



NONRESIDENT TRAINING COURSE

November 1996



Steelworker, Volume 1

NAVEDTRA 14250

Although the words “he,” “him,” and “his” are used sparingly in this course to enhance communication, they are not intended to be gender driven or to affront or discriminate against anyone.

COMMANDING OFFICER
NETPDT
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ERRATA #1

29 May 2001

Specific Instructions and Errata for
Nonresident Training Course

STEELWORKER, VOLUME 1, NAVEDTRA 14250

1. This errata supersedes all previous errata. No attempt has been made to issue corrections for errors in typing, punctuation, etc., that do not affect your ability to answer the question or questions.
2. To receive credit for deleted questions, show this errata to your local course administrator (ESO/scorer). The local course administrator is directed to correct the course and the answer key by indicating the questions deleted.
3. Assignment Booklet

Delete the following questions, and leave the corresponding spaces blank on the answer sheets:

Questions

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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 a knowledge of the subject matter by correctly answering questions on the following subjects:

- Properties and Uses of Metals
- Basic Heat Treatment
- Introduction to Welding
- Gas Cutting
- Gas Welding
- Soldering, Brazing, Braze Welding, and Wearfacing
- Shielded Metal-Arc Welding and Wearfacing
- Gas Shielded-Arc Welding

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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Sailor's Creed

"I am a United States Sailor.

I will support and defend the Constitution of the United States of America and I will obey the orders of those appointed over me.

I represent the fighting spirit of the Navy and those who have gone before me to defend freedom and democracy around the world.

I proudly serve my country's Navy combat team with honor, courage and commitment.

I am committed to excellence and the fair treatment of all."

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SUMMARY OF STEELWORKER, VOLUME I TRAINING MANUALS

VOLUME 1

Steelworker, Volume 1, NAVEDTRA 14250, consists of chapters on the following subjects: Properties and Uses of Metal; Basic Heat Treatment; Introduction to Welding; Gas Cutting; Gas Welding; Soldering, Brazing, Braze Welding, and Wearfacing; Shielded Metal-Arc Welding and Wearfacing; and Gas Shielded-Arc Welding.

VOLUME 2

Steelworker, Volume 2, NAVEDTRA 14251, consists of chapters on the following subjects: Construction Administration and Support; Sheet Metal and Fiber Glass Duct Layout and Fabrication; Structural Steel and Pipe Layout and Fabrication; Fiber Line; Wire Rope; Rigging and Hoisting; Concrete Construction (Reinforcing Steel); Pre-engineered Buildings, Towers, and Antennas; Pre-engineered Storage Tanks; Pontoons; and SATS matting.

INSTRUCTIONS FOR TAKING THE COURSE

ASSIGNMENTS

The text pages that you are to study are listed at the beginning of each assignment. Study these pages carefully before attempting to answer the questions. Pay close attention to tables and illustrations and read the learning objectives. The learning objectives state what you should be able to do after studying the material. Answering the questions correctly helps you accomplish the objectives.

SELECTING YOUR ANSWERS

Read each question carefully, then select the BEST answer. You may refer freely to the text. The answers must be the result of your own work and decisions. You are prohibited from referring to or copying the answers of others and from giving answers to anyone else taking the course.

SUBMITTING YOUR ASSIGNMENTS

To have your assignments graded, you must be enrolled in the course with the Nonresident Training Course Administration Branch at the Naval Education and Training Professional Development and Technology Center (NETPDTC). Following enrollment, there are two ways of having your assignments graded: (1) use the Internet to submit your assignments as you complete them, or (2) send all the assignments at one time by mail to NETPDTC.

Grading on the Internet: Advantages to Internet grading are:

- you may submit your answers as soon as you complete an assignment, and
- you get your results faster; usually by the next working day (approximately 24 hours).

In addition to receiving grade results for each assignment, you will receive course completion confirmation once you have completed all the

assignments. To submit your assignment answers via the Internet, go to:

<http://courses.cnet.navy.mil>

Grading by Mail: When you submit answer sheets by mail, send all of your assignments at one time. Do NOT submit individual answer sheets for grading. Mail all of your assignments in an envelope, which you either provide yourself or obtain from your nearest Educational Services Officer (ESO). Submit answer sheets to:

COMMANDING OFFICER
NETPDTC N331
6490 SAUFLEY FIELD ROAD
PENSACOLA FL 32559-5000

Answer Sheets: All courses include one “scannable” answer sheet for each assignment. These answer sheets are preprinted with your SSN, name, assignment number, and course number. Explanations for completing the answer sheets are on the answer sheet.

Do not use answer sheet reproductions: Use only the original answer sheets that we provide—reproductions will not work with our scanning equipment and cannot be processed.

Follow the instructions for marking your answers on the answer sheet. Be sure that blocks 1, 2, and 3 are filled in correctly. This information is necessary for your course to be properly processed and for you to receive credit for your work.

COMPLETION TIME

Courses must be completed within 12 months from the date of enrollment. This includes time required to resubmit failed assignments.

PASS/FAIL ASSIGNMENT PROCEDURES

If your overall course score is 3.2 or higher, you will pass the course and will not be required to resubmit assignments. Once your assignments have been graded you will receive course completion confirmation.

If you receive less than a 3.2 on any assignment and your overall course score is below 3.2, you will be given the opportunity to resubmit failed assignments. **You may resubmit failed assignments only once.** Internet students will receive notification when they have failed an assignment--they may then resubmit failed assignments on the web site. Internet students may view and print results for failed assignments from the web site. Students who submit by mail will receive a failing result letter and a new answer sheet for resubmission of each failed assignment.

COMPLETION CONFIRMATION

After successfully completing this course, you will receive a letter of completion.

ERRATA

Errata are used to correct minor errors or delete obsolete information in a course. Errata may also be used to provide instructions to the student. If a course has an errata, it will be included as the first page(s) after the front cover. Errata for all courses can be accessed and viewed/downloaded at:

<http://www.advancement.cnet.navy.mil>

STUDENT FEEDBACK QUESTIONS

We value your suggestions, questions, and criticisms on our courses. If you would like to communicate with us regarding this course, we encourage you, if possible, to use e-mail. If you write or fax, please use a copy of the Student Comment form that follows this page.

For subject matter questions:

E-mail: n314.products@cnet.navy.mil
Phone: Comm: (850) 452-1001, Ext. 1826
DSN: 922-1001, Ext. 1826
FAX: (850) 452-1370
(Do not fax answer sheets.)
Address: COMMANDING OFFICER
NETPDTC N314
6490 SAUFLEY FIELD ROAD
PENSACOLA FL 32509-5237

For enrollment, shipping, grading, or completion letter questions

E-mail: fleetservices@cnet.navy.mil
Phone: Toll Free: 877-264-8583
Comm: (850) 452-1511/1181/1859
DSN: 922-1511/1181/1859
FAX: (850) 452-1370
(Do not fax answer sheets.)
Address: COMMANDING OFFICER
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NAVAL RESERVE RETIREMENT CREDIT

If you are a member of the Naval Reserve, you may earn retirement points for successfully completing this course, if authorized under current directives governing retirement of Naval Reserve personnel. For Naval Reserve retirement, this course is evaluated at 9 points. (Refer to *Administrative Procedures for Naval Reservists on Inactive Duty*, BUPERSINST 1001.39, for more information about retirement points.)

Student Comments

Course Title: Steelworker, Volume 1

NAVEDTRA: 14250 **Date:** _____

We need some information about you:

Rate/Rank and Name: _____ SSN: _____ Command/Unit _____

Street Address: _____ City: _____ State/FPO: _____ Zip _____

Your comments, suggestions, etc.:

Privacy Act Statement: Under authority of Title 5, USC 301, information regarding your military status is requested in processing your comments and in preparing a reply. This information will not be divulged without written authorization to anyone other than those within DOD for official use in determining performance.
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NETPDTC 1550/41 (Rev 4-00)

CHAPTER 1

PROPERTIES AND USES OF METAL

In the seabees, Steelworkers are the resident experts on the properties and uses of metal. We lay airfields, erect towers and storage tanks, assemble pontoon causeways, and construct buildings. We use our expertise to repair metal items, resurface worn machinery parts, and fabricate all types of metal objects. To accomplish these tasks proficiently, one must possess a sound working knowledge of various metals and their properties. As we learn their different properties and characteristics, we can then select the right type of metal and use the proper method to complete the job. Steelworkers primarily work with iron and steel; however, we also must become familiar with the nonferrous metals coming into use more and more each day. As Steelworkers, we must be able to identify various metals and to associate their individual properties with their proper application or use.

The primary objective of this chapter is to present a detailed explanation of some of the properties of different metals and to provide instruction on using simple tests in establishing their identity.

METAL PROPERTIES

There is no simple definition of metal; however, any chemical element having "metallic properties" is classed as a metal. "Metallic properties" are defined as luster, good thermal and electrical conductivity, and the capability of being permanently shaped or deformed at room temperature. Chemical elements lacking these properties are classed as nonmetals. A few elements, known as metalloids, sometimes behave like a metal and at other times like a nonmetal. Some examples of metalloids are as follows: carbon, phosphorus, silicon, and sulfur.

Although Steelworkers seldom work with pure metals, we must be knowledgeable of their properties because the alloys we work with are combinations of pure metals. Some of the pure metals discussed in this chapter are the base metals in these alloys. This is true of iron, aluminum, and magnesium. Other metals discussed are the alloying elements present in small quantities but important in their effect. Among these are chromium, molybdenum, titanium, and manganese.

An "alloy" is defined as a substance having metallic properties that is composed of two or more elements. The elements used as alloying substances are usually metals or metalloids. The properties of an alloy differ from the properties of the pure metals or metalloids that make up the alloy and this difference is what creates the usefulness of alloys. By combining metals and metalloids, manufacturers can develop alloys that have the particular properties required for a given use.

Table 1-1 is a list of various elements and their symbols that compose metallic materials.

Table 1-1.—Symbols of Base Metals and Alloying Elements

Element	Symbol
Aluminum	Al
Antimony	Sb
Cadmium	Cd
Carbon	C
Chromium	Cr
Cobalt	Co
Copper	Cu
Iron	Fe
Lead	Pb
Magnesium	Mg
Manganese	Mn
Molybdenum	Mo
Nickel	Ni
Phosphorus	P
Silicon	Si
Sulfur	S
Tin	Sn
Tungsten	W
Vanadium	V
Zinc	Zn

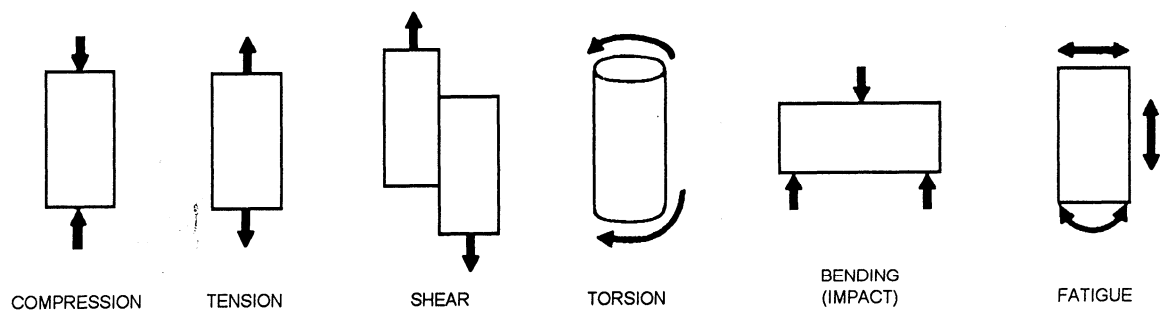


Figure 1-1.—Stress applied to a material.

Very rarely do Steelworkers work with elements in their pure state. We primarily work with alloys and have to understand their characteristics. The characteristics of elements and alloys are explained in terms of physical, chemical, electrical, and mechanical properties. Physical properties relate to color, density, weight, and heat conductivity. Chemical properties involve the behavior of the metal when placed in contact with the atmosphere, salt water, or other substances. Electrical properties encompass the electrical conductivity, resistance, and magnetic qualities of the metal. The mechanical properties relate to load-carrying ability, wear resistance, hardness, and elasticity.

