METAL-ARC WELDING AND CUTTING

CHAPTER 10

Hull Maintenance Technician

NAVEDTRA 14119

DEPARTMENT OF THE NAVY

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OCT 2015

Preface

The intent of this document is to provide some insight into the basics of the welding and cutting processes The intent is to help welding inspectors get a basic grasp of the vocabulary and concepts involved with welding and cutting processes.

With all that being said- this document is cut from Hull Maintenance Technician

NAVEDTRA 14119 DEPARTMENT OF THE NAVY written by the DEPARTMENT OF THE NAVY. What I did is go through the aforementioned document and "weed out" things that I deemed are not so relevant to what the average weld inspector needs to know about basic metallurgy

Bottom line- this document was written by the US Navy and I did some cutting to whittle it down to what is needed.

NONRESIDENT
TRAINING
COURSE

Hull Maintenance Technician

NAVEDTRA 14119

PREFACE

By enrolling in this self-study course, you have demonstrated a desire to improve yourself and the Navy. Remember, however, this self-study course is only one part of the total Navy training program. Practical experience, schools, selected reading, and your desire to succeed are also necessary to successfully round out a fully meaningful training program.

COURSE OVERVIEW: In completing this nonresident training course, you will demonstrate an understanding of course materials by correctly answering questions on the following: safety; ship repair; woodworking cuts and joints; small boat repair and deck coverings; tools and equipment; metallurgy; introduction to cutting and welding; oxyacetylene cutting and welding; brazing and braze welding; metal-are welding and cutting; nondestructive tests and inspection of welds; sheet metal layout and fabrication; structural steel fabrication; shop mathematics; piping systems; piping system repairs; and sewage systems.

THE COURSE: This self-study course is organized into subject matter areas, each containing learning objectives to help you determine what you should learn along with text and illustrations to help you understand the information. The subject matter reflects day-to-day requirements and experiences of personnel in the rating or skill area. It also reflects guidance provided by Enlisted Community Managers (ECMs) and other senior personnel, technical references, instructions, etc., and either the occupational or naval standards, which are listed in the *Manual of Navy Enlisted Manpower Personnel Classifications and Occupational Standards*, NAVPERS 18068.

THE QUESTIONS: The questions that appear in this course are designed to help you understand the material in the text.

VALUE: In completing this course, you will improve your military and professional knowledge. Importantly, it can also help you study for the Navy-wide advancement in rate examination. If you are studying and discover a reference in the text to another publication for further information, look it up.

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Published by
NAVAL EDUCATION AND TRAINING
PROFESSIONAL DEVELOPMENT
AND TECHNOLOGY CENTER

NAVSUP Logistics Tracking Number
0504-LP-026-7820

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

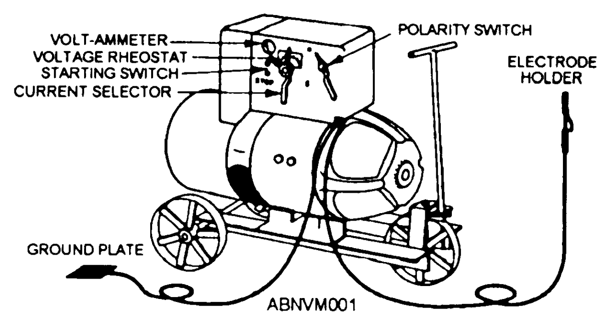


Figure 10-1.—Variable-voltage dc generator welding unit (dual-control type).

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

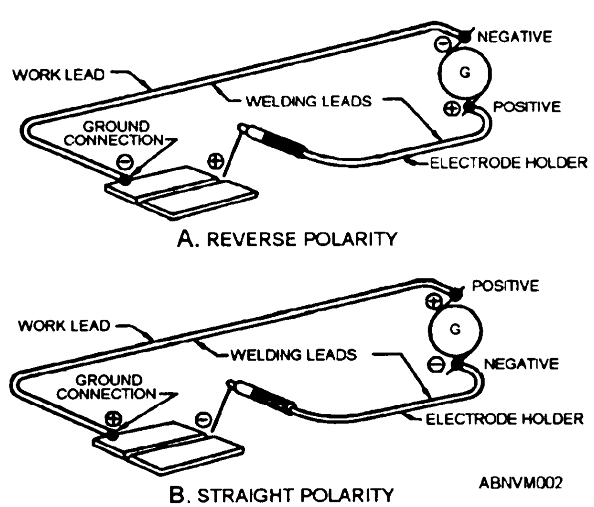


Figure 10-2.—Reverse polarity and straight polarity.

polarity (electrode positive), the greatest amount of heat is concentrated on the electrode side of the arc.

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.

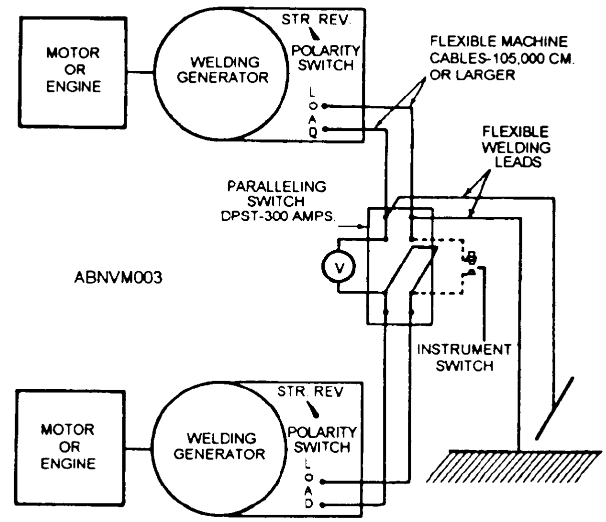


Figure 10-3.—Paralleling connection for a single-operator welding generator.

- 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.

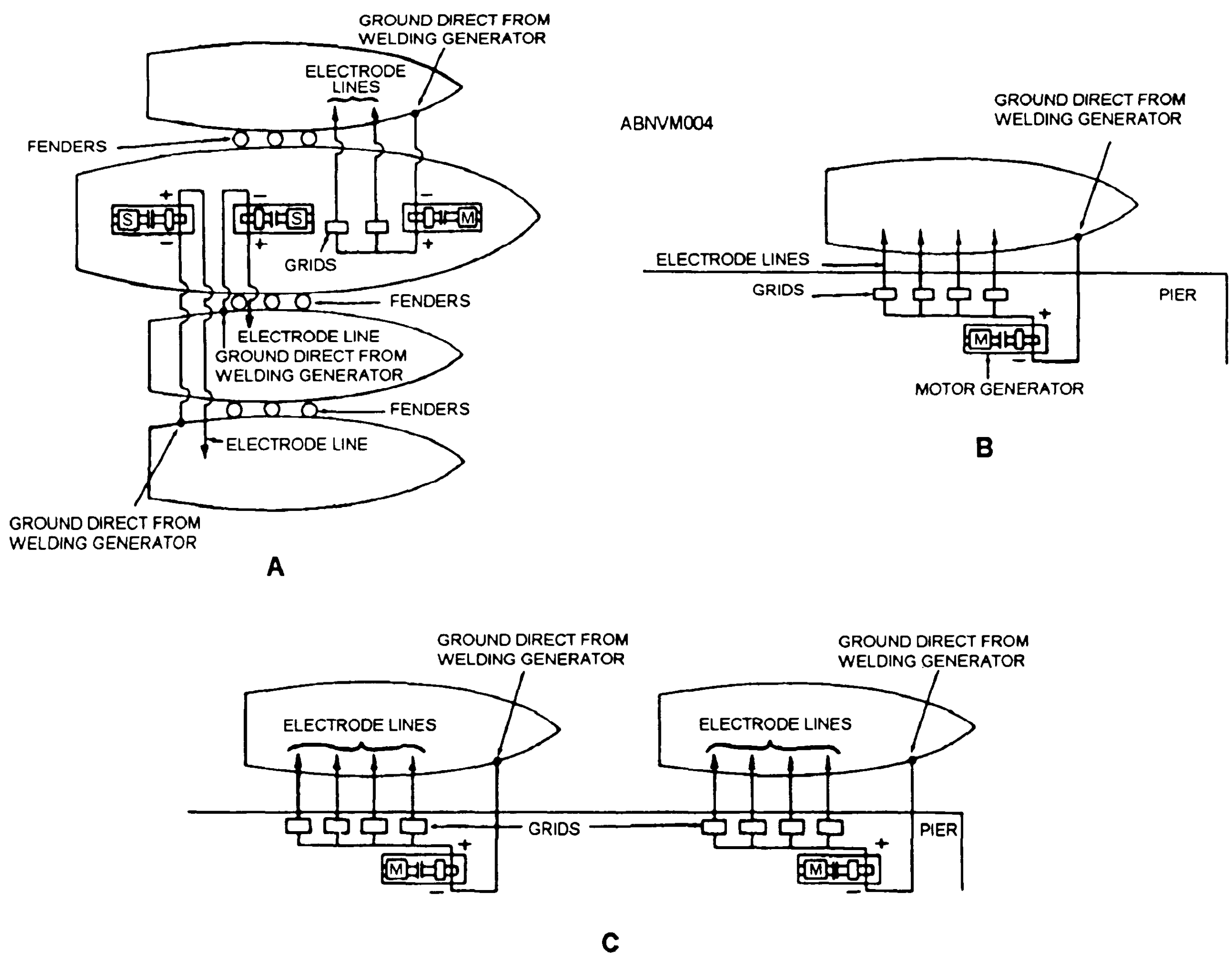


Figure 10-4.—Correct grounding procedure for metal-arc welding. (A) Arrangement for ships afloat. (B) Arrangement for a single ship at a pier. (C) Arrangement for two ships at a pier.

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 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.

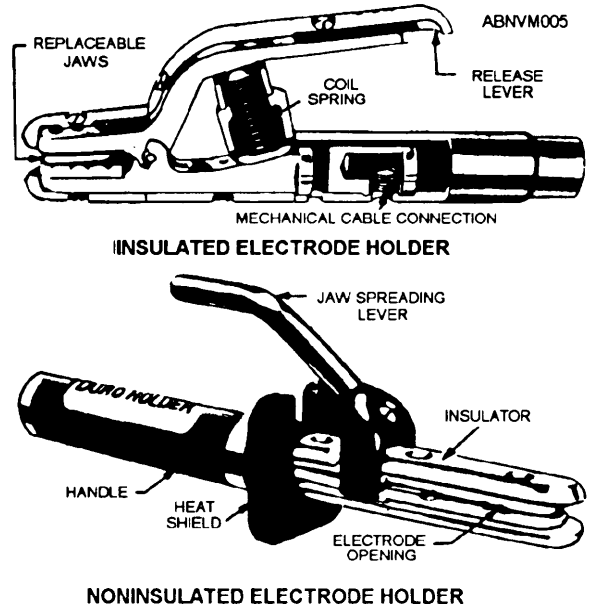


Figure 10-5.—Electrode holders.

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.

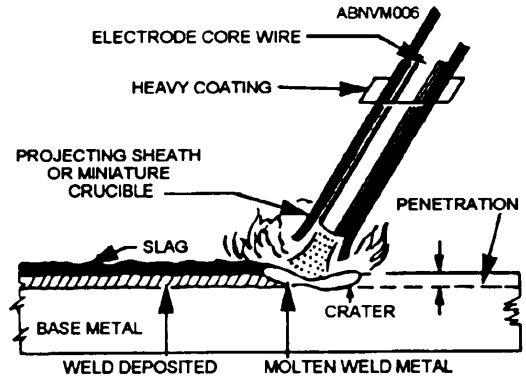


Figure 10-6.—Welding with a heavy coated electrode.

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

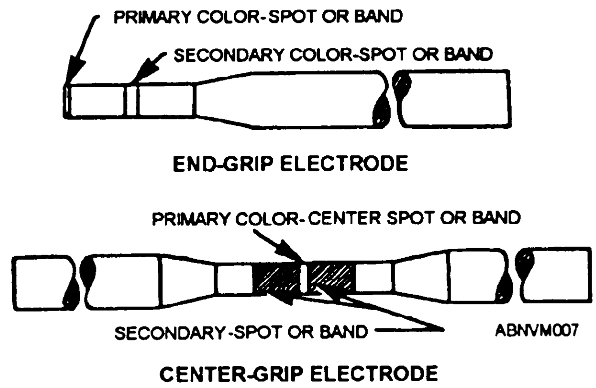


Figure 10-7.—Electrode color markings.

Table 10-2.—Color Markings For Electrode Identification

Spot or secondary color	Primary colors: Mild steel and low alloys (See Note I): All position	Horizontal fillets & flat	Flat position only	Special purpose	Hard surfacing (See Note II)
	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.

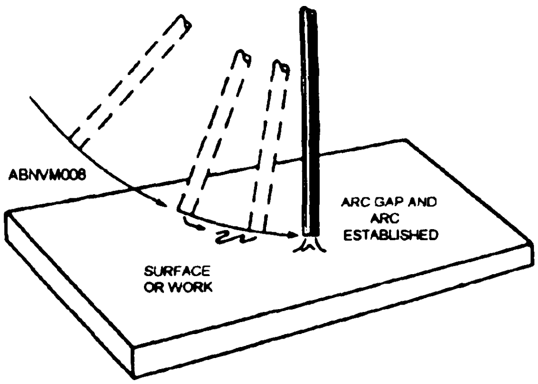


Figure 10-8.—Striking or brushing method of starting the arc.

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.

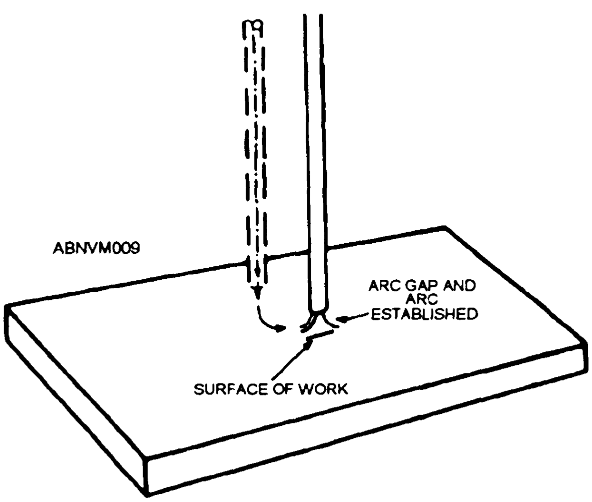


Figure 10-9.—Tapping method of starting the arc.

