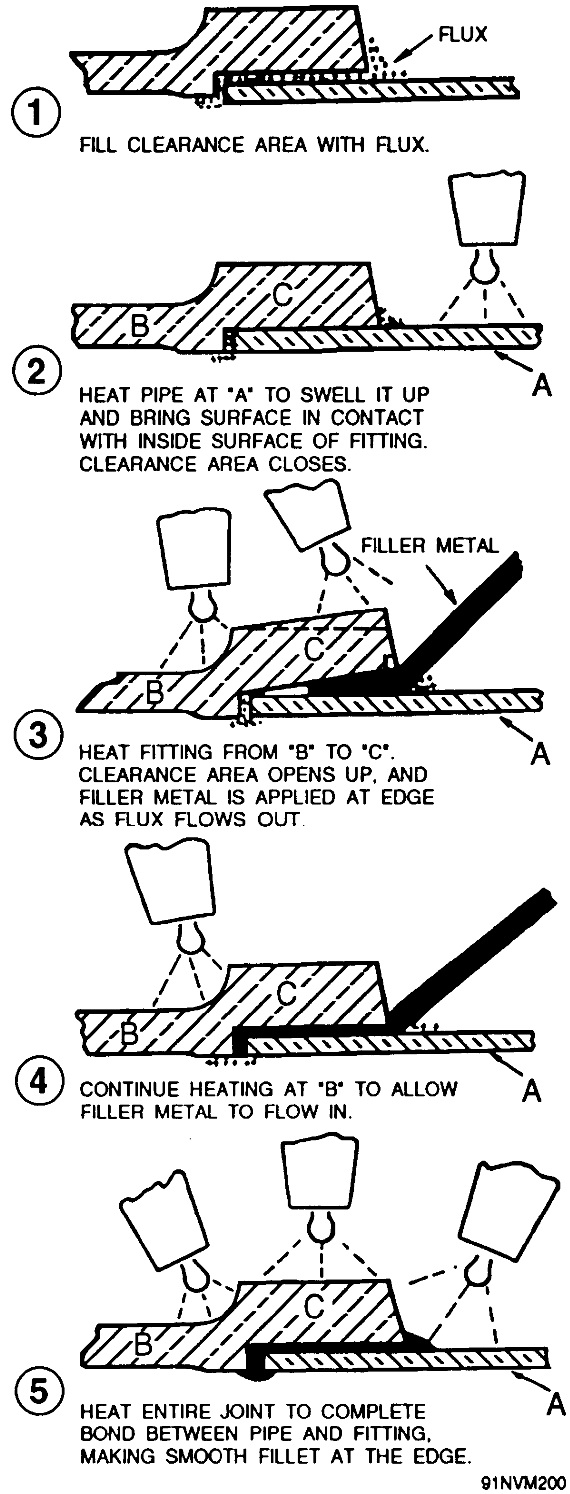


Figure 9-10.—Feed-in method of silver brazing.

Table 9-5.—Class P-3a Special Brazed Joint Categories

Category	SYSTEMS SERVICE	SUBMARINES	SURFACE SHIPS
A	Steam and Steam Drain Sys	2.375" O.D. and Larger & above 300 psi	2.375" O.D. and Larger & above 300 psi
B	Sea Water Sys Subject to Submergence Pressure	(1)	NA
C	Missile Booster Suppression Sys	NA	1.315" O.D. and Larger
D	Hydraulic Sys	1.660" O.D. and Larger & above 600 psi (2)	2.375 O.D. and Larger & above 600 psi
E	Lube Oil Sys	2.375" O.D. and above	2.375" O.D. and above
F	Flammable or Lethal Fluid Sys (e.g., Gasoline, Cleaning Fluids, JP-5, Fuel Oil, Oil Sys other than Hydraulic, Lube Oil and Freon	0.840" O.D. and Larger (3)	2.375" O.D. and Larger (3)
G	Oxygen Sys	0.840" O.D. and Larger & above 10 psi	2.375" O.D. and Larger & above 10 psi
H	Air Sys (including compressed gases-Nitrogen, Helium, and Fixed CO_2	0.840" O.D. and Larger & above 600 psi (4)	2.375" O.D. and Larger & above 600 psi
I	Other systems where specified by NAVSHIPS	0.840" O.D. and Larger	0.840" O.D. and Larger

Inspection Requirements: (See 7.3.1.)

Ultrasonic inspection is required on all brazed joints of sizes and pressures shown for the various categories in this table except ultrasonic inspection is not required on freon (halocarbon) refrigerant systems.

NA = Not applicable

NOTES TO TABLE 3-1

(1) Joints in systems, 0.840" O.D. and larger, subject internally to sea water at submergence pressure where failure of the joint would result in direct internal flooding within the full and which normally operate at depths in excess of 200 feet.

(2) Joints in the following hydraulic piping having a system design pressure above 600 psi also require ultrasonic inspection.

a. Tubing and piping 0.830" O.D. and larger in supply mains which supply components in more than one compartment, and in the branch supply lines from these mains up to the first isolation valve in the branch.

b. Tubing and piping 0.840" O.D. and larger, failure of which could result in simultaneous loss of normal and emergency modes of control for any steering or diving control service.

c. Piping, 0.840" O.D. and larger, in the emergency sea water valve control system necessary to ensure the integrity of the independent system (this includes all joints from the hydraulic actuator for the sea valve to the isolation valve(s) in the branch line(s) serving the flood control and normal operating station).

(3) Joints excluded from this category include those in segments of piping within their respective tanks, piping passing through tanks which contain identical fluid, and all sounding tubes, air escapes, vents and overflow piping.

(4) This includes low pressure MBT blow piping external to the pressure hull which is designed for external pressure greater than 600 psi.

—Conduct a hot recirculating procedure with fresh water for a period of 1 hour for systems where such an arrangement is feasible. Again the system temperature must be monitored so that no part of the system falls below 110°F. Following the recirculation, flush the system with fresh water for 15 minutes at a minimum temperature of 60°F.

—Cold soak the system for 12 hours using fresh water at a minimum of 60°F. At the completion of the 12-hour soak, flush the systems with fresh water at a minimum of 60°F for 4 hours.

The description of the brazing techniques in the preceding paragraphs apply specifically to joints between tubes and fittings in piping systems. Except for minor differences, the procedure is the same when brazing sheet, strap, or bar stock. Here you probably will use the feed-in method rather than the insert method. Lap joints are used with material less than one-eighth inch thick, while scarfjoints are usually used when the section thickness is greater than oneeighth inch. The following description points out the difference between pipe brazing and seam brazing.

Seam brazing requires some means for holding the parts in position. Short pieces can be clamped or riveted at the ends. Longer pieces are wired to size by using wire clamps. After the parts are wired or clamped in position, place additional flux along the outside of the seam. Then, tack weld both ends of the seam. Make additional tack welds along the seam approximately 8 inches apart. To make a tack weld, direct the flame to both parts of the seam on a spot approximately 6 inches in diameter. As soon as the flux becomes liquid in this spot, direct the flame to the sheet forming the underneath part of the seam. Place a layer of silver brazing filler metal approximately 1 inch long on the edge of the seam. Now direct the flame to the sheet forming the upper part of the seam. This will draw the silver brazing filler metal through the joint, completing the tack weld. When all tacks are completed the seam is ready for brazing.

The seam is brazed in sections 4 or 5 inches in length. Start the braze about 3 inches away from the tack at the edge of the seam. Hold the torch so that the flame is pointed in the direction that brazing is to be done. Direct the flame first along one sheet and then along the other until the flux becomes liquid. When this happens, direct the flame to the sheet forming the underneath part of the seam. At the same time, deposit a layer of filler metal along the edge of the seam. Brazing filler metal is drawn into and through the joint by a wiping motion of the torch, forming the brazed joint in that section. Repeat this procedure continuously along the joint until the entire seam has been completed.

Remember that silver brazing filler metal flows along a sheet in the direction of the hottest point. This point is usually where the torch flame is being applied. Apply heat long enough to draw the filler metal through the seam. Take care to avoid forming beads or globules along the inside edge of the seam.

Repairs to or alterations of a piping system often involve the disassembly of silver-brazed joints. For operations of this kind, use a tip one or two sizes larger than that used for brazing a similar joint. The fitting or tube must be held securely in a fixed position before heat is applied. With the exception of the initial tube-heating phase, the same rotary torch manipulation you used to make the joint is used to break the joint. Cover the joint with flux and use it to gauge the temperature. Add a little new filler metal while heating. When the filler metal flows, pull the parts apart.

Fittings and valves are easily damaged by shock when they are hot. Therefore, handle them carefully.

Piping and fittings removed from a system can be cleaned, resized, and reused if they meet the following inspection criteria (cracked piping and fittings must not be reused):

- Old flux and brazing alloy can be removed to the extent necessary to facilitate a new joint assembly. Do not use hand grinding to prepare the inside diameter of a fitting for reuse. All traces of tightly adherent brazing alloy need not be removed.

- After brazing alloy removal, the fitting must be liquid penetrant inspected or visually inspected at 5X magnification on both the inside and outside diameter surfaces in areas that have been heated to brazing temperatures for cracks.

- The wall thickness of fittings must not be reduced below the allowable minimum.

- Brazing alloy rings may be slightly rounded on the outer comers to fit insert grooves of reused fittings to aid in the assembly of joints.

- With the exception of copper-nickel alloy pipe, pipe may be reused without inspection, unless otherwise specified.

- After sizing copper-nickel alloy pipe intended for reuse, perform a liquid penetrant inspection or visually inspect at 5X magnification the entire pipe periphery for a length of 2D (nominal) or 2 inches (whichever is less) plus the socket depth.

Reassemble piping and fittings by using the same method you used for new installations. All silver-brazed piping sections that have been removed for repairs, and newly fabricated sections, must be hydrostatically tested before they are installed. Procedures for conducting hydrostatic tests will be discussed in chapter 11.

BRAZE WELDING

Braze welding is used to make a groove, fillet, plug, or slot weld using a copper-base alloy filer metal with a melting point above 800°F but below that of the base metal. The filler metal is not distributed in the joint by capillary attraction. In the past, this process has been called brazing. Earlier in this chapter, we said that all brazing is done by capillary attraction. Braze welds are made without melting the base metal, although some fusion may occur between the filler metal and the base metal. This method is very useful for repairing cast iron and steel.

The fact that braze welds are made without melting the base metal simplifies the welding procedure. Since braze welding requires less heat, the speed of welding is increased.

The lower temperatures required for braze welding mean that preheating is also easier. As a rule, braze welding operations can be done with only local preheating; that is, preheating only that portion of the part to be braze welded. This makes it possible to repair broken castings and other parts in place, thus saving the time and expense of disassembling and reassembling.

Braze welding is widely used to repair gray iron castings. It is used not only to repair broken castings, but also to rebuild worn parts, such as gear teeth or valve disks and seats. You can also repair and rebuild pistons, rotary valves, guides, and other sliding surfaces on pumps, engines, and machinery.

Braze welding should not be used to repair or rebuild castings where the difference in color between the filler metal and cast iron would be objectionable. Nor should it be used to join parts that will be subjected to temperatures above 650°F, or to repair working parts or containers used in chemical processes.

The best filler metal for braze welding is a naval brass that has a copper-zinc ratio of about 60 percent copper and 40 percent zinc. This ratio produces the best combination of high tensile strength and ductility. This filler metal has considerable strength when hot, and it has the narrowest freezing range (solidifies quickest) of the entire usable copper-zinc combinations. This is an additional advantage, since a quick-freezing filler metal has much better weldability than one that remains mushy over a wide temperature range.

Most of the commercial braze welding filler metals are modifications of this 60/40 copper-zinc-zinc alloy, with small additions of tin, iron, nickel, manganese, silicon, and other elements.

Strong braze-welded joints depend on proper preparation, the use of the correct technique, the strength of the filler metal, and coalescence of the filler metal and the base metal. The strength of a braze-welded joint does not depend upon a thin film of filler metal between close fitting surfaces as is true in a silver-brazed joint. Heavy deposits of silver-base filler metals have low strength values. However, heavy deposits of copper-base braze welding filler metals frequently attain strength comparable to welded joints.

Adequate preparation, which includes thorough cleaning, is essential in braze welding. Remove all foreign matter such as oil, grease, and oxides. The metal on the underside and on the top of the joint must be bright and clean. If the parts to be joined or repaired are less than one-fourth inch thick, it is not necessary to vee the edges. Cross sections of base metal one-fourth inch or larger must be beveled to about a 90-degree vee.

Coarse-grained soft castings are harder to tin than close-grained castings. A cast-iron part that has been in contact with fire will sometimes be difficult to tin. The same is true of castings that have been exposed too long to steam and oil at high temperatures. Also, it may be difficult to tin castings that have been in salt water or chemicals for some time. One way to make such pieces easier to tin is to alternately heat and cool the casting. When tinning is difficult, it may be necessary to remove the affected surfaces of the metal so that it will take the filler metal.

When you have cleaned the parts, the next step is to align them. Obviously, the parts must be kept in proper alignment and kept that way during the brazing process. You can do this best by using clamps and by tack welding.

In braze welding, a casting must be heated along the line of the weld. This sets up strains caused by expansion and contraction, unless the casting is properly preheated. In a small casting, up to about a hundred pounds, the heat from the torch is enough to preheat the entire casting. Larger castings should be more thoroughly preheated. This relieves stresses, speeds up the braze welding operation, and requires less oxygen and acetylene.

Preheating can be done with a torch, or with an improvised firebrick furnace covered with insulating-type fire-retardant cloth. At times, castings attached to a machine may be welded in place. These castings often can be preheated if you play the flame along the line of the weld and protect the surrounding surfaces with insulating cloth. Large castings should be postheated to relieve stresses. Flux is essential in braze welding with an oxyacetylene flame for two reasons: (1) it removes oxide that forms ahead of the welding zone due to the oxygen in the air, and (2) it dissolves the oxides formed in the braze welding operation. Use plenty of flux in the tinning operation, but use flux sparingly to fill the vee. When you see that more flux is required, add it carefully. The puddle should not be made mirror clear, but it should be left slightly clouded with oxide. Where the braze welding is rapid, coat the rods entirely with flux. If the operation is slow, as with heavy castings, dip the hot end of the welding rod into the flux and add to the puddle as required.

Use a slightly oxidizing flame for braze welding. Make periodic checks to be sure that this adjustment is maintained. A slightly oxidizing flame makes a better bond between the filler metal and the base metal. It also keeps a slight film of oxide over the puddle. This film protects the weld metal from the oxygen in the air.

After the parts have been properly prepared—cleaned, fluxed, aligned, and preheated if necessary—they should be tack welded together. Heat the metal with a torch at the point where the braze weld is to start. Play the torch flame over the part to be heated, using a circular motion. As the base metal gets hot, test its temperature with a drop of metal from the welding rod. When the base metal is at the right temperature, molten filler metal spreads evenly over the surface. This produces a tinning coat on the base metal.

You can tin the base metal in braze welding only when the conditions are just right for it. If the base metal is too cold, the filler metal will not run out and spread over the heated surface as it should. If the base metal is too hot, the filler metal will form little balls like drops of water on a hot stove. If the temperature of the base metal is right and the tinning is done properly, the molten filler metal will spread over the surface like water spreading over a clean, moist surface. Tinning is the most important step in the braze welding process. This free-flowing film of deposited filler metal forms the intimacy of contact necessary for coalescence between the base metal and the filler metal. When the immediate area under the torch flame is tinned, additional metal is added as necessary to fill the vee. Tinning must, at all times, continuously precede filling the joint.

As the tinning action is in progress, continue to feed the brazing filler metal into the molten puddle to build the weld up to the desired size. The puddle should be small in size, but increased as it is moved forward, until it completely fills the vee and a full-sized braze weld is made. Be sure that the tinning action takes place continuously, just ahead of the puddle. Good braze welding makes one continuous operation of the tinning action and the building up of the braze weld to the desired size.

The inner flame cone is kept from oneeighth to one-fourth inch away from the surface of the metal. Usually the flame is pointed ahead of the completed part of the weld at an angle of about 45°, with the puddle under and slightly behind the flame. You vary the angle, however, when welding in flat, overhead, and vertical positions. Also, the angle will vary with the size of the puddle being carried, the nature of the surface, and the speed of welding. Braze welding can be done in any position, but the flat position should be used if possible.

Bright spots on the metal in the puddle mean that oxides and impurities are present. They should be worked out with the torch flame or with flux. Don't use too much flux; it is wasteful and prevents making the best joint. Use just enough to get a good tinning action between the filler metal and the base metal. The proper rate of braze welding is controlled by the rate of tinning; never allow the puddle to get ahead of the tinning action.

If it is necessary to deposit filler metal in layers, as when braze welding heavy materials, the tinning of the base metal is particularly important. If the tinning is good and fusion between the layers is complete, a strong braze weld is assured.

After you have finished the braze welding operation, the internal stresses will need to be relieved. To do this, play the torch over the weld and on either side of the weld for several inches. The size of the weld and the size of the casting determine the size of the area that should be heated. Continue to heat until all sections of the part have been brought to even heat. If the repaired part is small, bury it in dry slaked lime. If it is large, cover it with an insulating-type fire-resistant cloth. Always cool the repaired part slowly. The part should be protected from drafts and cold air, which cause uneven cooling. Never subject a braze-welded joint to stress until it has completely cooled.

SURFACING

Surfacing is a process in which a layer of some special ferrous or nonferrous alloy is welded to the surface of new or old parts. The purpose is to increase their resistance to abrasion, impact, corrosion, and erosion, or to obtain other properties. Surfacing is also used to build up undersized or worn parts. In this latter instance, the procedure restores the efficiency of pistons, guides, shafts, and other parts. The filler alloy used for such jobs is the copper-base alloy used for braze welding. In fact, the technique is essentially the same. A word of caution: COPPER-ZINC FILLER METAL SHOULD NOT BE USED IF THE WORKING TEMPERATURE OF THE BUILT-UP SURFACE EXCEEDS 500°F. Steel parts subjected to high stress should be built up or resurfaced only once. Cast iron and copper-base alloys may be resurfaced as often as necessary.

Figure 9-11 shows the principal steps used to build up a worn steel piston with copper-base alloy. For this kind of job, Machinery Repairmen will cut the grooves and machine the finished job to size. Your job is to apply the surfacing alloy.

Weld the rough-turned grooves first. Then, build up the surface with one, two, or three layers of bronze as required by the finished dimensions. When built-up repairs are made on cylindrical objects, the work should be set up to allow the surfacing operation to progress up a slight incline of about 30°. When building up a thick surface, it's a good idea to do the job in several passes. On the first pass, concentrate on tinning. On the following passes, concentrate on good fusion between the layers of surfacing alloy. Use flux sparingly after the tinning pass or you'll wind up with a porous weld. The two most important safety precautions in repair welding operations are as follows:

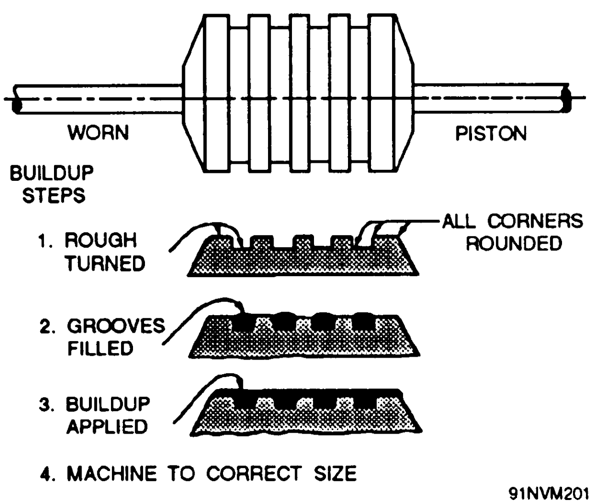


Figure 9-11.—Surfacing a steel piston.

1. CORED OR OTHERWISE ENCLOSED SPACES MUST BE VENTED. If not vented, they will vent themselves in a drastic manner—by exploding. Play safe by removing vent plugs or by drilling small holes through which expanding gases may escape when the part is heated.

2. DON'T BREATHE ZINC FUMES. Provide plenty of ventilation and wear a respirator when you're working with brasses and bronzes, because they contain up to 45 percent zinc.

A surfacing operation using a copper-base alloy filler metal produces a relatively soft surface. Use other types of alloys to produce a surface that is corrosion- and wear-resistant at relatively high temperatures. Two examples are facings for valve seats and disks used in high-pressure steam lines.

While many rods and electrodes are manufactured, only a few meet Navy specifications. Be sure your filler alloys are approved by the Naval Sea Systems Command for the work you are doing.

Three types of hard-surfacing materials are generally used in the Navy. They are chromium-cobalt, tungsten carbide, and iron-base alloys containing manganese, chromium, carbon, nickel, and other hardening elements. Of these, the chromium-cobalt (MIL-R-17131) alloy is probably the most important. It is used to repair disks and seats of high-pressure steam system valves. At present, no electrodes meet the Naval Sea Systems Command specification for this purpose. Noncritical surfacing operations, that is, disks and seats of valves manufactured from material other than carbon-molybdenum or chromium-molybdenum steels, need different materials. A MIL-E-19141 electrode or a 46R3C oxyacetylene welding rod may be used if a hard surface is required. For critical carbon or chrome-moly steel surfacing jobs, use a chromium-cobalt rod applied with the oxyacetylene flame.

Chromium-cobalt surfacing filler metal is an alloy of about 60 percent cobalt, 30 percent chromium, 5 percent tungsten, and 5 percent other alloys, including molybdenum and traces of iron. At room temperature this alloy is about as hard as ferrous tool steels. However, chromium-cobalt has the property to retain its hardness at high temperatures. With the exception of high-speed tool steels, common ferrous alloys do not have this characteristic.

Surfacing alloys are usually applied so that the material forms a thin layer over the base metal to which it is applied. The thickness of the deposit is usually from one-sixteenth to one-eighth inch, is seldom over one-fourth inch, and is generally deposited in a single pass. Cleanliness is just as important for surfacing as it is for braze welding. Scale, rust, and foreign matter must be removed before surfacing to prevent the formation of blow holes. If the surface of the base metal is clean and properly prepared, then these three points are important for a good hard-surfacing job using chromiumcobalt ahoy: (1) flame adjustment, (2) base metal surface appearance at the time the ahoy is applied, and (3) surfacing ahoy application to the base metal.

When you are surfacing with chromium-cobalt, use an oxyacetylene flame with an excess acetylene feather about three times as long as the inner cone. Your success depends upon the flame adjustment and the condition of the base metal surface when the surfacing ahoy is applied. Unless the excess acetylene flame is used, you cannot develop the proper base metal surface condition, and the surfacing ahoy will not spread over the surface of the part.

The torch manipulation used and the surfacing procedure itself are similar to those used in braze welding. However, you need higher temperatures (about 2,200°F) and tips one size larger than normal. The heating phase of the surfacing operation is as follows: With a sweeping motion of the torch, heat a small area of the base metal until the surface takes on a sweating appearance. Then, bring the end of the surfacing ahoy into the flame and allow it to melt. Do not stir or puddle the ahoy; let it flow. If the surface area has been properly sweated, the ahoy will flow freely over the surface of the base metal.

Good surfacing requires that you are able to recognize a sweated surface. This sweating occurs when the temperature of steel is raised to a white heat with a carburizing flame. An extremely thin layer of the base metal is carburized. The carburized layer has a lower melting point than the rest of the base metal. As a result, it becomes a liquid while the underlying metal remains a solid. This liquid film provides the medium for flowing the filler metal over the surface of the base metal. The liquid film is similar to, and serves the same purpose as, a tinned surface in soldering and braze welding. The carburized layer is approximately 0.001 inch thick.

The surfacing ahoy is added to the carburized layer at this time. It flows over the sweated surface and absorbs the film of carburized metal. It is easy to see this surface condition, but you should make several practice passes before you try to surface a valve disk or seat for the first time. Perfect the technique on scrap metal before you try it on critical metal. A typical stepby-step application of chromium-cobalt surfacing is illustrated in figure 9-12.

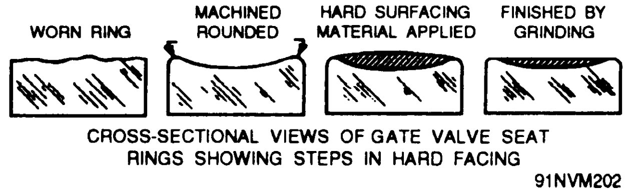


Figure 9-12.—Surfacing a valve seat ring.

Tungsten-carbide is another surfacing material that is applied with the oxyacetylene flame. This material is used to build up wear-resistant surfaces on steel parts that must withstand severe abrasion. It is used for such noncritical applications as aircraft tailskids and earth- and rock-moving equipment. The melting point of this material is so high that it cannot be applied by gaseous flame melting procedures. It is applied either in the form of inserts, which are welded or brazed to the base metal, or through the use of composite cast rod in which tungsten-carbide particles are evenly distributed. When this latter material is used, the surfacing technique is the same as that used for oxyacetylene welding with a slightly carburizing flame adjustment.

Iron-base surfacing alloys are used for a number of applications requiring various degrees of hardness. They can be applied by using either oxyacetylene or electric arc welding. Hard-surface deposits are so hard they cannot be filed or machined. They must be ground to size and shape. Because of their extreme hardness, they should be built up only slightly larger than the exact size, to eliminate unnecessary grinding.

Figure 9-13 shows the method used to make lathe and shaper tools by applying a surfacing ahoy. Other uses for surfacing material aboard ship are lathe centers, shear blades, and similar tools. When you prepare any

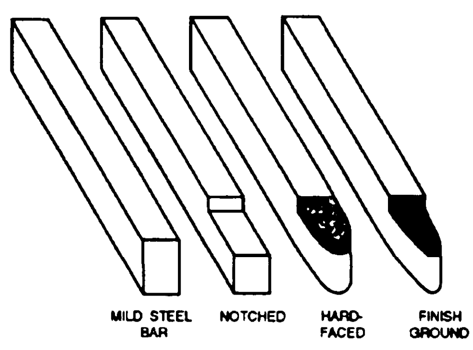


Figure 9-13.—Surfacing a lathe cutting tool.

of these jobs for surfacing, be sure that the edges of grooves, comers, or recesses are well rounded to prevent overheating of the base metal.

Hard surfacing may be applied to all low-carbon ahoy and stainless steels as well as to Monel and cast iron. It is not intended for aluminum, copper, brass, or bronze. Tool steels can also be surfaced, but they offer difficulties caused by shrinkage and strain cracks. If tool steels are surfaced, they should be in an annealed, not a hardened, condition. If necessary, heat treating and hardening can be done after the surfacing operation.

Surfacing with special alloys is not done as often as brazing or braze welding. But when the technique is used, it must be done perfectly, especially when chromium-cobalt ahoy is applied to carbon or chrome-moly valve parts for high-pressure, high-temperature piping systems. On the whole, the silver brazing, braze welding, and surfacing processes are important among the welding procedures you will use in the welding shop.

POWDERED METAL FLAME PROCESS

Another welding process being used throughout the Navy is the eutalloy process, which is most commonly called the powdered metal flame spray process. This process was developed by the Eutectic Corporation, formerly the Eutectic Welding Alloys Corporation.

The powdered metal flame spray process can, and should, be used alone for certain applications, but it is not necessarily a separate, isolated technique. It combines with, and works to supplement, conventional oxyacetylene and electric arc welding, if overlays and joining metals cannot be done by either of the two other processes. It is very useful where the control of the shape and thickness of the deposit helps reduce machining time. This process is used for the repair of both small and large parts. It is also used for surfacing parts that are subject to abrasion, friction, and corrosion.

The powdered metal flame spray process uses the low heat input principle. Control of the surface temperature enables the powder to surface bond in the shortest time. This eliminates unnecessary saturation of the base metal with needless heat. Such overheating does nothing to promote bonding, and usually results in distortion and stresses in the base metal.

The main elements of the powdered metal flame spray process are a unique gas torch with special features for feeding powders and a group of powdered metal alloys developed especially for this process. These powders are packaged in moistureproof bellows modules to prevent contamination.

ADVANTAGES OF THE POWDERED METAL FLAME SPRAY PROCESS

This process offers many advantages over the conventional oxyacetylene and metal arc welding processes. Absolute control of the thickness, width, and deposition of the deposit can be attained by regulating the amount of ahoy released, the rate of travel, and the path of the torch. Deposits can be placed with pinpoint precision because only the torch tip is used rather than a tip and filler rod, or electrode holder and electrode. This is especially true when it is used in confined and hard-to-get-at spaces.

Powdered metal deposits are surface alloyed to the base metal. They do not dig into the base metal and set up fracture zones. There is also little or no problem with underbead cracking. Deposit dilution, caused by base metal pickup, is held to a minimum because of surface alloying.

The powdered metal flame spray process also has advantages over the metal spray process. Although fusion sometimes occurs when the metal spray process is used, the deposits have, essentially, a mechanical bond. On the other hand, powdered metal deposits actually surface ahoy to the base metal and, as a result, give a higher strength bond. Since the fuel gases propel the alloy to the base metal surface, there is no compressed air equipment that might offer additional complications. Deposits made by the powdered metal flame spray process also have greater density than those made by the metal spray process. When you prepare the base metal, you need to ensure only that the surface is free of all dirt and grease. No time-consuming knurling and roughing of the surface is necessary, as is required with the metal spray.

TORCHES

The torches used in the powdered metal flame spray process are precision instruments, manufactured to very close tolerances. They have very few moving parts and require only routine cleaning and maintenance. These torches are designed specifically for this process. They should not be used for other gas welding applications.

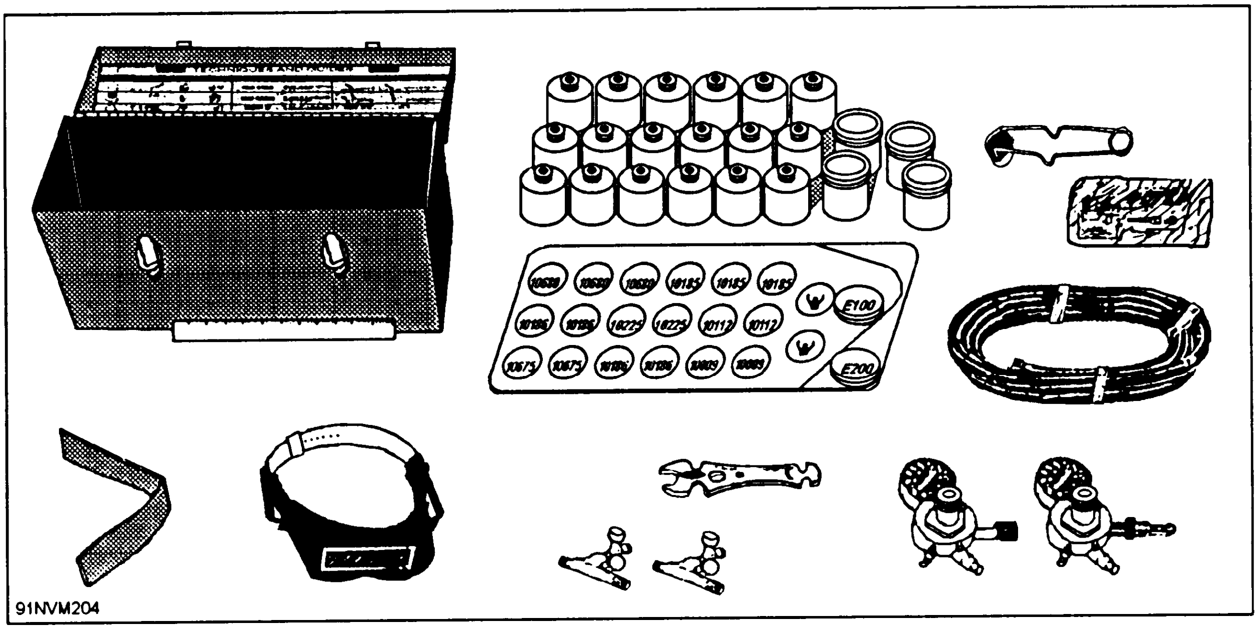


Figure 9-14.—Powdered metal torch and accessories.

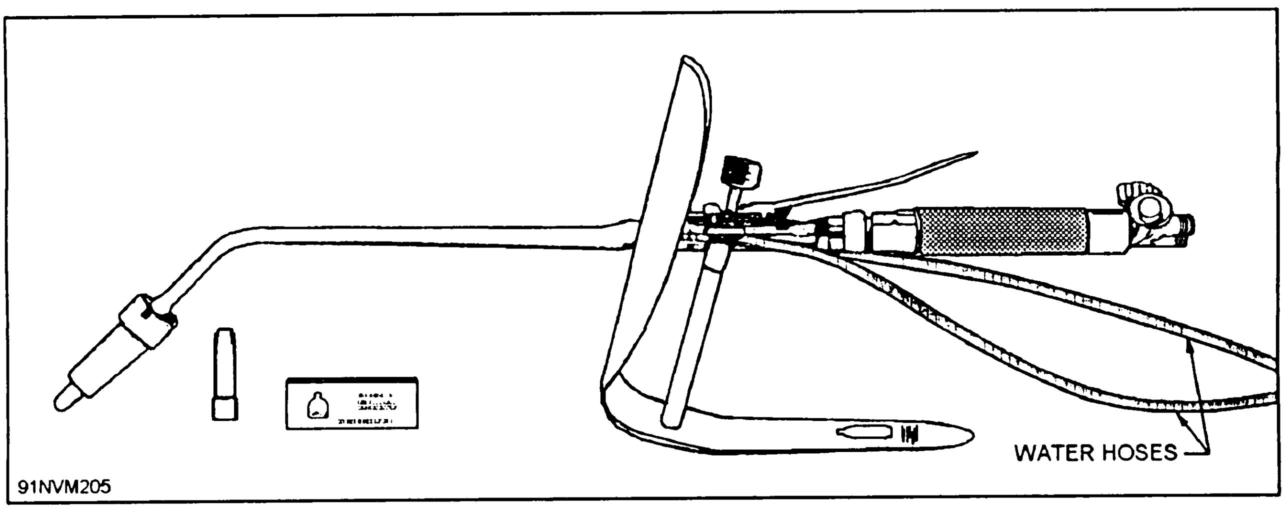


Figure 9-15.—Powdered metal torch with a water-cooled tip.

The torch shown in figure 9-14 is used to overlay and join metals where there is no danger of the torch tip overheating from reflected heat. The nucleus of the torch is a precision forged chamber that contains the vacuum mixer and the control valve. Internal design prevents hazardous detonation and assures positive control over the powder flow. This torch is supplied with three welding tips to help you weld a variety of thicknesses of metals.

The torch shown in figure 9-15 is similar to the torch in figure 9-14, but it has the added feature of a water-cooled tip. This torch was designed especially for overlaying surfaces in areas where there would be danger of overheating the tip. Overheating of the torch

Table 9-6.—Powdered Metal Alloys and Some of Their Uses

Powdered Metal Ahoy		General Uses
BOROTEC 10009	Hardness: RC 55-62	Abrasion-resistant nickel-base ahoy for steel, stainless, nickel-base alloys and cast irons. Corrosion resistant. Good hardness at high temperature. Low coefficient of friction. Nonmachinable.
GRITALLOY 10011	Tungsten carbide	Ahoy for a thin, rough surface that will abrade, grip, or resist. Uniformly distributed tungsten carbide grit firmly anchored in a hard, corrosion-, and heat-resistant nickel-base matric. Nonmachinable.
COBALTEC 10091	Hardness: RC 46-52	Cobalt-base ahoy overlay for steel, stainless, cast iron, and nickel alloys. Corrosion and abrasion resistant. Holds hardness at high heat. Low coefficient of friction.
TUNGTEC 10112	Hardness: RC 57-64	Severe abrasion-resistant ahoy overlay for steel, stainless steel, cast iron, and nickel alloys. Tungsten carbide particles held in a nickel-base matrix. Nonmachinable.
BRONZOTEC 10146	Tensile Strength: 65,000 psi	High-strength, machinable ahoy for joining steels, copper, and high-melting copper alloys. Copper-base ahoy deposits offer good corrosion resistance and electrical conductivity. For fillet forming and poor fit-up.
CUPROTEC 10180	Tensile Strength: 42,000 psi	High-strength, joining ahoy for copper and copper alloys. Copper-base ahoy with good corrosion resistance and excellent electrical conductivity in joints of proper clearance.
BRONZOCHROM 10185	Hardness: RC 36-42	Abrasion-, corrosion-, and heat-resistant nickel-base ahoy overlay for steel, nickel alloys, cast iron, and stainless. Crack-resistant deposits, for both overlaying and joining, are machinable.
STAINTEC 10670	Tensile Strength: 70,000 psi Hardness: RC 80-90	High-strength, corrosion-resistant nickel-base ahoy for joining or cladding steels, stainless, cast irons, and nickel alloys. Excellent machinability.

tip will cause the torch to backfire; the weld deposit will be blown away, and the torch tip may be damaged. Cooling water is circulated around the tip of the torch, preventing reflected heat from affecting it. This torch is often used to surface valve seats where the seat cannot be removed from the valve body.

POWDERED METALS

Powdered metals are available to cover a wide variety of applications. Table 9-6 contains some of the different powders developed by the Eutectic Welding Alloys Corporation. The ahoy chemistry and particle size of each powder assures complete metal-melt during passage across the torch flame. It also makes certain of the optimum bonding and wetting of the deposit with the surface of the workpiece.

These powders are contained in a bellows module that locks directly into the torch. The unique bellows action helps the flow of the powder through the torch. The modules are capped when not in use to prevent contamination from moisture or foreign matter.

SETTING UP THE POWDERED METAL TORCH

When you assemble the powdered metal torch, hand tighten the large threaded nut on the mixing chamber onto the torch body. (Synthetic O-rings are used to ensure sealing of the seats; a wrench is not required for tightening.) The double O-ring seats must be properly seated for the torch to perform satisfactorily. The O-rings or seats should be replaced if they are damaged through wear or misuse. Next, thread on the tip assembly and tighten it wrenchtight. The tip should point downward for normal flat work. Remove the closure from the bellows module, invert the torch, and insert the module into the connective junction at the top of the valve assembly. To do this, you will need to align the lugs on the module with the openings in the junction. Next, seat the module by turning it 90° clockwise; take care that the connective junction on the torch is clean and free of all foreign matter.

CAUTION: Do not turn the module beyond 90°, as improper seating may occur. Connect the torch body to oxyacetylene hoses which have standard 1/4-inch fittings.

The gas pressures used with the powdered metal torch will vary according to the size of tip being used. When using the larger tips, set the oxygen regulator pressure from 25 to 30 psi and the acetylene regulator pressure from 4 to 5 psi. When using the small tip, set the oxygen regulator pressure from 15 to 18 psi and the acetylene regulator pressure from 2 to 3 psi. When all connections have been properly made and the appropriate gas pressures set, the powdered metal torch is ready for operation.

OPERATING PROCEDURES

The powdered metal torch is lit in the same manner as an oxyacetylene torch. Open the acetylene valve and ignite the gas. Then, open the oxygen valve and adjust the flame to suit the work. A neutral flame is generally best. In the event that you experience difficulty in maintaining the flame, adjust both the needle valves and the regulators until the right combination is reached. The smaller tip should be used for small flames. (Cutting back the gases will choke the flame and cause the tip to overheat.)

After adjusting the flame for the alloy being used, preheat the base metal, keeping the torch in constant motion. The method and amount of preheat are determined by the type of work. When color begins to show in the base metal, concentrate the flame at the starting area until a dull red color (for steels) is reached. At this point, slowly depress the lever and observe the passage of powder through the flame.

The torch is best operated with the lever fully depressed, but you should experiment with the lever to achieve proper powder supply. Powder supply depends upon base metal temperature. The powder may be applied and fused simultaneously or it may be sprayed to the work surface and then fused (wetted-out). Whether you spray and fuse simultaneously or fuse after spraying, do not travel forward with the torch, leaving unfused powder behind.

Once sufficient base metal temperature is reached, you should usually make the balance of the deposit with the torch lever in the fully depressed position. However, you may experiment with the position of the lever to ensure continuous operation. If necessary, you can adjust either the needle valves or the regulators to get better operating conditions. When making powdered metal deposits, a slight weaving motion is generally your best technique. The exact area and shape of the surface where the deposit is being made will determine the extent of the weaving motion. To ensure proper fusion at the end of the beads, shut off the powder supply by releasing the lever, and fill the final crater by using previously deposited powder.

The actual distance between the torch tip and the work surface will vary depending upon the type of work and the operator of the torch. Usually, this distance will vary from one-fourth to three-fourths inch. In some joining applications, it may be best to hold the gap more than three-fourths inch, depending upon joint design and base metal thickness.

When you apply powdered metal to flat surfaces, hold the tip vertical to the work, and keep the bellows module as near perpendicular as possible. You can rotate the tip assembly a full 360° to help you apply powder in the vertical, horizontal, and overhead positions, and the module will still be maintained in a near perpendicular position. The thickness of the deposits will depend on any or all of these five factors:

- Size of tip
- Quantity of powder fed into the flame
- Speed of torch over work (slower speeds are used for greater buildups)
- Temperature of base metal
- Rate of (continuous or intermittent) power fed into the flame

POWDERED METAL APPLICATION

When you apply powdered metals, preparation of the base metal is very important. The surface to be overlayed should be free of all rust, oxides, or grease and oil. The surface may be machined, filed, or cleaned with emery cloth to ensure that it is clean.

Figures 9-16 through 9-21 show repairs being made to an output shaft using the powdered metal torch. The assembled output shaft unit is chucked up in a lathe as true as possible. The thinnest possible machine-cut is then made to remove the plating in the scored seal area only (fig. 9-16). All grease, contaminants, and other foreign matter have been removed with a good solvent. A finished preparation lathe-cut of the scored area is then made (fig. 9-17). The unit is then removed from the lathe and the spline section is separated. The part is now ready for the powdered metal overlay deposit.

The hollow shaft is slipped over a suitable mandrel or other similar device for hand turning (fig. 9-18). The best position of the shaft is horizontal, but the deposit can also be made with the shaft in the vertical position.

The oxygen and acetylene pressures used should be those recommended by the manufacturer for the tip you are using. Use a neutral flame with a slight feather so that when the powder feed lever is depressed a true neutral flame is formed. Keep a minimum distance of one-fourth inch between the flame cone and the work.

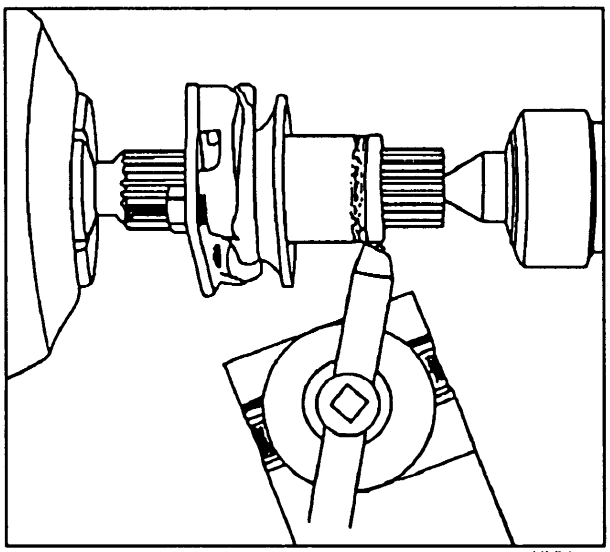


Figure 9-16.—Removing plating from the scored area of an output shaft.

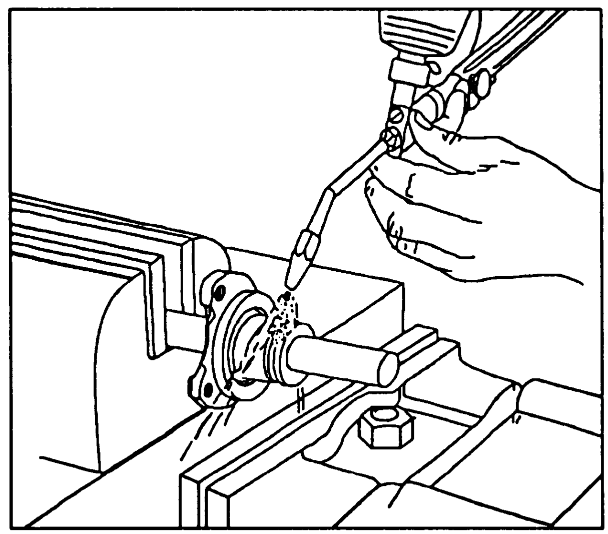


Figure 9-18.—Making a powdered metal overlay deposit.

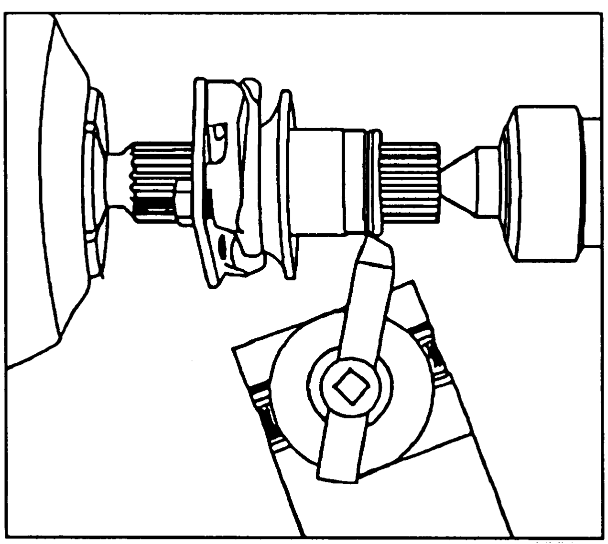


Figure 9-17.—Final lathe-cut being made prior to making an overlay deposit.

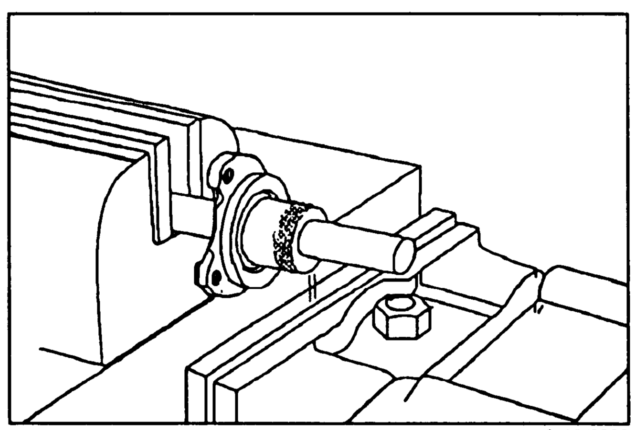


Figure 9-19.—Completed overlay deposit cooling prior to machining.

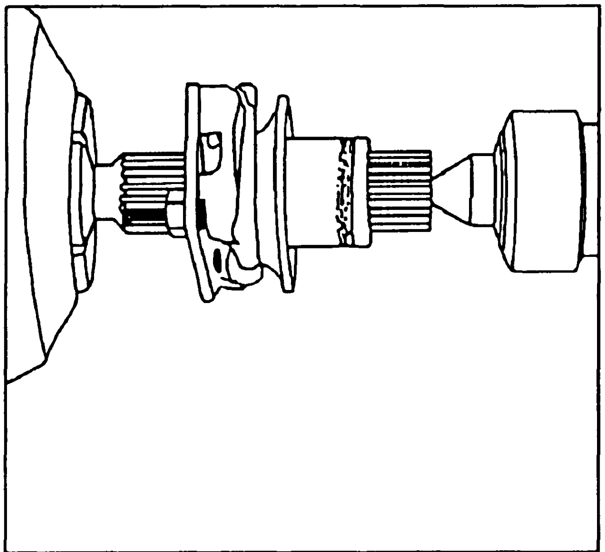


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Figure 9-20.—Machining the overlayed section of an output shaft to its original dimensions.

That way you will not obstruct the flow of the alloy powder or overheat the oxidation of the base metal. When you reach the proper preheat, depress the powder feed lever to apply and fuse the powdered metal simultaneously. Use gloves or pliers when you turn or move the hot part.

Figure 9-19 shows the completed overlay being cooled before it is machined. This deposit was made with Bronzochrom 10185 and has a Rockwell "C" scale hardness of 36. The finished deposit will work harden in service. You can get a harder grind finish and specific corrosion- and wear-resistant characteristics by using Cobaltec 10091 or Borotec 10009. Follow the same procedure regardless of the alloy powder used. After the overlayed part has cooled, reassemble it to the spline and chuck it up in the lathe for machine cutting or grinding (fig. 9-20). Clean all overspray areas by wirebrushing with a stainless steel brush.

Figure 9-21 shows the completed repairs and the output shaft assembled and ready for reuse. Consider factors such as corrosive media, wear patterns, base metal, and desired hardness before you select the powdered metal alloy. The repairs made to this output shaft and similar repairs makes it unnecessary to have to premachine for an undersize shaft, silver braze a collar sleeve on the shaft, and remachine to the required dimensions. The parts will last longer than the original or new replacement parts, saving time, material, and money.

PRECAUTIONS

To improve safety and to ensure proper operation and care of the powdered metal torch, you should take the following precautions:

- Be sure all connections are tight. The connection between the torch body and the mixing chamber has neoprene scats. These should be tightened only by hand.
- Keep the tip orifice clean and unclogged at all times.
- Use tip cleaners as often as necessary for proper flame adjustment and powder passage.

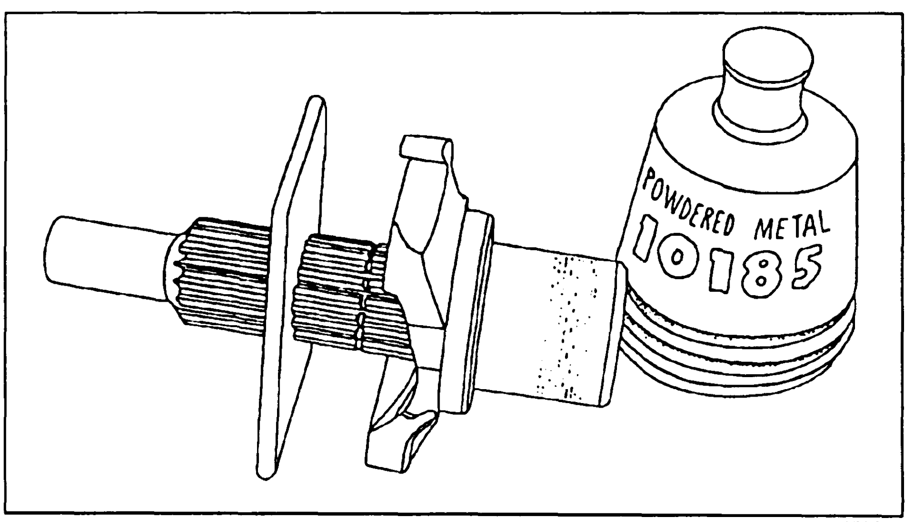

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Figure 9-21.—Repaired output shaft unit reassembled.

- Never rub the tips against a fire brick to remove clogged powder.
- Do not drill the tip orifice to a different size.
- When changing from one type of powder to another, be sure the torch is free of all previously used powders.
- Be sure the powdered metal module is properly seated (90-degree turn only) and the connective junction is free of all foreign matter.
- Observe all standard safety precautions for handling and using oxyacetylene equipment.
- Handle all maintenance and repairs according to the manufacturer's instructions.

SOLDERING

Soldering is used to join iron, nickel, lead, tin, copper, zinc, aluminum, and many alloys. Soldering is a simple, fast, and effective joining process. It is particularly useful for securing electrical connections, joining sheet metal, and sealing seams against leakage. Soldered joints are not as strong as welded joints, and should not be used where any great mechanical strength is required. Soft solders always have melting points below 800°F and below the melting points of the metals to be joined.

SOLDERING EQUIPMENT

Soldering requires only a small amount of equipment. For most soldering jobs, you will need only a source of heat, irons, solder, and a flux. The sources of heat vary according to the method used and the equipment that is available. Welding torches, furnaces, and other heating devices may be used. In most cases, the heating devices are used to heat soldering irons, which are then used to heat the surfaces and thus to melt the solder. However, the heating devices are sometimes used for the direct heating of the surfaces to be joined. In this case also, the solder is melted by the heated surfaces.

If you use a welding torch as a source of heat for soldering, use it carefully. A welding torch gives out much more heat than is actually required for soldering. If you overheat the soldering coppers, you will have to retin them and perhaps reforge them. Excessive heat also may damage or warp the metal that is being joined and may cause deterioration of the solder.

Soldering Gun

The soldering gun (fig. 9-22) operates from any standard 115-volt outlet and is rated in size by the number of watts it consumes. The guns used in the Navy are rated between 100 and 250 watts. All good quality soldering guns operate in a temperature range of 500° to 600°F. The important difference in gun sizes is not the temperature. Instead, it is the capacity of the gun to generate and maintain a satisfactory soldering temperature while giving up heat to the joint soldered. The tip heats only when the trigger is depressed, and then very rapidly. These guns afford easy access to cramped quarters, because of their small tip. Most soldering guns have a small light that is focused on the tip working area.

The tip of a soldering gun should be removed occasionally to clean away the oxide scale that forms between the tip and the metal housing. This increases the heating efficiency of the gun. If the tip does get damaged, replace it.

A Hull Maintenance Technician seldom works on electronic equipment. Still, you should remember never to use a soldering gun on solid-state equipment. The strong electromagnetic field surrounding the tip can cause serious damage to solid-state components.

Soldering Irons

There are two general types of soldering irons in use by the Navy. One is electrically heated and the other is nonelectrically (externally) heated.

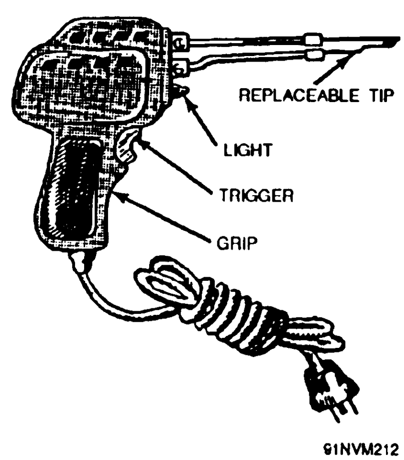


Figure 9-22.—Electric soldering gun.

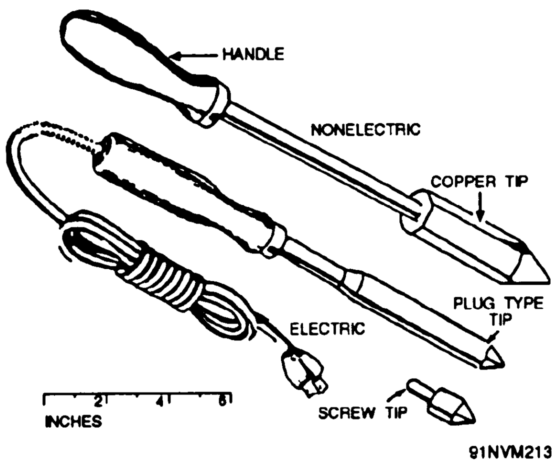


Figure 9-23.—Soldering irons

A nonelectric soldering iron (fig. 9-23) is sized according to its weight. The commonly used sizes are the 1/4-, 1/2-, 3/4-, 1-, 1 1/2-, 2-, and 2 1/2-pound irons. The 3-, 4, and 5-pound sizes are not used in ordinary work Nonelectric irons must be heated over a gas flame.

The electric soldering iron (fig. 9-23) transmits heat to the copper bit after the heat is produced by an electric current that flows through a self-contained coil of resistance wire; this coil is called the heating element. Electric soldering irons are rated according to the number of watts they consume when operated at the voltage stamped on the iron, and the diameter of the copper bit in inches (table 9-7).

There are two types of bits on electric irons. They are plug bits that slip into the heater head and that are held in place by a setscrew, and screw bits that are threaded and that screw into or onto the heater head. Some bits are offset and have a 90-degree angle for soldering joints that are difficult to reach.

Electric iron bits must be securely fastened in the heater unit. The bits must be clean and free of copper oxide. Sometimes the shaft oxidizes and causes the bit to stick in place. Remove the bit occasionally and scrape off the scale. If the shaft is clean, the bit will receive more heat from the heater element, and it will be easier to remove when you need to replace the bit.

Table 9-7.—Selection of Soldering Iron for Work to be Done by Copper Bit Size

Work to be done	Electrically Heated Irons		Externally Heated Irons
	Choice of Bit Dia.	Heat Rating Watts	Size of Bit, lb.
Very light soldering.	1/4 to 7/16	44-52	1/2
Medium soldering of electrical appliances and light manufacturing.	3/8 to 1/2	60-70	1
Fast soldering on radios, electrical appliances, and light medium manufacturing.	3/8 to 9/16	85-100	1-1/2
Medium light soldering on tin ware, plumbing, and wiring.	5/8 to 7/8	130-150	2
High-speed soldering of light tin ware and small metal patterns.	5/8 to 1	170-200	2-1/2
Medium manufacturing such as ventilation ducts and other shipboard repairs.	7/8 to 1-318	225-250	3
Heavy tin ware, metal patterns, galvanized iron and copper.	1-1/8 to 1-3/8	300-350	4
Heavy ventilation ducts, tanks, plumbing, and ship building.	1-3/8 to 1-7/8	350-650	5

Filing and Tinning Copper Bits

New copper bits must be tinned (coated with solder) before they are used. Also, bits must be filed and retinned whenever they have been overheated or have lost their coating of solder. The procedure for filing and tinning a bit is as follows:

1. Heat the bit to a cherry red.

2. Clamp the bit in a vise, as shown in figure 9-24.

3. File the bit with a single-cut bastard file. Rear down on the forward stroke, and release pressure on the return stroke. Do not rock the file. Continue filing the tapered sides of the bit until they are bright and smooth.

CAUTION: Remember that the bit is hot! Do not touch it with your bare hands.

4. Smooth off the point of the bit and smooth off any sharp edges.

5. Reheat the bit so that it will be hot enough to melt the solder.

6. Rub each filed side of the bit back and forth across a cake of sal ammoniac, as shown in figure 9-25.

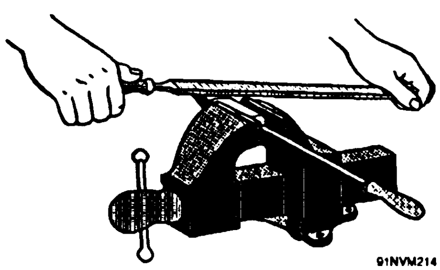


Figure 9-24.—Filing a soldering copper.

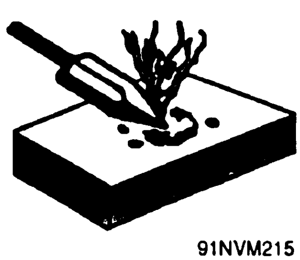


Figure 9-25.—Tinning a copper (solder placed on a cake of sal ammoniac).

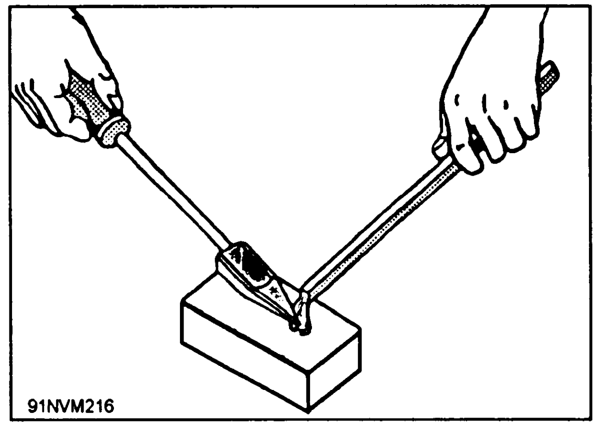


Figure 9-26.—Tinning a copper (solder placed directly on copper).

7. Apply solder to the bit until it is tinned. The solder may be rubbed directly on the bit or it may be placed on the cake of sal ammoniac.

If sal ammoniac is not available, use rosin. Dip the filed bit into a container of rosin, then apply the solder as shown in figure 9-26.

Commercially prepared soldering salts may also be used to tin soldering bits. These salts are available in powder form. Dissolve the powder in water to make a solution, following the directions that accompany the material. Dip the soldering bit into the solution, and then apply the solder.

Cleaning Soldering Bits

Soldering bits should be cleaned just before they are used. Sal ammoniac is usually used for this purpose. Rub the copper on a cake of sal ammoniac or dip it into a container of powdered sal ammoniac. Wipe it clean with a cloth to remove all grams of sal ammoniac. Another way to clean soldering bits is to dip the bit in a solution made by dissolving a small amount of sal ammoniac in water.

SOLDERS

Most soft solders are alloys of tin and lead. Occasionally, antimony, silver, arsenic, or bismuth are added to give special properties to the solders. Solders used for joining aluminum are usually alloys of tin and zinc or of tin and cadmium. As mentioned before, soft solders have melting points below 800°F and below the

Table 9-8.—Tin-lead Melting Points

TIN-LEAD MELTING POINTS	
Composition (percent)	Melting Point (° F)
10/90	573
20/80	533
30/70	496
40/60	460
50/50	418
60/40	374
70/30	376
80/20	396
90/10	421

Table 9-9.—Fluxes Used for Soldering Some Common Metals

FLUX	METAL SOLDERED
Muriatic Acid (raw acid)	Galvanized Iron Dull Brass Dull Copper
Zinc Chloride (cut acid)	Black Iron Copper Brass Iron Zinc Monel Tarnished Tin Plate
Rosin	Tin Plate Lead Bright Copper Terne Plate
Phosphoric Acid	Stainless Steel

melting points of the metals being joined. Table 9-8 shows the melting points of most tin-lead solders.

Tin-lead solders are usually identified by numbers, which indicate the percentage of tin and the percentage of lead. The first number gives the percentage of tin, the second gives the percentage of lead. For example, a 30/70 solder is an alloy of 30 percent tin and 70 percent lead. Solders containing a high percentage of tin are more expensive than those containing a high percentage of lead. In general, the solders that contain a high percentage of tin have lower melting points than those that contain a high percentage of lead. Solders are available in bars, wires, ingots, and powders. Wire solder is available with or without a flux core.

FLUXES

To make a satisfactory joint, you must be sure that the metal to be joined and the solder are free of dirt, grease, oxides, and other foreign matter that would keep the solder from adhering to the metal. Fluxes are used to clean the joint area, to remove the oxide film that is normally present on any metal, and to prevent further oxidation. Fluxes also decrease the surface tension of the solder and thus make the solder a better wetting agent. Table 9-9 shows the fluxes that are generally used with some common metals.

Fluxes are generally classified as corrosive, mildly corrosive, and noncorrosive. Corrosive fluxes have the best cleaning action. However, any trace of corrosive flux that remains on the work will cause corrosion of the metal. Therefore, corrosive fluxes are not used for soldering electrical connections, for other work in which thorough cleaning is not possible, or where corrosion would cause a serious problem.

The most commonly used corrosive fluxes are sal ammoniac (ammonium chloride) and zinc chloride. The fluxes are frequently used in solution or in paste form. The solvent evaporates as the work is heated, leaving a layer of solid flux on the work. At the soldering temperature, this layer of flux melts and partially decomposes, releasing hydrochloric acid. The hydrochloric acid dissolves the oxides from the surface of the work and from the solder.

Zinc chloride (sometimes called cut acid or killed acid) should be made up in small amounts, as required for use. To prepare zinc chloride, pour a small amount of muriatic acid (the commercial form of hydrochloric acid) into a container. Then, add pieces of zinc to the muriatic acid until the liquid no longer boils and bubbles when the zinc is added. The zinc and the acid enter into a chemical reaction that produces zinc chloride and hydrogen gas. When the liquid no longer boils and bubbles, the reaction is complete and the liquid in the container is no longer muriatic acid. Instead, it is a solution of zinc chloride in water.

Strain the zinc chloride solution before using it as a flux. Any solution that is not used immediately should be stored in a tightly sealed glass container.

Observe the following precautions when you prepare zinc chloride:

- Do not inhale the fumes given off by muriatic acid or by the mixture of muriatic acid and zinc.

These fumes are dangerous to you and corrosive to metals.

- Do not prepare zinc chloride in a closed space. Hydrogen gas is released as the zinc reacts chemically with the muriatic acid. HYDROGEN IS VIOLENTLY EXPLOSIVE! Because of this, zinc chloride should always be prepared out in the open or very near openings to the outside. Also, take all necessary steps to prevent flames or sparks from coming in contact with the released hydrogen.

Another type of corrosive flux that you may use is known as soldering salts. Commercially prepared soldering salts are usually furnished in powder form. The powder is dissolved in water to make a solution.

When a corrosive flux has been used for soldering, the flux residue should be removed from the work as completely as possible. Most corrosive fluxes are soluble in water. Wash the work with soap and water and then rinse thoroughly with clear water to remove the residue of corrosive fluxes. Do this cleaning immediately after you finish soldering.

Mildly corrosive fluxes, such as citric acid in water, are sometimes used for soldering. These fluxes have some of the advantages of the more strongly corrosive fluxes, and some of the advantages of the noncorrosive fluxes. The mildly corrosive fluxes clean the surfaces of the work but do not leave a strongly corrosive residue. These fluxes are generally used for soldering parts that can be rinsed with water after they have been soldered or for work in which a mildly corrosive residue can be tolerated.

Noncorrosive fluxes are used for soldering electrical connections and for other work that must be completely protected from any trace of corrosive residue. Rosin is the most commonly used noncorrosive flux. In the solid state, rosin is inactive and noncorrosive. When it is heated, it becomes active enough to reduce the oxides on the hot metal and thus perform the fluxing action. Rosin is available in powder, paste, and liquid forms.

Rosin fluxes frequently leave a brown stain on the soldered metal that is difficult to remove. You can prevent it to some extent by adding a small amount of turpentine to the rosin. You can also add glycerine to the rosin to make the flux more effective.

SOLDERING WITH IRONS

When you are soldering with irons, follow this procedure:

1. Select a soldering bit of the proper size and shape for the work to be done. File and tin the bit if necessary.
2. Heat the bit.
3. Position the work on a suitable support. When a seam is to be soldered, position the work as shown in figure 9-27 so that the seam does not rest on the support. This will ensure that you do not lose heat to the support.
4. Apply the flux with one or two strokes of a brush or a swab.
5. Clean the hot soldering bit with sal ammoniac, as described earlier in this chapter.
6. Touch the solder with the hot bit so that a small amount of solder flows over the tip of the bit, as shown in figure 9-28.
7. Tack the pieces together, if necessary, so that the work will stay in position while you are

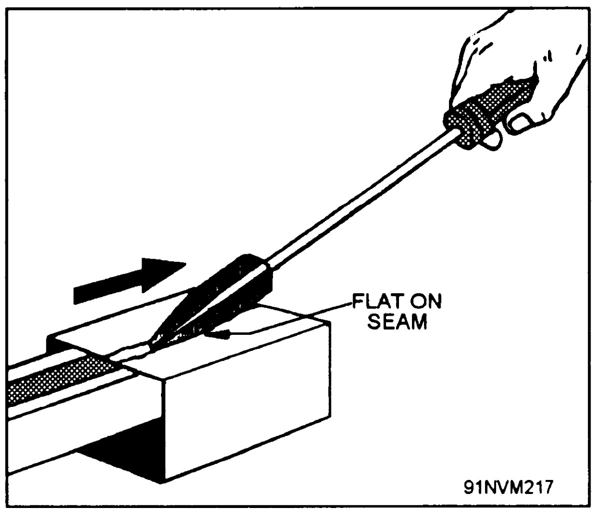


Figure 9-27.—Soldering a seam.

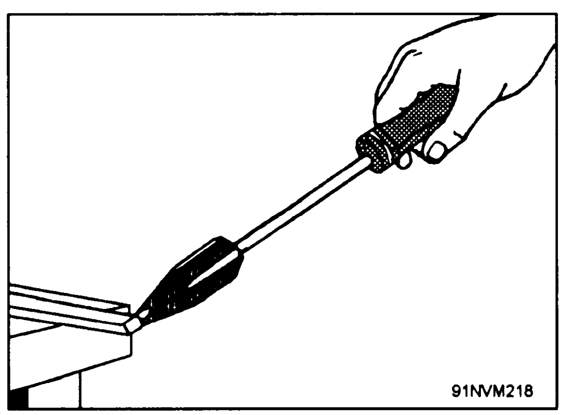


Figure 9-28.—Picking up solder.

soldering it. Heat the spot by holding the bit against the work. The metal to be soldered must absorb enough heat from the bit to melt the solder, or the solder will not adhere.

8. After the pieces have been firmly fastened together, solder the seam. Hold the bit so that one tapered side of the head is flat against the seam, as shown in figure 9-27. When the solder begins to flow freely into the seam, draw the bit along the seam with a slow, steady motion. Add as much solder as necessary, without raising the bit from the work.

9. To make the best soldered seams, solder without lifting the bit from the work and without tracing completed work.

10. Allow the joint to cool and the solder to set before moving the joint.

11. If you used a corrosive flux, clean the joint by rinsing it with water and then brushing or wiping it with a clean, damp cloth.

Riveted seams are often soldered to make them watertight. Figure 9-29 shows the procedure for soldering a riveted seam.

Sometimes solder beads or solder shots are used to solder square, rectangular, or cylindrical bottoms. To make the solder beads, hold solder against a hot bit and allow the beads to drop onto a clean surface, as shown in figure 9-30.

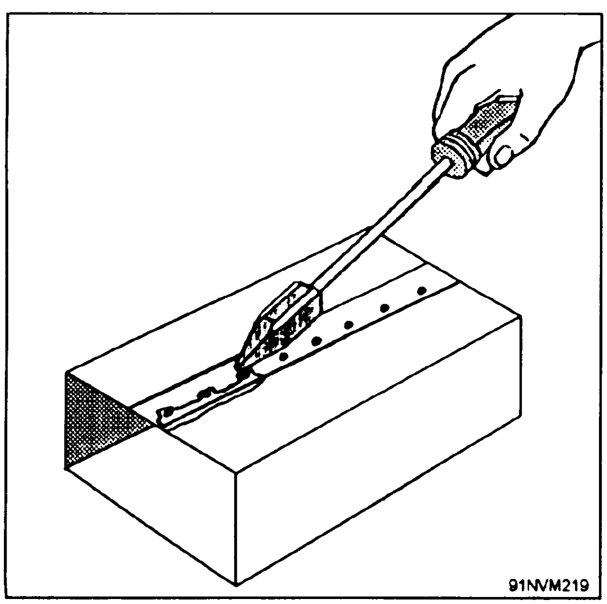


Figure 9-29.—Soldering a riveted seam.

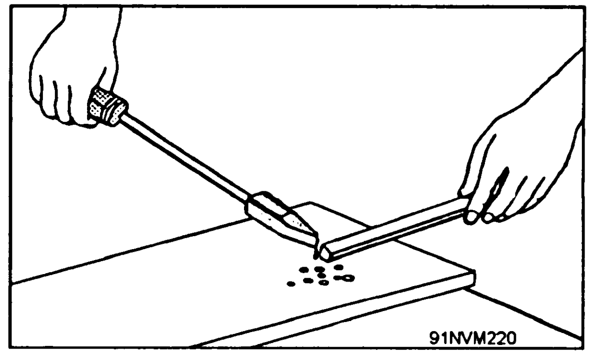


Figure 9-30.—Making solder beads.

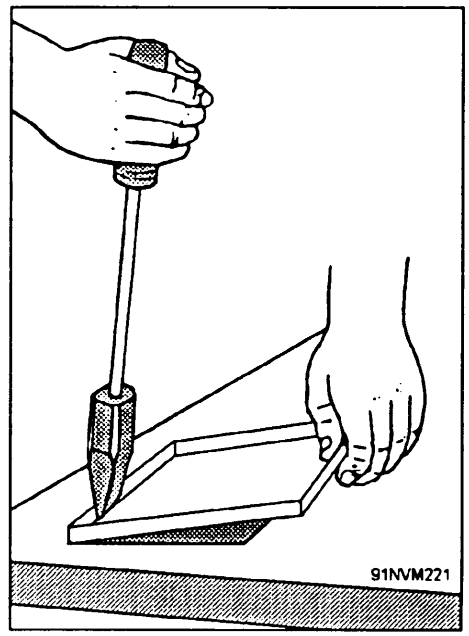


Figure 9-31.—Soldering a bottom seam.

To solder the bottom seam with solder beads, first flux the seam. Then drop one of the cold beads of solder in the bottom of the container. Heat, clean, and dip the soldering bit and place it against the seam, as shown in figure 9-31. Hold the soldering bit in one position until the solder starts to flow freely into the seam. Draw the bit slowly along the seam, turning the work as you go. Add more beads as you need them. Reheat the copper as necessary.

Be very careful not to overheat an electric soldering bit. Never go off and leave an electric soldering iron plugged in. Overheating will probably bum out the electrical element and damage the tinning.

TORCH SOLDERING

Parts to be joined may be too large to be heated by a soldering bit, or shaped in a way that would make rapid soldering difficult. In these cases, the soldering heat may be provided by an oxyacetylene torch. Play the flame of the torch on adjacent surfaces and then apply the solder cold, in bar or wire form, to an appropriate cross section of the area to be soldered. Flames should not impinge directly on the fluxed surfaces. The heated surfaces melt the solder, and the excess solder is removed by wiping the joint with a damp cloth before complete solidification of the solder.

Soldered joints in low-pressure, low-temperature piping systems are sometimes made up by the torch soldering method. If you must solder a joint near a previously soldered joint, wrap the previously soldered joint with a cool wet rag to keep the solder from melting.

SOLDERING BY SWEATING

Sweating is commonly used to make electrical connections. To make a sweated joint, clean and flux each surface to be joined; then tin each surface. Hold the pieces firmly together and heat the joint with a soldering copper or with a torch until the solder melts and begins to run out. Remove the source of heat and hold the parts firmly in position until the solder has completely hardened.

SOLDERING ALUMINUM ALLOYS

Soldering aluminum alloys is more difficult than soldering many other metals because aluminum alloys are always covered with a layer of oxide. The thickness of the layer depends on the type of alloy and the conditions to which it has been exposed.

Many aluminum alloys can be successfully soldered, if you use the proper techniques. Wrought aluminum alloys are normally easier to solder than cast aluminum alloys. Heat-treated aluminum alloys are extremely difficult to solder, just as are aluminum alloys containing more than 1 percent magnesium.

The solders used on aluminum alloys are generally tin-zinc or tin-cadmium alloys. They are usually called aluminum solders. Most of these solders have higher melting points than the tin-lead solders used for ordinary soldering. Both corrosive and noncorrosive fluxes are used for soldering aluminum.

The first step in soldering aluminum is to clean the surfaces completely and remove the layer of oxide. If a thick layer of oxide is present, remove the main part of it mechanically by filing, scraping, sanding, or wire brushing. You can use a corrosive flux to remove a thin layer of oxide. The flux, of course, must be completely removed from the joint after the soldering is finished.

After you clean and flux the surfaces, tin them with aluminum solder. Apply flux to the work surfaces and to the solder. You can tin the surfaces with a soldering iron or with a torch. If you use a torch, do not apply heat directly to the work surfaces, to the solder, or to the flux. Instead, play the torch on a nearby part of the work and let the heat be conducted through the metal to the work area. Do not use any more heat than is necessary to melt the solder and tin the surfaces. Work the aluminum solder well into the surfaces. After the surfaces have been tinned, the parts may be sweated together.

SUMMARY

The knowledge you have gained here will be helpful to you. Silver brazing is a daily job for the Hull Maintenance Technician. Braze welding, surfacing, powdered metal flame spraying, and soldering are not done as often as silver brazing, but they are done on a frequent basis. Review each of the processes and then practice them on scrap material. Knowledge is the first step in being efficient in your job. However, practice is also required.

CHAPTER 10

METAL-ARC WELDING AND CUTTING

LEARNING OBJECTIVES

Upon completion of this chapter, you will be able to do the following:

- *Identify the equipment of arc-welding systems and describe the procedures and techniques used in shielded metal-arc welding.*
- *Identify the different types and classes of bare and covered electrodes and select the proper electrode and heat settings for typical welding.*
- *Describe the safety equipment used in metal-arc welding and the correct procedures for striking, establishing, maintaining, and breaking the arc.*
- *Describe the characteristics of aluminum, their effect on its weldability, and the procedures required to prepare aluminum for welding.*
- *Recognize the basic techniques used in gas tungsten-arc (GTA) welding, and describe the function and maintenance requirements of associated welding equipment.*
- *Specify the methods used in making gas metal-arc (GMA) welds in various positions, and describe some of the equipment used.*
- *State the procedures to be followed in metal and carbon-arc cutting operations.*
- *Explain the procedures to follow in air carbon-arc cutting.*

INTRODUCTION

Electric welding processes include shielded metal-arc welding, shielded gas metal-arc welding, stud welding, and resistance welding. This chapter deals primarily with the first two processes; shielded metal-arc welding and shielded gas metal-arc welding. The other processes are summarized briefly at the end of the chapter along with the arc cutting processes.

To understand the operation of electrical welding equipment, you must have a basic understanding of electricity. In particular, you must be familiar with the terms used to describe electrical equipment and with the units of measurement used with electricity. If you do not understand the terms or units of measurement used in this chapter, study the applicable parts of NEETS, modules 1 and 2.

SHIELDED METAL-ARC WELDING

Most of your metal-arc welding will be done by the shielded metal-arc process. This is a nonpressure process, and the heat necessary for coalescence is generated by an electric arc between a heavily covered electrode and the base metal. The arc develops an intense heat that melts the base metal and forms a molten pool of metal. At the same time, the electrode tip is also melted, and metal from the tip is carried across the arc into the molten pool. The decomposition of the electrode covering shields the molten metal from oxidation. The temperature of the arc between the electrode and the base metal is approximately 6500°F.

WELDING MACHINES

The Navy has a wide variety of shielded metal-arc welding equipment. In general, this equipment is classified as either ac or dc; either stationary or portable; and either single-operator or multiple-operator equipment. In addition, it may be classified according to the source of power and the number of amperes delivered at certain arcvoltages.

The types of equipment available on any particular ship or IMA will depend upon the kind of electrical power available and the size and mission of the ship. Since most ships are equipped with ac power, we will discuss only the welding machines that use an ac power supply or are diesel-driven. Small combatant-type ships, such as destroyers, may be equipped with two motor-driven, single-operator, dc generator sets; whereas, cruisers and aircraft carriers will have a larger number of these types of welders. The motor-driven dc generator set uses an ac power supply to run the motor, and the generator provides dc welding current. Repair ships and tenders may also be equipped with diesel-driven, motor-generator sets as well as the electric motor-generator sets.

All types of arc-welding machines require a source of power that will allow you to strike and maintain a stable arc suitable for welding. The principal sources of power for shipboard welding are as follows:

- A dc generator with variable voltage characteristics may be used in a single-operator welding system. The generator is so designed that it delivers a voltage high enough to start the arc and reduce the voltage as required to maintain the arc during the welding.

- A rectifier may be used to convert ac to dc for welding.

The power from these sources is used in various types of welding equipment to provide the necessary current. The basic types of welding equipment used for shielded metal-arc welding are (1) the variable-voltage, dc generator welding unit, and (2) the rectifier-type welding machine.

Variable-Voltage, DC Generator Welding Unit

This unit consists of a dc generator driven by an ac electric motor or by a gasoline or diesel engine. The voltage produced by the generator usually ranges from 15 to 45 volts across the arc, and the current output varies from 40 to 400 amperes, depending on the type of unit. In most units, the voltage and ampere output of the generator is controlled automatically by the self-regulating or drooping voltage characteristics in the generator. (An increase in current through the generator results in a decrease in voltage.) In addition, the generator output is manually controlled by one or two manual adjustments.

Welding machines of this type may have single or dual controls. In the usual single-control generator, output is adjusted by shifting the position of generator brushes or by moving a portion of the magnetic field structure of the generator. In the usual dual-control generator, output is adjusted by varying the generator shunt field strength and varying the strength and direction of the series field. The machine shown in figure 10-l is a dual-control type fastened on an ordnance handling truck. A ground plate is attached to the work to be welded, and the electrode is clamped in the electrode holder.