When selecting stock for a job, your main concern is the mechanical properties of the metal. The various properties of metals and alloys were determined in the laboratories of manufacturers and by various societies interested in metallurgical development. Charts presenting the properties of a particular metal or alloy are available in many commercially published reference books. The charts provide information on the melting point, tensile strength, electrical conductivity, magnetic properties, and other properties of a particular metal or alloy. Simple tests can be conducted to determine some of the properties of a metal; however, we normally use a metal test only as an aid for identifying a piece of stock. Some of these methods of testing are discussed later in this chapter.

MECHANICAL PROPERTIES

Strength, hardness, toughness, elasticity, plasticity, brittleness, and ductility and malleability are mechanical properties used as measurements of how metals behave under a load. These properties are described in terms of the types of force or stress that the metal must withstand and how these are resisted.

Common types of stress are compression, tension, shear, torsion, impact, 1-2 or a combination of these stresses, such as fatigue. (See fig. 1-1.)

Compression stresses develop within a material when forces compress or crush the material. A column that supports an overhead beam is in compression, and the internal stresses that develop within the column are compression.

Tension (or tensile) stresses develop when a material is subject to a pulling load; for example, when using a wire rope to lift a load or when using it as a guy to anchor an antenna. "Tensile strength" is defined as resistance to longitudinal stress or pull and can be measured in pounds per square inch of cross section. Shearing stresses occur within a material when external forces are applied along parallel lines in opposite directions. Shearing forces can separate material by sliding part of it in one direction and the rest in the opposite direction.

Some materials are equally strong in compression, tension, and shear. However, many materials show marked differences; for example, cured concrete has a maximum strength of 2,000 psi in compression, but only 400 psi in tension. Carbon steel has a maximum strength of 56,000 psi in tension and compression but a maximum shear strength of only 42,000 psi; therefore, when dealing with maximum strength, you should always state the type of loading.

A material that is stressed repeatedly usually fails at a point considerably below its maximum strength in tension, compression, or shear. For example, a thin steel rod can be broken by hand by bending it back and forth several times in the same place; however, if the same force is applied in a steady motion (not bent back and forth), the rod cannot be broken. The tendency of a material to fail after repeated bending at the same point is known as fatigue.

Table 1-2.—Mechanical Properties of Metals/Alloys

<u>TOUGHNESS</u>	<u>BRITTLINESS</u>	<u>DUCTILITY</u>	<u>MALLEABILITY</u>	<u>CORROSION RESISTANCE</u>
Copper	White Cast Iron	Gold	Gold	Gold
Nickel	Gray Cast Iron	Silver	Silver	Platinum
Iron	Hardened Steel	Platinum	Aluminum	Silver
Magnesium	Bismuth	Iron	Copper	Mercury
Zinc	Manganese	Nickel	Tin	Copper
Aluminum	Bronzes	Copper	Lead	Lead
Lead	Aluminum	Aluminum	Zinc	Tin
Tin	Brass	Tungsten	Iron	Nickel
Cobalt	Structural Steels	Zinc		Iron
Bismuth	Zinc	Tin		Zinc
	Monel	Lead		Magnesium
	Tin			Aluminum
	Copper			
	Iron			
* Metals/alloys are ranked in descending order of having the property named in the column heading				

Strength

Strength is the property that enables a metal to resist deformation under load. The ultimate strength is the maximum strain a material can withstand. Tensile strength is a measurement of the resistance to being pulled apart when placed in a tension load.

Fatigue strength is the ability of material to resist various kinds of rapidly changing stresses and is expressed by the magnitude of alternating stress for a specified number of cycles.

Impact strength is the ability of a metal to resist suddenly applied loads and is measured in foot-pounds of force.

Hardness

Hardness is the property of a material to resist permanent indentation. Because there are several methods of measuring hardness, the hardness of a material is always specified in terms of the particular test that was used to measure this property. Rockwell, Vickers, or Brinell are some of the methods of testing. Of these tests, Rockwell is the one most frequently used. The basic principle used in the Rockwell test is that a hard material can penetrate a softer one. We then measure the amount of penetration and compare it to a scale. For ferrous metals, which are usually harder than nonferrous metals, a diamond tip is used and the hardness is indicated by a

Rockwell “C” number. On nonferrous metals, that are softer, a metal ball is used and the hardness is indicated by a Rockwell “B” number. To get an idea of the property of hardness, compare lead and steel. Lead can be scratched with a pointed wooden stick but steel cannot because it is harder than lead.

A full explanation of the various methods used to determine the hardness of a material is available in commercial books or books located in your base library.

Toughness

Toughness is the property that enables a material to withstand shock and to be deformed without rupturing. Toughness may be considered as a combination of strength and plasticity. Table 1-2 shows the order of some of the more common materials for toughness as well as other properties.

Elasticity

When a material has a load applied to it, the load causes the material to deform. Elasticity is the ability of a material to return to its original shape after the load is removed. Theoretically, the elastic limit of a material is the limit to which a material can be loaded and still recover its original shape after the load is removed.

Plasticity

Plasticity is the ability of a material to deform permanently without breaking or rupturing. This property is the opposite of strength. By careful alloying of metals, the combination of plasticity and strength is used to manufacture large structural members. For example, should a member of a bridge structure become overloaded, plasticity allows the overloaded member to flow allowing the distribution of the load to other parts of the bridge structure.

Brittleness

Brittleness is the opposite of the property of plasticity. A brittle metal is one that breaks or shatters before it deforms. White cast iron and glass are good examples of brittle material. Generally, brittle metals are high in compressive strength but low in tensile strength. As an example, you would not choose cast iron for fabricating support beams in a bridge.

Ductility and Malleability

Ductility is the property that enables a material to stretch, bend, or twist without cracking or breaking. This property makes it possible for a material to be drawn out into a thin wire. In comparison, malleability is the property that enables a material to deform by compressive forces without developing defects. A malleable material is one that can be stamped, hammered, forged, pressed, or rolled into thin sheets.

CORROSION RESISTANCE

Corrosion resistance, although not a mechanical property, is important in the discussion of metals. Corrosion resistance is the property of a metal that gives it the ability to withstand attacks from atmospheric, chemical, or electrochemical conditions. Corrosion, sometimes called oxidation, is illustrated by the rusting of iron.

Table 1-2 lists four mechanical properties and the corrosion resistance of various metals or alloys. The first metal or alloy in each column exhibits the best characteristics of that property. The last metal or alloy in each column exhibits the least. In the column labeled "Toughness," note that iron is not as tough as copper or nickel; however, it is tougher than magnesium, zinc, and aluminum. In the column labeled "Ductility," iron exhibits a reasonable amount of ductility; however, in the columns labeled "Malleability" and "Brittleness," it is last.

METAL TYPES

The metals that Steelworkers work with are divided into two general classifications: ferrous and nonferrous. Ferrous metals are those composed primarily of iron and iron alloys. Nonferrous metals are those composed primarily of some element or elements other than iron. Nonferrous metals or alloys sometimes contain a small amount of iron as an alloying element or as an impurity.

FERROUS METALS

Ferrous metals include all forms of iron and steel alloys. A few examples include wrought iron, cast iron, carbon steels, alloy steels, and tool steels. Ferrous metals are iron-base alloys with small percentages of carbon and other elements added to achieve desirable properties. Normally, ferrous metals are magnetic and nonferrous metals are nonmagnetic.

Iron

Pure iron rarely exists outside of the laboratory. Iron is produced by reducing iron ore to pig iron through the use of a blast furnace. From pig iron many other types of iron and steel are produced by the addition or deletion of carbon and alloys. The following paragraphs discuss the different types of iron and steel that can be made from iron ore.

PIG IRON.— Pig iron is composed of about 93% iron, from 3% to 5% carbon, and various amounts of other elements. Pig iron is comparatively weak and brittle; therefore, it has a limited use and approximately ninety percent produced is refined to produce steel. Cast-iron pipe and some fittings and valves are manufactured from pig iron.

WROUGHT IRON.— Wrought iron is made from pig iron with some slag mixed in during manufacture. Almost pure iron, the presence of slag enables wrought iron to resist corrosion and oxidation. The chemical analyses of wrought iron and mild steel are just about the same. The difference comes from the properties controlled during the manufacturing process. Wrought iron can be gas and arc welded, machined, plated, and easily formed; however, it has a low hardness and a low-fatigue strength.

CAST IRON.— Cast iron is any iron containing greater than 2% carbon alloy. Cast iron has a high-compressive strength and good wear resistance; however, it lacks ductility, malleability, and impact strength. Alloying it with nickel, chromium, molybdenum, silicon, or vanadium improves toughness, tensile strength, and

hardness. A malleable cast iron is produced through a prolonged annealing process.

INGOT IRON.— Ingot iron is a commercially pure iron (99.85% iron) that is easily formed and possesses good ductility and corrosion resistance. The chemical analysis and properties of this iron and the lowest carbon steel are practically the same. The lowest carbon steel, known as dead-soft, has about 0.06% more carbon than ingot iron. In iron the carbon content is considered an impurity and in steel it is considered an alloying element. The primary use for ingot iron is for galvanized and enameled sheet.

Steel

Of all the different metals and materials that we use in our trade, steel is by far the most important. When steel was developed, it revolutionized the American iron industry. With it came skyscrapers, stronger and longer bridges, and railroad tracks that did not collapse. Steel is manufactured from pig iron by decreasing the amount of carbon and other impurities and adding specific amounts of alloying elements.

Do not confuse steel with the two general classes of iron: cast iron (greater than 2% carbon) and pure iron (less than 0.15% carbon). In steel manufacturing, controlled amounts of alloying elements are added during the molten stage to produce the desired composition. The composition of a steel is determined by its application and the specifications that were developed by the following: American Society for Testing and Materials (ASTM), the American Society of Mechanical Engineers (ASME), the Society of Automotive Engineers (SAE), and the American Iron and Steel Institute (AISI).

Carbon steel is a term applied to a broad range of steel that falls between the commercially pure ingot iron and the cast irons. This range of carbon steel may be classified into four groups:

Low-Carbon Steel 0.05% to 0.30% carbon
Medium-Carbon Steel 0.30% to 0.45% carbon
High-Carbon Steel 0.45% to 0.75% carbon
Very High-Carbon Steel 0.75% to 1.70% carbon

LOW-CARBON STEEL.— Steel in this classification is tough and ductile, easily machined, formed, and welded. It does not respond to any form of heat treating, except case hardening.

MEDIUM-CARBON STEEL.— These steels are strong and hard but cannot be welded or worked as

easily as the low-carbon steels. They are used for crane hooks, axles, shafts, setscrews, and so on.

HIGH-CARBON STEEL/VERY HIGH-CARBON STEEL.— Steel in these classes respond well to heat treatment and can be welded. When welding, special electrodes must be used along with preheating and stress-relieving procedures to prevent cracks in the weld areas. These steels are used for dies, cutting tools, mill tools, railroad car wheels, chisels, knives, and so on.

LOW-ALLOY, HIGH-STRENGTH, TEMPERED STRUCTURAL STEEL.— A special low-carbon steel, containing specific small amounts of alloying elements, that is quenched and tempered to get a yield strength of greater than 50,000 psi and tensile strengths of 70,000 to 120,000 psi. Structural members made from these high-strength steels may have smaller cross-sectional areas than common structural steels and still have equal or greater strength. Additionally, these steels are normally more corrosion- and abrasion-resistant. High-strength steels are covered by ASTM specifications.

NOTE: This type of steel is much tougher than low-carbon steels. Shearing machines for this type of steel must have twice the capacity than that required for low-carbon steels.

STAINLESS STEEL.— This type of steel is classified by the American Iron and Steel Institute (AISI) into two general series named the 200-300 series and 400 series. Each series includes several types of steel with different characteristics.

The 200-300 series of stainless steel is known as AUSTENITIC. This type of steel is very tough and ductile in the as-welded condition; therefore, it is ideal for welding and requires no annealing under normal atmospheric conditions. The most well-known types of steel in this series are the 302 and 304. They are commonly called 18-8 because they are composed of 18% chromium and 8% nickel. The chromium nickel steels are the most widely used and are normally nonmagnetic.

The 400 series of steel is subdivided according to their crystalline structure into two general groups. One group is known as FERRITIC CHROMIUM and the other group as MARTENSITIC CHROMIUM.