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

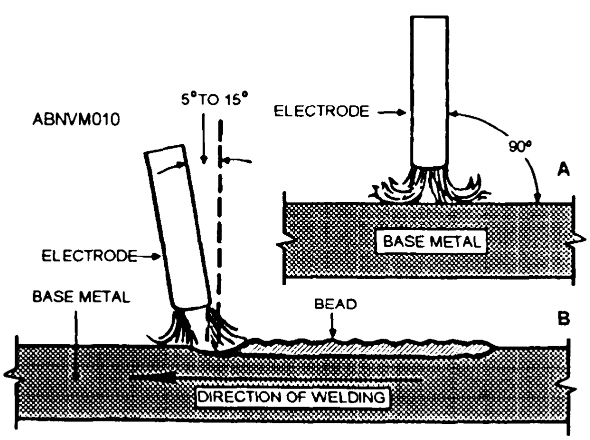


Figure 10-10.—Position of the electrode in making a bead in the flat position.

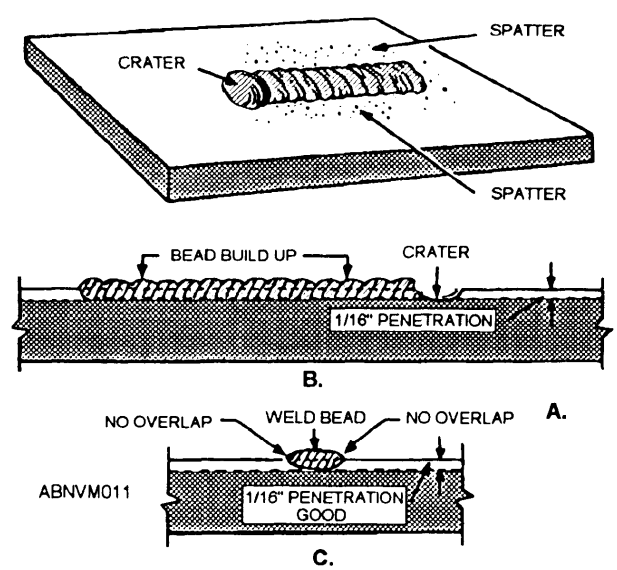


Figure 10-11.—Properly made weld beads (flat position).

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.

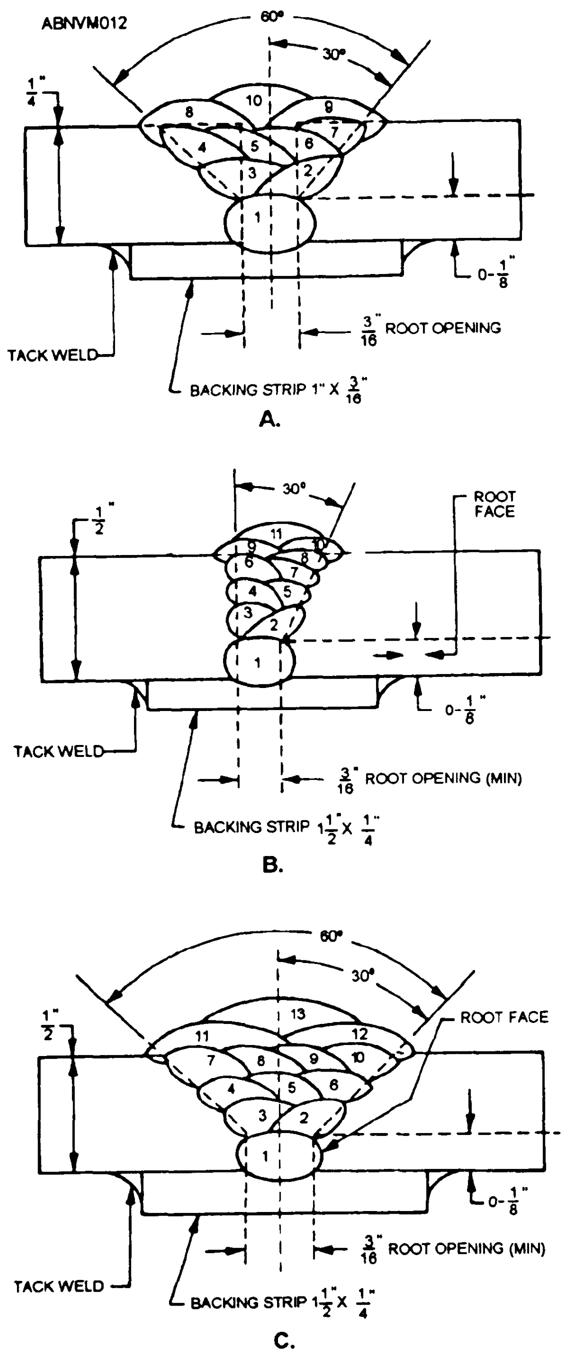


Figure 10-12.—Use of backing strips in welding butt joints.

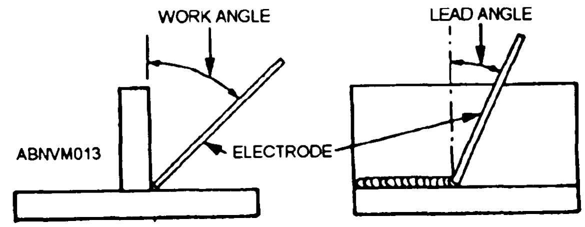


Figure 10-13.—Electrode work angle and lead angle.

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

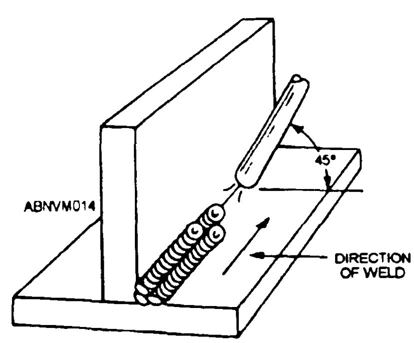


Figure 10-14.—Fillet welding a T-joint (flat position).

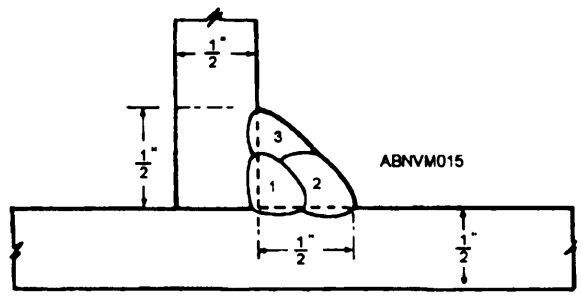


Figure 10-15.—Order of making stringer beads for a T-joint in heavy plate.

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.

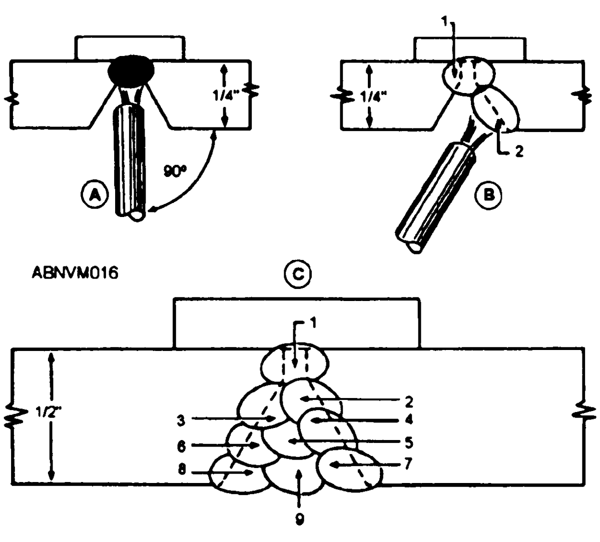


Figure 10-16.—Bead sequence and electrode angle for welding a butt joint in the overhead position.

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

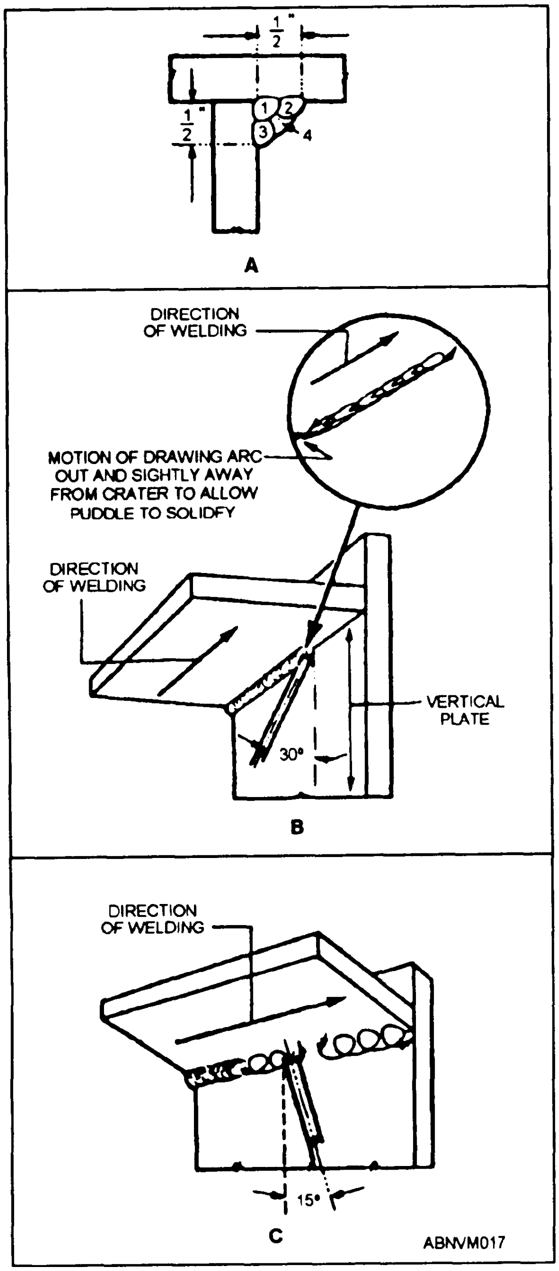


Figure 10-17.—Fillet welding of a T-joint in the overhead position.

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.

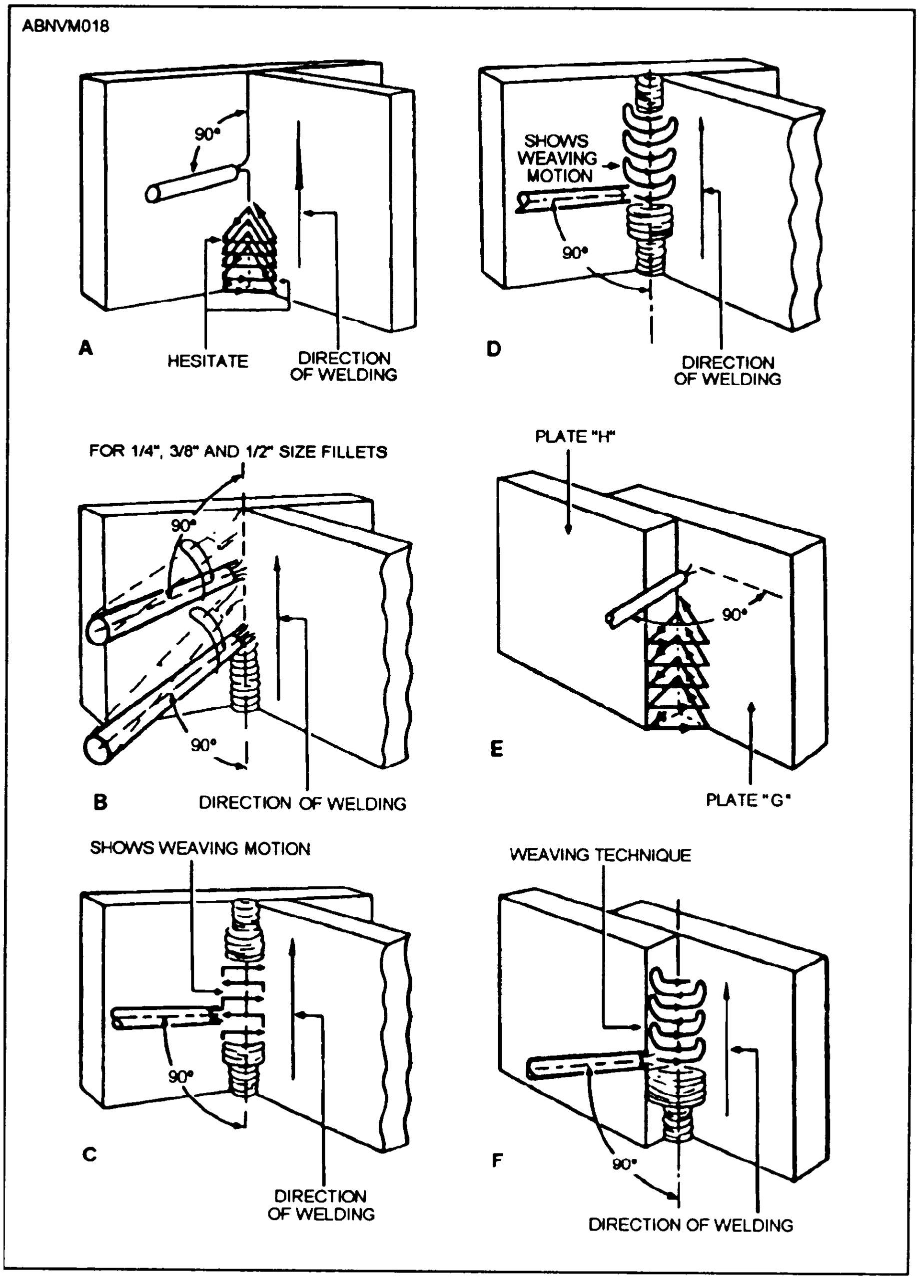


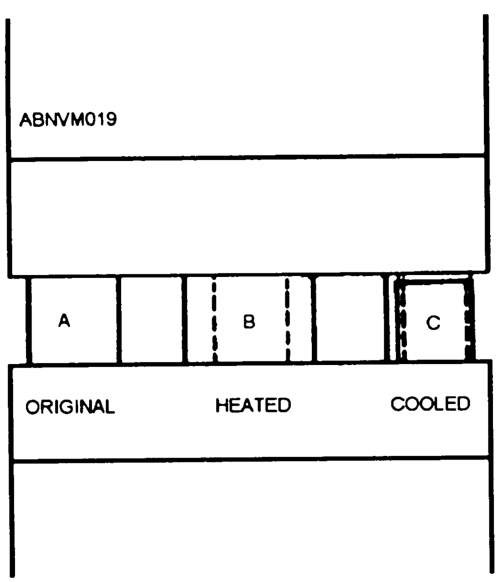
Figure 10-18.—Welding in the vertical position.