When an electric power supply is available, welding generators are usually driven by an electric motor connected to the generator by a flexible coupling. Others are set up with the generator and the motor on the same shaft. When an electric power supply is not available, you must have a

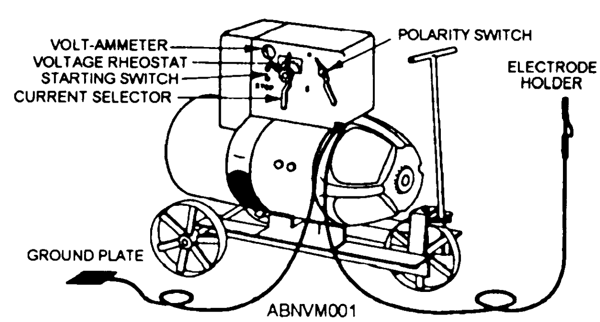


Figure 10-1.—Variable-voltage dc generator welding unit (dual-control type).

gasoline or diesel engine to rotate the generator. In this case, the engine is equipped with a governor to compensate for the varying loads imposed by the welder.

All dc generator welding units deliver either straight or reverse polarity welding current. The correct polarity is essential in metal-arc welding, so let's see what the term *polarity* really means. To understand polarity, you must first have a clear understanding of the welding circuit. The welding circuit consists of (1) a source of welding current, (2) a lead attached at one end to the power source and at the other end to the electrode holder, and (3) a ground lead or work lead attached at one end to the power source and at the other end to the work. In any electrical circuit, current flows only when the circuit is closed. When a dc welding circuit is closed, electrons flow from the negative terminal, through the circuit, to the positive terminal of the generator. The polarity can be changed by use of the polarity switch located on the machine. (See fig. 10-1.) If the machine does not have a polarity switch, simply reverse the hookup of the electrode lead and the ground lead, as shown in figure 10-2.

Polarity is important because it determines the location of the major portion of the welding heat. About two-thirds of the heat of the arc is developed at the positive pole. In straight polarity welding (electrode negative), the greatest amount of heat is concentrated on the work side of the arc. In reverse polarity (electrode positive), the greatest amount of heat is concentrated on the electrode side of the arc.

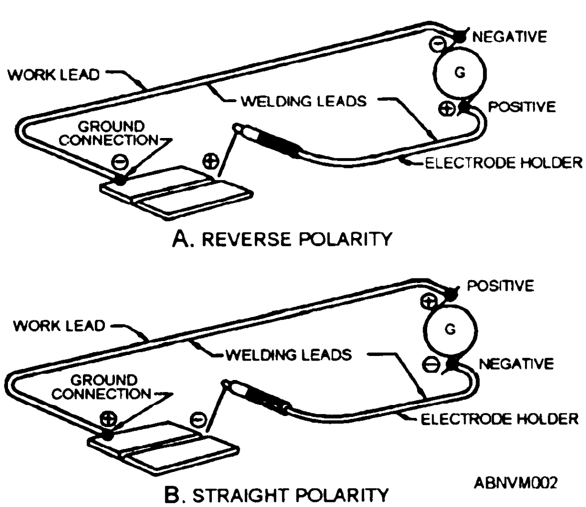


Figure 10-2.—Reverse polarity and straight polarity.

Note that the concept of polarity applies only to dc welding circuits. In ac circuits, the direction of current flow is constantly reversing; therefore, an ac circuit has no polarity affecting the operation of the electrode.

The polarity recommended for a particular type of electrode is specified by the manufacturer. If you use the wrong polarity for a given electrode, the arc will have a hissing sound and will be very difficult to control. When the proper polarity is used, the arc will have a sharp, crackling sound.

In general, reverse polarity gives a slower rate of electrode burn-off, together with deeper and more certain penetration. Reverse polarity also causes greater fluidity and slower solidification of the weld metal.

Joints in sheet metal are usually welded with straight polarity. Reverse polarity is specified for many other types of welds, particularly for welds made in the vertical or overhead position.

Before placing any unit in operation, check the nameplate data and the manufacturer's technical manual for exact instructions on setting up the unit. Check the following points in particular:

1. If the generator is driven by an electric motor, be sure that the power supply agrees with the motor requirements. Never attempt to operate a dc motor on ac power or an ac motor on dc power.

2. Check the motor supply cable and the fuses. Make sure the wiring to the motor is large enough to carry the load, and be sure the line fuses are adequate. If you have any reason to doubt the adequacy of the cable or the fuses, have the equipment checked by an Electrician's Mate.

3. On machines using an ac power supply for the motor, ensure that the rotation of the motor is in the indicated direction. You may reverse the rotation of three-phase ac motors by interchanging any two supply leads.

4. Before applying power to the motor, turn the shaft by hand to make sure it turns freely.

Check to see that the generator and motor brushes are in place and that they fit properly.

5. Before starting the motor, insulate the electrode holder from the ground and attach the work and electrode welding leads to the proper generator terminals. On machines equipped with reversing switches, connect the ground (or work) lead to the terminal marked GROUND and the electrode lead to the terminal marked ELECTRODE. Then set the reversing switch for the desired polarity. On machines not equipped with reversing switches, connect the leads to the terminals in the manner indicated on the nameplate or in the manufacturer's technical manual. To change polarity on these machines, interchange the leads.

6. Adjust the welding current according to the manufacturer's instructions. Single-control machines are designed to give adequate voltage at each current setting. Dual-control machines have separate voltage and current adjustments.

Some values required for a given welding job are beyond the capacity of a single-operator welding generator. When this happens, the required current can be obtained by interconnecting or paralleling two single-operator generators (fig. 10-3). As a rule, the sets that are paralleled should be of identical rating. However, it is usually possible to parallel sets of different ratings if you observe the proper precautions. If sets with different current ratings are paralleled, take special care to ensure that the total load is divided in proportion to machine ratings and that the current rating of neither machine is exceeded. Paralleling instructions are contained in the manufacturer's technical manuals furnished with your equipment.

All dc generator welders should be located in clean, dry, well-ventilated places, away from acid fumes or steam. Given proper care, the unit should give many years of trouble-free service. Like most mechanical devices, welding generators occasionally fail to operate properly. Common problems include the following:

- The machine fails to start.
- The machine runs but fails to generate current.

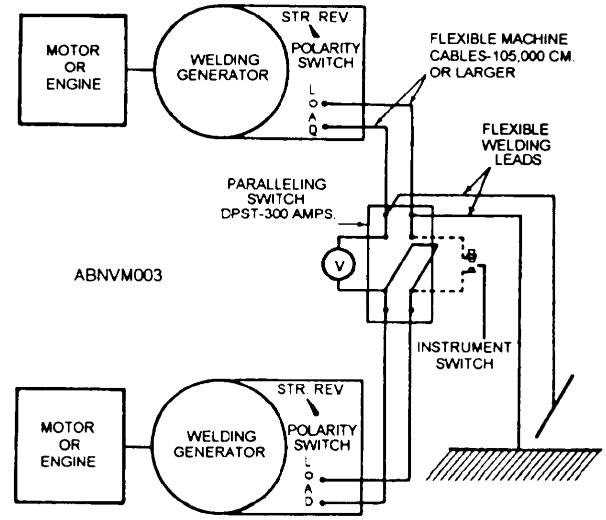


Figure 10-3.—Paralleling connection for a single-operator welding generator.

- The overload device does not hold the motor in the circuit.
- The machine fails to hold its amperage.
- The welding arc spatters excessively.

An Electrician's Mate is usually needed to determine causes and to make repairs. However, there are some things that you can and should do before you call in the Electrician's Mate.

If the machine fails to start, the trouble may be an open or disconnected switch. You can check switches yourself. If the machine runs but will not generate current for the welding circuit, the motor may be rotating in the wrong direction. You can check the direction of rotation with the direction arrow on the outside housing of the equipment. On a three-phase motor, rotation may be changed by interchanging any two of the motor power leads. Have an Electrician's Mate change the motor power leads if the rotation is wrong. If rotation is correct and the machine still will not generate, the trouble is elsewhere. You should call an Electrician's Mate if the motor repeatedly cuts out of the circuit, or if the machine does not hold its amperage after you ensure that all welding cable connections are tight and that the unit is properly adjusted.

Excessive arc spatter may result from several causes, such as arc blow, poor welding technique, incorrect current setting, incorrect electrode, or incorrect polarity. Check the current output settings and make any needed adjustment. If that does not solve the spatter problem, check the polarity. Either reverse the polarity of the generator or try an electrode of the opposite polarity. Excessive spatter should not occur if you use the proper welding technique, the right polarity, and the correct current output adjustment.

Most difficulties with generator welding units can be avoided through routine maintenance and periodic overhaul. Here again the Electrician's Mate has primary responsibility. However, you are responsible for keeping the outside of the equipment clean. Once each month, blow the outside and inside of the unit free of dust with clean, dry, compressed air. At that time, oil the wheel bearings on portable welding units. Operate each of the machines for at least a few minutes once a week. In addition to routine maintenance, inspection, and testing, each machine should be completely dismantled, thoroughly cleaned, and overhauled as necessary every 2 years. Again, this is a job performed by Electrician's Mates. Instructions governing maintenance and overhaul of electrical equipment, including welding machines, are discussed in the *NSTM*, chapter 074.

Rectifier-Type Welding Machine

The rectifier-type welding machine operates from an ac power source but delivers ac high frequency and dc welding current. There are several types of rectifier welders, but they are basically the same. The majority of the units consist of three major parts: (1) a transformer, to change the power supply voltage (220 or 440 volts) to lower voltage suitable for welding; (2) a movable core reactor, to adjust the welding current; and (3) a rectifier cell (copper oxide or selenium plates), to change the ac to dc.

WELDING CABLES

The welding cables conduct the welding current from the power source to the weldment and then back to the source. They must be flexible, durable, well insulated, and large enough to carry the required current. Only cable that is designed for welding should be used for welding. A highly flexible cable must be used between the welding machine and the electrode holder. The ground cable, which connects the work and the machine, need not be so flexible as the cable that connects the machine and the electrode holder.

Two factors determine the size of the welding cable that should be used: the amperage rating of the machine, and the distance between the work and the machine. If either amperage or distance is increased, the cable size must also be increased. A cable that is too small for the amperage used will become overheated. A cable that is too small for the distance between the machine and the work will not carry enough current to the arc without becoming overheated. On the other hand, the larger sizes of cable are more difficult to handle. The best size, therefore, is one large enough to meet the manufacturer/*NSTM* requirements.

As a rule, the cable between the machine and the work should be as short as possible, preferably one continuous length of cable. If it is necessary to 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.

GROUNDING ELECTRICAL WELDING EQUIPMENT

Most shipboard welding is done by the shielded metal-arc welding process, and you will frequently be responsible for seeing that the equipment is properly set up and properly grounded. Incorrect grounding permits the electric current to return to the welding generator through the water, the ship’s hull, and the piping systems. This may result in electrolytic corrosion and cause serious damage to the ship’s underwater body, shafting, and propellers.

CAUTION

Grounding must comply with the criteria of *NSTM*, chapter 074, volume 1.

Location of ground cables should be a major concern when setting up welding machines. When welding on systems, such as piping, pressure vessels, or machinery, the ground-return cable connection should be located as close to the work as possible. This ensures that welding current does not flow through bearings, threaded joints, and other joints where arcing could occur. If arcing is allowed to happen across bearings in motors, lathes, and other similar components, they could be fused together. Also, you should NEVER use electrical equipment as a grounding circuit. They are not designed for such use and the induced magnetic field produced by welding could damage electrical equipment. You should install ground-return cable connections no further than 10 feet from your work.

The requirements for grounding welding equipment vary slightly, depending upon the situation. However, there are a few basic rules to follow. Set up the equipment so that electrode and ground leads are connected only to the vessel on which welding is to be done. Secure the ground lead to an integral part of the vessel, making a good metal-to-metal contact. Be sure that both the electrode and ground leads are thoroughly insulated and that they are NOT in contact with water. Figure 10-4 shows the correct methods for hooking up welding leads in three common situations. Note that in each case, the only ground in the circuit is to the ship where the welding is to be done.

When welding leads and grounds are arranged as shown in figure 10-4, all the welding current flows through the cables. When the welding equipment is NOT correctly grounded, some or all of the welding current returns to the generator by way of the water. The portion of current that will flow through the water will depend upon the particular grounding error that is made.

One very common error is to attach the ground to one ship and then to weld on another ship. This situation often occurs when a welding generator on a repair ship or tender is used to weld on a ship alongside. When this occurs, all of the welding current returns through the water.

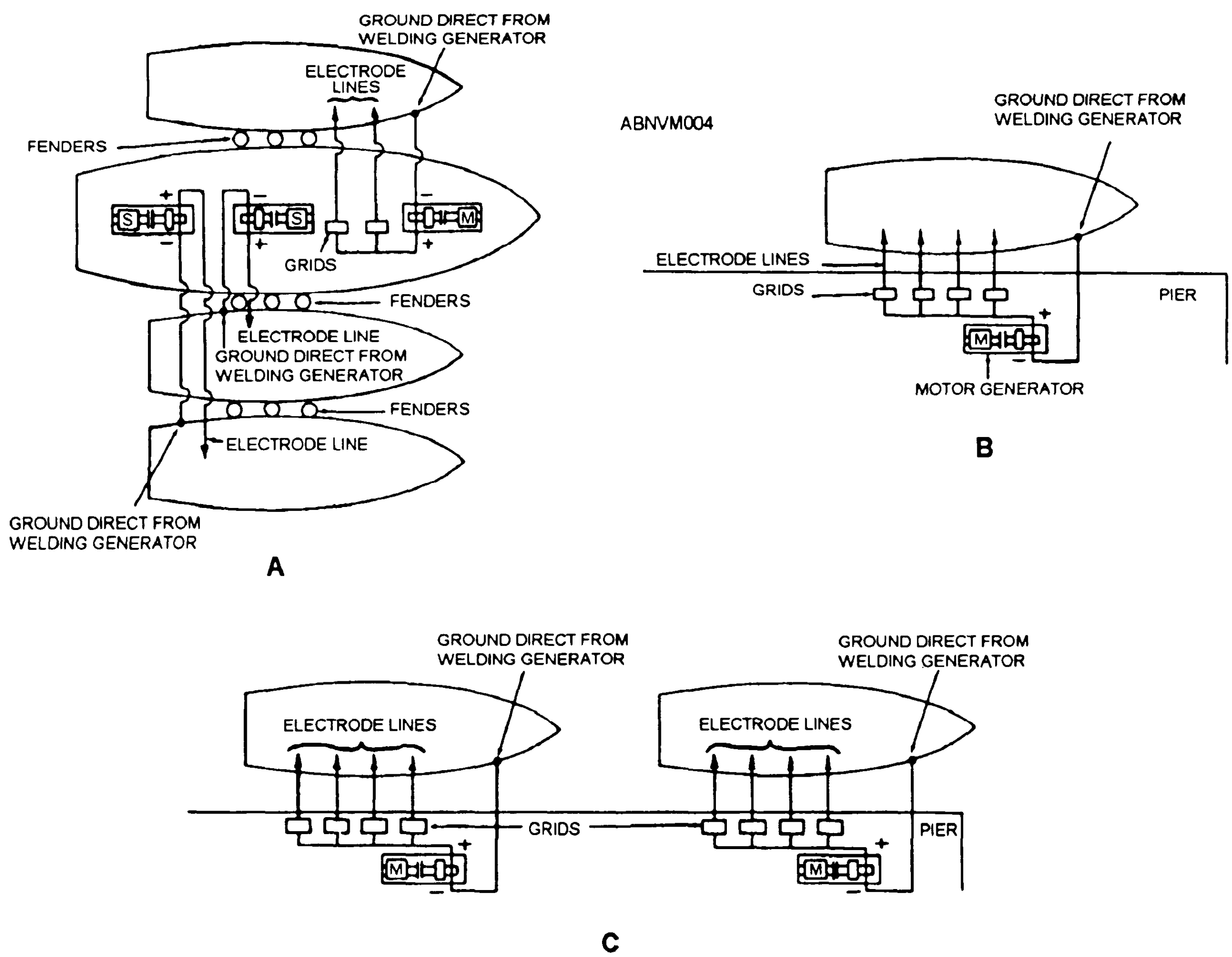


Figure 10-4.—Correct grounding procedure for metal-arc welding. (A) Arrangement for ships afloat. (B) Arrangement for a single ship at a pier. (C) Arrangement for two ships at a pier.

Another incorrect grounding procedure occurs when the ground is connected to both the ship on which the generator is located and the ship on which the welding is being done. In this situation, part of the welding current returns through the water.

When grounding welding equipment, always insulate the negative cable of the generator from the ship on which the generator is located and run both the positive and negative leads to the ship where the welding is being done.

As an additional precaution, make a ship-to-ship connection with a heavy copper cable. The cable should be welded or bolted securely to bare metal on each ship. If properly attached, the copper cable will prevent most of the welding current from returning through the water.

> **CAUTION**
>
> This is an additional precaution, NOT a substitute for correct use of the regular welding grounds.

ELECTRODE HOLDERS

An electrode holder is essentially a clamping device for holding the electrode securely in any position. The welding cable passes through the hollow, insulated handle of the holder. The advantage of an insulated holder is that it may be touched to any part of the work without danger of short circuiting. Electrode holders permit quick and easy change of electrodes.

Electrode holders are made in a number of different sizes and designs (fig. 10-5). Each holder is intended for use within a specified range of electrode diameters and within a maximum welding current amperage. A larger holder isrequired when welding with a machine having a 300-ampere rating than when welding with a 100-ampere unit. A holder will overheat if it is smaller than that specified for use with a particular amperage.

WELDING ELECTRODES

Electrodes are manufactured in a variety of metals and are available for use with any alloy that is classed as weldable by the electric arc-welding

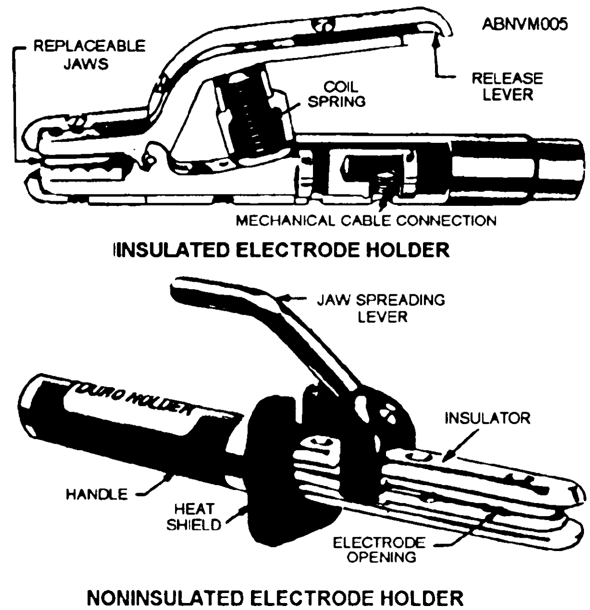


Figure 10-5.—Electrode holders.

process. This includes various types of stainless steel, high-tensile steels, and manganese steels. Electrodes are also available for welding nonferrous metals and alloys such as aluminum, copper, nickel, and certain types of bronze and brass, some of which were originally considered unweldable.

Electrodes are manufactured for use with either straight polarity, reverse polarity, or both. They are also designed to be used in the different welding positions. For example, an E6030 electrode is designed for flat welding and is not suitable for vertical or overhead welding positions. Electrodes are available in a variety of diameters ranging from one-sixteenth to three-eighths inch and in lengths generally shorter than the rods used in gas welding. Standard lengths are 9, 12, 14, and 18 inches. They are also available in rolls for use in machine welding. Some of these coatings may produce a slag, but it is quite thin and does not act in the same manner as the shielded arc type of electrode slag.

Heavy Coated Electrodes

The surface of heavy coated electrodes is comparatively thick. These coatings have been designed to improve the physical properties of the weld. They also control arc stability and, as a result, increase the speed and ease of welding in the vertical and overhead positions. These electrodes are manufactured by the extrusion, wrapping, or heavy dipping processes, or combinations of these methods.

The coatings used on these electrodes consist of two basic materials: mineral coatings and cellulose coatings. However, a combination of the two materials may also be used. The mineral coatings consist of metallic oxides such as clay, feldspar, and titanium. The cellulose coatings consist of materials such as wood pulp, sawdust, and cotton.

These heavy coating materials on the electrodes accomplish the following:

—They produce a reducing or nonoxidizing atmosphere, which acts as a shielding medium around the weld deposit, excluding the oxygen and nitrogen of the air.

—They stabilize the arc and improve the flow of metal from the end of the electrode to the puddle on the work.

—The coating controls fluidity of the puddle and shape of the bead by providing those ingredients (oxides and silicates) that, when melted, form a slag over the molten metal. This slag, being quite slow to solidify, holds the heat and allows the metal to solidify and cool slowly. This slow solidification allows dissolved gases to escape and permits solid impurities to float to the surface. The slow cooling also has an annealing effect on the weld deposits.

—They control the physical properties of the weld deposit and the composition of the deposit by the addition of various metals and alloys to be deposited during the welding process.

Figure 10-6 shows the arc characteristics when using a heavy coated electrode.

Coated electrodes should be kept stored in their original containers or in a dry area, such as holding ovens, to prevent the coating from absorbing moisture from the air, especially when the relative humidity is very high. This is especially true of the iron powder and low hydrogen coatings. An increase in their moisture content will produce unsatisfactory welds. In some cases, it is necessary to dry out the electrode coatings by baking the electrodes in a furnace or oven before using them to weld.

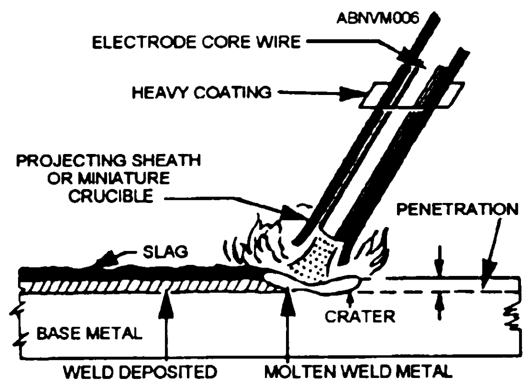


Figure 10-6.—Welding with a heavy coated electrode.

CLASSIFICATION OF ELECTRODES

Electrode classification tables are prepared and published jointly by the American Welding Society (AWS) and the American Society for Testing Materials (ASTM). These tables are available in booklet form from either of these organizations. Electrodes are also classified with MIL SPEC classification of MIL-E-22200 or other classifications according to type and use of the electrode. To illustrate these tables, the E60 series classifications are shown in table 10-1. As shown in the table, the electrode classifications contain the electrode classification number, type of coating, welding positions, and recommended current and polarity.

To understand the significance of classification numbers, consider the E6010 classification shown in table 10-1. The E represents the word electric. The first two numbers, 60, refer to the minimum tensile strength in the nonstress-relieved (as welded) condition, or 60,000 psi. The third number explains the possible welding positions, such as 1 for all welding positions (flat, vertical, overhead, and horizontal); or 2, which designates a greater restriction in choice by being usable only in the horizontal and flat positions. Whereas, a 3 as the third number indicates that these electrodes may be applied in the flat position only. The fourth number in the classification is used to indicate such things as the proper power supply, quality, type of arc, amount of penetration, type of flux, and so on.

Some electrodes are classified in five-digit numbers instead of four. In this case, the first three digits apply to the minimum tensile strength as previously explained for the four-digit classification.

Table 10-1.—Electrode Classifications

AWS-ASTM classification	Type of coating or covering	Capable of producing satisfactory welds in posit ions shown	Type of current
E60 Series.-Minimum Tensile Strength of Deposited Metal in As-Welded Condition 60,000 psi (or higher).			
E6010	High cellulose sodium	F, V, OH, H	For use with dc, reverse polarity (electrode positive) only.
E6011	High cellulose potassium	F, V, OH, H	For use with ac or dc reverse polarity (electrode positive).
E6012	High titania sodium	F, V, OH, H	For use with dc, straight polarity (electrode negative) or ac.
E6013	High titania potassium	F, V, OH, H	For use with ac or dc, straight polarity (electrode negative).
E6014	Iron powder, titania	F, V, OH, H	For use with dc, either polarity or ac.
E6015	Low hydrogen sodium	F, V, OH, H	For use with dc, reverse polarity (electrode positive) only.
E6016	Low hydrogen potassium	F, V, OH, H	For use with ac or dc reverse polarity (electrode positive).
E6018	Iron powder, low hydrogen	F, V, OH, H	For use with ac or dc, reverse polarity.
E6020	High iron oxide	H-Fillets, F	For use with dc, straight polarity (electrode negative), or ac for horizontal fillet welds; and dc, either polarity, or ac, for flat-posit ion welding.
E6024	Iron powder, titania	H-Fillets, F	For use with dc, either polarity, or ac.
E6027	Iron powder, iron oxide	H-Fillets, F	For use with dc, straight polarity (electrode negative), or ac for horizontal fillet welds; and dc, either polarity, or ac, for flat-posit ion welding.
E602a	Iron powder, low hydrogen	H-Fillets, F	For use with ac or dc, reverse polarity.
E6030	High iron oxide	F	For use with dc, either polarity, or ac.

The abbreviations F, H, V, OH, and H-Fillets indicate welding positions as follows:

F = Flat
V = Vertical
H = Horizontal
OH = Overheard
H-Fillets = Horizontal Fillets

} For electrodes 3/16 in. and under, except 5/32 in. and under for classifications EXX14, EXX1S, EXX16 and EXX18.

In addition to the electrode classification numbers, iron and steel electrodes may be identified by a standard color code set up by the National Electrical Manufacturers' Association (NEMA).

This method of electrode identification uses a two-color system consisting of a primary color located on the end of the electrode and a secondary color located near the top end of the electrode. Figure 10-7 shows the location of the primary and secondary on the end grip and center grip electrodes. Part of the electrode color identification table produced by NEMA is reproduced in table 10-2.

PREPARATIONS FOR WELDING

Before beginning to weld, be sure you have all the required equipment for welding and all the equipment needed for your personal protection. Be sure the welding machine is in good condition. Do

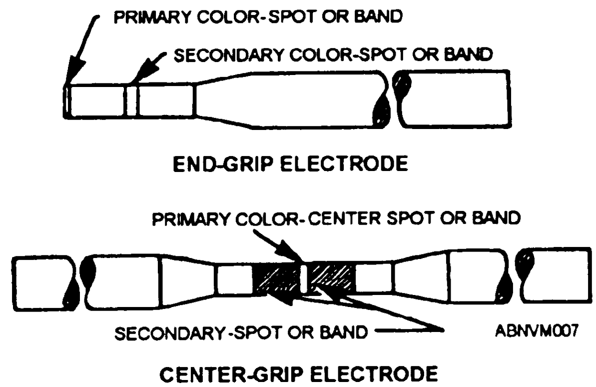


Figure 10-7.—Electrode color markings.

Table 10-2.—Color Markings For Electrode Identification

Spot or secondary color	Primary colors				
	Mild steel and low alloys (See Note I)			Special purpose	Hard surfacing (See Note II)
	All position	Horizontal fillets & flat	Flat position only		
	No color	Blue	White	Orange	Brown
No color	E6010	E6020	E6030	Mild steel for cast iron	0.40-0.70% Carbon
Blue	E6011				0.90-1.10% Carbon
White	E6012			Cast iron for cast iron	Brinell 200 min
Brown	E6013			051.0% Ni	Brinell 300 min
Green	E7010	E7020	E7030	2.0-3.0% Ni	Brinell 400 min
Red	E7011			12.0-14.0% Mn	Brinell 500 min
Yellow	E8010 E8011	E8020	E8030	Ni Mn	Brinell 600 min
Black	E9010 E9011	E9020	E9030	Ni Cr MO	Brinell 700 min
Orange	El0010 E10011	El0020	El0030	Ni Cr Cu	
Violet					
Gray					

Note I: Electrodes listed with prefix letter are AWS designated grades.

Note II: Hardness shall be determined as follows:
(a) Use a base plate of mild steel 5” square × 1” thick.
(b) Use 3/16” electrode.

Table 10-3.—Typical Current Ranges in Amperes for Electrodes

Electrode diameter, inch	E6010 and 6011	E6012	E6013	E6020 and E6030	E6027	E6014 and E7014	E6015, E6016, E7015, and E7016	E6018 and E7018	E6024, E6028, E7024, and E7028
1/16	...	20 to 40	20 to 40	...	...	...	...	...	...
5/64	...	25 to 60	25 to 60	...	...	...	...	...	...
3/32	40 to 80	35 to 85	45 to 90	...	...	80 to 125	65 to 110	70 to 100	100 to 145[a]
1/8	75 to 125	80 to 140	80 to 130	100 to 150	125 to 185	110 to 160	100 to 150	115 to 165	140 to 190
5/32	110 to 170	110 to 190	105 to 180	130 to 190	160 to 240	150 to 210	140 to 200	150 to 220	180 to 250
3/16	140 to 215	140 to 240	150 to 230	175 to 250	210 to 300	200 to 275	180 to 255	200 to 275	230 to 305
7/32	170 to 250	200 to 320	210 to 300	225 to 310	250 to 350	260 to 340	240 to 320	260 to 340	275 to 365
1/4	210 to 320	250 to 400	250 to 350	275 to 375	300 to 420	330 to 415	300 to 390	315 to 400	335 to 430
5/16	275 to 425	300 to 500	320 to 430	340 to 450	...	390 to 500	375 to 475	375 to 470	...

[a]These values do not apply to the E6028 and E7028 classifications.

not attempt to use a welding machine until you are entirely familiar with the procedures for setting it and using it. Procedures for setting welding machines vary according to the type of machine and the manufacturer. Remember, you must set a welding machine for the correct amperage, the correct voltage, and the correct polarity.

There are a number of variable factors affecting the machine setting. These include size and type of electrode, thickness of metal to be welded, type of joint, and skill and technique of the welder. With these variables to be considered, it is apparent that any set of current values could be merely generalization. Current ranges as published by different manufacturers vary considerably for the same classification and size of electrode.

Table 10-3, compiled by the AWS, is included for information, but the current values in this chart are merely suggestive. A setting on the welding machine within these ranges should be used only as a preliminary setting since the table is intended to cover all welding positions.

The proper welding current for a given set of conditions can be determined from the degree of electrode heat. If the electrode is too hot, then the current is too high. Welds of good quality cannot be made if the electrode overheats. In these instances, the current must be reduced or the size of the electrode increased. With proper current and electrode, you should get a smooth, uniform bead.

In addition to the major items of equipment that we have considered so far, you may also need a container for carrying electrodes, a chipping hammer and a wire brush for removing slag from the weld between passes, fillet weld gauges, a hammer, a center punch, a scriber, a flexible rule, and other supplementary equipment. Some welding shops may have a welding positioner, a device fitted with T-slots to help secure the work. It also has a system of hand-operated or power-operated gears used to adjust the weldment so that all welds can be made in the flat position. After all equipment has been assembled and the machine has been properly set, clamp the bare end of the electrode in the electrode holder so that the entire length of the electrode can be used without breaking the arc. Safety note: NEVER INSERT AN ELECTRODE IN A HOLDER WITH YOUR BARE HANDS.

STRIKING THE ARC

The arc may be started either by the striking or brushing method or by the tapping method. In either case, the arc is formed by short-circuiting the welding current between the electrode and the work. The length of an arc is normally equal to the diameter of the electrode's filler metal. The heat of the current at the arc melts both the end of the electrode and the part of the work that it touches.

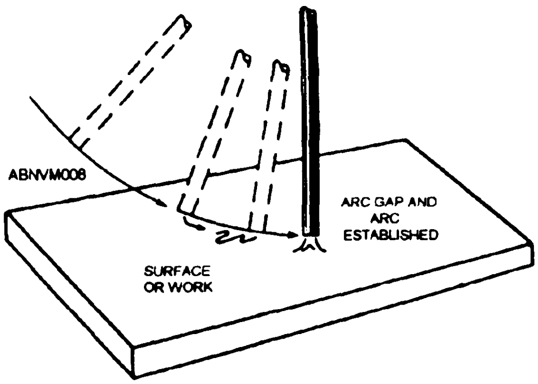


Figure 10-8.—Striking or brushing method of starting the arc.

To start the arc by the striking or brushing method, bring the end of the electrode down to the work in a continuous motion that describes the arc of a circle. In other words, strike your arc in the same manner that you would strike a wooden match. As soon as the electrode touches the base metal, check the downward motion and raise the electrode to make the arc. The distance between the electrode and the base metal should be about equal to the diameter of the electrode. You can tell when the distance is right by the sharp, cracking sound the arc will make. Figure 10-8 shows the striking or brushing method of starting the arc.

To start the arc by the tapping method, hold the electrode at right angles to the work, as shown in figure 10-9. To establish the arc, lower the electrode and tap it or bounce it on the surface of the base metal, and then slowly raise it a short distance. If you raise the electrode too quickly, you will lose the arc. If you raise it too slowly, the electrode will freeze or stick to the base metal. If this happens, you can usually free the electrode by giving it a quick, sidewise twist. If you cannot free the electrode in this way, remove the holder from the electrode or stop the machine. Then chip off the electrode with a chisel, to free it from the base metal.

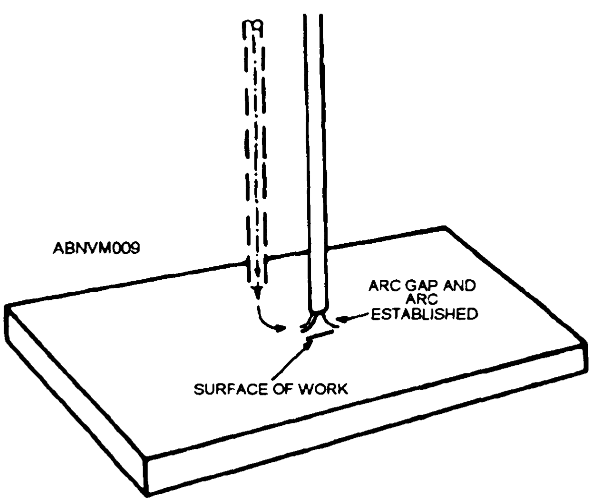


Figure 10-9.—Tapping method of starting the arc.

CAUTION

NEVER REMOVE YOUR HELMET OR THE SHIELD FROM YOUR EYES AS LONG AS THERE IS ANY POSSIBILITY THAT THE ELECTRODE WILL ARC.

After the arc is struck, particles of metal melt off the end of the electrode and are fed into the molten crater of the base metal. The length of the electrode is thus gradually shortened. Unless you keep moving the electrode closer to the base metal, the length of the arc will increase. If the electrode is fed down to the plate and along the surface at a constant rate, a bead of metal will be deposited or welded on to the surface of the base metal. Before advancing the arc, hold it for a short time at the starting point to ensure good fusion and to build up the bead slightly. Good arc welding depends upon good control of the motion of the electrode down to and along the surface of the base metal.

BREAKING THE ARC

There are two correct methods for breaking an arc. The most commonly used method is to shorten the arc, and then quickly move the electrode sidewise out of the crater. The other method is to hold the electrode stationary until the crater is filled, and then slowly withdraw the electrode.

REESTABLISHING THE ARC

When it is necessary to reestablish the arc (as when the length of weld requires the use of more than one electrode), the crater must be cleaned before striking the arc. Strike the tip of the new electrode at the forward (cold) end of the crater.

Move the arc backward over the crater, and then move forward again to continue the weld. This procedure fills the crater, and it prevents porosity and slag.

ARC-WELDING TECHNIQUES

The types of welds, the types of joints, and the welding positions used in shielded metal-arc welding are generally the same as those used in oxyacetylene welding. The techniques, of course, are somewhat different because of the different equipment involved.

In arc welding, the position of the electrode in relation to the joint being welded is a matter of great importance. Increasing the electrode angle in the direction of welding builds up a bead.

When welding a bead in the flat position (fig. 10-10), you should hold the electrode at a 90-degree angle to the base metal. To get a good view of the molten puddle, you may find it convenient to tilt the electrode forward, in the direction of welding, to the angle that is 5° to 15° off from the 90-degree angle. Do not move the electrode from side to side as you run a bead. To keep the arc constant, move it forward just fast enough to deposit the weld metal uniformly, and move it downward as rapidly as necessary.

Use a short arc, about one-eighth inch in length, and weld in a straight line at a constant speed. You cannot judge the length of an arc by looking at it. You will have to depend upon experience and the sharp, cracking sound that is made by a good, short arc. This sound should be heard all during the time the arc is being moved along the joint.

A good weld bead made by the shielded metal-arc welding process should have little or no spatter on the surface of the plate. The arc crater in the bead should be approximately the same size as the electrode diameter or larger when the arc has been broken. The bead should be built up slightly, but should not have any metal overlap at the top surface. There should be good penetration of approximately one-sixteenth inch into the base metal. Figure 10-11 shows properly made weld beads in the flat position.

A butt joint in the flat position should be set up in the same manner as for oxyacetylene welding. Plates less than one-fourth inch in thickness can be welded in one pass. They do not require any edge preparation, but the pieces should be tacked together to keep them in alignment. Use the same electrode motion that you used for forming a bead in the flat position. Plates one-fourth inch or more in thickness require edge preparation by beveling or U-grooving.

The first bead or root pass is deposited to seal the space between the two pieces of the joint at the root. This bead must be thoroughly cleaned of all slag before any other weld layers are made. The second, third, and fourth layers of weld metal are deposited using stringer beads in the order shown in

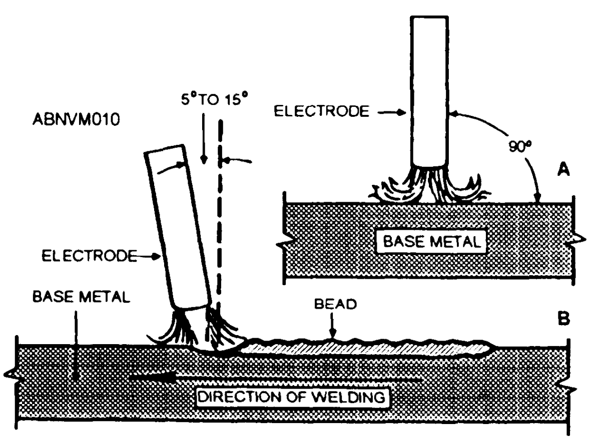


Figure 10-10.—Position of the electrode in making a bead in the flat position.

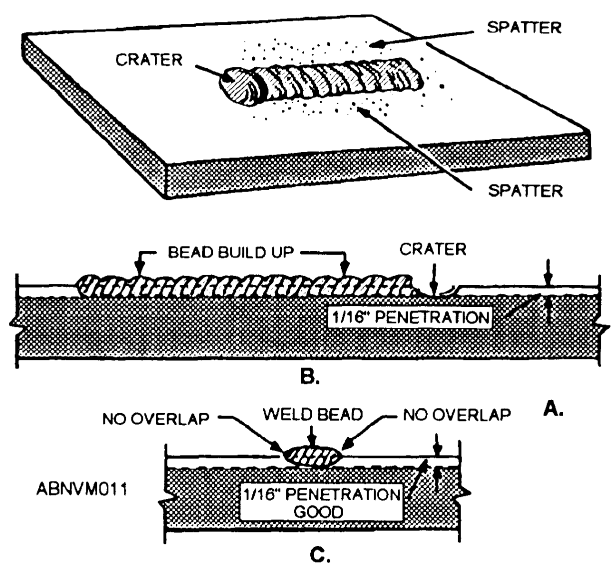


Figure 10-11.—Properly made weld beads (flat position).

view A of figure 10-12. Each bead must be cleaned prior to depositing additional beads.

To ensure adequate penetration at the root, use a backing strap when you make a butt weld in any position. The backing strap should be about 1/2 to 1 1/2 inches wide and from 1/8 to 1/4 inch thick.

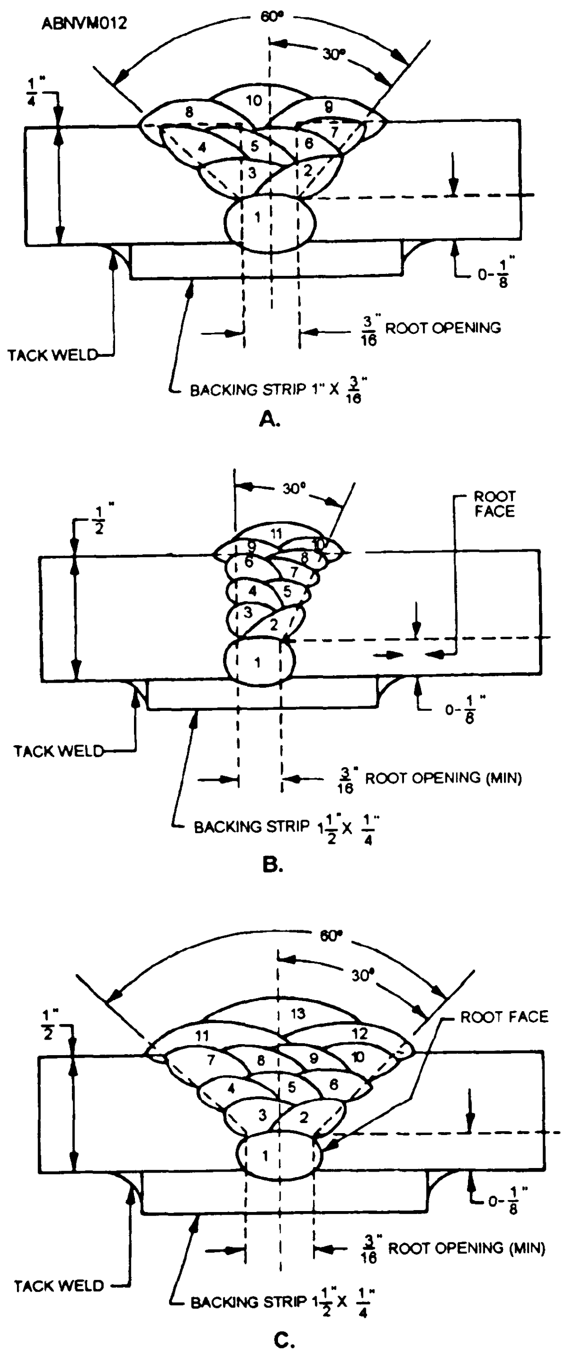


Figure 10-12.—Use of backing strips in welding butt joints.

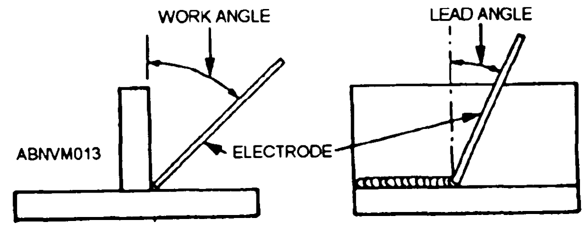


Figure 10-13.—Electrode work angle and lead angle.

The thickness and width of backing straps depend upon the thickness of the plate being welded. You should consult MIL-STD-22 for correct dimensions. Tack weld the strap to the base of the joint and use it as a cushion for the first layer of weld metal deposited in the joint. Then complete the joint by adding additional layers of weld metal in the regular way. If the backing strap must be removed, do so with a cutting torch or grinder. You must be careful when cutting a backing strap with a torch so that you do not gouge the plate or remove excess material. If excess metal is removed, weld repair will be required. The use of backing straps in welding butt joints is shown in figure 10-12.

In making fillet welds, pay particular attention to lead angles and work angles. In figure 10-13, the work angle is the angle between the electrode and the work in a plane at right angles to the long axis of the joint.

The lead angle is the angle between the electrode and the joint in the direction of the welding. Work angles and lead angles for various types of electrodes are usually specified by electrode manufacturers.

Figure 10-14 shows the fillet welding of a T-joint in the flat position. The surfaces of the pieces to be

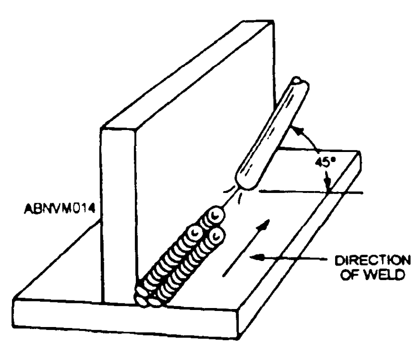


Figure 10-14.—Fillet welding a T-joint (flat position).

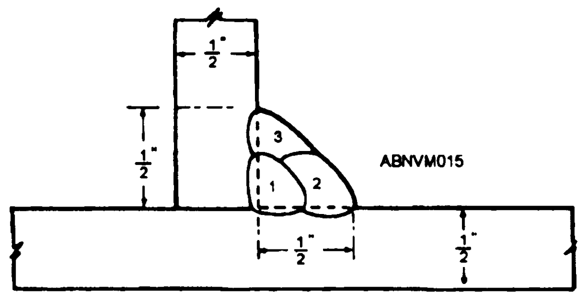


Figure 10-15.—Order of making stringer beads for a T-joint in heavy plate.

joined make a 90-degree angle with each other. First weld a tack at each end to hold the pieces in position. To make the fillet weld, use a short arc and hold the electrode at a work angle of 45° to the plate surfaces. Tilt the electrode to a lead angle of about 15°. Light plate can be welded in one pass, without any weaving motion of the electrode. Heavier plate may take two or more passes, and you must use a semicircular weave motion with the second pass to get good fusion without undercutting. To weld plate that is one-half inch or more in thickness, use stringer beads in the order shown in figure 10-15. Lap joints in the flat position are made in the same way as T-joints, except that the electrode should be held so as to form a 30-degree angle with the vertical.

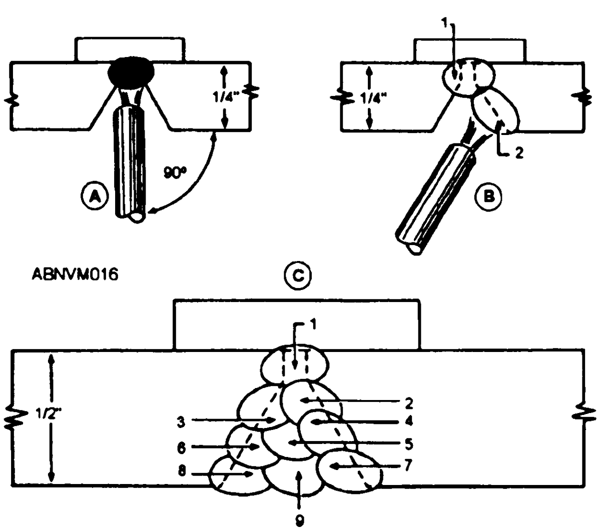


Figure 10-16.—Bead sequence and electrode angle for welding a butt joint in the overhead position.

When welding in the overhead position, keep a short arc of about one-eighth inch, hold the arc at an angle of 90° to the base metal, and avoid weaving. Butt joints in the overhead position are most easily made with backing straps. If backing straps are not permitted, the root can be welded from the top of the joint. Each bead must be cleaned and any rough places should be removed before the next pass is made. Figure 10-16 shows the correct electrode angle and the correct sequence for running beads when making a butt joint in the overhead position.

Figure 10-17 shows the fillet welding of a T-joint in the overhead position. The welding should be done with a short arc, using stringer beads. Hold the electrode about 30° from the vertical plate, and move it uniformly in the direction of welding. Control the arc motion so as to get good root penetration and good fusion with the side walls. If the pool of molten metal gets too large and begins to sag, shorten the arc and speed up the travel rate of the electrode. Then return the electrode to the crater, and continue the welding. On heavy plate, several passes may be required to make either T-joints or lap joints in the overhead position. Make the second, third, and fourth passes of a weld, like the one shown in figure 10-18, with a slight circular movement of the end of the electrode. The lead angle should be about 15°. Each bead must be cleaned of all slag and oxides before the next bead is added.

Welding in the vertical position is difficult because molten metal tends to run down. A short arc and careful control of voltage are particularly important for welding in the vertical position. Current setting (amperage) is lower for welding in the vertical position than it is for welding in the flat position. Also, less amperage is used for welding down than for welding up in the vertical position. When welding up in the vertical position, hold the electrode at an angle of 90° to the vertical.

ARC BLOW

Welding with dc involves a special problem known as arc blow (also known as magnetic arc blow). It is important that you understand what arc blow is and that you know how to recognize it and what to do about it.

Arc blow is caused by distortion in the electromagnetic field that surrounds a

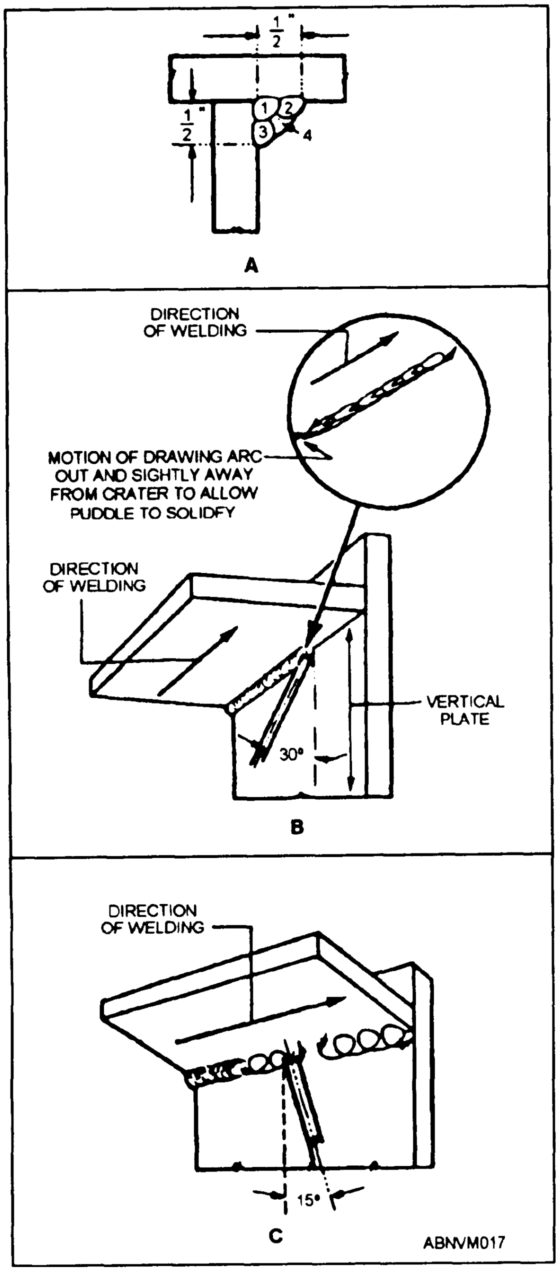


Figure 10-17.—Fillet welding of a T-joint in the overhead position.

current-carrying conductor. The distortion occurs as you approach any sudden turn in the welding; for example, when you are welding on an I-beam or a U-beam. When the field is distorted, a greater pull exists on one side than on the other. When that happens, the arc tends to blow out the side of the electrode, consuming the covering faster on that side than on the other side. The magnetic force takes control of the arc and causes it to pull this way and that in a wild and uncontrollable fashion. The situation must be corrected at the first sign of trouble or the heat will become intense and the arc will fluctuate wildly. In a very short time, the arc will be lost, usually with an explosive burst that carries away the molten metal of the weld. Arc blow causes incomplete fusion and excessive spatter.

Arc blow can often be overcome. Following is a list of some of the methods used most often by experienced welders:

- Changing the direction of the current flow (Remember some electrodes can only be welded with straight or reverse polarity)
- Changing ground connections
- Modifying the magnetic field with metal bars across the weld groove
- Working toward the ground from any bend in the line of weld, or by tilting the electrode

You will have to learn by experience which of these measures works best under various conditions.

DISTORTION

Distortion is a temporary or permanent change in the shape or dimensions of a welded part as a result of welding.

Expansion and contraction are the principal causes of distortion in welding operations. During welding, the metal is differentially heated and subjected to drastic temperature gradients. It becomes weaker and more easily deformed as it is heated, and the tendency to distort is aggravated by the degree of restraint at the weld joint.

During all welding operations, the weld metal and heated base metal undergo considerable contraction when they are cooled to room temperature. The surrounding cold metal offers resistance to the shrinking of the heated area. The weakness of the metal at elevated temperatures and the small mass of heated metal compared to the structure as a whole means that most of the adjustment must be made by the weld metal.

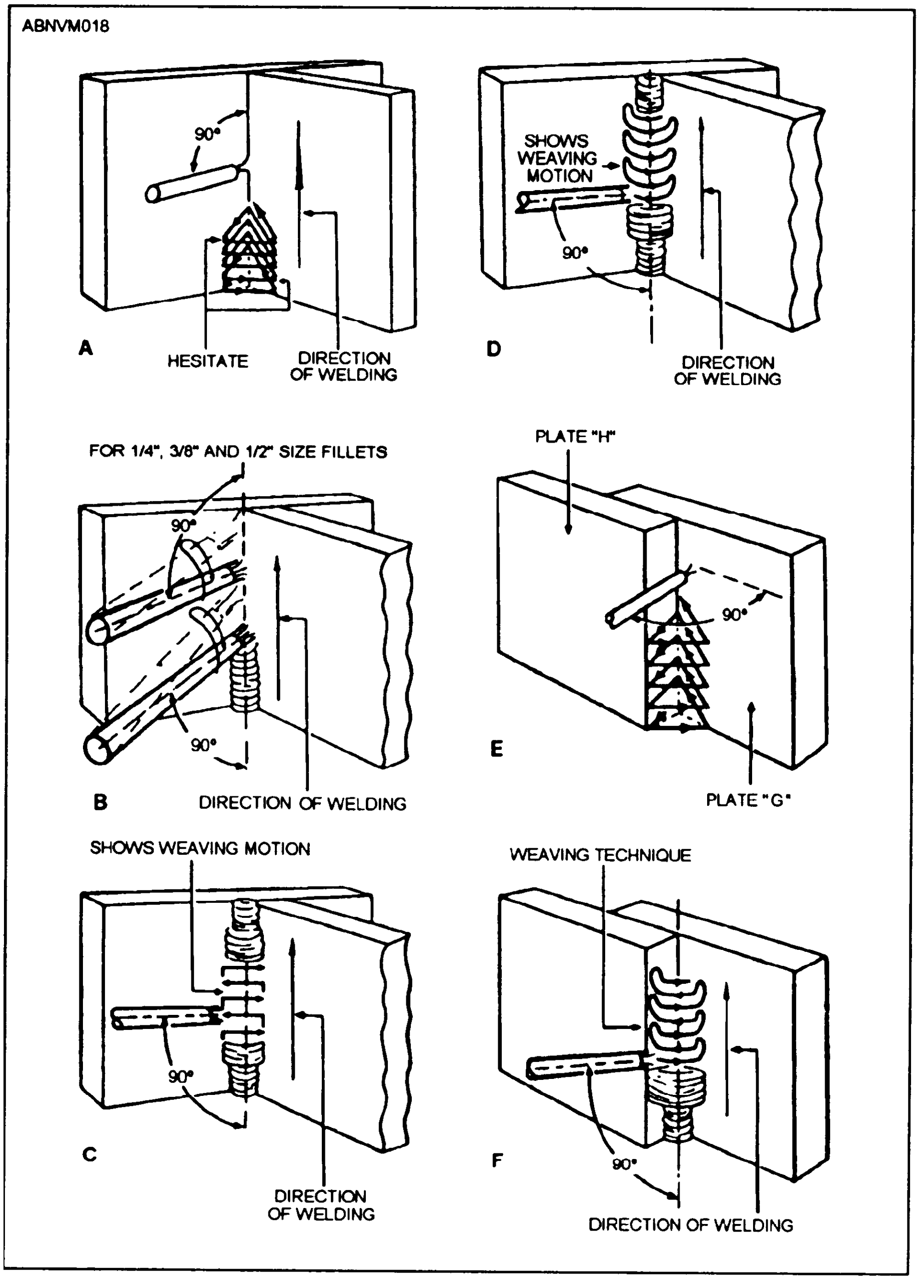


Figure 10-18.—Welding in the vertical position.

When the part being welded is free to move, distortion will be caused by contractual stresses. Distortion may be prevented by the restraint of jigs, structural rigidity, or the support of previous welding. Under such conditions, you may expect residual stresses up to the yield point of the metal. If the required plastic flow exceeds the metal's capacity to flow, cracking may result. When a bar of steel is heated thoroughly and uniformly, it will expand in all directions. If it is allowed to cool evenly, and without restraint of any kind, it will contract to its original shape and size. On the other hand, if the bar is restrained in any way during heating, it will not be able to expand in the direction of the restraint. For example, a metal bar placed in a vise so that the jaws close against the two ends, as shown in figure 10-19, cannot expand towards the two ends. Any expansion would have to be lateral. When it contracts upon cooling, however, there is no restraint and it will contract in all directions. It does not return to its original shape and size but becomes shorter and thicker, as shown in figure 10-19. Thus, a return to an original shape and size is possible only when a part is free to expand and contract freely and without restraint.

If a bar is heated over a small area, the expansion will be local and uneven. The mass of surrounding metal will not expand, and tends to prevent expansion of the heated metal in all directions except upon the surface. Consequently, when the yield point has been reached, the metal becomes permanently deformed. When the bar cools, it does not return to its original form, and distortion results.

The factors governing distortion are the resistance of the structure to the free contraction of the weld metal; the temperature gradient, which is determined by the rate at which heat is applied and the rate at which heat is conducted away from its point of application; the coefficient of expansion of the metal, which determines the total amount of plastic movement; and the yield strengths of the base and weld metal, which limit the residual forces that can exist within the structure. Generally speaking, there are six basic means of controlling distortion:

Stretching the metal, preferably while still hot, by a series of hammer blows (peening)

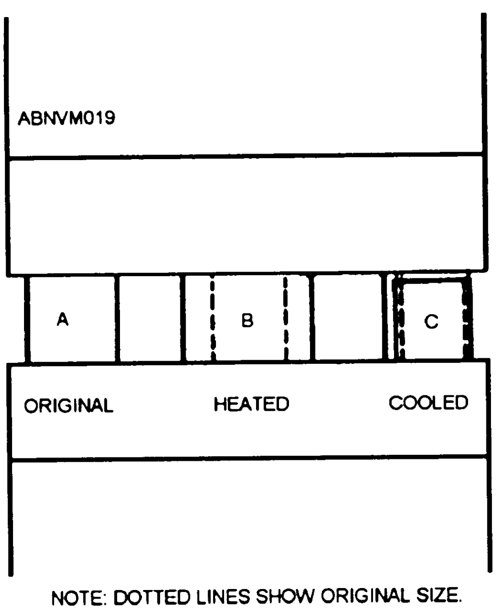


Figure 10-19.—Dimensional changes due to restrained expansion and unrestrained contraction.

- Distributing and balancing the forces and stresses produced by weld shrinkage by special welding techniques and sequences
- Forcibly restraining the parts being joined from movement during welding by suitable jigs and fixtures
- Selecting the joint and the geometry of the joint selected
- Selecting the welding process
- Selecting the weld joint bead procedure

Preheating involves raising the temperature of the base metal or a section of the base metal above the ambient temperature before welding. Preheat temperatures may vary from as low as 60°F to as high as 600°F for highly hardenable steels and 1200°F for ductile cast iron.

Preheating is a very effective means of reducing weld metal and base metal cracking. Preheating may improve weldability generally, but has two major beneficial effects: it retards the cooling rates in the weld metal and heat-affected base metal, and it reduces the magnitude of shrinkage stresses. However, when you are welding quenched or age-hardened materials, the effects of preheating can be detrimental unless they are controlled within allowable limits.

In many operations, the temperature to which the base metal is heated must be carefully controlled. The best means of control is to heat the part in a furnace held at the desired temperature, by electric induction coils, or by electric resistance heating blankets. In these methods, temperature indicators are attached to the part being preheated. Figure 10-20 shows electric induction coils set up for preheating pipe prior to welding.

When using the oxyacetylene torch for preheating, it is important to prevent localized overheating and deposits of incomplete combustion of gases on the surfaces of the joints of areas to be welded. Temperature-indicating crayons that melt at known temperatures are used for measuring the temperature of the preheated part.

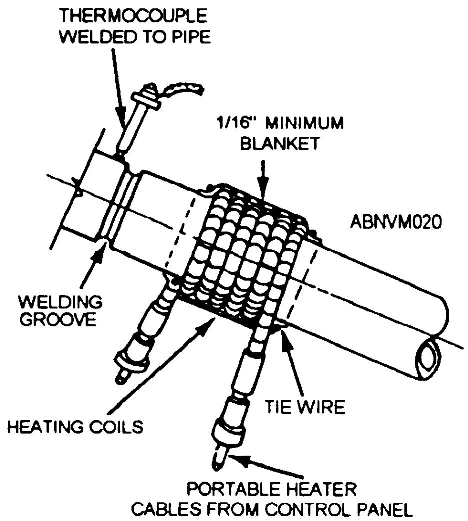


Figure 10-20.—Electric induction coils set up for preheating pipe.

Cooling rates are usually faster for a weld made without preheat. The higher the preheating temperature, the slower the cooling rates after the weld is completed. The temperature gradient is reduced and, in the case of iron, the thermal conductivity is decreased. At 1100°F, the thermal conductivity of iron is 50 percent less than at room temperature. At 1472°F, the thermal conductivity of many carbon steels is approximately 50 percent less than at room temperature. Low thermal conductivity ensures slow cooling rates because the heat is transferred from the welding zone at a lower rate.

Distortion, weld metal and base metal cracking, and porosity may be eliminated or reduced by an appropriate modification of the welding technique and sequence. Certain sequences, such as backstep, cascade, block, and wandering, minimize cracking near the bond and are used to advantage in poor-fit work. Whenever possible, welding should proceed toward the unrestrained end of a joint, because free movement of the parts will reduce the danger of weld metal cracking.

When postheat is applied immediately to a completed carbon steel or low-alloy steel weld, it will retard cooling, minimize the formation of underbead cracks, and slightly temper the structure. Figure 10-21 shows postheat being applied to a welded pipe, using electric induction coils. Although postheat can prevent cracks, it cannot remove cracks or porosity. Very highly hardenable

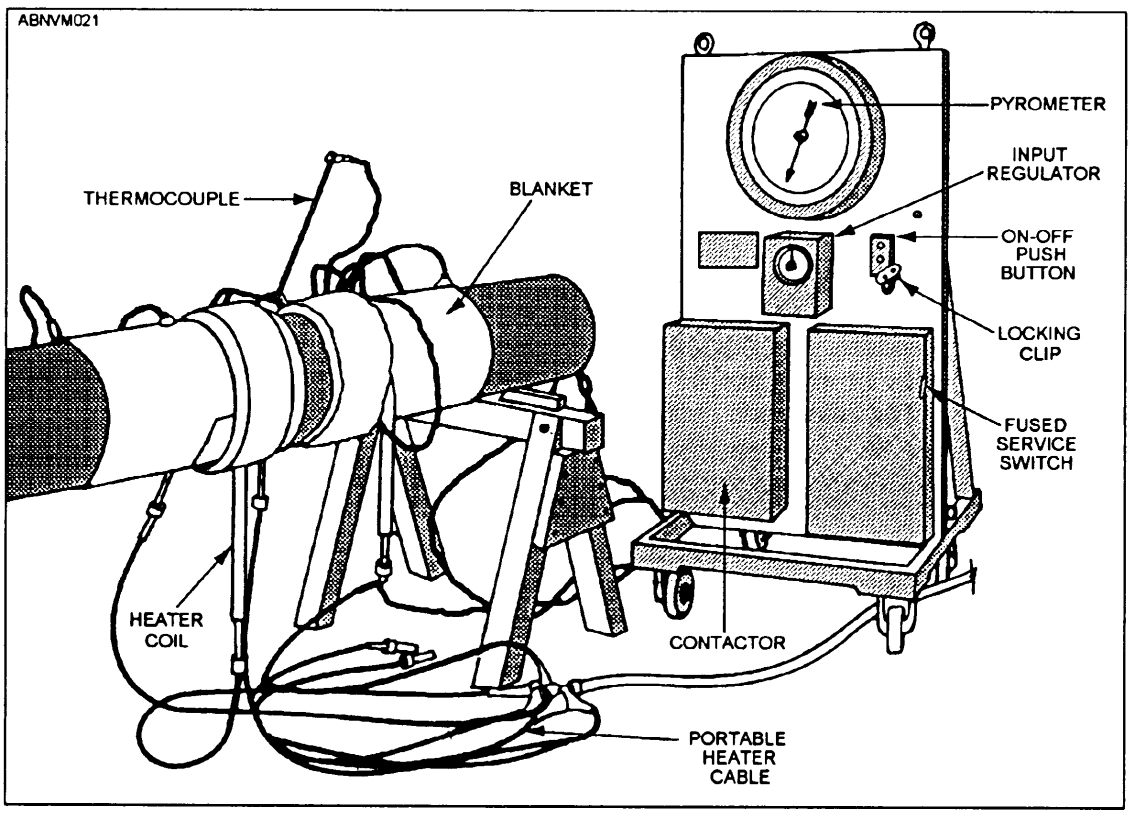


Figure 10-21.—Postheating welded pipe with electric induction coil equipment.

steels should be transferred directly to a stress-relief furnace without loss of preheat.

The peening of weld metal helps minimize cracking of weld metal and reduces distortion because it distributes the residual stresses created by welding.

Various specifications and codes require that the first and last layer of weld metal not be peened. Peening of the first layer could pierce the weld or displace the members being welded. Peening of the last layer can cause brittle fractures due to the cold working of the weld metal. Use peening on each weld bead or layer except the first and last. The effectiveness decreases as the thickness of the bead or layer increases. Peening becomes of doubtful value for deposits on one-fourth inch or thicker, except in special instances where the rigidity or weight of the weldments permits the use of heavy blows.

Peening equipment should be selected with care. The hammer, pneumatic tools, and so on, should be heavy enough in striking force to be effective without producing excessive work hardening, but not so heavy that bending moments are involved or cracks produced in the weld.

The general causes of weld metal cracking, base metal cracking, porosity, and inclusions are outlined in table 10-4.

GAS SHIELDED-ARC WELDING

This process uses a shielding gas to protect the electrode, arc, molten weld metal, and weld area from exposure to the atmosphere. The shielding gas is noncombustible and may or may not be inert (chemically inactive). The electrode may be nonconsumable, or it may be a consumable wire electrode that is fed automatically into the weld.

There are two different types of gas shielded-arc welding processes. One is the gas tungsten-arc (GTA) process, which uses a nonconsumable tungsten electrode. The other is the gas metal-arc (GMA) process, which uses a consumable wire electrode that is fed automatically into the weld.

These two processes were formerly known as tungsten inert-gas (TIG) welding and metal inert-gas (MIG) welding. The names were changed by the AWS because carbon dioxide is used as a shielding gas when welding mild steel by the GMA process, and carbon dioxide is not an inert gas.

A big increase has occurred in the use of the GTA and GMA processes for all types of structural and piping systems. This is especially true in aluminum fabrication. For that reason, we have given special attention to these two processes. Our discussion includes basic information on the characteristics of aluminum that affect its weldability, as well as on the effect of heat on the aluminum part being welded. The importance of surface preparation is explained. Detailed information is given on both the GTA and GMA processes. Practice exercises are provided to help you develop techniques in various operations used in each process.

BASIC THEORY OF ALUMINUM WELDING

Selection of the arc-welding method to use on aluminum depends largely upon the individual application. You need to consider thickness; design of the parts, components, or assemblies; and available equipment. The best welding methods for aluminum are the GTA and the GMA processes. Both use noncombustible gas (argon, helium, or a mixture of gases) to keep air away from the arc and molten weld pool and to eliminate the need for a welding flux. The gas shield is transparent; the welder can see the fusion zone and make neater and sounder welds. Aluminum can be welded in any position by either method.

The GTA process is best for welding aluminum sections less than one-eighth inch in thickness. This method can also be used on heavier sections, but the GMA process is usually chosen for its higher welding speed and economy.

General Considerations

The factors that affect the welding of aluminum and the properties of aluminum weldments include melting point, thermal conductivity, thermal expansion and contraction, oxidation, gas porosity, and the effects of welding.

Pure aluminum melts at 1210°F, and weldable aluminum alloys start to melt at 1050°F. This compares with steel, which melts at about 2800°F and copper at about 1980°F. Unlike these metals,

Table 10-4.—Causes and Cures of Common Welding Problems

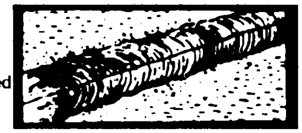
ABNVM022

porous welds

WHY
1. Short arc with extension of low hydrogen and stainless
2. Insufficient puddling time
3. Impaired bas 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
5. 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 possibe
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

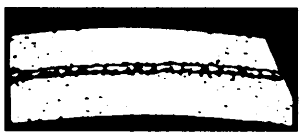
WHAT TO DO
1. Use enough current to obtain desired penetration- weld slowly
2. Select electrode according to welding groove size
3. Leave proper gap at bottom of weld

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

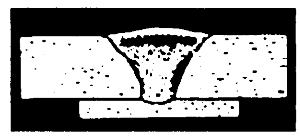
warping



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 beforewelding
2. Weld more rapidily
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 curerent 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

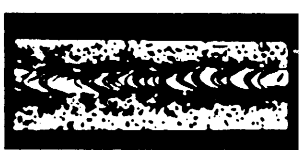
WHAT TO DO
1. Use a uniform weave in butt welding
2. Avoid using an overly large electrode
3. Avoid excessive weaving
4. Use moderate current, weld slowly
5. Hold electrode at safe distance from vertical plane in making horizontal fillet weld

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 short arc length
5. Locate the ground properly on the work
6. Use A-C welding

there is no color change in aluminum during heating. However, it is possible to know when the aluminum is near its melting point and at welding temperature by watching the weld pool. The GTA weld pool, for example, develops a glossy appearance, and a liquid pool or spot forms under the arc when the metal becomes molten.

Aluminum conducts heat three times faster than iron, so you need a higher heat input to weld the aluminum. On the other hand, copper has a higher thermal conductivity than aluminum; therefore, less heat is required to weld aluminum than copper. It is usually helpful to preheat heavy sections of aluminum to reduce heat loss and, when using the

GTA process for joining such sections, to get better welding results.

Aluminum welds decrease about 6 percent in volume when solidifying from the molten state. This contraction may cause excessive weld joint distortion unless correct allowances are made before welding.

Thermal expansion of aluminum is approximately twice that of steel and one-third greater than copper. The surrounding surface expands due to the heat of welding. Thermal expansion of the adjacent aluminum may reduce the root opening on butt joints during the welding. Then, when the metal cools it contracts. This contraction, coupled with shrinkage of filler metal on cooling, may put the weld in tension and cause cracking. Excessive restraint of the component sections during cooling of the weld may also result in weld cracking.

Speed is also a factor in preventing distortion. Welding at a slow rate may cause greater area heating, thus creating more expansion and subsequent contraction.

Weldable aluminum alloys are of two types: the work-hardenable alloys, such as EC (electrical conductor grade), 1100, 3003, 5052, 5083, and 5086; and the heat-treatable alloys, such as 6061, 6062, 6063, and 7039.

Although alloys in the 2000 and 7000 series are also heat-treatable, most of them are not recommended for arc-welded fabrication because weldments are low in ductility. Better properties are obtained with the resistance-welding method. A notable exception is alloy 7039, now employed for armor plate and other critical applications. Welding qualities of alloys in the 2000 and 7000 series with either resistance or GMA processes are excellent. As-welded (GMA) strengths are upward of 48,000 psi, and ductility of these welds ranges from 8 to 12 percent elongation, in 2-inch increments.

Mechanical properties can be improved in heat-treatable alloys by heat treatment at temperatures above 900°F, followed by a low-temperature aging treatment above 300°F.

Aluminum alloys lose hardness and strength when reheated to high temperatures. When heated above 900°F, the aluminum alloys revert to the annealed condition almost immediately. The degree of loss is a function of time and temperature. We mentioned earlier that the weld metal is over 1050°F when deposited; therefore, welding causes some annealing of the parent metal. With the heat-treatable alloys, welding also lowers the ductility of the joint.

Preheating is necessary if the mass of the parent metal causes heat to be conducted away from the joint so fast that the welding arc cannot supply the heat required to produce fusion. Insufficient heat causes poor fusion of the weld bead and inadequate melting of the parent metal. Preheating of the parts being joined helps to produce a satisfactory weld, reduces distortion or cracking in the finished product, and increases welding speed.

Preheating is necessary in GTA welding of heavy plate. For the heat-treatable alloys, such as 6061, preheat should be used carefully. Too high a temperature or too long a preheat period can decrease the as-welded strength of the joint. Recommended preheat temperatures for various thicknesses of aluminum plate and tube are shown in table 10-5.

In GMA welding, preheat is seldom required regardless of plate thickness. This is one advantage of the GMA process over GTA. Another advantage is the greater welding speed of GMA.

Residual stresses created in aluminum alloy by the heat of welding may become excessive, due to the total amount of heat input, thickness of metal, and design of the weldment. In extreme cases, such stresses may cause early failure of the weldment. One common method of modifying residual stresses is by peening (localized working of the metal by hammering) to effect limited distribution of the stresses. However, peening usually is not advisable on thin sections. For these and certain other cases, stress relieving by thermal treatment is recommended, where required.

All aluminum alloys can be completely annealed by heating them to the proper temperatures for specified periods of time. Annealing of the metal relieves all residual stresses. The temperatures required for substantial stress relief have an adverse effect on the mechanical properties. This may lower the resistance to corrosion in some alloys.

For aluminum-magnesium alloys (5000 series), high residual stresses may be reduced by heating the

Table 10-5.—Preheat Temperatures for Welding Sheet, Plate, and Tubular Aluminum Sections (Butt Joints)

Tubular Sections			
Outside Diameter Inches	Wall Thickness Inches	Approximate Preheat Degrees F	
		GTA	GMA
1-3	1/3	None	NR*
4-6	1/8	Optional—400	NR
1-3	l/4	None	None
4-6	l/4	400	None

Sheet and Plate		
Thickness	Approximate Preheat Degrees F	
	GTA	GMA
l/8-1/4	None	None
l/2	600	None
3/4		None
1	NR	None
2	NR	Optional—500
3	NR	Optional—500

*Not recommended

Note: These preheat temperatures are only for use as a guide. Most weldors prefer to increase the welding current and thereby avoid preheating. Preheating is another operation and increases overall costs. Also, if welding the heat-treatable alloys such as 6061, it should be realized that the temperature and length of preheating time can affect the as-welded strength of the joint. It is seldom necessary to preheat when using the GMA process.

alloys at temperatures below 650°F, the temperature for complete annealing. The principal limitation on post-weld heating is whether the weldment can fit inside the available oven. Heating the entire weldment in a furnace is recommended. Local heating for stress relieving is effective in some cases, but only where testing or performance data proves its effectiveness.

The aluminum-magnesium alloys (5000 series) can usually be stress relieved by post-weld heating them at 450°F for approximately 4 hours. As previously mentioned, complete annealing is achieved upon heating these alloys to 650°F. Cooling rate is unimportant.

Aluminum and its alloys rapidly develop an oxide surface film upon exposure to air. This oxide has a melting point in excess of 3600°F or about 2400°F above the melting point of pure aluminum. Temperature differential allows the aluminum to melt before the oxide film. When this happens, the film prevents fusion between the filler metal and its base plate. Therefore, the oxide film must be disrupted or removed by a chemical cleaner, flux, mechanical abrasion, or by the action of the welding arc.

Particles of oxide entrapped in the weld will impair ductility of the weldment. The joint should be cleaned with a stainless-steel wire brush immediately before welding to reduce the oxide level.

The GTA and the GMA welding processes have a major advantage over other methods, in that no fluxes are required. The action of the welding arc breaks up the oxide film. The noncombustible gas shield envelops both the arc and weld pool, preventing oxidation from recurring while the metal is molten.

Molten aluminum readily absorbs available hydrogen. When the weld pool solidifies, most of the hydrogen is released because it is practically insoluble in solid aluminum. This released hydrogen may become entrapped and cause porosity in the weld, which may impair its strength and ductility. Also, hydrogen may get into the molten weld metal from surface oils or from moisture on the filler wire. To reduce weld porosity, the metal surfaces must be carefully cleaned and care must be taken to maintain the cleanliness of the filler wire supplied by the manufacturer.

Cleaning the surfaces to be welded is of major importance in all aluminum joining, regardless of the welding process. This cleaning should be done just before welding. Cleanliness cannot be overemphasized. Oxide, grease, or oil films remaining on the edges to be joined will cause unsound welds. Unsoundness (porosity caused by gas, dross inclusions, ships, and so on) reduces the mechanical and electrical efficiency of the weld. Mildly alkaline solutions, and commercial degreasers that do not produce toxic fumes during welding, are used to remove surface contaminants before welding. One common method of cleaning is for the welder to wipe the edges of the joint with a cloth that has been dipped in a solvent, such as alcohol or acetone. All welding surfaces should be dried after cleaning to prevent porosity in the weld metal. Avoid use of carbon-chlorine solvents.

Oxide films should be removed from the surface of the aluminum by a suitable abrading process such as brushing with a clean, stainless-steel wire brush immediately prior to welding. If you are ever in doubt whether to wire brush, DO IT. Black, sooty-surfaced welds mean insufficient brushing.

Preparing Aluminum for Welding

The choice of joint design for welding aluminum depends upon the thickness of the material and the process used for joining. On relatively thin materials, one- to three-sixteenths inch thickness, the square butt joint is usually satisfactory for both processes. For thicker metal, either a single-vee bevel or double-vee bevel may be necessary.

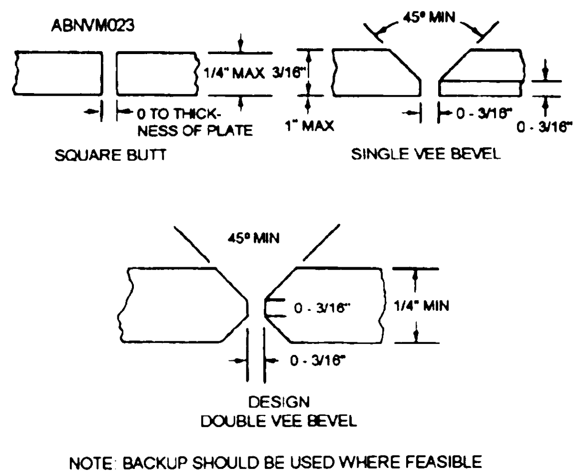


Figure 10-22.—Recommended joint designs for common thickness of plate.

The joint design and root openings required for GTA welding are determined by the thickness of the aluminum to be joined and the structural requirements of the weldment. Design varies from a square butt for one-eighth inch sheet to a 45-degree minimum included-angle vee joint for one-half inch or thicker plate. For tubular sections having a wall thickness greater than one-eighth inch, the edges should be beveled with a minimum 60-degree included angle and have a zero to one-sixteenth inch square butt lip. Recommended joint designs for common thicknesses of plate and pipe are shown in figures 110-22 and 10-23. For one-eighth inch thick and up, some root opening is recommended to ensure complete penetration.

The joint design and root openings required for GMA welding are determined by metal thickness and structural requirements as in GTA welding. Aluminum sheet up to one-fourth inch thick can be welded manually with complete penetration using a square butt design. For manual welding, material greater than one-fourth inch thick may have a

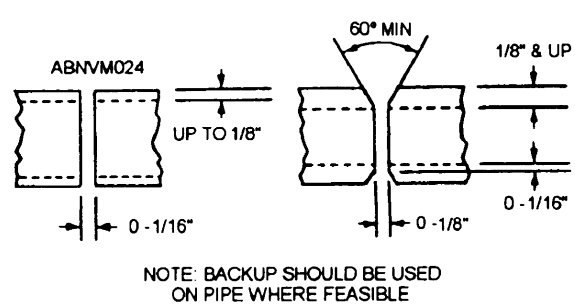


Figure 10-23.—Recommended joint design for pipe.

single-vee groove or a double-vee groove, as shown in figure 10-24. The edges of tubular sections are prepared the same as the edges of plate of corresponding thickness.

The welding of tubular sections employs the same techniques as those used for plate and pipe, with the exception that a backup is not used when welding is to be done from both sides. In this case, the back-chipping technique is used to ensure high-quality welds in the finished product. Backup plates are recommended wherever possible to control weld penetration. These plates also permit faster welding speeds.

Good joint fit-up makes welding easier, saves filler metal and shielding gas, and helps to assure quality welds. If jigs are not used to hold the joint members in their correct position, tack welding may be necessary. Tack welds should be short in length, one-fourth to one-half inch. They should also be small in size, one-eighth to three-sixteenths inch, depending upon the size of the metal. In addition, tack welds should be sufficient in number and correctly placed to maintain proper alignment of units or components being welded. The number of tacks to be made is determined by the workpiece to be welded.