Ferritic Chromium.— This type of steel contains 12% to 27% chromium and 0.08% to 0.20% carbon. These alloys are the straight chromium grades of stainless steel since they contain no nickel. They are nonhardenable by heat treatment and are normally used in the annealed or soft condition. Ferritic steels are magnetic

and frequently used for decorative trim and equipment subjected to high pressures and temperatures.

Martensitic Chromium.— These steels are magnetic and are readily hardened by heat treatment. They contain 12% to 18% chromium, 0.15% to 1.2% carbon, and up to 2.5% nickel. This group is used where high strength, corrosion resistance, and ductility are required.

ALLOY STEELS.— Steels that derive their properties primarily from the presence of some alloying element other than carbon are called ALLOYS or ALLOY STEELS. Note, however, that alloy steels always contain traces of other elements. Among the more common alloying elements are nickel, chromium, vanadium, silicon, and tungsten. One or more of these elements may be added to the steel during the manufacturing process to produce the desired characteristics. Alloy steels may be produced in structural sections, sheets, plates, and bars for use in the “as-rolled” condition. Better physical properties are obtained with these steels than are possible with hot-rolled carbon steels. These alloys are used in structures where the strength of material is especially important. Bridge members, railroad cars, dump bodies, dozer blades, and crane booms are made from alloy steel. Some of the common alloy steels are briefly described in the paragraphs below.

Nickel Steels.— These steels contain from 3.5% nickel to 5% nickel. The nickel increases the strength and toughness of these steels. Nickel steel containing more than 5% nickel has an increased resistance to corrosion and scale. Nickel steel is used in the manufacture of aircraft parts, such as propellers and airframe support members.

Chromium Steels.— These steels have chromium added to improve hardening ability, wear resistance, and strength. These steels contain between 0.20% to 0.75% chromium and 0.45% carbon or more. Some of these steels are so highly resistant to wear that they are used for the races and balls in antifriction bearings. Chromium steels are highly resistant to corrosion and to scale.

Chrome Vanadium Steel.— This steel has the maximum amount of strength with the least amount of weight. Steels of this type contain from 0.15% to 0.25% vanadium, 0.6% to 1.5% chromium, and 0.1% to 0.6% carbon. Common uses are for crankshafts, gears, axles, and other items that require high strength. This steel is also used in the manufacture of high-quality hand tools, such as wrenches and sockets.

Tungsten Steel.— This is a special alloy that has the property of red hardness. This is the ability to continue

to cut after it becomes red-hot. A good grade of this steel contains from 13% to 19% tungsten, 1% to 2% vanadium, 3% to 5% chromium, and 0.6% to 0.8% carbon. Because this alloy is expensive to produce, its use is largely restricted to the manufacture of drills, lathe tools, milling cutters, and similar cutting tools.

Molybdenum.— This is often used as an alloying agent for steel in combination with chromium and nickel. The molybdenum adds toughness to the steel. It can be used in place of tungsten to make the cheaper grades of high-speed steel and in carbon molybdenum high-pressure tubing.

Manganese Steels.— The amount of manganese used depends upon the properties desired in the finished product. Small amounts of manganese produce strong, free-machining steels. Larger amounts (between 2% and 10%) produce a somewhat brittle steel, while still larger amounts (11% to 14%) produce a steel that is tough and very resistant to wear after proper heat treatment.

NONFERROUS METALS

Nonferrous metals contain either no iron or only insignificant amounts used as an alloy. Some of the more common nonferrous metals Steelworkers work with are as follows: copper, brass, bronze, copper-nickel alloys, lead, zinc, tin, aluminum, and Duralumin.

NOTE: These metals are nonmagnetic.

Copper

This metal and its alloys have many desirable properties. Among the commercial metals, it is one of the most popular. Copper is ductile, malleable, hard, tough, strong, wear resistant, machinable, weldable, and corrosion resistant. It also has high-tensile strength, fatigue strength, and thermal and electrical conductivity. Copper is one of the easier metals to work with but be careful because it easily becomes work-hardened; however, this condition can be remedied by heating it to a cherry red and then letting it cool. This process, called annealing, restores it to a softened condition. Annealing and softening are the only heat-treating procedures that apply to copper. Seams in copper are joined by riveting, silver brazing, bronze brazing, soft soldering, gas welding, or electrical arc welding. Copper is frequently used to give a protective coating to sheets and rods and to make ball floats, containers, and soldering coppers.

True Brass

This is an alloy of copper and zinc. Additional elements, such as aluminum, lead, tin, iron, manganese, or phosphorus, are added to give the alloy specific properties. Naval rolled brass (Tobin bronze) contains about 60% copper, 39% zinc, and 0.75% tin. This brass is highly corrosion-resistant and is practically impurity free.

Brass sheets and strips are available in several grades: soft, 1/4 hard, 1/2 hard, full hard, and spring grades. Hardness is created by the process of cold rolling. All grades of brass can be softened by annealing at a temperature of 550°F to 600°F then allowing it to cool by itself without quenching. Overheating can destroy the zinc in the alloy.

Bronze

Bronze is a combination of 84% copper and 16% tin and was the best metal available before steel-making techniques were developed. Many complex bronze alloys, containing such elements as zinc, lead, iron, aluminum, silicon, and phosphorus, are now available. Today, the name bronze is applied to any copper-based alloy that looks like bronze. In many cases, there is no real distinction between the composition of bronze and that of brass.

Copper-Nickel Alloys

Nickel is used in these alloys to make them strong, tough, and resistant to wear and corrosion. Because of their high resistance to corrosion, copper nickel alloys, containing 70% copper and 30% nickel or 90% copper and 10% nickel, are used for saltwater piping systems. Small storage tanks and hot-water reservoirs are constructed of a copper-nickel alloy that is available in sheet form. Copper-nickel alloys should be joined by metal-arc welding or by brazing.

Lead

A heavy metal that weighs about 710 pounds per cubic foot. In spite of its weight, lead is soft and malleable and is available in pig and sheet form. In sheet form, it is rolled upon a rod so the user can unroll it and cut off the desired amount. The surface of lead is grayish in color; however, after scratching or scraping it, you can see that the actual color of the metal is white. Because it is soft, lead is used as backing material when punching holes with a hollow punch or when forming shapes by hammering copper sheets. Sheet lead is also used to line

sinks or protect bench tops where a large amount of acid is used. Lead-lined pipes are used in systems that carry corrosive chemicals. Frequently, lead is used in alloyed form to increase its low-tensile strength. Alloyed with tin, lead produces a soft solder. When added to metal alloys, lead improves their machinability.

CAUTION

When working with lead, you must take proper precautions because the dust, fumes, or vapors from it are highly poisonous.

Zinc

You often see zinc used on iron or steel in the form of a protective coating called galvanizing. Zinc is also used in soldering fluxes, die castings, and as an alloy in making brass and bronze.

Tin

Tin has many important uses as an alloy. It can be alloyed with lead to produce softer solders and with copper to produce bronze. Tin-based alloys have a high resistance to corrosion, low-fatigue strength, and a compressive strength that accommodates light or medium loads. Tin, like lead, has a good resistance to corrosion and has the added advantage of not being poisonous; however, when subjected to extremely low temperatures, it has a tendency to decompose.

Aluminum

This metal is easy to work with and has a good appearance. Aluminum is light in weight and has a high strength per unit weight. A disadvantage is that the tensile strength is only one third of that of iron and one fifth of that of annealed mild steel.

Aluminum alloys usually contain at least 90% aluminum. The addition of silicon, magnesium, copper, nickel, or manganese can raise the strength of the alloy to that of mild steel. Aluminum, in its pure state, is soft and has a strong affinity for gases. The use of alloying elements is used to overcome these disadvantages; however, the alloys, unlike the pure aluminum, corrodes unless given a protective coating. Threaded parts made of aluminum alloy should be coated with an antiseize compound to prevent sticking caused by corrosion.

Table 1-3.—Surface Colors of Some Common Metals

Metals	Color of unfinished, unbroken surface	Color and structure of newly fractured surface	Color of freshly filed surface
White cast iron	dull gray	silvery white; crystalline	silvery white
Gray cast iron	dull gray	dark gray; crystalline	light silvery gray
Malleable iron	dull gray	dark gray; finely crystalline	light silvery gray
Wrought iron	light gray	bright gray	light silvery gray
Low-carbon and cast steel	dark gray	bright gray	bright silvery gray
High-carbon steel	dark gray	light gray	bright silvery gray
Stainless steel	dark gray	medium gray	bright silvery gray
Copper	reddish brown to green	bright red	bright copper color
Brass and bronze	reddish yellow, yellow-green, or brown	red to yellow	reddish yellow to yellowish white
Aluminum	light gray	white; finely crystalline	white
Monel metal	dark gray	light gray	light gray
Nickel	dark gray	off-white	bright silvery white
Lead	white to gray	light gray; crystalline	white

Duralumin

One of the first of the strong structural aluminum alloys developed is called Duralumin. With the development of a variety of different wrought-aluminum alloys, a numbering system was adopted. The digits indicate the major alloying element and the cold-worked or heat-treated condition of the metal. The alloy, originally called Duralumin, is now classified in the metal working industries as 2017-T. The letter *T* indicates that the metal is heat-treated.

Alclad

This is a protective covering that consists of a thin sheet of pure aluminum rolled onto the surface of an aluminum alloy during manufacture. Zinc chromate is a protective covering that can be applied to an aluminum surface as needed. Zinc chromate is also used as a primer on steel surfaces for a protective coating.

Monel

Monel is an alloy in which nickel is the major element. It contains from 64% to 68% nickel, about 30% copper, and small percentages of iron, manganese, and cobalt. Monel is harder and stronger than either nickel or copper and has high ductility. It resembles stainless steel in appearance and has many of its qualities. The strength, combined with a high resistance to corrosion, make Monel an acceptable substitute for steel in systems where corrosion resistance is the primary concern. Nuts, bolts, screws, and various fittings are made of Monel. This alloy can be worked cold and can be forged and welded. If worked in the temperature range between 1200°F and 1600°F, it becomes "hot short" or brittle.

K-Monel

This is a special type of alloy developed for greater strength and hardness than Monel. In strength, it is

comparable to heat-treated steel. K-monel is used for instrument parts that must resist corrosion.

Inconel

This high-nickel alloy is often used in the exhaust systems of aircraft engines. Inconel is composed of 78.5% nickel, 14% chromium, 6.5% iron, and 1% of other elements. It offers good resistance to corrosion and retains its strength at high-operating temperatures.

METAL IDENTIFICATION

Many methods are used to identify a piece of metal. Identification is necessary when selecting a metal for use in fabrication or in determining its weldability. Some common methods used for field identification are surface appearance, spark test, chip test, and the use of a magnet.

SURFACE APPEARANCE

Sometimes it is possible to identify metals by their surface appearance. Table 1-3 indicates the surface colors of some of the more common metals. Referring to the table, you can see that the outside appearance of a metal helps to identify and classify metal. Newly fractured or freshly filed surfaces offer additional clues.

A surface examination does not always provide enough information for identification but should give us enough information to place the metal into a class. The color of the metal and the distinctive marks left from manufacturing help in determining the identity of the metal. Cast iron and malleable iron usually show evidence of the sand mold. Low-carbon steel often shows forging marks, and high-carbon steel shows either forging or rolling marks. Feeling the surface may provide another clue. Stainless steel is slightly rough in the unfinished state, and the surfaces of wrought iron, copper, brass, bronze, nickel, and Monel are smooth. Lead also is smooth but has a velvety appearance.

When the surface appearance of a metal does not give enough information to allow positive identification, other identification tests become necessary. Some of these tests are complicated and require equipment we do not usually have; however, other tests are fairly simple and reliable when done by a skilled person. Three of these tests are as follows: the spark test, the chip test, and the magnetic tests.

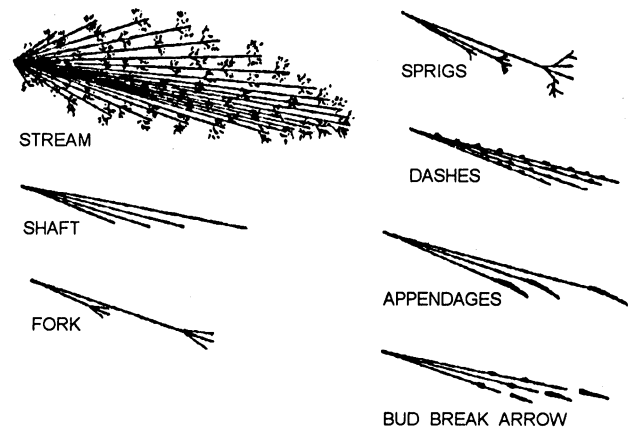


Figure 1-2.—Terms used in spark testing.