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)



NOTE: DOTTED LINES SHOW ORIGINAL SIZE.

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.

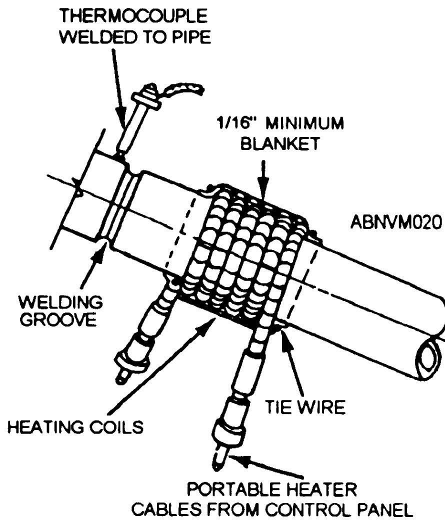


Figure 10-20.—Electric induction coils set up for preheating pipe.

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

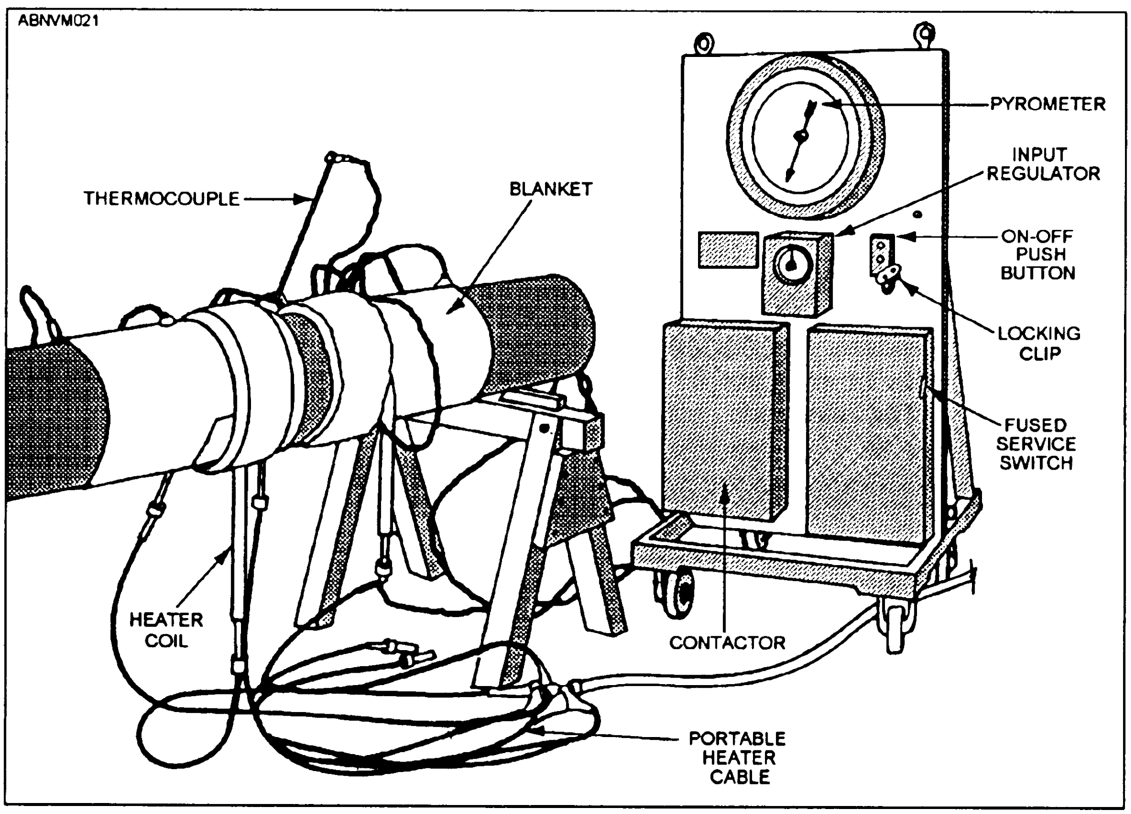


Figure 10-21.—Postheating welded pipe with electric induction coil equipment.

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

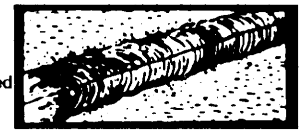
WHY

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

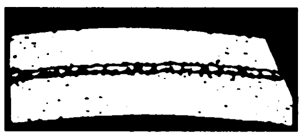
WHY

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



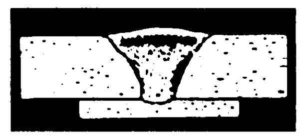
WHY

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 rapidly
3. Avoid excessive space between parts
4. Preform parts before welding
5. Use proper sequence
6. Clamp or tack parts properly -back up to cool
7. Adopt a proper welding procedure
8. Use high speed, moderate penetration process

poor fusion



WHY

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

WHAT TO DO

1. Adjust electrode to match joint
2. Weave must be sufficient to melt sides of joint
3. Select proper 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

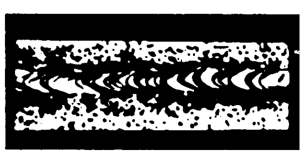
WHY

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.

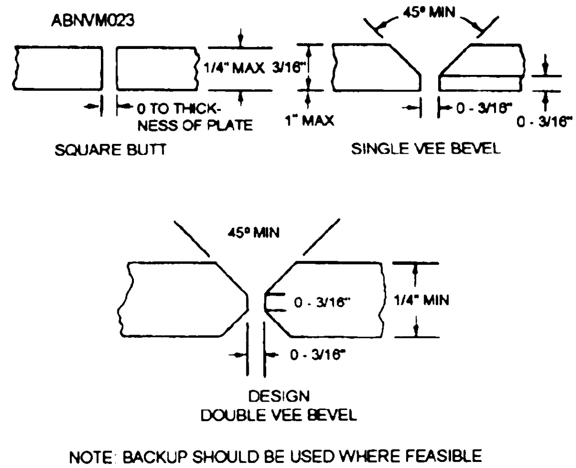


Figure 10-22.—Recommended joint designs for common thickness of plate.

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

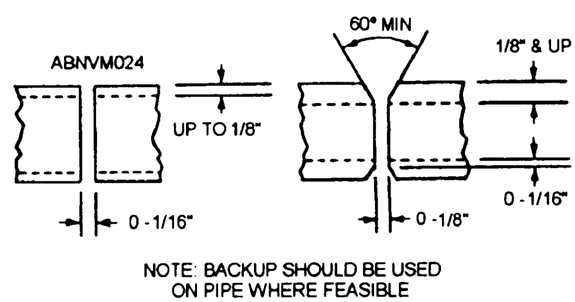


Figure 10-23.—Recommended joint design for pipe.

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.

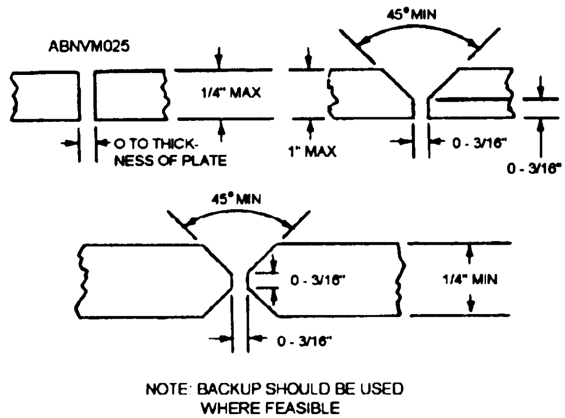


Figure 10-24.—Single-vee and double-vee groove welds.

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.

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

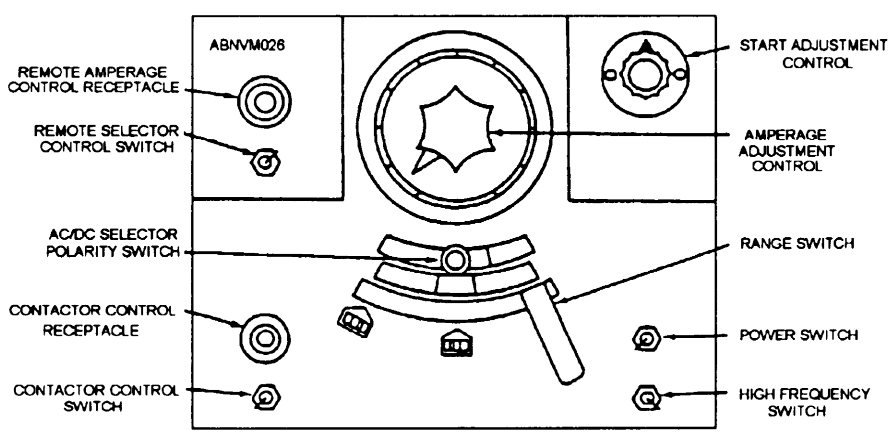


Figure 10-25.—Equipment for GTA welding.

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.

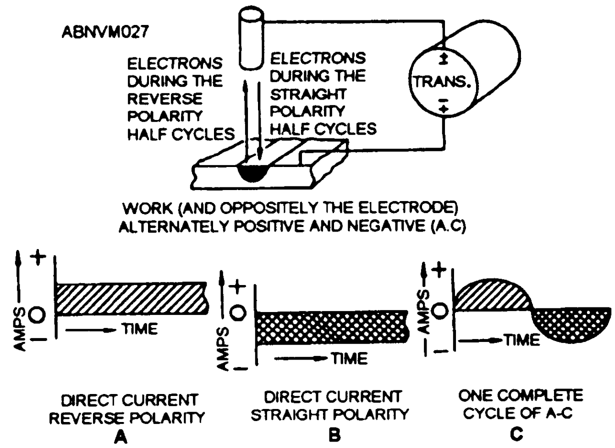


Figure 10-26.—Ac welding as a combination of dc straight and reverse polarity welding.

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

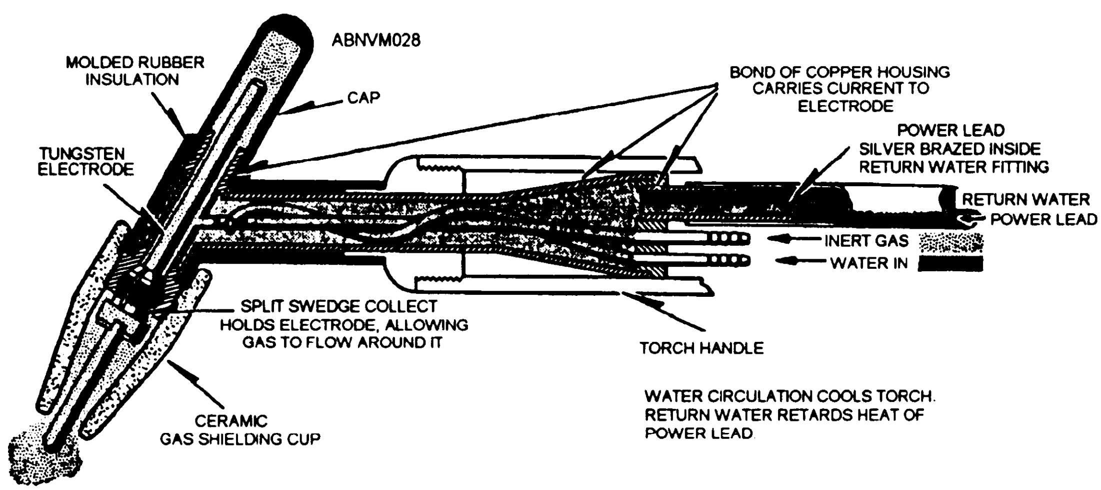


Figure 10-27.—Sectional sketch of a GTA water-cooled torch.

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.

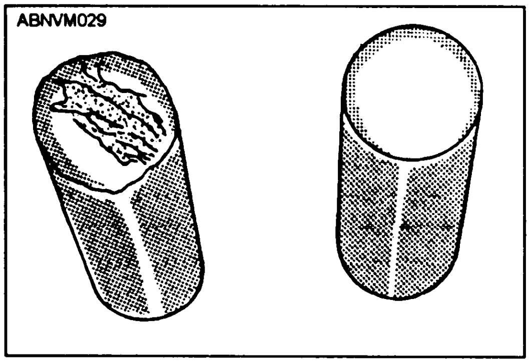


Figure 10-28.—Contaminated and good tungsten electrodes.

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.

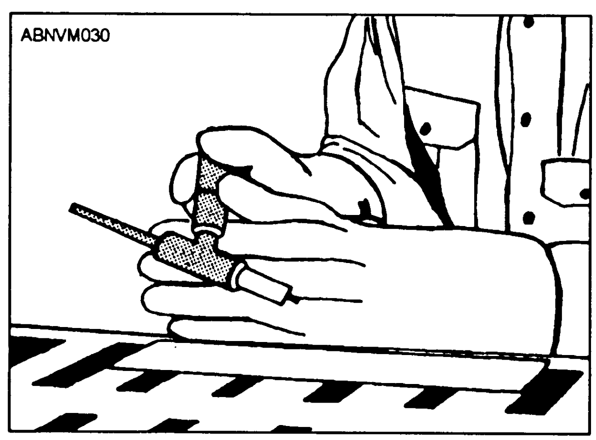


Figure 10-29.—Torch position for the starting swing to strike the arc.

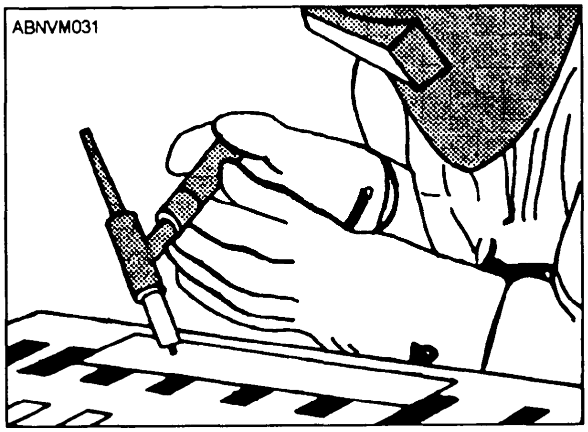


Figure 10-30.—Position of the torch at the end of the swing when the arc strikes.