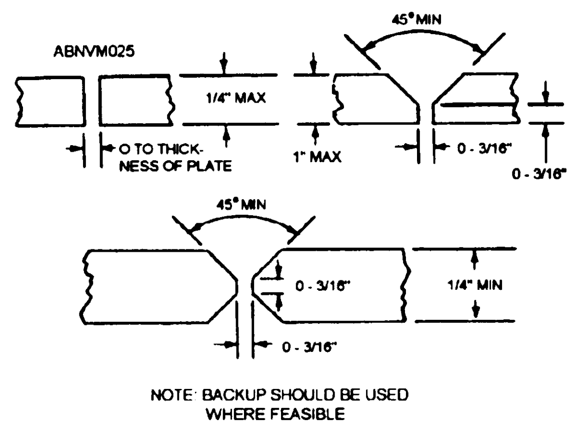


Figure 10-24.—Single-vee and double-vee groove welds.

GAS TUNGSTEN-ARC (GTA) WELDING PROCESS

The GTA process is widely used for welding relatively thin aluminum sections. In this process, an arc is established between a nonconsumable tungsten electrode and the aluminum parts to be welded with a shield of gas enveloping the arc and weld pool. The arc melts the aluminum base metal, and a bare filler rod of suitable alloy is manually added to the molten pool. Welding can be done rapidly from all positions. No flux is required in GTA welding because the action of the arc breaks up the oxide film and allows good weld-metal flow. A shield of gas, either argon or helium or a mixture of argon and helium, surrounds the electrode and the weld pool to prevent oxidation during welding.

Since the heat of the tungsten arc is concentrated in a small area, it is much faster than oxyacetylene welding. Distortion in GTA welds is also appreciably less than for oxyacetylene welds.

Welding Power Source

The heat for any arc-welding process is generated by the arc between the electrode and the base metal. The welding current for GTA welding is supplied by the ac/dc transformer-rectifier welder (fig. 10-25). This machine will deliver ac

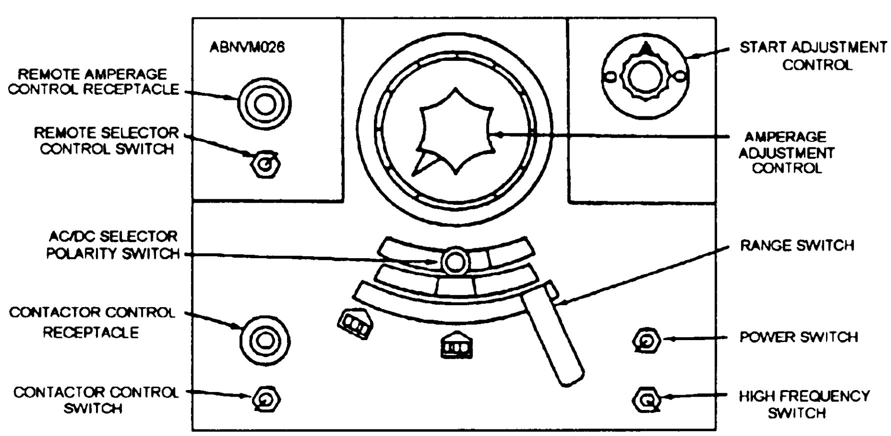


Figure 10-25.—Equipment for GTA welding.

high-frequency, dc reverse polarity (DCRP), and dc straight polarity (DCSP) welding current. Except for high frequency, ac welding is only authorized for use on tenders and shore facilities. Exceptions will require approval.

High-frequency ac is recommended for the welding of aluminum. It offers both the advantages of DCSP and DCRP welding. Theoretically, ac welding can be called a combination of DCSP and DCRP welding, as shown in figure 10-26.

In ac welding, when the current passes through zero (fig. 10-26), the arc is broken. To restart the arc, a high-voltage, high-frequency, low-power additional current is used. This establishes an ionized path for welding current to follow, when the arc is struck at zero current.

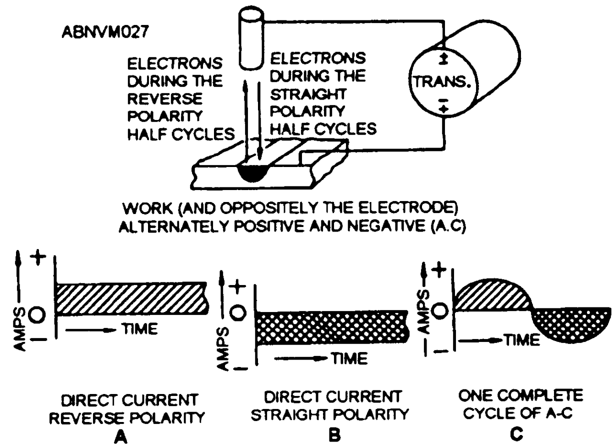


Figure 10-26.—Ac welding as a combination of dc straight and reverse polarity welding.

In any GTA welding operation, selection of the proper current is of utmost importance. Table 10-6 may be used as a guide for the selection of current for welding some of the more common metals.

Table 10-6.—Current Selection for GTA Welding

Material	Alternating Current	Direct Current	
	with high frequency stabilization	Straight Polarity	Reverse Polarity
Aluminum-up to 3/32 inch thich	1	2	N.R.
Aluminum-over 3/32 inch thich	1	N.R.	N.R.
Aluminum castings	1	N.R.	N.R.
Brass alloys	2	1	N.R.
Silicon 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

Welding Equipment and Supplies

In addition to the ac power source, the following equipment is needed for GTA welding:

- GTA welding torch. (Note that the word *torch* is commonly used for this GTA welding device. It is also termed *electrode holder*. However, throughout this discussion the word *torch* will be used.)
- Gas supply, regulator-flowmeter, hose, and fittings
- Filler metal
- Water supply and fittings
- Helmet or eye shield, and protective clothing
- Stainless-steel wire brush

For currents above 200 amperes, cooling the torch and power cable is necessary because of heat generated by the arc and the current passing through the cable. For welding currents below 200 amperes, air-cooled torches are satisfactory. A sectional sketch of a GTA water-cooled torch is shown in figure 10-27.

Water used to cool the welding torch should be clean to prevent clogging or flow restriction. Overheating can melt the silver-brazed metal joints in the torch and the plastic water tube that sheaths the electric cable. A control mechanism is available that does not allow the welding current to start unless the water is flowing. Some GTA welding equipment is provided with a solenoid valve that automatically shuts off the water supply when the welding stops. This prevents excessive cooling and moisture condensation inside the torch. Moisture can contaminate the electrode and cause porosity in the weld during the initial weld period. When GTA equipment is to be used in the field and if water is not available, a small water tank and pump can be used to circulate water between the tank and the torch. The GTA welding torch carries the welding current and directs the gas to the weld area. The torch must be properly insulated for the maximum current ranges to ensure operational safety. Current is transmitted from the ac transformer through the power cable to a collet holding the tungsten electrode. Gas ports surrounding the electrode permit the gas to enter the nozzle or cup.

The electrode should extend beyond the end of the gas cup a distance of l/8 to 3/16 inch. 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 will cause tungsten particles to transfer to the weld, while insufficient current allows the arc to wander erratically over the end of the electrode. With correct current the electrode will have a stable hemispherical end. Recommended electrode sizes

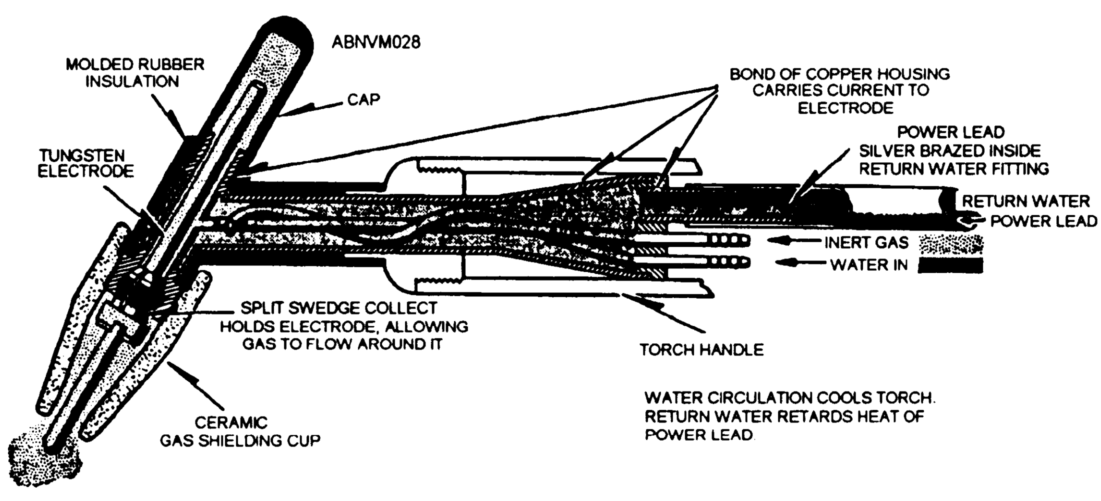


Figure 10-27.—Sectional sketch of a GTA water-cooled torch.

for various ranges of welding current are shown in table 10-7.

We will not describe in detail the advantages and disadvantages of the various types of electrodes made of pure tungsten, thoriated tungsten, or tungsten-zirconium alloy. Many welders prefer pure tungsten for GTA welding with ac. Thoriated tungsten is preferred for automatic GTA welding using dc straight polarity current. A note of interest here is that tungsten electrodes are usually color-coded on one end. A medium green indicates that the rod is pure tungsten. A yellow color indicates a 1 percent thoriated tungsten rod. A light red color indicates a 2 percent thoriated tungsten rod. A tan color indicates that the rod is zirtung (tungsten zirconium).

The gas cup or nozzle of the torch can be either ceramic or metal. Ceramic nozzles are generally unsatisfactory for welding at high-current levels because the nozzle may melt at the tip and partially close the orifice. On the other hand, metal nozzles of too small diameter will short out the high-frequency current if the work is touched by the nozzle. Torch manufacturers usually recommend the type and size of nozzle for different current ranges. Generally, the nozzle diameter should be equal to or slightly greater than the molten weld pool.

Dual Action of the AC Arc

The first function of the ac arc is to provide the heat necessary to melt the base and filler metals. The second arc function is to break up and remove the surface oxides from the aluminum. This is called the "cleaning action," and takes place during that part of the ac cycle when the electrode is positive. The cleaning action is either a result of the electrons leaving the base plate or the gas ions striking the surface or a combination of both.

Shielding Gas

Initially the arc breaks up the oxide on the area where it is directed. The gas shields the arc and weld pool, preventing oxidation from reoccurring. The gas also shields and prevents oxidation of the hot tip of the tungsten electrode; and because of this, the flow of gas should not be stopped until the tungsten electrode tip has cooled. Shutoff can be either manual or automatic; the latter is preferred. Another function of the gas shield is to provide a more easily ionized path, thus aiding smooth transfer of current. Either argon or helium can be used for shielding the arc in the GTA process. Helium requires a higher gas flow, but gives greater penetration and faster welding speeds than argon. This deeper penetration is obtained because the arc in the helium atmosphere is hotter than in the argon atmosphere. Argon is preferred by most welders because the cleaning action is greater and the arc more stable. The flow of gas necessary for good GTA welding depends on the welding current, size of nozzle, joint design, speed of welding, and freedom from draft in the area where the welding is being done. This last factor can affect gas coverage considerably. Recommended gas flows are shown in table 10-8.

Table 10-7.—Recommended Current Ranges for Thoriated and Nonthoriated Tungsten Electrodes

Electrode Diameter Inches	Current, Amperes	
	Standard Tungsten Electrodes	Thoriated Tungsten Electrodes
0.04	10-60	15-80
l/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
l/4	300-490	500-800
5/16	450-600	

Table 10-8.—Recommended Practices for GTA Welding of Aluminum

Material Thichness Inches	Welding Position	Joint Design [1]	Current Amps AC	Dia. of [2] Tungsten Electrode Inches	Argon [3] Gas Flow CFH	Filler Rod Dia. Inches	No. of Passes
1/16	Flat	Sq. Butt	70-100	1/16	20	3/32	1
	Horiz & Vert.	Sq. Butt	70-100	1/16	20	3/32	1
	Overhead	Sq. Butt	60-90	1/16	25	3/32	1
1/8	Flat	Sq. Butt	125-160	3/32	20	1/8	1
	Horiz & Vert.	Sq. Butt	115-150	3/32	20	1/8	1
	Overhead	Sq. Butt	115-150	3/32	25	1/8	1
1/4	Flat	60° Single Bevel	225-275	5/32	30	3/16	2
	Horiz & Vert.	60° Single Bevel	200-240	5/32	30	3/16	2
	Overhead	100° Single Bevel	210-260	5/32	35	3/16	2
3/8	Flat	60° Single Bevel	325-400	1/4	35	1/4	2
	Horiz & Vert.	60° Single Bevel	250-320	3/16	35	1/4	3
	Overhead	100° Single Bevel	275-350	3/16	40	1/4	3
1/2	Flat	60° Single Bevel	375-450	1/4	35	1/4	3
	Horiz & Vert.	60° Single Bevel	250-320	3/16	35	1/4	3
	Overhead	100° Single Bevel	275-340	3/16	40	1/4	4
1	Flat	60° Single Bevel	500-600	5/16-3/8	35-45	1/4-3/8	8-10

(1) See exercises for joint designs.

(2) For standard (non-thoriated) tungsten electrodes.

(3) Helium is not generally used on gas tungsten-arc welding; however, gas flow rates for it are slightly higher than for argon.

Filler Metal

Additional filler metal is not necessary in GTA welding when enough parent metal is provided by the joint design to form the weld bead. For other welds, it is often necessary to add filler metal. For filler metal in the form of straight length, bare rod is used for manual welding, while filler metal in wire form, spool wound is used for automatic welding.

Filler rods of EC, 1100, 4043, 5154, 5183, 5356, 5556, and other alloys are available in various diameters. Take care to see that a compatible filler metal is used in welding different aluminum alloys. Weld craters and longitudinal cracks may result from using incorrect filler alloy. Make a special effort to see that only clean rods are used. Dirty rods contaminate the weld. Store rods in a hot locker or warm dry area and keep them covered.

PRACTICE EXERCISES FOR GTA WELDING

Now that we have covered various fundamentals of GTA welding of aluminum, let us turn our attention to some practical exercises that will help you acquire skill in performing GTA welding operations. A thorough knowledge of the procedures covered in the following projects will aid you in assignments as the operator on GTA welding jobs.

Setting Up Equipment

This exercise in setting up equipment will acquaint you with the equipment and accessories commonly used in GTA welding. The basic equipment and accessories required for GTA welding of aluminum are as follows:

—Ac welding transformer with capacity range of 90 to 500 amperes having superimposed high-frequency current

—GTA welding torch and 0.040-inch, 1/16-inch, l/8-inch, 3/32-inch, 5/32-inch, 3/16-inch, and 1/4-inch diameter tungsten electrodes, collets, and suitable gas cup nozzles

—Argon gas, usually a cylinder with a regulator-flowmeter, a solenoid control valve interlocked with the welding circuit, or a manual cut-off valve (called an economizer) in the gas line before the torch

—Water supply, main shut-off valve, and solenoid control valve interlocked with the welding circuit

—Steel worktable and C-clamps

—Welding helmet, gloves, and protective clothing

—Stainless-steel wire brush for cleaning oxide from the surfaces on which weld metal will be deposited

NOTE: Reference to standard equipment in the following exercises will be briefly summarized, but anticipates all previously indicated items.

Specific information on the different makes of GTA welding equipment is not given in this training manual. We suggest the operator read the manufacturer's instruction pamphlets for specialized information.

Most GTA welding transformers are operated from a 220- or 440-volt ac power source. Normally, an Electrician's Mate is the only one allowed to connect or disconnect a transformer. However, you should know the electrical hookup and be aware that high voltages, if incorrectly handled, may cause a fatal injury.

The high-frequency current imposed on the welding current often affects radio reception unless the transformer is properly installed, grounded, and adjusted. Therefore, the manufacturer's instructions on these points should be carefully followed.

The power cable to the GTA welding torch, and the ground cable to the work, should be connected according to the manufacturer's directions. The welding torch should be hung in a safe location so that the tungsten electrode cannot touch anything grounded and thus complete an electrical circuit. The switch controlling power to the torch should always be in the "off" position when welding is not being done.

The following checks should be made before starting to weld with GTA units:

1. 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.

2. Check the size, appearance, and position of the tungsten electrode in the torch. It should be clean and silvery, and the diameter should be that recommended for the welding current to be used. A dirty, rough electrode surface usually means that the inert gas was shut off before the electrode cooled, that there was air leakage in the gas supply system or torch proper, or that the electrode tip was contaminated by touching metal. A dirty tungsten electrode can sometimes 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. (NOTE: The dust produced from grinding thoriated electrodes is radioactive. However, this contamination normally does not exceed the maximum permissible concentrations. Even though the radioactive hazard of grinding thoriated tungsten is slight, care should be taken to grind electrodes on specially designed and constructed grinders.) When you are welding, the tip should be hemispherical in shape. The needlepoint tips used for stainless steel should not be used for aluminum. A contaminated and a good tungsten electrode are shown in figure 10-28. Note the hemispherical tip on the good electrode. The electrode should extend beyond the end of the gas cup a distance of l/8 to 3/16 inch. It must be securely held in the torch both for positioning and for good electrical contact. Because small diameter electrodes are easily bent, check to see that the electrode is straight and centered in the cup. If necessary, straighten or replace the electrode.

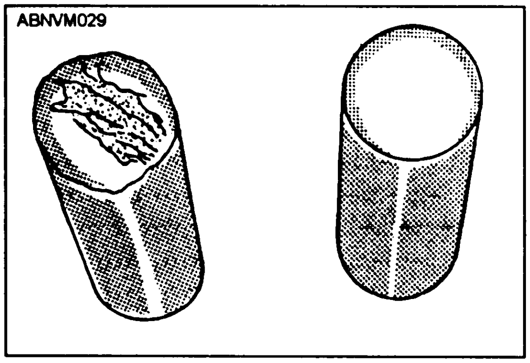


Figure 10-28.—Contaminated and good tungsten electrodes.

3. Check the connections on the gas supply for leaks with soapy water.

4. Select the proper gas cup size according to the torch manufacturer's instructions. Make sure the gas cup is free of spatter. Clean or replace it if necessary.

5. Check the ground cable connections to the workpiece. The connections should also be periodically checked after welding begins, as they tend to work loose. This causes the welding current to vary.

6. Preset the current range (see table 10-7) for the joint to be welded, and switch on the transformer, as shown in view A of figure 10-25.

7. Open the main shut-off valve on the cylinder of gas and adjust the flow, as shown in view B of figure 10-25. Table 10-8 lists the recommended flow for various welding currents.

8. Be sure the water supply to be used is not at a higher pressure than that recommended by the torch manufacturer. If satisfactory, the water shut-off valve is usually opened fully and the flow is controlled by the water ports in the gun.

9. Never look at a welding arc without a hand shield or welding helmet with the proper shade of protective glass, or your eyes will be injured. Eye fatigue indicates a different shade of glass is required or there is leakage around the protective filter glass. A No. 10 glass is satisfactory for most GTA welding at current ranges of 75 to 200 amperes. Gauntlet gloves and protective clothing must be worn as protection from hot metal. Bare skin should never be exposed to the rays of the welding arc because painful burns may result.

If you are teaching a person how to set up the equipment, you should demonstrate turning on the water and gas supply, switching on the transformer, presetting the gas flow and current range, and then shutting down the equipment. You should then have the person repeat the start-up and shut-down procedures until the procedures are thoroughly understood.

Establishing an Arc and Forming a Weld Pool

This exercise is intended to acquaint you with the correct technique of initiating an arc and forming the weld pool.

As material for this exercise, 1/4" by 6" by 12" plate of any aluminum alloy recommended for welding may be used. You will need a standard ac transformer, GTA welding torch equipped with 5/32-inch diameter tungsten electrode, argon gas, and necessary accessories. The procedure calls for regulating the argon gas flow 30 to 35 cubic feet per hour. Also, select a welding current of 175 to 225 amperes.

When using ac high-frequency current, the electrode does not need to come in contact with the workpiece to strike the arc. The high-frequency current will jump the gap between the tungsten electrode and the workpiece and establish the welding current path. To strike the arc, hold the torch in a horizontal position, as shown in figure 10-29, about 2 inches above the work surface.

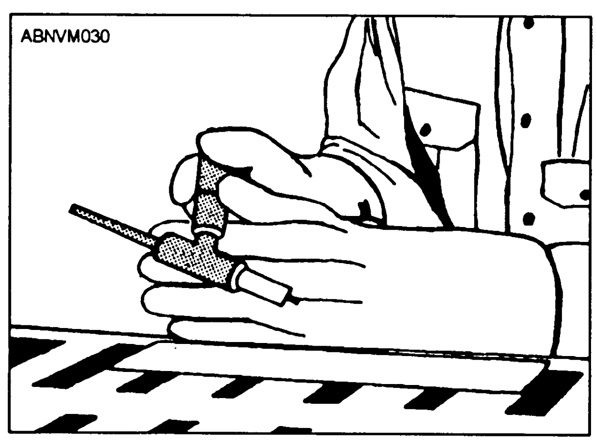


Figure 10-29.—Torch position for the starting swing to strike the arc.

paragraphs. When the puddle becomes bright and fluid, 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. When the puddle becomes bright and fluid again, repeat these steps. Figure 10-32 shows the correct procedure for adding filler metal. This sequence is continued until the weld joint has been completed. The width and height of the weld bead is determined by the speed of travel, movement of the torch, and amount of filler metal added.

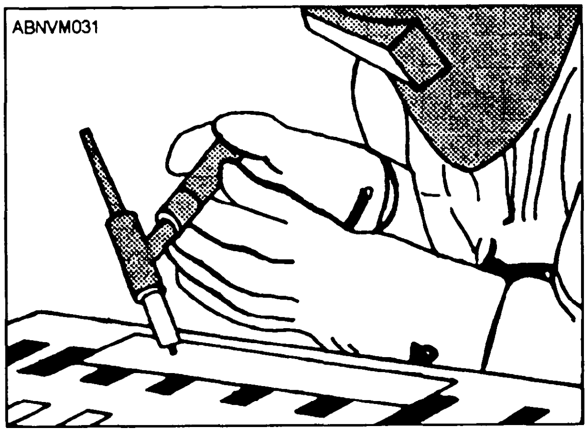


Figure 10-30.—Position of the torch at the end of the swing when the arc strikes.

Then, with a rapid motion, swing the electrode end of the torch down to within an eighth of an inch of the work surface. The arc will then strike. Figure 10-30 shows the torch position at the time the arc strikes. After the arc has been struck, hold the torch at a 90-degree angle to the workpiece surface and with small circular motions, as shown in figure 10-31, form a molten puddle. When the molten puddle has been formed, hold the torch at a 75-degree angle to the work surface and move the torch slowly and steadily along the joint at a speed that will produce a bead of uniform width. Move the torch slow enough to keep the puddle bright and fluid. No oscillating or other movement of the torch is necessary except the steady forward movement.

When the use of a filler metal is necessary, form the molten puddle as described in the previous

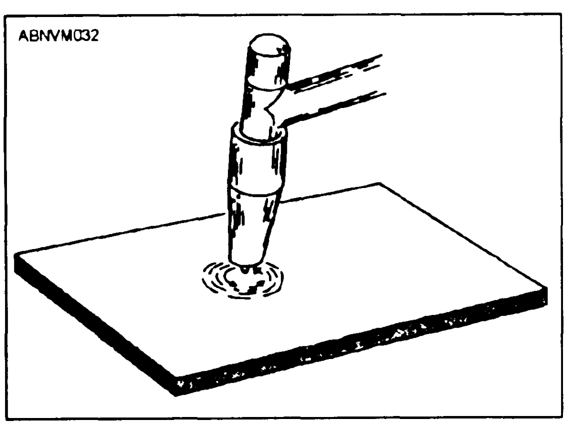


Figure 10-31.—Forming a molten puddle with a GTA torch.

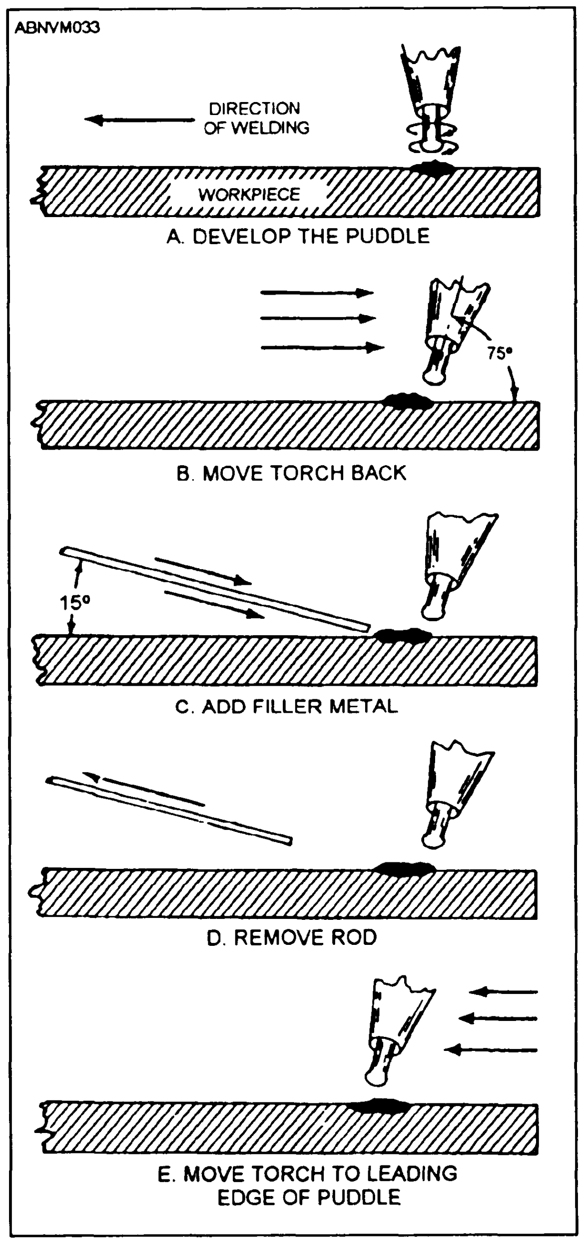


Figure 10-32.—Addition of filler metal (flat position).

When using dc straight or reverse polarity welding current, the same motion is used for striking the arc, but the electrode must come in contact with the workpiece to start the flow of welding current, unless the dc welder has high frequency to give it a self-starting arc. When the arc has been struck, withdraw the electrode approximately one-eighth inch from the work surface to avoid contaminating the electrode with the molten metal. To make the weld bead, follow the same steps as described for ac welding.

To stop an arc, snap the electrode quickly back to the horizontal position. This must be done rapidly so the arc will not damage the weld surface or the workpiece.

You will find that welding technique improves when you learn to weld in a comfortable position. Quality welding is dependent upon smooth, even manipulation of the torch and filler rod. This cannot be accomplished if you are in an awkward or uncomfortable position.

A common mistake often made by new operators in GTA welding is improperly feeding the filler rod into the arc. The arc heat should be used to form and hold the molten pool, and the filler rod should be melted by the leading edge of the pool. In this way, the weld metal will always be fused into the base metal of the workpiece. By watching the edges of the weld pool, you can learn to judge the pool's fluidity, buildup, and fusion into the parent material. Incorrect torch angle, improper torch manipulation, too high a welding current, or too low a welding speed can cause undercutting in the base plate along one or both edges of the weld bead.

The surface appearance and etched cross sections of three weld beads on a flat plate are shown in figure 10-33.

The welding current employed in each weld determines its quality. The weld bead shown in view A indicates that the current selected for welding is too high; view B indicates that the welding current used is correct; and view C indicates that the welding current is too low.

Weld beads made with sufficient and insufficient shielding gas are shown in figure 10-34. Insufficient shielding gas gives an unsound weld bead having a very poor appearance. Using too much shielding gas is wasteful.

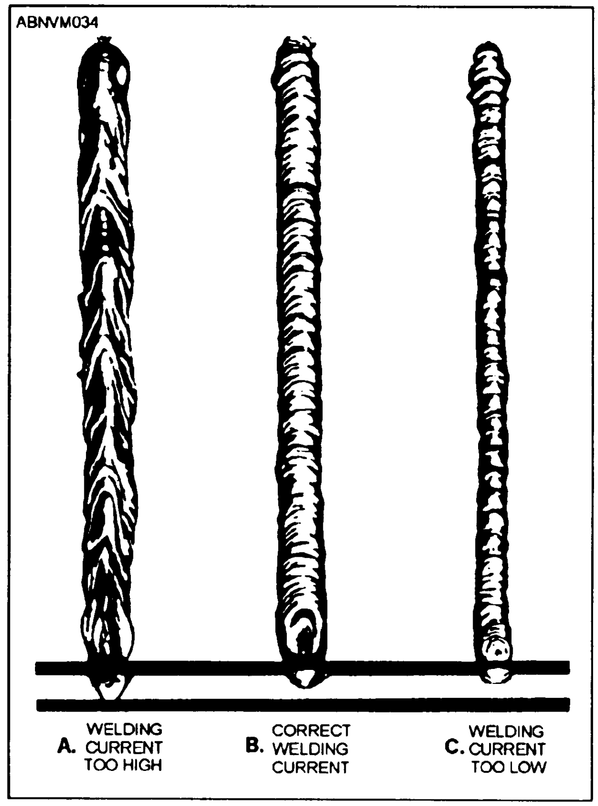


Figure 10-33.—Comparative GTA weld beads as determined by electrical current.

Good weld bead appearance resulting from using two different techniques of torch-filler rod manipulation is shown in figure 10-35. In view A, a bead was made using a two-step technique, namely, intermittent filler rod addition to the weld pool and intermittent torch movement. In view B, a bead was made by moving the torch forward in a relatively steady motion, feeding the filler rod intermittently as the pool required it. This latter technique gives improved weld bead appearance needing little or no finishing.

You should practice making weld beads on a flat plate until you are satisfied with the workmanship. In making satisfactory beads, practice is necessary to develop a "steady hand." If the appearance of weld beads made are equivalent to the ones shown in figure 10-36, and the sample proves satisfactory by visual examination, you should continue on to the next exercise. Should the sample show evidence of poor or careless workmanship with poor bead appearance, spatter, or cracks, as indicated in figure 10-37, you must practice until you make a weld bead that will meet visual inspection requirements.

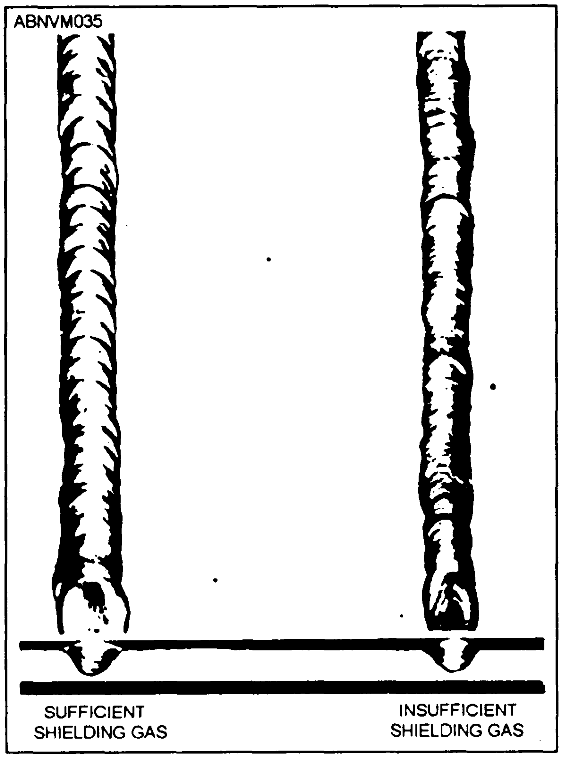


Figure 10-34.—Comparative GTA weld beads as determined by shielding gas.

Flat-Position Single-Pass Butt Welds

This exercise will help you learn the technique of making a single-pass butt weld in the flat position on aluminum. You should use 3/16" by 6" by 12" EC aluminum and 1/8-inch diameter 1100 alloy filler rod, or any other recommended combination of parent sheet-filler alloy. You will also need a 3/16 by 1" by 12" backing strap of EC aluminum or the same sheet-filler alloy.

The GTA welding torch should be equipped with a l/8-inch diameter tungsten electrode. Of course, you will need the ac transformer, argon gas, and necessary accessories.

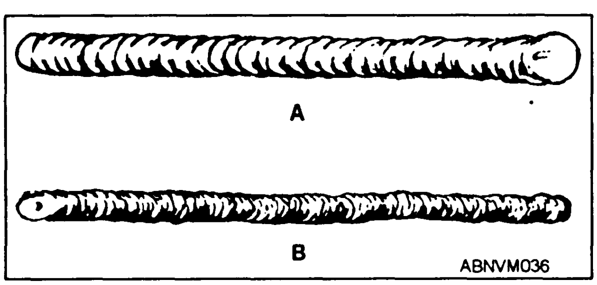


Figure 10-35.—Comparative GTA weld beads with filler rod manipulation.

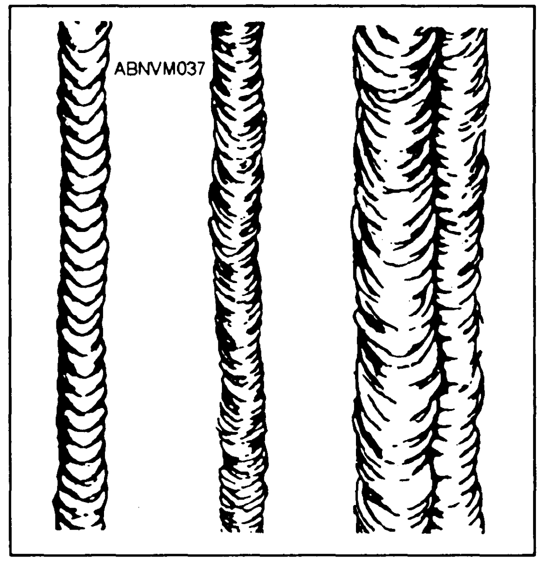


Figure 10-36.—Visual inspection standards for GTA welds.

The procedure for welding is to bevel abutting edges of sheet as indicated in figure 10-38. Clean all surfaces, including the backing strap, with solvent, and wipe dry. Brush the weld surface areas with a stainless-steel wire brush. Inspect and clean the filler rod if necessary. Regulate the argon gas flow 25 cubic feet per hour, and select a welding current of 175 to 210 amperes. Arrange the plates

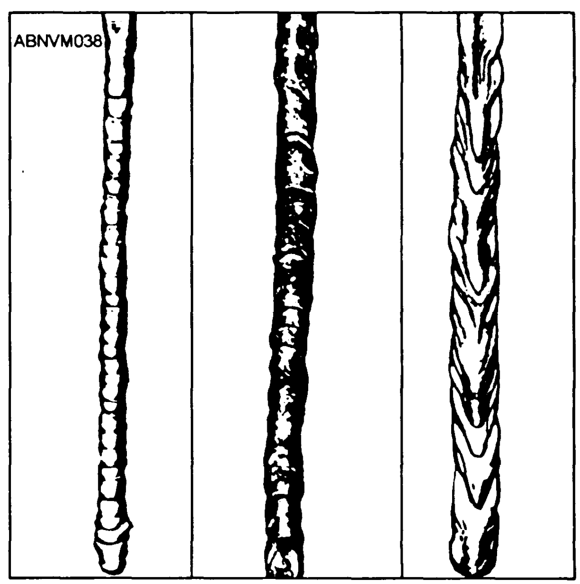


Figure 10-37.—Unacceptable GTA welds.

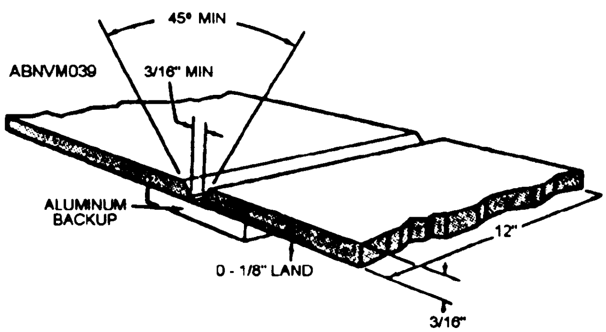


Figure 10-38.—Joint design flat-position single-pass butt welds in aluminum sheet.

as shown in figure 10-38 without jigs. Position the plate and backup strap with all units supported and level. Then tack weld.

In welding practice, remember that good GTA welding is dependent upon this definite procedure-form the molten pool in the parent sheet. Then feed the filler rod intermittently to the leading edge of the pool as the torch is being moved forward. DO NOT feed the filler rod into the arc. You should practice making single-pass butt welds until they are satisfactory. Workmanship must pass visual inspection standards.

Horizontal-Position Multipass Fillet and Butt Welds

This exercise will help you learn horizontal-position welding. Use 1/2" by 6" by 12" EC aluminum plate and 3/16-inch diameter 1100 alloy filler rod, or any recommended parent plate-filler alloy combination. You will also need cleaning materials and backing strap, if they are used.

The ac transformer with superimposed high-frequency current, a GTA welding torch equipped with 3/16-inch diameter tungsten electrode, argon gas, and necessary accessories are the items of equipment needed.

The procedure is to bevel the abutting edge of plates, as shown in figure 10-38. Clean all areas, including the backing strap, if one is used. Brush surfaces with a stainless-steel wire brush to remove oxide film, and between passes if contamination is apparent.

Regulate argon gas flow at 35 cubic feet per hour, and select a welding current of 250 to 320 amperes.

Tack weld the assembly in the flat position, and then arrange units as shown in figure 10-39. Use a suitable jig to hold parts steady.

Rules for quality welding in the flat position 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 will find it advisable not to use high welding current or to deposit large weld beads. Direct the arc so that there is no overheating at any one area that produces sagging or undercutting. The filler metal addition, bead size, and sequence have to be placed so that there is complete fusion between passes.

The welding of a fillet joint and a butt joint in a horizontal position is shown in figure 10-40, views

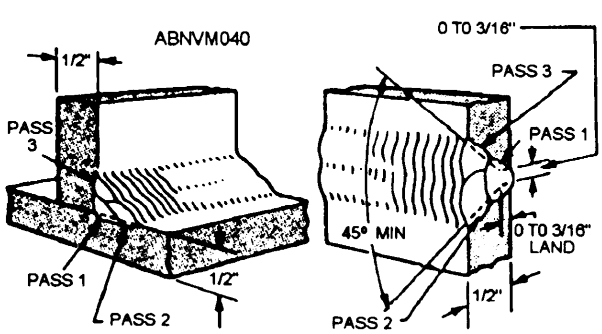


Figure 10-39.—Jolt design and weld pass sequence horizontal-position multipass fillet and butt welds.

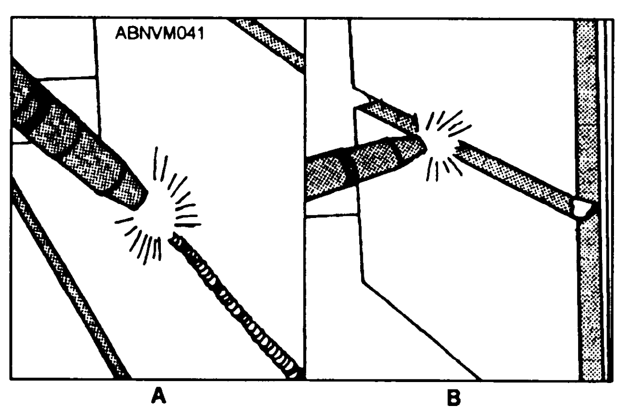


Figure 10-40.—Welding a fillet and butt joint in the horizontal position.

A and B. The correct positioning of the torch and addition of the filler metal at the weld pool edge to prevent undercutting when making a horizontal position fillet weld is shown in figure 10-41.

Vertical-Position Multipass Fillet and Butt Welds

This exercise will brief you on the technique of vertical position welding. You will need 1/2" by 6" by 12" EC aluminum plate and 3/16-inch diameter 1100 alloy filler rod or any other recommended parent plate-filler rod combination. You will also need a backing strap, if one is used.

The equipment needed is the ac transformer with superimposed high-frequency current, a GTA welding torch equipped with 3/16-inch diameter tungsten electrode, argon gas, and the necessary accessories.

Prepare the abutting edges of plate as shown in figure 10-22. Clean and dry the joint area thoroughly. Brush with a stainless-steel wire brush to remove oxide where the filler metal will be deposited. Examine and clean the filler rod, if needed.

Regulate the argon gas flow at 35 cubic feet per hour, and select a welding current from 250 to 320 amperes.

Position sections as shown with all units supported. Tack weld in the most convenient position. Holding jigs may be used. Follow the weld pass sequence as shown in figure 10-42.

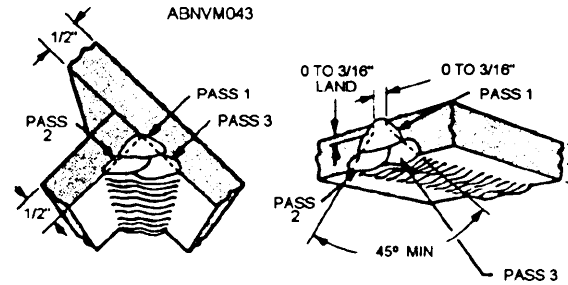


Figure 10-42.—Joint design and weld pass sequence vertical-position multipass fillet and butt welds.

Butt and fillet welds in the vertical position are made as shown in figure 10-43.

All of the factors presented concerning out-of-position welding also apply here. Do not use too high a welding current or deposit too large a weld bead. If the molten pool is too large, it will be difficult to control. Bead size, filler metal addition, and bead sequence should be carefully handled to ensure complete fusion between passes. Some welders find that a slight weave in vertical welding will smooth out the bead. Practice your work until it passes satisfactory visual inspection.

Overhead-Position Multipass Fillet and Butt Welds

This exercise will acquaint you with the technique of overhead-position welding. The

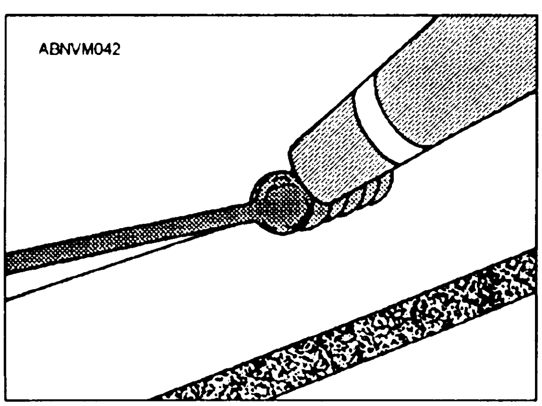


Figure 10-41.—Correct position of the welding torch and proper addition of the tiller metal to form a weld pool.

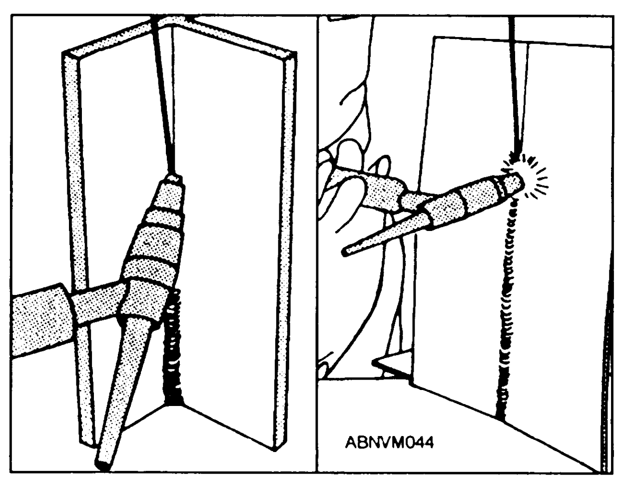


Figure 10-43.—Butt and fillet welds made in the vertical position.

materials, gas flow, and equipment needed for this exercise are the same as those described for vertical-position multipass fillet and butt welds.

Bevel the edges of abutting plates as shown in figure 10-44. Tack weld the backing strap. Clean and dry all joint surfaces with cleaner. Wire brush to remove joint area oxides, and also any apparent weld contamination after each pass.

Tack weld the parts in the most convenient position. Position the sections as shown in figure 10-44 with all units supported. Use holding jigs, if necessary. Follow the weld pass sequence as numbered.

Overhead multipass butt and fillet welds are shown in figure 10-45. Here, as in vertical welding, a slight weave may or may not be used. A lower welding current and travel speed are used as compared to flat-position welding. Conversely, a higher flow of shielding gas is used. Take care to avoid sagging and poor penetration by adding too much filler and carrying too large a pool. Let the established pool wet out enough before adding more filler. Most inexperienced welders find overhead welding awkward. Therefore, try to get in as comfortable and relaxed a position as possible when welding. This will help with steady, even torch and filler rod manipulation.

The new operator should practice both fillet and butt welding in the overhead position until satisfied with the work. If the weld passes visual inspection, continue on to the next exercise.

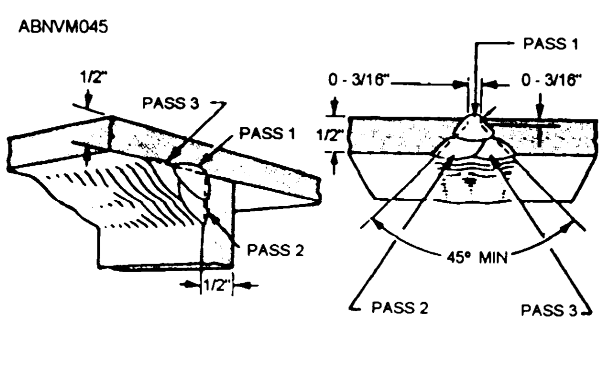


Figure 10-44.—Joint design and weld pass sequence overhead-position multipass fillet and butt welds.

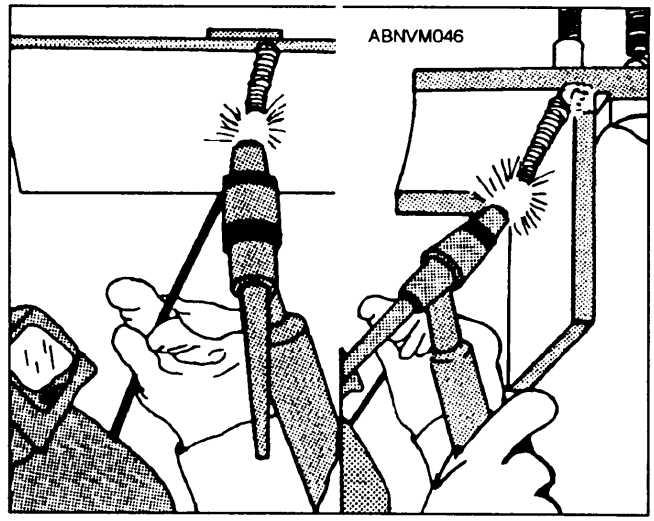


Figure 10-45.—Making overhead multipass groove and fillet welds.

Horizontal Fixed-Position Multipass Welding

This exercise will help you acquire the technique of welding aluminum pipe in the horizontal fixed position, with or without backup. Use 2 1/2-inch diameter, schedule 80 aluminum pipe; l/8-inch diameter, 4043 alloy filler rod, or any other recommended parent pipe alloy-filler rod combination; a backing ring for backup; and cleaning solution or solvent.

With the ac transformer, you will need a GTA welding torch equipped with l/8-inch diameter tungsten electrode, argon gas, and necessary accessories. You also will need a jig for holding pipe in position and a pipe and backing ring.

The procedure involves beveling pipe edges as indicated in joint design and weld pass sequence shown in figure 10-46. Clean, dry, and brush the weld areas and backup ring. Insert the ring in the proper position after the pipe sections are clamped on the jig. Clean the filler rod, if required.

Regulate the argon gas flow at 30 cubic feet per hour, and select a welding current of 160 amperes.

Position sections as shown in figure 10-46, with all units supported. Tack weld in the most convenient position. Follow the weld pass sequence as shown.

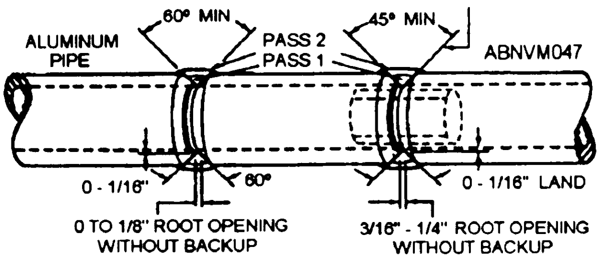


Figure 10-46.—Joint design and weld pass sequence horizontal fixed-position multipass (GTA) welding.

Most welders prefer to use a backup ring for pipe welding when possible because it makes the operation easier. With backup, the joint fit and penetration control are not so critical. You should, however, learn to make the weld without a backup ring.

Horizontal fixed-position pipe welding is often considered a test to qualify for welding in any position. It includes welding in the flat, vertical, and overhead positions. Figure 10-47 shows the technique of torch and filler rod handling.

GAS METAL-ARC (GMA) WELDING PROCESS

The GMA welding process is also known as gas consumable electrode welding (fig. 10-48). It uses a dc (reverse polarity) and a shield of argon or helium or a mixture of both. A small diameter aluminum wire serves both as electrode and filler metal and is fed automatically from the welding gun at high speed. Commercially available equipment for GMA welding is designed to initiate gas coverage and automatically feed the aluminum electrode into the weld area when the arc is struck. A welding pool is formed immediately when the arc is established. Welding progresses by moving the welding gun along the line of the joint at a rate to build up a bead of the desired dimensions. The electrode and weld pool are protected from oxidation by the shield of gas during welding. No flux is required.

GMA Welding Equipment

Numerous types and models of GMA welding equipment are used in the Navy. They all have the same basic requirements. Each must have a source of DCRP welding current, a wire feed unit for feeding the wire filler metal, a control unit that controls the automatic feed of the wire filler metal and shielding gas, and a welding gun for directing the wire filler metal and shielding gas to the weld area. Figure 10-49 shows one type of GMA welding equipment that is used quite often for short run welds and welds in hard-to-get-to places that are inaccessible to larger welding guns.

The 200 dc amp rectifier welder shown in figure 10-49 was designed specifically for the GMA welding process and is a constant potential power source. The constant potential power source compensates for changes in arc length, thus providing more uniform welding.

The welding gun shown in figure 10-49 contains the wire drive motor and drive roll assembly, the control switch for control of the wire feed and gas flow, and a replaceable l-pound spool of wire filler

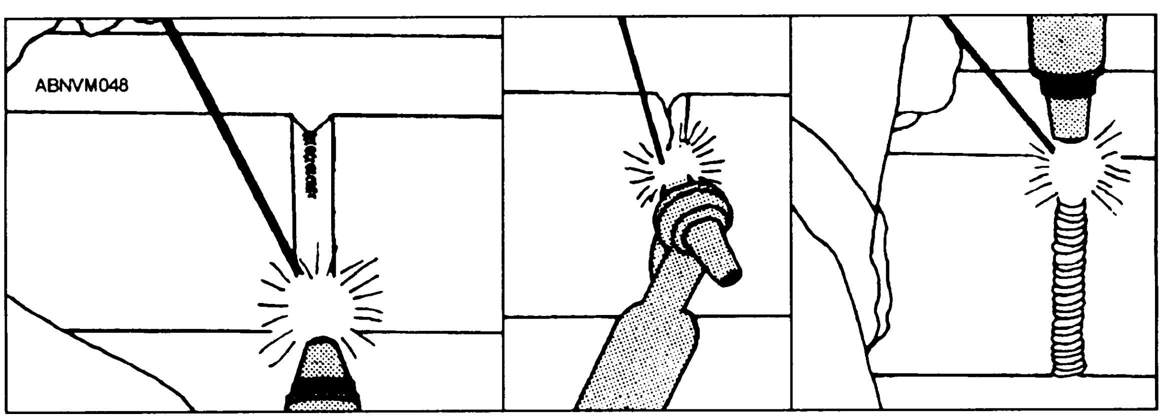


Figure 10-47.—Techniques of torch and filler rod handling for tubular sections.

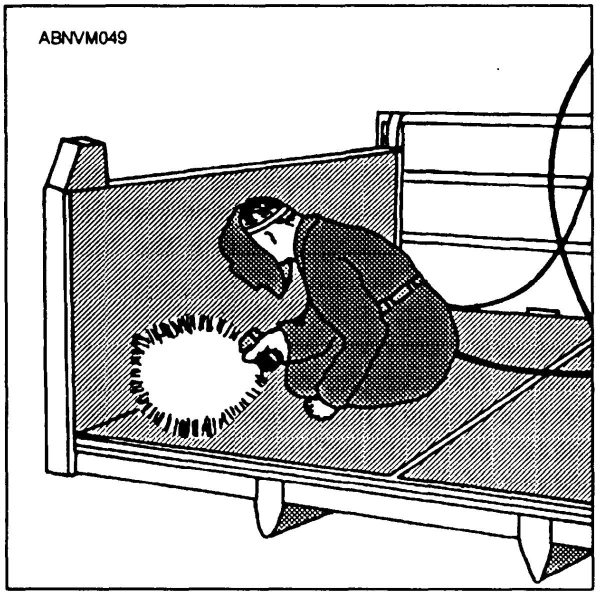


Figure 10-48.—CMA welding aluminum truck bed.

metal. The welding gun is connected directly to the dc rectifier welder. This eliminates the need for a separate control unit and wire drive assembly. Wire filler metal in sizes 0.030, 3/64, and l/16 inches may be used with this gun. The weight of the gun, including a l-pound spool of wire, is about 3 pounds.

Another GMA welding unit is shown in figure 10-50. It consists of a 250-amp dc rectifier welder, the welding gun, and a canister. This equipment differs from that shown in figure 10-49 in that the welding gun does not contain the spool of filler metal. The filler metal is on a 12-inch diameter spool that is inside the canister. The filler metal is fed through a lo-foot long plastic guide liner to the drive rolls in the gun and then to the weld area. The dc rectifier welders shown in figures 10-49 and 10-50 are connected to a 440-volt ac electrical supply source. These welders may be used with a 220-volt ac supply source by making the necessary electrical changes according to the manufacturer's technical manual.

In addition to the equipment already mentioned, the following supplies and equipment are needed for the GMA welding of aluminum:

- Gas supply, regulator-flowmeter valve, hose, and fittings
- Filler wire
- Helmet or eye shield, and protective clothing
- Stainless-steel wire brush

DCRP is most often used for GMA welding of aluminum. In DCRP welding, the electrons flow from the plate to the filler wire. This provides the heating effect necessary on the end of the filler wire electrode to form molten aluminum droplets. These droplets, in turn, are transferred into the weld pool. The GMA process deposits filler metal at higher rates than the GTA process, making faster, more

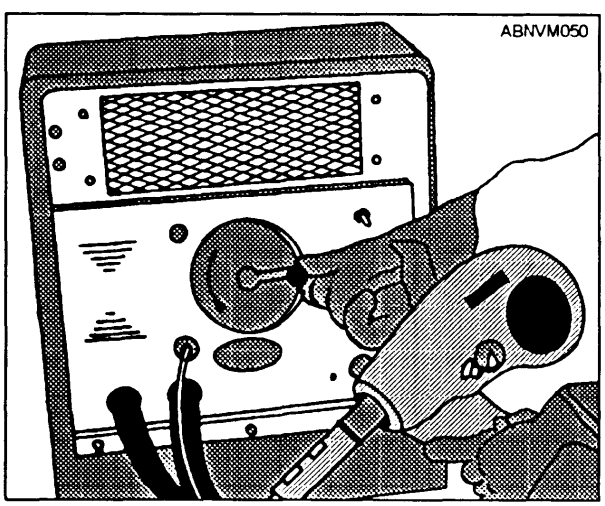


Figure 10-49.—GMA welding equipment (AIRCO products).

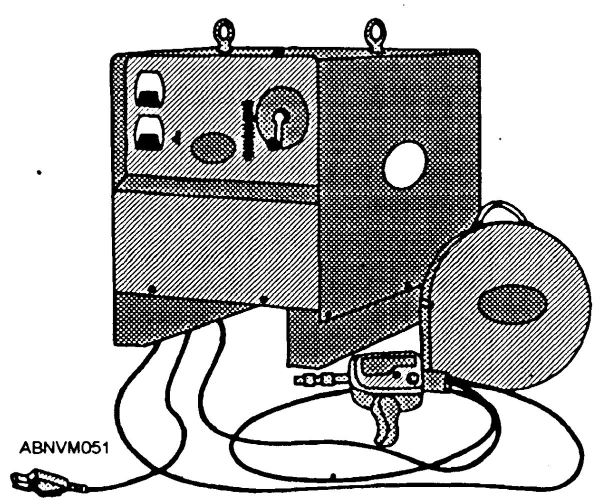


Figure 10-50.—Heavy-duty GMA welding equipment (AIRCO products).

economical welds with less heat effect on the workpiece.

Dual Action of the Arc

The reverse polarity arc supplies heat to melt the consumable filler wire and the workpiece. The arc also breaks up the surface oxide on the aluminum. This cleaning action is due to the electrical characteristics of the DCRP arc. Arc action is not intermittent as in ac GTA welding, but is continuous because there is no change in current direction using dc GMA welding.

Shielding Gas

The GMA welding gun deposits molten aluminum where directed on the workpiece. The gas shields the arc and weld pool while the filler wire is being melted and transferred in spray or droplet form to the pool. Another purpose of the gas shield is to provide a more easily ionized path than air.

Helium, argon, or mixtures of the two are suitable for GMA welding of aluminum. At any given current, the helium shielded arc has a higher voltage than the argon arc. A smoother, more stable arc is obtained with argon. Pure argon is used most widely on aluminum plate less than three-fourths inch thick. Combinations of argon and helium are often employed for welding heavy plate. This combination is used particularly for out-of-position welding to obtain the "hotter arc" characteristics of helium with the stabilizing effects of argon. Mixtures of 75 percent helium and 25 percent argon are commercially available. Other gas mixtures, for example, 60 percent helium and 40 percent argon, are mixed by combining flows from separate tanks of helium and argon. Helium additions of over 10 percent markedly change the arc characteristics.

The flow of gas necessary for good quality GMA welding depends upon the gas used, welding current, diameter of gun nozzle, joint design, welding position, speed of welding, and freedom from draft

Table 10-9.—Recommended Practices for GMA Welding of Aluminum Alloys

Material Thickness Inches	Welding Position	Joint Degree (1)	Current Amps DC	Arc Voltage	Filler Wire Dia. Inches	Argon (2) Gas Flow CFH	No. of Passes
l/8	Flat	None	110-130	20	3/64	30	1
	Horiz. & Vert.	None	100-120	20	3/64	30	1
	Overhead	None	100-120	20	3/64	40	1
l/4	Flat	None or Single Bevel	200-225	26-28	l/16	40	1
	Horiz. & Vert.	Single Bevel	170-190	26-28	l/16	45	2 or 3
	Overhead	Single Bevel	180-200	26-28	l/16	50	2 or 3
3/8	Flat	Single or Double Bevel	230-300	26-28	l/16	50	1 ot 2
	Horiz. & Vert.	Single or Double Bevel	180-225	26-28	l/16	50	3
	Overhead	Single or Double Bevel	200-230	26-28	l/16	50	5
l/2	Flat	Single or Double Bevel	280-320	26-30	3/32	50	2 or 3
	Horiz. & Vert.	Single or Double Bevel	210-250	26-30	l/16	50	3 or 4
	Overhead	Single or Double Bevel	225-275	26-30	l/16	80	8 to 10
1	Flat	Single or Double Bevel	320-375	26-30	3132	60	4 to 5
	Horiz. & Vert.	Single or Double Bevel	225-275	26-30	l/16	60	4 to 6
	Overhead	Single or Double Bevel	225-275	26-30	l/l6	80	15 or more
2 (3)	Flat	Single or Double Bevel	350-425	26-30	3/32	60	12 or more
3 (3)	Flat	Single or Double Bevel	350-450	26-30	3/32	60	20 or more

(l) See exercises for Joint Designs.

(2) Gas flows for helium are slightly higher than for argon. Lower flows are possible as mentioned in Part I-Basic Theory.

(3) Preheat optional.

in the welding area. This last factor can affect gas usage and weld quality considerably, so it is recommended that the welding area be essentially draft-free. When welding in the field, suitable shielding with curtains or other type of windbreak should be provided to prevent natural air currents from interfering with the gas flow. Recommended gas flows for GMA welding are shown in table 10-9.

Filler Metal

Filler wire of EC, 1100, 4043, 5154, 5183, and 5356 and others are available in 0.030-, 3/64-, l/16-, and 3/32-inch diameters. It is necessary that the correct alloys be used for the specific welding job. The recommended alloy of filler wire for the various alloys is shown in table 10-10. The recommended filler wire diameters for welding various metal thicknesses and in different current ranges are listed in table 10-11.

The wire that you use must be clean. Unsound welds result from wire that has been contaminated by oil, grease, dust, or shop fumes. Your best welding results are obtained by using wire that has just been taken out of its carton. Wire should be

Table 10-10.—Recommended Filler Materials for GMA Welding of Various Aluminum Alloys

Parent Metal Sheet, Plate or Tube	Filler Alloy
EC	EC/1100
1100	1100/4043
2219	2319
3003	1100/4043
3004	5356/4043
5005	5356/4043
5050	5356/4043
5052	5138/5356
5154	5138/5356
5083	5138/5356
5086	5356/5138
5454 (l)	5554/5356
5456	5556/5138
6061	5356/4043
6063	5356/4043
7039	X5039/5183

(1) For high temperature applications, first choice for filler metal is alloy 5554 otherwise, use 5356 or 5183 for higher strength weldments.

Table 10-11.—Recommended Welding Current Ranges for Various Diameters of GMA Filler Wire

Filler Wire Diameter Inches	Welding Current Amperes
0.030	75-150
3/64	120-210
l/16	165-300
3132	240-450
l/8 (l)	400 and up (2)

(1) Normally used for automatic welding.

(2) Maximum welding current dependent on the power source.

stored in a hot locker or in a warm dry area and should be kept covered. If welding is stopped for any length of time, remove the wire and place it in the original carton to prevent possible contamination.

PRACTICE EXERCISES FOR GMA WELDING

Before welding with GMA equipment, be sure that all controls are properly adjusted, all connections are correctly made, and all safety precautions are being observed. Wear protective clothing, including a helmet with a suitable filter lens. Hold the welding gun as shown in figure 10-51. Support the weight of the welding cable and

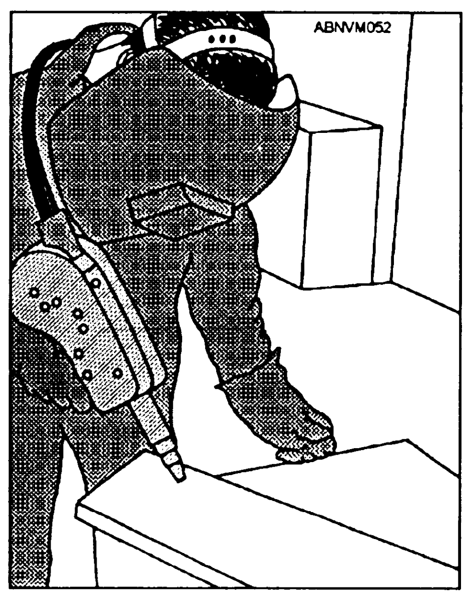


Figure 10-51.—Positioning the GMA gun prior to welding.

gas hose across your shoulder to ensure free movement of the welding gun. Hold the gun close to, but not touching, the workpiece. Lower your helmet and squeeze the trigger on the gun. Squeezing the trigger starts the flow of shielding gas and energizes the welding circuit. The wire-feed motor is not energized until the wire electrode comes in contact with the workpiece. Move the gun toward the work, touching the wire electrode to the work with a sidewise scratching motion as shown in view A of figure 10-52. To prevent sticking, pull the gun back quickly, about one-half inch, the instant contact is made between the wire electrode and the workpiece. The arc will strike as soon as contact is made and the wire-feed motor will feed the wire automatically as long as the trigger is held.

To break the arc, just release the trigger. This breaks the welding circuit and also de-energizes the wire-feed motor. The wire electrode may stick to the work when you strike the arc, or at any time during welding. If that happens, release the trigger and clip the wire with a pair of pliers or side cutters.

A properly established arc has a soft, sizzling sound. The arc itself is about one-fourth inch long, or about one-half the distance between the gun nozzle and the work. If the arc does not sound right, adjust the wire-feed control dial or the welding machine itself. For example, a loud, crackling sound indicates that the arc is too short and that the wire-feed speed is too fast. Correct this by moving the wire-feed dial slightly counterclockwise. This decreases wire-feed speed and increases arc length. A clockwise movement of the dial has the opposite effect. With experience, you will be able to recognize the sound of the proper length of arc.

Use the forehand technique for welding. Hold the gun at an angle of 5° to 20° from the vertical position, as shown in view B of figure 10-52. A right-handed person welds from right to left. The forehand technique provides the best coverage of shielding gas to the weld area, and the operator has a better view of the weld joint. A left-handed person holds the gun in the same position relative to the surface of the base metal, but welds from left to right.

You should first learn to strike and establish an arc and to adjust the wire feed and welding current to obtain the proper arc characteristics. Then you should learn to run a bead. To run a practice bead, select the proper current setting, gas flow, and correct size filler wire as recommended in table 10-9; then, proceed as follows:

1. Hold the gun in the proper position, close to but not touching the surface of the work, and squeeze the trigger.

2. Lower your welding helmet and strike the arc.

3. Hold the gun at the starting point until a puddle forms.

4. As soon as you see a puddle, move the gun forward steadily at a rate that permits the work and the electrode to melt at the same time. Keep the arc in the pool of weld metal. Do not direct it into

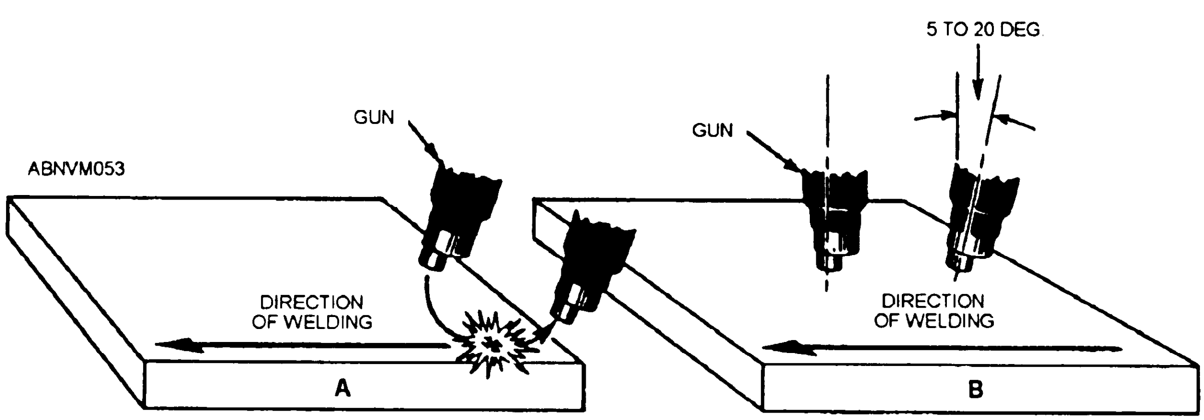


Figure 10-52.—GMA welding. (A) Striking the arc. (B) Gun angle.

the base metal. A thin, irregular bead will result if you move forward too rapidly. Undercutting may result if you move the gun forward too slowly. A good bead is uniform in width and height. The ripple is uniform, and there is no overlap or undercut at the edges.

Some of you may want to move the gun along the line of weld with a steady forward motion. Others prefer to run a bead with a reciprocating technique like that shown in figure 10-53. When you use this technique, strike the arc and then slowly move the gun forward along the line of weld about one-half inch and then back about one-fourth inch. Continue this one-half inch forward and one-fourth inch backward motion along the line of weld. If you want a wide bead, use a side weave. Here, the gun is moved uniformly back and forth across the line of weld while steadily moving along the line of weld. The width of the bead determines the amount of sidewise movement.

Although GMA welding does not require the use of a flux, it does require that the base metal be clean. Aluminum and aluminum alloys should be cleaned with an approved compound, or with a stainless-steel wire brush. Any grease should be removed with a solvent before cleaning with a compound. Stainless-steel wire brushes that have picked up grease should be cleaned with a solvent before they are used to clean aluminum for welding.

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 procedures. However, there are some pitfalls. Porous welds may result from the following causes:

- Low arc voltage (less than 26 volts)
- Low welding current
- Inadequate shielding gas flow resulting from a low cylinder pressure, from restrictions in the gas passages of the equipment, or from improper adjustment of the flowmeter
- Excessive weaving or whipping of the welding gun
- Poor fit-up of parts
- Improperly cleaned base metal, or dirty welding wire
- Nonuniform wire-feed speed

Welder fatigue is often the cause of poor weld quality and low output. You will learn that the quality and quantity of your work improves as you learn to weld comfortably. Out-of-position welding is usually more awkward than flat position; therefore, arrange the work for flat position welding whenever possible for economy and quality.

Satisfactory weld results also depend on good maintenance of the GMA equipment. Maintenance procedures are outlined in the manufacturer’s technical manual furnished with the equipment. Weld beads made with too low, too high, and the correct current are shown in figure 10-54.

Notice the lack of penetration and "ropy" appearance of the weld bead made with insufficient welding current. Also, note the deep penetration

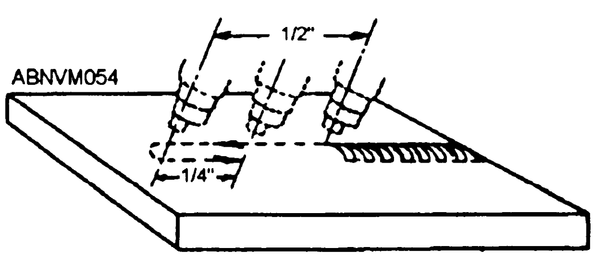


Figure 10-53.—Reciprocating technique for GMA welding.

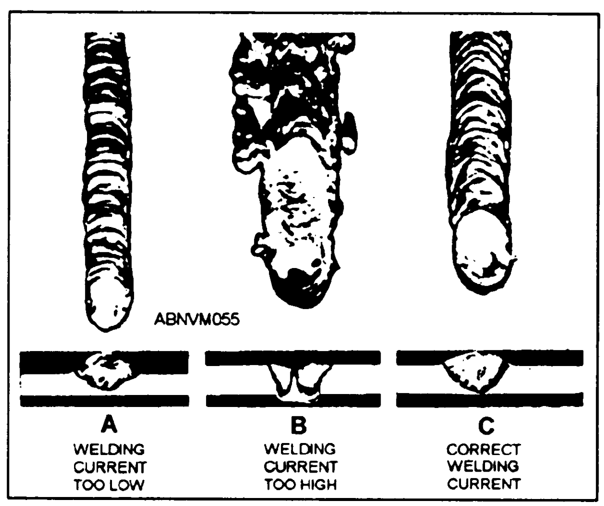


Figure 10-54.—Weld bead characteristics determined by welding current.

and flat appearance of the bead made with excessive welding current.

Weld beads made with sufficient and insufficient shielding gas are shown in figure 10-55. Inadequate shielding gas gives an unsound weld bead having a dirty appearance. Using too much shielding gas is wasteful and may cause weld turbulence and porosity. Note the appearance and penetration of the bead made with the proper current and gas flow. Recommended flows of shielding gas for various thicknesses of plate are shown in table 10-9.

If the sample weld shows evidence of poor or careless workmanship, having spatter and cracks, or has bead appearance as indicated in views A and B of figure 10-54 or view B of figure 10-55, it is unsatisfactory. Continue to practice until you can make a weld that will pass visual inspection. Practice making weld beads on flat plate until satisfactory workmanship results. Practice is necessary to develop a "steady" hand. If the appearance of your weld beads is equivalent to the ones shown in figure 10-56, the sample is satisfactory to visual examination.

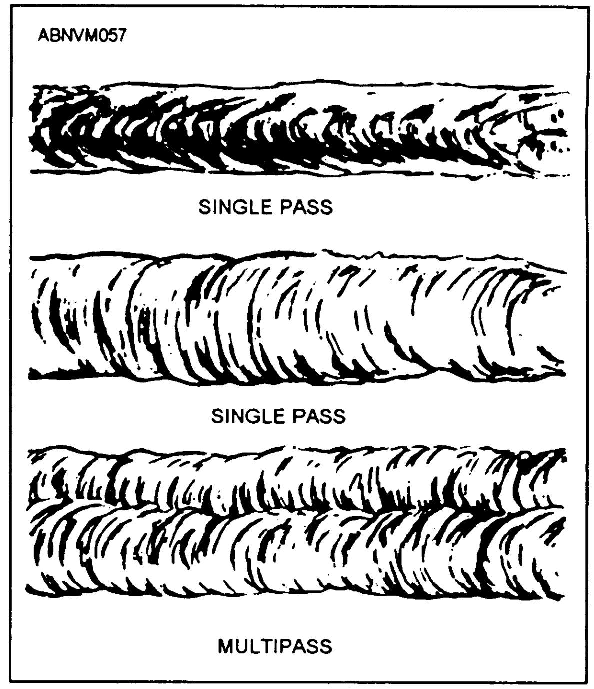


Figure 10-56.—Acceptable single-pass and multipass GMA welds.

To be proficient as a welder, you must be able to make all the various types of welds in the flat, vertical, horizontal, and overhead positions. The following exercises will aid you in learning the techniques employed in making different types of welds in all positions.

Flat-Position Single-Pass Butt Welds

This exercise will help you make a single-pass butt weld in aluminum plate. You will need 3/8" by 6" by 12" EC aluminum plate and l/16-inch diameter 1100 alloy filler wire, or any other recommended parent plate-filler wire alloy combination. You will also need a backing strap 1/4" by 1 1/2" by 12", cut from the parent plate or thinner aluminum alloy section compatible with the workpiece. In addition, you will need a suitable solvent or cleaner for removing dust or grease. Use the standard equipment and necessary accessories. Saw or machine bevel the abutting plate surfaces, allowing for land. Thoroughly clean the weld surface areas, including the backing strap. Regulate the gas flow at 50 cubic feet per hour, and select a welding current of 230 to 300 amperes.

Aluminum plates should be prepared and placed as shown in figure 10-57. When so placed, there should be a slight gap between the two aluminum

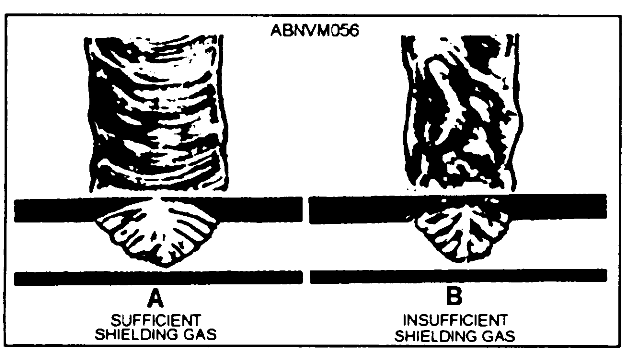


Figure 10-55.—Weld bead characteristics determined by shielding gas.

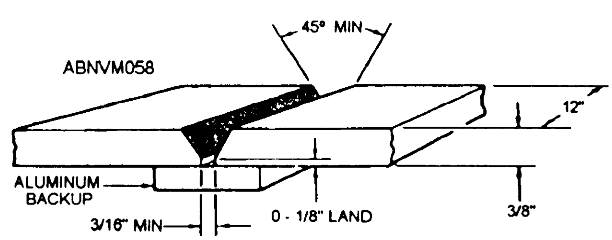


Figure 10-57.—Joint design flat-position, single-pass butt welds in aluminum plate.

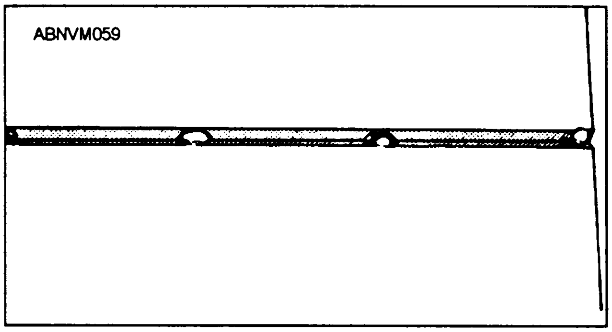


Figure 10-58.—Plates tack-welded and aligned for GMA welding.

sections to permit good root fusion in the butt weld. Ordinarily, when using a backing strap, the gap between the parts to be welded should be not less than the diameter of the filler wire. Slightly more space is preferable. After the plates are aligned and rigidly supported, tack weld, as shown in figure 10-58, before making the single weld pass. Bring the gun into the forehand welding position, as shown in figure 10-51. Hold the gun 5° to 20° from the vertical, pointing in the direction of travel. After the arc is initiated, move the gun forward at the proper angle and speed as shown in figure 10-59.

The angle of the gun is dependent upon both the speed of travel and the position of the joint. Adjust this angle to give the proper cleaning action, depth of penetration, and bead contour. When welding unequal sections, direct the arc against the heavier piece to obtain equal fusion in the two edges.

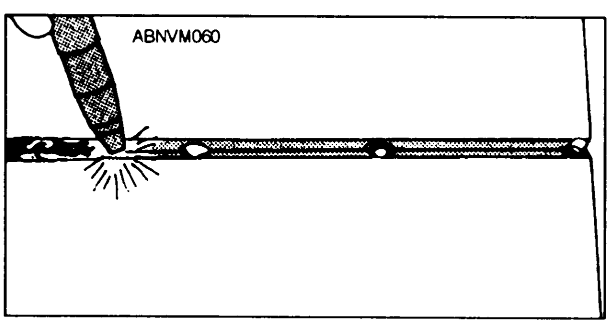


Figure 10-59.—Moving the welding gun forward at the proper angle.

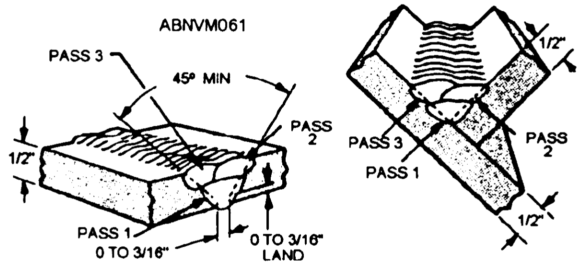


Figure 10-60.—Joint design and weld pass sequence flat-position multipass butt welds in aluminum plate.

The correct arc length is very important. Too short an arc will cause porosity; too long an arc will result in lack of fusion. A proper arc is between one-eighth inch to three-eighths inch long, depending on the current, joint, and filler wire alloy. The correct arc length, when struck, will produce a smooth sizzling or hissing sound.

Practice making single-pass butt welds, according to the procedure outlined, until your weldments can pass the usual inspection standards. Defective tack welds or defective sections of the main weld can be chipped out and the area rewelded.

Flat-Position Multipass Butt Welds

This exercise will help you make multipass flat-position GMA butt welds in aluminum plate. The material requirements include 1/2" by 6" by 12" EC aluminum plate and 3/32-inch diameter 1100 alloy filler wire, or any other parent plate-filler wire alloy combination recommended for welding; a compatible aluminum alloy backing strap, if used, and degreasing solvent or solution.

Prepare the abutting plate edges by milling or sawing to the proper angles, shown in figure 10-60. Clean the weld area and backing strap, if used. Use solvent, and wipe dry. When more than a single pass is made, wire brush after each pass if contamination is visible. Regulate the gas flow at 50 cubic feet per hour, and use a welding current of 280 to 320 amperes.

One method of weld pass sequence is shown in figure 10-60. You should always watch the weld pool. This is the only way to determine if there is proper penetration and fusion. The fluidity of the

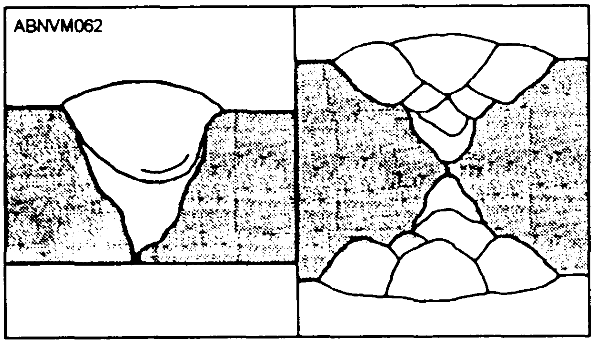


Figure 10-61.—Gross section of two welds showing poor root fusion and too heavy a root face.

molten pool, especially near its edges, is important. The gun angle used for making multipass butt welds in the flat position is the same as that used in making single-pass butt welds. It is sometimes necessary to lower the welding current when making later successive passes because of heat buildup. Clean between passes with a stainless-steel wire brush for improved welding results. Etched cross sections of two welds, shown in figure 10-61, illustrate poor root fusion caused by too heavy a root face and/or inadequate joint spacing. Welding with too low a welding current or too high a welding speed may also cause this condition.