SPARK TEST

The spark test is made by holding a sample of the material against an abrasive wheel. By visually inspecting the spark stream, an experienced metalworker can identify the metals with considerable accuracy. This test is fast, economical, convenient, and easily accomplished, and there is no requirement for special equipment. We can use this test for identifying metal salvaged from scrap. Identification of scrap is particularly important when selecting material for cast iron or cast steel heat treatment.

When you hold a piece of iron or steel in contact with a high-speed abrasive wheel, small particles of the metal are torn loose so rapidly that they become red-hot. As these glowing bits of metal leave the wheel, they follow a path (trajectory) called the carrier line. This carrier line is easily followed with the eye, especially when observed against a dark background.

The sparks given off, or the lack of sparks, aid in the identification of the metal. The length of the spark stream, the color, and the form of the sparks are features you should look for. Figure 1-2 illustrates the terms used in referring to various basic spark forms produced in spark testing.

Steels having the same carbon content but differing alloying elements are difficult to identify because the alloying elements affect the carrier lines, the bursts, or the forms of characteristic bursts in the spark picture. The effect of the alloying element may slow or accelerate the carbon spark or make the carrier line lighter or darker in color. Molybdenum, for example, appears as a detached, orange-colored spearhead on the end of the carrier line. Nickel appears to suppress the effect of the carbon burst; however, the nickel spark can be identified

by tiny blocks of brilliant white light. Silicon suppresses the carbon burst even more than nickel. When silicon is present, the carrier line usually ends abruptly in a white flash of light.

Spark testing may be done with either a portable or stationary grinder. In either case, the speed on the outer rim of the wheel should not be less than 4,500 feet per minute. The abrasive wheel should be rather coarse, very hard, and kept clean to produce a true spark

To conduct a spark test on an abrasive wheel, hold the piece of metal on the wheel in a position that allows the spark stream to cross your line of vision. By trial and error, you soon discover what pressure is needed to get a stream of the proper length without reducing the speed of the grinder. Excessive pressure increases the temperature of the spark stream. This, in turn, increases the temperature of the burst and gives the appearance of a higher carbon content than actually is present. When making the test, watch a point about one third of the distance from the tail end of the spark stream. Watch only those sparks that cross your line of vision and try to form a mental image of the individual spark. Fix this spark image in your mind and then examine the whole spark picture.

While on the subject of abrasive wheels, it is a good idea to discuss some of the safety precautions associated with this tool.

- Never use an abrasive wheel that is cracked or out of balance because the vibration causes the wheel to shatter. When an abrasive wheel shatters, it can be disastrous for personnel standing in line with the wheel.

- Always check the wheel for secure mounting and cracks before putting it to use. When you install a new wheel on a grinder, be sure that it is the correct size. Remember, as you increase the wheel radius, the peripheral speed at the rim also increases, even though the driving motor rpm remains the same. Thus, if you should use an oversized wheel, there is a distinct danger the peripheral speed (and consequent centrifugal force) can become so great that the wheel may fly apart. Use wheels that are designed for a specific rpm. Guards are placed on grinders as protection in case a wheel should shatter.

- Never use a grinder when the guards have been removed. When turning the grinder on, you should stand to one side. This places you out of line with the wheel in case the wheel should burst.

- Never overload a grinder or put sideways pressure against the wheel, unless it is expressly built to withstand such use.

- Always wear appropriate safety goggles or a face shield while using the grinder. Ensure that the tool rest (the device that helps the operator hold the work) is adjusted to the minimum clearance for the wheel. Move the work across the entire face of the wheel to eliminate grooving and to minimize wheel dressing. Doing this prolongs the life of the wheel.

- Keep your fingers clear of the abrasive surface, and do not allow rags or clothing to become entangled in the wheel.

- Do not wear gloves while using an abrasive wheel.

- Never hold metal with tongs while grinding.

- Never grind nonferrous metals on a wheel intended for ferrous metals because such misuse clogs the pores of the abrasive material. This buildup of metal may cause it to become unbalanced and fly apart.

- Grinding wheels require frequent reconditioning. *Dressing* is the term used to describe the process of cleaning the periphery. This cleaning breaks away dull abrasive grains and smooths the surface, removing all the grooves. The wheel dresser shown in figure 1-3 is used for dressing grinding wheels on bench and pedestal grinders. For more information on grinding wheels, you should consult chapter 5 of NAVEDTRA 10085-B2 (*Tools and Their Uses*).

Referring now to figure 1-4, notice that in low-carbon steel (view A), the spark stream is about 70 inches long and the volume is moderately large. In high-carbon steel (view B), the stream is shorter (about 55 inches) and the volume larger. The few sparklers that may occur at any place in low-carbon steel are forked,

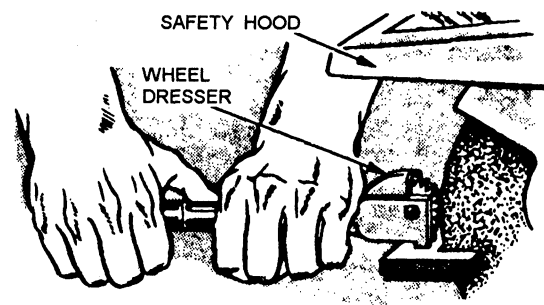


Figure 1-3.—Using a grinding wheel dresser.

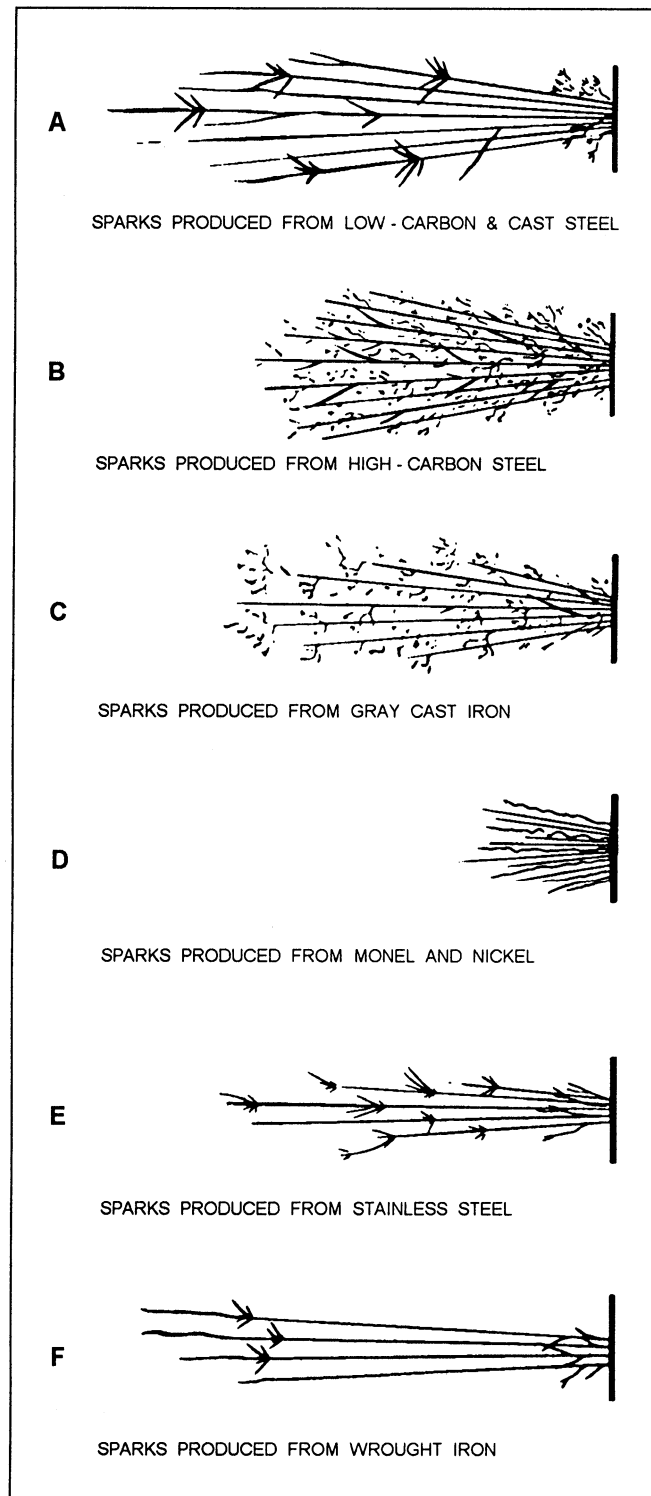


Figure 1-4.—Spark patterns formed by common metals.

Table 1-4.—Metal Identification by Chip Test

METALS	CHIP CHARACTERISTICS
WHITE CAST IRON	Chips are small, brittle fragments. Chipped surfaces not smooth.
GRAY CAST IRON	Chips are about 1/8 inch in length. Metal not easily chipped; therefore, chips break off and prevent smooth cut.
MALLEABLE IRON	Chips vary from 1/4 to 3/8 inch in length (larger than chips from cast iron). Metal is tough and hard to chip.
WROUGHT IRON	Chips have smooth edges. Metal is easily cut or chipped, and a chip can be made as a continuous strip.
LOW-CARBON AND CAST STEEL	Chips have smooth edges. Metal is easily cut or chipped, and a chip can be taken off as a continuous strip.
HIGH-CARBON STEEL	Chips show a fine-grain structure. Edges of chips are lighter in color than chips of low-carbon steel. Metal is hard, but can be chipped in a continuous strip.
COPPER	Chips are smooth, with sawtooth edges where cut. Metal is easily cut as a continuous strip.
BRASS AND BRONZE	Chips are smooth, with sawtooth edges. These metals are easily cut, but chips are more brittle than chips of copper. Continuous strip is not easily cut.
ALUMINUM AND ALUMINUM ALLOYS	Chips are smooth, with sawtooth edges. A chip can be cut as continuous strip.
MONEL	Chips have smooth edges. Continuous strip can be cut. Metal chips easily.
NICKEL	Chips have smooth edges. Continuous strip can be cut. Metal chips easily.
LEAD	Chips of any shape may be obtained because the metal is so soft that it can be cut with a knife.

and in high-carbon steel, they are small and repeating. Both metals produce a spark stream white in color.

Gray cast iron (view C) produces a stream of sparks about 25 inches in length. The sparklers are small and repeating, and their volume is rather small. Part of the stream near the wheel is red, and the outer portion is straw-colored.

Monel and nickel (view D) form almost identical spark streams. The sparks are small in volume and orange in color. The sparks form wavy streaks with no sparklers. Because of the similarity of the spark picture,

these metals must be distinguished from each other by some other method.

Stainless steel (view E) produces a spark stream about 50 inches in length, moderate volume, and with few sparklers. The sparklers are forked. The stream next to the wheel is straw-colored, and at the end, it is white.

The wrought-iron spark test (view F) produces a spark stream about 65 inches in length. The stream has a large volume with few sparklers. The sparks appear near the end of the stream and are forked. The stream next to the wheel is straw-colored, and the outer end of the stream is a brighter red.

One way to become proficient in spark testing ferrous metals is to gather an assortment of samples of known metals and test them. Make all of the samples about the same size and shape so their identities are not revealed simply by the size or shape. Number each sample and prepare a list of names and corresponding numbers. Then, without looking at the number of the sample, spark test one sample at a time, calling out its name to someone assigned to check it against the names and numbers on the list. Repeating this process gives you some of the experience you need to become proficient in identifying individual samples.

CHIP TEST

Another simple test used to identify an unknown piece of metal is the chip test. The chip test is made by removing a small amount of material from the test piece with a sharp, cold chisel. The material removed varies

from small, broken fragments to a continuous strip. The chip may have smooth, sharp edges; it may be coarse-grained or fine-grained; or it may have sawlike edges. The size of the chip is important in identifying the metal. The ease with which the chipping can be accomplished should also be considered. The information given in table 1-4 can help you identify various metals by the chip test.