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 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.

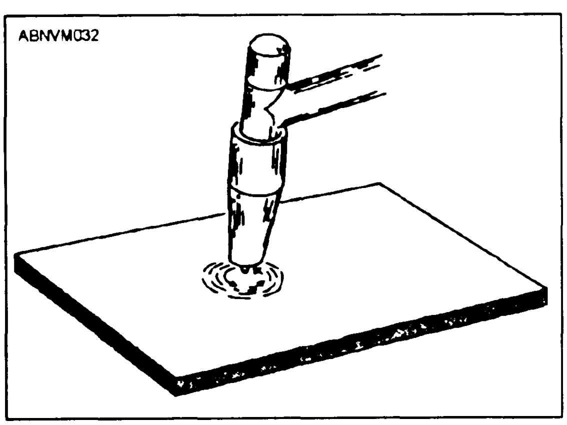


Figure 10-31.—Forming a molten puddle with a GTA torch.

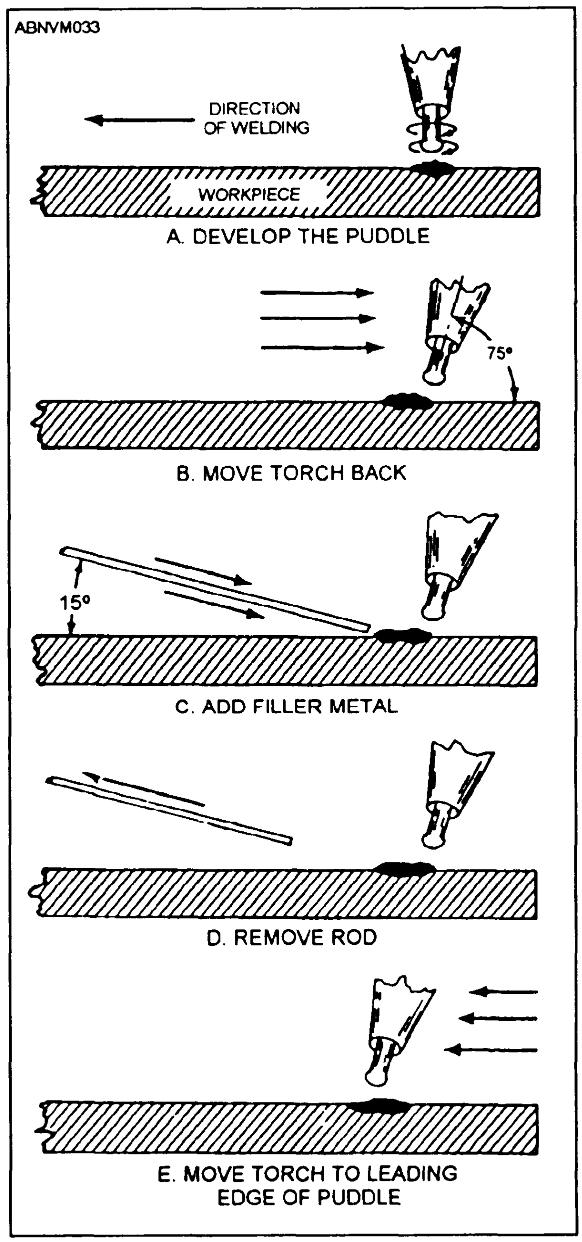


Figure 10-32.—Addition of filler metal (flat position).

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.

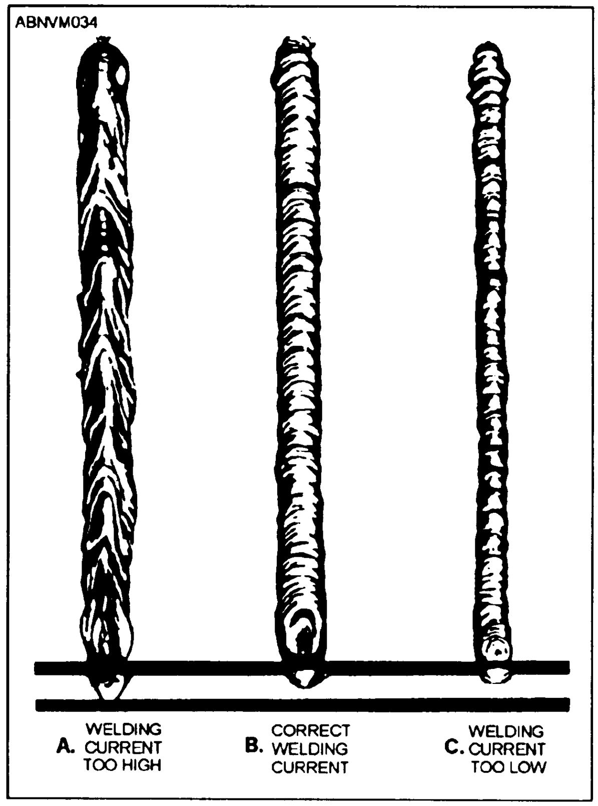


Figure 10-33.—Comparative GTA weld beads as determined by electrical current.

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.

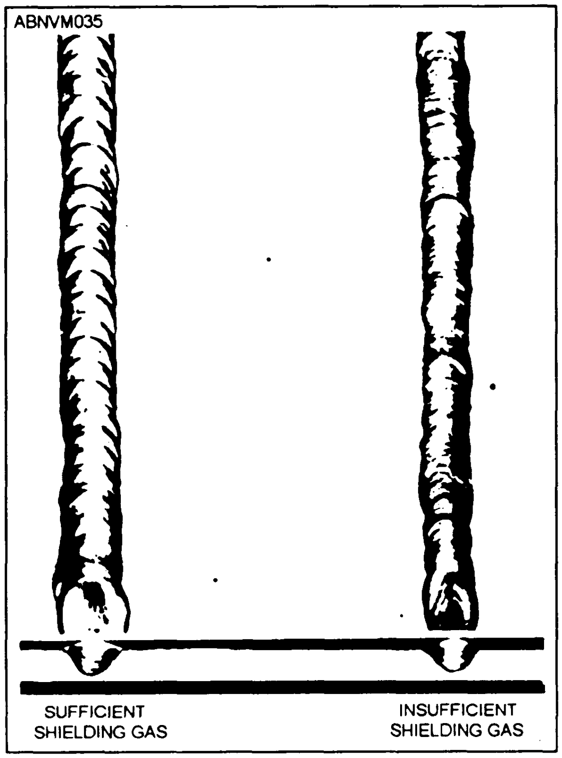


Figure 10-34.—Comparative GTA weld beads as determined by shielding gas.

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.

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

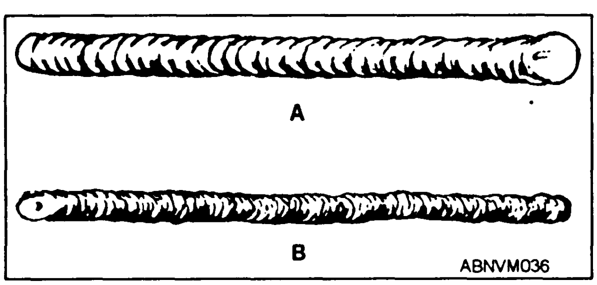


Figure 10-35.—Comparative GTA weld beads with filler rod manipulation.

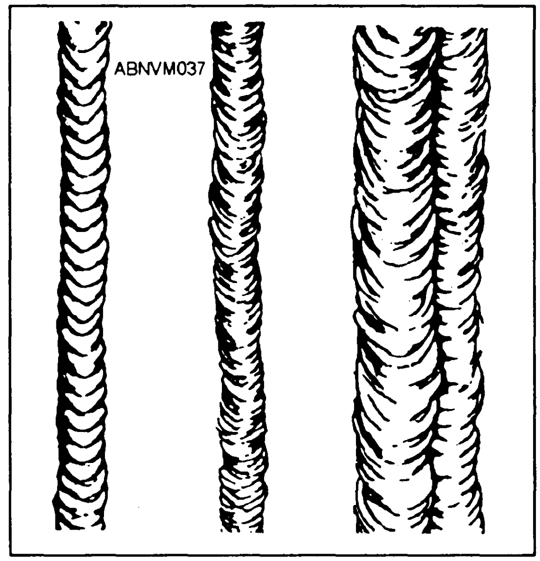


Figure 10-36.—Visual inspection standards for GTA welds.

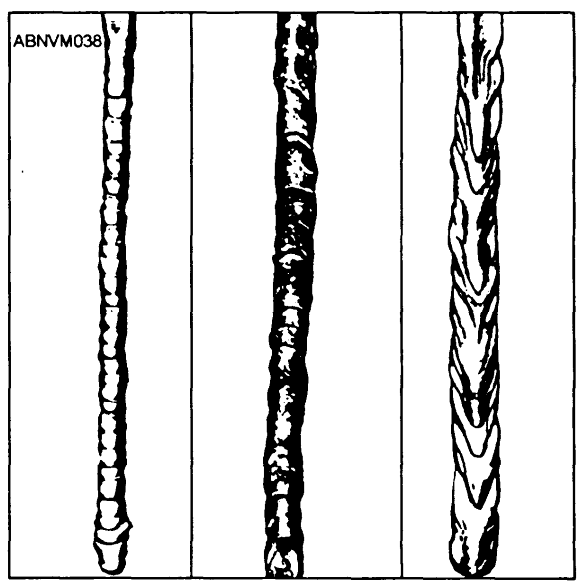


Figure 10-37.—Unacceptable GTA welds.

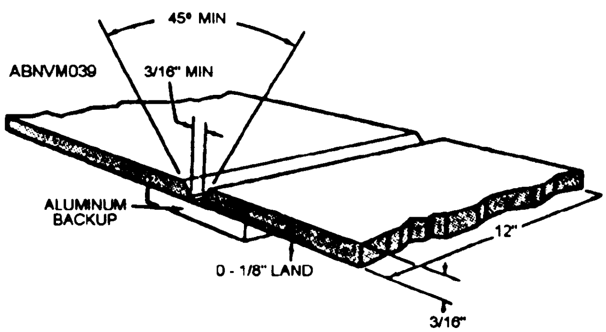


Figure 10-38.—Joint design flat-position single-pass butt welds in aluminum sheet.

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

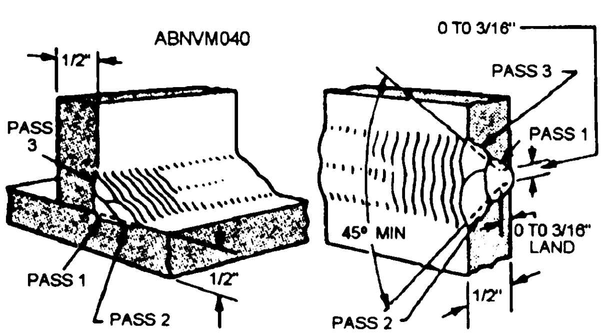


Figure 10-39.—Jolt design and weld pass sequence horizontal-position multipass fillet and butt welds.

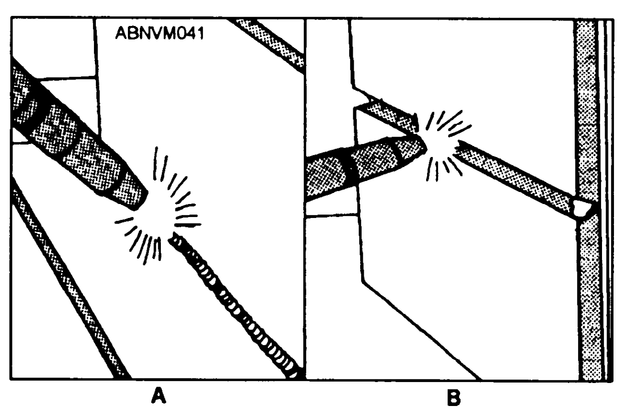


Figure 10-40.—Welding a fillet and butt joint in the horizontal position.

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.

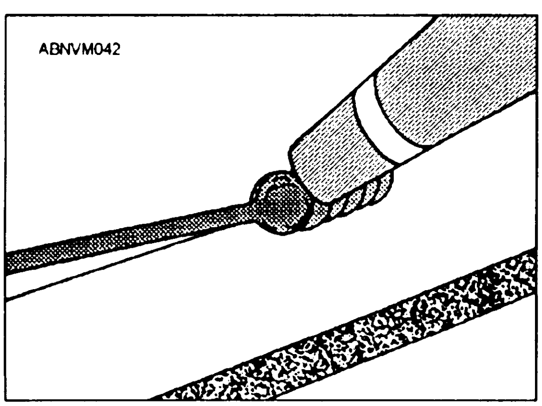


Figure 10-41.—Correct position of the welding torch and proper addition of the tiller metal to form a weld pool.

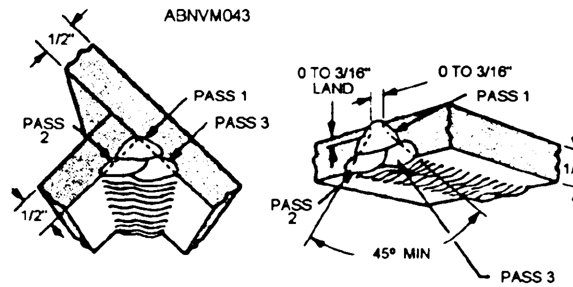


Figure 10-42.—Joint design and weld pass sequence vertical-position multipass fillet and butt welds.

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

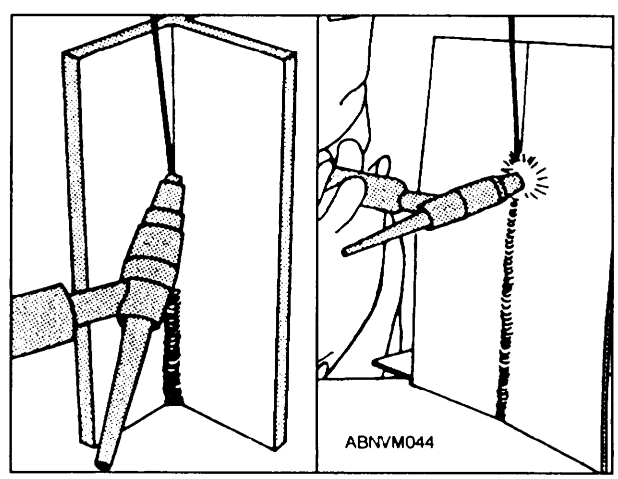


Figure 10-43.—Butt and fillet welds made in the vertical position.