Gross porosity in a weld is clearly shown in figure 10-62. Insufficient shielding gas, improperly cleaned plate, or dirty filler wire will cause such porosity.

Voids in multipass butt welds are often caused by dirty plate, dirty filler wire, or improper welding technique. (See fig. 10-63.)

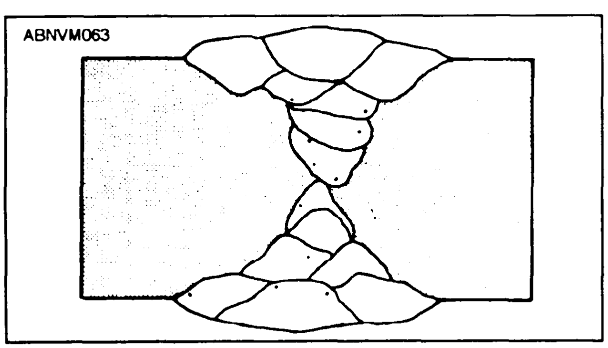


Figure 10-62.—Grass porosity in a multipass butt weld.

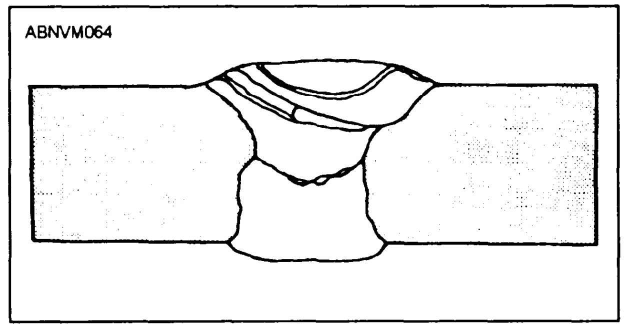


Figure 10-63.—Voids in multipass butt welds.

Cross sections of good multipass GMA butt welds are shown in figure 10-64. The welds have good root fusion and are free from weld skips, inclusions, and porosity.

Practice the weld joints shown in figure 10-60 until your workmanship is satisfactory. Take care that you do not melt or fuse the backup when making the root pass of a joint using a steel orcopper backup. If this does happen, the root pass

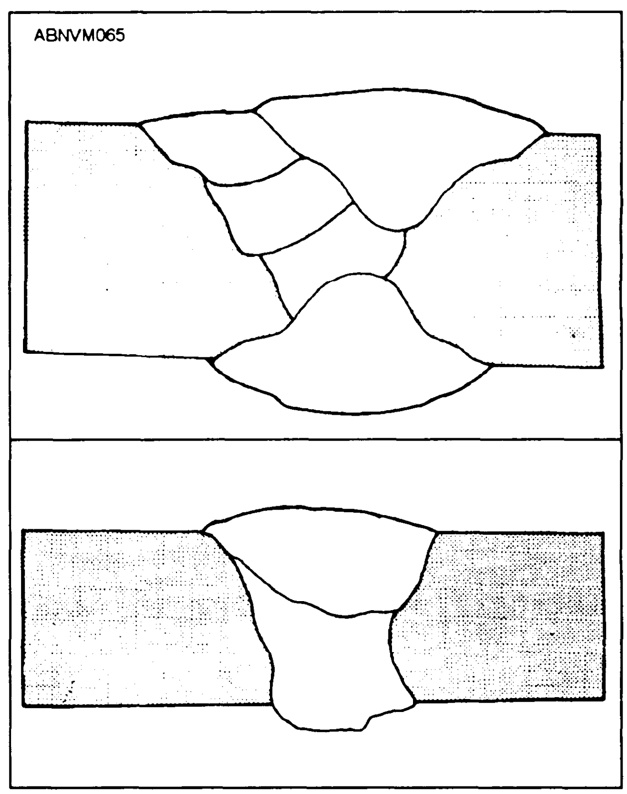


Figure 10-64.—Cross section of good multipass GMA welds free from defects.

may become contaminated with steel or copper and will be less ductile.

In addition, complete an extra weldment without backup. If there is a lack of penetration, make a seal or finishing bead along the root of the weld. When high-quality welds are required, the fused back side of the joint may be chipped or burred out to sound metal, making a groove suitable for welding. This is shown in figure 10-65.

Horizontal-Position Multipass Fillet and Butt Welds

This exercise will help you learn horizontal-position GMA welding. You will need 1/2" by 6" by 12" EC aluminum plate and l/16-inch diameter 1100 alloy filler wire, or any other recommended parent plate-filler wire alloy combination. You will also need a cleaning solvent or solution.

The equipment will be the dc rectifier, GMA welding gun, filler wire, gas, and necessary accessories. You will also need a jig to hold the plates in position.

Prepare the abutting edges of the plate by machining or grinding to the proper angles, shown in figure 10-39. Clean and dry the weld areas. Brush with a stainless-steel wire brush before the initial weld pass is made, and also after each successive pass if contamination is apparent.

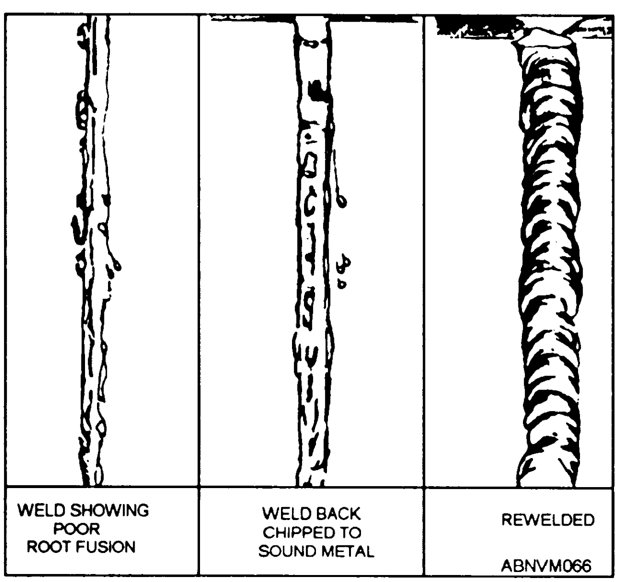


Figure 10-65.—Chipping out the fused back side of a joint to make a high-quality weld.

Regulate the gas flow at 50 cubic feet per hour, and use a welding current of 210 to 250 amperes.

Follow the pass sequence as indicated in figure 10-39. Make certain that sections are properly fitted and jigged.

All rules for quality welding in the flat position must be followed for out-of-position GMA welding. Cleanliness, good joint fit-up, sufficient shielding gas, correct welding current, and so on, are important. You should not use a high welding current or deposit too large a weld bead. Welding wire one-sixteenth inch in diameter is recommended when butt welding one-half inch thick plate in the horizontal position. This compares to 3/32-inch diameter welding wire for the same thickness of plate in the flat position.

Take special care to direct the arc so that you do not overheat any one area. This may cause sagging or undercutting. The welding speed, bead size, and bead sequence have to be such that there is no lack of fusion between passes. The welding of a fillet and a butt joint in the horizontal position is shown in figure 10-66. Practice welding these two joints until your workmanship is satisfactory.

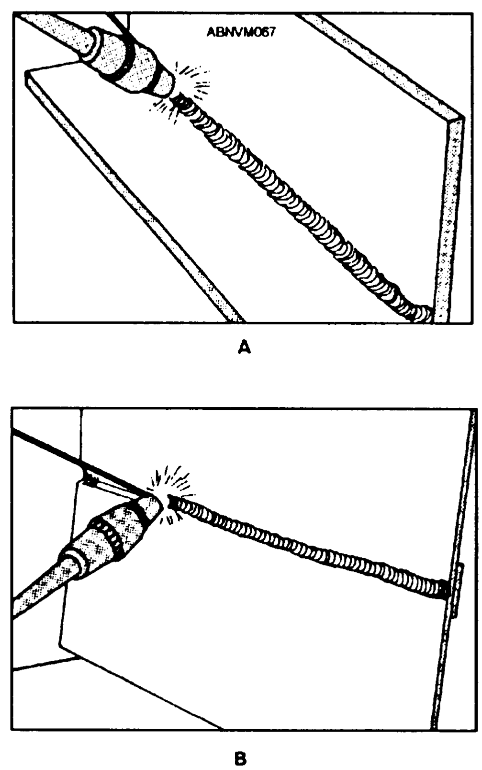


Figure 10-66.—Welding a fillet and butt joint in the horizontal position.

Vertical-Position Multipass Fillet and Butt Welds

This exercise will help you learn vertical-position GMA welding. The materials and equipment needed are the same as those described for horizontal-position welding. The gas flow and current range are also the same. Machine or grind the abutting plate edges to the angles shown in figure 10-42. Thoroughly clean and dry the weld areas. Clean with a wire brush between passes if contamination shows in the weld area.

Follow the weld sequence shown in figure 10-42. Make all welds in the upward direction. Take care to fit the parts to be welded with the root space shown.

Fillet and butt welds made in the vertical position are shown in figure 10-67. Note that the welding is done upward. All factors concerning out-of-position horizontal welding also apply here. Do not use too high a welding current or deposit too large a weld bead. If the molten pool is too large, the effects of gravity will make it difficult to control. Bead size, weld speed, and bead sequence must be such that there is no lack of fusion between passes. Some welders find that a slight side-to-side weave, approximately one-eighth inch, when done smoothly and evenly, is helpful in vertical welding.

Overhead-Position Multipass Fillet and Butt Welds

This exercise will help you learn overhead-position GMA welding. The materials and equipment are the same as those used for horizontal- and vertical-position welding. However, in overhead-position welding, the gas flow is regulated to flow at 60 cubic feet per hour, and the welding current is selected at 225 to 275 amperes.

Prepare edge angles of abutting plates by machining or grinding as shown in figure 10-44. Clean and thoroughly dry the weld areas, using solvent to degrease the metal. Surfaces on which weld metal will be deposited should be wire brushed to remove aluminum oxide coating. Brush with a stainless-steel brush after every pass if there is contamination. Follow the weld sequence shown in figure 10-44. Figure 10-68 shows a welder making overhead multipass fillet and butt welds.

Here, as in vertical welding, a slight weave may or may not be used. A lower welding current and travel speed are used as compared to flat-position welding. Conversely, a higher flow of shielding gas is used. Take extreme care to avoid sagging and poor penetration. Trying to deposit too much metal and carrying too large a weld pool is the direct cause of such conditions. Most inexperienced welders find overhead welding awkward. Assume as comfortable and relaxed a position as possible, and

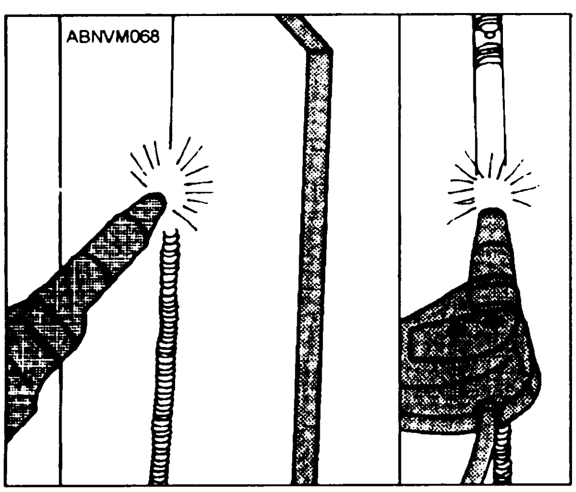


Figure 10-67.—Welding fillet and butt joints in the vertical position.

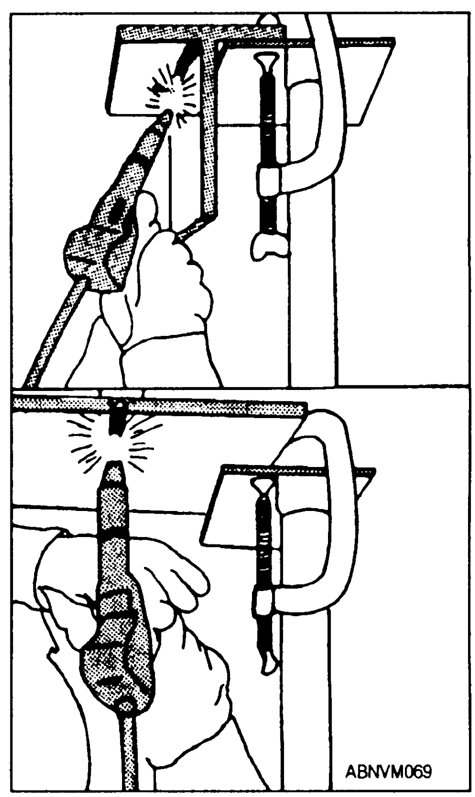


Figure 10-68.—Welding overhead multipass fillet and butt welds.

this will help you with the steady gun handling necessary for quality welding. Practice until your overhead welds pass visual inspection.

Horizontal Fixed-Position Multipass Welding

This exercise will help you learn GMA welding of aluminum pipe, with and without backup, in the horizontal fixed position. For this exercise, use 5-inch diameter standard aluminum pipe 6061 alloy and 1/16-inch diameter 4043 or 5356 alloy filler wire, or any recommended parent metal-filler wire alloy combination. You will also need a backing ring. Equipment requirements include a dc generator or rectifier, a GMA welding gun, filler wire, gas, and necessary accessories. You will also need a jig for holding the pipe in the welding position.

Pipe edges should be angled to the degree indicated in figure 10-69. Insert a backup ring and place the assembly in a holding jig; or, place two abutting sections in the jig if a backing ring is not used. Thoroughly clean and dry the weld area.

Wire brush the tile surface to remove the protective oxide coating. Brush again after each pass if contamination appears. Regulate the gas flow at 60 cubic feet per hour, and select a welding current of 150 to 190 amperes. Follow the weld sequence as shown in figure 10-69.

Horizontal fixed-position welding is often considered a test to qualify for welding in any location. You must weld in the flat, vertical, and overhead positions. Manipulation of the GMA gun for welding pipe in the horizontal fixed position is shown in the photographic sequence in figure 10-70.

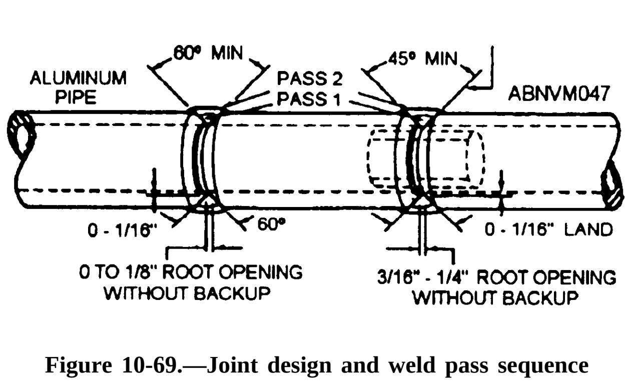


Figure 10-69.—Joint design and weld pass sequence horizontal fixed-position multipass GMA welding.

Since this welding involves flat, vertical, and overhead welding, you should be able to weld satisfactorily in all of these positions before attempting fixed-position welding. Determining factors for quality welds, previously discussed, also hold true here.

Most welders prefer to use a backing ring for pipe welding, when possible, because it makes welding easier and faster. With backup, the joint

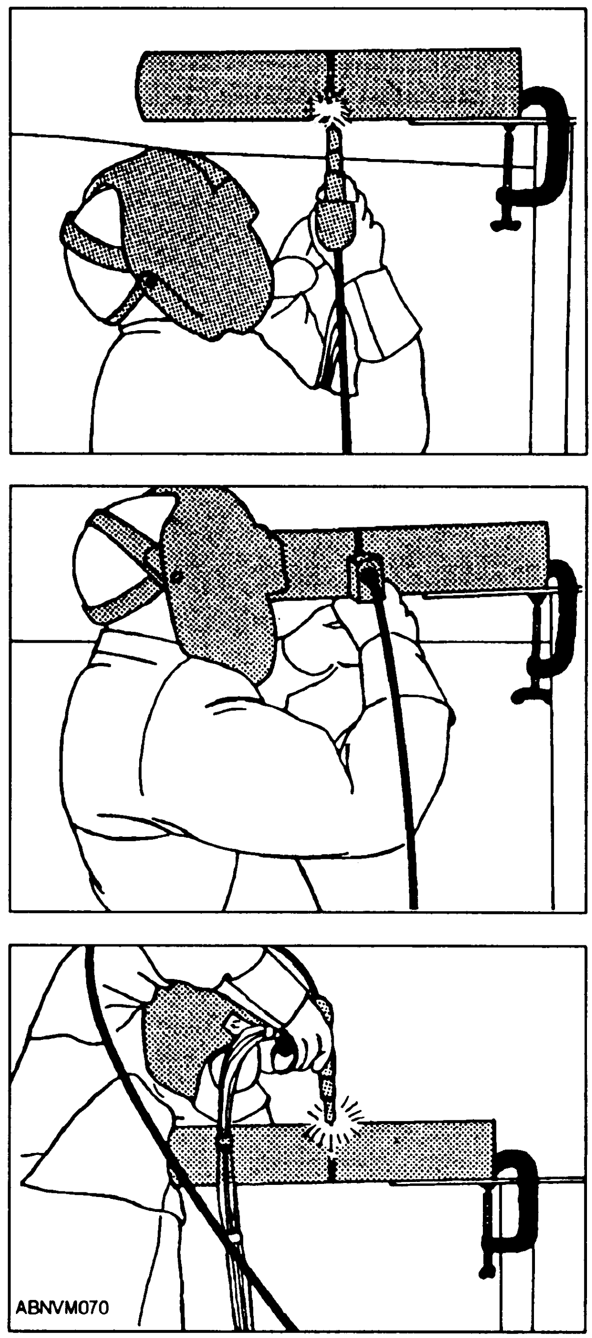


Figure 10-70.—CMA gun manipulation for welding pipe in the horizontal fixed position.

fit-up and the control of penetration are not as critical.

SAFETY

Safety must be observed in GTA and GMA welding as in any other welding process. In addition to the safety precautions listed in chapter 1 of this manual, the following general precautions should also be observed:

1. The welding area must be properly ventilated without excessive drafts that can affect the welding arc and shielding gas. Carbon tetrachloride or other chlorinated hydrocarbons should NOT be used for cleaning aluminum before welding. Alcohol and acetone are recommended as chemical cleaners, but surfaces cleaned with these materials should be thoroughly dried before welding. Welding should not be done in any area where fumes from such solvents are present.

2. The ac transformer used for GTA welding or the dc generator rectifier for GMA welding is normally fed from a 220- to 440-volt circuit. These voltages can cause severe or fatal injuries: **DO NOT** work on any wiring in an energized circuit. The deck where welding is being done must be dry.

3. Welding transformers or rectifiers must have a power ground so that welders cannot get a shock from stray current.

4. Do not lay the torch on the work or worktable. Hang it up in a safe place so the electrode is not touching metal that may be grounded.

5. Do not change a tungsten electrode before it has cooled or while the transformer switch is in the "on" position. Do not change spools of filler wire while the generator or rectifier is on.

6. Do not use defective welding cable. If any of the connections are operating hot, you may have a poor electrical connection.

7. Use a welding helmet when looking at the arc. Use the correct shade of lens, usually No. 10 for GTA and No. 12 for GMA. If your eyes become irritated, see the doctor immediately. If not treated promptly, the irritation caused by burning rays of the arc becomes very painful and feels like hot sand in the eyes. The doctor will give you eye drops that will relieve unnecessary suffering.

8. Wear suitable clothing as protection from the spatter or molten particles and to shield your body from rays of the arc.

9. Do not strike an arc on a compressed gas cylinder.

10. Do not weld in the vicinity of inflammable or combustible materials. Degreasing of aluminum with alcohol or other inflammable solvents in an improperly ventilated welding area creates a fire hazard.

11. Do not weld on containers that have held combustible or inflammable materials without first exercising the proper precautions.

12. Do not weld in confined spaces without adequate ventilation or individual respiratory equipment. Do not weld on workpieces without wiping off the degreasing solvent.

13. Mark metal "HOT" because aluminum does not change color when heated.

14. Do not chip or grind without safety goggles and a suitable face shield.

15. Do not move individual cylinders unless the valve protection cap, where provided, is in place and tight.

16. Do not drop or abuse cylinders in any way.

17. Make certain that cylinders are well fastened in their stations so that they will not fall.

18. Do not use a hammer or wrench to open cylinder valves.

19. Never force connections that do not fit.

20. Never tamper with cylinder safety devices.

21. Always protect hose and welding cable from being trampled or run over. Avoid tangles and kinks. Do not leave the hose and cable so they can trip people.

22. Protect the hose, cable, and cylinders from flying sparks, hot metal, hot objects, and open flame.

23. Do not allow hose to come in contact with oil or grease; these rot the rubber and cause a hazard.

24. Be sure the connections between the regulators, adaptors, and cylinder valves are gas tight. Test them with soapy water under gas pressure.

25. When welding is to be stopped for an extended length of time, release the pressure-adjusting screws of the regulators.

26. When welding is to be stopped for a longer time, close the cylinder valves and then release all gas pressure from the regulators and hose.

27. If the equipment is to be taken down, close the cylinder valves, make certain that all gas pressures are released from the regulators and hose, and see that the pressure-adjusting screws are turned in the counterclockwise direction.

28. Use flat black paint on bulkheads and overhead of weld areas to reduce ultraviolet light reflected from GTA or GMA welding areas.

OTHER ELECTRIC WELDING PROCESSES

In addition to the shielded metal-arc process and the two shielded gas processes already described in this chapter, there are two other welding processes that you should know about. These are stud welding and resistance welding. Each of these processes is summarized briefly in the following sections.

STUD WELDING

Stud welding is a relatively simple electric welding-arc process that is used to end-weld studs to plate or other pieces. Stud welding was first developed to fasten wooden decking to steel plates, but it has become widely used for a variety of other applications. The equipment required for stud welding includes (1) a stud welding gun, (2) a timing device to control the time of current flow, (3) a source of dc power for welding, and (4) a supply of specially designed metal studs and ferrules. A typical portable stud welding gun is shown in figure 10-71. Figure 10-72 shows the connections between the various units in the system.

The heat necessary for coalescence is produced by an electric arc that is drawn between the metal stud (held in the gun) and the other workpiece part. When the stud and the other piece have reached the required temperature, they are brought together under slight pressure from a spring in the gun. The process requires relatively little skill, since many factors are controlled automatically. When you press the trigger of the gun, the arc is established and controlled, the welding time is controlled, and the stud is plunged against the plate at the proper time and held in place until the weld is completed.

If you have problems getting sound welds, check these three common errors made while stud welding.

- Improper amperage supplied to the stud gun from the power source. Welding of 5/8-inch studs requires amperage settings of up to 750 amps. Most stud guns require special power sources that can deliver such high amperages. Most shop welding machines cannot deliver enough amperages to properly weld studs over l/4 inch.

- Improper welding time selected. Consult owner's manual or process instruction for proper weld time selection.

- Base metal not cleaned properly. Remove all rust, paint, oil, or grease from weld area and grind to bare metal.

RESISTANCE WELDING

Of all the electric welding processes discussed in this chapter, resistance welding is the only one that cannot be considered as an arc process. Electrodes are used in resistance welding, but they do not create an arc. Instead, the electrodes (there are usually two of them) are pressed against the workpieces. Current is applied, and the heat necessary for coalescence is produced by the resistance of the workpieces to the flow of a low-voltage, high-amperage current.

Among the processes included in the resistance welding group are spot welding, seam welding, and projection welding. The discussion here is confined to spot welding, since this is the only type of resistance welding that is commonly used aboard ship. Figure 10-73 shows a type of spot welding

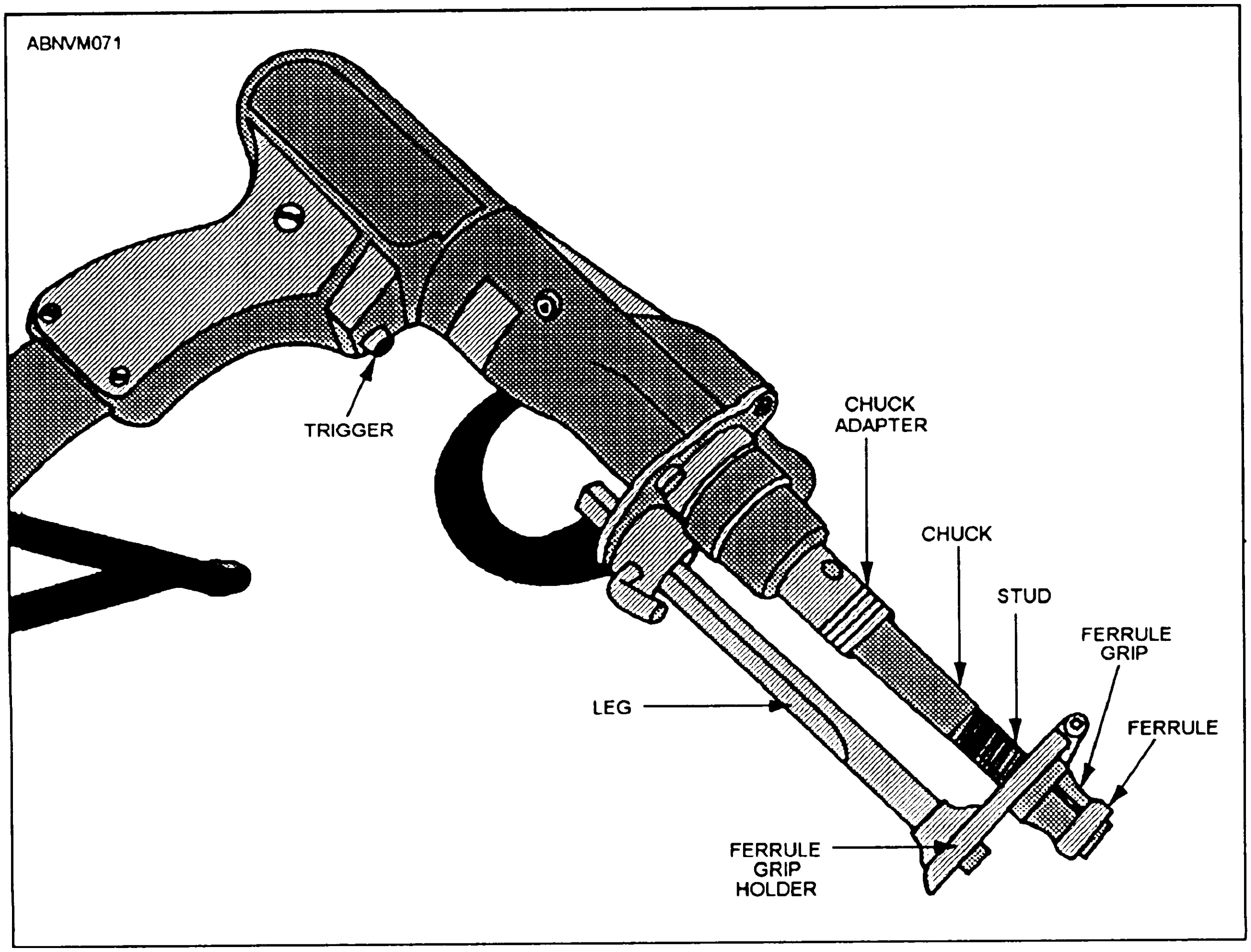


Figure 10-71.—Stud welding gun.

machine that is commonly used on repair ships. The machine serves to (1) transform the available power supply to a suitable welding current; (2) apply

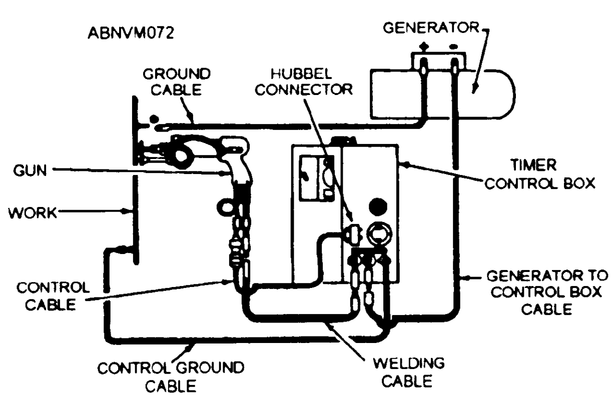


Figure 10-72.—Connection diagram for stud welding.

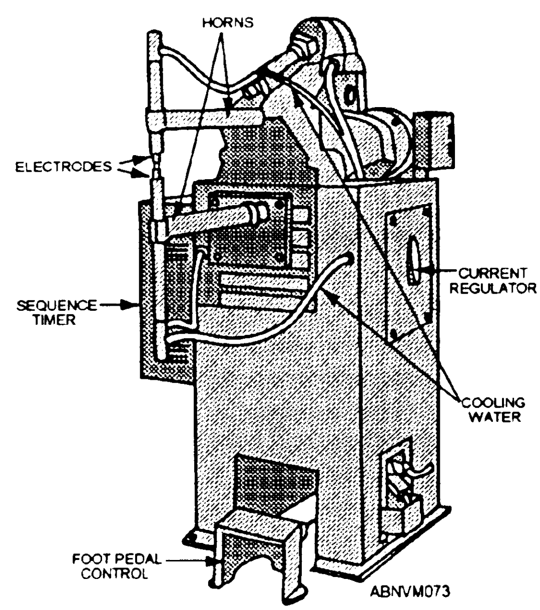


Figure 10-73.—Spot welding machine.

pressure to the work; (3) transmit current to the work; and (4) control the intensity and the duration of both current and pressure.

As may be seen in figure 10-79, the electrodes are held in arms (often called horns). The work is placed between the two electrodes, and the machine is adjusted for the control of current, pressure, and time. The electrode in the lower horn supports the work, provides backing as pressure is applied by the electrode in the upper horn, and completes the welding circuit from the transformer that is located in the machine. A foot pedal control permits the operator to start the welding sequence while using both hands to position the work between the electrodes. When the foot pedal is depressed, the upper electrode moves down into contact with and applies pressure to the work. At the instant the foot pedal is depressed, a preset, automatic timing device takes over. First, the timer provides for SQUEEZE TIME, during which pressure is built up in the pressure system and is applied to the work. Next, at the end of squeeze time, the timer provides WELD TIME, which controls the duration of current flow. Finally, the timer provides HOLD TIME, during which pressure is maintained on the electrodes after current flow stops. Hold time permits the weld nugget to cool and solidify under pressure. The weld that results depends on many factors, including current, pressure, and timing settings; the condition of the electrodes; and the surface condition of the workpiece. Each kind and thickness of material requires an individual setup. These adjustments are based on tables of resistance welding data furnished by the manufacturer.

ARC CUTTING

Arc cutting is a melting process rather than a burning process. The heat of the arc is used to melt the metal along the line of cut. This method does not produce cuts of the quality produced by oxyacetylene cutting, but it has the advantage of being applicable to almost all metals (including nonferrous metals).

Two arc-cutting procedures are commonly used. CARBON-ARC CUTTING is done with a carbon or graphite electrode. SHIELDED METAL-ARC CUTTING is done with a covered metal electrode. DC and straight polarity are preferred for both of these types of arc cutting. Conventional arc welding power sources are used for both of these types of arc cutting.

The procedure for arc cutting is shown in figure 10-74. When cutting thin plate (under one-half inch), you do not need to manipulate the electrode except as required to maintain the arc and to advance the arc as the cut progresses (fig. 10-74, view A). When cutting heavier plate, manipulate the electrode with an up-and-down motion in the cut so as to displace the molten metal; keep the electrode at an angle to the plate (fig. 10-74, view B) so that the bottom of the plate is cut slightly before the top. In general, metal-arc cutting is better than carbon-arc cutting through heavy sections. Metal-arc cutting is also generally preferred for rivet cutting and for hole piercing. Gas tungsten-arc cutting is an arc-cutting process used for cutting aluminum alloys. A high-temperature, high-velocity arc is established between the tungsten arc and the workpiece. A shielding gas mixture of hydrogen and argon emerges from the nozzle at a sufficiently high velocity to blow the molten metal from the cut. Most of the safety precautions concerning arc welding that are given in chapter 1 of this training manual also apply to arc cutting. Be sure that you are entirely familiar with all appropriate safety

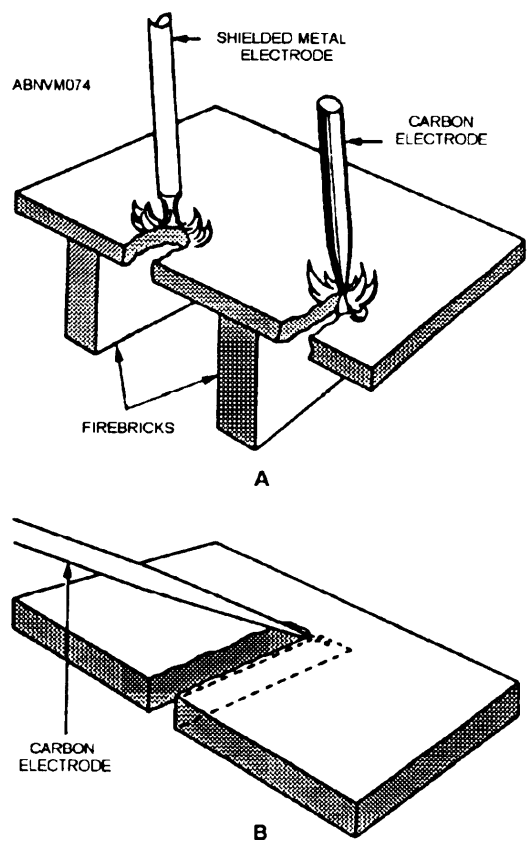


Figure 10-74.—Techniques for arc cutting. (A) Thin plate. (B) Heavy plate.

precautions before attempting any arc-cutting operation.

Air carbon-arc cutting is a method of cutting or gouging metal by melting it with the heat of an electric arc and blowing away the molten metal with a high-velocity jet of compressed air. The flow of compressed air is parallel and external to the carbon electrode. Because it does not depend upon oxidation of the metal, air carbon-arc cutting is very effective in cutting nonferrous metals.

The air carbon-arc gun shown in figure 10-75 is used to clamp a carbon-graphite electrode in such a position that air emitted from orifices in the gun nozzle is directed parallel to the electrode. The air then strikes the molten metal immediately behind the arc. The gun also contains an air control valve and the cable that carries both the current and the air. This cable is connected to a dc welding machine delivering reverse polarity current, and also to a source of compressed air.

The carbon electrodes used for this cutting process are copper coated to increase their life, provide a uniform cut, increase their current-carrying capacity, and reduce the radiated heat. The carbon electrodes, used with the gun shown in figure 10-75, may vary in diameter size

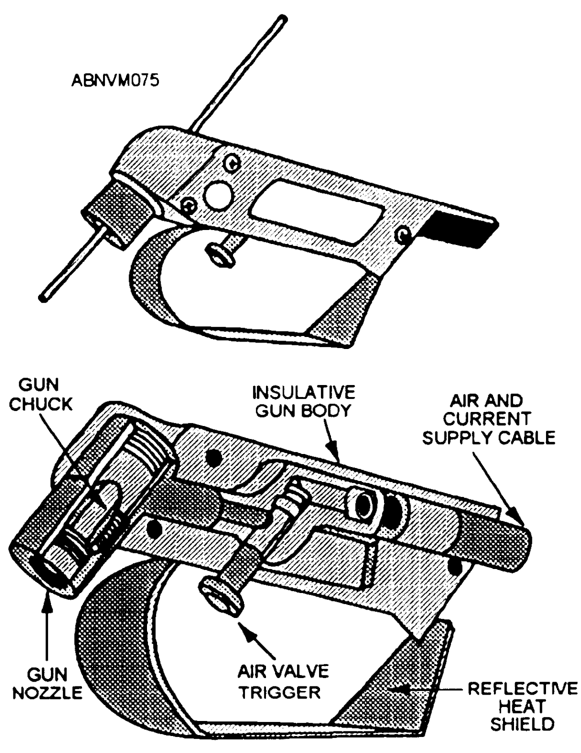


Figure 10-75.—Air carbon-arc gun.

from 5/32 to 3/8 inch. The amperage settings for these rods should be according to the recommendations of the manufacturer, but may vary from a minimum of 75 amps for the 5/32-inch rod to a maximum of 800 amps with the 3/8-inch rod.

The compressed air for this process is supplied by the ship’s low-pressure air system or by an appropriate air compressor. Most cutting applications require 80 to 100 psi air pressure, although pressures as low as 40 psi can be used for light work. On heavy work, pressures up to 125 psi may be necessary. The air supply hoses for this process should have a minimum inside diameter of one-fourth inch, and there should be no restrictions of the air flow through the hoses.

To make a cut, hold the gun with the electrode at the desired angle of cut and strike an arc between the end of the electrode and the metal to be cut. The jet of compressed air is then turned on by depressing the air valve trigger. After being depressed, the trigger may be turned a quarter turn in either direction for continuous flow of air. The air jets are directed immediately behind the point of arcing, and the electrode is moved forward as the molten metal is blown away by the air jets. Speed of travel is determined by the electrode size, type of metal being cut, amperage setting, and air pressure used. Proper speed of travel produces a good clean cut and is recognized by a smooth hissing sound.

Air carbon-arc cutting offers certain advantages over oxyacetylene cutting. The heat penetration is shallower with this process, and the volume of metal adjacent to the cut which is subjected to a high rise in temperature during cutting is also less. As a result, there is less warpage and distortion of the metal being cut.

In all cutting operations, be careful that hot slag does not come in contact with any combustible material. Globules of hot slag can roll along a deck for quite a distance. Do not cut within 30 or 40 feet of unprotected combustible materials. If combustible materials cannot be removed, cover them with sheet metal or another noncombustible material.

Many of the safety precautions discussed in chapter 1 of this training manual apply to cutting as well as to welding. Be sure that you are entirely familiar with all appropriate safety precautions before attempting any cutting operation.

SUMMARY

You have been introduced to welding equipment, its use, and the safety precautions associated with the equipment. Various processes and techniques were also discussed to give you an insight to welding and arc-cutting operations. However, knowing both the equipment and the safe operation of this equipment is only the first step. Your ultimate goal is to put your knowledge to use.

CHAPTER 11

NONDESTRUCTIVE TESTS AND INSPECTIONS OF WELDS

LEARNING OBJECTIVES

Upon completion of this chapter; you will be able to do the following:

- Describe the various types of nondestructive tests (NDTs) performed on welded or brazed joints.
- Discuss some of the equipment used to perform NDTs
- Describe the various nondestructive testing symbols used.
- Discuss the procedures for hydrostatic and operational tests of ships' systems and piping systems.

INTRODUCTION

A component is only as good as its weld. If the weld is not sound and is subject to cracking under normal wear and use, then the material that has been welded is of no use. Nondestructive tests (NDT) ensure that the welds, castings, forging, and components are of good quality. This chapter will discuss the various NDT methods used.

When tests are specified, the specifications or standards will outline in detail (1) which part is to be inspected, (2) the testing procedure that must be used, (3) the extent of the part that will be inspected, (4) the qualifications of the persons making the test, (5) the qualifications of the persons evaluating the results of the test, (6) the acceptance levels that the test must show, and (7) the materials and equipment to be used.

Unspecified tests (tests not in the standards) may be made, but they cannot be considered as final acceptance tests unless they are specifically approved by the Naval Sea Systems Command. Welders are not permitted to inspect their own welds for final acceptance.

There is no standardized waiver of any specified test regardless of the type of organization making or repairing the item. This should be understood by all concerned.

Official (acceptance) tests must be performed by personnel with current certification by the Naval Sea Systems Command. These include radiography, liquid penetrant, ultrasonic, and magnetic particle tests. If you are not certified, you may still take part in radiographic tests (RTs) made under the direct supervision of a qualified radiographer if you have had formal training in the *Radiological Affairs Support Manual*, NAVSEA SO420-AA-RAD-010 (RAD-10), rules and regulations. Under these conditions, you may help prepare an item for testing and assist with radiographic exposures according to RAD-10 radiation protection rules.

In the following pages, we will discuss the use of radiography and ultrasonic testing (UT) and some of the limitations of each. We will also provide some information on the uses and limitations of magnetic particle (MT) and liquid penetrant (PT) inspections. The last section of this chapter discusses hydrostatic testing of components.

Before you begin any NDT of welds, you should make a visual inspection (VT) to detect undercutting, weld, spatter, arc strikes, cracks, and other obvious surface defects.

RADIOGRAPHY

To determine the quality of a weld, we must examine the interior of a weld for defects. To detect internal defects, the Navy relies heavily on an inspection method known as radiography. In this method, a beam of radiant energy is passed through the metal and recorded on a radiographic film, which is similar to photographic film. The source of the energy is an X-ray tube of radioactive isotope (Iridium-192). X-ray machines that are practical for use on ships are generally of medium power; that is, they can penetrate metal that is about 3 inches thick. The source used must be according to the guidelines of MIL-STD-271, *Requirements for Nondestructive Testing Methods.*

The action of the penetrating radiation, or "beam," works almost exactly as a beam of sunlight or electric light through air. But instead of being stopped or reflected, as light is by metal or solids, it penetrates the solid and travels through it. Some of the radiation is scattered or absorbed by the solid, and does not get through. A thin section of metal will "pass" more radiation than a thick section. A radiographic film is placed on the side of the metal opposite the source. The image on the film (after development) will show black where more radiation passed through and will show lighter shades or clear white where less radiation, or no radiation, passed through. A hole or other defect in the metal, of even a few thousandths of an inch, will allow more radiation to pass through than passes through the solid metal. The film will show a shadow that is darker at the defect and lighter AROUND the defect.

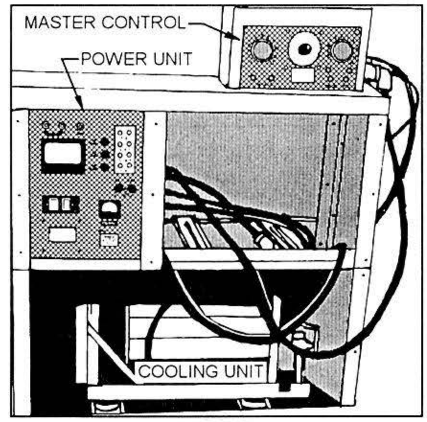
Radiography is used where the full thickness of a part must be inspected, or seen. For best results, use only enough energy to get the picture on the film. The exposure time is figured from factors such as the type of energy, type and thickness of material, film type, screens, distance, and required image density. A thick piece of metal will need a longer exposure time than a thin piece.

X-RAY EQUIPMENT

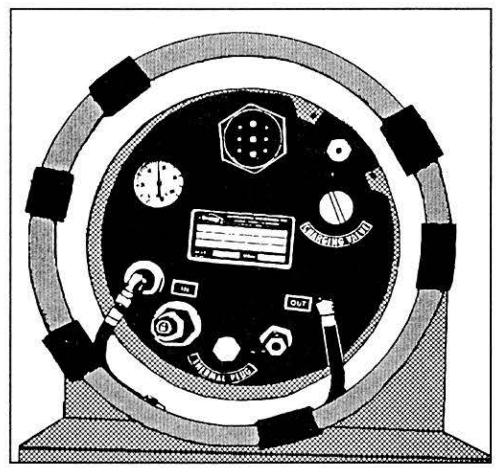
The X-ray equipment used for radiography on some repair ships, tenders, and at shore stations is the 275-kilovolt-peak (LVP), 10-milliamperage (mA) portable X-ray machine. Figure 11-1 shows that the machine consists of three principal units plus electrical cable and water hose.

Power Supply

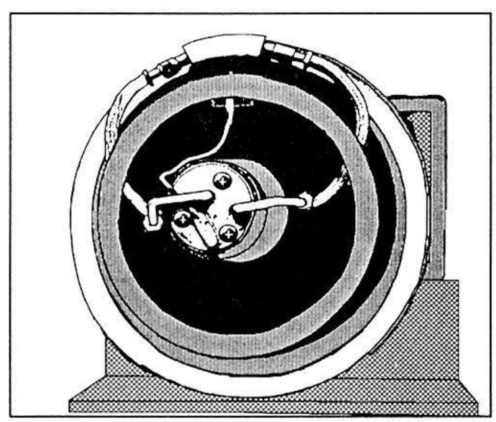
The power supply and cooling unit shown in view A converts 220-volt or 440-volt, three-phase, 60-cycle



PART A
MASTER CONTROL, POWER AND COOLING UNIT.



PART B
FRONT VIEW OF X-RAY TUBE HEAD.



PART C
REAR VIEW OF X-RAY TUBE HEAD.

Figure 11-1.—Portable X-ray unit for a radiographic inspection of metals.

current from the power source to 2,000-cycle, single-phase current. It also circulates a coolant through the X-ray tube head (views B and C) by means of a radiator, water pump, and interconnecting hose.

Master Control

The master control (fig. 11-1, view A), when properly set up with the power supply and tube head (fig. 11-2), provides the means for energizing and adjusting the kilovoltage and milliamperage of the tube head. A timer automatically indicates the elapsed exposure time, and de-energizes the tube at the completion of the exposure. Indicating instruments show the kilovoltage and milliamperage of the X-ray beam emerging from the X-ray tube window.

Transformer

A transformer within the head assembly converts low voltage to the kilovoltage required for the production of X rays by the X-ray tube located in the head. The unit also contains a heat exchanger and blower for removing heat from the transformer and X-ray tube parts. The head is charged with an insulating gas (sulfur hexafluoride) to prevent electrical leakage. The tube that actually produces the X rays is a vacuum tube containing a negative and a positive terminal. The negative terminal is a filament that provides a source of electrons. The positive terminal is a target at which the stream of electrons is focused. A high voltage applied to the tube drives electrons from the cathode, or negative terminal, to the anode, or positive terminal. The higher the voltage, the greater the speed of the electrons; resulting in a higher range of radiation.

PRINCIPLES OF X-RAY GENERATION

The principle of X-ray generation is illustrated in figure 11-3. Heat and X rays are generated when rapidly moving, negatively charged particles

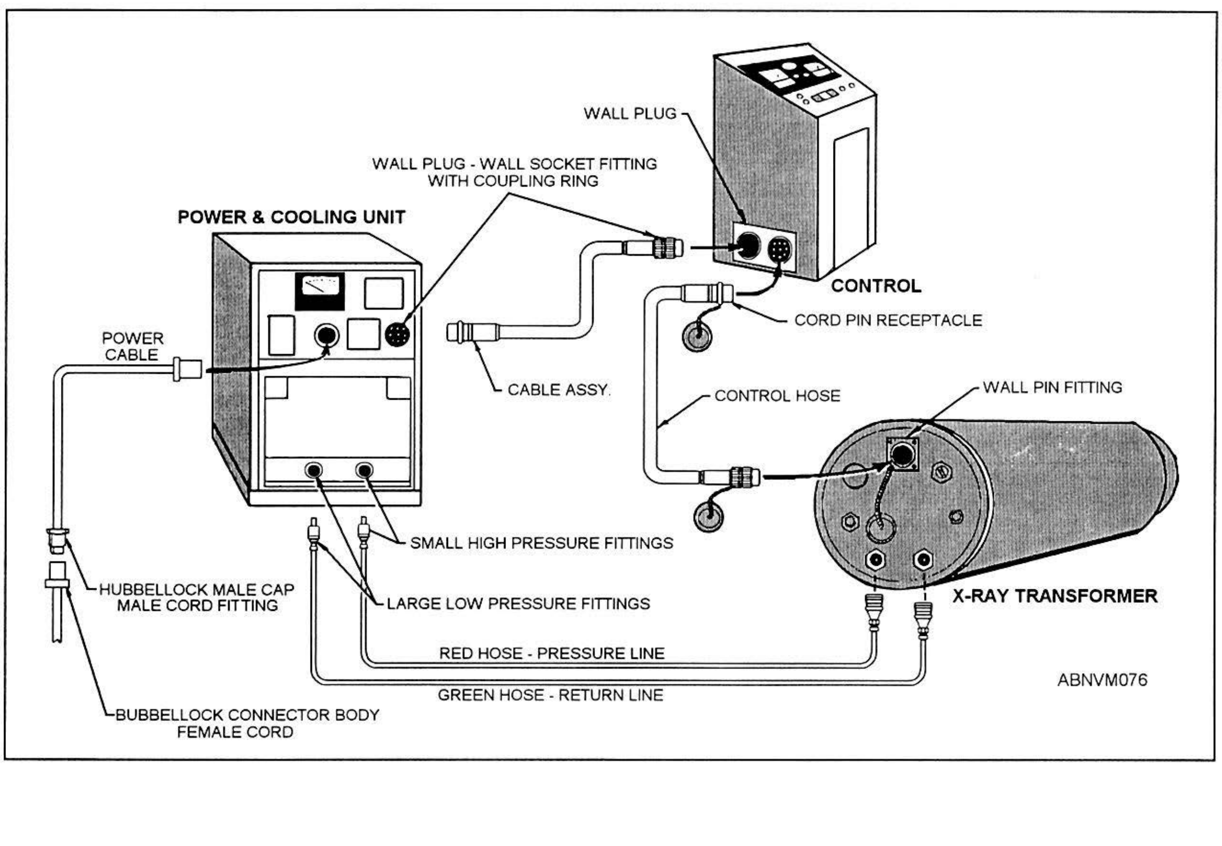


Figure 11-2.—Connections for portable X-ray machine.

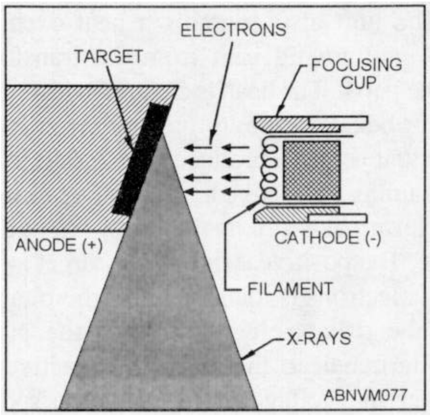


Figure 11-3.—Principle of X-ray generation.

(electrons) collide with a mass of matter. The collision transforms the energy of motion (kinetic energy) of the electron into radiant energy. The faster the particles are moving, the shorter the wavelength of the X rays. The greater the current (milliamperes), the greater the intensity of the radiant energy produced. Most of the kinetic energy is transformed into heat. Only a small portion is transformed into electromagnetic waves (X rays) with the ability to travel in straight lines without displacing the matter through which they pass.

Figure 11-2 shows how the several units of the portable X-ray equipment are interconnected. You can find a complete description of this setup, as well as the details for the operation and care of the equipment, in the handbook furnished with the machine. This equipment should be operated only by qualified personnel who have had the required special training on this equipment.

The diagram in figure 11-4 illustrates the fundamentals of radiographic exposure and the setup of the film, specimen, and radiation source. Note that the film assembly is placed as close as possible to the test specimen, while the X-ray source is some distance away. A definite space ratio must be maintained between the specimen and the X-ray source if a satisfactory radiograph is to be obtained.

Screening

Almost all industrial radiographs are made with lead intensifying screens. Normally, lead intensifying screens decrease the exposure time required by

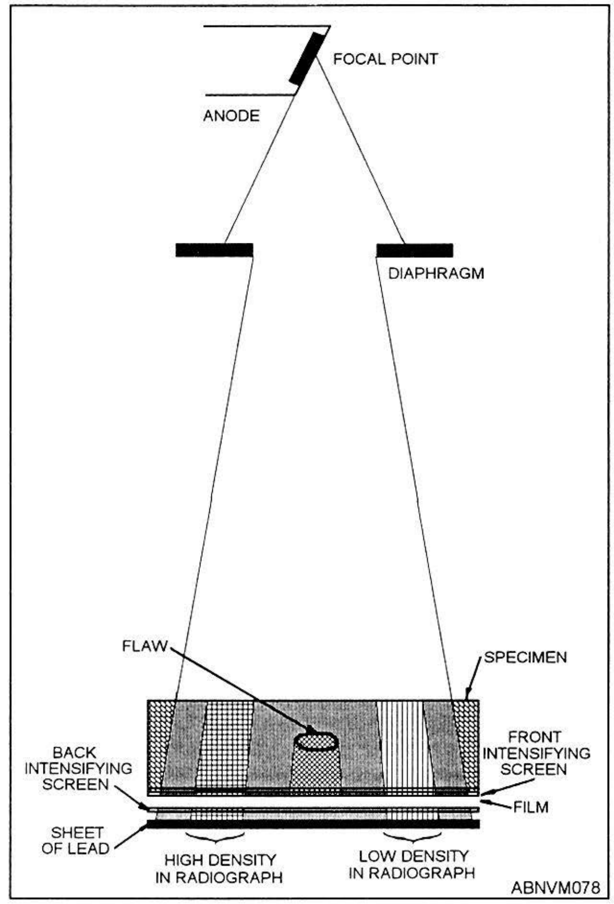


Figure 11-4.—Shematic diagram for making a radiograph.

increasing the effects of the X rays on the film. These screens perform two functions. First, they absorb long rays from the X-ray tube and the scattered rays from the object being radiographed and from the surrounding area. Second, the primary X rays striking the screens cause the screens to emit secondary rays that react on the film in the same manner as do the primary rays. This intensifies the amount of radiation striking the film. The film and screens are packaged in a lightproof device known as a cassette, which is positioned snugly against the specimen that is to be radiographed.

Other Factors

Many factors govern the results obtained in radiography. The principal factors are the kind and thickness of the test specimen, the type of film used, the focal distance between the specimen and the radiation source, the voltage applied, the exposure time, and the location, size, and orientation of the defect. Each of these factors has a bearing on the radiograph produced.

RADIOACTIVE SOURCE

Radioactive sources disintegrate with a time scale rate expressed in terms of half-life. This may be days for Iridium-192. Any source aboard ship must be considered as "live" or potentially dangerous to health, because the source cannot be turned on and off as can an X-ray machine. NO person is to use (expose) radioactive sources unless the use and users are licensed by NAVSEA.

SAFETY PRECAUTIONS

X rays and gamma rays are potentially very dangerous to health. Therefore, the operator must be thoroughly familiar with and use all prescribed safety precautions when using radiation-producing equipment. When operating radiographic equipment, all personnel, including the operator, must be at a safe distance from the source of radiation. A heavy bulkhead or lead shielding is usually provided between the radiation source and the operating personnel. The first step before you begin the operation is to clear all personnel from the area in which the radiograph is to be made. The area must then be roped off. Remember that secondary radiation scattered from the test piece or nearby and overhead objects is potentially as dangerous as the direct radiation from the beam itself.

Distance

The best radiation safety precaution is distance between personnel and the radiation source. This is true because the intensity of radiation varies inversely with the square of the distance from the radiation source. X rays, like a beam of light, cover an increasingly larger area with lessened intensity as they travel from the source. This principle, known as the inverse square law, is illustrated in figure 11-5. When the distance (D) from the radiating source is doubled (2D), the area covered by the beam (Cl) is quadrupled (C2). At the same time, though, the intensity per unit of area is only one-quarter of the value at the original distance. Thus, with sufficient distance, the area covered by the beam may be tremendously large, but its intensity per unit area will

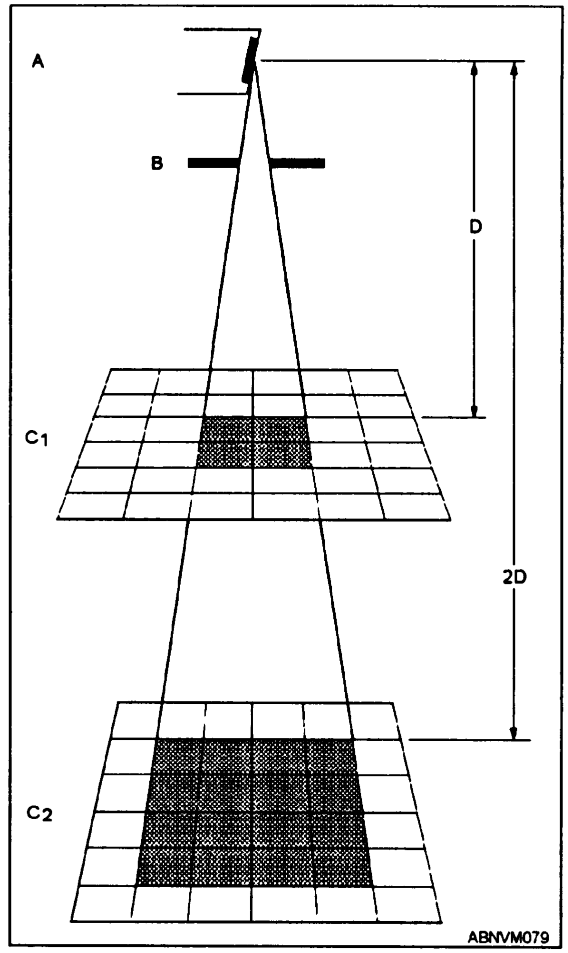


Figure 11-5.—Diagram illustrating inverse square law.

be slight. The intensity at any given distance, however, depends upon the intensity of the radiation source.

Time

An important factor in minimizing exposure to radiation is to reduce the amount of time material is exposed to X rays. It stands to reason that if the exposure time is reduced, the amount of radiation will also be reduced. Mathematical calculations are used to determine the amount of exposure required for different types and thicknesses of metals.

Shielding

Shielding also reduces radiation exposure. If a shield is placed between the operator and the source of radiation, the amount of radiation received by the operator will be reduced. The denser the shielding material, the better the protection provided. Lead is the best shielding material available due to its dense structure. Steel bulkheads, decks, overheads, and machinery also provide good shielding provided that they form a solid partition between the source and the operator.

RADIOGRAPHIC LIMITATIONS

Some of the limitations of the use of radiography are pointed out in the information that follows. The greatest limitation is the shortage of qualified film interpreters. The accessibility of the item to be radiographed is an important limitation. Accessibility controls the placement of both the radiation source and the film, which, in turn, controls the amount of distortion involved. The distortion factor will be discussed later with the interpretation of radiographs.

Other limitations are the thickness and type of material being radiographed. A 300 kVP X-ray machine that can penetrate 3 inches of steel in a reasonable length of time can only penetrate approximately 2 inches of various copper-base alloys using the same kVP rating. The thickness range for steel, using Iridium-192 is 1/4 inch to 2 1/2 inches. The thickness range for copper-base alloys is approximately the same as steel.

INTERPRETATION OF RADIOGRAPHS

The interpretation of radiographs is guided by radiographic standards set by the Naval Sea Systems Command and published in MIL-STD-2035, *Nondestructive Testing Acceptance Criteria.* Copies of these standards are available aboard each ship or station that have radiographic equipment. A decision on whether or not a part is acceptable is based on a comparison of the radiograph of the part with the appropriate radiographic standards. The standards provide specific guidance on the size, number, and dispersion of various defects, and on what decisions for either acceptance or rejection should be made by a qualified radiographic inspector.

You must be familiar with what is and what is not acceptable, and with the design of the part. Unless all sections of the metal radiographed are of uniform thickness, a radiograph of a perfectly sound section of metal will vary in density. Thin sections and cored internal cavities appear as darker areas on the radiograph. Density differences caused by the design must not be confused with density differences caused by defects. Film should be viewed only in an enclosure where all background light is prevented from causing reflections on the film. The light source for viewing should have enough intensity to allow you to view film that ranges in density from gray to black. The light intensity source should have a variable control, a cooling fan, and masking facilities. All radiographs are required to be within given density ranges. A densitometer is used to measure the density ranges of a film to ensure compliance with the requirements.

Shadow Formation

Remember, a radiograph is a shadow picture. Like any shadow cast by an object in a visible light source, the radiograph of a specimen containing a defect is subject to distortion. The shadow cast by your body depends on the relative position of your body to both the light source and the surface upon which the shadow is cast. In the same way, the different positions of the source of radiant energy, the defect, and the film determine the extent to which the shadow cast by the defect is distorted.

The principles of shadow formation are shown in figure 11-6. Note that enlargement and distortion arise in several different ways. First, view A shows that enlargement occurs unless the surface upon which the shadow is cast is flush with the object itself. The greater the distance between the object and the surface upon which the shadow is cast, the greater the enlargement. Second, views E and F show that if the angle of the radiating beam or the surface upon which the shadow is cast is other than at a right angle (90”) to the object or film, the shadow is distorted as well as enlarged. A third kind of distortion occurs when the radiating source is not an ideal point source, as shown in views A, E, and F, but radiates from a beam area containing innumerable points, as shown in B, C, and D. As a consequence, a halo effect results, as shown in B, C, and D, which adds to the distortion stemming from other causes. You can minimize this halo effect by keeping the proper focal distance between the test specimen, the radiating source, and the surface upon which the shadow is cast.

Keep the principles of shadow formation in mind. Remember that the size of the shadow cast by any defect other than a spherical defect is influenced by the way the beam is aimed at the defect. For example, if the defect is cylindrical and the beam is parallel to the long axis of the cylinder, the shadow cast is that of a circle. On the other hand, if the beam is parallel to the diameter of the cylindrical defect, the shadow has a rectangular shape. In other instances, what appears to be a hairline crack may in reality be a cold shut. It is sometimes possible to overcome this difficulty by radiographing the specimen twice, with the direction of the radiating

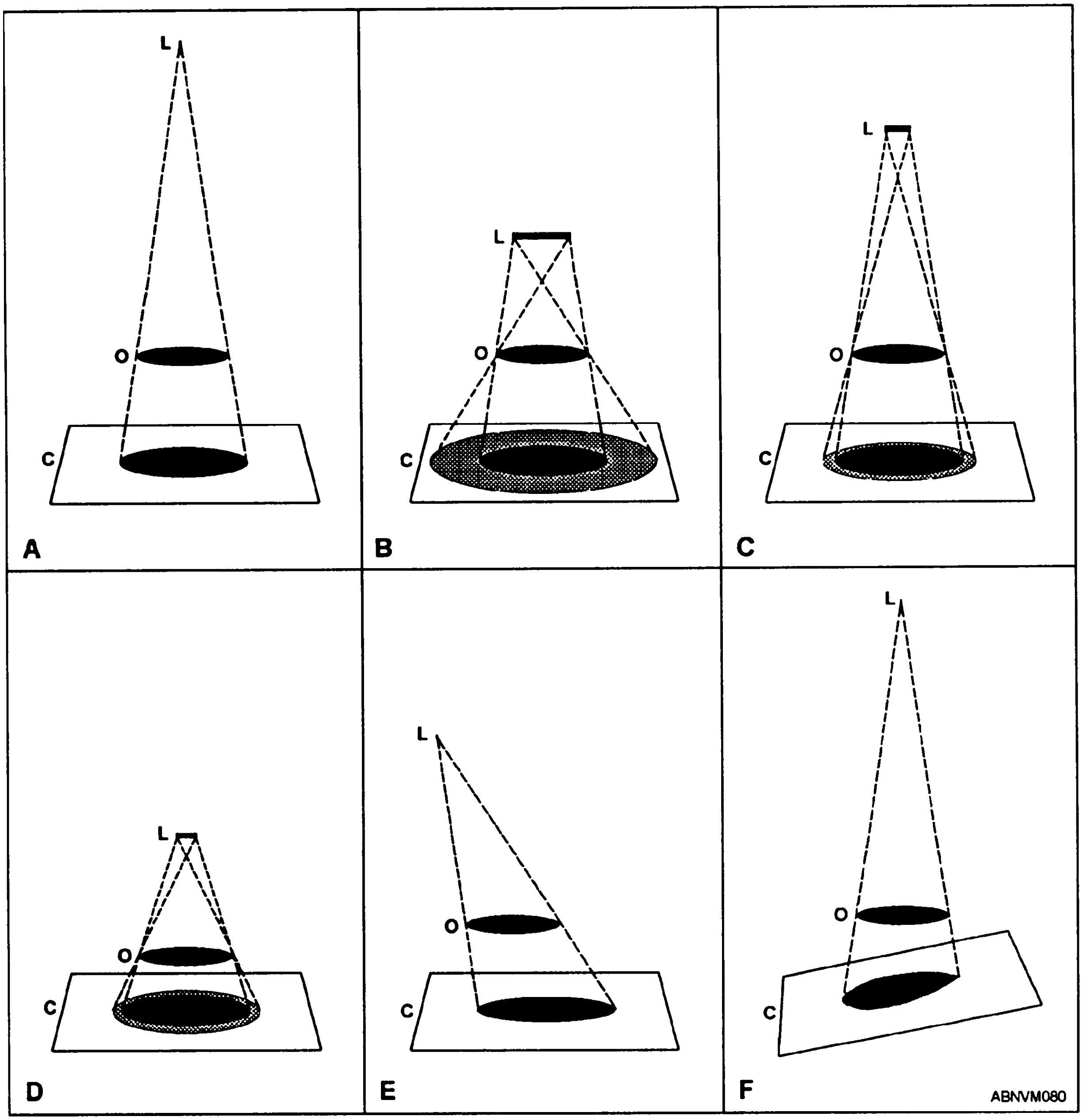


Figure 11-6.—Principles of shadow formation.

sources varied 90° from each other. Unfortunately, many parts do not lend themselves to this procedure.

Defects

The defects most frequently detected in steel welds through the use of radiography are slag inclusion, porosity, cracks, and incomplete fusion. Sand inclusions, porosity, shrinkages, and hot tears are some of the defects revealed in steel castings. These defects are less dense than the surrounding steel. Therefore, they absorb a smaller portion of the beam passing through the metal, and they show up on the radiograph as darkened areas. The characteristics of the more common defects revealed by a radiograph are briefly described as follows:

- Surface roughness appears as irregular light and dark areas having contours identical to the combined surfaces.

- Gas cavities are indicated by round dark areas.

- Inclusions may appear as regular or irregular light or dark areas, depending on the density of the included material.

- Shrink porosity is indicated by a lacy, honeycombed, discontinuous pattern, while individual shrink cavities appear as localized dark spots, usually with a branching, or tree-like, pattern.

- Cold shuts appear as dark lines or bands that tend to be curved. When two streams of molten metal that are significantly different in temperature meet and do not fuse together, the flow is known as a cold shut.

- Cracks are shown as dark lines of various widths, while hot tears are seen as dark lines containing many branches.

Standard radiographic plates are valuable guides in determining the acceptability of a weld. However, the individual who views the plates must depend a great deal on training and experience. Further, the individual must be sure that the radiograph plate was properly exposed and developed. If it is not, a radiograph showing characteristic defects may, in fact, be sound. If there is doubt, the part should be rejected or submitted for further radiographic inspection.

Frequently, an unacceptable weld can be salvaged by chipping or grinding out the defects and rewelding. When this is done, the area must be re-radiographed to determine the acceptability of the repaired area. Before you start to grind or chip, though, be sure that the defects are real to avoid grinding into or through a perfectly good section.

In addition to the use of radiographs to determine acceptability, an analysis of radiographs can lead to a correction of the conditions leading to the defects. By comparing the results of the inspection procedures with your knowledge of the causes of defects, you can improve the overall quality of the product and rejects can be reduced or eliminated.

MAGNETIC PARTICLE INSPECTION

Magnetic particle (MT) inspection can be used for the detection of weld defects in metals or alloys in which magnetism can be induced. While the test piece is magnetized, finely divided iron powder is applied to it. As long as the magnetic field is not disturbed, the iron particles will form a regular pattern on the surface of the test piece. If the magnetic field is disturbed by a crack or some other defect in the metal, the pattern is interrupted and the particles cluster around the defect.

CIRCULAR AND LONGITUDINAL MAGNETIZATION

The test piece may be magnetized either by passing an electric current through it, as shown in view A of figure 11-7, or by passing an electric current through a coil of wire that surrounds the test piece, as shown in view B of figure 11-8. When an electric current flows in a straight line from one contact point to the other, magnetic lines of force are in a circular direction, as shown in view A of figure 11-7. When the current flow is through a coil around the test piece, the magnetic lines of force are longitudinal through the test piece. In order for a defect to show up as a disturbance in the pattern of the iron particles, the direction of the magnetic field must be close to a right angle to the major axis of the defect. Since the orientation of the defect is unknown, a minimum of two current directions must be used during the test. In figure 11-7, circular magnetism is induced in the test piece so that the piece may be inspected for lengthwise cracks. Longitudinal magnetism (fig. 11-8) is induced so that the piece may be inspected 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.

MT INSPECTION EQUIPMENT

The type of MT inspection unit most commonly used in the Navy is the portable unit shown in view B of figures 11-7 and 11-8 It is a high-amperage, low-voltage unit having a maximum magnetizing current output of 1,000 amperes, either alternating or direct current. It is ready to operate when it is plugged into the voltage supply specified by the manufacturer. The unit consists of magnetizing current source, controls, indicating meters, three 10-foot lengths of flexible cable for carrying the current to the test piece, 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 any cable may be fitted to the unit, to the prods, or to any other cable. The unit has

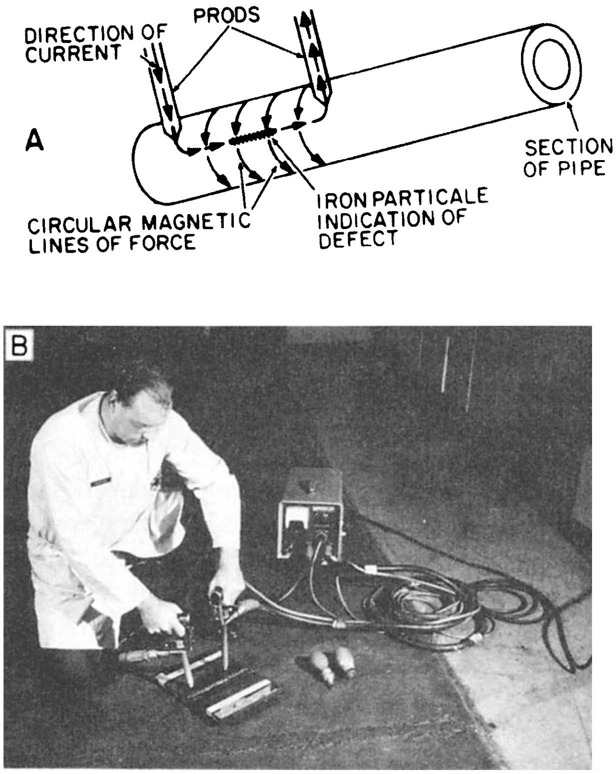


Figure 11-7.—Circular magnetization—prod method.

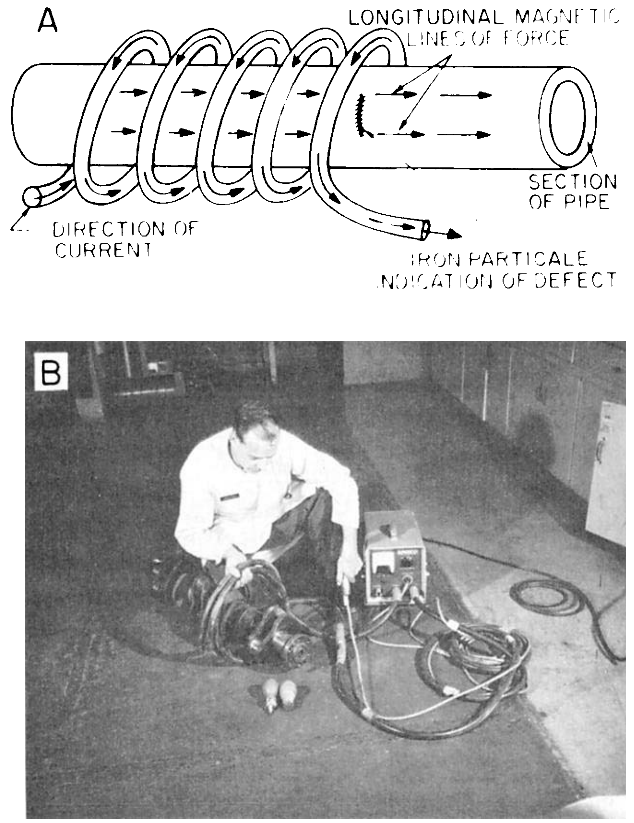


Figure 11-8.—Longitudinal magnetization—coil method.

three outlets on the front, which makes it easy to change from alternating to direct current or vice versa. The outlet on the left is labeled ac, the center is COMMON, and the right is dc. One cable will always be plugged into the COMMON outlet. The other cable is plugged into the ac or dc outlet, depending upon what type of current the test requires. For most work, alternating current magnetization will locate fatigue cracks and similar defects extending through to the surface. Direct current is used when a more sensitive inspection is required to locate defects that are below the surface.

The unit can be used to produce alternating or direct current in either of two ways:

- View B of figure 11-7 shows prods attached to the flexible cable and used as contacts through which current is passed into and out of a portion of the test piece. This sets up a circular magnetization in a local area between the prod contact points.

- View B of figure 11-8 shows a flexible cable wrapped around the work. This forms a coil which, with the passage of current, induces longitudinal magnetism in the part of the workpiece that is surrounded by the coiled cable.

Either of these two methods may be used, but the prod method is probably the easiest to apply. It will detect surface defects in most instances. With the prods, however, only a relatively 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 to a few inches on each side of the current path. To check the entire surface, it is necessary to successively test adjacent areas by changing the location of the prod contact points after a given area has been tested. Each area of the test piece must be inspected twice; once with the current passing through the metal in one direction and again 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 direction. Therefore, if you think a given area is defective, you can conduct magnetic field tests in various directions to locate the defect.

The prod method is used by adjusting the unit for a current output suitable for the magnetizing and testing to be performed for any particular kind of metal. The amperage setting will depend on the distance between prod contact points. The prod kit supplied with the unit has a space between prod contact points of 4 to 6 inches. For this space and a material thickness of less than 3/4 inch, a current setting between 300 and 400 amperes is satisfactory. When the material thickness is 3/4 inch and over, use 400 to 600 amperes. You can get the same magnetic field force with less amperage if the prod contact points are closer together. When you hold the prods constantly at the same spacing, you can use a greater amperage to induce a field of greater strength.

After adjusting the unit, place the prods in position. Hold them in firm contact with the metal and turn on the current. Then apply magnetic particles to the test area with the duster bulb and observe 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; otherwise the current will arc, and you would have a flash similar to that occurring in arc welding.

DEFECT IDENTIFICATION AND REPAIR

MT inspection will help you locate hairline cracks that are otherwise invisible. The particles form an unmistakable outline of the defect. Large voids beneath the surface are more easily detected than small voids, but then, any defect below the surface is more difficult to detect than one that extends through to the surface. Since false indications occur frequently, you must be able to accurately interpret the particle indications to make correct repairs to the weld.

Defect Identification

Some of the factors that help you to 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 indication, they do serve to identify the kind of defect indicated.

A crack is indicated by a sharp, well-defined pattern of magnetic particles with 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 indications or similar defects are difficult to detect if you are inexperienced. A high magnetizing current continuously applied is usually required. The particle patterns for these defects are fuzzy in outline and have a medium buildup.

Defect Repair

Whether or not an indicated defect is to be chipped or ground out and repaired by welding depends on the specifications governing the job. Surface cracks are always removed and repaired. Indications of subsurface defects are evaluated by the inspector. If the indication is positive, it is usually best to grind or chip down to the solid metal and make the repair. Unless you have had considerable experience and can differentiate accurately between true and false indications, it is best to use the magnetic particle inspection only to locate surface defects. The magnetic particle inspection is almost foolproof for this purpose. After the defects have been repaired, the areas should be reinspected to ensure that the repair is sound.

Demagnetization

The final step is to demagnetize the workpiece. This is especially important when the workpiece is made of high-carbon steel. Demagnetization is essential when direct current has been used to induce the magnetic field. It is not as necessary when alternating current has been employed in the test. In fact, the usual demagnetization procedure involves placing the workpiece in an ac coil or solenoid and slowly withdrawing it while the current passes through the coil.

Demagnetization can be done 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. Be sure 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. Then gradually decrease the amperage until the ammeter indicates zero. If the piece is large, it may be necessary to demagnetize a small portion of the work at a time.

You can use a small compass to check for the presence of a magnetic field. When the compass is held near the workpiece, deviation of the needle from its normal position indicates the presence of a magnetic field. If a magnetic field is present, the workpiece will require demagnetization.

LIQUID PENETRANT INSPECTION

Liquid penetrant (PT) inspection is used to inspect metals for surface defects similar to those revealed by the MT inspection. Unlike the MT inspection, which can reveal subsurface defects, the PT inspection reveals only those defects that are open to the surface. Both ferrous and nonferrous metals can be inspected by the use of the PT inspection.

Seven groups of penetrant are listed in MIL-STD-271. According to MIL-STD-271, group 1 penetrant material should be used for all welds. The use of a group other than group 1 penetrant material for welds requires approval of the authorized representative of NAVSEA. The application of all PT inspections must be according to the appropriate MIL-STD or NAVSEA document. Instructions prescribed for each penetrant should be followed carefully according to the applicable procedure, since there are some differences in the procedures and safety precautions required for various penetrants.

PT INSPECTION PROCEDURES

The following procedures should be followed when you use liquid penetrants to inspect a weld.

Surface Preparation

First, you must prepare the surface. Remove all slag 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 is in accordance with applicable specifications and as long as the weld contour blends into the base metal without undercutting. If a specific finish is required, PT inspections may be made before the finish is made. This will detect defects that extend beyond the final dimensions, but a final liquid penetrant must he made AFTER the specified finish is made.

Surface Cleaning

After surface preparation, you should clean the surface of the material, including areas adjacent to the inspection area, very carefully. You can clean the surface by swabbing it with a clean, lint-free cloth saturated in a solvent, such as acetone or isopropyl alcohol, or by dipping the entire piece into a solvent. After you have cleaned the surface, remove all traces of the cleaning materials. It is extremely important that all dirt, grease, scale, lint, salt, and other materials are removed. Make sure that the surface is completely dry before the liquid penetrant is used.

Application

You must maintain the temperature of the liquid penetrant and the workpiece between 50° and a maximum of 150°. Do NOT attempt to use liquid penetrant when this temperature cannot be maintained. Do NOT use an open flame to increase the temperature, since liquid penetrant materials are flammable.

When the material is clean and dry, coat the surface with the liquid penetrant. The penetrant may be sprayed on, brushed on, or the entire piece may be immersed in the penetrant. You must allow time for the penetrant to get into all cracks, crevices, or other defects that are open to the surface. Wet the surface of the piece with the penetrant and keep it wet for a minimum of 15 to 20 minutes. The time limits will vary depending upon which group of penetrant is being used. Follow the instructions prescribed by the appropriate MIL-STD or NAVSEA document concerning the length of time the surface must be kept wet.

When the surface has been kept wet with the penetrant for the required length of time, remove the excess penetrant from the surface with a clean, dry, lint-free cloth or absorbent paper towel. Then, dampen a clean, lint-free cloth or absorbent paper towel with penetrant remover and wipe the remaining excess penetrant from the test surface. Dry the test surfaces after removal of excess penetrant only by normal evaporation, or with the clean, lint-free cloth or absorbent paper towel previously mentioned. When you are drying the surface, be very careful so that you do not contaminate the surface with any oil, lint, dust, or other materials that would interfere with the inspection.

After the surface has been dried, you must apply another substance called a “developer.” The developer (powder or liquid) must be allowed to stay on the surface for a minimum of 7 minutes before the inspection is started. It can be left on no longer than 30 minutes; this leaves a total of 23 minutes to evaluate the indications.

Let's stop for a moment and examine what takes place when these penetrant materials are applied. First of all, the penetrant applied to the surface of the material will seep into any passageway open to the surface, as shown in view A of figure 11-9. The penetrant is normally red in color and, like penetrating oil, it seeps into any cracks or crevices that are 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 (view B, fig. 11-9); thus, only the penetrant that has seeped into the defect is left.

Finally, the white developer is applied to the surface of the metal. (See view C, fig. 11-9.) The developer, an absorbing material, will actually draw the penetrant from the defect. Therefore, the red penetrant indications in the white developer represent the defective area. The amount of red penetrant drawn from the defective area will give an indication of the size and sometimes the type of defect.