MAGNETIC TEST

The use of a magnet is another method used to aid in the general identification of metals. Remember that ferrous metals, being iron-based alloys, normally are magnetic, and nonferrous metals are nonmagnetic. This test is not 100-percent accurate because some stainless steels are nonmagnetic. In this instance, there is no substitute for experience.

CHAPTER 2

BASIC HEAT TREATMENT

As Steelworkers, we are interested in the heat treatment of metals, because we have to know what effects the heat produced by welding or cutting has on metal. We also need to know the methods used to restore metal to its original condition. The process of heat treating is the method by which metals are heated and cooled in a series of specific operations that never allow the metal to reach the molten state. The purpose of heat treating is to make a metal more useful by changing or restoring its mechanical properties. Through heat treating, we can make a metal harder, stronger, and more resistant to impact. Also, heat treating can make a metal softer and more ductile. The one disadvantage is that no heat-treating procedure can produce all of these characteristics in one operation. Some properties are improved at the expense of others; for example, hardening a metal may make it brittle.

HEAT-TREATING THEORY

The various types of heat-treating processes are similar because they all involve the heating and cooling of metals; they differ in the heating temperatures and the cooling rates used and the final results. The usual methods of heat-treating ferrous metals (metals with iron) are annealing, normalizing, hardening, and tempering. Most nonferrous metals can be annealed, but never tempered, normalized, or case-hardened.

Successful heat treatment requires close control over all factors affecting the heating and cooling of a metal. This control is possible only when the proper equipment is available. The furnace must be of the proper size and type and controlled, so the temperatures are kept within the prescribed limits for each operation. Even the furnace atmosphere affects the condition of the metal being heat-treated.

The furnace atmosphere consists of the gases that circulate throughout the heating chamber and surround the metal, as it is being heated. In an electric furnace, the atmosphere is either air or a controlled mixture of gases. In a fuel-fired furnace, the atmosphere is the mixture of gases that comes from the combination of the air and the gases released by the fuel during combustion. These gases contain various proportions of carbon monoxide, carbon dioxide, hydrogen, nitrogen, oxygen,

water vapor, and other various hydrocarbons. Fuel-fired furnaces can provide three distinct atmospheres when you vary the proportions of air and fuel. They are called oxidizing, reducing, and neutral.

STAGES OF HEAT TREATMENT

Heat treating is accomplished in three major stages:

- Stage 1—Heating the metal slowly to ensure a uniform temperature
- Stage 2—Soaking (holding) the metal at a given temperature for a given time and cooling the metal to room temperature
- Stage 3—Cooling the metal to room temperature

HEATING STAGE

The primary objective in the heating stage is to maintain uniform temperatures. If uneven heating occurs, one section of a part can expand faster than another and result in distortion or cracking. Uniform temperatures are attained by slow heating.

The heating rate of a part depends on several factors. One important factor is the heat conductivity of the metal. A metal with a high-heat conductivity heats at a faster rate than one with a low conductivity. Also, the condition of the metal determines the rate at which it may be heated. The heating rate for hardened tools and parts should be slower than unstressed or untreated metals. Finally, size and cross section figure into the heating rate. Parts with a large cross section require slower heating rates to allow the interior temperature to remain close to the surface temperature that prevents warping or cracking. Parts with uneven cross sections experience uneven heating; however, such parts are less apt to be cracked or excessively warped when the heating rate is kept slow.

SOAKING STAGE

After the metal is heated to the proper temperature, it is held at that temperature until the desired internal structural changes take place. This process is called SOAKING. The length of time held at the proper

temperature is called the SOAKING PERIOD. The soaking period depends on the chemical analysis of the metal and the mass of the part. When steel parts are uneven in cross section, the soaking period is determined by the largest section.

During the soaking stage, the temperature of the metal is rarely brought from room temperature to the final temperature in one operation; instead, the steel is slowly heated to a temperature just below the point at which the change takes place and then it is held at that temperature until the heat is equalized throughout the metal. We call this process PREHEATING. Following preheat, the metal is quickly heated to the final required temperature.

When a part has an intricate design, it may have to be preheated at more than one temperature to prevent cracking and excessive warping. For example, assume an intricate part needs to be heated to 1500°F for hardening. This part could be slowly heated to 600°F, soaked at this temperature, then heated slowly to 1200°F, and then soaked at that temperature. Following the final preheat, the part should then be heated quickly to the hardening temperature of 1500°F.

NOTE: Nonferrous metals are seldom preheated, because they usually do not require it, and preheating can cause an increase in the grain size in these metals.

COOLING STAGE

After a metal has been soaked, it must be returned to room temperature to complete the heat-treating process. To cool the metal, you can place it in direct contact with a COOLING MEDIUM composed of a gas, liquid, solid, or combination of these. The rate at which the metal is cooled depends on the metal and the properties desired. The rate of cooling depends on the medium; therefore, the choice of a cooling medium has an important influence on the properties desired.

Quenching is the procedure used for cooling metal rapidly in oil, water, brine, or some other medium. Because most metals are cooled rapidly during the hardening process, quenching is usually associated with hardening; however, quenching does not always result in an increase in hardness; for example, to anneal copper, you usually quench it in water. Other metals, such as air-hardened steels, are cooled at a relatively slow rate for hardening.

Some metals crack easily or warp during quenching, and others suffer no ill effects; therefore, the quenching medium must be chosen to fit the metal. Brine or water

is used for metals that require a rapid cooling rate, and oil mixtures are more suitable for metals that need a slower rate of cooling. Generally, carbon steels are water-hardened and alloy steels are oil-hardened. Nonferrous metals are normally quenched in water.

HEAT COLORS FOR STEEL

You are probably familiar with the term *red-hot* as applied to steel. Actually, steel takes on several colors and shades from the time it turns a dull red until it reaches a white heat. These colors and the corresponding temperatures are listed in table 2-1.

During hardening, normalizing, and annealing, steel is heated to various temperatures that produce color changes. By observing these changes, you can determine the temperature of the steel. As an example, assume that you must harden a steel part at 1500°F. Heat the part slowly and evenly while watching it closely for any change in color. Once the steel begins to turn red, carefully note each change in shade. Continue the even heating until the steel is bright red; then quench the part.

The success of a heat-treating operation depends largely on your judgment and the accuracy with which you identify each color with its corresponding temperature. From a study of table 2-1, you can see that close observation is necessary. You must be able to tell the difference between faint red and blood red and between dark cherry and medium cherry. To add to the difficulty, your conception of medium cherry may differ from that of the person who prepared the table. For an actual heat-treating operation, you should get a chart showing the actual colors of steel at various temperatures.

TYPES OF HEAT TREATMENT

Four basic types of heat treatment are used today. They are annealing, normalizing, hardening, and tempering. The techniques used in each process and how they relate to Steelworkers are given in the following paragraphs.

ANNEALING

In general, annealing is the opposite of hardening. You anneal metals to relieve internal stresses, soften them, make them more ductile, and refine their grain structures. Annealing consists of heating a metal to a specific temperature, holding it at that temperature for a set length of time, and then cooling the metal to room temperature. The cooling method depends on the

Table 2-1.—Heat Colors for Steel

Color	Temperature	
	°F	°C
Faint red visible in dark	750	399
Faint red	900	482
Blood red	1050	565
Dark cherry	1075	579
Medium cherry	1250	677
Cherry or full red	1375	746
Bright red	1550	843
Salmon	1650	899
Orange	1725	940
Lemon	1825	996
Light yellow	1975	1079
White	2200	1204
Dazzling white	2350	1288

Table 2-2.—Approximate Soaking Periods for Hardening, Annealing, and Normalizing Steel

Thickness of Metal (inches)	Time of heating to Required Temperature (hr)	Soaking Time (hr)
Up to 1	3/4	1/2
1 to 2	1 1/4	1/2
2 to 3	1 3/4	3/4
3 to 4	2 1/4	1
4 to 5	2 3/4	1
5 to 8	3 1/2	1 1/2

metal and the properties desired. Some metals are furnace-cooled, and others are cooled by burying them in ashes, lime, or other insulating materials.

Welding produces areas that have molten metal next to other areas that are at room temperature. As the weld cools, internal stresses occur along with hard spots and brittleness. Welding can actually weaken the metal. Annealing is just one of the methods for correcting these problems.

Ferrous Metal

To produce the maximum softness in steel, you heat the metal to its proper temperature, soak it, and then let it cool very slowly. The cooling is done by burying the hot part in an insulating material or by shutting off the furnace and allowing the furnace and the part to cool together. The soaking period depends on both the mass of the part and the type of metal. The approximate soaking periods for annealing steel are given in table 2-2.

Steel with an extremely low-carbon content requires the highest annealing temperature. As the carbon content increases, the annealing temperatures decrease.

Nonferrous Metal

Copper becomes hard and brittle when mechanically worked; however, it can be made soft again by annealing. The annealing temperature for copper is between 700°F and 900°F. Copper may be cooled rapidly or slowly since the cooling rate has no effect on the heat treatment. The one drawback experienced in annealing copper is the phenomenon called “hot shortness.” At about 900°F, copper loses its tensile strength, and if not properly supported, it could fracture.

Aluminum reacts similar to copper when heat treating. It also has the characteristic of “hot shortness.” A number of aluminum alloys exist and each requires special heat treatment to produce their best properties.

NORMALIZING

Normalizing is a type of heat treatment applicable to ferrous metals only. It differs from annealing in that the metal is heated to a higher temperature and then removed from the furnace for air cooling.

The purpose of normalizing is to remove the internal stresses induced by heat treating, welding, casting, forging, forming, or machining. Stress, if not controlled, leads to metal failure; therefore, before hardening steel, you should normalize it first to ensure the maximum desired results. Usually, low-carbon steels do not require normalizing; however, if these steels are normalized, no harmful effects result. Castings are usually annealed, rather than normalized; however, some castings require the normalizing treatment. Table 2-2 shows the approximate soaking periods for normalizing steel. Note that the soaking time varies with the thickness of the metal.

Normalized steels are harder and stronger than annealed steels. In the normalized condition, steel is much tougher than in any other structural condition. Parts subjected to impact and those that require maximum toughness with resistance to external stress are usually normalized. In normalizing, the mass of metal has an influence on the cooling rate and on the resulting structure. Thin pieces cool faster and are harder after normalizing than thick ones. In annealing (furnace cooling), the hardness of the two are about the same.

HARDENING

The hardening treatment for most steels consists of heating the steel to a set temperature and then cooling it rapidly by plunging it into oil, water, or brine. Most steels require rapid cooling (quenching) for hardening but a few can be air-cooled with the same results. Hardening increases the hardness and strength of the steel, but makes it less ductile. Generally, the harder the steel, the more brittle it becomes. To remove some of the brittleness, you should temper the steel after hardening.

Many nonferrous metals can be hardened and their strength increased by controlled heating and rapid cooling. In this case, the process is called heat treatment, rather than hardening.

To harden steel, you cool the metal rapidly after thoroughly soaking it at a temperature slightly above its upper critical point. The approximate soaking periods for hardening steel are listed in table 2-2. The addition of alloys to steel decreases the cooling rate required to produce hardness. A decrease in the cooling rate is an advantage, since it lessens the danger of cracking and warping.

Pure iron, wrought iron, and extremely low-carbon steels have very little hardening properties and are difficult to harden by heat treatment. Cast iron has limited capabilities for hardening. When you cool cast iron rapidly, it forms white iron, which is hard and brittle. And when you cool it slowly, it forms gray iron, which is soft but brittle under impact.

In plain carbon steel, the maximum hardness obtained by heat treatment depends almost entirely on the carbon content of the steel. As the carbon content increases, the hardening ability of the steel increases; however, this capability of hardening with an increase in carbon content continues only to a certain point. In practice, 0.80 percent carbon is required for maximum hardness. When you increase the carbon content beyond 0.80 percent, there is no increase in hardness, but there is an increase in wear resistance. This increase in wear resistance is due to the formation of a substance called hard cementite.

When you alloy steel to increase its hardness, the alloys make the carbon more effective in increasing hardness and strength. Because of this, the carbon content required to produce maximum hardness is lower than it is for plain carbon steels. Usually, alloy steels are superior to carbon steels.