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.

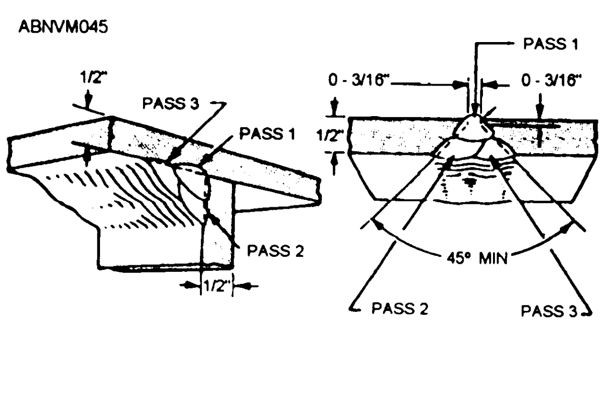


Figure 10-44.—Joint design and weld pass sequence overhead-position multipass fillet and butt welds.

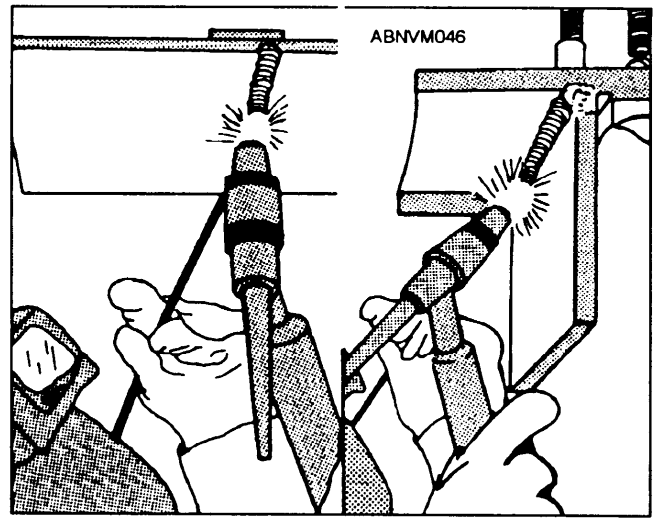


Figure 10-45.—Making overhead multipass groove and fillet welds.

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.

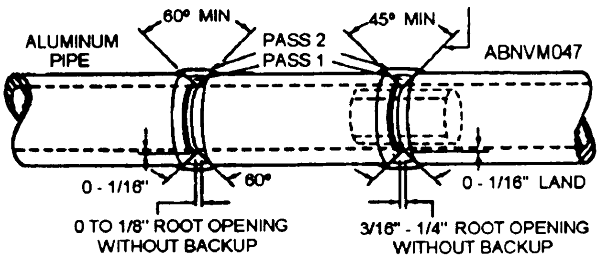


Figure 10-46.—Joint design and weld pass sequence horizontal fixed-position multipass (GTA) welding.

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

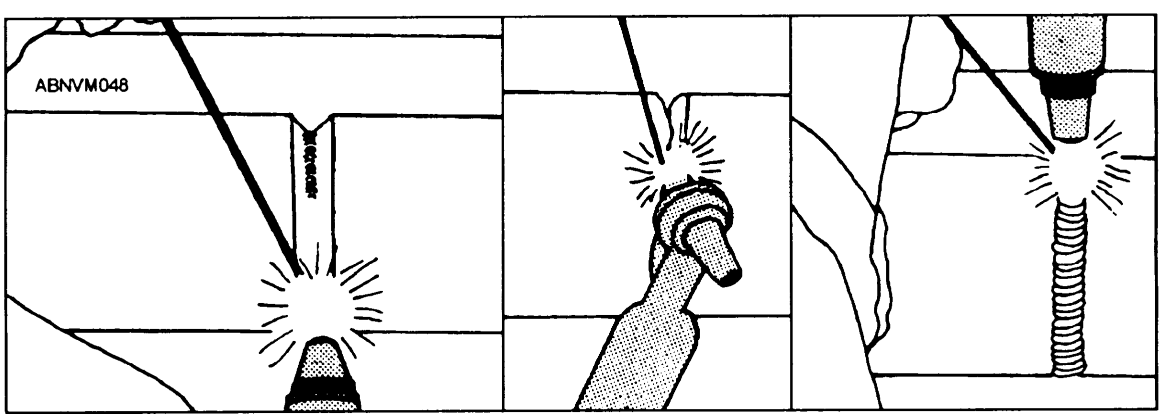


Figure 10-47.—Techniques of torch and filler rod handling for tubular sections.

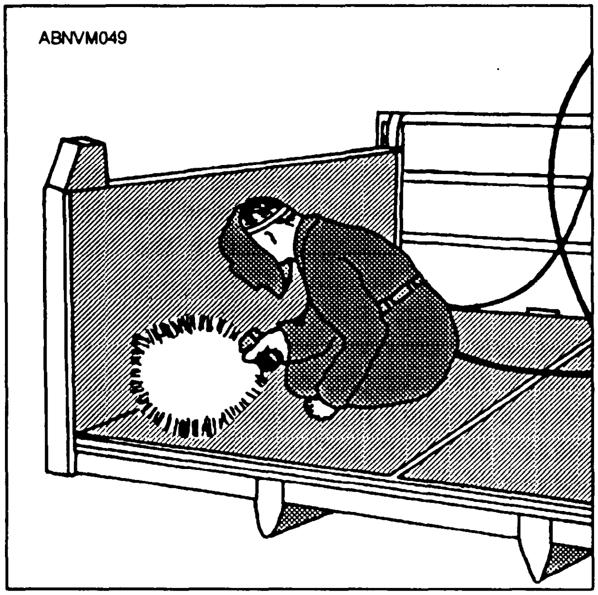


Figure 10-48.—CMA welding aluminum truck bed.

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

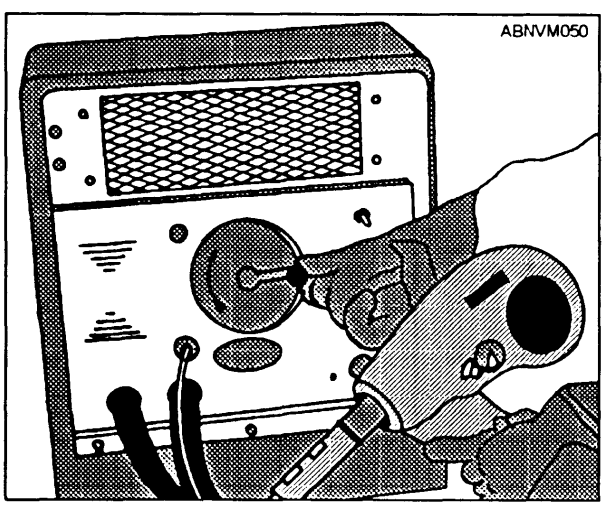


Figure 10-49.—GMA welding equipment (AIRCO products).

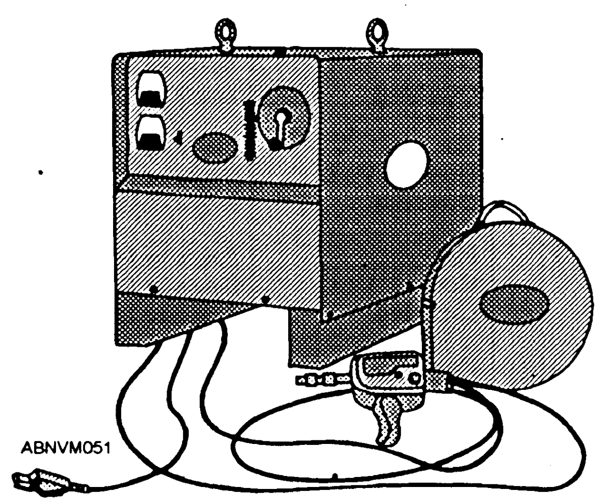


Figure 10-50.—Heavy-duty GMA welding equipment (AIRCO products).

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/16	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 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.

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.

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

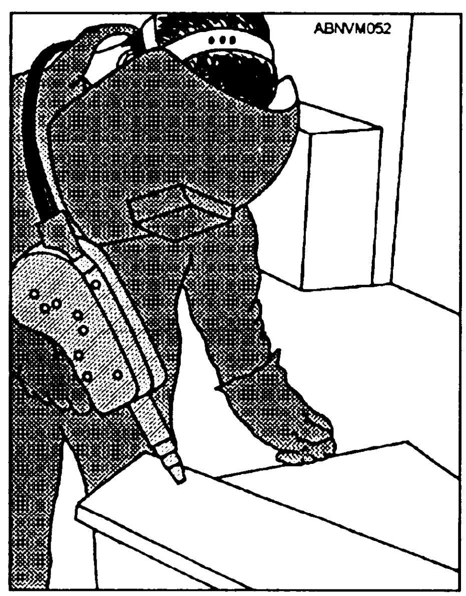


Figure 10-51.—Positioning the GMA gun prior to welding.

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

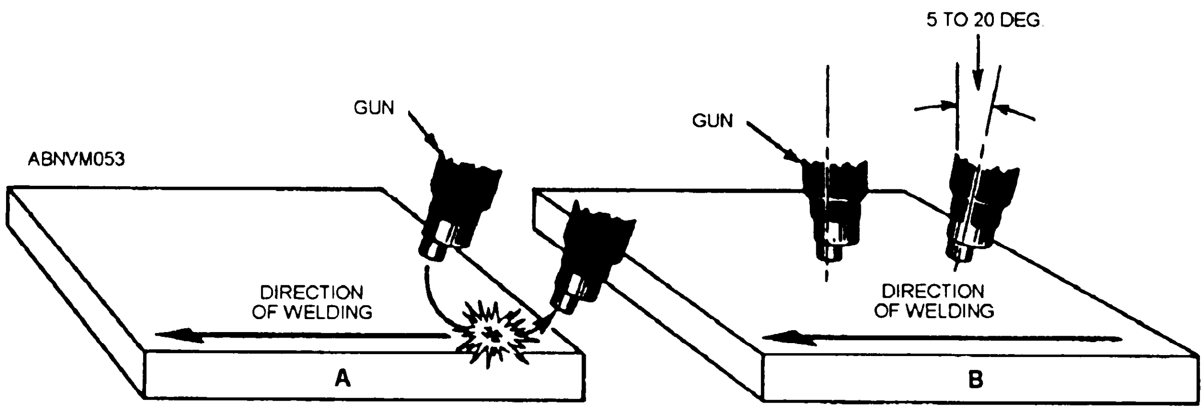


Figure 10-52.—GMA welding. (A) Striking the arc. (B) Gun angle.

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

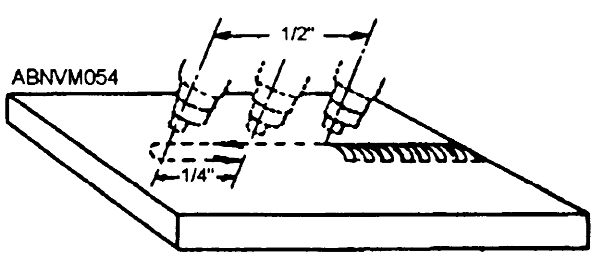


Figure 10-53.—Reciprocating technique for GMA welding.

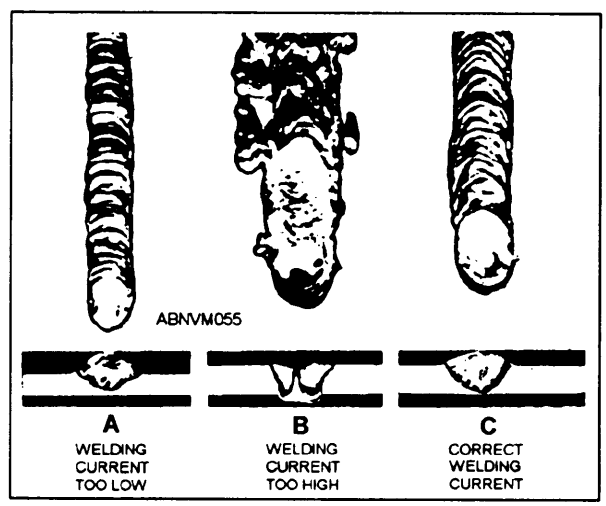


Figure 10-54.—Weld bead characteristics determined by welding current.

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.

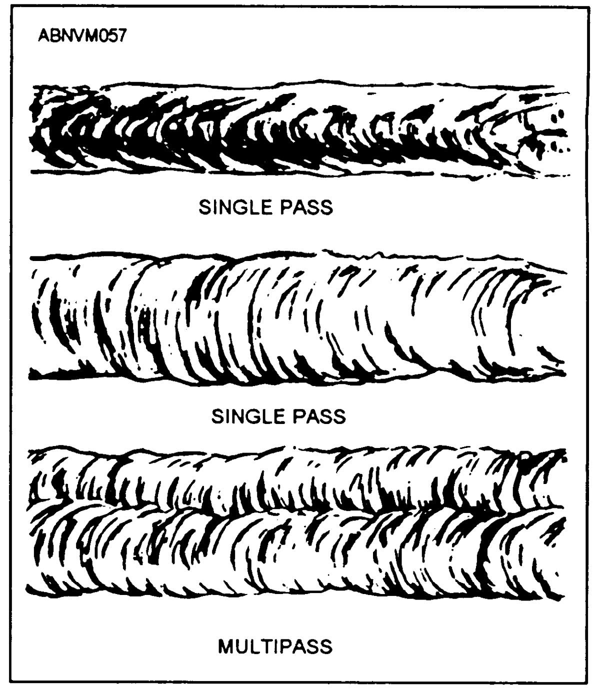


Figure 10-56.—Acceptable single-pass and multipass GMA welds.