Defect Interpretation

When liquid penetrants are used, the lighting in the test area must be bright enough so that you can see any indications of defects shown on the test surface. These indications must be carefully interpreted and evaluated. There are normally some insignificant indications in all inspections. Most of them are caused by failure to remove all excess penetrant from the surface. At least 10 percent of the areas that are questionable on the accuracy of the indications should have the penetrant and the developer removed from the surface. Then the area must be retested to determine whether defects are actually present, or whether the indications are merely caused by excess penetrant. If the second PT inspection does not reveal indications in the same locations, it is usually safe to assume that the first indications were not really indications of defects.

All penetrant inspection materials must be removed as soon as possible after the final inspection has been made. Use water or solvents, as appropriate.

SAFETY

You must observe a number of safety precautions while working with liquid penetrant materials. Since the materials are flammable, they must not be used near open flames, and they must not be applied to any surface that is at a temperature higher than 150°F. Many of the solvents are also poisonous in the vapor form and highly irritating to the skin in the liquid form. Handle all penetrant inspection materials with respect for their hazardous nature.

ULTRASONIC TESTING

In addition to radiography, ultrasonic tests (UT) are also used to inspect the interior of metal and welds. Defects lying throughout the thickness or depth of a weld are easily detected.

Several techniques for the ultrasonic testing of metals have been developed within the past few years and are now widely used in the Navy.

Some of the defects detectable by ultrasonic inspection are cracks, lack of fusion, slag inclusions, porosity, lamination, and incomplete penetration. The following section gives only basic information on the principle of ultrasonic weld inspection. More information can be found in MIL-STD-271.

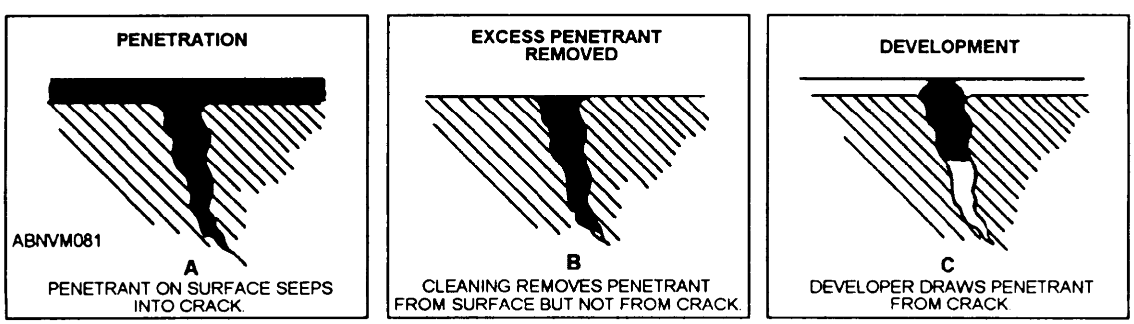


Figure 11-9.—Principles of liquid penetrant inspection.

ULTRASONIC PRINCIPLE

The term *ultrasonic* means vibrations or sound waves whose frequencies are greater than those that affect the human ear (greater than about 20,000 cycles per second). The Navy uses equipment that has, for practical purposes, a frequency range between 500,000 and 10,000,000 cycles per second.

UT Equipment

The UT equipment, shown in figure 11-10, includes a transmitter/transducer and CRT screen. These are the two basic components of all UT equipment regardless of make or model.

TRANSDUCER.—High-frequency electric energy from the transmitter is transformed into high-frequency mechanical energy by the transducer. The transducer is held against a piece of metal with some oil or glycerin (called a couplant) between the contacting surfaces to prevent air from remaining between them.

The high-frequency mechanical energy, in the form of high-frequency sound, is transmitted into and through the metal. After entering the metal, the sound travels in straight lines in what is known as the beam path. When the beam strikes the far surface of the piece or strikes the boundary of a defect, the beam reflects back toward the transducer. When the beam is reflected, it leaves the metal in the same area it entered, travels through the couplant, and enters the transducer where it is converted back to electrical energy. It is then relayed to an amplifier. The beam is then presented on a cathode ray tube (CRT) screen as vertical deflections of the base line. Figure 11-11 is a block diagram showing this principle.

CRT SCREEN.—The CRT screen shows a base line of light along the lower part of the screen. The initial pulse bounce between the transducer and the metal is shown as a peak rising from this line at the left or start position. It takes a certain amount of time for a signal or beam to travel through the metal, and approximately the same amount of time to bounce back. This time is calibrated along the base line as distance, or as the distance traveled by the beam front in a certain time. If a test piece has a certain thickness and no defects, the CRT screen will show the start position peak somewhere on the left of the base line and another peak (back reflection) to the right of the base line at a distance proportional to the thickness of the piece. The relationship of the actual thickness of the test piece to the distance shown on the base line may be determined from the calibration settings on the instrument. These two peaks will be relatively high on the screen and will represent the beam entrance into the piece and reflection from the opposite surface, respectively. If there were a defect between the two surfaces, SOME of the beam would BOUNCE from the boundaries of the defect and would show on the CRT somewhere along the base line at a distance relative to the two surface indications, usually as a smaller peak.

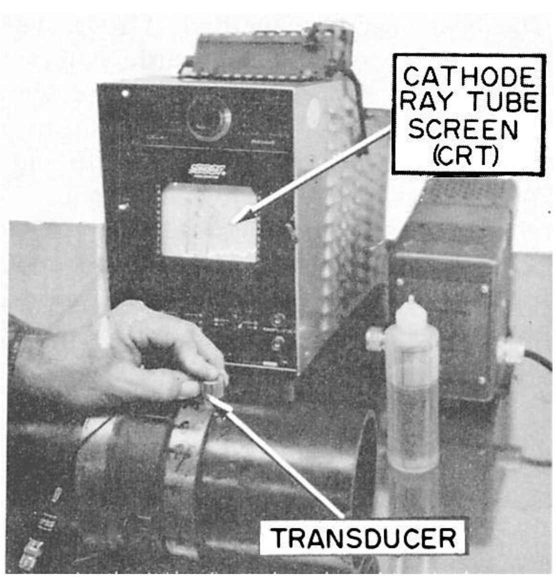


Figure 11-10.—Ultrasonic testing equipment.

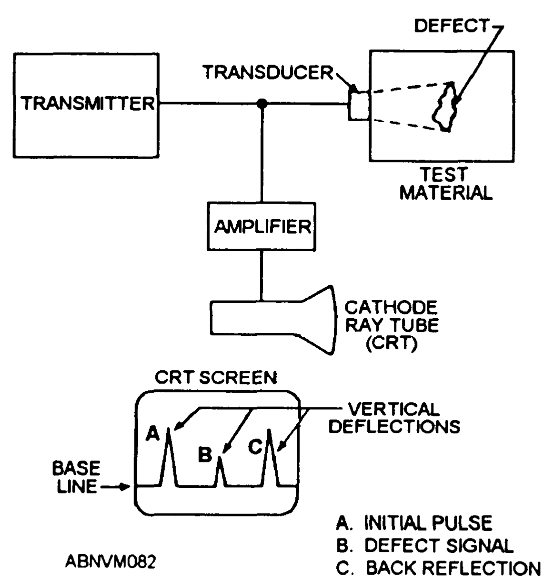


Figure 11-11.—Principle of ultrasonics.

If the defect shows at a point one-half of the distance along the base line (fig. 11-11) from the entrance peak, then the defect will actually lie one-half of the thickness of the piece from the entrance surface. If the piece is 1 inch thick, then the defect will lie 1/2 inch below the surface. If the defect peak is high, the defect is large (in a plane 90° from the beam); and if the peak is small, then the defect is small. If the defect is larger than the beam diameter, the defect surface will bounce back ALL the beam, and the back reflection peak will disappear. If the defect is smaller than the beam diameter, some of the beam will be stopped and bounced by the defect, and some will go on and be bounced by the back of the piece. The CRT will then show the near-surface peak, the small intermediate peak, and a slightly reduced peak (at the back or far side of the piece) at the right, or designated l-inch point, on the base line.

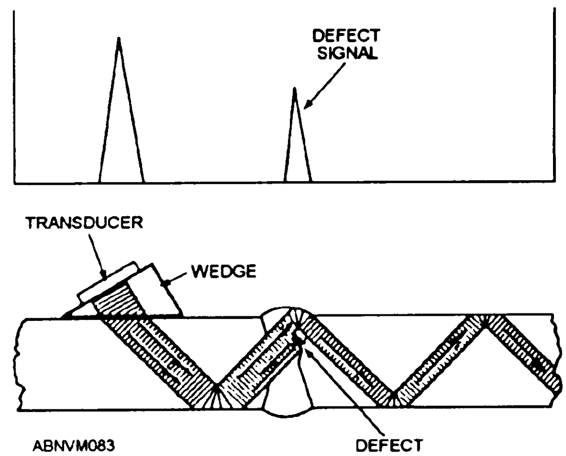


Figure 11-12.—Angle beam testing.

Calibration Block

You need to determine the size of a defect, and where possible, evaluate the nature of the defect. This means that some reference or standard for comparison (commonly called a calibration block) is absolutely necessary. The most common practice is to use a sample piece of material with a hole drilled in it and compare defect signals obtained from the calibration block. Calibration is the most important part of ultrasonic testing, since it is essentially a comparison test.

ULTRASONIC WELD INSPECTION

Detecting, locating, and measuring defects are the major requirements for weld inspection.

When testing welds for defects, you should use the greatest possible direct reflection of sound. This is easily done if the defects have a boundary that lies parallel to the plane upon which the transducer rests, and the face of the transducer lies flat upon that plane. Such placement results in a longitudinal (compressional) beam with its axis normal to the surface boundary. To obtain the greatest direct reflection, sound should strike a surface boundary or defect boundary that lies at right angles to its direction of travel. Since most weld defects are rotated 90° from the surface, you will need a way to change the direction of the sound beam. You can do this by securing a Lucite wedge to the transducer. This is known as the angle beam method, shown in figure 11-12.

As you can see in figure 11-12, the sound beam passes through the wedge and enters the part to be tested at an angle. The sound beam will continue to bounce at this angle until it is completely scattered or absorbed by the material. Weld inspections are performed when the sound has made only one or two bounces. If a flaw is present in the weld, as indicated in figure 11-12, some of the sound beam will reflect back and show up as an indication on the CRT screen.

The best scanning method is to move the search unit forward and backward. Alternately approach and move away from the weld a distance sufficient to permit the sound to pass through the full thickness of the plate and the weld in an upward and downward path. The search unit is also moved parallel to the weld itself, as shown in figure 11-13. In this manner, you will scan the complete volume of the weld, following the same pattern along the weld, as shown by the dotted line in figure 11-13.

NONDESTRUCTIVE TESTING SYMBOLS

Nondestructive testing symbols specify the type of test to be used and the extent to which the test will be

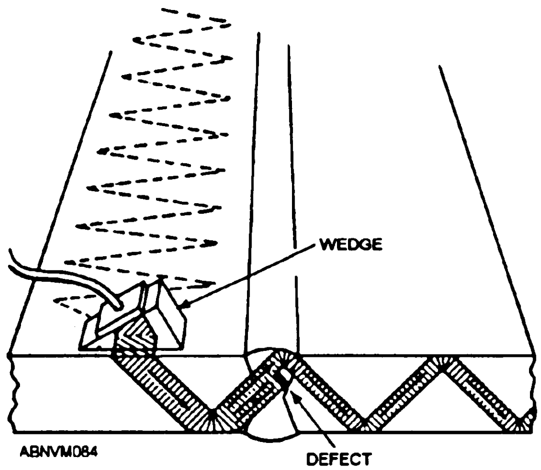


Figure 11-13.—Scanning a weld.

performed. The four basic nondestructive testing symbols are as follows:

TYPE OF TEST	SYMBOL
Radiographic	RT
Magnetic Particle	MT
Liquid Penetrant	PT
Ultrasonic	UT

An assembled nondestructive testing symbol consists of the following elements:

REFERENCE LINE	TAIL
● Arrow	Extent of test
● Basic testing symbol	Specification, process,
● (N) Number of tests	or other reference

Each of these elements should be used as necessary. They will have standard locations with respect to each other, as shown in figure 11-14.

The arrow connects the reference line to the part to be tested (fig. 11-15). The side of the part to which the arrow points is called the arrow side of the part. The side opposite the arrow is called the other side.

The location of testing symbols is shown in figure 11-16. Tests to be made on the arrow side of the part are indicated by a test symbol on the side of the reference line toward the reader, as shown in view A. Tests to be made on the other side of the part are

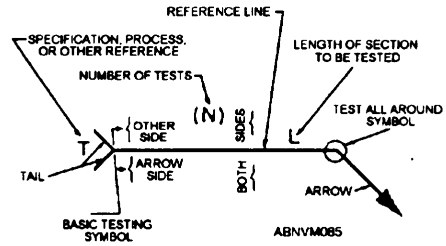


Figure 11-14.—Standard location of elements on a nondestructive testing symbol.

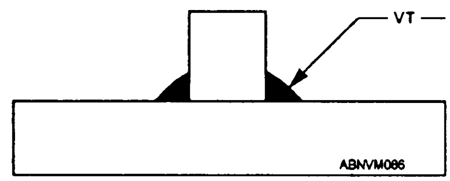


Figure 11-15.—Arrow connecting the reference line and part being tested.

indicated by the test symbol on the side of the reference line away from the reader, as shown in view B. Tests to be made on both sides of the part are indicated by test symbols on both sides of the reference line, as shown in view C. When nondestructive testing symbols have no arrow-side or other-side significance, the testing symbols are centered on the reference line, as shown in view D.

When a specification, process, classification, or other reference is used with testing symbols, the reference is placed in the tail, as shown in figure 11-17. Specification, process, classification, or other reference need not be used on testing symbols when the testing procedure is prescribed elsewhere.

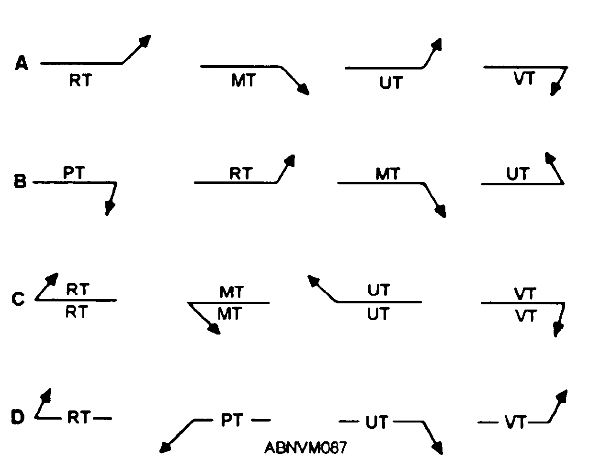


Figure 11-16.—Location of testing symbols.

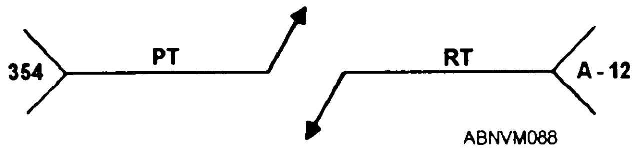


Figure 11-17.—Location of specification, process, classification, or reference.

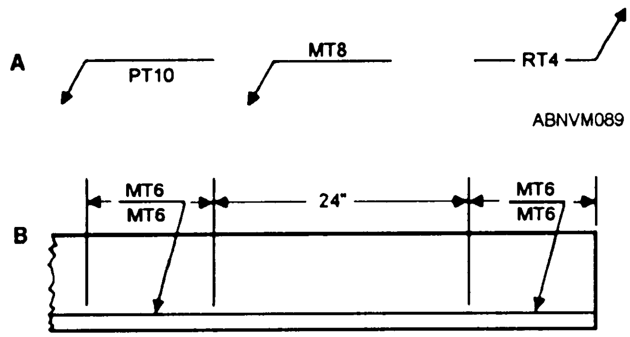


Figure 11-18.—Specifying length and exact location of area to be tested.

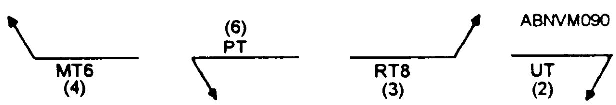


Figure 11-19.—Specify number of tests to be made at random.

The length of the section to be tested is specified as shown in figure 11-18. To specify tests of welds or parts where only the length of the section need be considered, the length in inches is shown to the right of the basic test symbol (fig. 11-18, view A). To show the exact location of the section to be tested as well as its length, dimension lines are used as shown in view B. When the full length of a part is to be tested, no length dimensions need be shown on the testing symbol.

If a number of tests are specified to be taken at random, the desired number of tests are placed in parentheses, as shown in figure 11-19.

To specify tests that are to be made all around a part, the test-all-around symbol is used with the basic test symbol, as shown in figure 11-20.

Nondestructive testing symbols may be combined with the standard welding symbols previously discussed. This feature increases the scope of all welding symbols. The length of a section to be tested can be indicated, and individual areas for testing can be specified by means of these symbols. Figure 11-21 shows the combining of nondestructive testing symbols and welding symbols.

Figure 11-20.—Specify tests to be made all around.

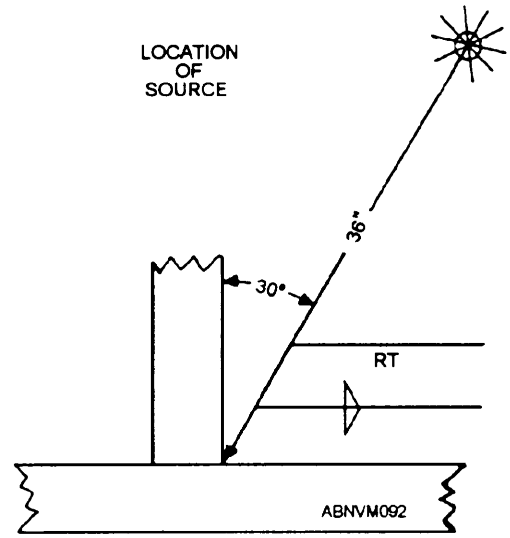


Figure 11-21.—Combining nondestructive testing symbols and welding symbols.

HYDROSTATIC TESTING

Fluid systems are hydrostatically tested during initial construction, subsequent to repairs, and periodically to verify the integrity of the system. All piping sections that have been removed for repairs and newly fabricated sections must be hydrostatically tested before installation to make sure that there will be no leaks under operating conditions. Operational tests are also preformed, instead of hydrostatic tests, after certain repairs involving mechanical joints. The basic purpose of all such tests is to ascertain that the system can perform its intended function safely and reliably. This section will discuss hydrostatic tests, operational tests, and the equipment used to conduct these tests.

HYDROSTATIC TESTS

Hydrostatic testing of piping systems is accomplished whenever repairs are made to piping system or any related components. Hydrostatic testing of ships' systems is required every 8 years, and should be conducted before or during the early stages of a scheduled major overhaul of the ship. Regardless of the reason for testing, all hydrostatic testing is accomplished in the same general manner using the same equipment. Hydrostatic testing of systems or components is commonly referred to as "H" pressure tests. These tests of piping systems should be at a pressure of 135 percent above the maximum system design pressure, but in no case less than 50 psi. The line drawing in figure 11-22 shows a simple hydrostatic test setup and associated equipment.

Hydrostatic Testing Equipment

Shop hydrostatic testing of piping systems or components should be conducted in an area that can be secured from all traffic. This area should also provide the operator protection in event of component failure. When hydrostatic testing the ship's piping system, set up the equipment in an area that can be secured from all unwanted traffic. The equipment required for hydrostatic testing includes a pump, two pressure gauges, two relief valves, a cutoff valve, blank flanges, gaskets, and clamps.

PUMPS.—There is no specific requirements for the type of pump to be used for hydrostatic testing. The pump must be large enough to deliver the required pressure and water volume to the system being tested. Pneumatic pumps are the most common type of pump used for hydrostatic testing and are operated by the ship's compressed air system. These pumps are usually rated in gallons per minute.

PRESSURE GAUGES.—When performing hydrostatic tests, use two independent pressure gauges. These two gauges will indicate actual hydrostatic test pressure. One of the gauges will be the master gauge and the other will be the backup gauge. Use the master hydrostatic test gauge readings as the true hydrostatic test pressure throughout the test.

Master Gauge.—Master test gauges are used to indicate actual hydrostatic test pressures. The scale range of the master test gauge should be greater than the maximum test pressure, but should not exceed 200 percent of the maximum test pressure. Master test gauges shall have a valid calibration label according to NAVSEA OD 54845, Metrology Requirements List.

Backup Gauge.—A backup gauge is used to check and verify the accuracy of the master test gauge. Like the master gauge, the backup gauge is also subject to actual test pressure. The scale range of the backup test gauge should also be greater than the maximum test pressure, but should not exceed 200 percent of the maximum test pressure. Backup test gauges shall also have a valid calibration label according to NAVSEA OD 54845, Metrology Requirements List.

RELIEF VALVES.—Relief valves provide for overpressure protection of the system or component, equipment, and safety of personnel. The relieving capacity, at test pressure of relief valves used for

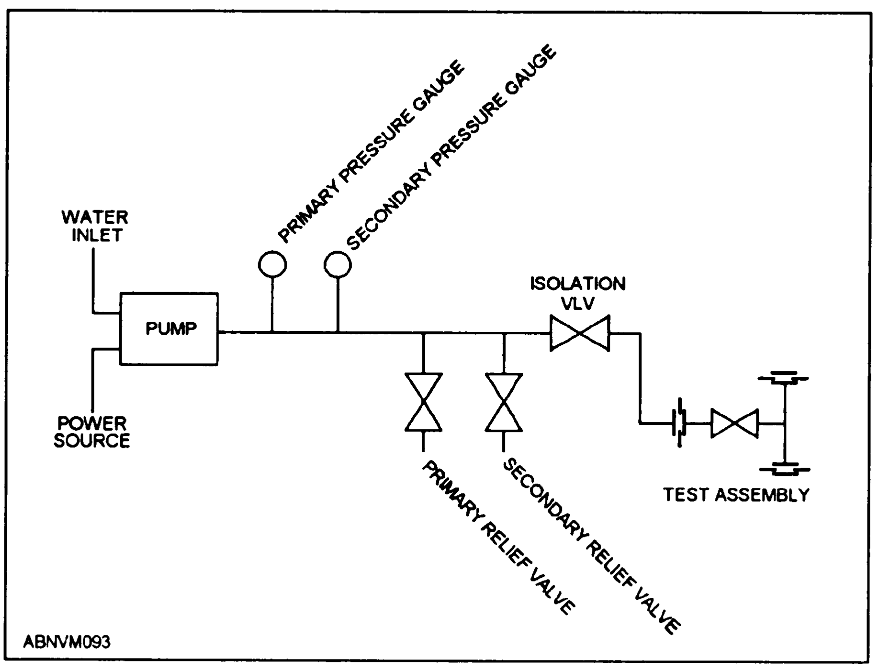


Figure 11-22.—Hydrostatic test equipment and set up.

over-pressure protection and their inlet and discharge piping, shall be greater than the capacity of the source being used to pressurize the system. Relief valves are classified as either the primary or secondary relief valve.

Primary Relief Valve.—The primary relief valve must be of the manual type that can be operated from the control station. Usually the primary relief valve is a manually operated valve with a drain to a sump or other suitable drainage system. The person controlling the source of pressure (pump operator) cannot also be a relief valve operator.

Secondary Relief—The secondary relief valve may be either manually or automatically operated. The secondary relief valve is usually located next to the primary relief valve on a hydrostatic testing unit but may also be remotely located. If the secondary relief valve is of the manual type, another operator must be stationed to operate this valve.

If the secondary relief is of the automatic type, test the set point of the relief valves to be used. If necessary, adjust the set point no more than 30 days before the relief valves ae to be used for the hydrostatic test. In conducting a 135 percent test, the set point of the relief valve shall be no greater than 100 lb/in^2 or 10 percent above the test pressure, whichever is less.

Hydrostatic Testing Equipment Setup

After assembling all required testing equipment and checking calibration dates, you are ready to set up the equipment for your test. Whether testing in the shop or a ship's system, the setup of the equipment is similar. Both shop and system testing will be discussed in this chapter.

SHOP HYDROSTATIC TEST SETUP.—Most shop testing is done in areas that are specifically designed and built for hydrostatic testing. These areas have installed pumps, gauges, and relief valves permanently mounted in the area. The operating station is isolated from the testing area to provide protection to the operator in case of failure of the component being tested.

When setting up a component for testing, each outlet of the component must be blanked off with blank flanges or other suitable blank fittings. One fitting should be drilled and tapped, and fitted with a nipple of suitable size for connecting the hose from the hydrostatic pump. Use appropriate bolts to secure the flanges or fittings with gaskets to all openings of the pipe. After blanking off all openings of the pipe, completely fill it with water through the nipple fitted to the one blank flange.

SYSTEM HYDROSTATIC TEST SETUP.—System setup is similar to the hydrostatic testing done in the shop. You will use a portable pump with the required gauges and relief valves incorporated into the pump control panel or on a separate manifold. You should also take the following precautions when hydrostatically testing shipboard systems:

- When setting up a component for testing, each outlet of the component must be blanked off with blank flanges or other suitable blank fittings. One fitting should be drilled and tapped, and fitted with a nipple of suitable size for connecting the hose from the hydrostatic pump.
- Protect equipment, tanks, gauges, and machinery that would be subjected to a test pressure higher than their specified test pressure by disconnecting from the system, or isolating from the test.
- Provide expansion joints with temporary restraints, if required, or isolate them from the test.
- Eliminate air pockets before any system is pressurized for a hydrostatic test to prevent the pressurization of gases in the system.
- Verify that all valves and equipment in or connected to the portion of the piping system to be pressurized are in the required position or condition.

Testing Procedures

After obtaining and setting up the equipment, you are ready to begin testing of the component. Generally, the sequence for testing is as follows:

1. Establish required prerequisites and initial conditions.
2. Align the system for testing.
3. Station the operator, manual relief valve operator, and inspector. Two manual relief valve operators may be required if a manual

relief valve is used for the secondary relief valve.

4. Establish communication between the operator, relief valve operator, and the inspector if their stations are separated.
5. Pressurize the system slowly and incrementally, checking for leaks at each increment.
6. Increase pressure to hydrostatic test pressure.
7. Perform required inspections.
8. Depressurize, remove temporary equipment, and restore the system to its original configuration.

In the following section, we will look at component pressurization, inspection requirements, and testing durations.

PRESSURIZATION.—During hydrostatic tests of systems havin a maximum system pressure in excess of 300 lb/in^2, raise the test pressure in increments of approximately 25 percent of the final test pressure. At each increment, make a check for leaks before proceeding to the next higher pressure increment. The final test pressure should be +2 to -0 percent of the final test pressure but should not exceed 50 lb/in^2. For test pressures less than 100 lb/in', a +1 to -0 percent tolerance is acceptable.

If any of the following events occur, you should take immediate action to terminate the test and depressuize the component:

- Pressure gauge fails to respond to changes in test pressure or gauge ruptures during the test.
- Pressure gauge readings do not agree within 2 percent of maximum test pressure or are not accurate within 2 percent of maximum test pressure.
- Changes in test pressure cannot be held constant.

VISUAL INSPECTIONS.—Visual inspections are required at specified intervals as the pressure is increased to the test pressure. Repaired areas that are being tested should remain uninsulated to allow examination for leakage.

TEST DURATION.—The test duration for hydrostatic testing of ships' systems and of repaired assemblies are different, although the end requirements of the hydrostatic testing is the same for both the repaired piping assembly and ships' systems. You will follow different testing parameters for each test.

Testing Ships' Systems.—For testing of a ship's system maintain the test pressure during hydrostatic tests for at least 1/2 hour before inspection. If the inspection is done prior to 1/2 hour, the system may not be pressurized evenly and you may get an indication of leakage due to valve packing and joint setting occurring. Test pressure should be maintained at 135 percent of system design pressure but not less than 50 lb/in^2 for the duration of the test. Some systems may require tests more or less than 135 percent. Always refer to the operator's manuals, systems' drawings, or other applicable documentation for correct test pressures.

Testing Repaired Piping Assemblies.—Always test piping or piping assemblies (except halocarbon refrigerant piping) removed for repair or replacement before reinstallation. Test pressure, in most cases, will be 135 percent of the system design pressure, but in no cases less than 40 lb/in^2. Hydrostatic test pressure will be held for a minimum of 15 minutes before inspection. Hold this pressure while a complete inspection of the piping assemble is made. Special attention should be given to renewed parts and repaired sections. Some assemblies may require tests of more or less than 135 percent. Always refer to the operator's manuals, systems, drawings, or other applicable documentation for correct test pressures.

ACCEPTANCE CRITERIA FOR HYDROSTATIC TESTS.—The criteria for an acceptable hydrostatic test is that there should be no leakage or permanent deformation of the pressure-containing parts. This acceptance criteria is determined by visual examination. The following are exceptions to the no leakage criteria for acceptable hydrostatic testing of ships' systems only:

- The leakage does not become hazardous to personnel.
- The leakage can be adequately contained to protect equipment.
- The leakage is within the capacity of the hydrostatic test pump to maintain pressure throughout the test.

Piping assemblies that have been repaired or replaced require zero leakage.

Do not consider the test complete until all specified inspection points have been recorded as satisfactory and test pressure has been maintained. Correct or repair all leaks. Rehydro all repaired assemblies or portion of affected assemblies to the required test pressure.

OPERATIONAL TESTS

Operational pressure tests (commonly called "J" pressure tests) are performed periodically to determine the integrity (leak tightness) of a system. Operational tests are nothing more than visually inspecting the system or repaired piping assembly while operating the system at design pressure. Operational pressure tests are also performed instead of hydrostatic tests after certain repairs involving mechanical joints. The basic purpose of an operational test, as with a hydrostatic test, is to ascertain that the system perform its intended function safely and reliably.

Periodic operational pressure tests should be conducted under operating pressure (with the service fluid) on all shipboard piping systems once a quarter. At least once a year, conduct this test by pressurizing the system one section at a time, to detect leaking valves and to ensure proper operation of all the valves in the system.

SUMMARY

This chapter has given you a basic knowledge of radiographic tests, magnetic particle inspections, liquid penetrant tests, ultrasonic inspections, hydrostatic tests, and nondestructive testing symbols. Use this knowledge along with the appropriate NAVSEA technical manuals and publications, and on-the-job experience under a qualified supervisor. You will soon perform these tests in a professional manner and with reliable results.

CHAPTER 12

SHEET METAL LAYOUT AND FABRICATION

LEARNING OBJECTIVES

Upon completion of this chapter; you will be able to do the following:

- *Define some of the basic terms used in the layout and fabrication of sheet metal*
- *Describe the basic techniques used to perform various sheet metal layout operations and define the three types of plans*
- *Recognize the various methods of pattern development*
- *Describe some of the tools and equipment generally found in the sheet metal shop, and describe their use and operation*
- *Describe the safety procedures and equipment used in sheet metal fabrication*

INTRODUCTION

As a Hull Maintenance Technician (HT), you may be assigned to lay out and fabricate ventilation ducts, drip pans, and other items made from sheet metal. In this chapter, we will look at the tools and methods that you will use for jobs of this sort. We will also look at pattern development, the transfer of a pattern to sheet metal, and the fabrication of the sheet metal projects.

NOTE: You will not be able to do the layouts in this chapter unless you learn each step of each process as you go along. Later in the chapter, you will simply be instructed to carry out many of the procedures you were taught earlier in this chapter. Before you can fabricate an item, you must have a plan and be able to read it. Your plan may be a sketch, a drawing, or a blueprint. Later on, you will be expected to make your own sketches and drawings.

A SKETCH is a rough outline of the structure to be fabricated, giving dimensions and details of the job to be done. The sketch includes such information as angles to be used and the type of material required.

A DRAWING is similar to a sketch, but it is made with mechanical drawing instruments and it is drawn to scale.

A BLUEPRINT is a duplicate of a drawing or sketch. Usually, only accurate drawings are blueprinted. These blueprints are furnished by the manufacturers of the machinery installed aboard your ship and also by the command concerned with the building and maintenance of the ship on which you are serving.

If you have not done so, this is a good time to study Blueprint Reading and Sketching, NAVPERS 12077-E You must be able to read plans accurately, and this book will help you to read almost any type of plan. A satisfactorily completed job is your objective, and the plans are essential guidelines. As you study this chapter, you may find that you also need to review portions of Use and Care of Hand Tools and Measuring Tools, NAVEDTRA 12085, and Mathematics, Volume 1, NAVEDTRA 10069-Dl.

USING LAYOUT TOOLS

The tools you will use most often to lay out sheet metal jobs and patterns are the scratch awl, flat steel square, circumference rule, straightedge, dividers, trammel points, prick punch, and center punch. When you make your practice layouts, you will probably be restricted in the amount of sheet metal you can use. If at all possible, use template paper instead of metal. This material has a rosin-coated surface that is well adapted to scribe and divider marks. If this type of paper is not available, use heavy brown wrapping paper or discarded chart paper, which you can get from the navigator or quartermaster. When you use paper, substitute a 4H pencil for the scribe and a pencil divider for your regular layout dividers. Take good care of your scribes, pencils, dividers, and rules because the accuracy of your work depends upon them. After you have made a few practice layouts, the importance of accurate measurements should be clear to you. You will have a feeling of satisfaction when your layout turns out as you planned it. If it does not quite fit, you were probably careless somewhere in your layout.

Figure 12-1 shows the correct way to scribe a line on metal using a scratch awl and rule. When you scribe your line, hold the scale or straightedge firmly in place. Set the point of the scriber as close to the edge of the scale as possible by tilting the scriber outward. Exert pressure on the point and draw the line, tilting the tool slightly in the direction of movement. For short lines, use the steel scale as the guide. For longer lines, use a circumference rule or a straightedge. When you draw a line between two points, prick punch each point. Start from one prick punch mark and scribe toward the center. To complete the line, start from the other prick punch mark and scribe towards the center as before.

The FLAT STEEL SQUARE is useful for laying out sheet metal jobs. Before using it, or at least at periodic intervals, check the square for accuracy, as shown in figure 12-2. When your square is off, your work will be proportionately off, no matter how careful you are. In parallel line development, use the flat steel square to construct lines that are parallel to each other as well as perpendicular to the baseline. This procedure is shown in figure 12-3. Just clamp the straightedge firmly to the base line. Slide the body of the square along the straightedge, and draw perpendicular lines through the desired points.

The COMBINATION SQUARE can be used to draw a similar set of lines, as shown in figure 124. Use

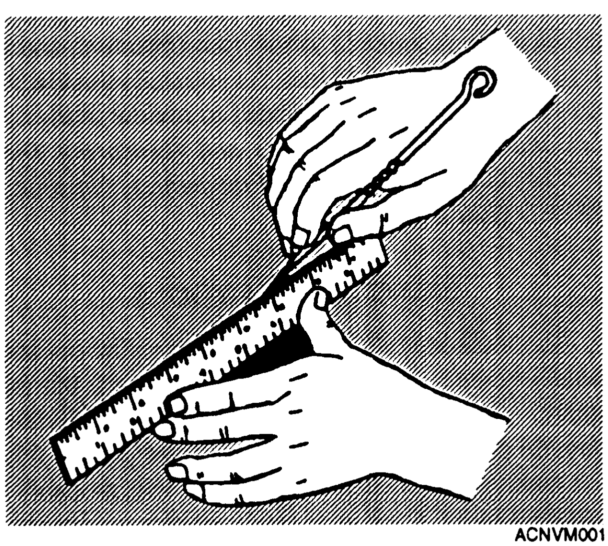


Figure 12-1.—Scribing a line.

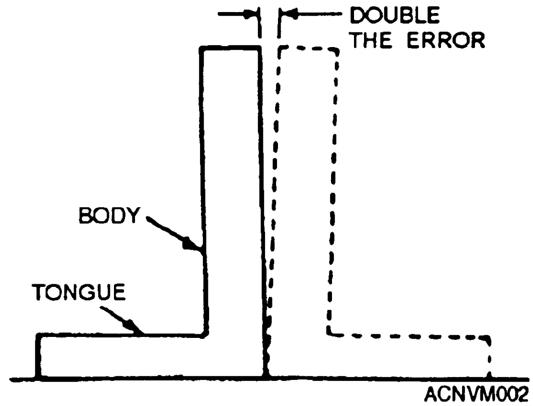


Figure 12-2.—Checking the square.

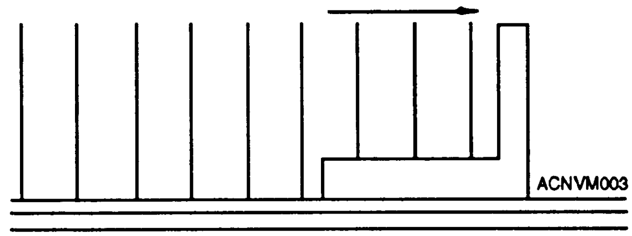


Figure 12-3.—Drawing perpendicular parellel lines.

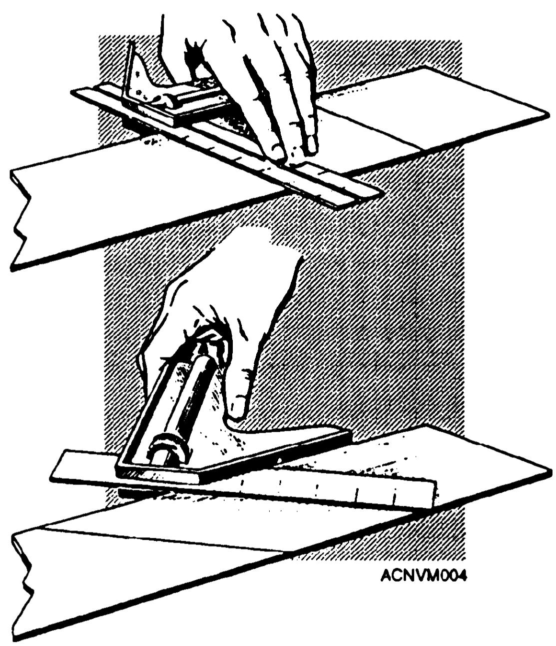


Figure 12-4.—Using a combination square.

an edge of the metal upon which you are working as the base line. One edge of the head of the combination square is 90 degrees and the other edge is 45 degrees. Lay either edge of the head on the edge of the metal to make either a 45- or 90-degree angle to the edge of the metal.

Combination squares are delicate instruments and will be of little value if they receive rough handling. Stow your tools properly when you are not using them. Keep them clean and in tiptop shape, and you will be able to construct 90-degree angles, 45-degree angles, and parallel lines without error.

Use a protractor to construct lines for angles other than 45 or 90 degrees. Mark the vertex of the angle on the base line with a prick punch. (See fig. 12-5.) Set the vertex of the protractor on the mark, and then scribe a V at the desired angle (in this illustration, 70°). Scribe the line between the vertex and the point located by the V and you have constructed an angle of 70°.

When you mark a point with the PRICK PUNCH, use very light taps with a small ballpeen hammer. The smaller the mark you make (so long as you can see it), the more useful and accurate that mark becomes.

Use DIVIDERS to scribe arcs and circles, to transfer measurements from a scale to the layout, and to transfer measurements from one part of the layout to another. Careful setting of the dividers is of extreme importance. When you transfer a measurement from a scale to the work, set one point of the dividers on the scale mark and accurately adjust the other leg to the desired length, as illustrated in figure 12-6.

To scribe a circle or an arc, grasp the dividers between the fingers and the thumb, as shown in figure 12-7. Place the point of one leg on the spot that will be the center of the circle or arc. Exert just enough pressure to hold the point at the center, slightly inclining the dividers in the direction in which they are to be rotated. Then rotate your dividers with both legs touching your work to make your circle or arc.

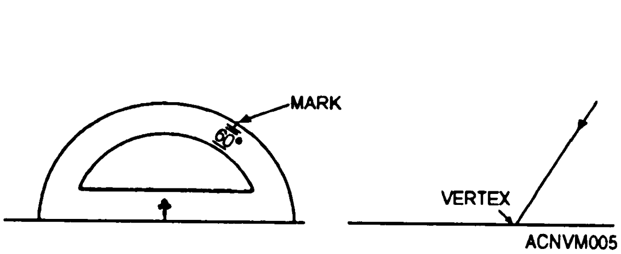


Figure 12-5.—Constructing an angle with the protractor.

When you need to scribe a circle with a radius larger than your dividers, you will have to use TRAMMEL POINTS. The points are adjusted as shown in figure 12-8. Set the left-hand point on one mark, sliding the right-hand point to the desired distance, and tighten the

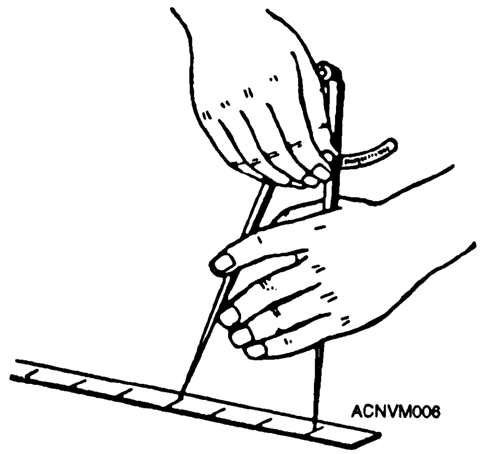


Figure 12-6.—Setting the dividers.

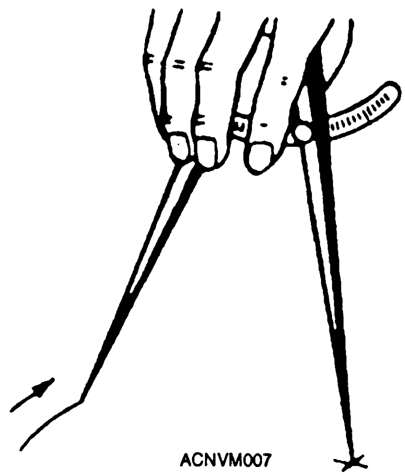


Figure 12-7.—Scribing an arc or circle with dividers.

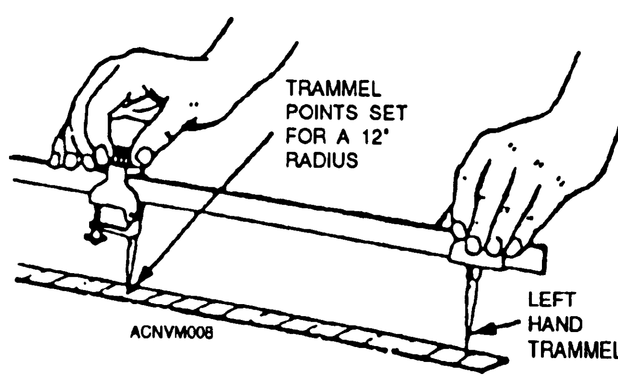


Figure 12-8.—Setting trammel points.

thumbscrew. Then scribe the arc or circle in the same manner as with the dividers.

MAKING SIMPLE LAYOUTS

A STRETCHOUT is a pattern on a flat sheet that has not been formed into a three-dimensional object. Figure 12-9 shows three-dimensional objects being formed from flat patterns. When jobs are laid out, you will need to add allowances for edges and scams.

A DRIP PAN is one of the objects you will have to make. Some of these pans, or boxes, will be used around the machinery in your shops. Take a look at them and see how they were made. Some have welded seams. Others are riveted and soldered. The welded seam is the fastest and easiest to lay out, but the riveted and soldered seam is by far the better of the two for sheet metal work. The various methods of seaming will be discussed later in this chapter.

Break out your layout tools. Select a piece of sheet metal or template paper about 1 foot square. Lay out a pan, or box, similar to that shown in figure 12-10. Make the sides about 1 l/2 inches in height, and the bottom about 9 inches square. Don't forget the tab if you are going to join the seam by riveting. The angle for the notch of the tab is 45 degrees (fig. 12-11). If this notch is not cut, you will have difficulty forming the side of the box. When you have the drip pan, or box, laid out, form the pan by breaking (bending) the side up 90 degrees. If you have made all of your measurements accurately, and have made your breaks on the line, the upper edge will be even all around, like the one shown in figure 12-11.

The STRETCHOUT OF A CYLINDRICAL JOB will be rectangular in shape, as shown in figure 12-12. One dimension of the rectangle will be the height of the cylinder, and the other dimension will be its circumference. When you are given measurements for a cylindrical job, however, you will be given the diameter rather than the circumference of the cylinder. You will have to find the circumference yourself.

The circumference may be determined by computation or with a circumference rule.

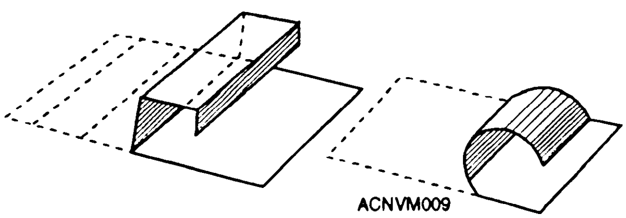


Figure 12-9.—Forming square and cylindrical shapes from flat patterns.

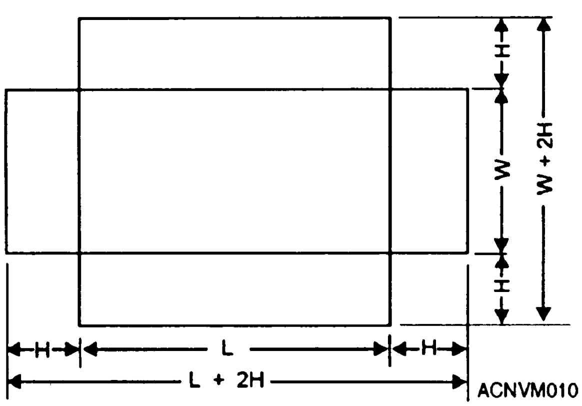


Figure 12-10.—Layout of a box or a drip pan.

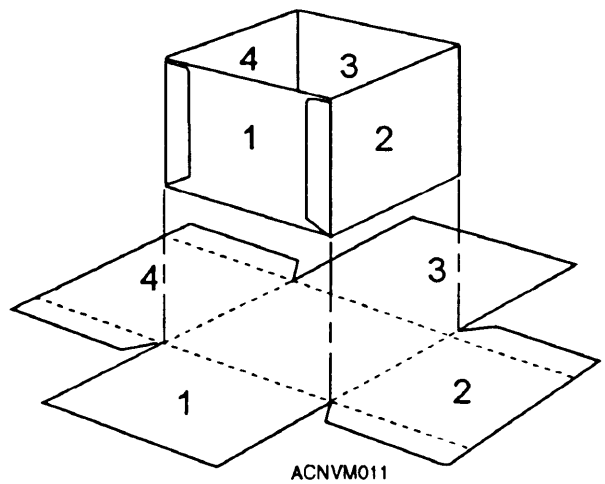


Figure 12-11.—Layout of a box.

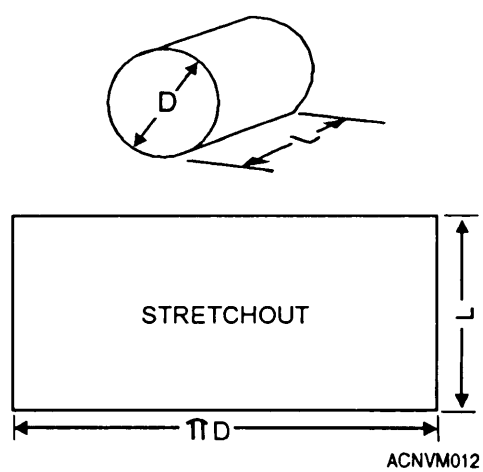


Figure 12-12.—Stretchout of a cylinder.

If you compute the circumference, multiply the diameter by pi (π), or 3.1416. This formula is read as $C = \pi D$. If the measurement is not critical, you can round off pi to 3.14 or 3 l/7. Either way, the formula will give you one dimension of your stretchout. The height or length is your other dimension.

Another method is by the use of the circumference rule. The upper edge of the circumference rule is graduated in inches in the same manner as a regular layout scale, but the lower edge is graduated, as shown in figure 12-13.

The lower edge gives you the approximate circumference of any circle within the range of the rule. You will notice in figure 12-13 that the reading on the lower edge directly below the 3-inch mark is a little over 9 3/8 inches. This reading would be the circumference of a circle with a diameter of 3 inches and would be the length of a stretchout for a cylinder of that diameter. The dimensions for the stretchout of a cylindrical object, then, are the height or length of the cylinder and the circumference. Do not forget that you will have to allow for the scams.

A VARIATION OF THE CYLINDRICAL JOB is a flat-sided structure with rounded ends (fig. 12-14).

To figure the stretchout for this shape, you will need two dimensions. The first is simply the length of the

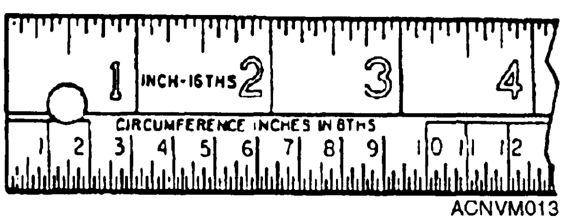


Figure 12-13.—Circumfcrcncc rule.

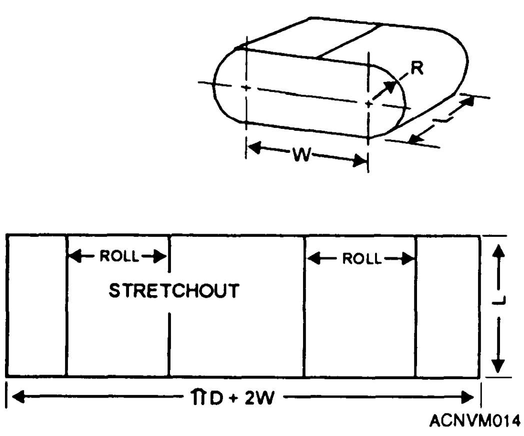


Figure 12-14.—Variation of a cylinder.

shape, which we will say is 12 inches. The second is the circumference, which is computed as follows. Use the formula $C = \pi D + 2W$. D is the diameter of the circle that you would have if both curved ends of the shape were put together. W is shown in figure 12-14. We will assume that D = 5 inches, and W = 6 inches.

$$C = \pi D+2W$$

$$C = 3.14 \times 5+2 \times 6$$

$$C = 15.7 + 12$$

$$C = 27.7$$

We find that the circumference is 27.7 inches. Therefore, our stretchout measures 27.7 inches by 12 inches.

USING GEOMETRY FOR LAYOUTS

Following are the procedures in using geometry for making various types of layouts.

CONSTRUCT A 90-DEGREE OR RIGHT ANGLE. This is no problem at all if you have a true steel square. We will describe three methods that you may use to erect a perpendicular to produce a right angle when you do not have a usable true steel square.

1. For the first method, break out your dividers, a scriber, and a straightedge. Draw a base line like the one labeled AB in figure 12-15. Set the dividers for a distance greater than one-half AB, then, with A as a center, scribe arcs like those at C and D. Then, without changing the setting of the dividers, use B as a center, and scribe another set of arcs at C and D. Draw a line through the points where the arcs intersect and you will have perpendiculars to line AB, forming four 90-degree or right angles. Not only have you constructed a

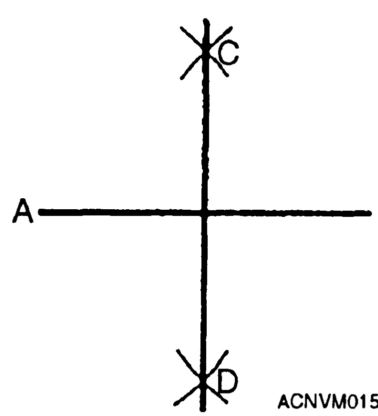


Figure 12-15.—Constructing a 90-degree angle by bisecting a line.

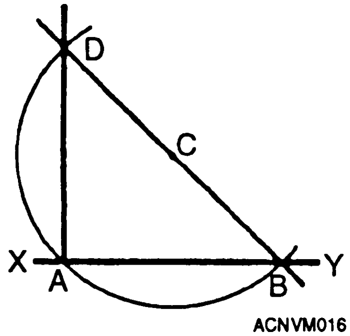


Figure 12-16.—Constructing a 90-degree angle at a given point.

perpendicular, but you also bisected, or divided, line AB into two equal parts.

2. Use a pair of dividers to CONSTRUCT A RIGHT ANGLE AT A GIVEN POINT. You will find this skill quite useful in making layouts. Figure 12-16 illustrates one method for constructing a right angle at a given point.

Suppose you have line XY with A as a point at which you need to erect a perpendicular to form a right angle. Select a point within the proposed angle that you wish to construct. In figure 12-16 that point is C. Set the dividers equal to CA, and using that distance for a radius, swing an arc BAD with C as a center. Lay a straightedge along the points B and C and draw a line that will intersect the other end of the arc at D. Now, draw a line connecting the points D and A and you have constructed a 90-degree angle.

3. Figure 12-17 shows another way to construct a perpendicular at a given point on a line:

Step 1: Take your dividers and place the point at point B on line XY.

Step 2: Lay arcs on line XY at equal distances from B on line XY. These arcs become points S and T on line XY.

Step 3: Before your next arcs are made, increase the distance between your divider points. Set your divider point at S on line XY. Lay arcs directly above and below P on line XY. These arcs become points W and M. Repeat this procedure from T on line XY without adjusting your dividers. You will have intersecting arcs at W and M.

Now draw a perpendicular between the intersecting arcs at W and M. You will have a right angle at B on line XY.

The three methods described in the preceding paragraphs may be used to form 90-degree comers in

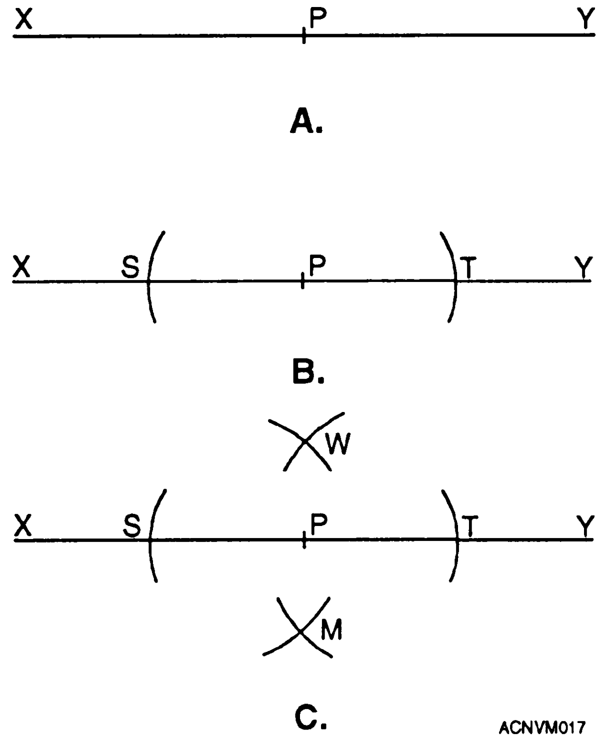


Figure 12-17.—Constructing a 90-degree angle by bisecting a line at a given point.

stretchouts that are square or rectangular, such as a drip pan or a box.

TO LAY OUT A DRIP PAN WITH A PAIR OF DIVIDERS, you will need dividers, a scriber, a straightedge, and a sheet of template paper. You know the length, width, and height or depth to which the pan must be made. Now proceed as follows:

Step 1. Draw a base line. (See fig. 12-18.) Select a point on this line for one corner of the drip pan layout. Erect a perpendicular through this point to form a 90-degree angle (W in fig. 12-18).

Now, measure off on the base line the required length of the pan (L in fig. 12-18). At this point erect another perpendicular. You now have three sides of the stretchout. Draw the fourth side parallel to the base line, connecting the two perpendiculars that you have erected. The fourth side will be drawn at a distance from the base line equal to the width of the drip pan.

Step 2. Now, set the dividers to mark off the depth of the drip pan. You can use a steel scale to measure off the correct radius on the dividers. Using each corner for

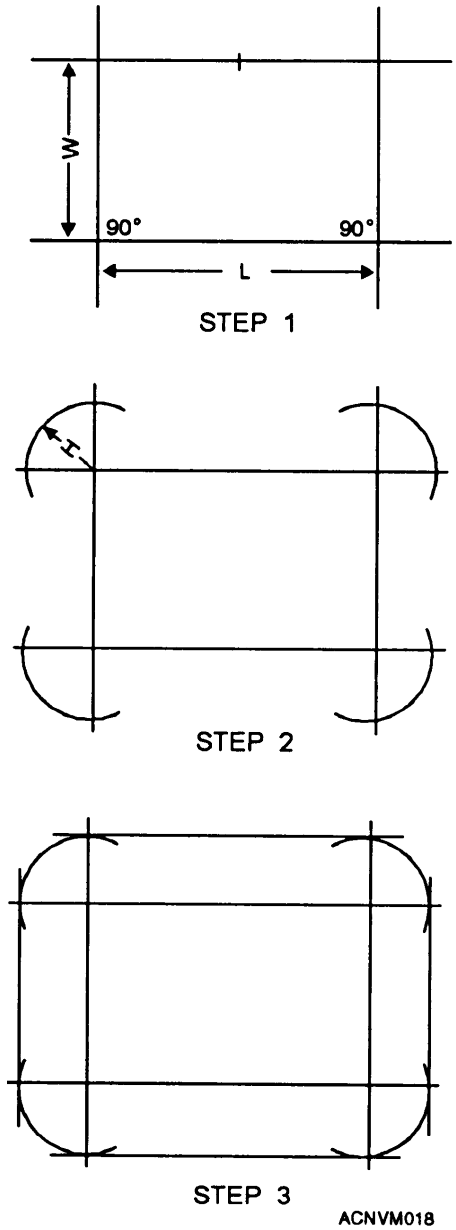


Figure 12-l8.—Laying out a drip pan with dividers.

a point, swing a wide arc like the one shown in the second step in figure 12-18.

Step 3. Extend the end and side lines as shown in the last step in figure 12-18, andcomplete the stretchout by connecting the arcs with a scriber and straightedge.

Step 4. Now lay out tabs like those shown in figure 12-11. Their size is determined by the diameter of the rivet, which in turn is determined by the thickness of the sheet. All that remains to be done now is to transfer the pattern to the sheet, cut the metal, and form it.

You have seen how a pan can be laid out without a steel square by the use of geometric construction. You bisected a line, erected a perpendicular from a given point on a line, and drew parallel lines by geometric construction. Use those geometrical principles to do a lot of layout problems rapidly and accurately.

You should also know how to BISECT AN ANGLE. Angle ABC (fig. 12-19) is given. With B as a center, draw an arc cutting the sides of the angle at D and E. With D and E as centers, and with a radius greater than half of arc DE, draw arcs intersecting at F. A line drawn from B through the point F bisects the angle ABC.

DIVIDE A LINE INTO ANY GIVEN NUMBER OF EQUAL PARTS. You need only a straightedge and a compass. Figure 12-20 illustrates the dividing of a line into 10 equal parts. To divide line AB into 10 equal parts, draw random line CB from B at a convenient acute angle to AB. Set a compass to a spread less than one-tenth of the length of CB, and lay off this spread 10 times from B on CB. Project the intermediate points of intersection on CB to AB by lines parallel to the line between the 10th point of intersection and A. The projected points of intersection divide AB into 10 equal Parts.

DIVIDE OR STEP OFF THE CIRCUMFERENCE OF A CIRCLE into six approximately equal parts. Set the dividers for the radius of the circle and select a point

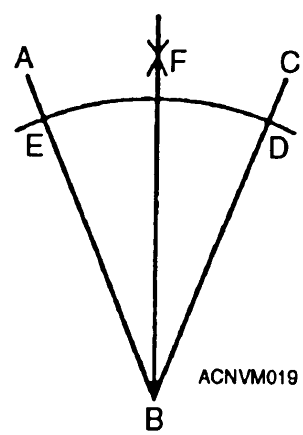


Figure 12-19.—Bisecting an angle.

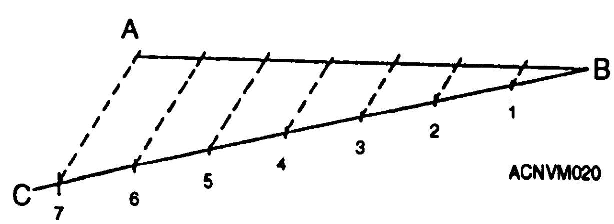


Figure 12-20.—Dividing a line into any number of equal parts.

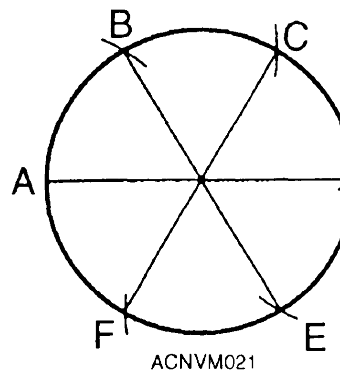


Figure 12-21.—Dividing a circle into six equal parts.

on the circumference for a beginning point. In figure 12-21, point A is selected for a beginning point. With A as a center, swing an arc through the circumference of the circle like the one shown at B in the illustration. Use B, then, as a point, and swing an arc through the circumference at C. Continue to step off in this manner until you have divided the circle into six equal parts. If the points of intersection between the arcs and the circumference are connected as shown in figure 12-21, the lines will intersect at the center of the circle, forming angles of 60 degrees.

If you need an angle of 30 degrees, all you have to do is to bisect one of these 60-degree angles by the method described earlier in this chapter. Bisect the 30-degree angle and you have a 15-degree angle. You can construct a 45-degree angle in the same manner by bisecting a 9O-degree angle. In all probability, you'll have a protractor to lay out these and other angles. But since you may not always have a steel square or protractor available, it's a good idea to know how to construct angles of various sizes and to erect perpendiculars.

LAY OUT A SQUARE OR RECTANGULAR ELBOW WITH A PAIR OF DIVIDERS. Take a look at figure 12-22. View A shows you what the completed job should look like. Now, to make your layout for this job, draw the base line OZ shown in view B. Set the dividers for a distance equal to the width of the cheek. This distance forms the throat radius. This rule will not always apply, as it must often be governed by the amount of space available to make the turn with the elbow. Now, with O as a center, scribe the arc YU. To get the heel radius, add the width of the cheek to the throat radius. Using 0 as a center, scribe the arc ZT. These layouts, when cut, will form the cheeks, or sides, of the elbow. The next operation is to lay out the heel and throat pieces. These arc the other two of the four

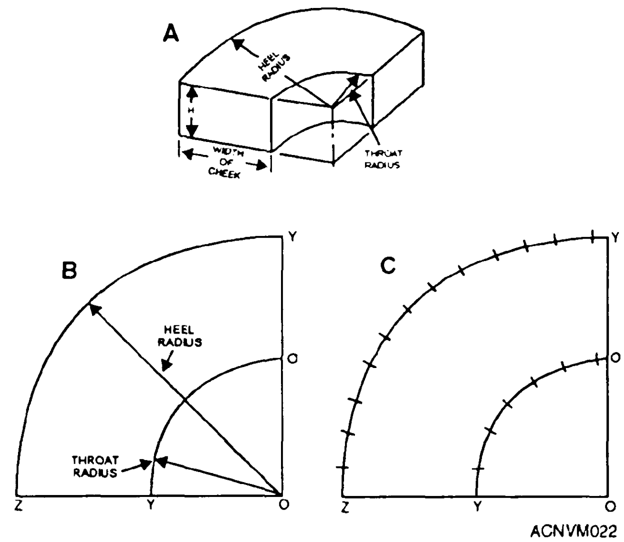


Figure 12-22.—Layout of a square or rectangular elbow.

sides of the elbow, the throat being the inside piece and the heel the outside piece. Set the dividers at exactly 1 inch, and step off the heel and throat arcs as shown in view C of figure 12-22. If there is a distance of less than 1 inch left at the end of the arc, measure it with another pair of dividers or a scale. To make the stretchout of the heel and throat, lay out one piece of metal equal to the height of the elbow (H in view A, fig. 12-22) and equal in length to the number of steps taken with the dividers, plus the fraction of an inch left over. One stretch out will be the heel and the other the throat. You can assemble this elbow by welding, in which case you do not need to allow for tabs. But welding will cause a thin section to warp, so you may need to use some of the other standard methods for joining this type of work.

ALLOWING FOR EDGES

So far, your practice jobs have been laid out to be formed with the edges left as they are. Very few of your jobs in the shop will actually be fabricated in this manner. Edges are formed to improve the appearance of the work, to strengthen the piece, or to eliminate a raw edge that could cut someone. These edges may be formed from the metal itself by inserting wire or by attaching a band or angle iron. The kind of edge that you will use on any job will be determined by the purpose, size, or strength of the edge needed.

The SINGLE-HEM EDGE is shown in figure 12-23. This edge can be made in any width. In general, the heavier the metal, the wider the hem is made. The allowance for the hem is equal to its width (W in fig. 12-23).

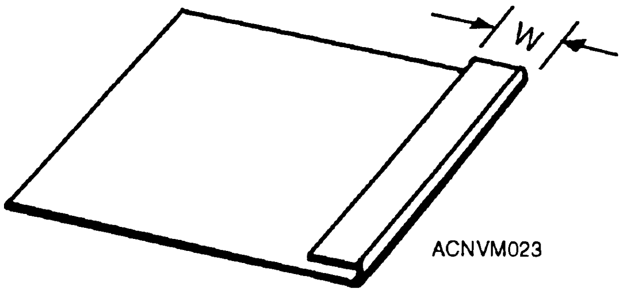


Figure 12-23.—Single-hem edge.

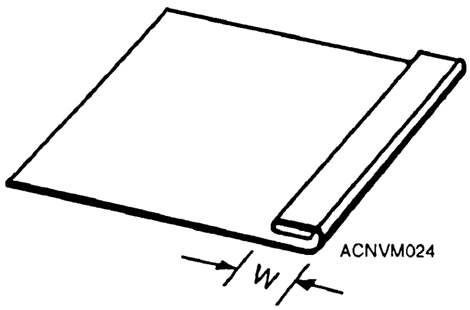


Figure 12-24.—Double-hem edge.

The DOUBLE-HEM EDGE (fig. 12-24) is used where additional strength is needed or when a smooth edge is desired inside as well as outside. The allowance for the double-hem edge is twice the width of the hem.

A WIRED EDGE (fig. 12-25) will often be specified in plans. Objects such as ice-cube trays, funnels, garbage pails, and other articles formed from sheet metal are manufactured with wired edges to strengthen and stiffen and to eliminate sharp edges. The allowance for a wired edge is 2 l/2 times the diameter of the wire used. For example, if you are using wire that has a diameter of l/8 inch, multiply l/8 by 2 l/2 and your answer will be 5/16 inch. This is the amount you will allow when laying out sheet metal for the wired edge.

ALLOWING FOR SEAMS

When you made your layout for a drip pan or box, you were told to allow for a tab for seaming with rivets. This method of joining sheet metal is known as lap seaming.

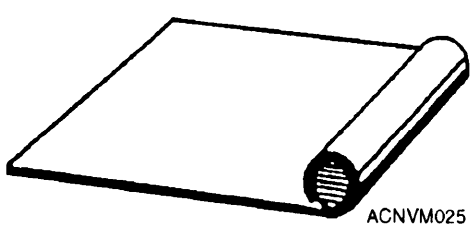


Figure 12-25.—Wired edge.

LAP SEAMS are shown in figure 12-26. They may be of three kinds: the plain lap seam; the offset, or "joggled," lap seam; or the corner lap seam. Lap seams may be joined by drilling and riveting, by soldering, or by a combination of both riveting and soldering. To figure the allowance for a lap seam, you must first know the diameter of the rivet that you plan to use. The center of the rivet must be set in from the edge a distance of two and one half times its diameter. The total allowance, then must be five times the diameter of the rivet that you are going to use. Figure 12-27 shows the manner in which a plain lap and a corner lap are laid out for seaming with rivets. For corner seams, allow an additional 1/16 inch for clearance.

GROOVED SEAMS are useful in the construction of cylindrical shapes. There are two types of grooved seams-the outside grooved seam and the inside grooved seam (fig. 12-28). The allowance for a grooved

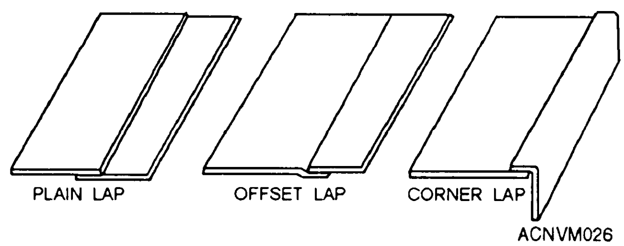


Figure 12-26.—Lap seams.

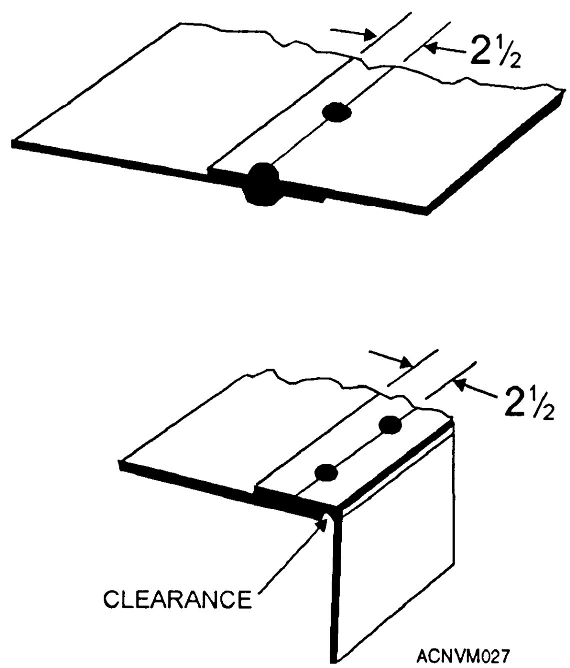


Figure 12-27.—Layout of lap seams for riveting.

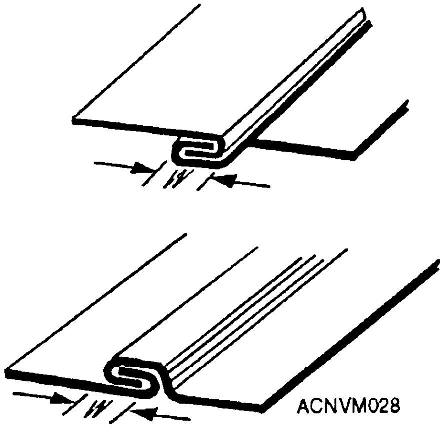


Figure 12-28.—Grooved seams.

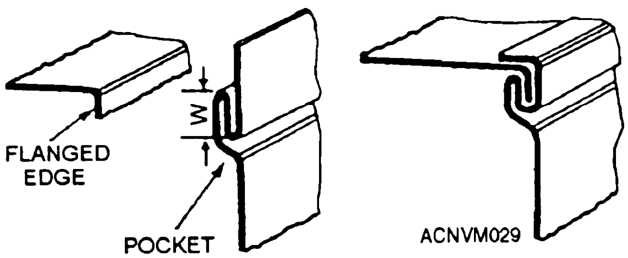


Figure 12-29.—Pittsburgh lock seams.

seam is three times the width (W in fig. 12-28) of the lock, one-half of this amount being added to each edge. For example, if you are to have a 1/4-inch grooved seam, 3 × l/4 = 3/4 inch, which is the total allowance; l/2 of 3/4 inch = 3/8 inch, which is the allowance you will add to each edge.

The PITTSBURGH LOCK SEAM (fig. 12-29) is a very useful corner seam that is used to advantage in rectangular ventilation lines, elbows, and boxes. At first glance, the seam appears to be quite complicated, but like lap and grooved seams it consists of only two pieces. The two parts are the flanged edge and the pocket with the projected edge, which is known as the locking flange after it has been bent over. After the pocket is formed, the flanged edge is inserted into the pocket, and the projected edge is then bent over the flanged edge. It then forms the locking flange that completes the Pittsburgh lock seam.

The allowance for the pocket and projected edge or locking flange is W + W + 3/16 inch. W is the width or depth of the pocket with 3/16 inch for the locking flange. The width of the flanged edge is l/l6 inch less than W to ensure a good tight fit. For example, if you are laying out a l/4-inch Pittsburgh lock (fig. 12-30, top view), your total allowance should be l/4 inch + l/4 inch + 3/16 inch, or 11/16 inch for the edge on which

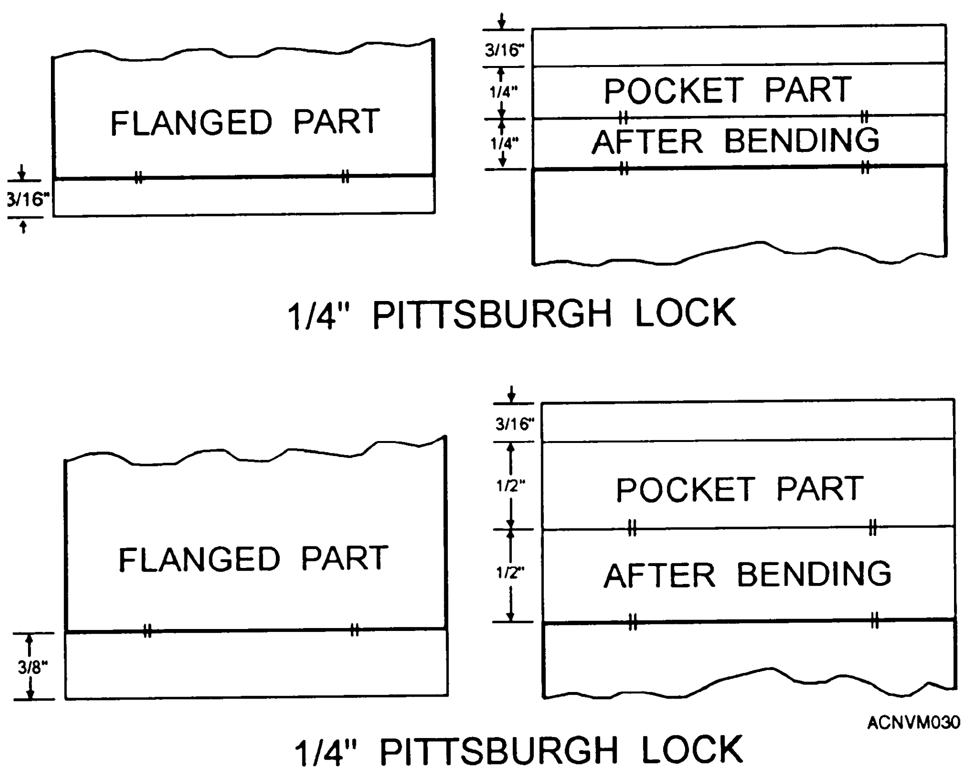


Figure 12-30.—Layout of Pittsburgh lock seam.

you are laying out the pocket, and 3/16 inch on your top piece for the flanged edge.

LAYING OUT NOTCHES

Notching is the last but not the least important step to be considered when you lay out a job. A notch is the spot on a piece of sheet metal that is cut out to allow the forming of a bend without the metal binding. Before you can mark a notch, you will have to lay out the pattern and add the seams, laps, or stiffening edges. If the patterns are not properly notched, you will have trouble when you start forming, assembling, or finishing the job.

There is no definite rule for selecting the proper notch for the job. But as soon as you can visualize the assembly of the job, you will have no trouble determining the shape of the appropriate notch. If the notch is made too large, a hole will be left in the finished job. If the notch is too small, or not of the proper shape, the metal will overlap and bulge at the seam or edge. Do not worry too much if your first notches do not come out very well; practice and experience will take care of that.

A SQUARE NOTCH is probably the first one you will make. That is the kind you were instructed to make in your practice layout of a box or drip pan. Take a look around the shop to see just how many different kinds of notches you can see in the sheet metal shapes.

SLANT NOTCHES are cut at a 45-degree angle across the corner, when a single hem is to meet at a 90-degree angle. Figure 12-31 shows the steps in forming a slant notch.

A V-NOTCH is used to seam the ends of boxes. You will also use a full V-notch when you construct a bracket with a toed-in flange or for similar construction. The full V is shown in figure 12-32.

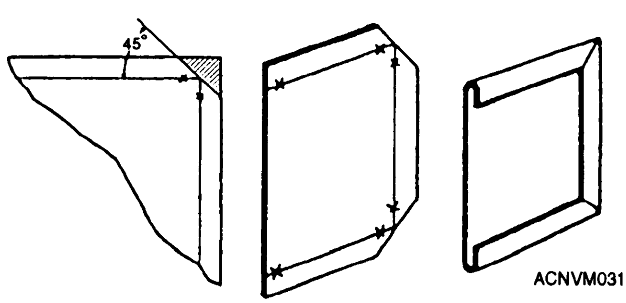


Figure 12-31.—Slant notch.

Your first 90-degree bends will be on line ADB, and the next ones will be on line CDE. But before you can make your bends, you will have to make your notch.

To make your notch, lay out your dimensions for the length and the width. Make sure you include the width the flange in your layout. Next lay out line ADB, which will be the width of the flange. Then lay out line CDE where your main bend will be, as shown in part V of figure 12-32. Next, bisect angles ADE and BDE on the flange, as shown in part W. Your final step prior to bending is to cut out your V-notch (angle FDG), as shown in part X of figure 12-32. Views Y and 2 show the bends being made.

When you are making an inside flange on an angle of MORE or LESS than 90 degrees, you will have to use a modification of the full V-notch to get flush joints. The angle of the notch will depend upon the bend angle. A modified V-notch is shown in figure 12-33.

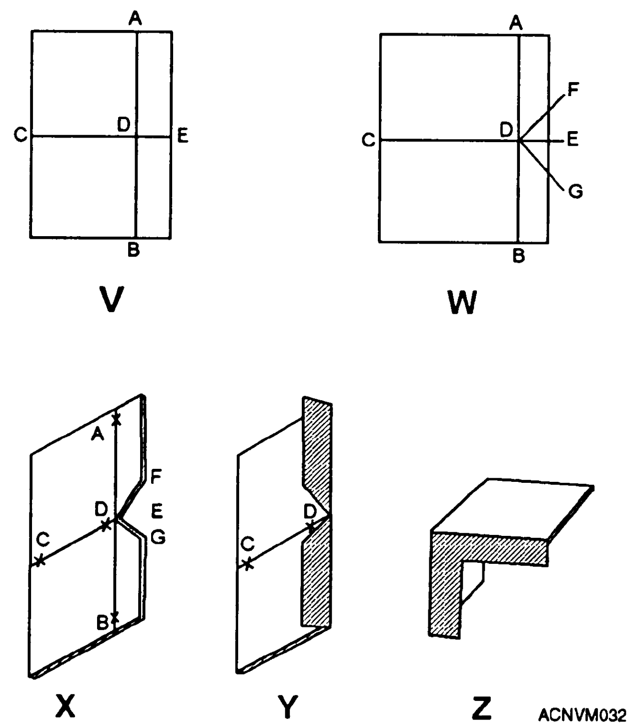


Figure 12-32.—V-notch.

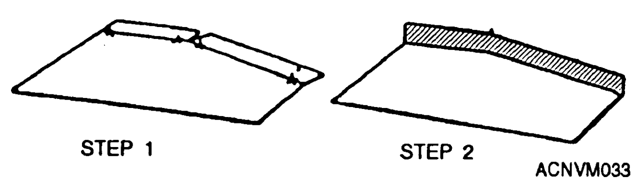


Figure 12-33—Modified V-notch.

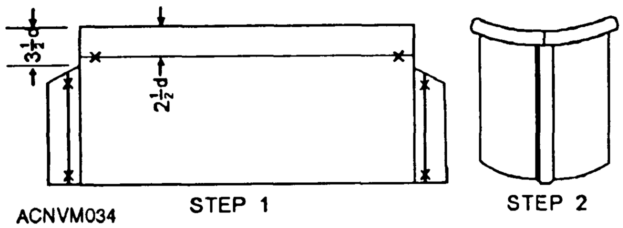


Figure 12-34.—Wire notch in cylindrical layout.