Carbon steels are usually quenched in brine or water, and alloy steels are generally quenched in oil. When hardening carbon steel, remember that you must cool the steel to below 1000°F in less than 1 second. When you add alloys to steel, the time limit for the temperature to drop below 1000°F increases above the 1-second limit, and a slower quenching medium can produce the desired hardness.

Quenching produces extremely high internal stresses in steel, and to relieve them, you can temper the steel just before it becomes cold. The part is removed from the quenching bath at a temperature of about 200°F and allowed to air-cool. The temperature range from 200°F down to room temperature is called the “cracking range” and you do not want the steel to pass through it.

In the following paragraphs, we discuss the different methods of hardening that are commercially used. In the Seabees, we use a rapid surface hardening compound called “Case” that can be ordered through the Navy supply system. Information on the use of “Case” is located in the *Welding Materials Handbook*, P-433.

Case Hardening

Case hardening produces a hard, wear-resistant surface or case over a strong, tough core. The principal forms of casehardening are carburizing, cyaniding, and nitriding. Only ferrous metals are case-hardened.

Case hardening is ideal for parts that require a wear-resistant surface and must be tough enough internally to withstand heavy loading. The steels best suited for case hardening are the low-carbon and low-alloy series. When high-carbon steels are case-hardened, the hardness penetrates the core and causes brittleness. In case hardening, you change the surface of the metal chemically by introducing a high carbide or nitride content. The core remains chemically unaffected. When heat-treated, the high-carbon surface responds to hardening, and the core toughens.

CARBURIZING.— Carburizing is a case-hardening process by which carbon is added to the surface of low-carbon steel. This results in a carburized steel that has a high-carbon surface and a low-carbon interior. When the carburized steel is heat-treated, the case becomes hardened and the core remains soft and tough.

Two methods are used for carburizing steel. One method consists of heating the steel in a furnace containing a carbon monoxide atmosphere. The other method has the steel placed in a container packed with charcoal or some other carbon-rich material and then

heated in a furnace. To cool the parts, you can leave the container in the furnace to cool or remove it and let it air cool. In both cases, the parts become annealed during the slow cooling. The depth of the carbon penetration depends on the length of the soaking period. With today's methods, carburizing is almost exclusively done by gas atmospheres.

CYANIDING.— This process is a type of case hardening that is fast and efficient. Preheated steel is dipped into a heated cyanide bath and allowed to soak. Upon removal, it is quenched and then rinsed to remove any residual cyanide. This process produces a thin, hard shell that is harder than the one produced by carburizing and can be completed in 20 to 30 minutes vice several hours. The major drawback is that cyanide salts are a deadly poison.

NITRIDING.— This case-hardening method produces the hardest surface of any of the hardening processes. It differs from the other methods in that the individual parts have been heat-treated and tempered before nitriding. The parts are then heated in a furnace that has an ammonia gas atmosphere. No quenching is required so there is no worry about warping or other types of distortion. This process is used to case harden items, such as gears, cylinder sleeves, camshafts and other engine parts, that need to be wear resistant and operate in high-heat areas.

Flame Hardening

Flame hardening is another procedure that is used to harden the surface of metal parts. When you use an oxyacetylene flame, a thin layer at the surface of the part is rapidly heated to its critical temperature and then immediately quenched by a combination of a water spray and the cold base metal. This process produces a thin, hardened surface, and at the same time, the internal parts retain their original properties. Whether the process is manual or mechanical, a close watch must be maintained, since the torches heat the metal rapidly and the temperatures are usually determined visually.

Flame hardening may be either manual or automatic. Automatic equipment produces uniform results and is more desirable. Most automatic machines have variable travel speeds and can be adapted to parts of various sizes and shapes. The size and shape of the torch depends on the part. The torch consists of a mixing head, straight extension tube, 90-degree extension head, an adjustable yoke, and a water-cooled tip. Practically any shape or size flame-hardening tip is available (fig. 2-1).

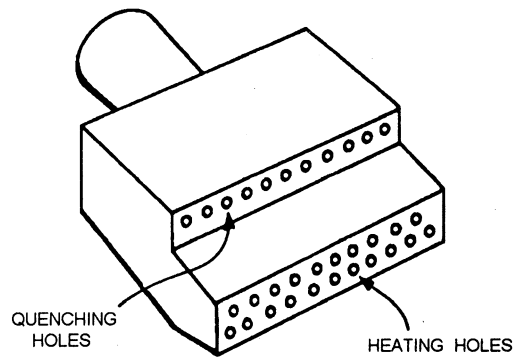


Figure 2-1.—Progressive hardening torch tip.

Tips are produced that can be used for hardening flats, rounds, gears, cams, cylinders, and other regular or irregular shapes.

In hardening localized areas, you should heat the metal with a standard hand-held welding torch. Adjust the torch flame to neutral (see chapter 4) for normal heating; however, in corners and grooves, use a slightly oxidizing flame to keep the torch from sputtering. You also should particularly guard against overheating in corners and grooves. If dark streaks appear on the metal surface, this is a sign of overheating, and you need to increase the distance between the flame and the metal.

For the best heating results, hold the torch with the tip of the inner cone about an eighth of an inch from the surface and direct the flame at right angles to the metal. Sometimes it is necessary to change this angle to obtain better results; however, you rarely find a deviation of more than 30 degrees. Regulate the speed of torch travel according to the type of metal, the mass and shape of the part, and the depth of hardness desired.

In addition, you must select the steel according to the properties desired. Select carbon steel when surface hardness is the primary factor and alloy steel when the physical properties of the core are also factors. Plain carbon steels should contain more than 0.35% carbon for good results in flame hardening. For water quenching, the effective carbon range is from 0.40% to 0.70%. Parts with a carbon content of more than 0.70% are likely to surface crack unless the heating and quenching rate are carefully controlled.

The surface hardness of a flame-hardened section is equal to a section that was hardened by furnace heating and quenching. The decrease in hardness between the case and the core is gradual. Since the core is not affected by flame hardening, there is little danger of spalling or flaking while the part is in use. Thus flame

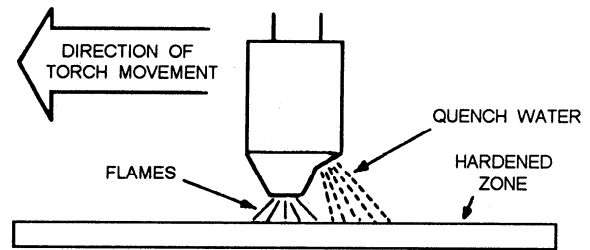


Figure 2-2.—Progressive hardening.

hardening produces a hard case that is highly resistant to wear and a core that retains its original properties.

Flame hardening can be divided into five general methods: stationary, circular band progressive, straight-line progressive, spiral band progressive, and circular band spinning.

STATIONARY METHOD.— In this method the torch and the metal part are both held stationary.

CIRCULAR BAND PROGRESSIVE METHOD.— This method is used for hardening outside surfaces of round sections. Usually, the object is rotated in front of a stationary torch at a surface speed of from 3 to 12 inches per minute. The heating and quenching are done progressively, as the part rotates; therefore, when the part has completed one rotation, a hardened band encircles the part. The width of the hardened band depends upon the width of the torch tip. To harden the full length of a long section, you can move the torch and repeat the process over and over until the part is completely hardened. Each pass or path of the torch should overlap the previous one to prevent soft spots.

STRAIGHT-LINE PROGRESSIVE METHOD.— With the straight-line progressive method, the torch travels along the surface, treating a strip that is about the same width as the torch tip. To harden wider areas, you move the torch and repeat the process. Figure 2-2 is an example of progressive hardening.

SPIRAL BAND PROGRESSIVE METHOD.— For this technique a cylindrical part is mounted between lathe centers, and a torch with an adjustable holder is mounted on the lathe carriage. As the part rotates, the torch moves parallel to the surface of the part. This travel is synchronized with the part's rotary motion to produce a continuous band of hardness. Heating and quenching occur at the same time. The number of torches required depends on the diameter of the part, but seldom are more than two torches used.

CIRCULAR BAND SPINNING METHOD.— The circular band spinning method provides the best

results for hardening cylindrical parts of small or medium diameters. The part is mounted between lathe centers and turned at a high rate of speed past a stationary torch. Enough torches are placed side by side to heat the entire part. The part can be quenched by water flowing from the torch tips or in a separate operation.

When you perform heating and quenching as separate operations, the tips are water-cooled internally, but no water sprays onto the surface of the part.

In flame hardening, you should follow the same safety precautions that apply to welding (see chapter 3). In particular, guard against holding the flame too close to the surface and overheating the metal. In judging the temperature of the metal, remember that the flame makes the metal appear colder than it actually is.

TEMPERING

After the hardening treatment is applied, steel is often harder than needed and is too brittle for most practical uses. Also, severe internal stresses are set up during the rapid cooling from the hardening temperature. To relieve the internal stresses and reduce brittleness, you should temper the steel after it is hardened. Tempering consists of heating the steel to a specific temperature (below its hardening temperature), holding it at that temperature for the required length of time, and then cooling it, usually in still air. The resultant strength, hardness, and ductility depend on the temperature to which the steel is heated during the tempering process.

The purpose of tempering is to reduce the brittleness imparted by hardening and to produce definite physical properties within the steel. Tempering always follows, never precedes, the hardening operation. Besides reducing brittleness, tempering softens the steel. That is unavoidable, and the amount of hardness that is lost depends on the temperature that the steel is heated to during the tempering process. That is true of all steels except high-speed steel. Tempering increases the hardness of high-speed steel.

Tempering is always conducted at temperatures below the low-critical point of the steel. In this respect, tempering differs from annealing, normalizing, and hardening in which the temperatures are above the upper critical point. When hardened steel is reheated, tempering begins at 212°F and continues as the temperature increases toward the low-critical point. By selecting a definite tempering temperature, you can predetermine the resulting hardness and strength. The minimum temperature time for tempering should be 1 hour. If the part

is more than 1 inch thick, increase the time by 1 hour for each additional inch of thickness.

Normally, the rate of cooling from the tempering temperature has no effect on the steel. Steel parts are usually cooled in still air after being removed from the tempering furnace; however, there are a few types of steel that must be quenched from the tempering temperature to prevent brittleness. These blue brittle steels can become brittle if heated in certain temperature ranges and allowed to cool slowly. Some of the nickel chromium steels are subject to this temper brittleness.

Steel may be tempered after being normalized, providing there is any hardness to temper. Annealed steel is impossible to temper. Tempering relieves quenching stresses and reduces hardness and brittleness. Actually, the tensile strength of a hardened steel may increase as the steel is tempered up to a temperature of about 450°F. Above this temperature it starts to decrease. Tempering increases softness, ductility, malleability, and impact resistance. Again, high-speed steel is an exception to the rule. High-speed steel increases in hardness on tempering, provided it is tempered at a high temperature (about 1550°F). Remember, all steel should be removed from the quenching bath and tempered before it is completely cold. Failure to temper correctly results in a quick failure of the hardened part.

Permanent steel magnets are made of special alloys and are heat-treated by hardening and tempering. Hardness and stability are the most important properties in permanent magnets. Magnets are tempered at the minimum tempering temperature of 212°F by placing them in boiling water for 2 to 4 hours. Because of this low-tempering temperature, magnets are very hard.

Case-hardened parts should not be tempered at too high a temperature or they may lose some of their hardness. Usually, a temperature range from 212°F to 400°F is high enough to relieve quenching stresses. Some metals require no tempering. The design of the part helps determine the tempering temperature.

Color tempering is based on the oxide colors that appear on the surface of steel, as it is heated. When you slowly heat a piece of polished hardened steel, you can see the surface turn various colors as the temperature changes. These colors indicate structural changes are taking place within the metal. Once the proper color appears, the part is rapidly quenched to prevent further structural change. In color tempering, the surface of the steel must be smooth and free of oil. The part may be heated by a torch, in a furnace, over a hot plate, or by radiation.