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

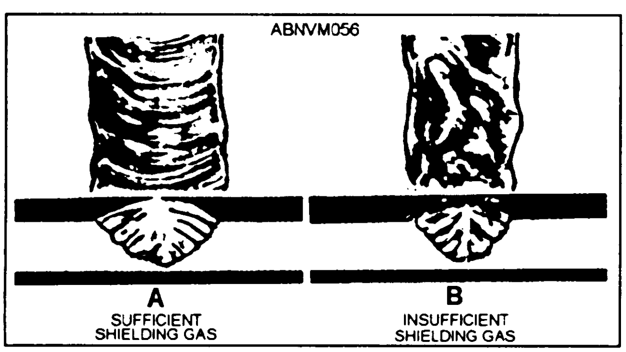


Figure 10-55.—Weld bead characteristics determined by shielding gas.

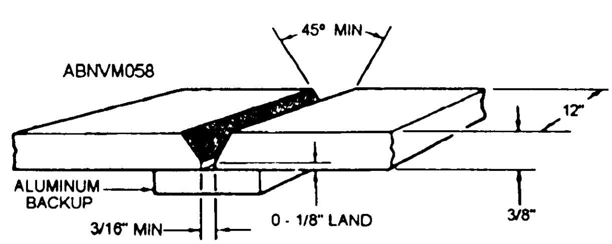


Figure 10-57.—Joint design flat-position, single-pass butt welds in aluminum plate.

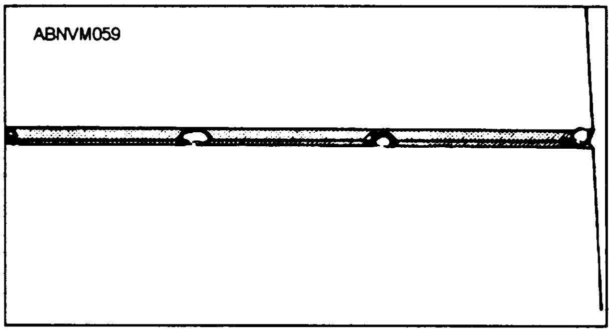


Figure 10-58.—Plates tack-welded and aligned for GMA welding.

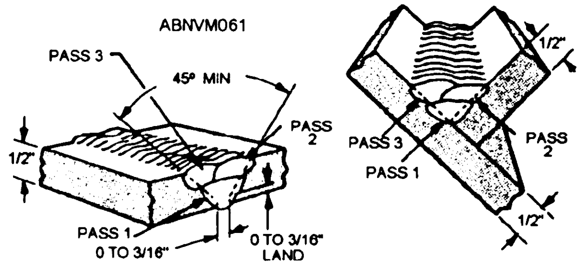


Figure 10-60.—Joint design and weld pass sequence flat-position multipass butt welds in aluminum plate.

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.

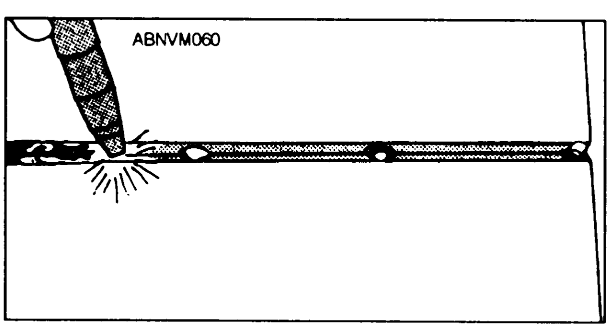


Figure 10-59.—Moving the welding gun forward at the proper angle.

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

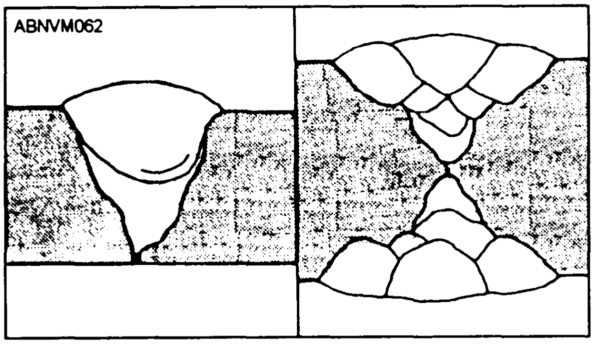


Figure 10-61.—Gross section of two welds showing poor root fusion and too heavy a root face.

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.)

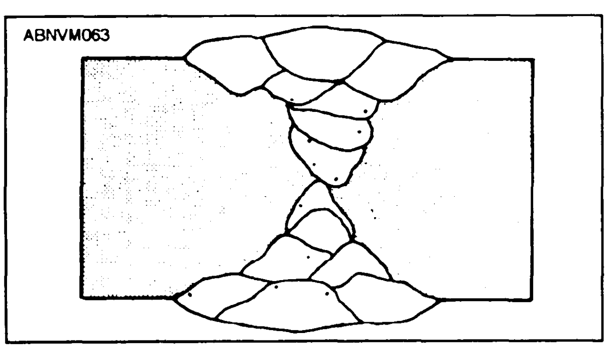


Figure 10-62.—Grass porosity in a multipass butt weld.

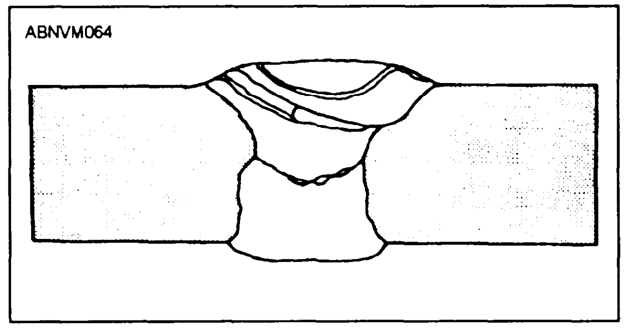


Figure 10-63.—Voids in multipass butt welds.

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

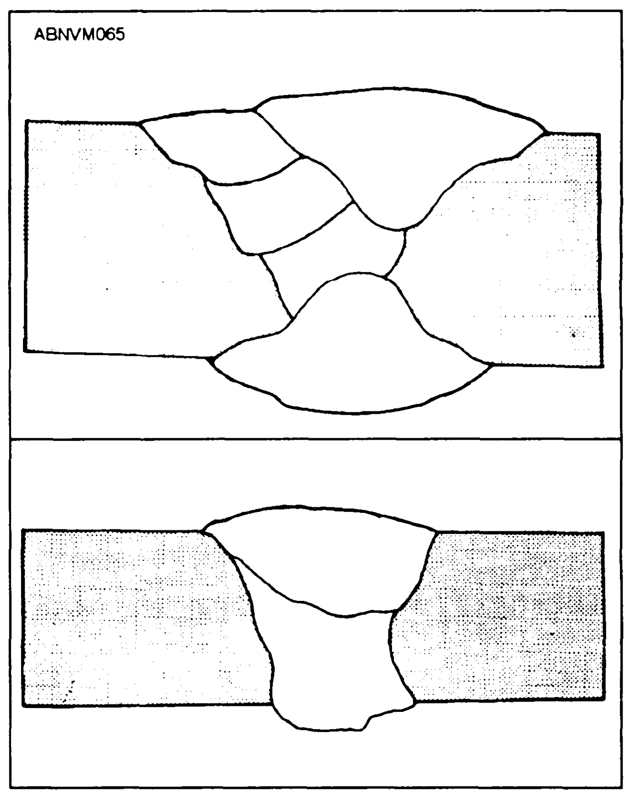


Figure 10-64.—Cross section of good multipass GMA welds free from defects.

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.

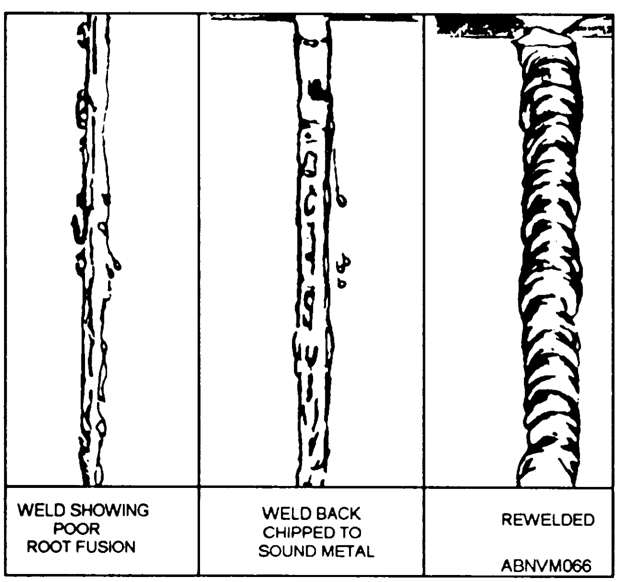


Figure 10-65.—Chipping out the fused back side of a joint to make a high-quality weld.

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.

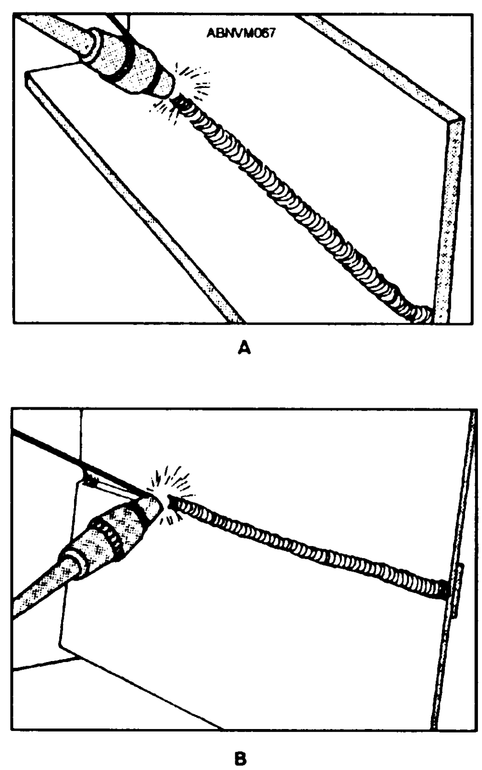


Figure 10-66.—Welding a fillet and butt joint in the horizontal position.

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

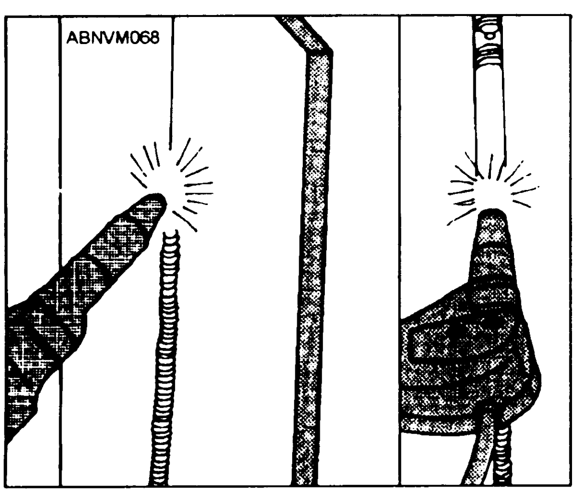


Figure 10-67.—Welding fillet and butt joints in the vertical position.

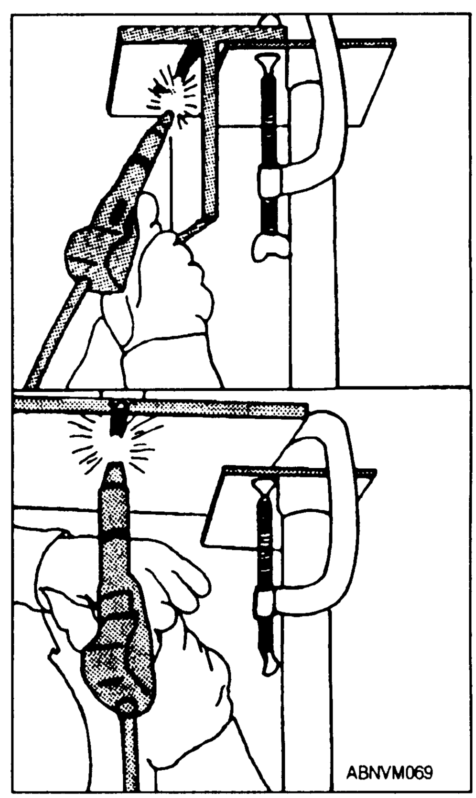


Figure 10-68.—Welding overhead multipass fillet and butt welds.

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.

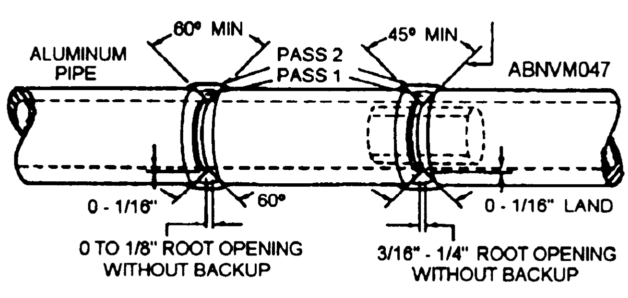


Figure 10-69.—Joint design and weld pass sequence horizontal fixed-position multipass GMA welding.

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

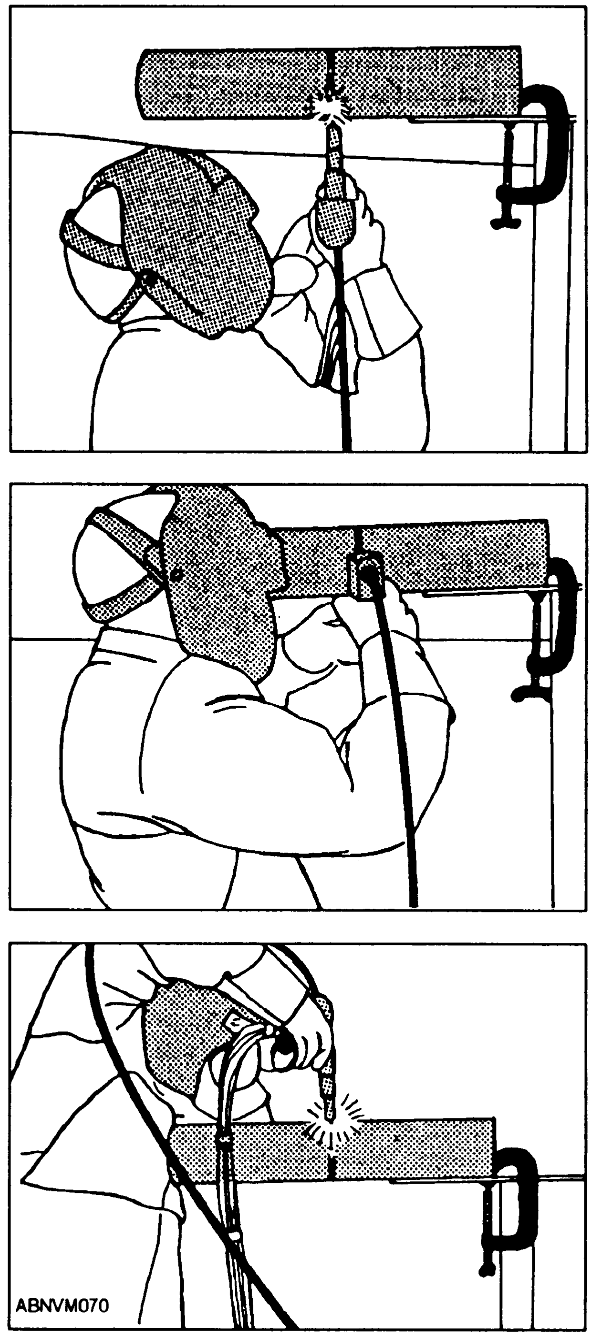


Figure 10-70.—CMA gun manipulation for welding pipe in the horizontal fixed position.