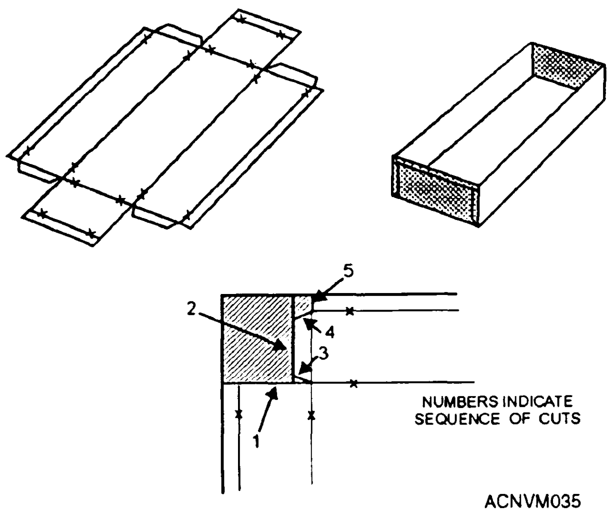


Figure 12-35.—Notching for an ice-cube tray.

A WIRE NOTCH is a notch used with a wired edge. The wire-edge cut-back allowance from the edge of the pattern will be one wire's diameter more than the depth of the allowance for the wired edge (2 1/2d), or 3 l/2 times the diameter of the wire (3 1/2d). The allowance on each side of the stretchout for the grooved seam is equal to 1 1/2 times the width of the seam (1 1/2W). That portion of the notch next to the wired edge will be straight, as shown figure 12-34. The shape of the notch on the seam will depend upon the type of seam used. The grooved seam shown in figure 12-34 requires a 45-degree notch.

Most of your work will require more than one type of notch. For example, in figure 12-34, notches are required for the wired edge and the grooved seam.

You will find another combination of notches when you lay out and make an ice-cube tray. The tray itself is similar to the drip pan you have already laid out, but the upper edge will require a wired edge. In this job, you will have to use the wire notch, the modified V, and the square notch (fig. 12-35).

PATTERN DEVELOPMENT

If all work that you were assigned to do consisted of laying out and fabricating drip pans, boxes, lockers, and straight sections of cylindrical and rectangular ventilation lines, your work would be much easier. Your layout would consist of nothing more than straight-line angular development, allowances for seams and edges, and visualizing the notch needed. But you will have to construct ventilation systems, or at least make repairs to those systems. This work calls for elbows and tees, which cannot be laid out unless you know how to do parallel line development.

PARALLEL LINE METHOD

Parallel line development assumes that a line that is parallel to another line is an equal distance from that line at all points. The main lines of a structure to be laid out by parallel line development are parallel to each other. Objects that have opposite lines parallel to each other, or that have the same cross-sectional shape throughout their length, are developed by this method.

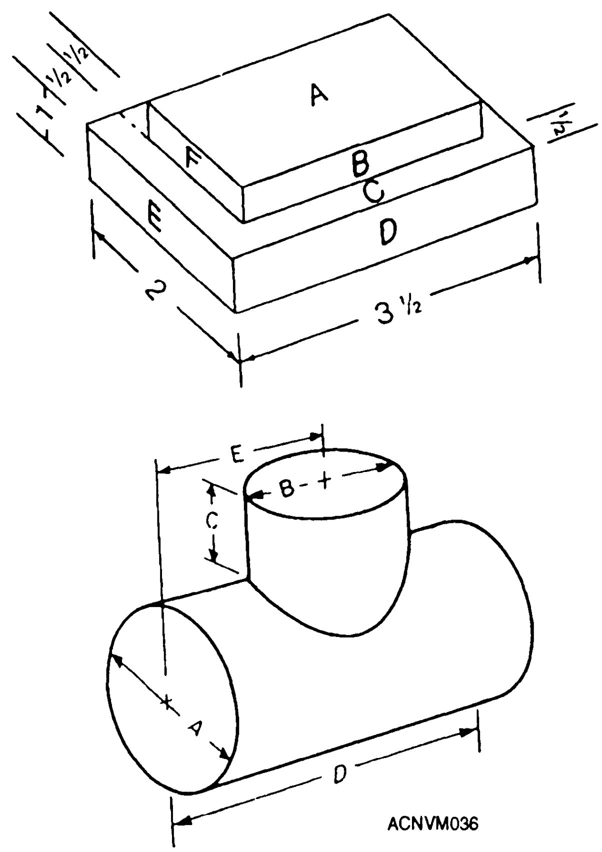


Figure 12-36.—Overall view of some objects fabricated by the parallel line method.

This includes such shapes as the cylinder and prism and their many variations.

You will have to use certain fixed principles as follows:

1. First, draw a plan and an elevation of the desired shape showing the parallel lines of the solid in their actual lengths.

2. Visualize the pattern from an angle in which the top, front, and side views are all present, as shown in figure 12-36.

3. Draw a stretchout or girth line perpendicular to the parallel lines of the solid. Each space contained in the section or plan view will be placed on the stretchout lines (fig. 12-37).

4. Draw measuring lines perpendicular to the stretchout lines of the pattern.

5. Draw lines from the points of intersection of the miter line, in the right view, intersecting similarly numbered measuring lines drawn from the stretchout, to show the outline of the development.

6. Trace a line through the points thus obtained to give the desired pattern.

Now, let us develop a layout of an intersected pipe following the parallel line method, step by step. A pipe like this could be used as a ventilation pipe on a slanting roof. Follow the instructions, checking each step with

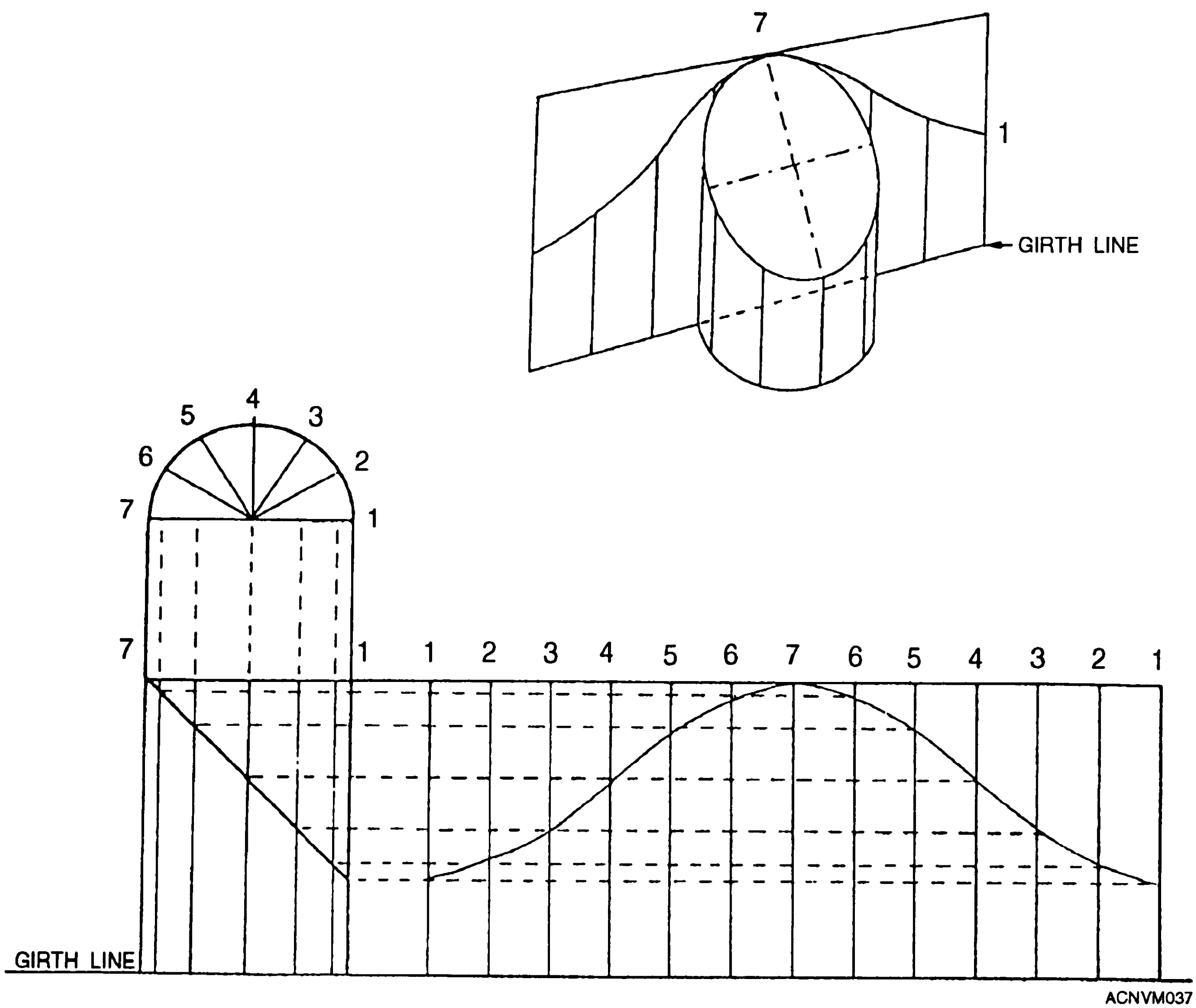


Figure 12-37.—Stretchout showing a girth line.

the illustration shown in figure 12-38. Then break out your layout tools and a sheet of template paper and try your skills at drawing an intersected pipe layout.

First, construct a base line. After the base line, draw your miter line at the same degree of angle as that of the slanting roof or inclined plane, as shown in figure 12-38. The elevation is the front view. Line AB represents the diameter of the pipe. The distance between line AB and the miter line is the height of the pipe, which will vary around the circumference of the pipe.

Now determine the center of line AB, and construct a center line as shown in figure 12-38. Set your dividers for one-half the distance of line AB. Develop the plan by the following steps:

1. Construct line 1-7 parallel to and just above AB. Using the point at which the center line of the elevation intersects line 1-7, swing an arc with the dividers and complete the half-plan as shown.

2. Step off the circumference of the half-plan with the dividers into six equal parts. To do this, place one leg of your dividers at point 1. With the same measurement used to scribe the half-plan, scribe a mark on the arc at point 3. Then from point 3 scribe a mark at point 5. You now have three equal parts. Bisect these three sections as an arc and you end up with your required six equal parts.

3. Set your straightedge at right angles to the center line. With the straightedge as a base line, use the flat steel square to draw lines parallel to the center line by the method shown earlier in figure 12-3. The parallel lines must be drawn from the points where the arcs intersect the circumference of the half-plan to the miter line (fig. 12-39).

4. with the straightedge draw EF (an extension of line AB), and step off twice the distance you stepped off in the circumference of the half-plan.

5. Draw line GH the same length as EF parallel to EF so that lines drawn from G to E and from H to F will both be perpendicular. The distance between line EF and line GH will be equal to the greatest height of the elevation.

6. Through the points located on the extended line, by stepping off with the dividers, draw parallel lines at right angles to the line extended from AB.

7. Number these lines in the proper order as shown (from 1 to 7 and back to 1).

You are now ready to transfer the miter line CD in the elevation to the stretchout and thus form the stretchout for the elevation. You may use either of two methods:

- Measure and transfer the measurement from the elevation to the stretchout with your dividers.
- Project the points in the elevation to the stretchout by parallel projection lines (broken lines).

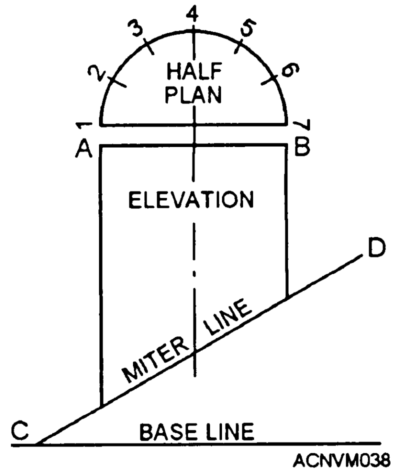


Figure 12-38.—Elevation and plan of intersected pipe.

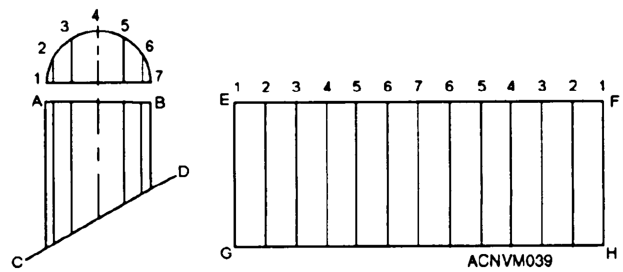


Figure 12-39.—Development of layout for intersected pipe.

Whichever method you use, the stretchout will be the same. However, your measurements must be accurate. Try both methods and make a habit of using the one that comes easiest to you.

To develop your pattern by the use of dividers, follow these step-by step instructions, working from figure 12-39.

1. Take your dividers and set them to the distance of line 1 where it intersects line AB to its intersection on line CD.

2. Transfer this measurement to the two lines numbered 1 in the stretchout. Use line EF as your base line for the measurements on the strecthout, and scribe an arc on line 1.

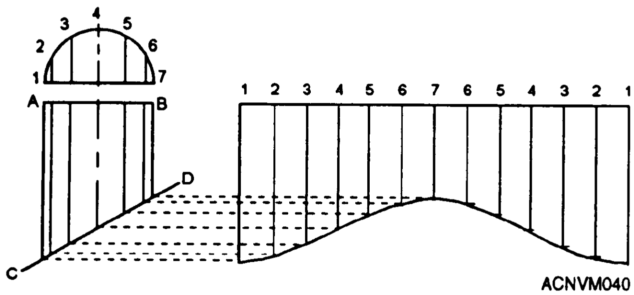


Figure 12-40.—Transfering from elevation to stretchout to making the pattern.

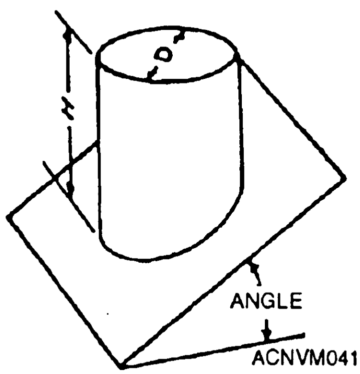


Figure 12-41.—Pictorial view of pipe intersected at an angle.

3. Then, measure line 2 in the elevation, and transfer this measurement to the two lines marked 2 in the stretchout. Repeat this procedure for lines 3, 4, 5, and 6.

4. Since there is only one line 7 in the stretchout, you will need to transfer the measurement of line 7 in the elevation to the stretchout only one time.

5. Finally, connect the points at which the arcs have intersected each of the elements, with a curve running from line A to the opposite line 1. Smooth out your curved line, add the allowances for seams, and the pattern is completed. If this final line has serious irregularities, you have made a mistake in your measurements. Your final stretchout should look exactly like the one made by projection in figure 12-40.

To obtain the pattern by projection, you simply project parallel broken lines from the points of intersection on the miter to lines with the same number in the stretchout. These broken lines are drawn at right angles to the numbered lines and parallel to line AB. They are drawn from the point where the numbered lines intersect the miter CD to the point at which they intersect the most distant line in the stretchout with the same number. Again, the pattern is completed by connecting the points of intersection on the stretchout with a curved line. Remember, the more care you take in drawing the elevation, stepping off the half-plan, and transferring the measurements from the elevation to the stretchout, the more accurate your pattern will be. Figure 12-41 is a pictorial view of the plan you have just laid out.

The parallel line method can also be used to develop an elbow of any desired diameter, depth of throat, or number of pieces. Figure 12-42 shows the development

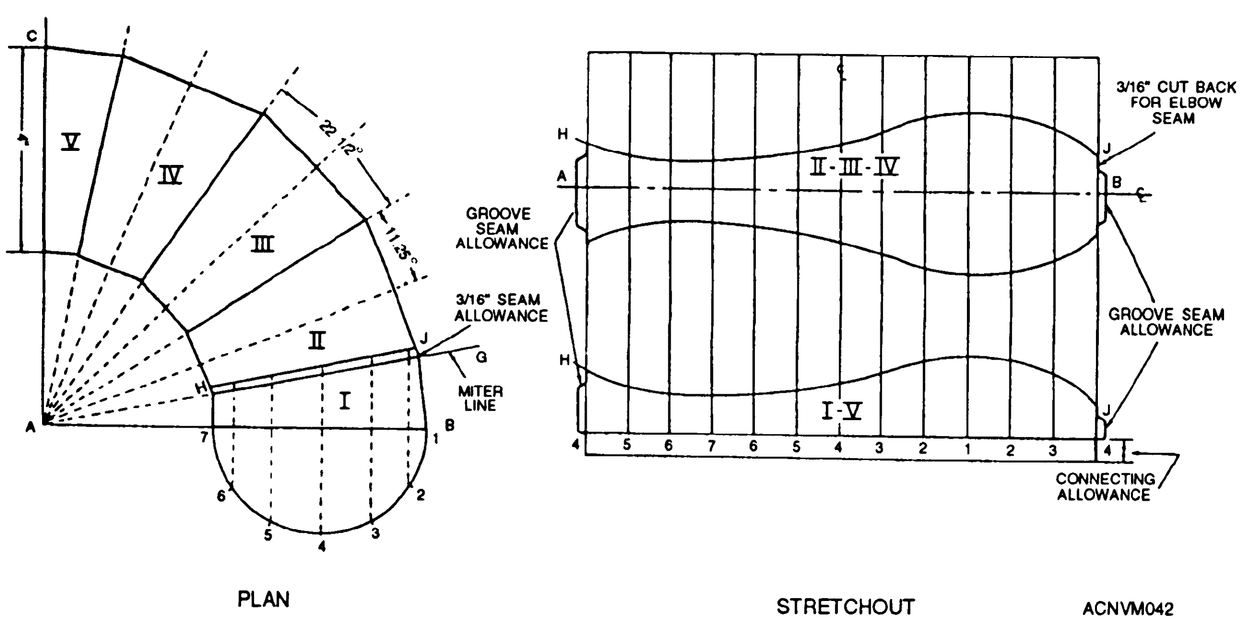


Figure 12-42.—Development of a five-piece 90-degree elbow.

of a five-piece 90-degree elbow. Take a pair of dividers and a straightedge and develop a five-piece 90-degree elbow using this method.

1. Using figure 12-42 as a guide, scribe horizontal line AB. From point A, scribe line AC to form angle CAB, which should be equal to the degree of angle that the elbow is to be. In this cast, we will use 90° for our elbow.

2. Set the dividers for the throat radius and scribe the arc, using A as the vertex.

3. Set your dividers for the heel radius, and using A as the vertex, scribe the heel arc. (The heel radius is determined by adding the diameter of the elbow to the throat radius.)

4. Divide the heel arc BC into equal spaces. To determine the number of spaces to use and the degree of angle per space, follow this rule: Multiply the number of pieces in the elbow by 2 and subtract 2. This will give you the number of equal spaces. Then, divide the degree of the elbow by the number of equal spaces. You now have the degree of angle for each space on the heel arc.

SAMPLE:

$5 \times 2 = 10 - 2 = 8$

$90° \div 8 = 11.25°$ of angle per space.

5. Now, draw lines from the vertex A to the points stepped off on the heel arc, making pieces I and V equal to one space each on the heel arc. Pieces II, III, and IV are made equal to two spaces each on the heel arc. They are twice the size of I and V.

6. Using AB for the base line, construct the half-plan.

7. Step off the circumference of the half-plan into equal spaces, and number the dividing lines from 1 to 7. For a larger diameter, use a greater number of equal spaces. The more spaces you use, the more accurate your plan will be.

8. Use AG for the miter line. You have now completed your elevation for making the stretchout of piece II, which will be the same for III and IV, and for making the stretchout of piece I, which will be the same as V.

9. To join the elbow together, you must make allowance for your elbow seam. Add the allowance from line AG up and draw line HJ.

10. Extend line AB to the right of the elevation to make the stretchout.

11. Set your dividers equal to one of the numbered divisions in the half-plan.

12. Step off twice the number of equal spaces in the stretchout that you have in the half-plan.

13. Erect perpendiculars from the base line of the stretchout and number them as shown in figure 12-42. The number with which you begin and end in your stretchout will determine the location of the seam in the finished elbow. The best location for a seam on an elbow is on the side, so you would number from 4 up to 7, then down to 1 and back up to 4. Numbering from 1 to 7 and back to 1, as was shown in the previous development, would place the seam on the heel. A layout done in this manner is undesirable because it would require more time and material to complete the seam. Numbering from 7 to 1 and back to 7 is also undesirable. This method would put the seam in the throat of the elbow; normally it would be too small to make a strong seam. The location of the scam is a matter of preference and is determined by the job you are laying out.

14. To transfer the pattern from the elevation to the stretchout using dividers, follow these steps:

a. Using line 4, measure its distance between lines AB and HJ with your dividers.

b. Using this distance, mark off three spaces on each of the three lines that are numbered as 4 in the stretchout. Start from the base line of the stretchouts.

c. The point on each line 4 that would divide the second and third space in half forms the center of the stretchout. To make the center line AB for the stretchout, draw a line to connect these three points.

d. Now, using the point where the center line and the numbered lines (elements) in the stretchout intersect, scribe arcs cutting each of the lines the same length as the corresponding lines in the elevation between the base line AB and line HJ.

e. Connect these points with smooth lines that will be curved. Your stretchout is now completed. Piece I in the stretchout (the lower piece) is the pattern for pieces I and V in the elbow, and piece II in the stretchout is the pattern for pieces II, III, and IV.

Figure 12-43 is a pictorial view of the five-piece elbow you have just laid out.

You have seen that you must draw an elevation and a plan view. For the intersected pipe and the elbow, it was necessary to draw only one elevation and plan view. However, some developments will require two or more elevations. An example of this type of development is the T-joint (fig. 12-44).

To develop the T-joint, you must draw a side elevation and an end elevation as well as plan views. For the side elevation, draw the object exactly as you would see it, looking directly at the side of the T. For the end elevation, draw the object exactly as you would see it if you were looking through the opening.

Follow these steps to construct the side and end elevation as shown in figure 12-44:

1. Draw a horizontal center line.

2. Construct two vertical parallel lines perpendicular to the center line, leaving sufficient space between them to lay out the side and end elevations. These lines will form the center lines for the elevations.

3. Draw the plan view above the constructed elevations, as shown in figure 12-45.

4. Step off the circumference of the plan view into seven equal spaces with your dividers.

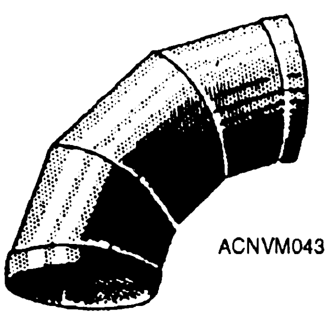


Figure 12-43.—Pictorial view of 8 five-piece elbow.

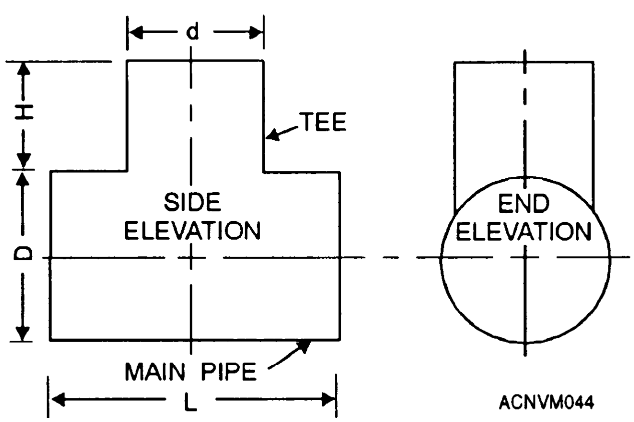


Figure 12-44.—Side and end elevation of a T-joint.

5. Number the elements of the plan as shown. The plan is numbered from 1 to 4 and back to 1 because each quarter section of the intersection, or miter, of the two pieces is the same as any other quarter section in the elevation. If the intersection of the T was other than a 90-degree angle, you would number from 1 to 7 as you did in developing the pattern for the elbow. As you can see, the number 4 element on the front view is in the center. If you rotate the T to look at the end view, the number 4 element is also rotated to represent its fixed position as the front and center element.

6. Extend lines parallel to the center lines in each of the views from the numbered points. In the end view, these lines will be drawn to the main pipe. To determine the lower end of the lines in the side elevation, proceed as follows: Place the straightedge at right angles to the number 4 vertical element of the end view. Draw a broken horizontal line from the number 4 element of the end view to the number 4 vertical element of the side view. Connect the other like-numbered elements in the same manner. Remember that there are two elements numbered 3, 2, and 1 in the side elevation to be connected.

7. Draw a curve through the intersections you have just located on the side view.

8. Now look at figure 12-46. To the right of the elevations, draw a stretchout equal in length to the

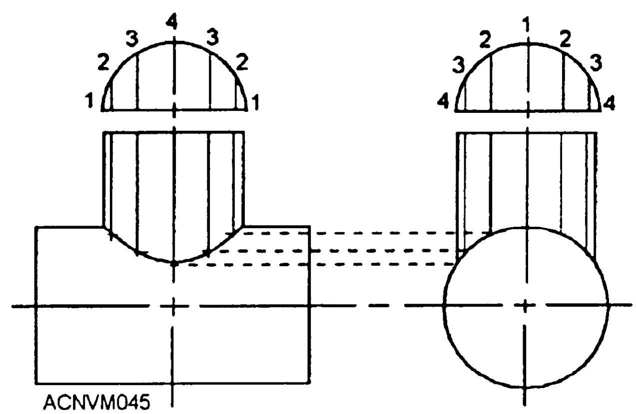


Figure 12-45.—Transferring elements to obtain miter line.

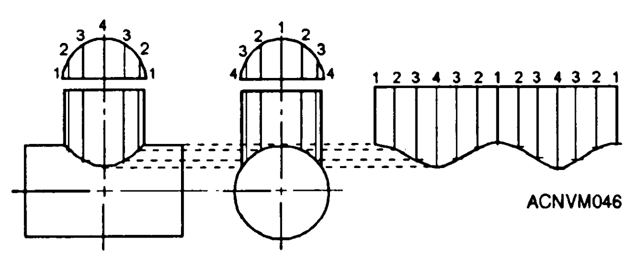


Figure 12-46.—Stretchout of the T.

circumference of the upper section of the T, or equal to twice the distance that you stepped off in the half-plan. The height of the stretchout, obtained by projection, is equal to the maximum height of the T. The height is equal to the length of the longest element in the side elevation—in figure 12-46, element number 4.

9. Step off, locate, and number the element lines in the stretchout.

10. Project the points of intersection locating the miter in the side elevation. Draw the curve through these points.

11. Now, using the circumference and length of the main pipe for dimensions, draw the stretchout for the main pipe as shown in figure 12-47.

12. Bisect the length of the stretchout with an element line, and number that line 1.

13. Set your dividers for the distance from 1 to 2 in the half-plan in the elevation. Using this radius and the point at which line 1 intersects the right-hand edge of the stretchout, scribe an arc on either side of 1 on the edge of the stretchout. Number each of these points 2. Now, setting the dividers for the distance from 1 to 3 in the half-plan of the elevation, scribe arcs, using 1 as a center, on either side of element 1 in the stretchout. Number both of these points 3. Repeat the procedure to get the points for the number 4 elements in the stretchout.

14. Through each of the points located, draw the element lines parallel to line 1.

15. Project the elements of the side elevation view to the correspondingly numbered elements in the stretchout. Connect the intersecting points with curved lines to outline the hole.

16. Add seams to the stretchout as required. Remember, the amount you will allow for seams will depend upon the method you plan to use for joining.

When the layout is completed, transferred to sheet metal, and formed, you should have a shape that looks like the one shown in figure 12-48.

You have been shown how to develop patterns for a drip pan or box by the straight line angular method of development, and methods for making stretchouts for elbows, pipe intersection angles, and T-joints by the parallel line method. Each of these methods has many more applications and you will use them often. However, you would not be able to develop some of the patterns that you will run into without a working knowledge of the method for radial line pattern development.

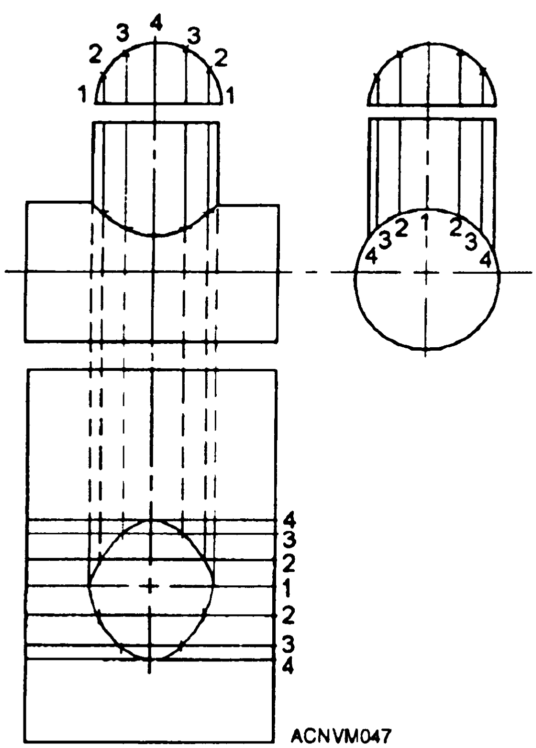


Figure 12-47.—Stretchout of the main pipe in the T-joint.

RADIAL LINE METHOD

The radial line method of pattern development uses some of the features of parallel line development. You will recognize them when you lay out a frustum of a right cone. You are familiar with the shape of a cone. A right cone is one that would stand straight, up and down, when resting on its large end. In other words, a center line drawn from the point, or vertex, to the base line, would form right angles with that line. The frustum of

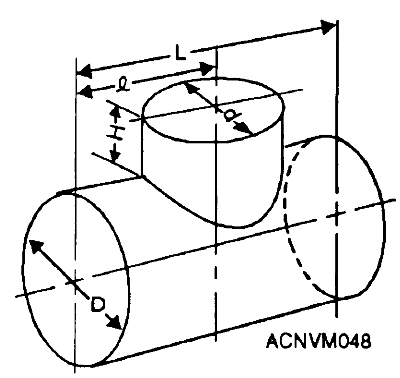


Figure 12-48.—Pictorial view of a T-joint.

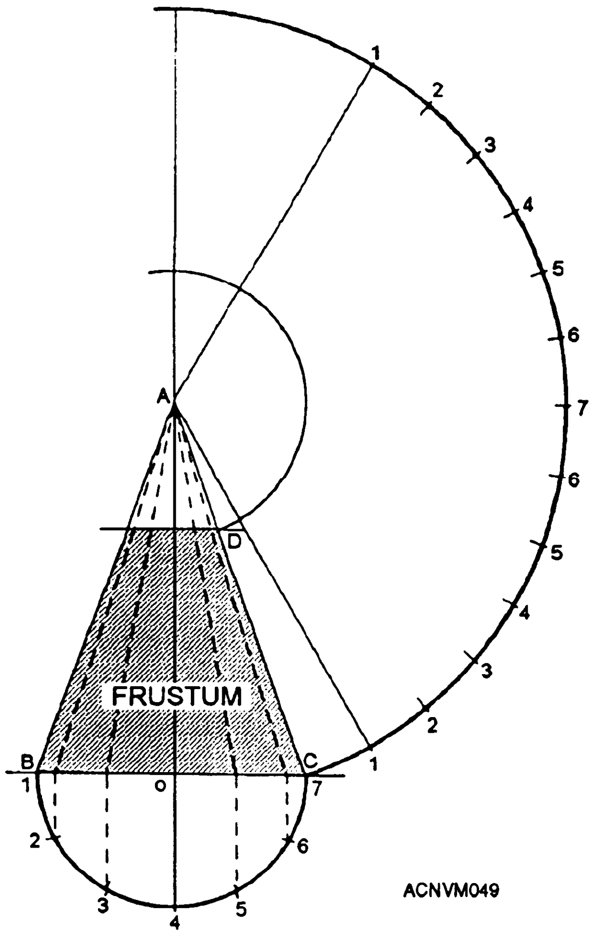


Figure 12-49.—Radial line development of frustum of a cone.

a cone is that part that remains after that point, or top, has been removed.

To develop a pattern for the frustum of a cone, check the following steps one-by-one with the illustration shown in figure 12-49.

1. Draw a front view of a cone, using such dimensions as your job at hand requires. Letter the vertex A, the base BC, and the axis AO.

2. At point D, and parallel to line BC, draw a line that cuts the top from the bottom of the cone. The bottom portion is called the frustum.

3. Draw a half-plan (using center 0 and radius OB) beneath the base of the frustum. Step the half-plan off into an equal number of spaces, and number them as shown in the illustration.

4. Set your dividers the distance of line AC, and using the vertex A as a center, scribe an arc of indefinite length.

5. Set your dividers equal to the distance of the step-offs on the half-plan, and step off twice as many spaces on the stretchout as you have in the half-plan.

6. Number the step-offs from 1 to 7 and back to 1, and draw connecting lines from vertex A to the number 1 at each end of the stretchout.

7. With vertex A as the center, set your dividers along line AC the distance of line AD, and scribe an arc that intersects both lines drawn from A to 1.

The area enclosed between the large and small arcs and the number 1 lines is the pattern for the frustum of a cone. Add allowances for seaming and edging and the stretchout is complete.

To develop a pattern for a cone cut at any angle, you need merely to elaborate the development of the pattern for a frustum. Such a pattern is shown in figure 12-50.

To develop a pattern for a cone cut at any angle, follow the method given here step by step:

1. Draw a cone with line ED cutting the cone at the required angle, as shown in figure 12-50.

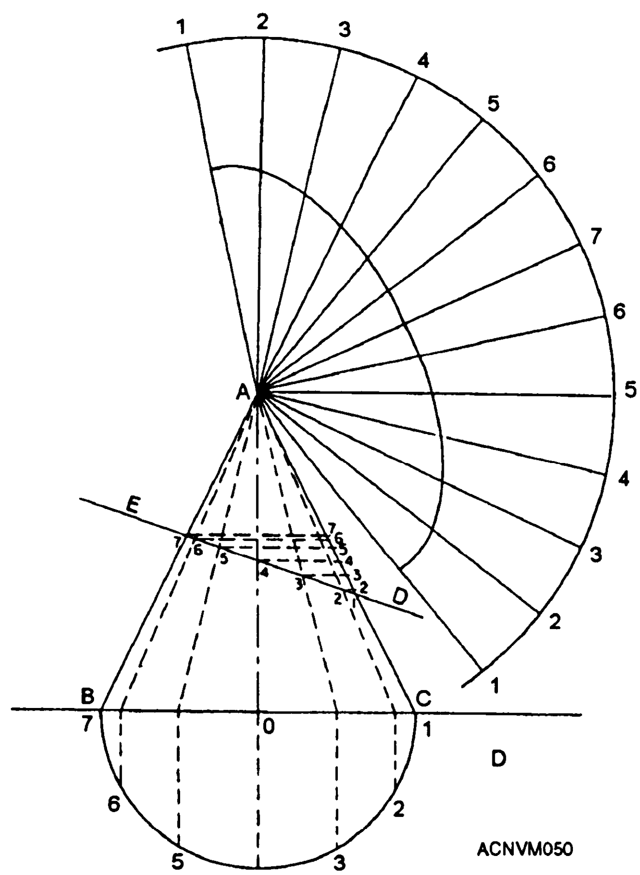


Figure 12-50.—Developement of a cone cut at any angle.

2. With center 0 and radius OB, draw a half-plan beneath the base line BC. Divide the half-plan into an equal number of parts and number them as shown.

3. From these points on the half-plan, draw lines perpendicular to the base line BC. From the points at which these lines intersect line BC, draw lines to vertex A.

4. Number the points of intersection on line DE, as shown in figure 12-50.

5. From the points of intersection of line DE, draw lines parallel to the base line BC and number the points of intersection on line AC.

6. With vertex A as a center and with dividers set to a distance equal to AC, draw an arc for the stretchout of the bottom of the cone.

7. Set the dividers equal to the distance of the step-offs on the half-plan and step off twice as many spaces on the arc as on the half-plan. Number the step-offs 1 to 7 and back to 1, as shown in figure 12-50.

8. Draw connecting lines from these points to vertex A.

9. Using vertex A as a center, transfer distances Al through A7 on line AC to each of the corresponding lines in the stretchout.

10. Join these points of intersection on the stretchout and a curved line to enclose the pattern of the cone.

11. Add allowances for seaming and edging, and the pattern is complete.

Thus far we have studied three principal methods of sheet metal development: angular, parallel line, and radial line development. Through the use of these three methods you can solve a large number of sheet metal layout problems. However, patterns for some objects are not readily developed by these methods. For example, a transition piece that changes the cross-sectional area of a duct from one geometric shape to that of another must be developed by triangulation rather than by the previous methods.

TRIANGULATION METHOD

It is often necessary to change the shape or area of a duct or pipe. This change is accomplished by transition pieces and other special fittings.

Most of the lines of the orthographic views on a transition piece are not shown in their true length because the lines slant away from the surface shown in the view. Because of this, you will have to find the TRUE LENGTH of some of the lines.

The true length of lines on transition pieces is found by triangulation. Using triangulation, the surface of the orthographic front view or elevation is divided into a number of triangles. Then the true length of each side of all triangles can be determined. This true length is then transferred to the development.

The general procedure for triangulation pattern development is as follows:

1. Construct the front view elevation and plan view in full scale.

2. Step off the plan view into four equal spaces.

3. Project the points stepped off on the plan view to the elevation (front view). Then draw the divisional lines.

4. Determine the true length of all the sides, edges, and divisional lines.

5. Develop the pattern from a center line, using the true length of all of the lines.

6. Sketch in the contours through the established points.

7. Add the necessary allowances for the seams.

The TWISTED SQUARE transition piece shown in figure 12-51 is quite simple to develop by triangulation.

Both of the openings, top and bottom, are parallel to each other. The centers of the openings are both on an axis perpendicular to the base. Because the openings are centered and have the same shape, the pattern could be obtained from a quarter-plan. However, a full-plan will be used here to illustrate the procedure. Here are the steps to be followed in making the layout:

1. Construct the elevation and plan views as shown in figure 12-5 1. The numbered lines indicate the elements that are shown in their true lengths. The lettered lines are those for which the true length must be found.

2. Extend the elevation's base line to the right of the elevation. Construct a perpendicular to the extension that is equal in length to the height of the elevation object. Mark these points A and H.

3. With your dividers, measure the distance from point 5 to point 6 in the full-plan view. From point A, on the extended base line, mark this distance to get point b. A line drawn from point b to point H is the true length of line b in the plan.

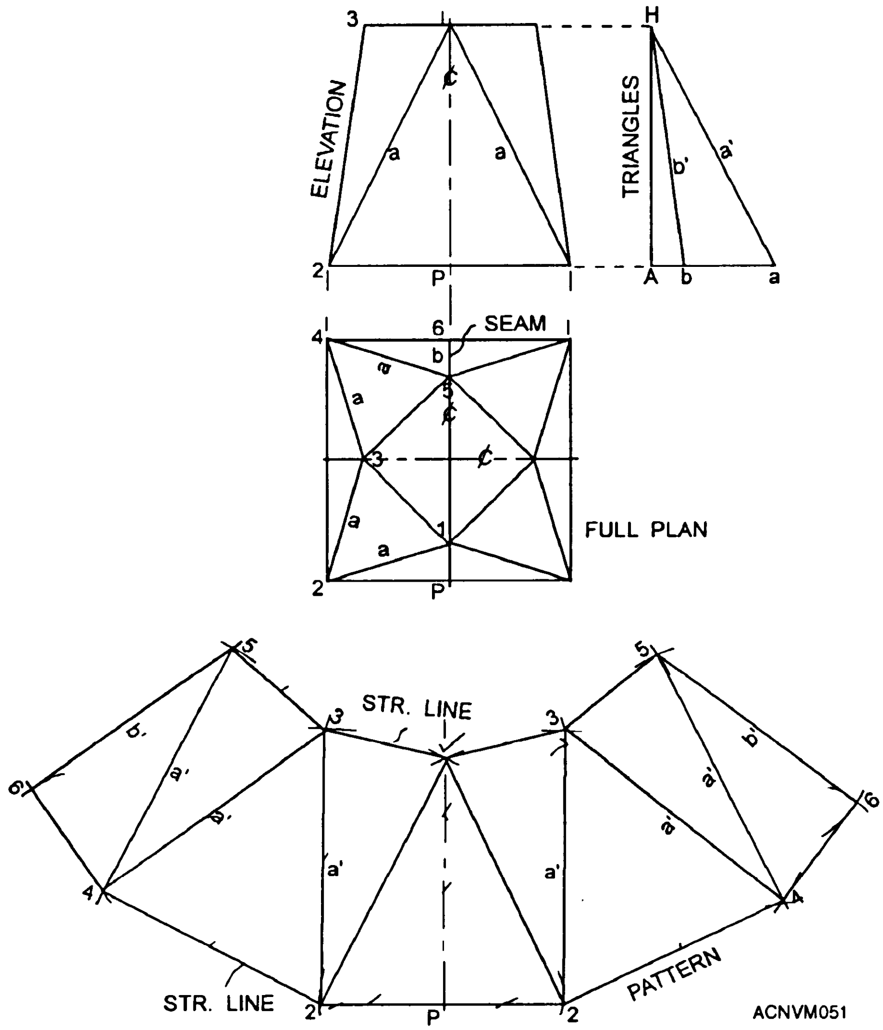


Figure 12-51.—Triangulation development of a twisted square.

4. Using the procedure for finding the length of line b, measure the distance between point 4 and point 5 to get the length of line a´.

5. Draw an extension to the vertical center line of the full-plan view. Construct a base line perpendicular to the center line. Mark the intersection of the two lines in the pattern as point P

6. Use your dividers to measure the distance from point P to point 2 in the full-plan view. Using this measurement as your radius and point P of your pattern as the pivot point, scribe an arc on each side of point P to get the true length of the base line. Label each of these points as point 2.

7. Using the true length of line a´ of step 3 as your radius, scribe an arc from each point 2 to intersect the center line to establish point 1 and your first triangle in the pattern.

8. Set your dividers for the distance between points 1 and 3 of the full plan. Using point 1 of the pattern for a pivot point, scribe an arc on each side of point 1.

9. With a´ as the radius, and using each point 2 as a pivot point in the pattern, scribe an arc to intersect each of two preceding arcs to establish points 3.

10. With 2-4 of the full plan as a radius, and using points 2 in the pattern for pivot points, scribe arcs at 4.

11. Set the dividers for the length of a´, and with points 3 in the pattern for pivot points, scribe arcs to establish points 4.

12. Set the dividers for the distance between 3 and 5 in the full plan. Using points 3 of the pattern for your pivot points, scribe arcs at 5.

13. With a´ as the radius and points 4 as the pivot points in the pattern, scribe your arcs establishing points 5.

14. Set your dividers to the length of line b´ in step 3. Now, using points 5 as the pivot points in the pattern, scribe your arcs at 6.

15. Set your dividers for the distance between 4 and 6 in the full plan. Using points 4 in the pattern as your final pivot points, scribe your arcs to establish points 6.

16. Draw straight lines between the established points, as shown in figure 12-5 1. Make your necessary allowances for the seams, and the pattern is completed.

Figure 12-52 illustrates the procedure for the development of a RECTANGULAR-TO-ROUND transition piece.

This is also a relatively easy development, and one that you can make on your own by following the drawing.

The OFFCENTER ROUND-TO-ROUND transition piece developed in figure 12-53 is a scalene conic section.

When the difference between the diameters of the top and bottom is small, as it often is, the vertex—if you could establish it—would fall in the next stop. When you have a scalene conic section to develop and that condition exists, you will have to develop the piece by the triangulation method. This type of development is shown in figure 12-53.

To develop the pattern, first draw the orthographic front view. Then swing in the half-circles at the top and the bottom. With the front view completed, follow these steps:

1. Divide the top half-circle into six equal parts to establish points A, B, C, D, and E.

2. Drop vertical lines from these points to intersect the top line of the front view at right angles. Number these points of intersection 1 through 7.

3. Divide the bottom half-circle into six equal parts to establish points F, G, H, J, and K.

4. Run vertical lines upward to intersect the bottom line of the front view at right angles. Number these points of intersection 8 through 14.

5. Construct the front view triangles as shown. Note that some of the lines are solid and some are broken. Make your lines the same way.

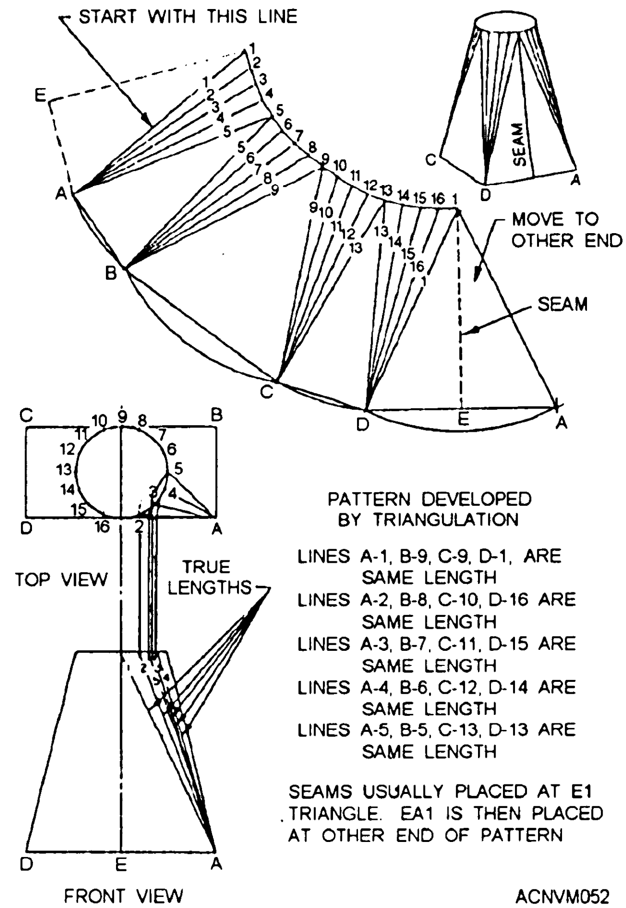


Figure 12-52.—Development of rectangular-to-round transition piece.

Now find the true length of each side of the triangles. The short side of each triangle that points downward is equal to one-twelfth the circumference of the TOP circle. The other two sides of each triangle are not shown in true length. Therefore, we must use triangulation to determine their true lengths. However, lines 1-8 and 7-14 are shown in their true length on the front view.

Work with the solid lines first. (See the top portion of fig. 12-53.) Set up two right angles to use as bases for true-length diagrams and work from point X and point Y. Take line 3-10 as an example. Set your dividers to the length of line 3-10 on the front view. Use point X as a center and swing an arc across line XZ. Then set the dividers equal to the DIFFERENCE between line G-IO and line B-3. Use X as a center and swing the arc to intersect line XY. A line connecting the two intersections is the true length of line 3-10.

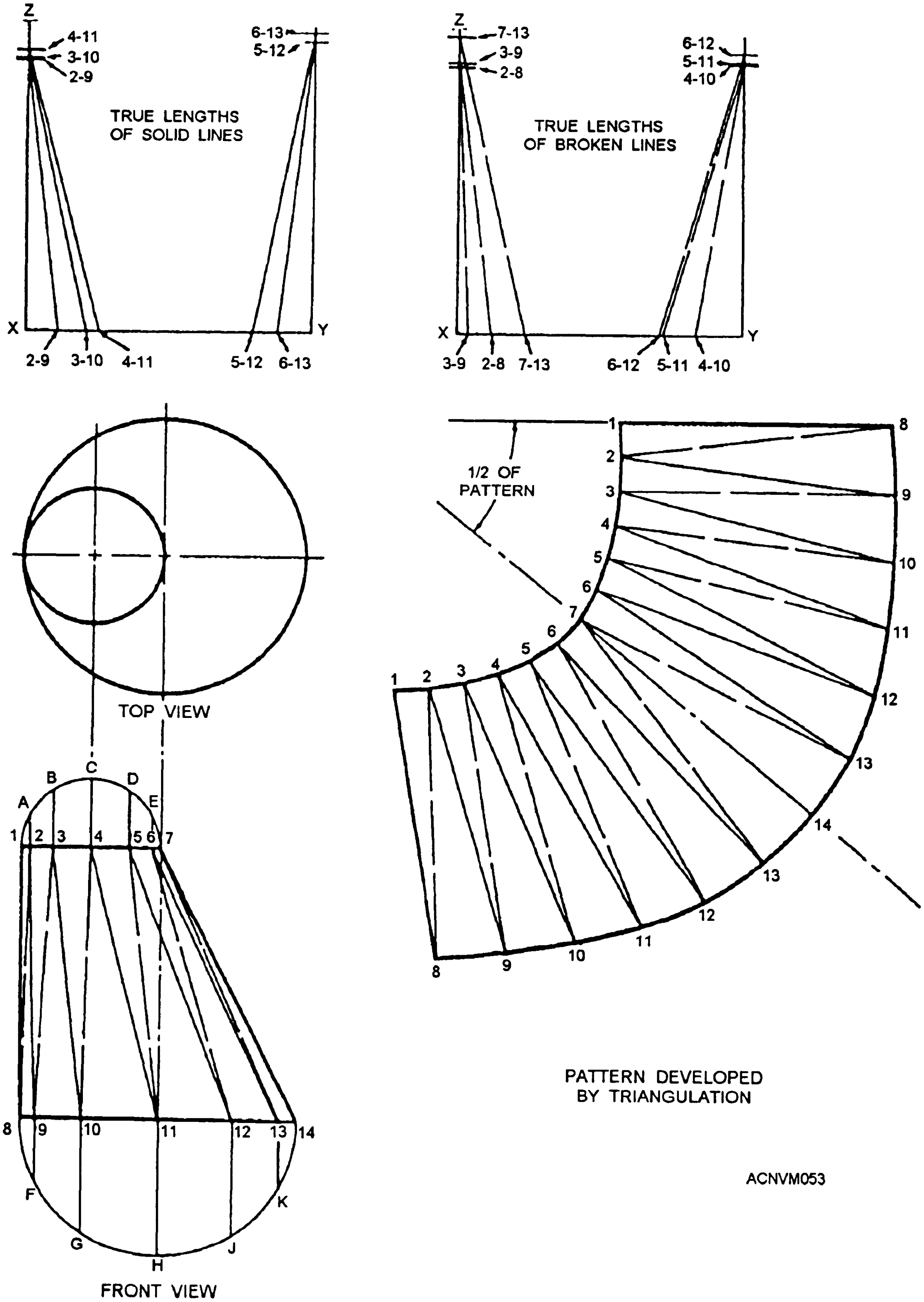


Figure 12-53.—Development of offcenter round-to-round transition piece.

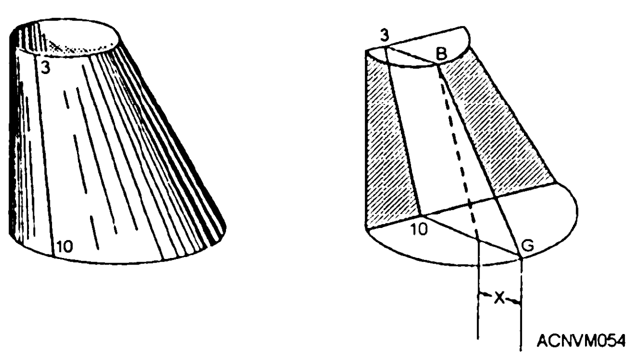


Figure 12-54.—Determining true length of a line.

Figure 12-54 shows why the difference between the lengths of line B-3 and line G-10 must be used as the length of the bottom leg of the triangle to get the true length of line 3-10.

If the half-plans of the front view (fig. 12-53) were bent forward 90 degrees and the entire front view revolved about 30 degrees to the right, the view would appear as shown in figure 12-54.

A perpendicular dropped from the top half-plan edge at B will be parallel to line 3-10 and intersect line G-10 as indicated. That intersection represents the proximity of the top edge to the bottom edge (top view, fig. 12-53). The distance between the point of intersection and point G (represented in the pictorial view by X shown in fig. 12-54) determines the length of the base leg required to plot the true length of line 3-10. Each line in the front view (fig. 12-53) is plotted, and the true length is obtained in the same manner.

With the true length of all the solid and broken lines established, lay out the development. First, draw a straight line that is almost vertical. Towards the top of the line, mark a point and label it point 1. Set your dividers for the length of line 1-8 in the front view of figure 12-53. Working from point 1 in the development, scribe an arc to locate point 8 as shown in figure 12-53. Using line 1-8 as a base line, you can now lay out the rest of the development. The first triangle to be laid out is 1-8-2. To obtain point 2 in triangle 1-8-2, use one equal spacing from the top half-circle of the front view. Using point 1 as a pivot point, scribe an arc. Then, using the true length of line 2-8, and using point 8 as the pivot point, scribe an arc across the first arc to locate point 2. Draw in your lines and you will have completed triangle 1-8-2. The next triangle to be developed is 8-2-9. To locate point 9, use one equal space of the lower half-circle from the front view of figure 12-53. Scribe an arc from point 8. Then, using the true length of line 2-9, strike an arc using point 2 as your pivot point. Point 9 is located where the two arcs intersect. Draw in your lines and your second triangle is completed. Continue this process until you reach line 7-14. At this point, you will have completed one-half of the pattern development. The other half is identical, so you will not have to lay out the other half.

TRANSFERRING THE PATTERNS TO METAL

Many of your patterns will be laid out right on the metal. However, there will be times when you will have to make the development on paper. Then, you must transfer the pattern to the metal that you plan to work. When you transfer these measurements, you must avoid mistakes or your piece will not come out as required.

Occasionally, you may cut out the pattern from template paper. Hold the pattern firmly in place and trace around the edges, as shown in figure 12-55. The break lines (where you bend the work) are located by using a prick or center punch and marking through the pattern on to the metal.

If you were in a large production shop where you made the same piece over and over again, you would make a metal pattern and use it to trace around and locate break lines and holes. Normally, your work is so varied that you will develop the stretchout when you need it. The future use of metal patterns is limited.

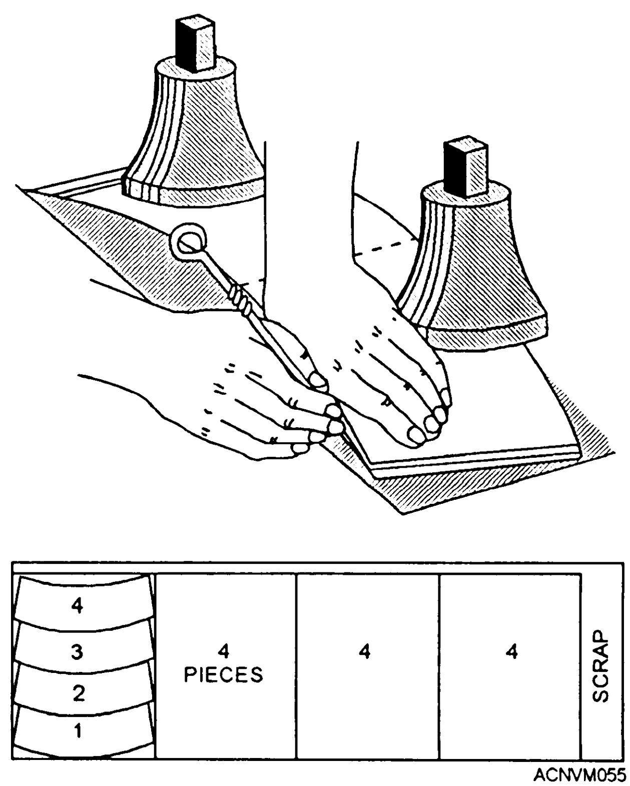


Figure 12-55.—Transfering patterns to metal.

Table 12-1.—Gauge and Decimal Measurement of Uncoated Low-Carbon Steel and Zinc-Coated Low-Carbon Steel

Gauge	Thickness (inches)
32	0.0097
30	0.0120
28	0.0149
26	0.0179
24	0.0239
22	0.0299
20	0.0359
18	0.0478
16	0.0598
14	0.0749
12	0.1046
10	0.1345

FABRICATING SHEET METAL

The various sheet metal alloys most commonly used aboard ship include zinc-coated low-carbon steel (often called galvanized iron), uncoated low-carbon steel, aluminum, Monel, copper-nickel alloy, copper, and brass.

Sheet metal will be identified by either a gauge number or by a decimal measurement. Table 12-1 shows the relationship between the gauge and decimal thickness for uncoated low-carbon steel and for zinc-coated low-carbon steel. Tables arc available for other materials. The gauge number of sheet metal is often stenciled on the metal. If by chance the gauge number does not appear on the sheet, you can find it by measuring the thickness of the material with a U.S. standard gauge for sheet and plate iron and steel. Then use table 12-1 to convert the measured thickness to its gauge.

CUTTING SHEET METAL

Several types of snips and shears are used to cut sheet metal. Snips are used to cut the lighter gauges of sheet metal. Bench shears, such as the type shown in figure 12-56, are used to cut heavier sheet metal.

Before using either the snips or the shears to cut sheet metal, make sure you have the right tool for the job.

Keep the blades at right angles to the work while you make the cut. The blades should be almost closed, but not quite, to their full length on each cut. If you close the blades all the way, the finished cut will tend to be jagged.

Figure 12-57 shows combination snips being used to cut an outside circle. The metal will be easier to handle during cutting if you cut away the excess metals on the corners first. When cutting out the circle, make a continuous cut, turning the metal as you cut.

Figure 12-58 shows the procedure for cutting out an inside circle with aviation snips. To start the cut,

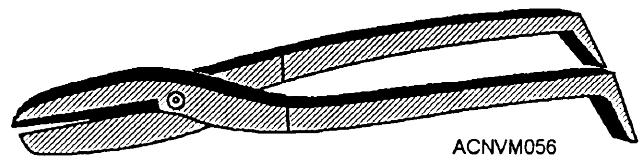


Figure 12-56.—Bench shears.

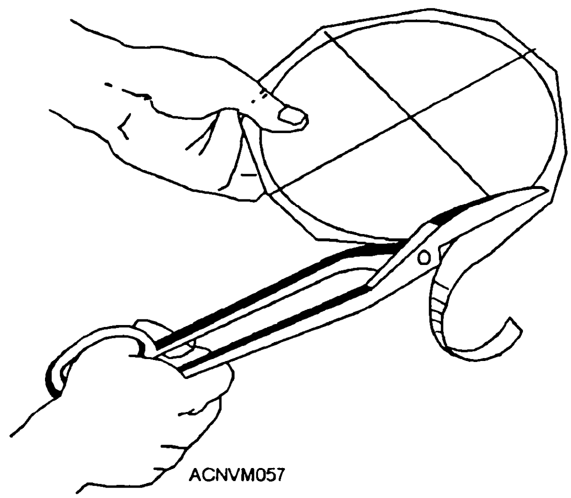


Figure 12-57.—Cutting an outside circle with combination snips.

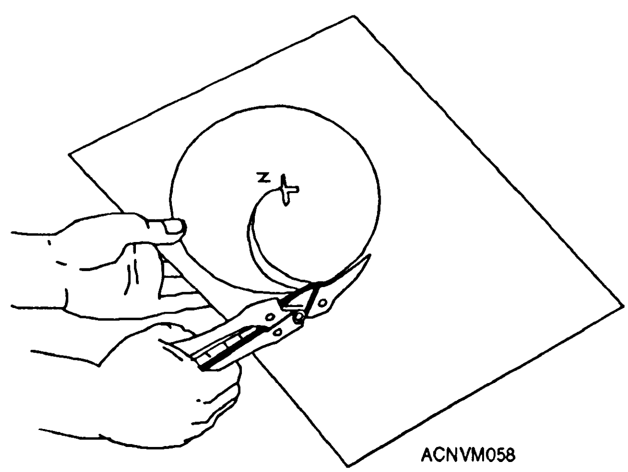


Figure 12-58.—Cutting an inside circle with aviation snips.

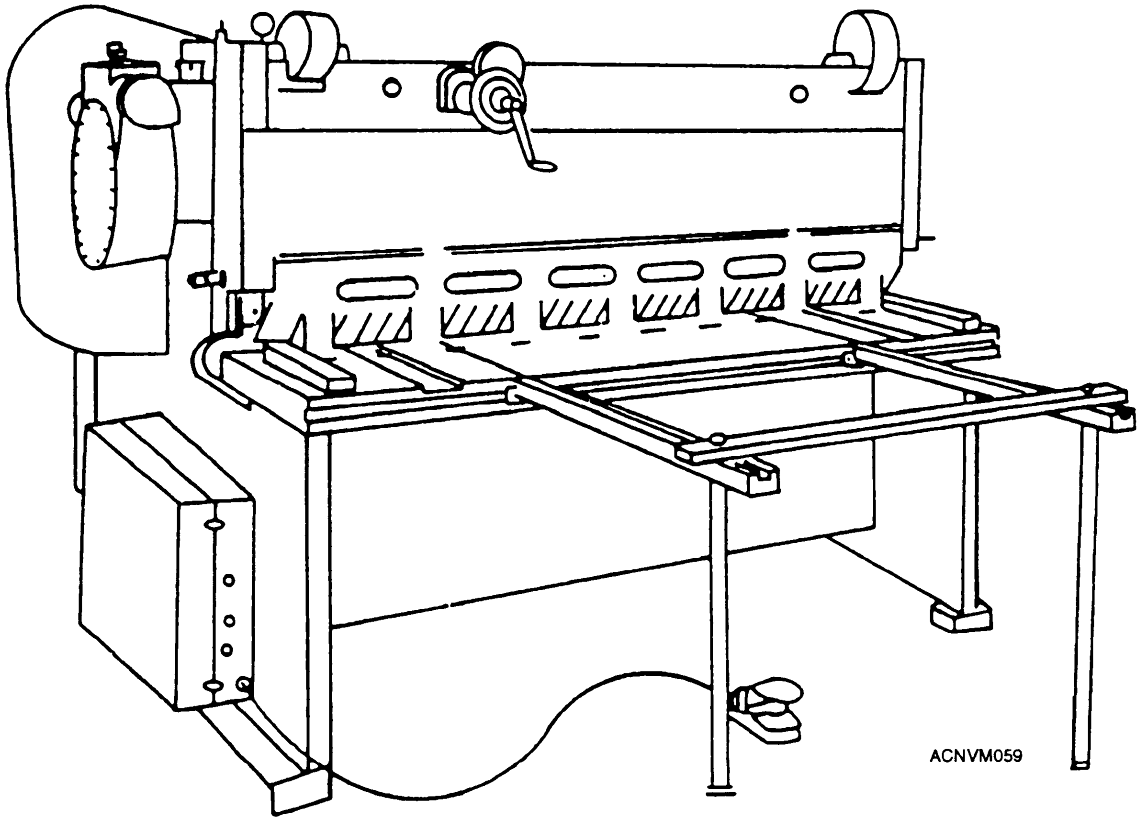


Figure 12-59.—Power-driven squaring shears.

punch a hole in the center of the circle to be cut. Then work your way out to the line of the circle and follow the line around until the cut is completed.

Unless otherwise specified, snips for cutting sheet metal are intended for use on mild steel of relatively light gauge. Stainless steel and other special alloy steels must be cut with special snips or shears that have special tool steel inlaid edges.

Some ships have squaring shears installed to use in making long straight cuts on heavy materials. The type of squaring shear installed depends on the nature and the amount of work to be done on that ship. Repair ships have large power-driven squaring shears such as the one shown in figure 12-59.

Squaring shears are designed for various capacities, which must never be exceeded. Nameplates indicating the maximum thickness of material to be cut are installed on each machine by the manufacturer. In general, the thickness specified by the manufacturer is for low-carbon or mild steel. If alloy steel must be cut, the thickness of the alloy steel also must not exceed that specified by the manufacturer.

Squaring shears are equipped with devices that serve as stops for sheets when more than one piece of the same size is required. The stops or gauges are located on the front, back, and sides of the bed of the shear. They can be adjusted to various lengths and angles.

Squaring shears are also equipped with hold-downs for clamping the sheet in place. The hold-downs used on powerdriven squaring shears are automatic. After the machine has been started and allowed to reach its operating speed, the metal is inserted; a foot treadle is then tripped, and the machine automatically clamps the sheet into position and makes the cut. Hand operated hold-downs are usually used on treadle-operated squaring shears. The sheet to be cut is inserted, the hold-down handle is adjusted, and the cut is then made by depressing the foot treadle. After the cut has been made, the hold-downs are released and the sheet can then be removed from the machine.

The principle of the shear is shown in figure 12-60. The lower blade of the shear is stationary and is attached in a parallel position to the bed of the machine. The upper blade, which is the movable blade, is attached to

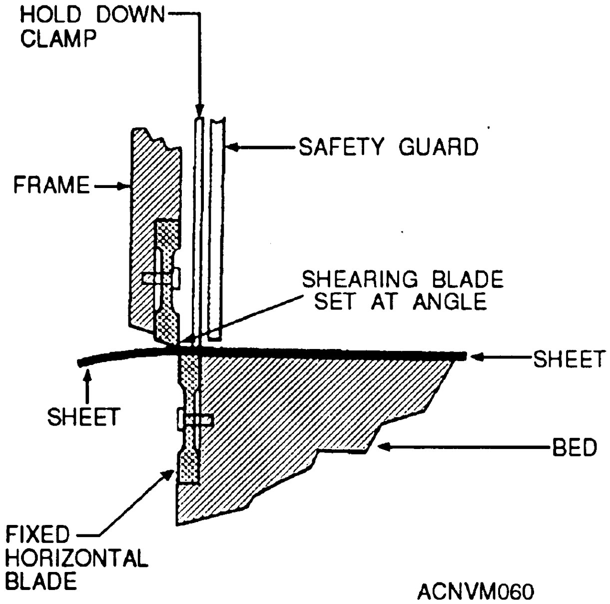


Figure 12-60.—Principle of a shear.

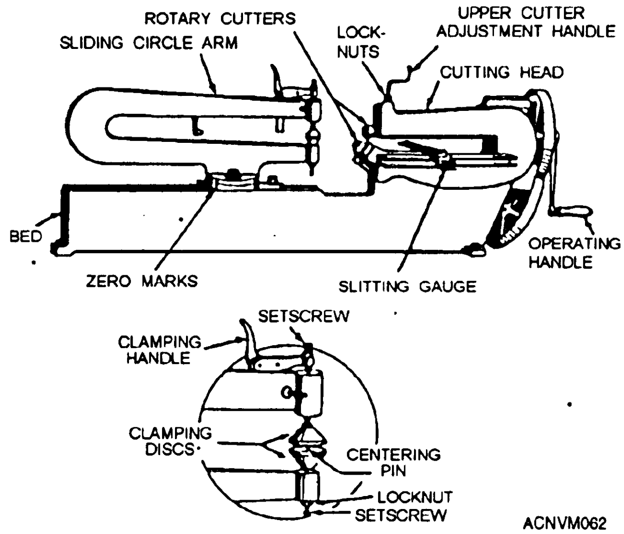


Figure 12-62.—Ring-and-circle shear.

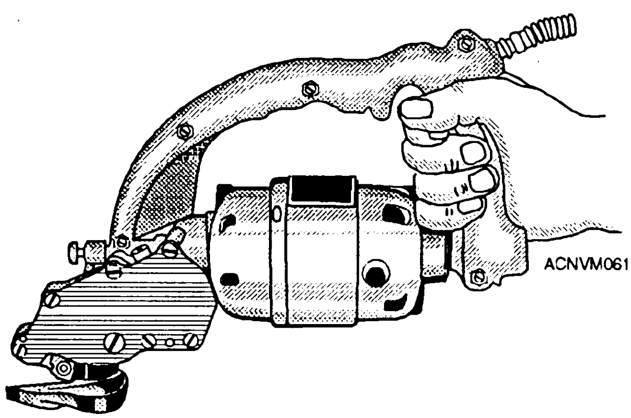


Figure 12-61.—Portable power-operated shearing tool.

a crosshead and at a slight angle to the position of the lower blade. The shearing action starts at one end of the sheet and continues across the sheet in much the same way that a pair of scissors cuts paper.

Portable, power-operated shears of the type shown in figure 12-61 are also used to cut sheet metal. They can be used to cut curves and notches as well as to make straight cuts. These tools cut metals of various gauges according to the capacity indicated on the nameplate.

There are special types of shears, some hand operated and some power driven, which are used on many ships for special types of cutting jobs. When available, these special shears can simplify your work.

Ring-and-circle shears are used to cut inside and outside circles. These shears may be hand operated, such as the one shown in figure 12-62, or they may be power driven. The following procedure is used to operate a ring-and-circle shear:

1. Select a piece of stock of the correct size, and locate the center of the piece. Mark the center with a prick punch.

2. Adjust the gauge arm of the machine to the radius of the desired circle.

3. Place the stock in the sliding circle arm. Locate the center of the stock by working the centering pin of the clamping device into the prick-punch mark.

4. Secure the metal in position by depressing the clamping handle.

5. Set the locknuts of the upper cutter adjustment handle so that the upper cutter, in its lowest position, produces a clean cut.

6. Lower the upper rotary cutter until it comes in firm contact with the metal.

7. If the shear is a hand-operated type, turn the operating handle. If it is a power-driven type, push the starting button. The blank feeds into the shear. Continue cutting until the disk is cut out completely.

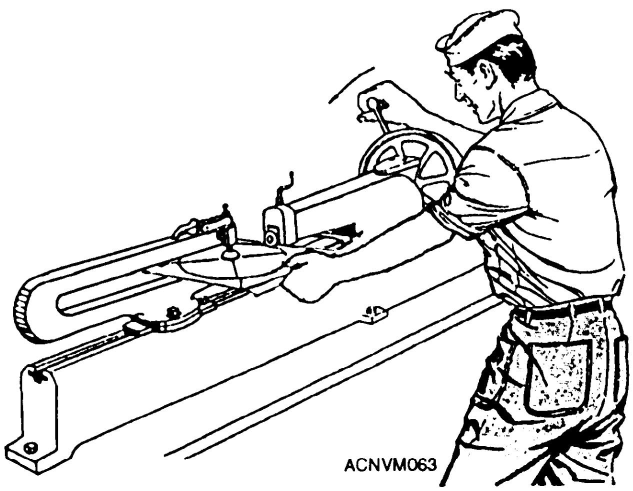


Figure 12-63.—Cutting a disk with the ring-and-circle shear.

The cutting of a disk with the ring-and-circle shear is shown in figure 12-63. To make a flange or ring, cut a disk in the manner just described. Then adjust the sliding circle arm to the new radius required for the inner circle. Make the inner cut by the same procedure used for the outer circle.

The ring-and-circle shear can also be used to cut straight or irregular curved sections as well as disks and rings. To cut light gauge material, the rotary cutters should be set to just touch, but not rub. To cut heavier gauge material, the cutters should be slightly separated. These adjustments should be made according to the instructions furnished by the manufacturer.

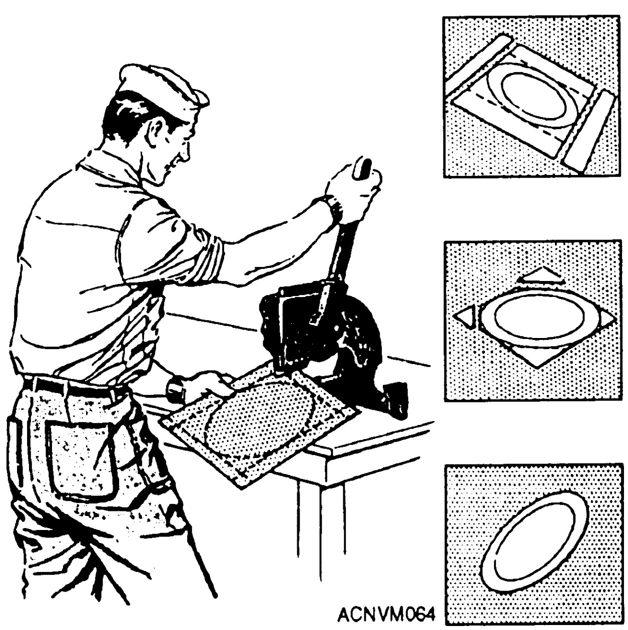


Figure 12-64.—Cutting outside of a circle with slitting or bench shear.

To cut a ring or a flange using only hand tools and a slitting shear or bench shear, follow the procedure shown in figures 12-64, 12-65, and 12-66.

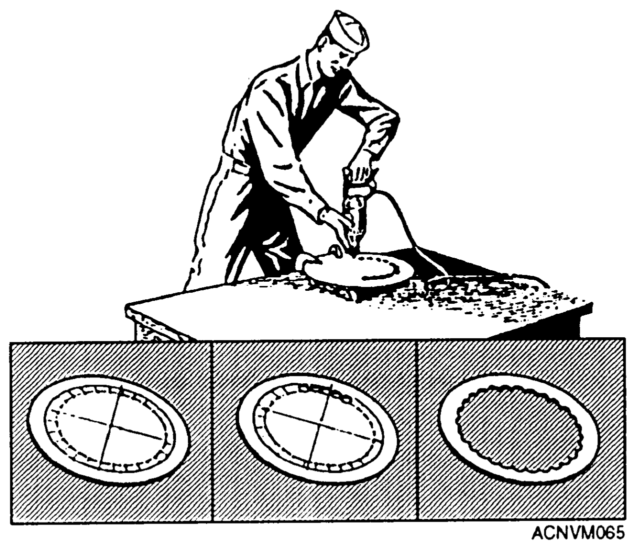


Figure 12-65.—Drilling holes around inner circumference.

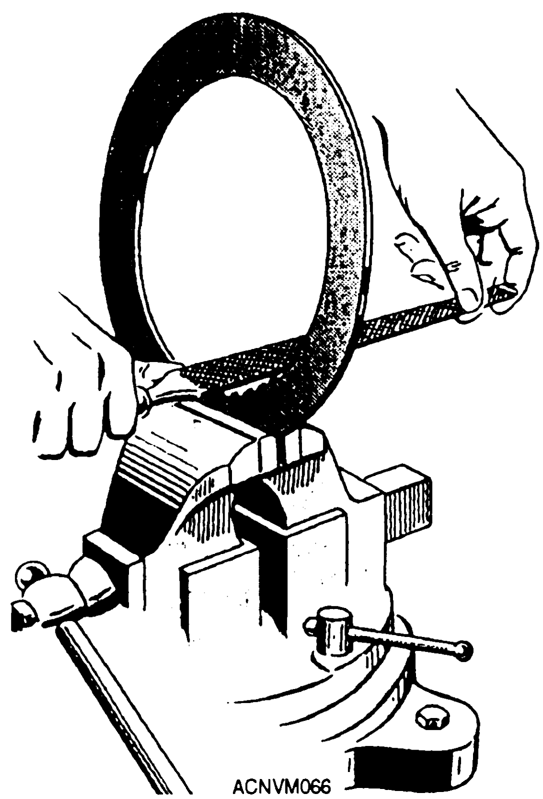


Figure 12-66.—Dressing the ring to final shape.

The steps used to make a ring by this method are as follows:

1. Scribe the inner and outer concentric circles using the desired radii.

2. Make a series of straight cuts on the slitting shears as close to the outer circumference as possible.

3. File or grind the outer circumference down to the scribed line.

4. Drill, punch, or chisel the inner material from the disk. Take care not to work too close to the inner scribed line.

A throatless shear is a heavy-duty machine that can take material up to l/4 inch in thickness. Smaller power-driven and hand-operated models are available. The throatless shear is normally used to cut out shapes that have an irregular curved edge. There are no guides on this type of machine. You control the cut by changing the direction of the sheet so that the blades cut along the lines scribed on the material.

There is a wide varity of equipment for cutting sheet metal. However, you may be assigned to a ship that does not have the equipment nor the room to keep it. In this case, you will have to depend on your normal shop tools. You can do a number of simple cutting operations on light sheet metal while the material is held firmly in a bench vise. Figure 12-67 shows the method used to cut sheet metal, held firmly in a vise, by using a chisel and hammer. Also you may use a hacksaw to make some of the cuts on the sheet metal held in a vise.

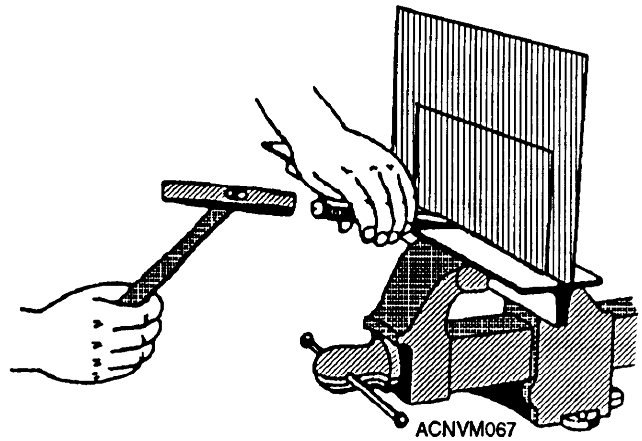


Figure 12-67.—Cutting light sheet metal with a cold chisel.

FORMING SHEET METAL

Sheet metal may be formed either by hand or with the aid of various special tools and machines. The hand forming of a bend is shown in figure 12-68.

The sheet is laid on a workbench or other flat surface, with the required amount projecting over the edge. A piece of angle iron is laid on top of the sheet with its edge even with the edge of the workbench. C-clamps are used to hold the angle iron and the sheet in place. Form the bend first by bending the entire length of the sheet with your hands. Then finish the bend by striking the bend area with a wooden mallet.

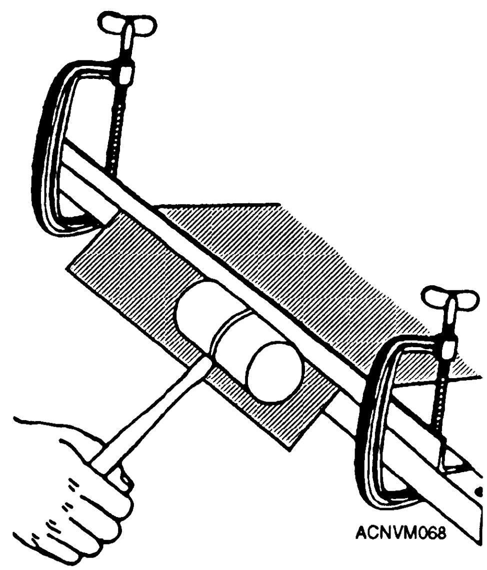


Figure 12-68.—Hand forming a bend in sheet metal.

Sheet Metal Brakes

Sheet metal brakes produce more uniform bends than those made by hand. They also require considerably less effort. A standard cornice brake is shown in figure 12-69. Before you use this machine, two adjustments must be made.

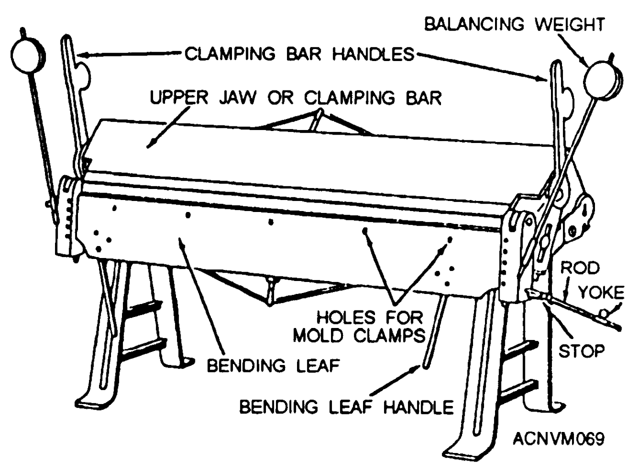


Figure 12-69.—Standard cornice brake.

1. Adjust the clamping adjustment screw for the gauge of sheet metal you are going to bend. The clamping device holds the work firmly in position, provided it is adjusted to the correct gauge. For example, if the clamping device is set for 18-gauge sheet and you are bending 24-gauge sheet, the sheet will most likely slip and the bend will be formed in the wrong position. If, on the other hand, you try to bend a thicker sheet while the machine is set for a thinner gauge, you may break the clamping handle of the machine.

2. Adjust the machine for the correct bend allowance. You can do this by moving the upper jaw to the correct position for the thickness of the metal and for the radius of the bend to be made. If the upper jaw is adjusted to the exact thickness of the metal, the bend will be sharp and will have practically no bend radius. If the jaw is set for a thickness greater than the metal, the bend will have a larger radius. If the jaw is set for a thickness less than the metal, the jaws of the machine may be sprung out of alignment and the edges of the jaws damaged.

After these two adjustments have been made, proceed as follows:

1. Scribe a line on the surface of the sheet metal where the bend is to be.

2. Raise the upper jaw with the clamping handle and insert the sheet. Bring the scribed line into a position even with the front edge of the upper jaw.