Table 2-3.—Oxide Colors for Tempering Steel

Color	Temperature	
	°F	°C
Pale yellow	428	220
Straw	446	230
Golden yellow	469	243
Brown	491	255
Brown dappled with purple	509	265
Purple	531	277
Dark blue	550	288
Bright blue	567	297
Pale blue	610	321

Cold chisels and similar tools must have hard cutting edges and softer bodies and heads. The head must be tough enough to prevent shattering when struck with shammer. The cutting edge must be more than twice as hard as the head, and the zone separating the two must be carefully blended to prevent a line of demarcation. A method of color tempering frequently used for chisels and similar tools is one in which the cutting end is heated by the residual heat of the opposite end of the same tool. To harden and temper a cold chisel by this method, you heat the tool to the proper hardening temperature and then quench the cutting end only. Bob the chisel up and down in the bath, always keeping the cutting edge below the surface. This method air-cools the head while rapidly quenching the cutting edge. The result is a tough head, fully hardened cutting edge, and a properly blended structure.

When the cutting end has cooled, remove the chisel from the bath and quickly polish the cutting end with a buff stick (emery). Watch the polished surface, as the heat from the opposite end feeds back into the quenched end. As the temperature of the hardened end increases, oxide colors appear. These oxide colors progress from pale yellow, to a straw color, and end in blue colors. As soon as the correct shade of blue appears, quench the entire chisel to prevent further softening of the cutting edge. The metal is tempered as soon as the proper oxide color appears and quenching merely prevents further tempering by freezing the process. This final quench has no effect on the body and the head of the chisel, because their temperature will have dropped below the critical point by the time the proper oxide color appears on the

cutting edge. When you have completed the above described process, the chisel will be hardened and tempered and only needs grinding.

During the tempering, the oxide color at which you quench the steel varies with the properties desired in the part. Table 2-3 lists the different colors and their corresponding temperatures. To see the colors clearly, you must turn the part from side to side and have good lighting. While hand tempering produces the same result as furnace tempering, there is a greater possibility for error. The slower the operation is performed, the more accurate are the results obtained.

QUENCHING MEDIA

The cooling rate of an object depends on many things. The size, composition, and initial temperature of the part and final properties are the deciding factors in selecting the quenching medium. A quenching medium must cool the metal at a rate rapid enough to produce the desired results.

Mass affects quenching in that as the mass increases, the time required for complete cooling also increases. Even though parts are the same size, those containing holes or recesses cool more rapidly than solid objects. The composition of the metal determines the maximum cooling rate possible without the danger of cracking or warping. This critical cooling rate, in turn, influences the choice of the quenching medium.

The cooling rate of any quenching medium varies with its temperature; therefore, to get uniform results,

you must keep the temperature within prescribed limits. The absorption of heat by the quenching medium also depends, to a large extent, on the circulation of the quenching medium or the movement of the part. Agitation of the liquid or the part breaks up the gas that forms an insulating blanket between the part and the liquid.

Normally, hardening takes place when you quench a metal. The composition of the metal usually determines the type of quench to use to produce the desired hardness. For example, shallow-hardened low-alloy and carbon steels require severer quenching than deep-hardened alloy steels that contain large quantities of nickel, manganese, or other elements. Therefore, shallow-hardening steels are usually quenched in water or brine, and the deep-hardening steels are quenched in oil. Sometimes it is necessary to use a combination quench, starting with brine or water and finishing with oil. In addition to producing the desired hardness, the quench must keep cracking, warping, and soft spots to a minimum.

The volume of quenching liquid should be large enough to absorb all the heat during a normal quenching operation without the use of additional cooling. As more metals are quenched, the liquid absorbs the heat and this temperature rise causes a decrease in the cooling rate. Since quenching liquids must be maintained within definite temperature ranges, mechanical means are used to keep the temperature at prescribed levels during continuous operations.

LIQUID QUENCHING

The two methods used for liquid quenching are called still-bath and flush quenching.

In still-bath quenching, you cool the metal in a tank of liquid. The only movement of the liquid is that caused by the movement of the hot metal, as it is being quenched.

For flush quenching, the liquid is sprayed onto the surface and into every cavity of the part at the same time to ensure uniform cooling. Flush quenching is used for parts having recesses or cavities that would not be properly quenched by ordinary methods. That assures a thorough and uniform quench and reduces the possibilities of distortion.

Quenching liquids must be maintained at uniform temperatures for satisfactory results. That is particularly true for oil. To keep the liquids at their proper temperature, they are usually circulated through water-cooled

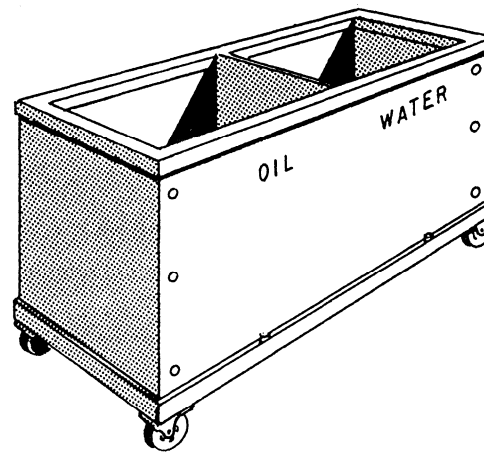


Figure 2-3.—Portable quench tank.

coils. Self-contained coolers are integral parts of large quench tanks.

A typical portable quench tank is shown in figure 2-3. This type can be moved as needed to various parts of the heat-treating shop. Some tanks may have one or more compartments. If one compartment contains oil and the other water, the partition must be liquid-tight to prevent mixing. Each compartment has a drain plug, a screen in the bottom to catch scale and other foreign matter, and a mesh basket to hold the parts. A portable electric pump can be attached to the rim of the tank to circulate the liquid. This mechanical agitation aids in uniform cooling.

Water

Water can be used to quench some forms of steel, but does not produce good results with tool or other alloy steels. Water absorbs large quantities of atmospheric gases, and when a hot piece of metal is quenched, these gases have a tendency to form bubbles on the surface of the metal. These bubbles tend to collect in holes or recesses and can cause soft spots that later lead to cracking or warping.

The water in the quench tank should be changed daily or more often if required. The quench tank should be large enough to hold the part being treated and should have adequate circulation and temperature control. The temperature of the water should not exceed 65°F.

When aluminum alloys and other nonferrous metals require a liquid quench, you should quench them in clean water. The volume of water in the quench tank should be large enough to prevent a temperature rise of more than 20°F during a single quenching operation. For

Table 2-4.—Properties and Average Cooling Abilities of Quenching Media

Quenching Medium	Cooling Rate Compared To Water	Flash Point (°F)	Fire Point (°F)
Sodium Hydroxide (10%)	2.06		
Brine (10%) at 65°F	1.96		
Caustic Soda (10%)	1.38		
Water at 65°F	1.00		
Prepared Oil	0.44	365	405
Fuel Oil	0.36	205	219
Cottonseed Oil	0.36	610	680
Neatsfoot Oil	0.33	500	621
Sperm Oil	0.33	500	581
Fish Oil	0.31	401	446
Castor Oil	0.29	565	640
Machine Oil	0.22	405	464
Lard Oil	0.19	565	685
Circulated Air	0.032		
Still Air	0.0152		

heavy-sectioned parts, the temperature rise may exceed 20°F, but should be kept as low as possible. For wrought products, the temperature of the water should be about 65°F and should never exceed 100°F before the piece enters the liquid.

Brine

Brine is the result of dissolving common rock salt in water. This mixture reduces the absorption of atmospheric gases that, in turn, reduces the amount of bubbles. As a result, brine wets the metal surface and cools it more rapidly than water. In addition to rapid and uniform cooling, the brine removes a large percentage of any scale that may be present.

The brine solution should contain from 7% to 10% salt by weight or three-fourths pound of salt for each gallon of water. The correct temperature range for a brine solution is 65°F to 100°F.

Low-alloy and carbon steels can be quenched in brine solutions; however, the rapid cooling rate of brine

can cause cracking or stress in high-carbon or low-alloy steels that are uneven in cross section.

Because of the corrosive action of salt on nonferrous metals, these metals are not quenched in brine.

Oil

Oil is used to quench high-speed and oil-hardened steels and is preferred for all other steels provided that the required hardness can be obtained. Practically any type of quenching oil is obtainable, including the various animal oils, fish oils, vegetable oils, and mineral oils. Oil is classed as an intermediate quench. It has a slower cooling rate than brine or water and a faster rate than air. The quenching oil temperature should be kept within a range of 80°F to 150°F. The properties and average cooling powers of various quenching oils are given in table 2-4.

Water usually collects in the bottom of oil tanks but is not harmful in small amounts. In large quantities it can interfere with the quenching operations; for example, the end of a long piece may extend into the water at

the bottom of the tank and crack as a result of the more rapid cooling.

Nonferrous metals are not routinely quenched in oil unless specifications call for oil quenching.

Caustic Soda

A solution of water and caustic soda, containing 10 percent caustic soda by weight, has a higher cooling rate than water. Caustic soda is used only for those types of steel that require extremely rapid cooling and is NEVER used as a quench for nonferrous metals.

WARNING

CAUSTIC SODA REQUIRES SPECIAL
HANDLING BECAUSE OF ITS HARMFUL
EFFECTS ON SKIN AND CLOTHING.

DRY QUENCHING

This type of quenching uses materials other than liquids. In most cases, this method is used only to slow the rate of cooling to prevent warping or cracking.

Air

Air quenching is used for cooling some highly alloyed steels. When you use still air, each tool or part should be placed on a suitable rack so the air can reach all sections of the piece. Parts cooled with circulated air are placed in the same manner and arranged for uniform cooling. Compressed air is used to concentrate the cooling on specific areas of a part. The air lines must be free of moisture to prevent cracking of the metal.

Although nonferrous metals are usually quenched in water, pieces that are too large to fit into the quench tank can be cooled with forced-air drafts; however, an air quench should be used for nonferrous metal only when the part will not be subjected to severe corrosion conditions and the required strength and other physical properties can be developed by a mild quench.

Solids

The solids used for cooling steel parts include cast-iron chips, lime, sand, and ashes. Solids are generally used to slow the rate of cooling; for example, a cast-iron part can be placed in a lime box after welding to prevent cracking and warping. All solids must be free of moisture to prevent uneven cooling.

CHAPTER 3

INTRODUCTION TO WELDING

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

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

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

WELDING PROCESSES

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

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

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

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

GAS WELDING

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

ARC WELDING

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

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

MASTER CHART OF WELDING AND ALLIED PROCESSES

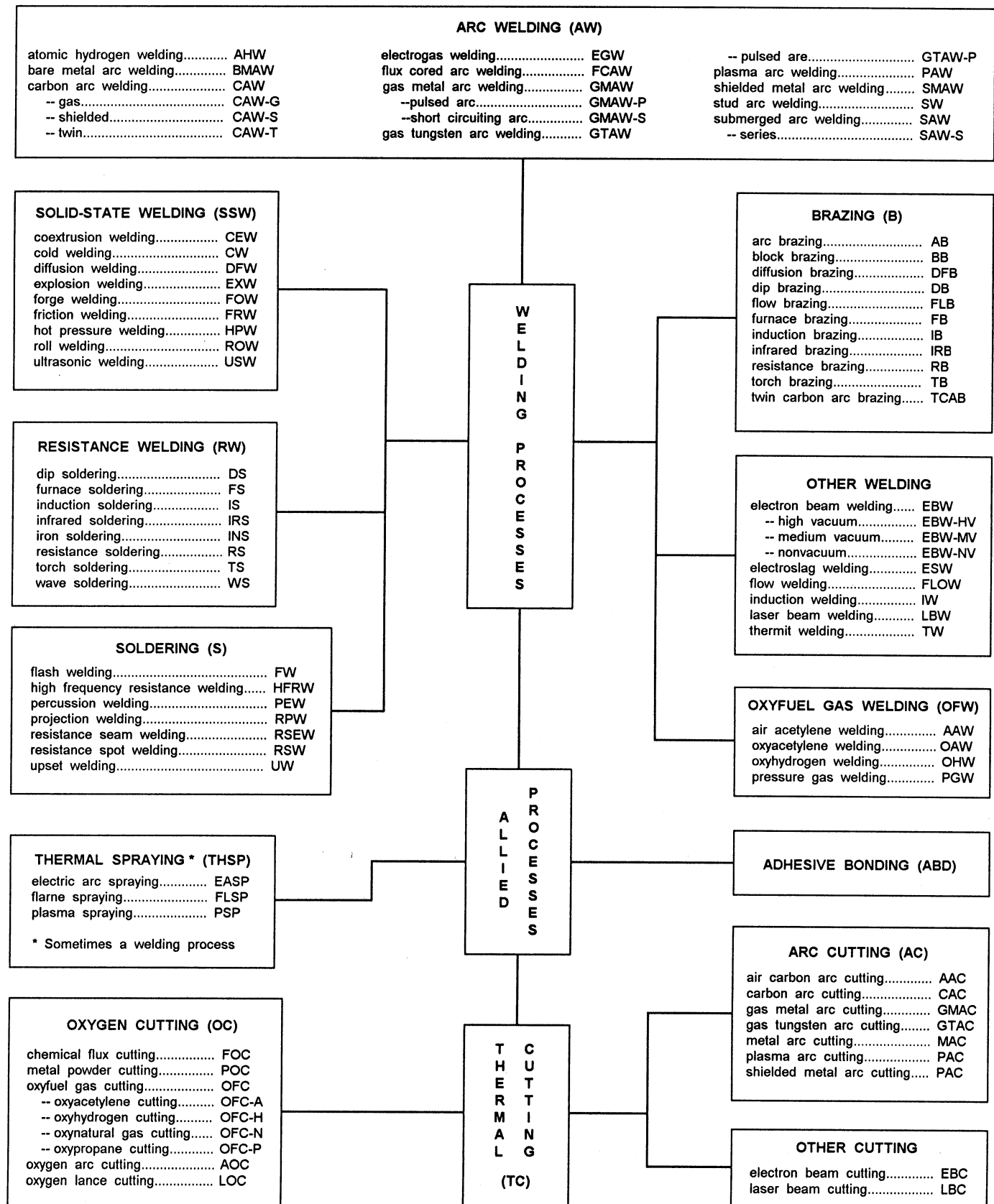


Figure 3-1.—Welding processes.