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

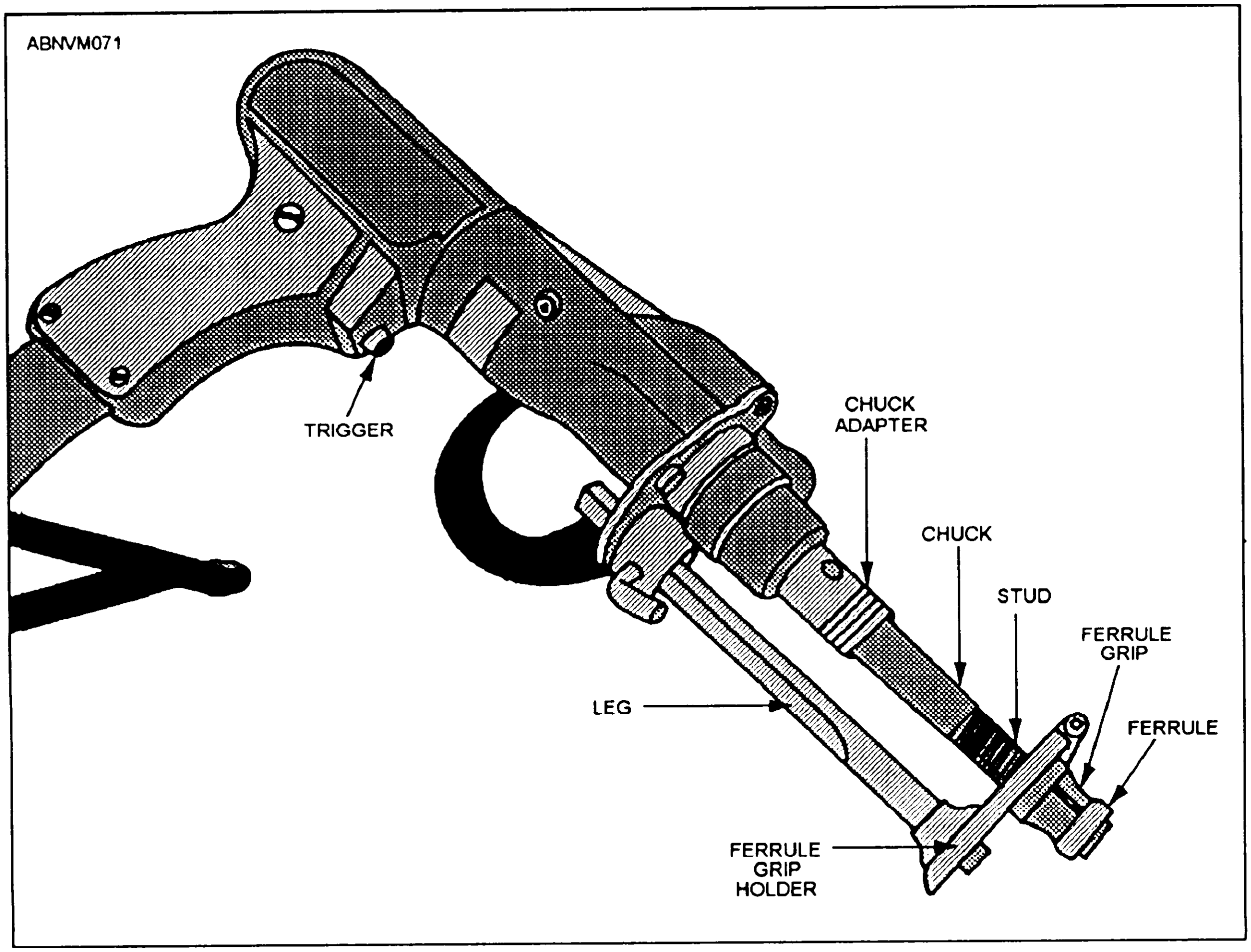


Figure 10-71.—Stud welding gun.

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

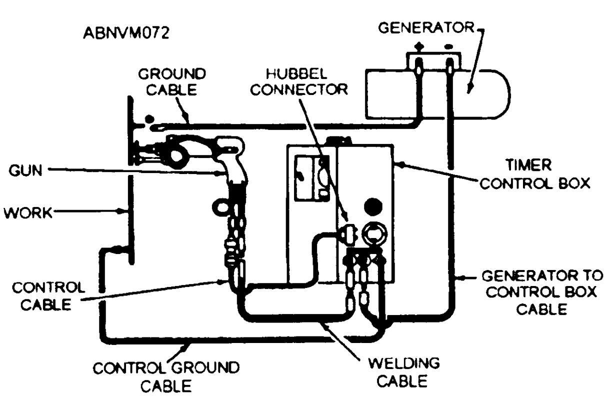


Figure 10-72.—Connection diagram for stud welding.

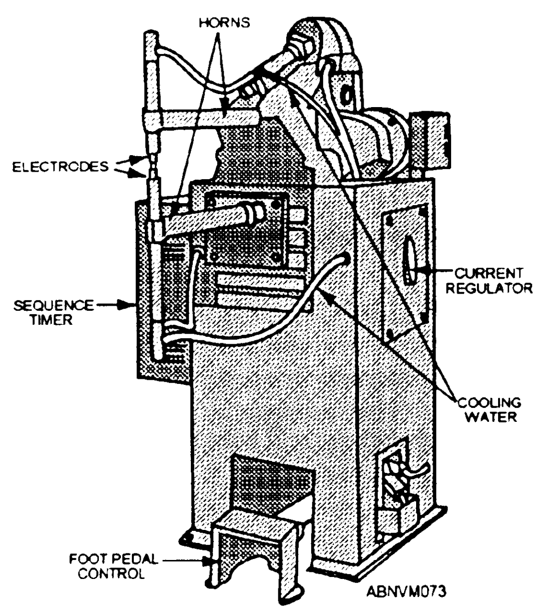


Figure 10-73.—Spot welding machine.

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

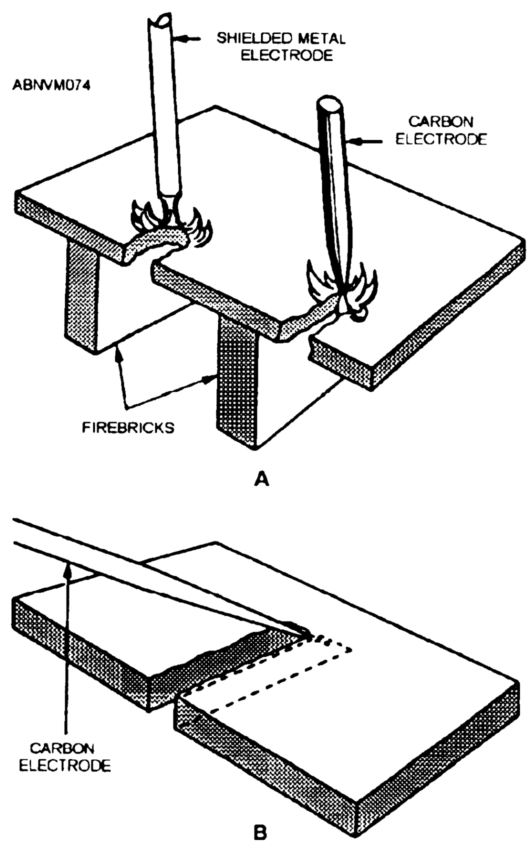


Figure 10-74.—Techniques for arc cutting. (A) Thin plate. (B) Heavy plate.

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

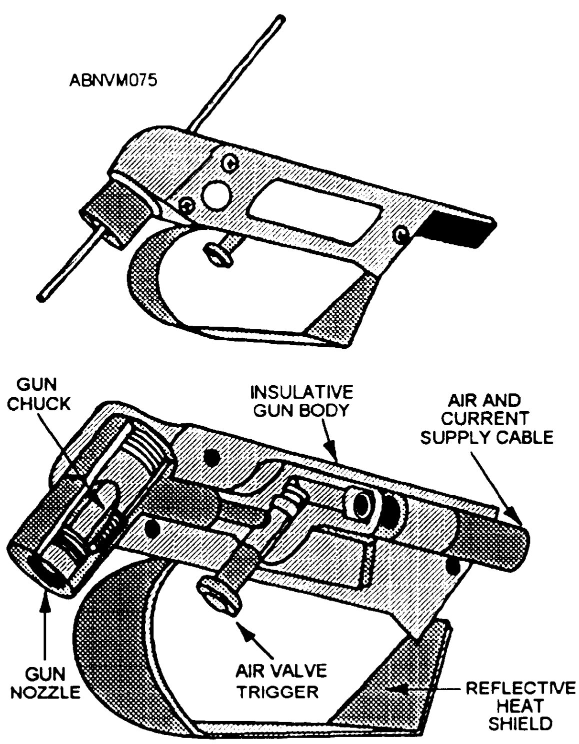


Figure 10-75.—Air carbon-arc gun.

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.

C.4.5 Submerged Arc Welding (SAW)

The submerged arc process is also very similar to GMAW; the major difference is the shielding. GMAW has a continuous solid wire consumable electrode with externally supplied gas shielding. Submerged arc welding utilizes a continuous solid wire consumable electrode with externally supplied flux shielding. The flux is granulated material which completely covers the wire, arc, and weld pool, thus the name "submerged arc". That portion of the granular flux closest to the molten weld pool, melts, covers the weld puddle and solidified weld deposit, solidifies, and functions as an insulator to prevent the weld from cooling too rapidly. Normally a flux recovery system recirculates the unfused granular flux.

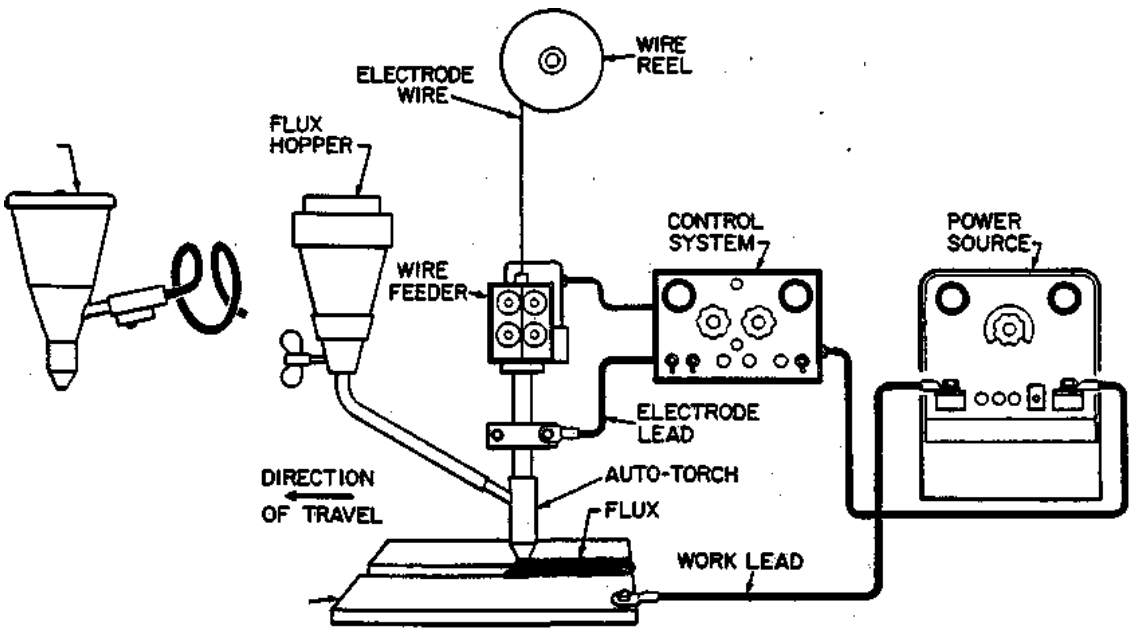


Fig. 12. SUBMERGED ARC WELDING PROCESS

Submerged-arc welding is adaptable to both semiautomatic and fully mechanized operation, although the latter is more widely used. Figure 5 illustrates the needed equipment and how this process works.

There are several characteristics which make SAW a very attractive process. One is that there is no visible arc so the welder does not need to wear dark welding lenses. (Some would argue that covering the arc with flux also makes it very difficult to tell where the wire is going). Another is the high quality of the weld. Typically, SAW welds are very clean and have good mechanical properties.

The most attractive characteristic of Submerged Arc Welding is the deposition rate. Deposition rates up to 10 times that of stick electrode welding (SMAW) makes SAW the most -productive welding process available. These high deposition rates are because of high current densities (the amount of amperage applied to a given diameter of wire.

To achieve even higher deposition rates, two or more electrodes can be fed simultaneously into the same joint. The multiple electrodes can be feeding into the same puddle, or spaced far enough apart to permit the weld puddle created by each electrode-wire to solidify independently. The latter method is often referred to as "tandem-arc", and enables a multiple pass weld to be deposited in one "pass". This tandem principle is sometimes employed when welding the circumferential joints of large tanks in a horizontal welding position. The two welding arcs are maintained on opposite sides of the tank shell, one trailing the other far enough to achieve the desired weld deposit configuration, but close enough to benefit from the preheat of the leading welding arc.