3. Clamp the sheet firmly in position. Check to make sure the scribed line is still in line with the front edge of the upper jaw.

4. Raise the lower leaf to the desired angle for the bend or flange. If you are bending soft and ductile metal such as copper, the bend will be formed to the angle to which you raised the lower leaf. If you are bending metal that has a good deal of spring to it, you will have to raise the lower leaf a few degrees higher. This will compensate for the tendency of the metal to spring back after it has been bent. The exact amount of springback that you will have to allow for will depend upon the type of metal you are bending.

5. Release the clamping device and remove the sheet from the brake.

The standard cornice brake is equipped with a stop gauge, consisting of a rod, a yoke, and a setscrew. These permit you to limit the travel of the bending leaf. This is a useful feature when you must make a lot of pieces with the same angle of bend. After you have made the first bend to the required angle, set the stop gauge so that the bending leaf will not travel beyond this angle. You can now make as many duplicate bends as are required.

The standard cornice brake is extremely useful for making single hems, double hems, lock seams, and various other shapes. As examples of how to actually use the standard cornice brake, we will consider first the forming of a single hem and then the forming of a Pittsburgh lock seam.

To form a single hem (fig. 12-23), proceed as follows:

1. Insert the sheet to be hemmed all the way into the brake. Line up the brake line with the front edge of the upper jaw.

2. Raise the lower leaf as far as it will go. If the stopgauge has been set, be sure the yoke is set far enough toward the end of the rod to permit the leaf to travel the maximum distance.

3. Lower the leaf, release the clamping device, and remove the sheet from the brake.

4. Close the left side of the brake, allowing the right side to remain open.

5. Insert the left hem edge of the sheet into the brake, holding the sheet with your left hand. Hold the sheet at an angle to the front edge of the brake.

6. Lower the upper jaw with your right hand. This action will flatten that portion of the hem that is between the jaws. The brake is thus being used as a press.

7. Raise the upper jaw and decrease the angle between the front edge of the brake and the edge of the sheet. When you decrease this angle slightly, you will bring another small portion of the hem under the jaws of the brake.

8. Continue lowering and raising the upper jaw until the entire hem has been flattened. Do the flattening operation in small sections. Do NOT attempt to flatten the entire hem in one operation. If you are working very springy metal, you may have to work the hem part of the way down with a mallet before you can finish it in the brake.

Figure 12-70 shows the procedure for making a Pittsburgh lock seam as follows:

1. Insert the sheet in the brake, making the first bend to just a little less than 90 degrees.

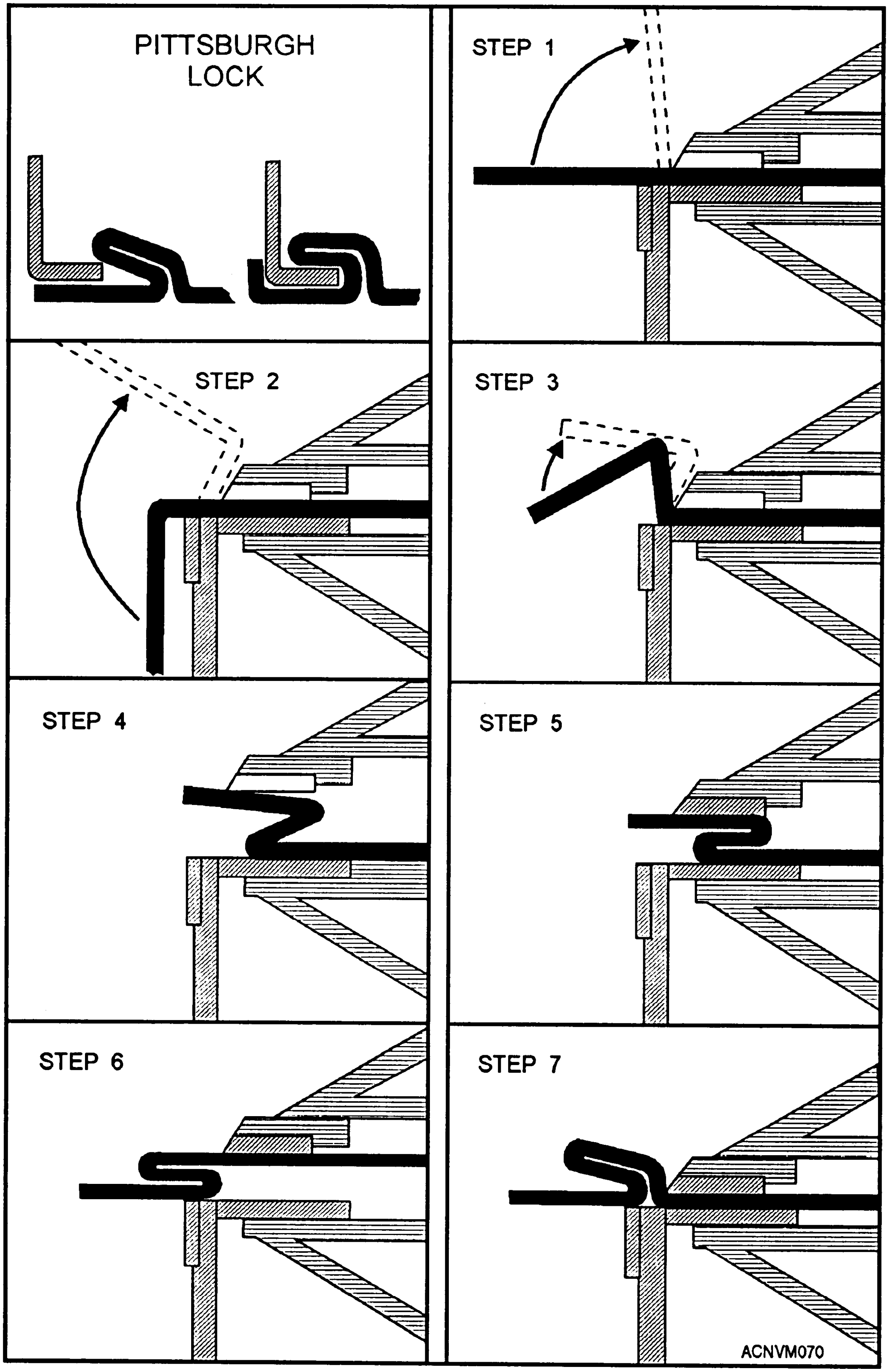


Figure 12-70.—Some steps in forming a Pittsburgh lock scam.

2. Remove the sheet. Insert the sheet, flanged edge down, all the way into the brake. Raise the lower leaf to make the maximum possible bend.

3. Remove the sheet from the brake. Turn the sheet so that the side with the 90-degree angle is up, and slide it into the brake until this angle is flush with the forward edge of the upper jaw. Raise the lower leaf through the maximum arc.

4. Raise the upper jaw and slide the sheet farther into the brake until the edge of the sheet once again is flush with the front edge of the upper jaw.

5. In the recess that will form the pocket of the seam, insert a strip of metal of the same gauge as the metal you are forming. One long strip running the length of the seam may be used, or several smaller lengths of stripping may be used. The stripping material should be about 1 inch wide.

6. Close the left-hand clamping device.

7. Use an easy up-and-down motion with the right-hand clamping device to start pressing the folds of the seam together. Complete the flattening operation in the manner described for flattening hems.

8. Turn the sheet over and line up the inner bent edge with the front edge of the upper jaw. Lower the upper jaw with the clamping handles.

9. The clamping procedure used in the preceding step will cause the formed edge of the seam to rise slightly. To bring this section back in line, work it down with a wooden mallet.

10. Bend the other portion that fits into the pocket to a 90-degree angle. Be sure the flange is the correct width.

11. Remove the strips from the pocket.

12. Insert the flanged edge into the pocket. Tap it firmly in place with a mallet. Bend the protruding edge over with a mallet, and the seam is finished.

Some brakes are equipped with molds, others are not. You will probably not have much occasion to use molds. However, they are useful for forming special shapes. The molds are fastened to the brake by means of friction clamps, in such a position that the work can be formed over them. Figure 12-71 shows sheet that is ready to be formed over a mold that is attached to a brake.

Occasionally one end of a sheet is bent at a sharper angle than the other end. The end that made the lower quality bend will then need to be adjusted. Normally this will be the right-hand end. After prolonged use on one end, that end is worn more than the other, thus requiring an adjustment.

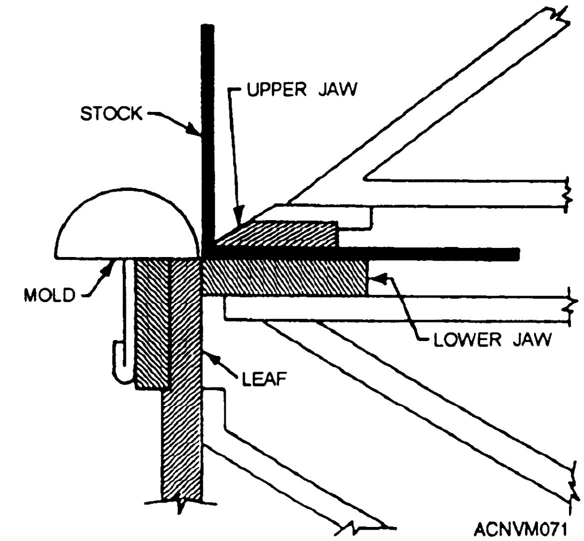


Figure 12-71.—Work ready to be formed over mold on standard cornice brake.

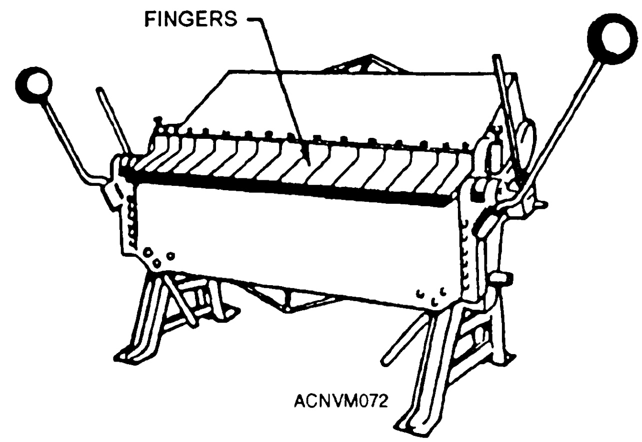


Figure 12-72.—Box and pan brake (finger brake).

The box and pan brake, normally called a finger brake, shown in figure 12-72, can do everything that the cornice brake can do and several things that the cornice brake cannot do.

The upper jaw of the finger brake consists of a series of steel fingers of varying widths, whereas the cornice brake has one long bar. The fingers are secured to the upper jaw by thumbscrews, as shown in figure 12-73.

The finger brake is particularly useful in forming boxes, pans, and other similar shapes. If these shapes were formed on a cornice brake, you would have to straighten part of the bend on one side of the box to

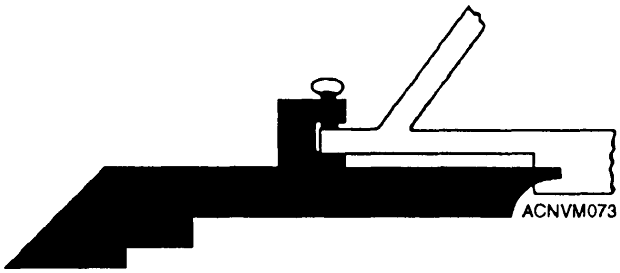


Figure 12-73.—Method of securing finger brake.

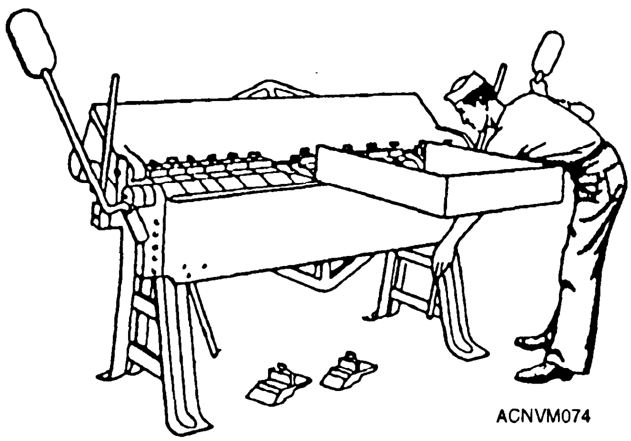


Figure 12-74.—Finger brake being used to form box (note fingers removed).

make the last bend. In the linger brake, you remove the fingers that are in the way and use only those fingers that arc required to make the bend (fig. 12-74). All fingers that are not removed for any operation must bc securely seated and fastened before the brake is used.

To maintain brakes in good condition, keep the working parts well oiled and be sure the jaws are free of rust and dirt. When operating the brakes, take care to avoid doing anything that would spring the parts, force them out of alignment, or otherwise damage them. Never use brakes for bending metal that is beyond their capacity such as thickness, shape, or type. Always bend short or small pieces in the center of the brake. Never try to bend rod, wire, strap iron, or spring steel sheets in a brake. Never hammer work while it is in a brake. If it is necessary to hammer the work, remove the work from the brake first.

Slip-Roll Forming Machines

Sheet metal can be formed into curved shapes over a pipe or a mandrel, but the slip-roll forming machine (fig. 12-75) is much easier to use and produces a more

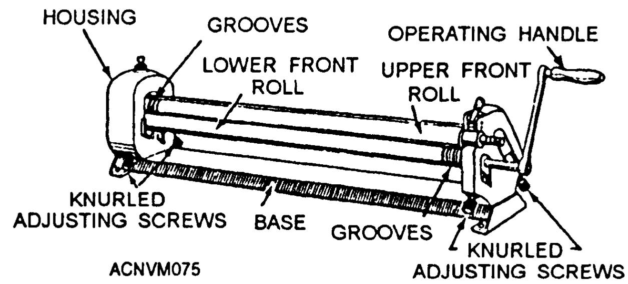


Figure 12-75.—Slip-roll forming machine.

accurate bend. Rolling machines are available in various sizes and capacities. Some are hand operated, as is the one shown in figure 12-75. Others are power operated.

The machine shown in figure 12-75 has two rollers in the front and one roller at the rear. Adjusting screws on each end of the machine control the height and angle of the rear roll and control the distance between the front rolls. By varying the adjustments, you can use the machine to form cylinders, cones, and other curved shapes. The front rolls grip the metal and pull it into the machine. Therefore, the adjustment of distance between the two front rolls is made on the basis of the thickness of the sheet.

To form a cylinder in the slip roll (fig. 12-76), follow this procedure:

1. Adjust the front rolls so that they will grip the sheet properly.

2. Adjust the rear roll to a height that is LESS THAN enough to form the desired radius of the cylinder.

3. Cheek to bc sure all three rolls are parallel.

4. Start the sheet into the space between the two front rolls. As soon as the front rolls have gripped the sheet, raise the free end of the sheet slightly.

5. Pass the entire sheet through the rolls. This will form part of the curve required for the cylinder.

6. Set the rear roll higher to form a shorter radius.

7. Rotate the sheet and pass it through the rolls again, feeding the opposite edge in first this time.

8. Continue rotating the sheet around and passing it through the rolls, each time adjusting the rear roll for a new radius, until a cylindrical shape has been formed.

9. Remove the cylinder from the slip roll. The top front roll has a device allowing you to release one end

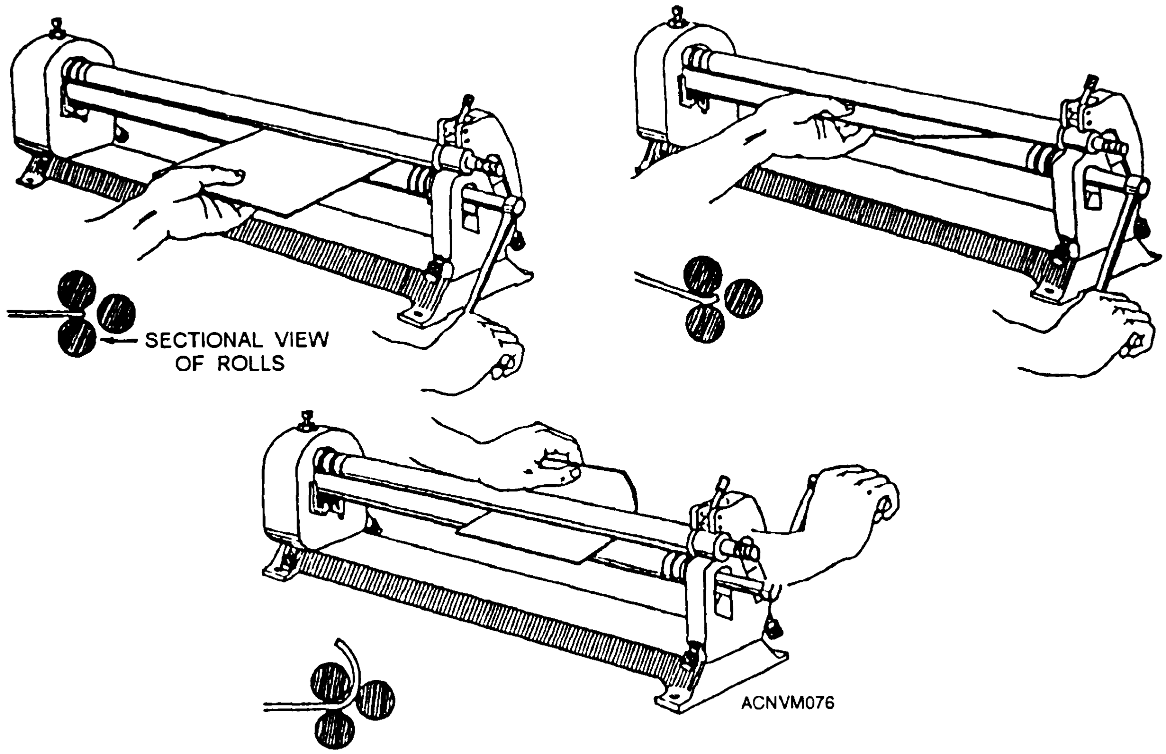


Figure 12-76.—Forming a cylinder on a slip-roll forming machine.

of the roll. Then you may raise the released end of the top front roll and slip the cylinder off.

Conical shapes can be formed by setting the back roll to an angle before running the sheet through it. Or they can be made with the rolls parallel, if you feed the sheet into the machine in such a way that the element lines of the cone pass over the rear roll in a line parallel to the rolls. The latter method of forming a cone is shown in figure 12-77.

The grooves at the end of the rolls can be used fo form circles out of wire or rod. They can also be used to roll wired edges, as shown in figure 12-78.

Metal Forming Stakes

Stakes are used to back up sheet metal for the forming of many different curves, angles, and seams in sheet metal. The stakes are available in a wide variety of shapes, some of which are shown in figure 12-79.

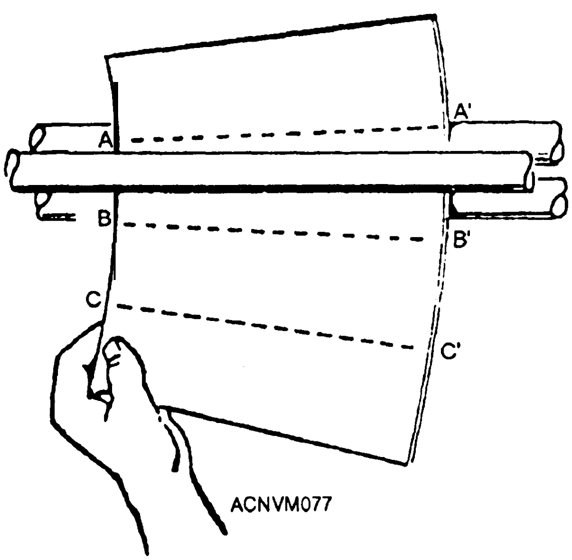


Figure 12-77.—Rolling a conical shape.

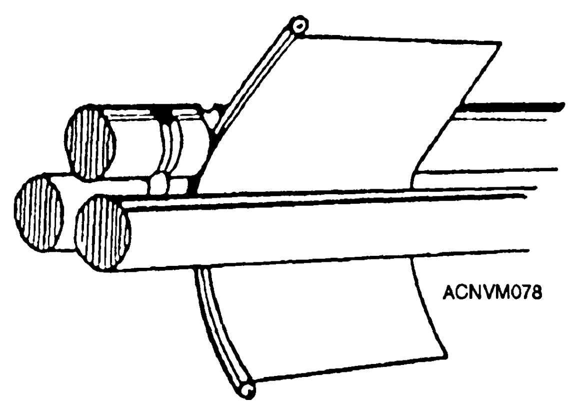


Figure 12-78.—Rolling a wired edge.

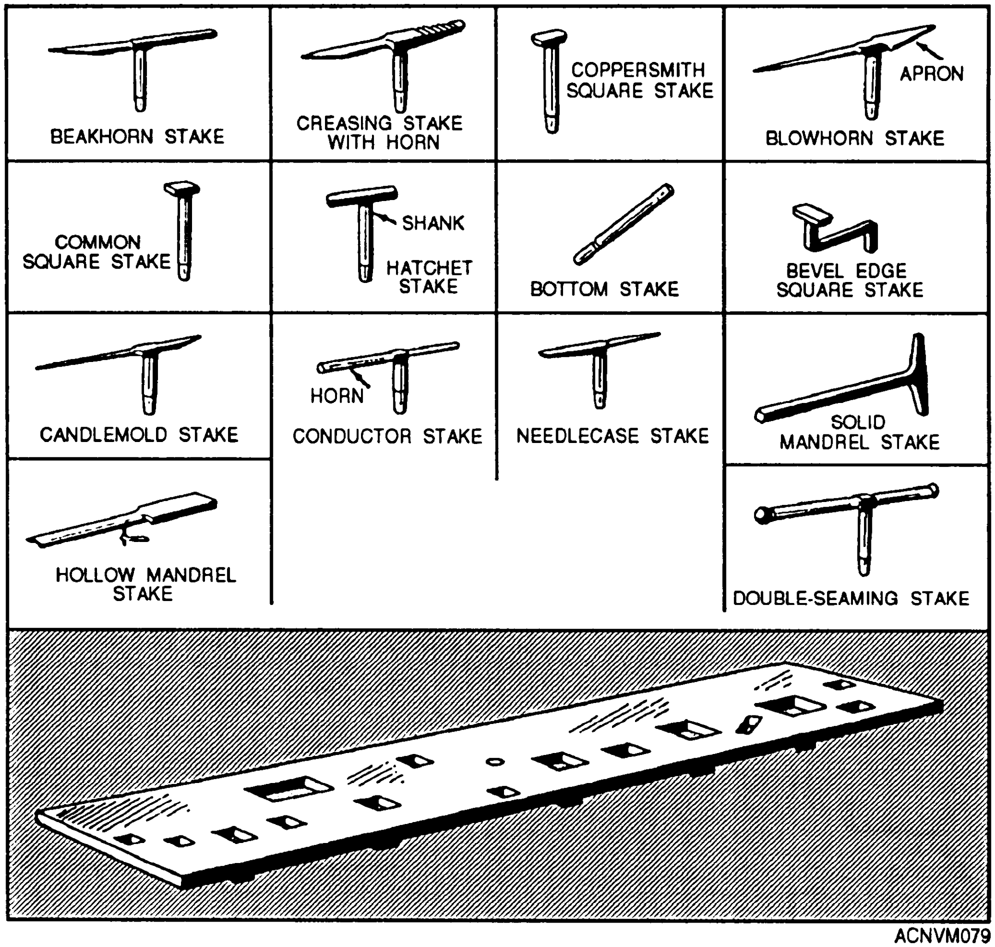


Figure 12-79.—Stakes and stake holder.

The stakes are held securely in a stake holder or stake plate (fig. 12-79) that is anchored in the workbench. The stake holder contains a variety of holes to fit a number of different types of stake shanks.

Stakes are not delicate, but they must be handled with reasonable care. They must not be used as backing when you are chiseling holes or notches in sheet metal, or when you are performing any other job that might damage the face of the stake.

The forming of a cone on a blowhorn stake is illustrated in figures 12-80 and 12-81. Figure 12-82 shows the forming of a bail (or handle) on a stake.

In forming sheet metal, you will often find it best to use a combination of several machines and some hand tools, rather than to do the whole job on any one machine. To form a cylinder with a grooved lock scam, for example, you would most likely use a brake, a slip-roll forming machine, a hand groover, and a hollow mandrel stake. The procedure for making a cylinder using these machines and tool is as follows:

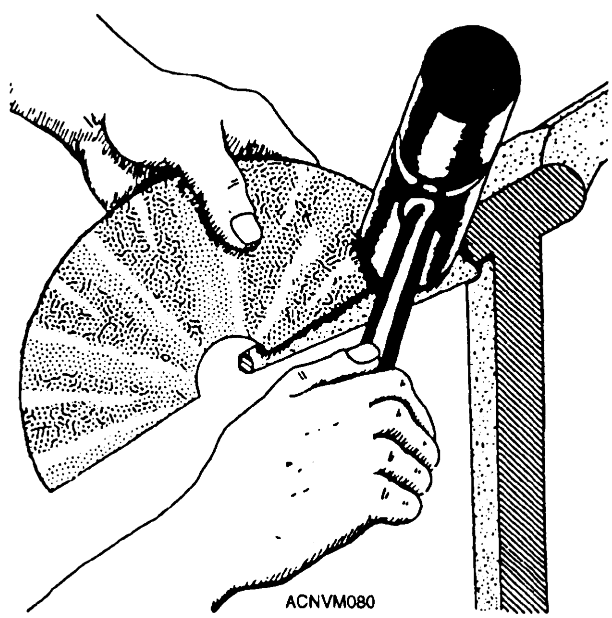


Figure 12-80.—Malleting a cone on a blowhorn stake.

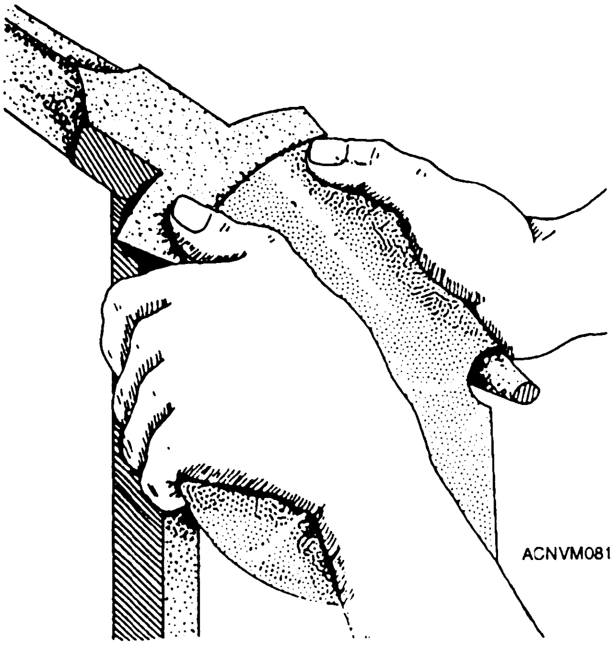


Figure 12-81.—Hand forming a cone on a blowhorn stake.

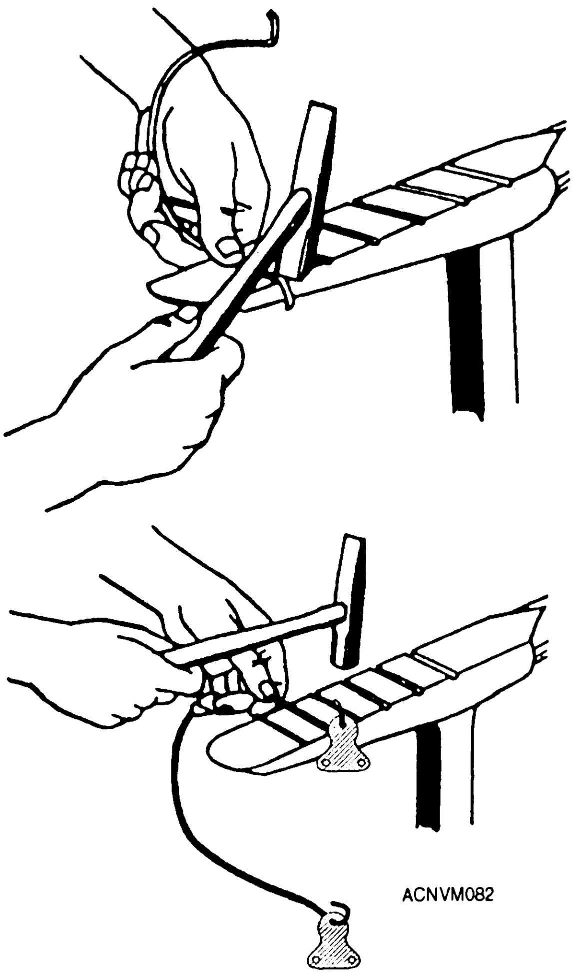


Figure 12-82.—Forming a bail on a hand stake.

1. Insert the sheet in the brake and form the first bend of the lock.

2. Rotate the sheet 180 degrees and then flip it over. Then form the bend for the other half of the lock, as shown in figure 12-83.

3. Adjust the rolls on the slip-roll forming machine, and roll the cylinder to shape.

4. Hook the seam together and slip the cylinder over a hollow mandrel stake, as shown in figure 12-84.

5. Select a hand groover of the proper size. The groover should be about 1/16 inch wider than the seam. Place the groover at one end of the seam and strike it with a hammer. Repeat the operation at the other end of the seam.

6. Complete the seam by moving the hand groover along the length of the seam and striking the head of the groover with a hammer or a mallet.

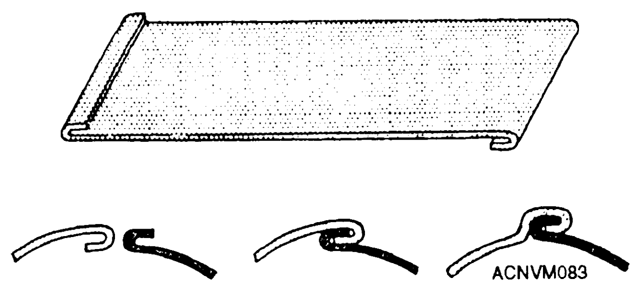


Figure 12-83.—Forming a grooved seam.

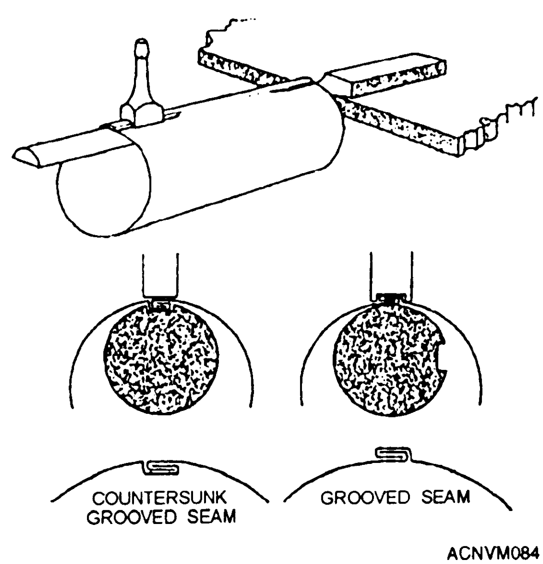


Figure 12-84.—Completing the grooved scam with a hand mandrel.

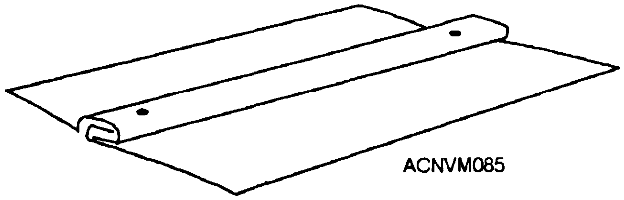


Figure 12-85.—Grooved scam locked with prick-punch indentations.

7. Secure the seam in position by making prick-punch indentations about l/2 inch in from each end of the seam, as shown in figure 12-85.

Specialized Metal Forming Machines

Large shops have rotary machines for burring, turning, wiring, beading, setting down, grooving, and crimping sheet metal. Some machines are of the combination type, having one head with several sets of rolls. A combination rotary head with burring rolls mounted is shown in figure 12-86. Sets of rolls for burring, turning, wiring, and elbow edging can be installed on this rotary head.

The burring rolls are used to turn an edge at right angles to form burrs or narrow flanges for seams and hems. A typical use of the burring rolls is for burring the disks that form the bottoms of some tanks and buckets.

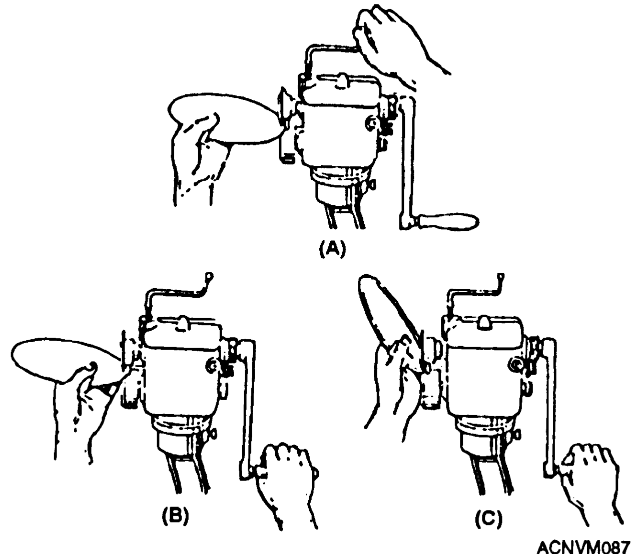


Figure 12-87.—Burring a disk.

Figure 12-87 shows the use of the burring rolls. The steps in burring a disk are as follows:

1. Adjust and align the rolls so that the inside edge of the top roll fits over the shoulder of the bottom roll. Make the clearance equal to the thickness of the metal. (Insufficient clearance will cause the top roll to act as a shear and damage the stock.)

2. Set the gauge to turn up the desired amount of metal. This is usually from l/8 inch to 3/16 inch.

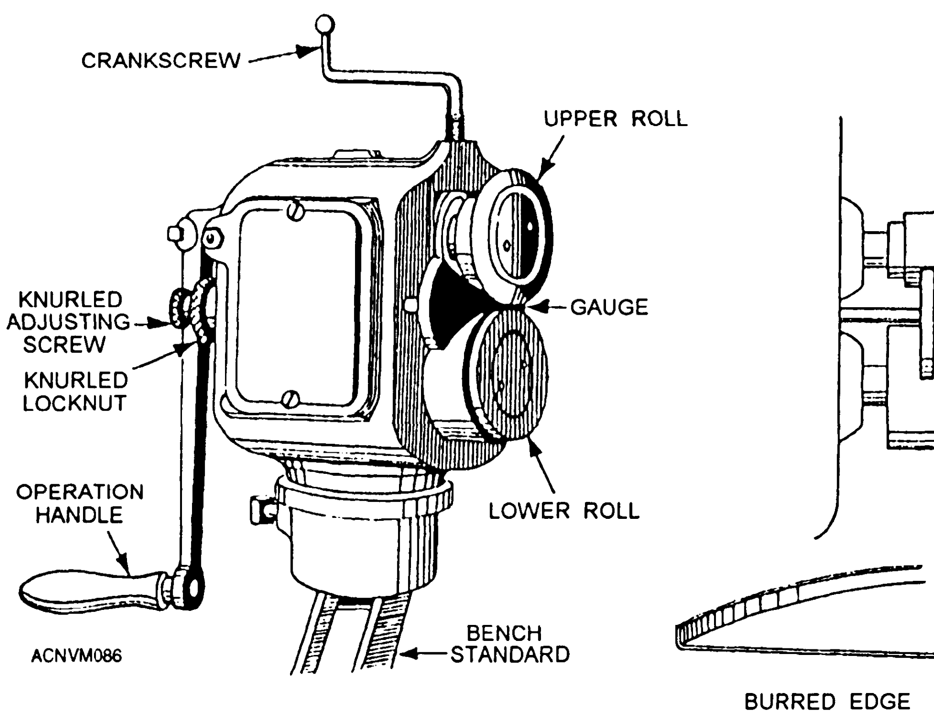


Figure 12-86.—Combination rotary machine (shown with burring rolls).

3. Place the disk in position, as shown in figure 12-87, and move the top roll down until it grips the stock and creases it slightly.

4. Crank the handle. Keep the edge of the disk tight against the gauge. Allow the disk to revolve as you turn the handle.

The first revolution should be made slowly so that you can get the burr established accurately. After you have made the first revolution, you can crank faster. Raise the disk slightly after each revolution.

Turning rolls (fig. 12-88) are used on the combination rotary machine for forming rounded flanges that are similar to burred edges except that they have radii. Several sets of turning rolls are usually provided. To use the turning rolls, be sure the rolls are properly aligned and the gauge is properly set. Then hold the edge of the metal firmly against the gauge during the first revolution.

Special wiring rolls are used to shape the metal around a wire. The edge of the metal is first turned on a brake or on the rotary turning rolls. The wiring rolls (fig. 12-89) are then used to complete the job. Wiring rolls may be used on either straight or curved edges. In making a wired edge, be sure to allow enough metal so that the wire will be completely covered; in general, the allowance for a wired edge is 1 l/2 times the diameter of the wire for thin metals, and slightly more than this for thicker metals.

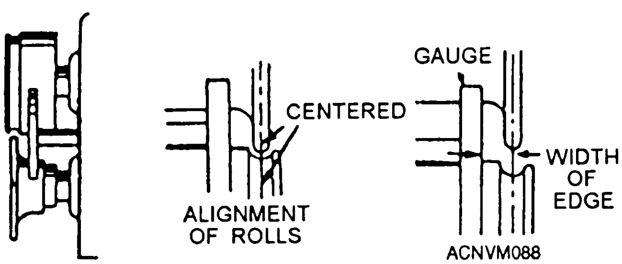


Figure 12-88.—Turning rolls for combination rotary machine.

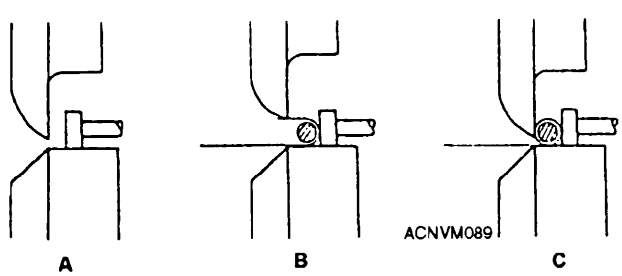


Figure 12-89.—Wiring rolls for combination rotary machine.

Elbow edging rolls are similar to turning rolls except that the elbow rolls have V-grooves in the lower rolls. Figure 12-90 shows a piece of an elbow being edged. One edge is turned in while the other is turned out. The pieces of the elbow are assembled and held together by interlocking the edges.

The setting-down machine, shown in figure 12-91, is used to close single seams. The beveled jaws grip the seam and mash it down tightly and smoothly.

Another specialized machine that you may have in your shop is the deep-throated beading machine (fig. 12-92). Several types of beading rolls may be used with

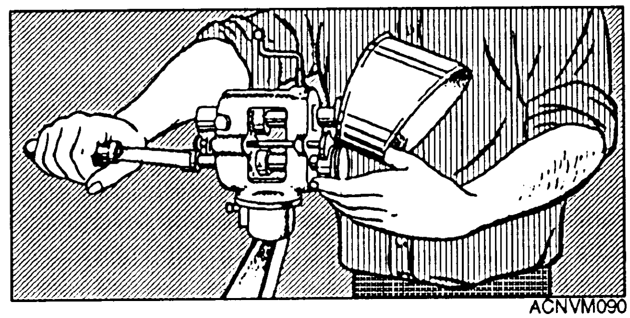


Figure 12-90.—Elbow edging rolls for combination rotary machine.

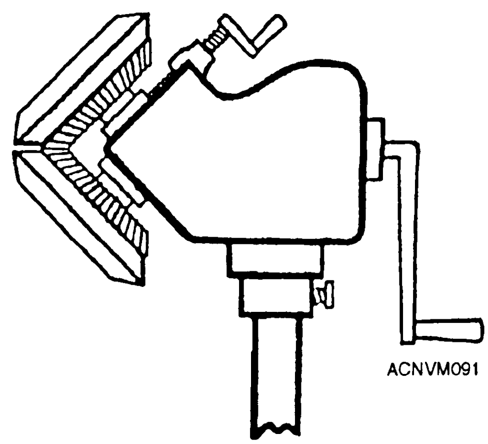


Figure 12-91.—Setting down machine.

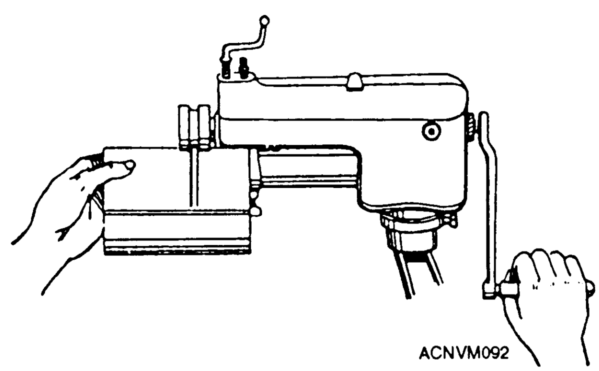


Figure 12-92.—Deep-throated beading machine.

this machine. Never allow seams to pass through the rolls of a beading machine. The machine would probably be sprung. Start the beading next to a seam and stop just before the seam is reached.

The crimping machine (fig. 12-93) is another specialized machine. It is used to corrugate the ends of a cylinder. Its diameter is reduced so that it can be fitted into another cylinder of the same diameter. Some crimping machines also have beading rolls next to the crimping rolls, as shown in the lower part of figure 12-93. The bead reinforces the cylinder and keeps it from slipping too far into the other cylinder. Be sure that you never run a riveted or grooved seam through the crimping machine.

RIVETING SHEET METAL

Once sheet metal has been cut and formed, it needs to be joined together. Most sheet metal seams are either locked or riveted. However, some are joined by brazing or welding. Lock seams are made primarily by the forming processes that have already been discussed. Welding and brazing are discussed in other chapters of this training manual. This section deals only with joining by riveting.

Rivets of different materials, sizes, and types are available. Rivets made of steel, copper, brass, and aluminum are widely used. However, rivets should be of the same material as the sheet metal they are joining.

For sheet metal work, you will probably use tinner's rivets, of the type shown in figure 12-94, more than any other kind of rivet. Tinner's rivets vary in size from the 8-ounce rivet to the 16-pound rivet. The weight of 1,000 rivets indicates the size designation. If 1,000 rivets weigh 8 ounces, each rivet is called an 8-ounce rivet. The diameter and length of the rivets increase as the weight per 1,000 rivets increases. For example, the 8-ounce rivet has a diameter of 0.089 inch and a length of 5/32 inch, and the 12-pound rivet has a diameter of 0.259 inch and a length of l/2 inch. For special jobs that require fastening several layers of metal together, rivets with extra long shanks are used. Use table 12-2 as a guide for selecting the proper size rivets.

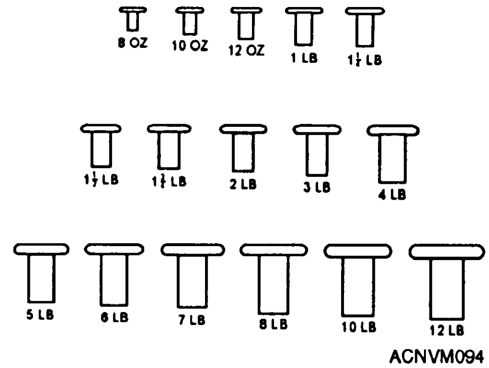


Figure 12-94.—Tinner rivets.

Rivet spacing is normally given on the blueprint or drawing. If the spacing is not indicated, space the rivets according to the service conditions the seam must withstand. For example, if the seam must be watertight, more rivets per inch are required than for a seam that does not need to be watertight. You must maintain a distance of at least 2 l/2 times the rivet diameter between the rivets and the edge of the sheet measuring from the center of the rivet holes to the edge of the sheet.

After the size and spacing of the rivets have been determined, mark the location of the centers of the rivet holes. Then pierce the holes by punching or by drilling.

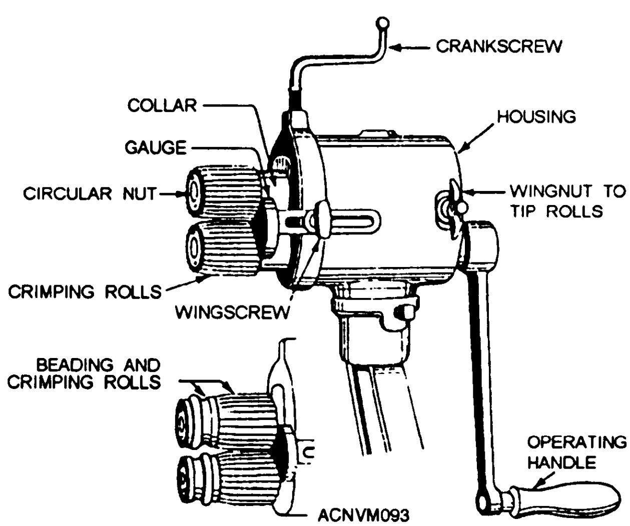


Figure 12-93.—Crimping machine.

Table 12-2.—Guide for Selecting Rivet Size for Sheet Metal Work

Gauge of sheet metal	Rivet size (weight in pounds per 1000 rivets)
26	1
24	2
22	2 l/2
20	3
18	3 l/2
16	4

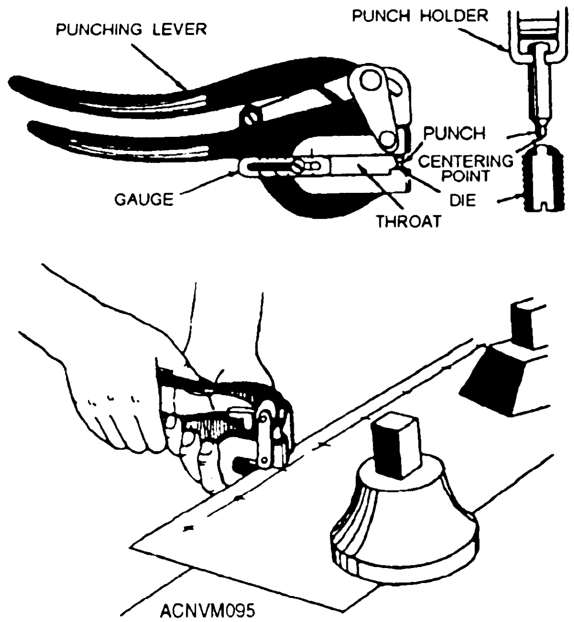


Figure 12-95.—A hand punch.

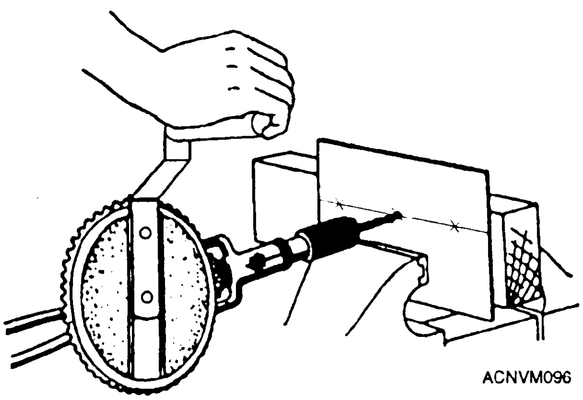


Figure 12-96.—Drilling holes with a breast drill.

If the holes are located near the edge of the sheet, a hand punch, similar to the one shown in figure 12-95, can be used to punch the holes. If the holes are farther away from the edge, you can use a deep-throated punch (either hand operated or power driven) or you can drill the holes. A breast drill used to drill holes for rivets is shown in figure 12-96. Drill the hole slightly larger than the diameter of the rivet to provide a slight clearance.

Riveting involves three operations: drawing, upsetting, and heading. These are illustrated in figure 12-97. A rivet set and a riveting hammer are used to perform these operations. The procedure for riveting sheet metal is as follows:

1. Select a rivet set that has a hole slightly larger than the diameter of the rivet.

2. Insert the rivets in the holes. Rest the sheets to be joined on a stake or on a solid bench top, with the rivet heads against the stake or bench top.

3. Draw the sheets together by placing the deep hole of the rivet set over the rivet and striking the head of the set with a riveting hammer. Use a light hammer for small rivets and a heavier hammer for larger rivets.

4. When the sheets have been properly drawn together, remove the rivet set. Strike the end of the rivet LIGHTLY with the riveting hammer. The process of spreading the end of the rivet to expand it so that it will hold the sheets together is known as upsetting the rivet. Do not strike the rivet too hard or else you might distort the metal around the rivet hole.

5. Place the heading die (dished part) of the rivet set over the upset end of the rivet and form the head. One or two hammer blows on the head of the rivet set

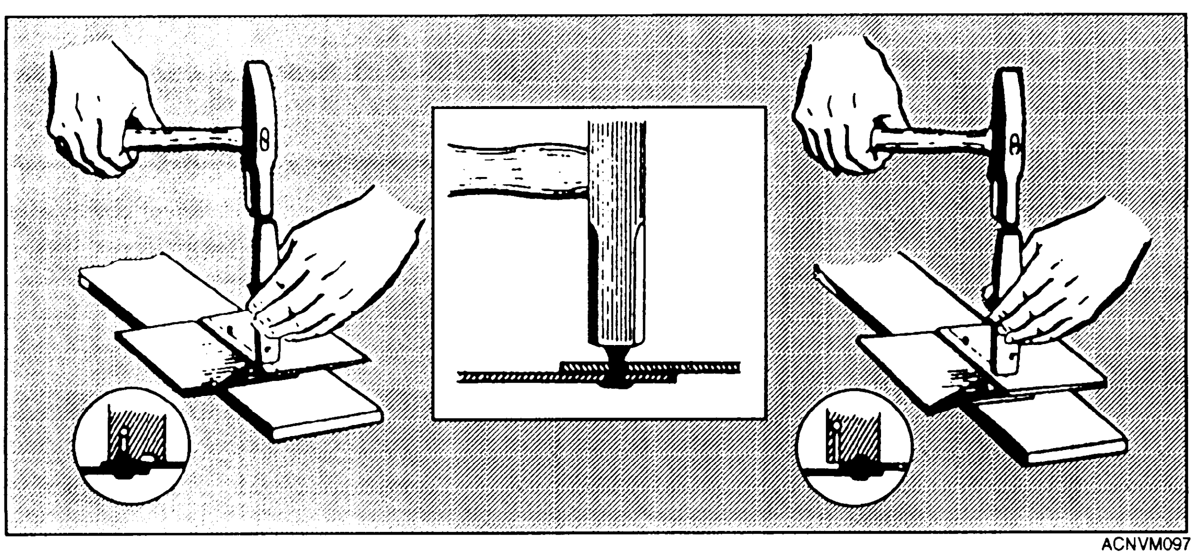


Figure 12-97.—Drawing, upsetting, and heading a rivet.

should be enough to form the head on the rivet. A correctly drawn, upset, and headed rivet is shown in the top part of figure 12-98. The lower part of this illustration shows the results of incorrect riveting procedures.

To rivet a seam when you cannot use a stake or a bench top to back up the rivet, use a hand dolly like the one in figure 12-99.

To rivet a seam of a cylinder, such as the one shown in figure 12-100, use a hollow mandrel stake or some other suitable bar as backing for the rivets. The procedure for riveting a seam in a cylinder is as follows:

1. Place rivets in the end holes, and slip the piece over the stake or bar.

2. Draw the seams together and upset the end rivets enough to hold the structure together.

3. Insert the center rivet. Draw, upset, and head this rivet.

4. Complete the seam by riveting from the center to one end and then from the center to the other end. Complete the drawing, upsetting, and heading of each rivet before you move on to the next rivet.

Besides the sheet metal rivets already discussed, you will also use the pop rivets like those shown in figure 12-101. These are high-strength, precision-made, hollow rivets assembled on a solid mandrel which forms an integral part of the rivet. They are especially useful for blind fastening, where there is either limited or no access to the reverse side of the work.

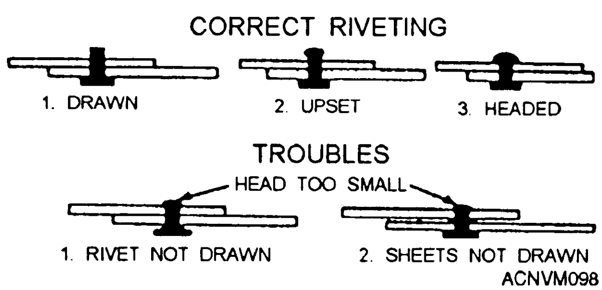


Figure 12-98.—Correct and Incorrect riveting.

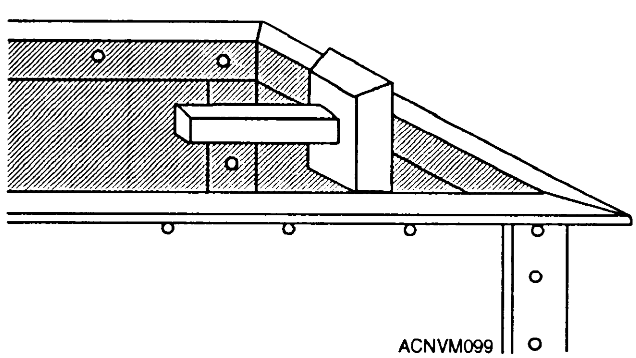


Figure 12-99.—Hand dolly used to back up rivets.

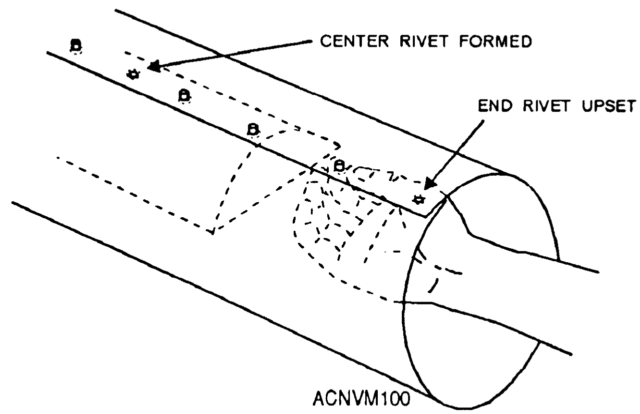


Figure 12-100.—Riveting a seam in a cylindrical section.

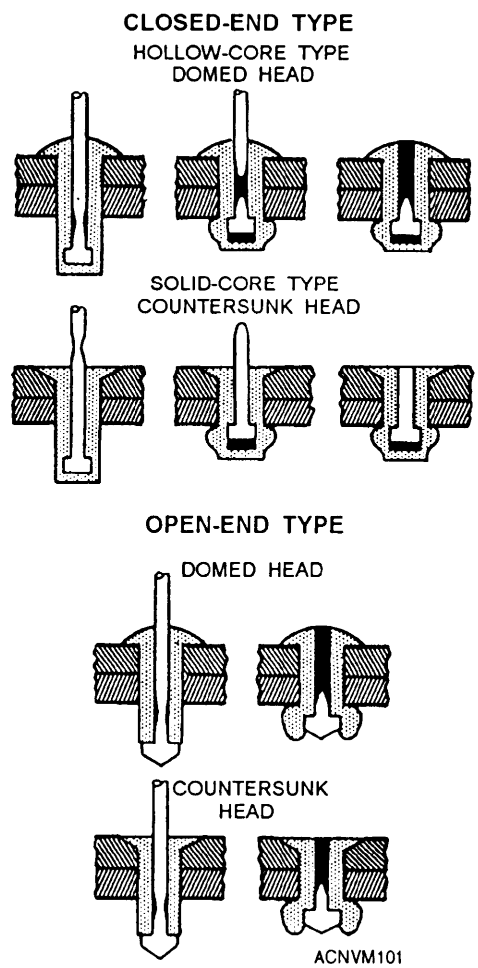


Figure 12-101.—Pop rivets.

Pop rivets are simple and easy to use. They require no complicated installations, expensive equipment, or skilled operators. Just drill a hole, insert and set the pop rivet from the same side, and high-riveting quality and strength is quickly accomplished.

There are two basic designs of pop rivets: closed end and open end. The closedend type of rivet tills the need for blind rivets, which seal as they are set. They are gas tight and liquid tight. They are installed and set from the same side just like the open-end type. As the rivet sets, a high degree of radial expansion is generated in the rivet body, providing hole-filling characteristics.

The open-end type of pop rivet resembles a hollow rivet from the outside. Because the mandrel head stays in the rivet body, the mandrel stem seals to a certain degree, but is now liquid tight.

Figure 12-102 shows two of the tools that are used for setting the pop rivets. These tools are lightweight and easy to use. For example, when using the small hand tool you need only to insert the mandrel of the rivet into the nosepiece, squeeze the handle, and the rivet is set. To operate the scissors type of tool, fully extend the lever linkage or gatelike mechanism. Then insert the rivet mandrel into the nosepiece of the tool. Place the rivet into the structure that is to be riveted. Apply firm pressure to the tool, making sure that the nosepiece remains in close contact with the rivet head. Closing of the lever linkage retracts the gripping mechanism, which in turn will withdraw the mandrel. The rivet is set when the mandrel head breaks.

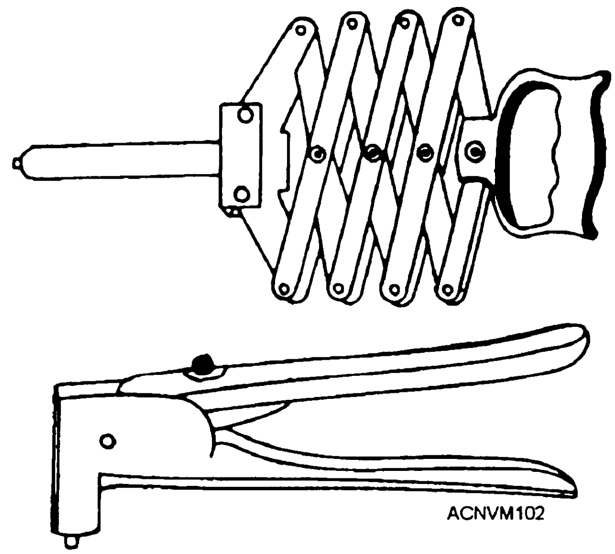


Figure 12-102.—Pop rivet tools.

Before inserting another rivet into the tool, make sure that the broken mandrel has been ejected from the tool. Fully extend the lever linkage and the mandrel will drop clear.

The scissors or expandable tool is unique because it can reach hard to get at areas and set the rivets with ease. This tool is particularly useful for installation of ventilation ducting.

Pop rivets that can be set by the tools shown in figure 12-102 are indicated by asterisks in table 12-3.

Table 12-3.—Pop rivet data

Rivet Material	Mandrel Material	Rivet Diameter (in inches)				
		3/32	7/64	l/8	5/32	3/16
		OPEN END RIVETS				
Aluminum	Aluminum	*		*	*	*
Aluminum	Steel	*		*	*	
Steel	Steel	*		*		
Monel	Steel		*	*		
Stainless	Stainless			*		
		CLOSED END RIVETS				
Aluminum	Aluminum			*	*	*
Aluminum	Steel			*		

SHEET METAL PRACTICE PROJECTS

As soon as you have learned the basic operations of laying out, cutting, forming, and joining sheet metal, you will be ready to try your hand at fabricating various objects. You should have no trouble in laying out and fabricating boxes, pans, cylinders, funnels, ells, tees, elbows, and many other sheet metal items, if you follow the procedures that were given in this chapter. It takes a lot of practice to develop a skill for sheet metal work. All your practicing should be done on scrap metal until you are good enough to turn out finished articles without wasting material.

Building a locker is a good practice project because it involves so many aspects of sheet metal layout and fabrication. The locker described here is fairly simple. You will have to develop your own plans for a more elaborate or an odd-shaped locker.

The first thing to consider in building a locker is the outside dimensions. Then decide on the thickness of metal you will use, the method of seaming, the number and location of shelves, and the type of door it will have. Plan out all of these details before you start your layout.

Figure 12-103 shows a locker that has one riveted shelf. The locker is assembled by using Pittsburgh lock seams and rivets. The door is flush to the front side and is swung on exposed hinges. A hasp and staple are used as a securing device.

Lay out the main body of the locker. Provide sufficient allowances for all of the scams and the doorjamb. One Pittsburgh lock seam is used for the main body of the locker, and another one is used for the back. The layout for the doorjamb is determined by the following factors:

1. The size of the door in its relation to the size of the locker. (The difference between the size of the door and the size of the locker controls dimension A in fig. 12-103.)

2. The thickness of the door. (This controls dimension B in fig. 12-103.)

3. The width of the stop (C in fig. 12-103). Normally the stop is about 3/8 inch to l/2 inch in width.

4. The allowance for the single hem (D in fig. 12-103). This allowance will be slightly less than that of the stop.

The next step is to lay out the notches. Square notches are used for the Pittsburgh lock scam. A combination of notches is required for the doorjamb. A is laid out at 45°, B at 90°, C at 45°, and D at 90° to the base line.

Now lay out the rivet holes for the seam and for fastening the shelf to the body of the locker. Then lay out the locker's back and shelf. Mark the locations of the rivet holes to match those on the main body of the locker. Be sure to provide for a stiffening flange on the front of the shelf when you lay out the shelf.

The next step is to lay out the door. Remember, all the layout lines will be on the inside of the sheet when it is folded up, so the actual door will be slightly larger than the layout. Make allowances for this so that the door will fit into the jamb. Also, the door must not make a tight fit. It must have clearance so that it can open and close freely. Generally, twice the thickness of the metal is allowed for this clearance.

After all the pieces have been laid out, trimmed, notched, and the rivet holes made, the next step is to form the locker to its shape. It does not matter which part of the locker you form first. The back has four 90-degree bends that will form the flanges of the Pittsburgh lock seam. Form the hem first on the shelf, then the stiffening flange. The tabs for riveting the shelf to the main body of the locker may be bent either up or down.

Form the pocket for the Pittsburgh lock seam on the main body of the locker. Then form the jamb on the opposite edge of the sheet. Follow these procedures for bending the jamb:

1. Transfer the lines of the jamb (indicated by X in fig. 12-103) to the reverse side of the sheet.

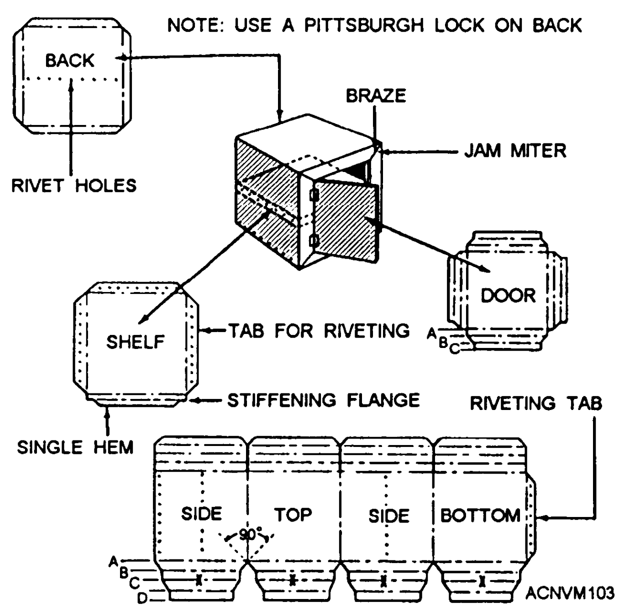


Figure 12-103.—Fabricating a locker.

2. Insert the sheet all the way into the brake, with the reverse side up and the layout lines down.

3. Completely form the single hem.

4. Remove the sheet from the brake and turn it over so that the layout lines are up. Reinsert the sheet in the brake and form the flange for the stop (C in fig. 12-103).

5. Remove the sheet again. This time, with the layout lines down, insert the sheet in the brake and form the depth of the jamb (B in fig. 12-103).

6. Slide the sheet out to the next line and form A (fig. 12-103).

The next step is to form the sides, top, and bottom of the locker. Start with the sheet all the way in the brake. Form the tab for riveting first, then slide the sheet out to the next brake line to form the bottom. Form one side, the top, and then the other side in the same way.

Form the door by making the single hem C all the way around. Then form flanges B and A on each section of the door.

Assemble the locker by riveting the side seam. Then install the back with the Pittsburgh lock seam. Solder or braze the jamb miters at the front of the locker and also at the corners of the door. (These miters and corners should NOT be welded. The extreme heat of welding will cause severe distortion of the structure.) File off any excess metal, and clean the soldered or brazed areas thoroughly to remove all traces of the flux.

Fit the door in the jamb. There should be enough clearance all around so that the door fits loosely. Insert thin strips of metal between the door and the jamb on all four sides to equalize the clearances. Then using either rivets or screws, fasten the hinges to the locker and to the door. Install a knob or handle on the door so that you can open and close it. The locker is completed.

MAINTENANCE AND REPAIR OF SHEET METAL STRUCTURES

The ventilation ducts and other sheet metal structures aboard ship are maintained and repaired by HTs. Such structures may require the fabricating of replacement parts, the patching of existing parts, and the overhauling of closures and other fittings. You will most likely repair or replace insulation and lagging, periodically clean the ventilation ducts, and do various other jobs.

In general, the principles of layout and fabrication that apply to making new objects also apply to making replacement parts. To replace a section of ventilation system ductwork, for example, you would make up a new section according to the layout and fabrication procedures described in the previous paragraphs.

Sometimes you will be able to patch ductwork rather than to manufacture a new section. Patches are installed by welding, brazing, or using sheet metal screws or pop rivets.

Many ducts throughout the ship are insulated to reduce the amount of heat and noise transferred between the duct and the surrounding spaces. When insulation and lagging are removed for the repair or replacement of a section, the area must be reinsulated and relagged.

Ducts are insulated by applying the specified insulating material, and tying the insulating material in place with galvanized steel wire or fibrous glass thread. The insulating material is then covered with lagging. The lagging is fastened with an adhesive.

Before applying insulation to bulkheads, inspect the area carefully and be sure that the protective coating of the metal is intact and that the surface is free of any oil, grease, or dirt. Insulation may be applied to bulkheads by one of two approved methods. In the first method, the studs are laid out and welded to the bulkhead and the insulation is then pushed onto the studs. In the second method, each piece of insulation is fitted into its proper place and the location of the studs is marked by punching through the insulation. The insulation is removed and the studs are welded to the marked spots. The insulation is then put on over the studs.

Detailed information concerning approved insulating materials and approved methods of using them may be obtained from NAVSEA plans and from *NSTM,* chapter 635.

SUMMARY

We have discussed the tools and procedures for sheet metal layout and fabrication. Study your pattern development methods and refer back to them while you are laying out your patterns. As with anything you do, experience will help you become more efficient in your work. However, accuracy is one of your major concerns. Double check your layout before you start making your cuts and bends. A little extra effort will save time and material.

CHAPTER 13

STRUCTURAL STEEL FABRICATION

LEARNING OBJECTIVES

Upon completion of this chapter you will be able to do the following:

- Describe some of the tools and equipment generally found in the shipfitter shop, and their use and operation.
- Describe the safety procedures and equipment used in structural steel fabrication.
- Describe the basic sections of a blueprint and interpret a blueprint using standard symbology.
- Identify the shapes and sizes of structural steel shapes.
- Understand the requirements for making repairs to ships' hulls and general structures.

INTRODUCTION

Structural steel repair is the broadest and most frequent type of repair done by HTs. It is the foundation upon which you will build your knowledge for the rest of the rate. In structural steel repair, you will use all the knowledge and skills learned in the preceding chapters. As a shipfitter working in the shipfitter shop or working in the HT shop on smaller ships, you will be called upon to weld, braze, cut metals, bend pipe, prep weld joints, fabricate general shipboard structures, and a host of other related tasks. This chapter will cover the basics of structural steel fabrication from reading and interpreting blueprints to making cuts in ships' hulls.

SAFETY

With any job you are tasked with, whether as a worker or as supervisor, safety should be your number one priority. As a shipfitter, you will be performing numerous tasks involving the operation of large equipment, working with heavy metal sections, and using heat producing equipment. Each of these jobs present unique safety considerations before, during, and after the job is complete. This section will address some of the common safety considerations for working in restricted access spaces and the handling and storage of structural steel. Other safety items for welding, cutting, brazing, and compressed gas storage have been covered in preceding chapters and will not be repeated in this chapter. Specific safety requirements for a specific type of machinery will be covered in the section of this chapter discussing that specific machine.

RESTRICTED ACCESS SPACES

As a shipfitter, you will be tasked to work in restricted access spaces such as voids and tanks. A restricted space is defined as a space with only one exit or where equipment or structural barriers prevent easy exit or entrance. When working in these spaces, there are several safety precautions to keep in mind to prevent injury or death of personnel. These safety precautions are as follows:

- Ensure the space has been certified gas free, if the space is unmanned and ventilation is nonexistent or the space is used to store hazardous material.
- Ensure proper ventilation is available to permit work in restricted access spaces. When

sufficient ventilation cannot be obtained without blocking the means of access, personnel in the confined space shall be protected by airline hose mask.

- Leave gas cylinders and heavy welding or cutting equipment outside the restricted access space.
- Station a watch outside the space to observe all workers at all times and to render assistance in an emergency.
- If entering a restricted access space through a manhole or other small opening, means shall be provided to remove personnel quickly in case of an emergency.
- If the access fitting to a restricted access space is remotely controlled, ensure measures are taken to secure and tagout (with a DANGER tag) remote control equipment to avoid accidental closing of the doors.
- If work in a restricted access space is suspended for any substantial period of time, remove all welding and torch leads, air hoses, and electrical cords from the space.
- When using gas-welding equipment, always close the torch valves and the gas supply to the torch, when not actually in use, to eliminate the possibility of the gas escaping through leaks or improperly closed valves. Torches shall remain in restricted spaces only for the period necessary to perform the required hot work.

STRUCTURAL STEEL STORAGE

The safe handling and stowage of structural steel shapes and plate has become a major safety concern in the past few years. There have been numerous mishaps on board ships and shore facilities involving the incorrect handling of steel shapes and plates. These incidents have caused loss of property, limb, and even life. One incident, on board a tender, caused the death of three people because of improperly stored steel plate. Always remember plate steel is extremely heavy. A 4 ft by 8 ft sheet of steel plate l/8 inch thick will weigh over 160 pounds. Multiply this by several sheets and not even the strongest man would be able to control its movement. Safety precautions for the storage and handling of structural steel plate are as follows:

—Store metal plates and shapes in properly designed and constructed racks. Plate metal should never be stored, standing on end, outside of storage racks.

—Storage racks will be orientated forward to aft, never port to starboard. Due to ships greater port to starboard movement at sea, plate stored in a port to starboard orientation could slide out of the rack and cause serious damage to material, equipment, or personnel.

—Ensure all storage racks have properly constructed doors or retaining devices to properly secure metal in the storage rack.

—Metal stored outside of racks should be stored flat on the deck. The metal should be secured with retaining devices to prevent the port to starboard or forward to aft movement of the material while at sea. The retaining device should be of proper strength and allow for the removal of an individual piece of metal without affecting the rest.

—When handling any kind of metal, wear gloves to protect your hands and prevent slipping.

—Use proper lifting procedures to prevent back injuries.

—To prevent injury from falling metal, never position any part of your body under a piece of metal being moved.

—If the material being moved is too heavy, get help before attempting to move the piece by yourself.

The attitude of metal workers towards safety is an important ingredient in a successful shop safety program. Aside from personnel injury, shop efficiency is lowered by damaged equipment and productivity is decreased. Be aware of all shop safety requirements. To be effective, the shop safety program must require 100 percent participation of all personnel.

BLUEPRINT READING

As an HT working in the shipfitter shop or any other shop manned with HTs, you will be required to use and interpret blueprints on a daily basis. You will also be required to make simple drawings and diagrams for planning or fabricating purposes. Having a good working knowledge of blueprints and drawings will greatly improve your productivity and efficiency.

Correctly interpreting blueprints will reduce mistakes and rework of jobs due to the wrong dimensions or improperly placed components.

This section will discuss the organization, lines and symbols, dimensions, and scales found on a blueprint. Views, detail drawings, and assembly prints will aid you in your job and will also be discussed in this chapter. Welding and NDT symbols, though a part of blueprints, have already been discussed in previous chapters. It isn't the intent of this section on blueprint reading to make you an expert on blueprints. But you should have the basic knowledge of blueprints to enable you to function in a shop environment until you gain further skill in reading blueprints. To gain further knowledge in blueprint reading, you should refer to *Blueprint Reading and Sketching,* NAVEDTRA 10077.

NOTE: Only standard blueprints will be discussed in this section.

PARTS OF A BLUEPRINT

Blueprints are broken down into numerous sections. Each section serves a different purpose. Understanding the purpose and information in each block of a blueprint will greatly increase your ability to use, understand, and interpret blueprints. Depending on their purpose, blueprints vary in size, format, and content. Only the title block, revision block, application block, zone numbers, and the bill of materials will be discussed in this section.

Title Block

The title block is usually located in the lower right-hand corner of all blueprints. This block contains the drawing number, the name of the part or assembly that the blueprint represents, and all information required to identify the part or assembly. The title block also includes the name and address of the government agency or organization preparing the drawing, scale, drafting record, authentication, and date the blueprint was approved (fig. 13-1).

Revision Block

The revision block, shown in figure 13-2, is in the upper right-hand corner of the print and is used for the recording of all changes (revisions) to a print. It could be quite detailed depending on the frequency of changes

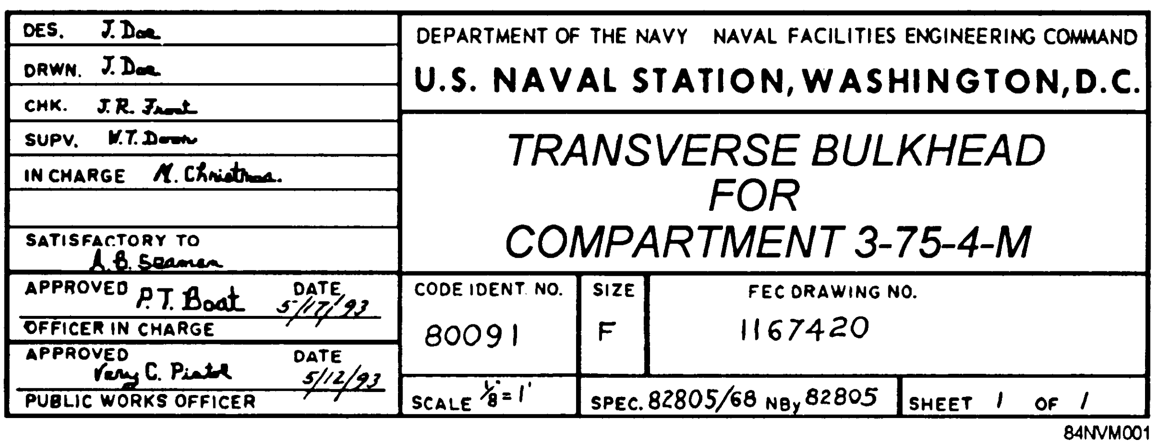


Figure 13-1.—Blueprint title block.

84NVM002		REVISIONS					
ZONE	REV.	DESCRIPTION	BY	CONTR.		USN	
				DATE	APPO.	DATE	APPO.
2 VAR 1 3 3	A	1. CORRECTED ASI DWG. NO. IN GEN NOTE NO. 14 2. DELETED ALL REFERENCES TO P/L NUMBERS 3. DELETED LIST OF REFERENCES 4. ALT. REF. NO. IN GEN . NOTE NO. 5 5. ALT GEN. NOTE NO. 8	CG	12/23/ 69	888	1/9/70	Jsl
3 VAR	B	1. ALT. ROD LENGTH & "X" DIMENSION FOR HGR. NO. S8-H1 2. HEAVIED UP LIGHT AREAS	Jsl	1/27/ 70	888	PRC DESIGN	

Figure 13-2.—Revision block.

made to a print. All revisions are noted in this block and are dated and identified by a letter and a brief description of the revision. Other information contained in the revision block is the name of the person who made the change and when the change was made. The revision block should always be reviewed prior to beginning a job to ensure you are familiar with the latest change. The most recent revision is noted in the title block

Application Block

The application block, located near the title block, identifies directly or by reference the larger units of which the detailed part of the assembly on the drawing forms a component. On most prints used by HTs, the application block will list the class of ship and those ships in that class that are equipped with that item. But you will also use prints that are generic to a class of ship (applicable to all ships of that class). These prints usually pertain to hull structures and other associated structures. A sample of an application block is shown in figure 13-3.

Zone Numbers

Zone numbers on blueprints and machine drawings serve the same purpose as the numbers and letters printed on borders of maps to help you locate a particular point. Zone numbers on blueprints are located on the top, bottom, and side margins of the print. The draftsman uses a combination of numbers and letters along the margins to identify the zone numbers. To locate a particular point, use the following steps:

1. Locate the given zone numbers for a given item on the top, bottom, and side margins of the blueprint.

2. Follow an imaginary line from each zone number toward the opposite side.

3. The point where the two lines cross gives the exact location of the particular point and a general location of the item.

DE - 101	A.C. FDN. # 1
DE - 102	A.C. FDN. # 2
DE - 103	A.C. FDN. # 3
DE - 104	A.C. FDN. # 4
DE - 105	A.C. FDN. # 5
NEXT ASS'Y	USED ON
APPLICATION	

84NVM003

Figure 13-3.—Application block.

Bill of Material

The bill of material is a list of parts or materials required by or used on the print. It is probably the most used section on a blueprint. Not only does the bill of material list all the material used, but it also gives a description of that item, the quantity of material used or required, material weight or thickness, MILSPECs or commercial standards to which that item must conform to, and other applicable information. Figure 13-4 shows an example of a bill of material.

Each item in the drawing on a blueprint is identified with a number designation or a combination of letter and numbers. An example of an item number for a piece of pipe between two fittings would be P-3 and the fittings F-1 and F-2. In this example, the letter P means pipe, and the number 3 identifies that particular pipe. The letter F means fitting and the numbers 1 and 2 identify the particular fittings. Next, locate the item number P-3 on the bill of material. You would find out that particular piece of pipe is 2-inch, schedule 40, carbon steel pipe, conforming to an applicable MILSPEC.

It is always important that you properly locate an item on a blueprint and read the bill of material to ensure that you know what materials you will be working with. You should never substitute material listed on a blueprint without first obtaining approval from competent authority. Also, by reading the bill of material, you will be able to determine the proper welding or brazing process to join the base metals.

LINES AND SYMBOLS

To properly read blueprints, you must be familiar with the lines and symbols used on a blueprint. These lines and symbols convey important information to the HT. Lines and symbols will also keep the reader from misinterpreting information shown on the blueprint. Various types of lines are used to show different objects and their positions. Commonly used lines and symbols are shown in figure 13-5 and are listed as follows:

— Visible lines are heavy unbroken lines.

—Hidden lines are medium lines with short, evenly spaced dashes.

84NVM004

BILL OF MATERIALS

ITEM NO.	DESCRIPTION	UNIT	ASSEMBLY OR FSN NO.	QUANTITIES	
				TROP	NORTH
3-1	LIGHTING CIRCUIT - NAVFAC DWG. NO. 203414	EA	3016	3	3
3-2	POWER BUS, 100A - NAVFAC DWG. NO. 304131	EA	3047	1	1
3-3	RECEPTACLE CKT - NAVFAC DWG. NO. 303660	EA	3019	2	2
3-4	BOX, RECEPTACLE W/CLAMP FOR NONMETALLIC SHEATH WIRE	EA	5325-102-604	3	3
3-5	LAMP ELECTRIC, MED. BASE, INSIDE FROSTED, 200W, 120V	EA	6240-180-314	60	60
3-6	PLUG ATTACHMENT, 3 WIRE, 15 AMP, 125 V	EA	5935-102-309	10	10
3-7	PLATE : BRASS, DUPLEX RECEPTACLE	EA	3325-800-101	5	5
3-8	RECEPTACLE, DUPLEX, 3 WIRE, 15 AMP, 125 V	EA	5325-100-102	5	5
3-9	ROD, GROUND, 3/4" X 10'-0"	EA	5306-200-180	12	12
3-10	WIRE, NO. 2 1/C STRANDED, HARD DRAWN, BARE	LB	6143-134-200	52	52
3-11	SWITCH SAFETY, 2 P, ST 30 AMP, 250 V, PLUS FUSE	EA	5930-142-401	2	2
3-12	CLAMP GROUND ROD	EA	5209-100-101	13	13
3-13	SWITCH, SAFETY, 200 AMP, 250 V, 3 P	EA	5930-201-903	1	1
3-14	FUSE, RENEWABLE, 200 AMP, 250V	EA	5920-100-000	6	6
3-15	LINK FUSE, 200 AMP, 250 V	EA	5920-100-001	6	6
	FUSE PLUG, 30 AMP, 125 V	EA	5920-100-102	12	12

Figure 13-4.—Bill of material.

—Center lines are thin lines made up of long and short dashes, alternately spaced and consistent in length.

—Dimension lines are thin lines ending with arrowheads at each end.

—Leader lines are thin lines ending with an arrowhead or a dot at one end.

— A phantom line is a medium series of one long dash and two short dashes, evenly spaced and ending with a long dash.

— A stitch line is a medium series of short dashes, evenly spaced and labeled.

—Thin solid ruled lines with freehand zig-zag indicate a break (long).

—Thick solid freehand zig-zag lines indicate a break (short).

—Thick solid lines with arrowheads indicate the direction in which a section or plane is viewed or taken.

DIMENSIONS

Dimensions on blueprints are used to indicate sizes and locations. Since items shown on a blueprint are drawn to a scale, the actual size shown on paper will be larger or smaller than the true item. Therefore, the actual dimensions are indicated by whole numbers, fractions, decimals, or angles. You will use the dimensions on prints to accurately locate, lay out, and manufacture an item to true size as shown on a blueprint. Dimensions are also used to outline shapes of objects on prints. The six major kinds of dimensions arc as follows (fig. 13-6):

- Conventional dimensions give the overall dimensions (length, width, and height) of an object.

- Base line dimensions give all the dimensions of an object and are indicated in relation to a designated base line or center line. Base line dimension is used to mark precision parts on a drawing.

- Chamfer and bevel dimensions indicate linear and angular dimensions of the edges of an object.

- Radius and arc dimensions indicate circular or rounded portions of an object.

LINE STANDARDS			
NAME	CONVENTION	DESCRIPTION AND APPLICATION	EXAMPLE
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	
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	
EXTENSION LINES		THIN UNBROKEN LINES USED TO INDICATE EXTENT OF DIMENSIONS	
DIMENSION LINES		THIN LINES TERMINATED WITH ARROW HEADS AT EACH END USED TO INDICATE DISTANCE MEASURED	
LEADER		THIN LINE TERMINATED WITH ARROW-HEAD OR DOT AT ONE END USED TO INDICATE A PART, DIMENSION OR OTHER REFERENCE	1/4 x 20 UNC-28 THD.
BREAK (LONG)		THIN, SOLID RULED LINES WITH FREE-HAND 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 BOLD LINES WITH ARROWHEADS 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 ARROWHEADS TO SHOW DIRECTION VIEWED	

84NVM005

Figure 13-5.—Line standards.

- Drilled hole dimensions are shown on a print by a leader and a note. The leader lists drill size, the number of holes to be drilled, and the depth of the hole to be drilled. If depth is not given, the hole is drilled completely through the object.

- Tolerance dimensions represent the amount by which a dimension can vary and remain within specification. Tolerances are indicated by a plus (+) or a minus (-) symbol.

SCALE

Most blueprints are drawn to scale for the simple fact that it would be impossible to draw a full-size representation of an item on paper due to the size of many items. Large objects are reduced and smaller items enlarged to fit standard sized paper. The scale of a blueprint is indicated in the title block. It indicates the size of the drawing as compared to the actual size of the object. The scale may be shown as 1" = 2", 1"= 12", ½"= l', and so on. It may also be indicated as full size, one-half size, one-fourth size, and so on.

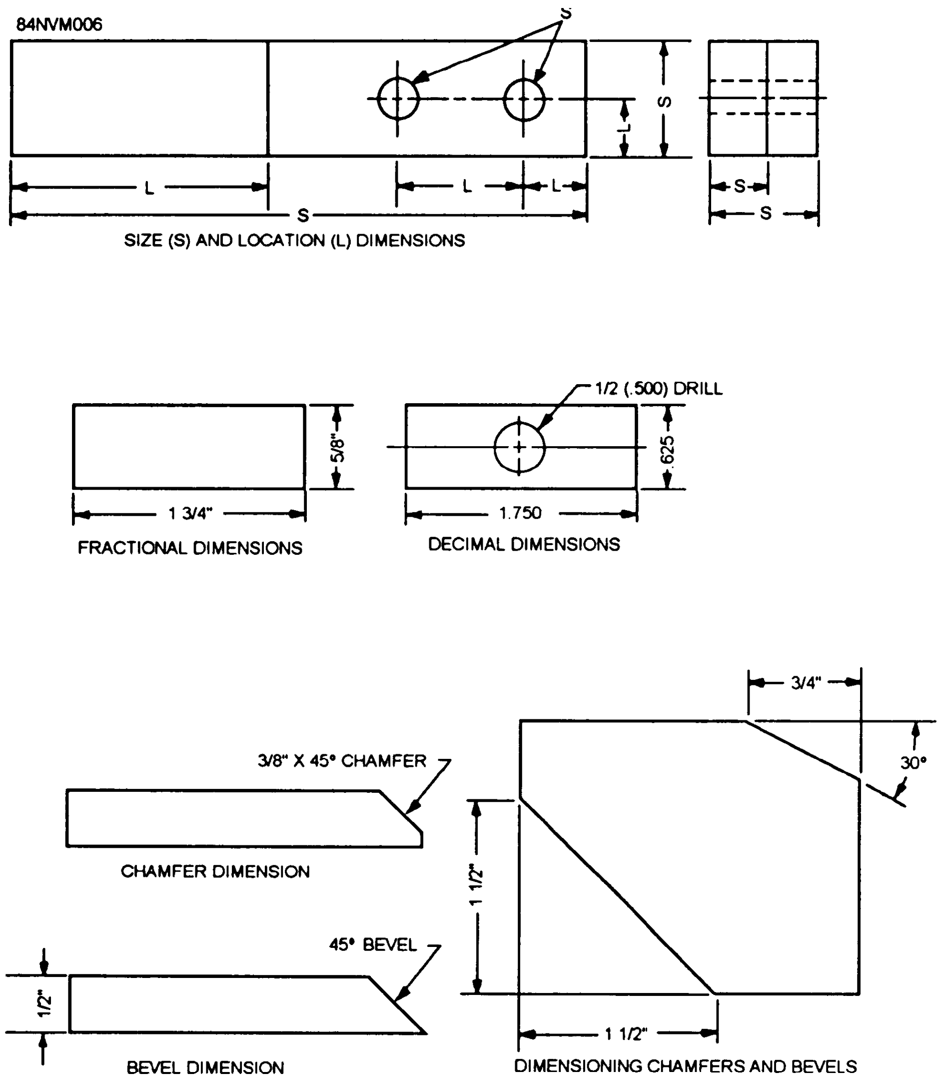


Figure 13-6.—Various dimensions that are shown on blueprints.

Remember: NEVER MEASURE A DRAWING. USE DIMENSIONS. Why? Because the print may have been reduced in size from the original drawing, or you might not take the scale of the drawing into consideration. Then too, paper stretches and shrinks as humidity changes, thus introducing perhaps the greatest source of error in actually taking a measurement by laying a rule on the print itself. Play it safe and read the dimensions on the drawing; they always remain the same.

ADDITIONAL GUIDES

Blueprints and drawings are made so that objects to be fabricated or repaired can easily be visualized by the reader. Views, detailed drawings, and assembly prints are used as guides to assist you in the fabrication and repair of structures and systems.

Views

There are numerous ways to project and draw an object, each with its own special characteristics and functions. On drawings and prints, a view is technically known as a projection. Orthographic and sectional views are the most commonly used, and will be discussed in the following paragraphs. This section will also discuss phantom, exploded, and development views.

ORTHOGRAPHIC VIEWS.—As an HT, you will be most concerned with a three-view orthographic projection, which shows all sides of an object. The sides, top, and bottom of the object are drawn in detail, but appear to be transparent, as shown in figure 13-7. Any features of an object that are hidden from view on any of the three projections are shown using hidden lines. The transparent effect of an orthographic view allows you to see exactly how the various components of an item fit together.

SECTIONAL VIEWS.—Sectional views are used to give a clearer view of the interior or hidden features of an object. These hidden features usually cannot be clearly observed in conventional outside views. Sectional views are made as if they were a cutaway part of the object along a given cutting plane. Full, half, and offset sectional views are the most commonly used on drawings. Figure 13-8 shows full- and half-sectional views. Notice the cutting plane line as shown by the letter AA. It shows where the imaginary cut has been made.

Full-Sectional View.—A full section (also known as a cross section) is shown as if the object were cut completely through along a certain plane. This type of view is usually used where hidden features vary throughout the object.

Half-Sectional View.—A half-sectional view is used when the object to be shown is symmetrical in both inside and outside details. It is assumed that the details shown in the uncut section are identical to the cutaway section. Only a quarter of the object is sectioned; the other quarter is shown as a standard view. The term *half section* means that only half of a full section is cut away. Again notice the cutting plane as shown in figure 13-8.

Offset Section.—An offset section is a section view that has the cutting plane changing directions. The cutting view plane changes direction to pass through features that are important to show. Figure 13-9 shows

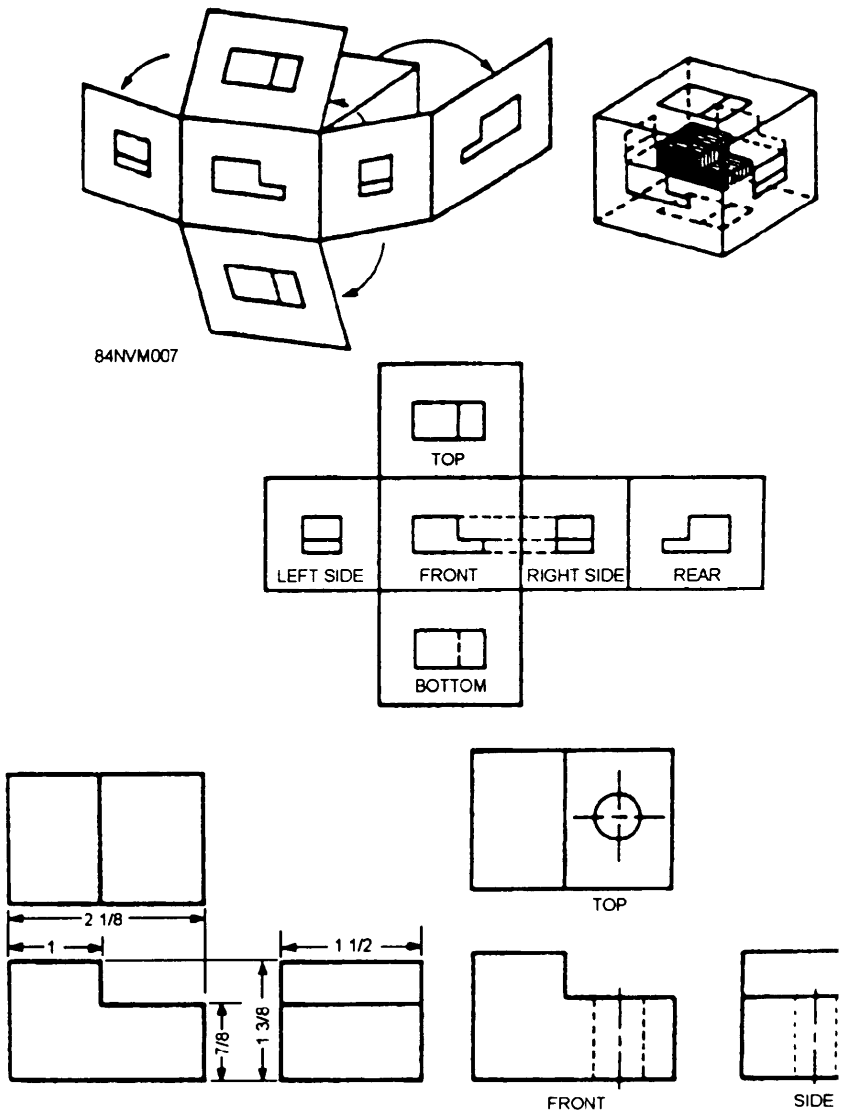


Figure 13-7.—Orthographic projections.

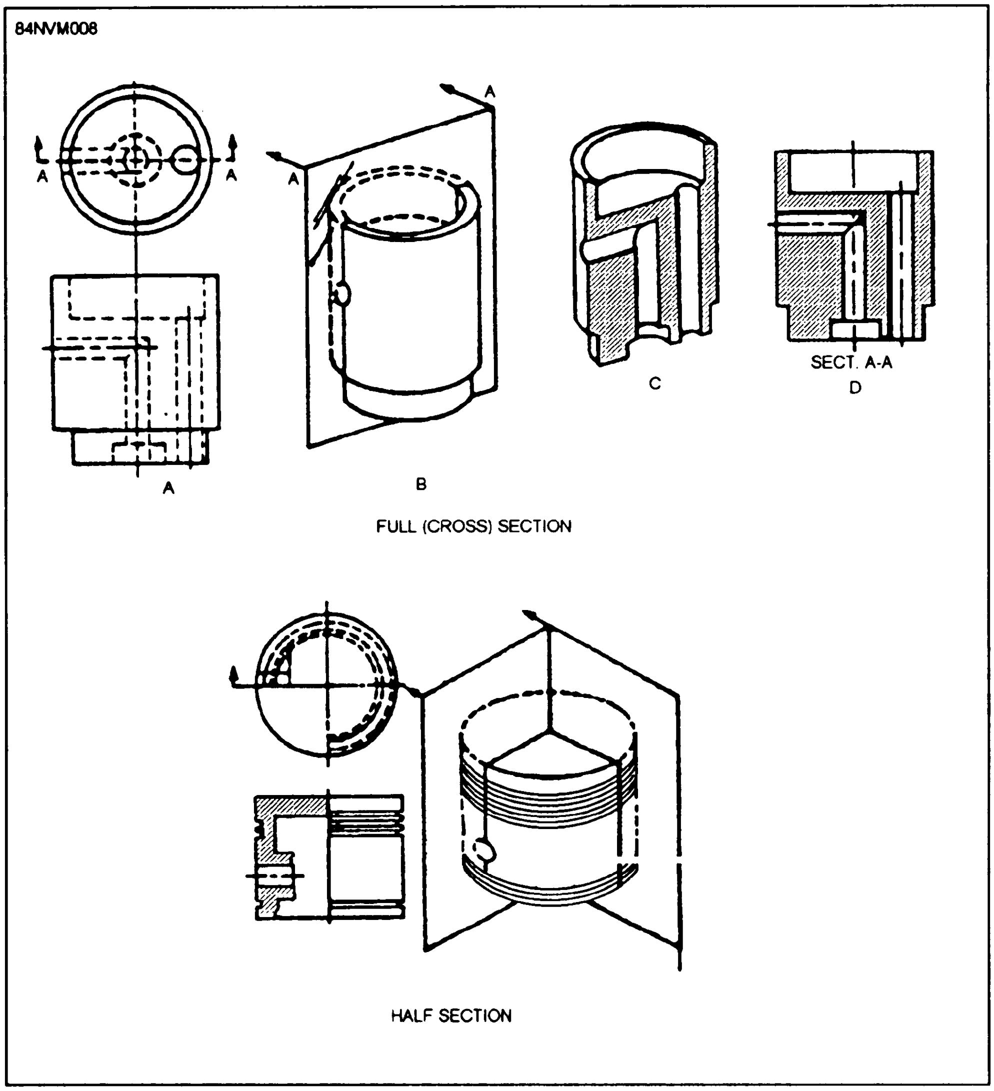


Figure 13-8.—Full- and half-sectional views.

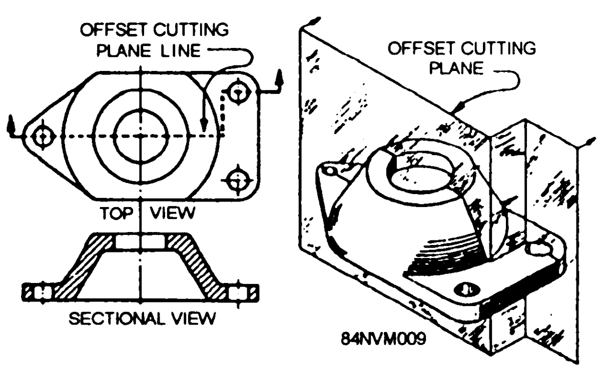


Figure 13-9.—Offset section.

an offset section view. Notice the different line used to show the cutting view.

PHANTOM VIEW.—Phantom views are used to indicate the alternate position of parts of the item drawn. It may also show repeated detail or the relative position of an absent part. Figure 13-10 shows a phantom view of a part in the alternate position. Notice the type of line (the part to the left of the figure is made up of one long line and two short dashes) used to represent the item in its original position.

EXPLODED VIEWS.—The exploded view is used to show relative location of parts; it is particularly helpful in assembling complex objects. Notice how the parts are spread out in a line to show clearly each part's relationship to the other parts, as shown in figure 13-11.

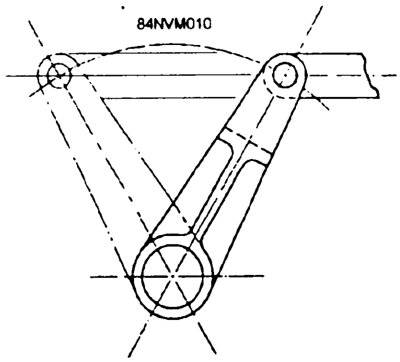


Figure 13-10.—Phantom view showing alternate position.

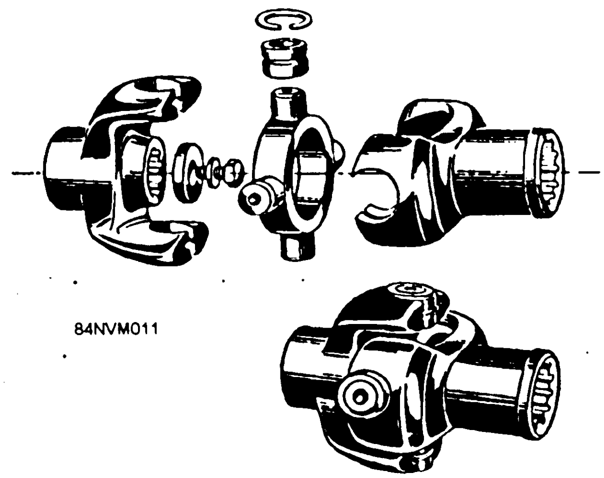


Figure 13-11.—Exploded view.

Detail Drawings and Assembly Prints

Detail drawings and assembly prints are additional guides for repairmen during the fabrication or assembly of a part.

DETAIL DRAWINGS.—Detail drawings are prints of single parts. The drawings provide an exact description of the part's shape, size, material, composition, surface finishes, tolerances, necessary shop operations, and other special requirements. Detail drawings often show where dimensions would be located on a part, as shown in figure 13-12.

ASSEMBLY PRINTS.—An assembly print (fig. 13-13) shows a unit either completely assembled or unassembled, usually without dimensions. One or more views of the assembled unit may be provided. Letters or numbers are used to identify parts on the print that correspond to various detailed drawings. Sectional views are generally used to show the assembled units. Exploded views show the exact location of each part and the sequence of assembly.

STRUCTURAL METAL SHAPES

Your work will require you to use some standard structural shapes rolled from steel and aluminum in a wide variety of cross-sectional shapes and sizes. Steel shapes are commonly used in the construction of ships' hulls, superstructures, and small crafts. Newer ships use extensive amounts of aluminum in the construction of their superstructures, and most small craft's hulls and superstructure are constructed of aluminum. This section will discuss the common shapes, sizes, types, and uses of common metal shapes and the different marking systems used to identify these structures. Angles, bars, rods, flats, and plate will also be discussed in this section.

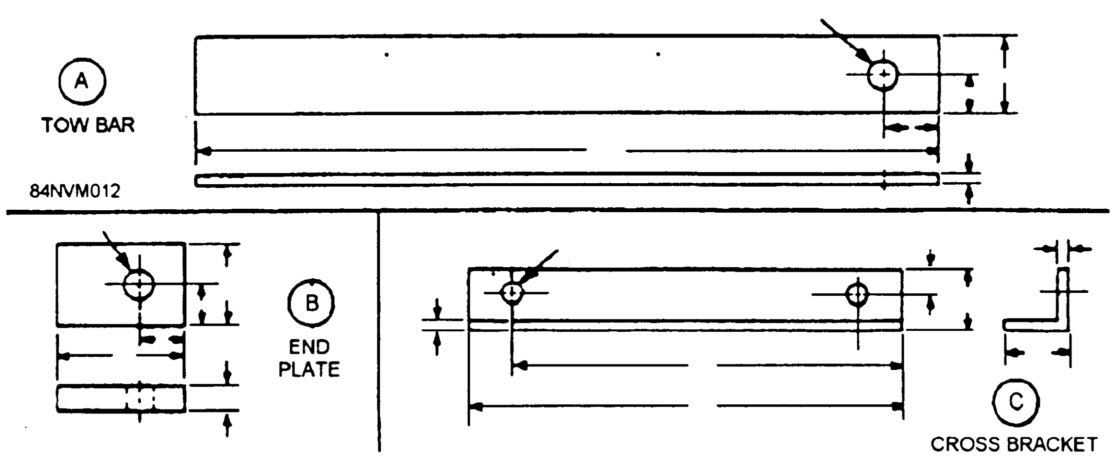


Figure 13-12.—Detail drawings.

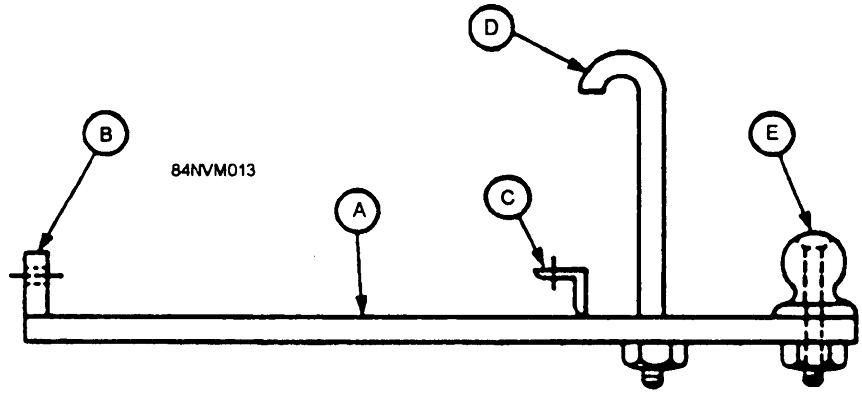


Figure 13-13.—Assembly print.

STRUCTURAL STEEL SHAPES

The HT uses standard steel shapes rolled from carbon steel. Figure 13-14 shows four structural steel shapes commonly used in the construction of ships. These are the wide-flange beam, the I-beam, the channel, and the tee-bar. These four shapes are identified by the nominal depth in inches along the web and the weight per foot of length. As an example, "12 inch WF 27" indicates a wide-flange beam section, 12 inches deep and weighing 27 pounds per foot.

Wide-Flanged Beams

The WIDE-FLANGE BEAM is a structural shape whose cross section forms the letter *H.* Wide-flange beams are the most widely used structural section. They are designed so that their flanges provide strength in a horizontal plane while the web gives strength in a vertical plane. Wide-flange beams are used as beams, columns, transverse and longitudinal framing, and in other applications where that particular shape is needed.

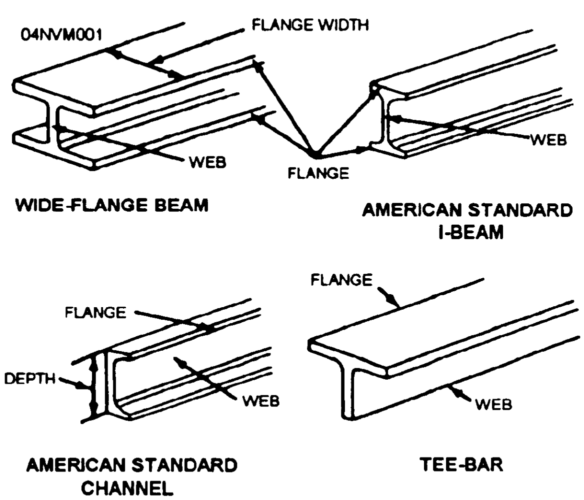


Figure 13-14.—Types of structural shapes.

I-Beams

The I-BEAM can be identified by its cross section, which is shaped like the letter I. I-beams are used less frequently than wide-flange beams because wide-flange beams have greater strength and are more adaptable than I-beams. You will find I-beams used as hoist tracks, booms, machinery foundations, and other similar applications.

Channel

The CHANNEL has a cross section similar to the letter *C.* It is especially useful in locations where a single flat face without protruding flanges on one side is required. The channel is not very efficient when used alone as a beam or column. However, you can construct effective members of channels assembled together with other structural shapes and then connected by rivets or welds. Channels are used in the construction of foundations, storage racks, tables, and other similar applications.

Tee-Bar

The TEE-BAR is similar to wide-flange beams or I-beams, but one side lacks the flange. In fact tee-bars can be manufactured from I-beams or wide-flange beams by cutting the beam down the middle or removing one of the flanges. The tee-bar offers the ideal cross section for stiffeners. The use of tee-bar stiffeners is now quite common in the construction of transverse and longitudinal frames in ships' hulls and superstructures.

OTHER STEEL SHAPES

Steel and aluminum come in numerous other shapes that are used for general structural and nonstructural usage. These shapes include angle, plates, sheets, and bars.

The designations generally used for flat steel have been established by the American Iron and Steel Institute. Flat steel is designated as bar, strip, sheet, or plate, according to the thickness, the width, and, to some extent, the rolling process by which the material was manufactured. Table 13-1 shows the designations normally used for hot rolled carbon steels. These terms are somewhat flexible, and sometimes may overlap. The terms used to designate cold rolled, flat carbon steel are very similar to those used for hot rolled, flat carbon steel, but differ in some details.

Angle

An ANGLE is a structural shape whose cross section resembles the letter L. It is also known as angle iron. Two types of angles (fig. 13-15) are in common use. The legs of these angles will be either equal or unequal. The angle is identified by the dimension and thickness of the legs, such as 6" × 4" × ½". The dimensions of the legs are found by measuring along the outside or backs of the legs. When an angle has unequal legs, the dimension of the wider leg is given first, as in the above example. The third dimension applies to the thickness of the legs, which always have equal thickness. Angles are used in general fabrication and have limited structural applications.

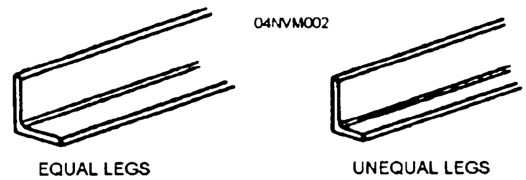


Figure 13-15.—Angles.

Plate and Sheet Metals

Metal that comes in flat rectangular pieces are known as plates and sheets. Metal is classified as a plate or sheet depending on its thickness. Generally metal l/8 inch and thicker is classified as plate. Metal less than l/8 inch thick is classified as sheet metal. Since plate and sheet are used extensively by HTs, both will be discussed in the following sections.

PLATE.—Plate is a structural shape whose cross section is in the form of a flat rectangle. Plates are generally used as connections between other structural members, or as component parts of built-up structural members. Plates are used extensively in the manufacture of ships' hulls, bulkheads, tanks, superstructures, and other similar applications. You will also form plate into numerous structural and nonstructural uses.

Plates cut to specific sizes may be obtained in widths ranging from a minimum of 6 inches to 120 inches or more. The thickness of plate will be l/8 inch or larger. The edges of these plates may be either cut by shears (sheared plates) or rolled square (universal mill plates).

Plates are frequently referred to by their width and thickness in inches, such as plate 24" × 1/2". In all cases, the length is given in feet and inches, such as 7'3". Thickness for ferrous and nonferrous plate are determined by different methods.

Steel Plate Sizes.—You will hear steel plate referred to by its nominal thickness or approximate weight per square foot for a specified thickness. Steel plate weighs about 2 l/2 pounds per square foot for each

Table 13-1.—Designations of Hot Rolled Carbon Steel According to Thickness and Weight

Width, inches	0.2500 and thicker	0.2499 to 0.2031	0.2030 to 0.1875	0.1874 to 0.0568	0.0567 to 0.0344	0.0343 to 0.0255	0.0254 to 0.0142
To 3 l/2 inclusive	bar	bar	strip	strip	strip	strip	sheet
Over 3 l/2 to 6 incl.	bar	bar	strip	strip	strip	sheet	sheet
Over 6 to 12 incl.	plate	strip	strip	strip	sheet	sheet	sheet
Over 12 to 32 incl.	plate	sheet	sheet	sheet	sheet	sheet	sheet
Over 32 to 48 incl.	plate	sheet	sheet	sheet	sheet	sheet	sheet
Over 48	plate	plate	plate	sheet	sheet	sheet	sheet

1/16 inch of thickness. Therefore, 5-pound plate is l/8 of an inch thick.

Note in figure 13-16 that 1 cubic foot of steel weighs 490 pounds. This figure divided by 12 is 40.8, which is the weight (in pounds) of a steel plate 1 foot square and 1 inch thick. In practice, the .8 is dropped and a l-inch steel plate is called 40-pound plate. Blueprints will normally list plate using the full decimal designation. The weight of plate, in a number of different thicknesses, is listed in figure 13-16.

Nonferrous Plate Sizes.—There are numerous types of nonferrous metals, such as aluminum, brass, copper, and stainless steel. Each of these metals have different weight per square foot. Therefore, nonferrous metals are simply measured by their nominal thickness, such as l/8, l/4, and l/2 inches.

SHEET METAL.—Sheet metal is very similar to plate metal. Sheet metal is used extensively in the sheet metal shop for the manufacture of lockers, bins, shelves, trim work, false bulkheads, and numerous other applications. Sheets cut to specific sizes may be obtained in widths ranging from a minimum of 6 inches to 120 inches or more. The thickness of sheets will be less than l/8 inch thick and measured by the gauge. The gauge of sheet metal is determined by a fixed standard and measured in thousands of an inch, as shown in figure 13-17. The edges of these plates may be either cut by shears (sheared plates) or rolled square (universal mill plates). Plates are frequently referred to by their width and thickness in inches, such as plate 24" X 1/2". In all cases, the length is given in feet and inches, such as 7’3".

Bars

The structural shape known as a BAR has a width of 6 inches or less and is thicker than 3/16 of an inch. The edges of bars usually are rolled square, just like the universal mill plates. The dimensions are expressed in the same manner as those for plates; for instance, bar 6" X 1/2". Bars are available in a variety of cross-sectional shapes, such as round, hexagonal, octagonal, square, and flat. Three different shapes are shown in figure 13-18. You may hear both the square and the round bars referred to as RODS or STOCK. Both squares and rounds are commonly used as bracing members for light structures. Their dimensions, in inches, apply to the side of the square or the diameter of the round.

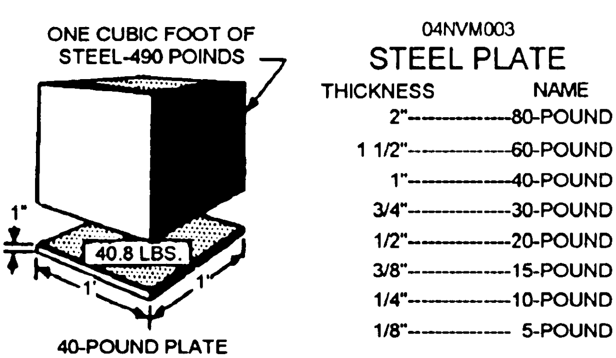


Figure 13-16.—Weight and thickness of steel plate.

METAL CLASSIFICATION AND MARKING SYSTEMS

As an HT, you will use different types and alloys of different metals on a daily basis. An understanding of the different classification and specification systems will greatly aid you in the proper selection and use of different metals.

There are different types of classifications and specifications for different metals used in the Navy. Metal components identified on all blueprints use one of these classifications or specifications. This section will discuss the SAE/AISI classification systems, federal, ASTM, and military specification systems and aluminum classifications used today. We will also look at the continuous metal marking system.

SAE/AISI Classification Systems

The Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI) each have devised systems to identify and classify carbon steels and steel alloys. These systems are almost identical except that the AISI adds a letter indicating the process by which the steel was made. Both systems use a four- or five-digit number to indicate the composition of the steel.

SAE NUMBERING SYSTEM.—The SAE numbering system uses a four-digit numbering system to identify the type of steel. Infix and suffix letters may be added to the numbering system. Each number has a significance as explained in the following paragraphs. Refer to figure 13-19.

—The first and second digits of the SAE numbering system indicates the main alloying element and the approximate percentage of the alloying element in the steel. Table 13-2 shows the numbers with their corresponding alloys.

—The third and fourth digits of the SAE number indicate the percentage of carbon in the steel. Table 13-3 shows the carbon content in hundredths of 1 percent.

Gauge No.	Birmingham wire gauge (B.W.G.) or Stubs iron wire gauge, for iron wires, hot and cold rolled sheet steel	American wire gauge, or Brown & Sharpe (for nonferrous sheet and wire)	U.S. Standard gauge for sheet and plate iron and steel	Steel wire gauge, or the W & M (Washburn & Moen) for steel wire
0	.340	.3249	.3125	.3065
1	.300	.2893	.2812	.2830
2	.284	.2576	.2656	.2625
3	.259	.2294	.2500	.2437
4	.238	.2043	.2343	.2253
5	.220	.1819	.2187	.2070
6	.203	.1620	.2031	.1920
7	.180	.1443	.1876	.1770
8	.165	.1285	.1718	.1620
9	.148	.1144	.1562	.1483
10	.134	.1019	.1406	.1350
11	.120	.0907	.1250	.1205
12	.109	.0808	1093	.1055
13	.095	.0719	.0937	.0915
14	.083	.0640	.0781	.0800
15	.072	.0570	.0703	.0720
16	.065	.0508	.0625	.0625
17	.058	.0452	.0562	.0540
18	.049	.0403	.0500	.0475
19	.042	.0359	.0437	.0410
20	.035	.0319	.0375	.0348
21	.032	.0284	.0343	.0317
22	.028	.0253	.0312	.0286
23	.025	.0225	.0281	.0258
24	.022	.0201	.0250	.0230
25	.020	.0179	0218	.0204
26	.018	.0159	.0187	.0181
27	.016	.0142	.0171	.0173
28	.014	.0126	.0156	.0162
29	.013	.0112	.0140	.0150
30	.012	.0100	.0125	.0140
31	.010	.0089	.0109	.0132
32	.009	.0079	.0101	.0128
33	.008	.0071	.0093	.0118
34	.007	.0063	.0085	.0104
35	.005	.0056	.0078	.0095
36	.004	.0050	.0070	.0090

Figure 13-17.—Steel plate and sheet metal gauges and thicknesses.

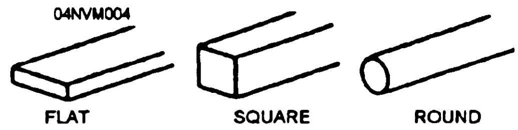


Figure 13-18.—Bars.

Table 13-2.—SAE Numbers with Corresponding Alloying Elements

Type of Steel	SAE Number
Carbon Steels	1XXX
Plain carbon	10XX
Free cutting (screw lock)	11XX
High manganese	13XX
Nickel Steels	2XXX
3.50% nickel	23XX
5.00% nickel	25XX
Nickel-Chromium Steel	3XXX
1.25% nickel, 0.60% chromium	31XX
3.50% nickel, 1.50% chromium	33XX
Molybdenum Steels (0.25% molybdenum)	4XXX
1.0% chromium	41XX
0.5% chromium, 1.8% nickel	43XX
2% nickel	46XX
3.5% nickel	48XX
Chromium Steels	5XXX
Low chrome	51XX
Medium chrome	52XX
Zhromium-Vanadium Steels	6XXX
Nickel-Chromium-Molybdenum (low amounts)	8XXX
Silicon-Manganese	92XX

Table 13-3.—SAE Specification for Plain Carbon Steel

SAE Number	Carbon range percent	SAE Number	Carbon range percent	SAE Number	Carbon range percent
1010	.08-.13	1040	.37-44	1070	.65-.75
1015	.13-.18	1045	.43-.50	1075	.70-.80
1020	.18-.23	1050	.48-.55	1080	.75-.88
1025	.22-.28	1055	.50-.60	1085	.80-.93
1030	.28-.34	1060	.55-.65	1090	.85-.98
1035	.32-.38	1065	.60-.70	1095	.90-1.03

—Infix letters are used occasionally to denote variations or modifications in the basic alloy composition. There are only two infix letters used: *B* (boron) and *L* (lead). When either of these letters are used, it indicates the addition of that element.

Example: 5040 basic composition

50B40 addition of boron

—Suffix letters are normally used when dealing with stainless steel. When used in this context, they indicate a variation in the basic chemical composition. The suffix letters used are as follows:

A, B, and C —Used to denote three types of steel differing only in carbon content

F—Denotes a free machining steel

Se—Denotes the addition of selenium

Example: 3033A .40% - .50% carbon

AISI CLASSIFICATION SYSTEM.—As previously mentioned, the AISI code system uses a letter before the number to show the process used in the making of the steel. The following letters are used:

- A—Acid

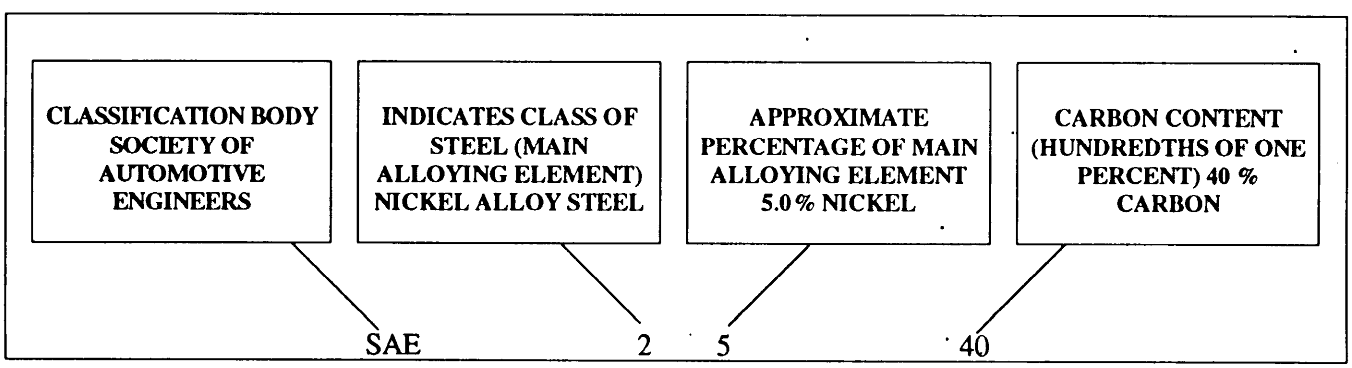


Figure 13-19.—SAE classification.

- B—Acid Bessemer, carbon steel
- C—Basic open hearth carbon steel
- CB—Either acid Bessemer or basic open hearth carbon steel at the option of the manufacture
- D—Acid open hearth carbon steel
- E—Electric furnace alloy steel

Examples of the SAE and ASIS classification code systems are as follows:

1010, 4340, 5220 = SAE steels

C1090, E4340, E3320 = AISI steels

4340 steel could be from either system.

Federal, Military, and ASTM Specification System

A knowledge of ASE/AISI identification codes is not enough to facilitate the selection of the materials used in the Navy today. The use of federal, military, and commercial specifications and the methods of cross-referencing them to other standards is becoming necessary to complete routine repairs and fabrication.

FEDERAL SPECIFICATIONS.—Federal specifications (FEDSPECs) are prepared for supplies used by several departments and offices of the federal government. As HTs, the group of materials we are most concerned with are the "QQ" (metals), and "WW" (pipe fittings, tubes, and tubing). You will find the FEDSPEC QQ used extensively in Navy sheet metal shops to identify sheet metal, especially aluminum. The FEDSPEC WW is used in the pipe shop to identify pipe fittings and pipe, but it is not as common as other material designators. To properly identify FedSpecs, you must have an understanding of the specification symbol used. The basic FEDSPEC symbol is divided into three basic parts:

- The group of materials to which the specification relates.
- The initial letter of the title materials.
- The serial number. If the serial number has been revised, the revision will be designated by a lowercase letter.

A complete FEDSPEC number would be broken down as follows for the specification QQ-A-225c:

- QQ—Refers to a metal
- A—Refers to aluminum
- 225—Is the assigned serial number
- c—Indicates the third revision to this specification

A complete list of current FEDSPEC numbers can be found in the technical library of most repair facilities.

MILITARY SPECIFICATIONS.—Military specifications (MILSPECs) are similar to FEDSPECs. MILSPECs use similar symbols for their meanings. The major difference is that MILSPECs were developed specifically for the military.

As in FEDSPECs, the symbol used to identify MILSPECs is divided into three parts. The MILSPEC, MIL-S-16216, is broken down as follows:

- MIL—Refers to military specification
- S—Identifies the material as metal plate
- 16217—Is the assigned number for HY-80

A complete list of current MILSPEC numbers can be found in the technical library of most repair facilities.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM).—The ASTM standards you will be most concerned with are those that cover ferrous and nonferrous metals. These standards, which were developed by a consensus of producers and consumers, are used widely by industry. Like federal or military specifications, the ASTM standard is a complete listing of specifications that generally include mechanical requirements, test procedures, dimensional tolerances, and chemical composition requirements. Like the MILSPEC and FEDSPEC, the symbol used to identify the ASTM specification is divided into three parts. The ASTM symbol A579-67 is broken down as follows:

- A—Identifies the general classification of the materials. "A" denotes ferrous metals, and "B" denotes nonferrous metals.
- 579—Is the assigned serial number.

- 67—Indicates the year the specification was issued or last revised.

Aluminum and Aluminum Alloy Classification

Aluminum is supplied in literally hundreds of different alloys. Making the most practical choice of aluminum to serve your needs depends largely on your knowledge and understanding of the identification and coding system. Aluminum alloys are broadly classed as castings or wrought alloys. Generally, you will not work much with aluminum castings; therefore, this section will only talk about wrought aluminum (plates, sheets, and shapes) and aluminum alloys.

NUMERICAL CLASSIFICATION SYSTEM.— A 4-digit numerical designation system is used to identify aluminum and aluminum alloys. The first digit indicates the alloy group as follows:

- 1xxx—Aluminum, 99.00% minimum purity, no alloying element
- 2xxx—Copper
- 3xxx—Manganese
- 4xxx—Silicon
- 5xxx—Magnesium
- 6xxx—Magnesium and silicon
- 7xxx—Zinc
- 8xxx—Other elements

The second digit indicates modifications of the original alloy or impurity limits. The last two digits identify the aluminum alloy or indicate the aluminum purity. Pure aluminum and aluminum alloys are classified in this manner and will be looked at further.

Pure Aluminum.—Pure aluminum is any aluminum product that is 99.00 percent aluminum and greater and classified in the 1xxx classification group. If there is a second digit after the 1, it will designate the control on impurities. These controls on individual impurities will be designated with the digits 1 through 9. If the second number is 0, it indicates natural impurity limits. The last two digits designate the minimum aluminum percentage. The following is an example of a 1xxx group aluminum metal and is broken down into its component parts:

- 1040—Is a pure aluminum. The second digit (0) indicates that there is no special control on impurities. The last two digits (40) indicate that it is 99.40 percent pure.

Aluminum Alloys.—In the 2xxx through 8xxx groups, the last two of the four digits in the designation have no special significance on the percentage of aluminum. Instead, the last two digits indicate the alloy modifications. The second digit, as in the lxxx group, indicates the control on impurities. The following is an example of a 2xxx group aluminum metal and is broken down into its component parts:

- 2117—Is an aluminum alloy with copper as the major alloying element. The second digit (1) indicates that there is some control on impurities and the last two digits (17) indicate that it is the 17th alloy of the 2xxx group.

NOTE: For complete chemical composition, specific identification numbers must be cross-referenced. These numbers can be found in most metal handbooks.

TEMPER AND HARDENING DESIGNATIONS.—In addition to the 4- digit alloy designation, a letter or letter/number combination is included as a temper/hardness designation. The temper/hardness of an aluminum alloy is one of the major factors governing strength, hardness, and ductility. As an HT, you will also need to have an understanding of the temper/hardness designation as it relates to mechanical and physical properties.

Temper Designations.—Some aluminum alloys are hardened and strengthened by cold working or strain hardening. Tempering is accomplished by cold rolling, drawing, stretching, or coining. Other aluminum alloys are heat treatable and their properties can be improved by thermal treatment methods. The following temper designations denote the condition of aluminum alloys and the method used to obtain that condition.

- F—As fabricated
- Q—Annealed and recrystallized (wrought only)

- H—Strained hardened (wrought only)

  H1—Strain hardened only

  H2—Strain hardened, then partially annealed

  H3—Strain hardened, then stabilized

- W—Solution heat treated—unstable temper

- T—Treated to produce stable tempers

  T2—Annealed (cast only)

  T3—Solution heat treated, then cold worked

  T4—Solution heat treated and naturally aged at room temperature to a substantially stable temper

  T5—Artificially aged

  T6—Solution heat treated, then artificially aged

  T7—Solution heat treated then stabilized to control growth and distortion

  T8—Solution heat treated, cold worked, then artificially aged

  T9—Solution heat treated, artificially aged, then cold worked

It is important that you be aware of these conditions as a metal worker. When you weld, heat, roll, or bend aluminum, you will change the temper of aluminum. In certain applications, you may have to use special precautions or post treatments to prevent changing the characteristics of the aluminum.

Hardness Designations.—In many cases, a second digit may appear to the right of the temper designation. This digit indicates the degree of hardening. The numbers 2 through 9 are used to express this hardness. Hardness is obtained by heat treatment, aging, or the cold working of aluminum. The following is a list of the numbers and their meaning:

- 2—1/4 hard

- 4—1/2 hard

- 6—3/4 hard

- 8—Full hard

- 9—Is sometimes used to express extra hard

As with temper, it is important that you are aware of hardness conditions as a metal worker, especially in welding applications. When you weld, heat, roll, or bend aluminum, you will change the hardness of aluminum. In certain applications, you may have to use special precautions or post treatments to prevent changing the characteristics of the aluminum. In some applications, you may not be able to use a repaired aluminum structure for a specific amount of time while the aluminum age hardens.

The following are two examples of a complete aluminum classification broken down into its component parts:

- 2218-T72—-Aluminum/copper alloy with special control over impurities, alloy #18 in the aluminum/copper group, solution heat treated (T7), then stabilized to 1/4 hard (2).

- 1060-H18—-99.60% pure aluminum with no special control over impurities, strain hardened (Hl) to full hard (8).

Material Cross-Referencing

Due to the numerous specification and classification systems used and the availability of specified material from blueprints, you will be required to cross-reference metal from one specification to another.

Continuous Identification Marking System

The continuous identification marking system is used to identify different metal shapes and forms. The marking is printed on the metal with heavy ink or paint in constantly recurring symbols at intervals of no more than 3 feet throughout the length of the material. The manufacturer is required to make these markings on the material before delivery. The marking system consists of the following information (refer to fig. 13-20):

- The name or trademark of the producer who performs the final processing before marking.

- The commercial designation or the material, such as the ASTM, AISI, ASE, or FED/MIL specification.

- Physical condition and quality designation that shows temper or other physical condition approved by a nationally recognized technical

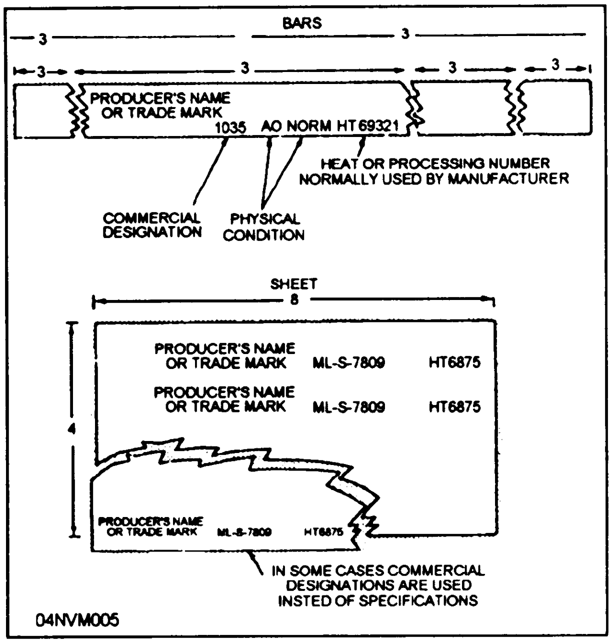


Figure 13-20.—Examples of continuous identification marking.

society or industrial association. Some of the designations used are as follows:

CR—Cold rolled

HR—Hot rolled

HT—Heat treated

AQ—Aircraft quality

1/4H—Quarter hard

HTQ—High tensile quality

- Specification data, such as the revision letter of the specification number, type, grade, class of material or manufacturer's specification data, such as heat number.

Small metal shapes, such as small tubing, coils of wire, and bar stock, cannot be marked readily by this method. On these items, the material may be tagged. Whenever a piece of material is removed from the original piece, you should mark the piece if the marking label is incomplete or destroyed. This will prevent the piece from being mistaken for another type of material or from being used where it shouldn't be used.

SHIPFITTER SHOP EQUIPMENT

Shipfitter shops, whether ashore are afloat, are equipped with some of the largest, most powerful, and dangerous equipment found in R-l division. All structural shops, regardless of the type of ship or shore facility you will be assigned to, have some or all of the equipment discussed in this chapter. It is important that you have a general understanding and knowledge of how to use these different types of equipment. It is not the intent of this training manual to make you an expert on the use and operation of the different machines. You should, however, be able to identify the types of machinery, the general operation, and safety precautions associated with this equipment.

The machinery found in most structural shops can be classified into two basic categories: cutting machines and forming machines.

CUTTING MACHINERY

This section will take a look at machinery associated with cutting metal plate and shapes. You have already studied some of the equipment associated with cutting plate, such as the oxyacetylene torch, mechanical hacksaw, and band saws that are found in some of the smaller shops in the fleet. This section will include such machinery as the shear, universal ironworker, Pullmax, and plasma arc machine.

Drop Shear

The drop shear enables the HT to produce quality work in minimum time. The drop shear is used to trim metal and make straight cuts with square sides. Metal, such as mild steel, black iron, copper, aluminum, and stainless steel, can be cut on the drop shear.

You have already been introduced to the squaring shear in chapter 12 of this text. The drop shear is very similar to the squaring shear but the drop shear is designed to cut thick plates. Most drop shears on ships and at shore facilities are designed to cut plate from l/8 to l/2 inch thick. Metal thinner than l/8 inch should be cut on a squaring shear in the sheet metal shop since the drop shear would just bend the sheet metal around the knives. Drop shears at some shipyards are designed to cut plate 1 inch and thicker.

SHEAR SAFETY.—As with any job or equipment, safety should be your primary concern. The drop shear is a very dangerous piece of equipment to operate due to the force required to cut thick metal. As you can imagine, it requires a lot of shearing force to cut thick plate. To compound this danger, the shearing force is accomplished in one stroke of the machine. Once you have tripped the release lever, the shearing action is nonstoppable until the machine has made one complete revolution. If you accidently trip the release lever, whatever is beneath the knives will be cut, including fingers.

The following is a list of some of the more common safety precautions:

—Become familiar with the type of drop shear installed in your shop. Qualify on its use and operation under qualified supervision prior to operating the shear.

—Determine the capacity of the machine being used from the manufacturer's technical manual and NEVER exceed its maximum capacity. Capacities for most machines are given in metal thickness, and length, and, unless otherwise noted, are given for mild steel not alloy steels. As metal hardness increases, machine capacity decreases.

—Never place any part of your body under the knives or dogs (holddowns) of the shear.

—Never place hands or fingers between the metal plate and the bed.

—Ensure that the metal plate is under a holddown dog.

—Never, never have your foot on the trip lever or pedal while loading or adjusting plate on the shear. Numerous accidents have occurred because of the shear being accidentally tripped.

—Never cut pipe, bar stock, round stock, flat bar less than 2 inches in width or other similar metal shapes. If you attempt to shear these types of metal shapes, you will damage the cutting knives and risk injury due the met al flying out from the holddown dogs, since the dogs are designed for flat plate.

SHEAR NOMENCLATURE.—As with any piece of equipment, you should have an understanding of the major parts of the equipment and their function. Figure 13-2 1 illustrates some of the parts common to all drop shears. These parts arc listed as follows:

- The finger guard is located on the front of the machine and is designed to prevent your fingers from king cut.

- Holddowns (dogs) are located behind the linger guard and arc designed to automatically operate when the release lever is tripped. These dogs clamp the plate in place with

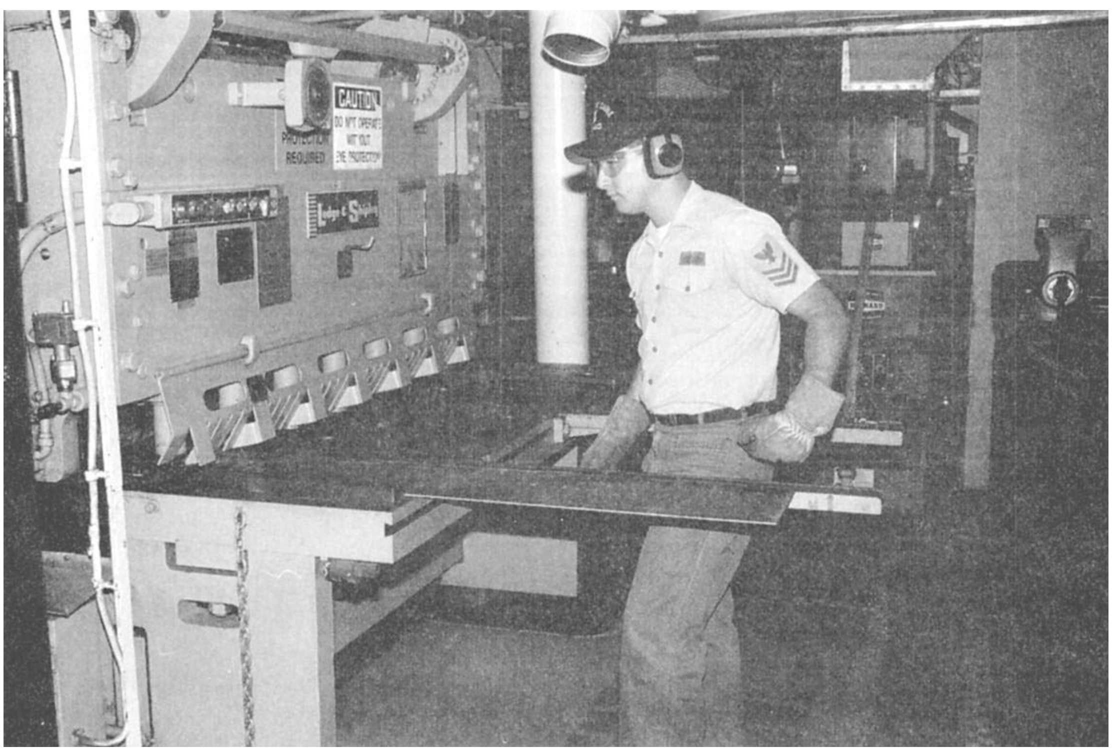


Figure 13-21.—Common drop shear.

several tons of pressure to prevent movement of the plate during the shearing action.

- The back gauge (not shown) is at the back of the machine and provides a stop for the exact measurements for shearing more than one piece of plate. The back gauge is usually set from an adjustment wheel on the front of the machine.

- The bed is the flat part of the shear that provides a surface and support for the metal to be sheared.

- The flywheel is on the left side of the machine. It is part of the pulley system that sets the machine in motion. Some machines use a hydraulic system and cylinder in place of the flywheel/pulley system.

- A set of upper and lower cutting knives provide the shearing action.

- The control panel is a station from which the shear is operated. The control panel has a stop/start button, a control lever for the dogs so that they can engage manually, and a control lever for the shearing action. The control lever for the shearing action usually has three positions: OFF, JOG, and ONCE. In the JOG position, the machine will cut repeatedly as long as the trip lever is depressed. In the ONCE position, the shear will only make one cutting revolution when the trip lever is depressed.

- The final item is the trip device that sets the machine in motion. This lever is usually foot operated and is of the foot pedal type or the bar type (which runs the length of the machine).

OPERATION OF THE DROP SHEAR.— Operation of the drop shear is a relatively simple operation provided you follow all manufacturers' directions and safety precautions. The following is a list of procedures to follow when setting and loading the machine for operation.

1. Determine that the plate to be sheared does not exceed the capacity of the machine.

2. Adjust the back gauge for the proper cutoff length.

3. Start the machine and cycle it through one complete revolution to check the machine for proper operation and binding.

4. Stop the machine and place the plate flat on the bed and snug against the back gauge. Ensure the metal is under a holddown.

5. Start the machine and engage the holddowns manually, if desired, or check the holddown lever to ensure that it is in the proper mode. For inexperienced operators, the shear lever should always be in the ONCE position.

6. Depress the trip lever and shear the plate. If the dogs were not previously set, they will automatically engage when the trip lever is depressed.

KNIFE SETTING AND CLEARANCE.—After repeated use of the shear, the knives will begin to wear. You will begin to notice that the sheared plate will have rough edges and burrs left on the edge. A worn blade will decrease machine efficiency and will require additional work to remove the burrs from the edge. You should also inspect the knives periodically for indentations, cracks, dullness, and other signs of wear that could cause inefficient operation.

Setting The Knives.—If the knives show signs of wear but do not need replacement, you may simply rotate the knives to a new cutting edge. Each knife has four cutting edges that enable the knives to be rotated until each edge has been used. When rotating the knives, rotate the upper and lower blades together so that you have two new cutting edges exposed. The following is a general description of how to rotate or replace the knives:

NOTE: Always refer to the manufacturer's technical manual for the particular machine installed in your shop for the correct procedure for blade setting.

- Block the ram in the up position while removing the upper knife.

- Remove the knives from the scats. The knives will have shims installed between the knife and the blade, so ensure that you save the shims and mark the location of each shim for reinstallation.

- Rotate or install new knives, as required.

- Tighten the knife by holding it firmly against the seat. Pry the upper knife with a wooden lever placed at the center of the blade and tighten the center bolt. Continue prying and tighten from the center to the right bolts and from the center to the left bolts until the knife is secure.

- Repeat the above step for the lower knife.

Knife Clearance.—After the knives has been installed, you must set the proper clearance (fig. 13-22) between the upper and lower knives. This is the most important adjustment on most drop shears. Unlike a pair of regular handheld shears that have the blades scraping next to each other during the cutting stroke, the knives on the drop shear have a clearance between the two knives to prevent binding during the shearing stroke. If the knives are set too close, the shear will bind and cause damage to the machine. If the blades are set too far apart, the plate will be sheared with rough edges and burrs. If the knives have excessive clearance, thin plate may even be bent between the knife edges, causing binding. The following procedure should be used to set knife clearance:

1. Select the proper knife clearance for the metal type and thickness being sheared. (Always refer to the manufacturer's technical manual when selecting knife clearance.) Most drop shears in shipfitter shops are adjusted with a side clearance of 0.010 inch at the edge dogs and 0.008 inch in the center, which is satisfactory for general shearing requirements.

2. Rotate the flywheel by hand until the knives cross the first holddown and the clearance of 0.010 inch is reached using a feeler gauge.

3. Slowly lower the ram until the knives cross at the last holddown, adjusting to 0.010 inch at each holddown.

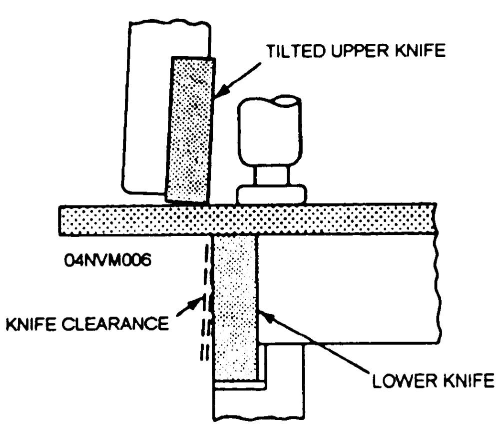


Figure 13-22.—Drop shear knife clearance.

4. Tighten the remaining bolts that hold the knife in place.

5. Lower the ram again and recheck the knife clearances. Make additional adjustments if you do not get a reading of 0.010 inch at the first and last holddowns and 0.008 inch in the center. As a rule of thumb, the center measurement should be 0.002 inch less than the end measurements to allow for flexing of the knives during shearing.

Universal Ironworker

The universal ironworker performs many of the basic machine operations in the shipfitter shop. It is best used for performing identical operations on many pieces of standard metal stock. The universal ironworker is capable of several operations, including punching, stock cutting, notching, and coping.

There are two basic types of ironworkers used in the Navy: the old mechanical driven type, as shown in figure 13-23, and the newer hydraulic version, as shown in figure 13-24. In this section, we will discuss safety associated with the universal ironworker and the punching, stock cutting, and coping evolutions.

UNIVERSAL IRONWORKER SAFETY.—As with the shear, safety should be of great concern. The ironworker is a very dangerous piece of equipment to operate due to the force required to work thick metal. A special safety concern for the ironworker is the operation of several different stations from one foot pedal or trip lever. The following is a list of some of the more common safety precautions:

—Become familiar with the type of ironworker installed in your shop. Prior to operating the machine, qualify on its use and operation under qualified supervision.

—Determine the capacity of the machine being used from the manufacturer’s technical manual and never exceed its maximum capacity. Capacities for most machines are given in metal thickness, length, and, unless otherwise noted, are given for mild steel not alloy steels. As metal hardness increases, machine capacity decreases.

—Stay alert! Never insert hands between tooling for any reason, keep them out of strippers and holddowns.

—Properly align and tighten all tooling. Check clearance before proceeding.

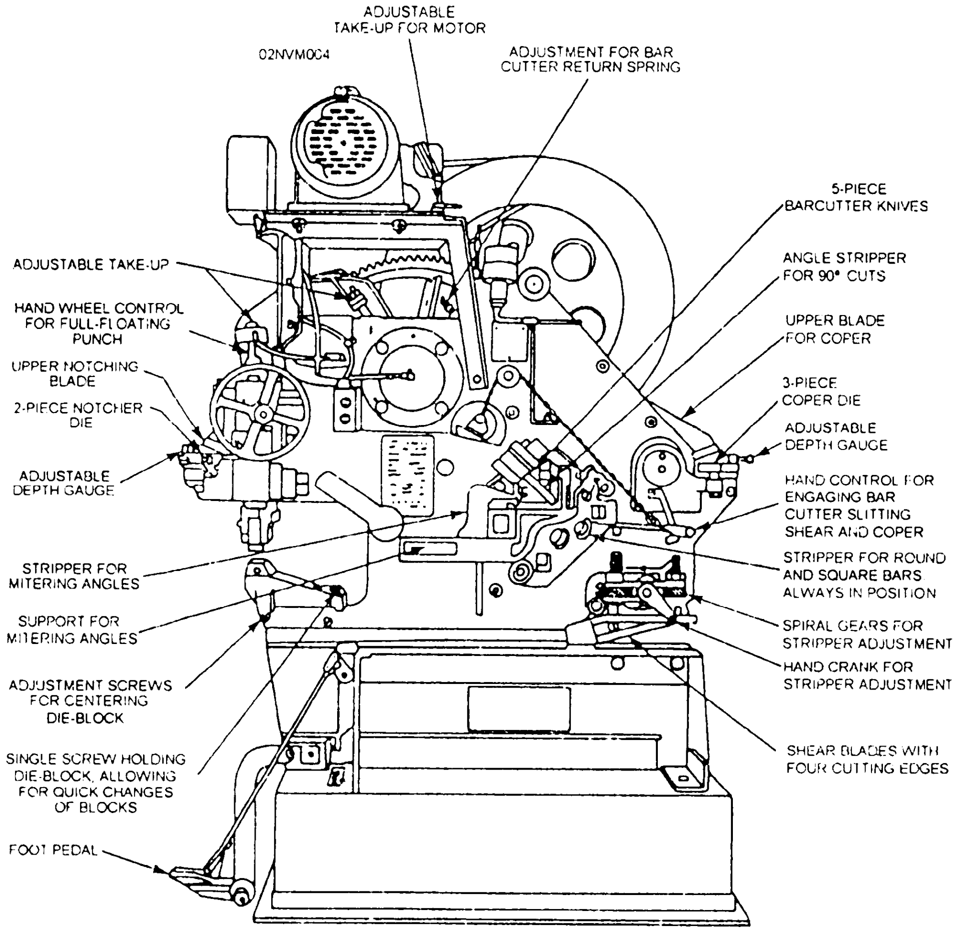


Figure 13-23.—Universal ironworker.

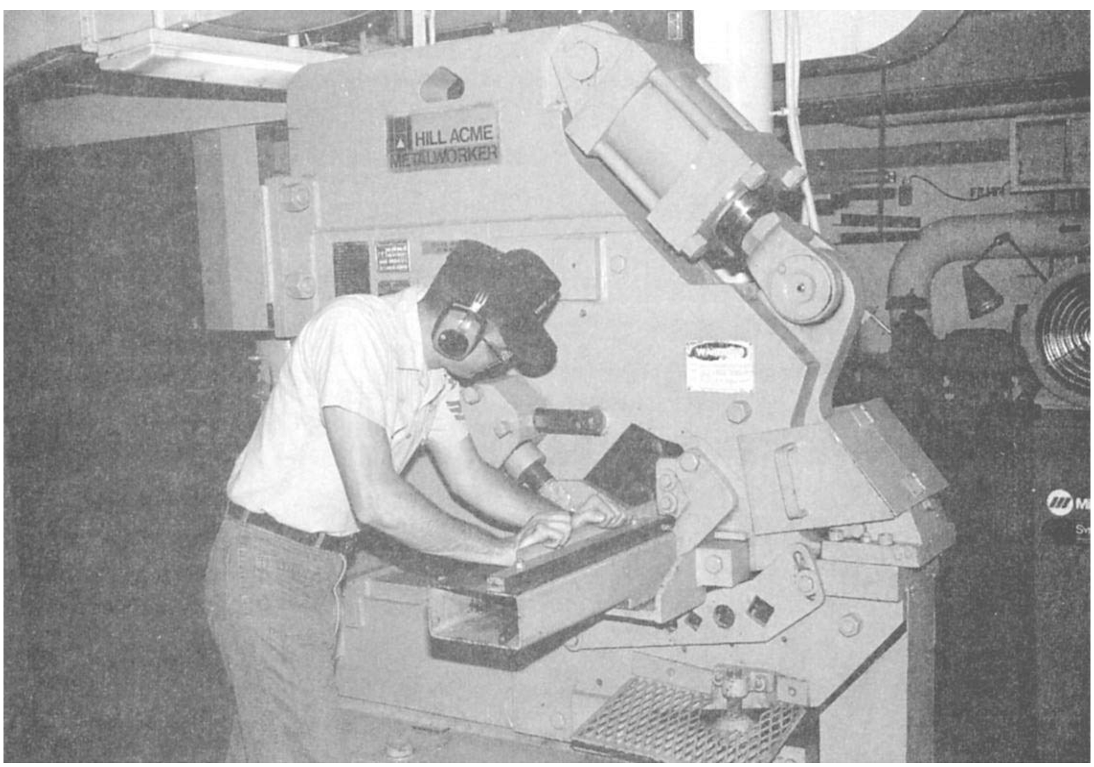


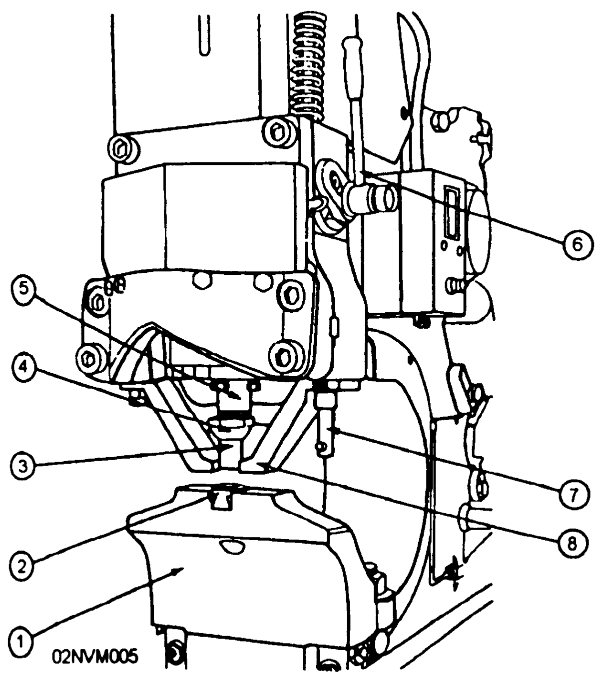
Figure 13-24.—Hydraulically operated universal ironworker.

—Make no modifications that will speed up or continually cycle machine.

PUNCHING OPERATIONS.—The punch end of the universal ironworker punches rounds, squares, and oblongs. The deep punch throat allows punching to the center of wide plates. The standard universal die block permits punching a full range of angles, beams, and channels.

Punch Head.—The main part of the punching device is a punch head. In the older machines, the punch head is referred to as a full-floating head since the dieblock is adjustable to allow the alignment of the die to the punch. In the newer machines, the dieblock is stationary while the die is adjusted for alignment with the punch. The major components of the punch end are as follows (fig. 13-25).

Punch and Die Selection.—On the punch end, the punch to die selection is the utmost importance. Select the proper size and shape of the punch and die according to the type and thickness of material to be punched. Refer to the manufacturer's manual for standard tooling sizes. You should keep the following points in mind when selecting punches and dies.



1. Dieblock
2. Die
3. Punch
4. Coupling Nut
5. Punch Holder
6. Hand Lever
7. Stripper ACS Lever
8. Stripper

Figure 13-25.—Punch floating head.

—Select the appropriate die, depending on the punch-to-die clearance. Figure 13-26 shows the punch-to-die clearance. The punch-to-die clearance is the distance between the outer circumference of the punch and the inner circumference of the die, when the punch sits in the die.

—The punch diameter must be the same thickness or greater than the plate thickness being punched.

—The punch-to-die clearance for mild steel with a thickness of l/4 inch through 5/8 inch should be l/32 inch.

—The punch-to-die clearance for 3/4-inch mild steel should be l/16 inch.

—For metal less than l/4 inch, the recommended punch-to-die clearance is l/10 of the thickness of the material.

—The punch-to-die ratio should never be less than 0.010 inch due to working clearances necessary in the punch head.

Operating Procedure.—To operate the punch, refer to figure 13-25 and proceed according to the following precautions and steps:

- Install the punch and die and check the alignment and adjust as necessary. Ensure that the punch passes through the die without striking the shoulders of the die.
- Cycle the machine through one complete revolution checking the machine for binding or misalignment.
- Place the workpiece under the punch and "spot" the punch to the workpiece. This may be accomplished by using the hand lever in the older mechanical machines or by the jog button on the hydraulic machines.

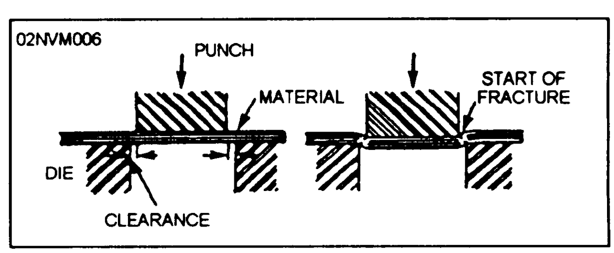


Figure 13-26.—Punch-to-die clearance.

- Step on the foot pedal and hold the pressure until the punch has penetrated the workpiece.

STOCK CUTTING OPERATIONS.—The bar cutter of the universal ironworker cuts and miters angles and shears flat, round, and square stock (fig. 13-27).

Special knives can be added to the ironworker to shear beams, channels, tees, and other structural shapes. Most stock cutting operations are performed in the center of the machine with special cutting knives, as shown in figure 13-28, or at one end, as shown in figure 13-29.

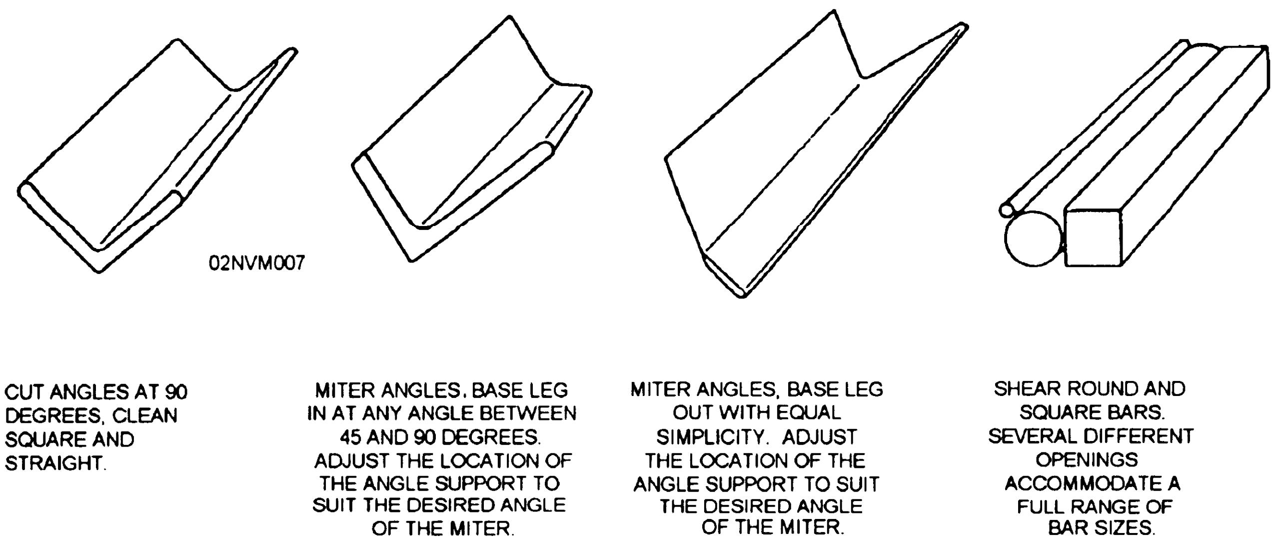
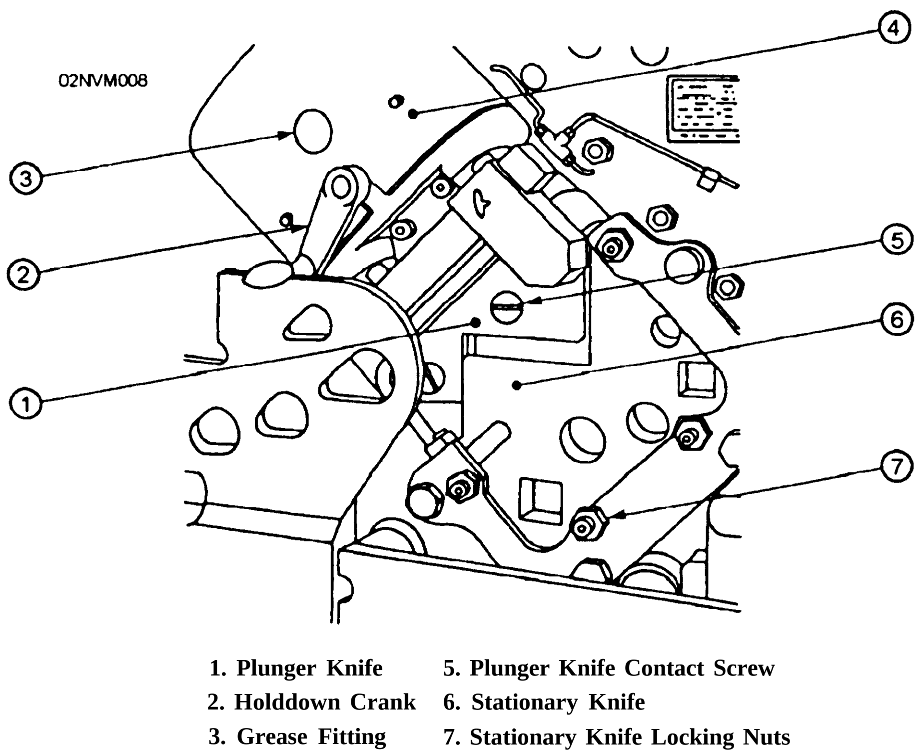
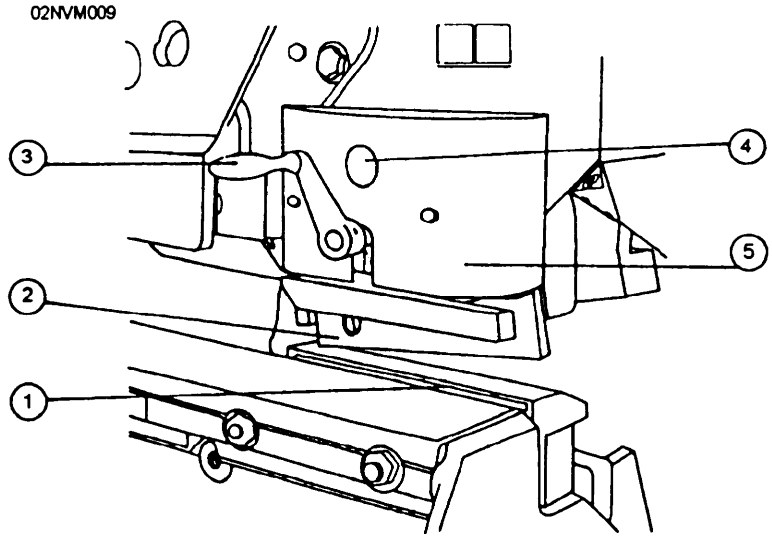


Figure 13-27.—Typical bar cutting work.



1. Plunger Knife
2. Holddown Crank
3. Grease Fitting
4. Plunger
5. Plunger Knife Contact Screw
6. Stationary Knife
7. Stationary Knife Locking Nuts

Figure 13-28.—Universal ironworker bar cutter.



1. Stationary Blade
2. Shear Blades
3. Holddown Adjusting Crank
4. Grease Fitting
5. Holddown

Figure 13-29.—Universal ironworker shear end.

Knife Clearances.—There are two sets of knife clearances for the stock cutting stations. For the bar cutter station (fig. 13-28), the proper knife clearance is 0.006 inch. The shearing station has a clearance of 0.002 inch to 0.003 inch. If shimming is required to maintain clearances, always shim the stationary knife, never the plunger (moveable) knife.

Operating Procedure.—To operate the bar cutting stations, proceed according to the following precautions and steps:

1 .Check the alignment and clearances of the cutting knives and adjust as necessary. Ensure that the knives are firmly fastened since they have a tendency to work loose during use.

2. Cycle the machine through one complete revolution to check the machine for binding or misalignment.

3. Place the workpiece between the cutting knives and adjust the holddowns to support the material being cut and prevent kickup.

4. Step on the foot pedal and hold the pressure until the knives have cut the workpiece.

COPING AND NOTCHING OPERATIONS.—Coping and notching operations are performed at individual stations on some machines and at the same station on other machines. Regardless of the physical arrangement of the machine, a punch and die are used to perform the cutting action. The notcher makes angle cuts of 90 degrees to permit the bending of angle shapes. The coper makes partial rectangularcuts into metal stock. On some machines the coper punch is also designed for notching. Figure 13-30 shows some of the typical notching and coping work and figures 13-31 and 13-32 show the notching and coping stations.

Knife Clearances.—There are two sets of knife clearances for the notching and coping stations if they are separate stations. If the stations are combined, there will only be one set of clearances. For the coping station (fig. 13-32) the proper knife clearance is l/16 inch. The notching station (fig. 13-31) has a clearance of l/64 inch. If shimming is required to maintain clearances, always shim the stationary knife, never the plunger (moveable) knife. On combined stations, the knife clearance is l/l6 inch.

Operating Procedure.—To operate the notching and coping stations, proceed according to the following precautions and steps:

1. Check the alignment and clearances of the cutting knives and adjust as necessary. Ensure that the