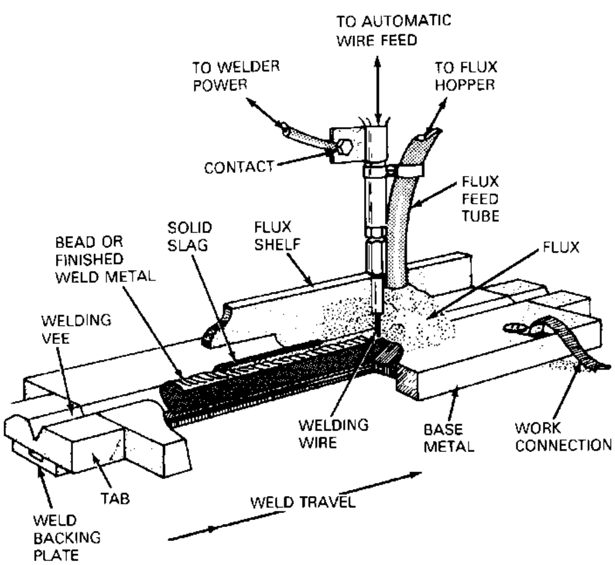


Fig. 13. SUBMERGED ARC WELDING PROCESS

SAW may be used with either AC or DC (straight or reverse polarity). DC is customarily used with the higher current values when welding on thicker sections. DCRP provides maximum penetration and better control over the configuration of the weld bead. DCSP provides a higher deposition rate.

Submerged arc electrodes are generally supplied as bare solid wires although there are now composite electrodes on the market. Electrodes are produced in various ferrous alloy compositions, ranging from plain carbon steel to special high-alloy steel and stainless steel.

Fluxes used in SAW are minerals in granular form, usually composed of oxides of manganese or silicon, and other slag-forming compounds. They are selected to produce the required weld properties, in combination with electrode compositions. They are used only in the dry condition. Flux which has not been fused is usually vacuumed up, run through a strainer and reused. Solidified flux covering the weld bead is a brittle, glass-like material which must be removed between passes and from finished welds. When the parameters are correctly set, the fused flux slag will usually peel off by itself.

In addition to all the regular types of weld joints, submerged arc is very useful for surfacing. Because of the high current densities employed, the SAW process typically has a large, hot weld pool and as a result it cannot be used in the vertical or overhead positions.

Advantages

- Lends itself to the production of consistently high quality welds with minimum operator skills.
- Minimum of welding fume and of arc visibility (radiation).
- Well suited to welding thick sections.
- Suitable for welding carbon, low alloy and alloy steels.
- Relatively high metal deposition rates ut to ten times higher deposition rates than SMAW.

Disadvantages

- Flat or horizontal position welding only
- Care required to preserve correct electrode alignment, as electrode
- Tip and weld pool are underneath solid flux cover

C.4.6 Stud Welding

This is a variation of arc welding in which studs are welded to plane surfaces automatically (Figure 14). The stud, which may be a plain or threaded bar (if plain it will have a head) is the electrode and it is held in the chuck of a welding gun which is connected to the power supply. The stud is first touched onto the surface of the steel plate or section. As soon as the current is switched on, the stud is moved away automatically to establish an arc.

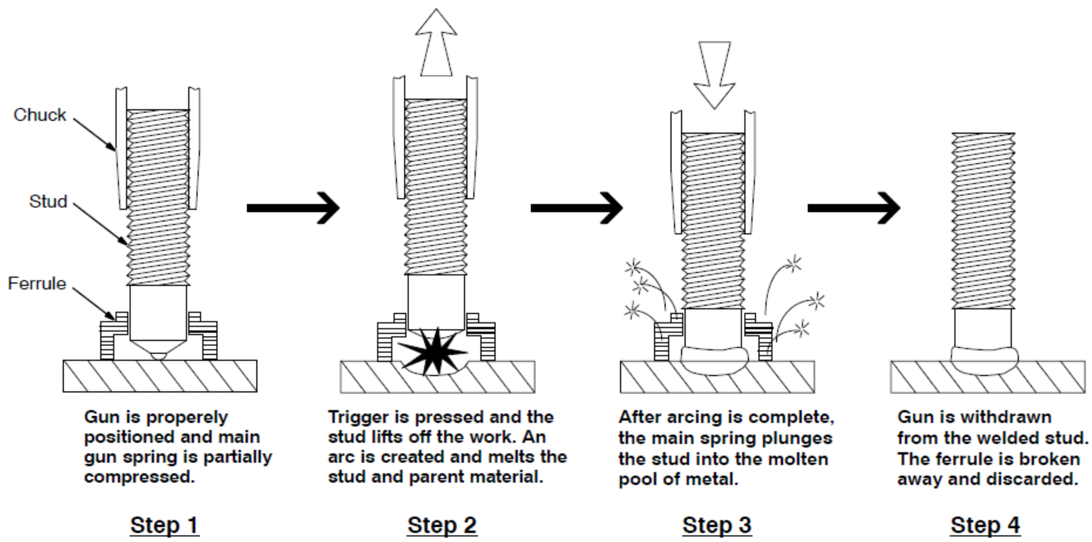


Fig. 14. STUD WELDING SEQUENCE

When a weld pool has formed and the end of the stud is molten, the latter is automatically forced into the steel plate and the current is switched off. The molten metal which is expelled from the interface is formed into a fillet by a ceramic collar which is placed around the stud arc at the beginning of the operation. This ferrule also provides sufficient protection against atmospheric contamination.

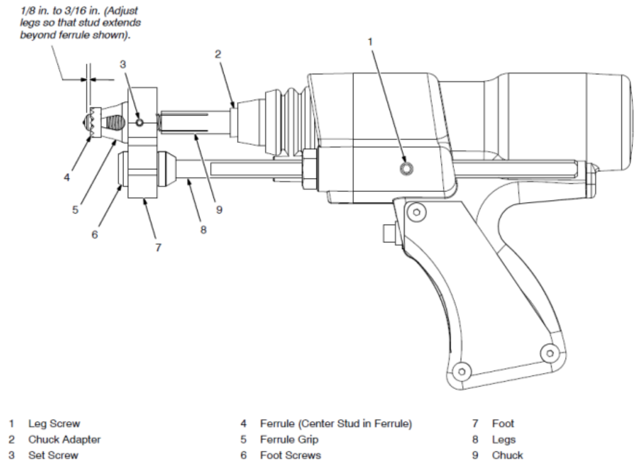


Fig. 15. STUD WELD GUN

Stud welding offers an accurate and fast method of attaching shear connectors, etc., with the minimum of distortion. Whilst it requires some skill to set up the weld parameters (voltage, current, arc time and force), the operation of the equipment is relatively straight forward.

C.4.7 Air Carbon Arc Gouging

Air carbon-arc Gouging (ACAG) is a process of gouging metal by heating it to a molten state and then using compressed air to blow away the molten metal. Figure 16 shows the process. The equipment consists of a special holder, as shown in figure 17, that uses carbon or graphite electrodes and compressed air fed through jets built into the electrode holder. A push button or a hand valve on the electrode holder controls the air jet.

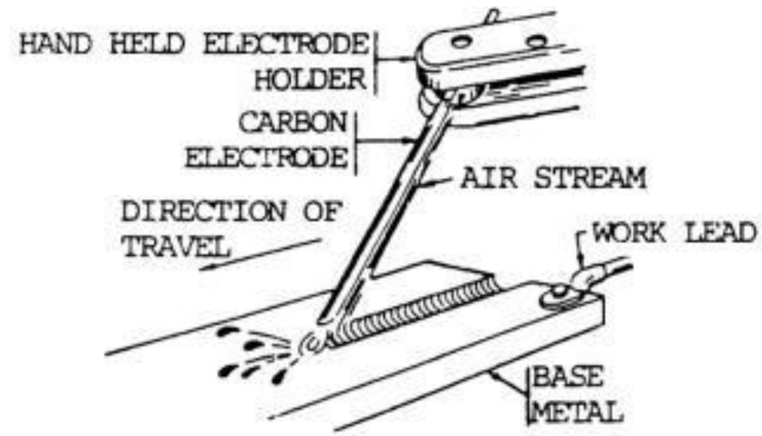


FIG. 16. AIR CARBON ARC GOUGING ELECTRODE HOLDER

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

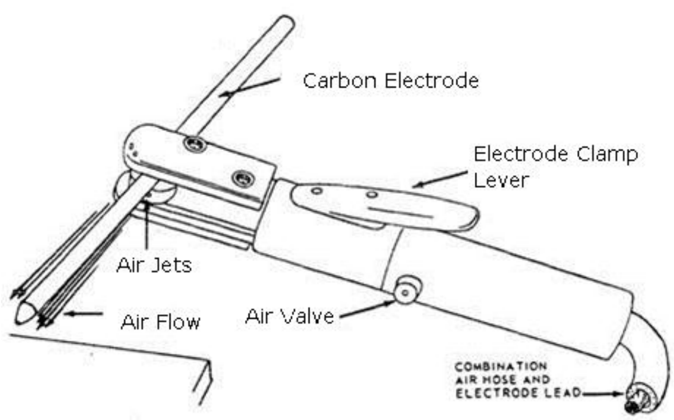


FIG. 17. AIR CARBON ARC GOUGING ELECTRODE HOLDER

When cutting or gouging a shallow groove on the surface of a piece of metal, you should position the electrode holder at a very flat angle in relation to the work. The speed of travel and the current setting also affect the depth of the groove. The slower the movement and the higher the current, the deeper the groove.

D. Summary

So in this document we got a crash course on the main arc welding processes that most engineers will encounter in thier careers. This is not to say this is a complete compulation of all welding processes just the more popular and economic ones in use in manufacturing and construction.

There are numerous arc welding processes but as we discussed the following are the most common:

(1) Shielded Metal Arc Welding

(2) Gas Tungsten Arc Welding

(3) Gas Metal Arc Welding

(4) Flux Cored Arc Welding

(5) Submerged Arc Welding

(6) Stud Welding

(7) Air Carbon Arc Gouging

With these processes numerous electrodes, fluxes, shielding gases, guns and power sources are available which sometimes can take a simple metal joining task and can turn it into a herculean task.

With that being said the main concept that we touched on is that all of these processes depend on a shielding mechanism (gas , flux or both) to keep outside contaminants such as oxygen and moisture out of the weld pool. This is the key concept for shielded arc welding.

ARC WELDING PROCESSES OVERVIEW

Course Quiz

1. What is the major function of the flux coating on a SMAW arc welding electrode?
   a. Protect the molten weld pool from the atmosphere
   b. Influence incomplete penetration
   c. help liquefy the base metal
   d. Add moisture and accelerates the cooling rate

2. Which welding process is also referred to as "stick welding"?
   a. FCAW
   b. SMAW
   c. SAW
   d. GMAW

3. Which of the following is a non-fusion processes of joining?
   a. soldering
   b. brazing
   c. Gas Tungsten Arc Welding GTAW
   d. Both a and b

4. Metals at high temperatures are reactive chemically with ?
   a. Argon
   b. Nitrogen
   c. Oxygen
   d. Both b and c

5. Filter lenses must be used to watch the electric arc for all processes except?
   a. FCAW- Flux Cored Arc Welding
   b. SMAW-Shielded Metal Arc Welding
   c. SAW- Submerged Arc Welding
   d. GMAW- Gas Metal Arc Welding

6. Which welding process has some limitations in regards to joint configurations and portability.?

a. FCAW- Flux Cored Arc Welding
b. SMAW-Shielded Metal Arc Welding
c. SAW- Submerged Arc Welding
d. GMAW- Gas Metal Arc Welding

7. Which of the following is not an advantage of the SMAW process?

a. Equipment is inexpensive.
b. Equipment is portable.
c. Applications are simple and adaptable to job requirements.
d. Used with or without filler wire

8. Which of the following is an advantage of the GTAW process?

a. Used for welding ferrous materials only.
b. Equipment is not portable.
c. Applications are simple and adaptable to job requirements.
d. Used with or without filler wire

9. Gas tungsten arc welding especially suited for welding

a. on thick materials.
b. on dirty farm equipment.
c. joints requiring the highest quality and surface appearance.
d. jobs where high deposition rates are required.

10. Inert gas is kept flowing after the welding arc is broken in order to

A. shield the ceramic cup
B. purge the torch lines of argon
C. shield the tungsten and the work from contamination
D. keep the flow meter from freezing up.

11 Which of the following is not an advantage of the GTAW process?

a. Easily automated
b. Used in all positions
c. High deposition rates.
d. Used with or without filler wire

12. In GMAW semi-automatic welding, the equipment is set

A. for voltage and current
B. for voltage and electrode-wire feed rate
C. for current and electrode-wire feed rate
D. none of the above.

13. Most carbon steel GMAW electrode wire is copper plated to

A. protect surfaces during storage

B. provide good feeding characteristics
C. good conductive characteristics
D. all of the above.

14. How many commonly employed modes of filler metal transfer across the arc are there for the GMAW processes?
a. Two.
b. Four
c. Seven.
d. Nine

15. Which mode of transfer in GMAW is the amperage and voltage are high enough to blast the metal across the arc in a fine spray of tiny particles.
a. Short Circuiting Transfer
b. Globular Transfer
c. Spray Transfer
d. All of the above

16. Which two welding processes have essentially the same equipment?
a. FCAW and GTAW
b. SMAW and SAW
c. SAW and GTAW
d. GMAW and FCAW

17. DCRP in the SAW process provides
a. maximum penetration
b better control over the configuration of the weld bead
c. a higher deposition rate.
d. both a and b

18 Which of the following is not an advantage of the SAW process?
a. Suitable for welding carbon, low alloy and alloy steels.
b. Used in all positions
c. Well suited to welding thick sections.
d. Minimum of welding fume and of arc visibility (radiation).

19. Stud Welding is often used for
a. high quality repairs on thick materials.
b. accurate and fast attaching of shear connectors to steel beams
c. joints requiring the highest quality and surface appearance.
d. pipe welding repairs where high deposition rates are required.

ARC WELDING PROCESSES OVERVIEW

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b. Used in all positions
c. Well suited to welding thick sections.
d. Minimum of welding fume and of arc visibility (radiation).

19. Stud Welding is often used for
a. high quality repairs on thick materials.
b. accurate and fast attaching of shear connectors to steel beams
c. joints requiring the highest quality and surface appearance.
d. pipe welding repairs where high deposition rates are required.