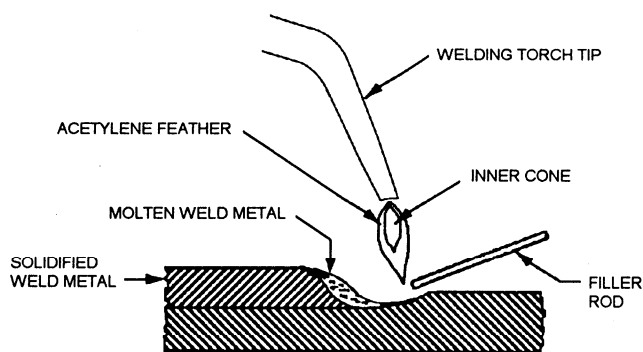


Figure 3-2.—Oxyfuel gas welding (OFW).

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

Shielded Metal Arc Welding (SMAW)

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

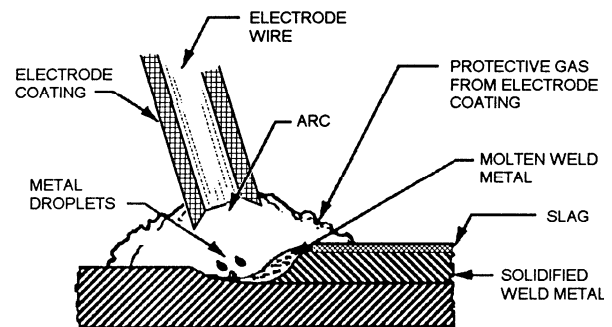


Figure 3-3.—Shielded metal arc welding (SMAW).

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

Gas Shielded Arc Welding

The primary difference between shielded metal arc welding and gas shielded arc welding is the type of shielding used. In gas shielded arc welding, both the arc and the molten puddle are covered by a shield of inert gas. The shield of inert gas prevents atmospheric contamination, thereby producing a better weld. The primary gases used for this process are helium, argon, or carbon dioxide. In some instances, a mixture of these gases is used. The processes used in gas shielded arc welding are known as **gas tungsten arc welding**

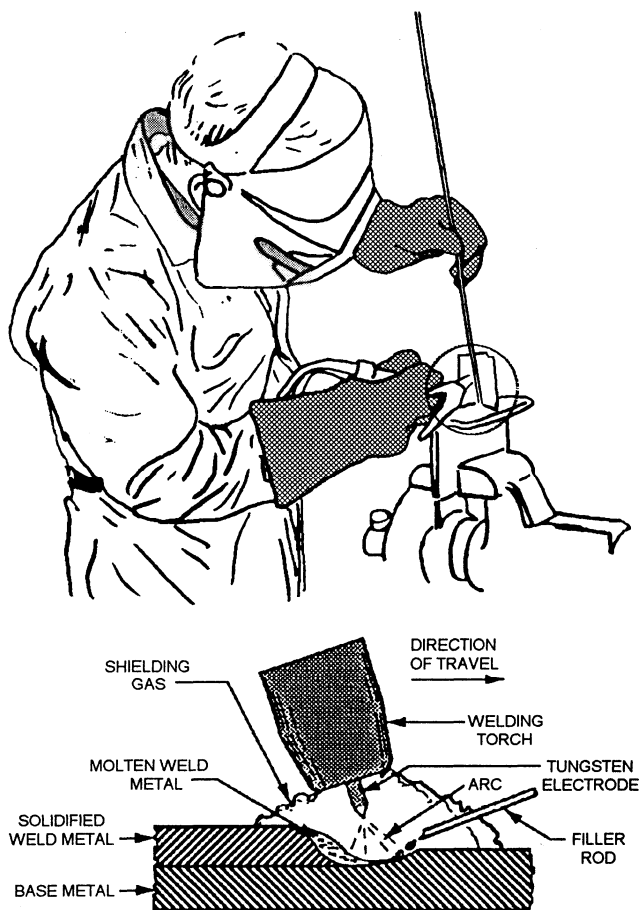


Figure 3-4.—Gas tungsten arc welding (GTAW).

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

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

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

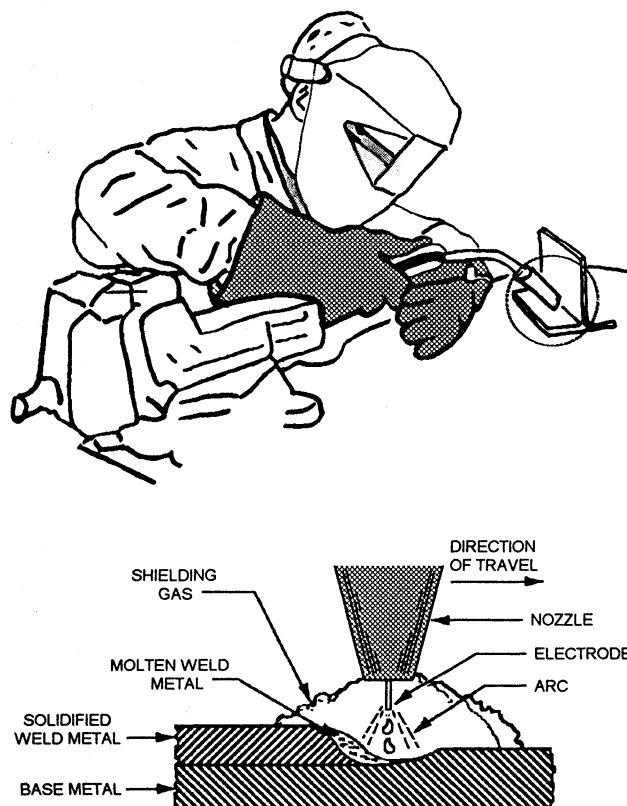


Figure 3-5.—Gas metal arc welding (GMAW).

WELDING TERMINOLOGY

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

FILLER METALS

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

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

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

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

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

FLUXES

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

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

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

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

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

- It remains stable and does not change to a vapor rapidly within the temperature range of the welding procedure.
- It dissolves all oxides and removes them from the joint surfaces.
- It adheres to the metal surfaces while they are being heated and does not ball up or blow away.
- It does not cause a glare that makes it difficult to see the progress of welding or brazing.
- It is easy to remove after the joint is welded.
- It is available in an easily applied form.

CAUTION

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

WELD JOINTS

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

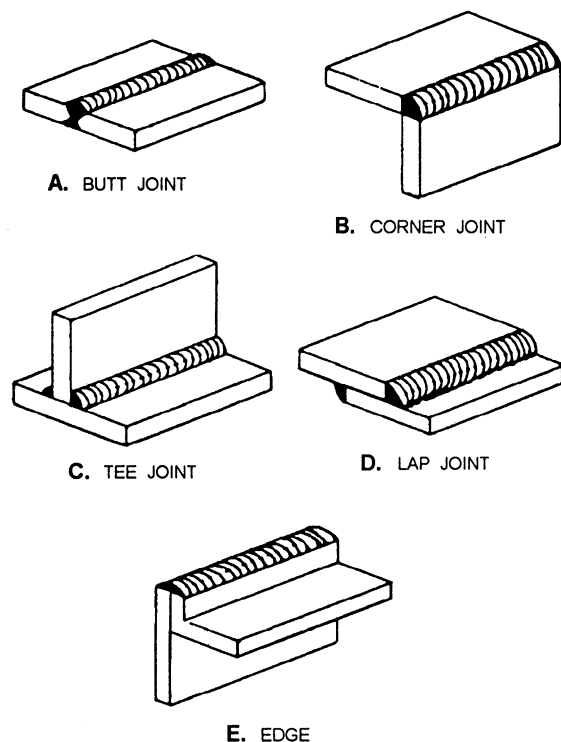


Figure 3-6.—Basic weld joints.

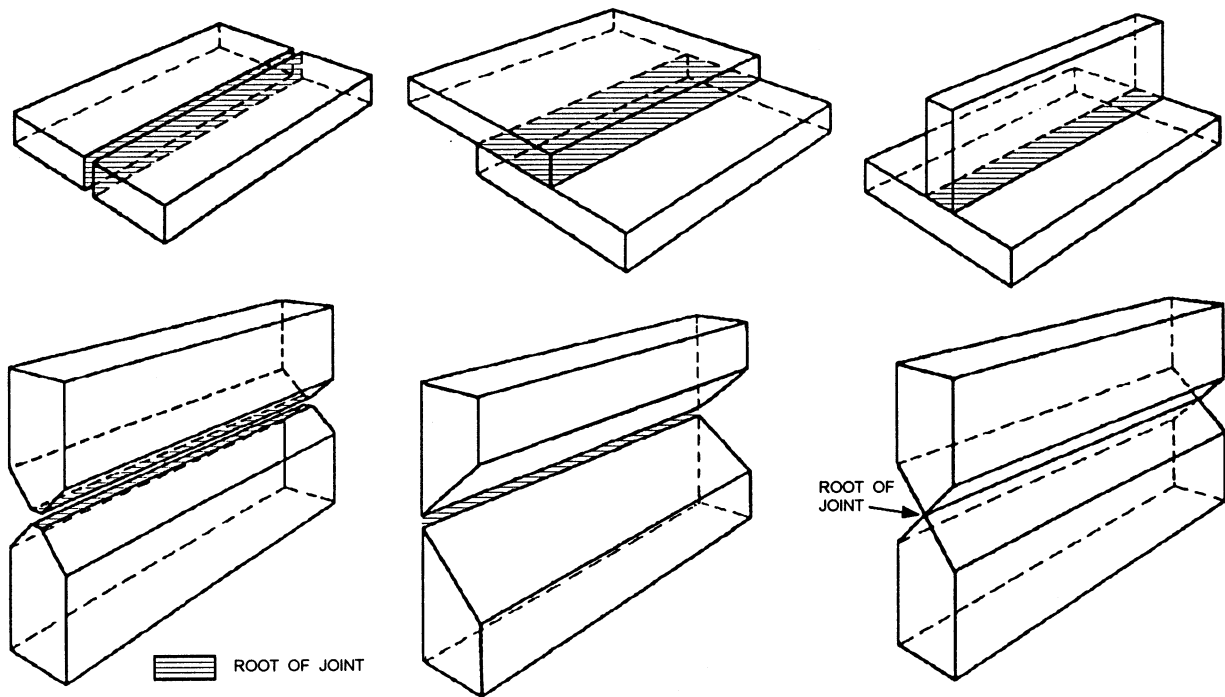


Figure 3-7.—Root of joint.

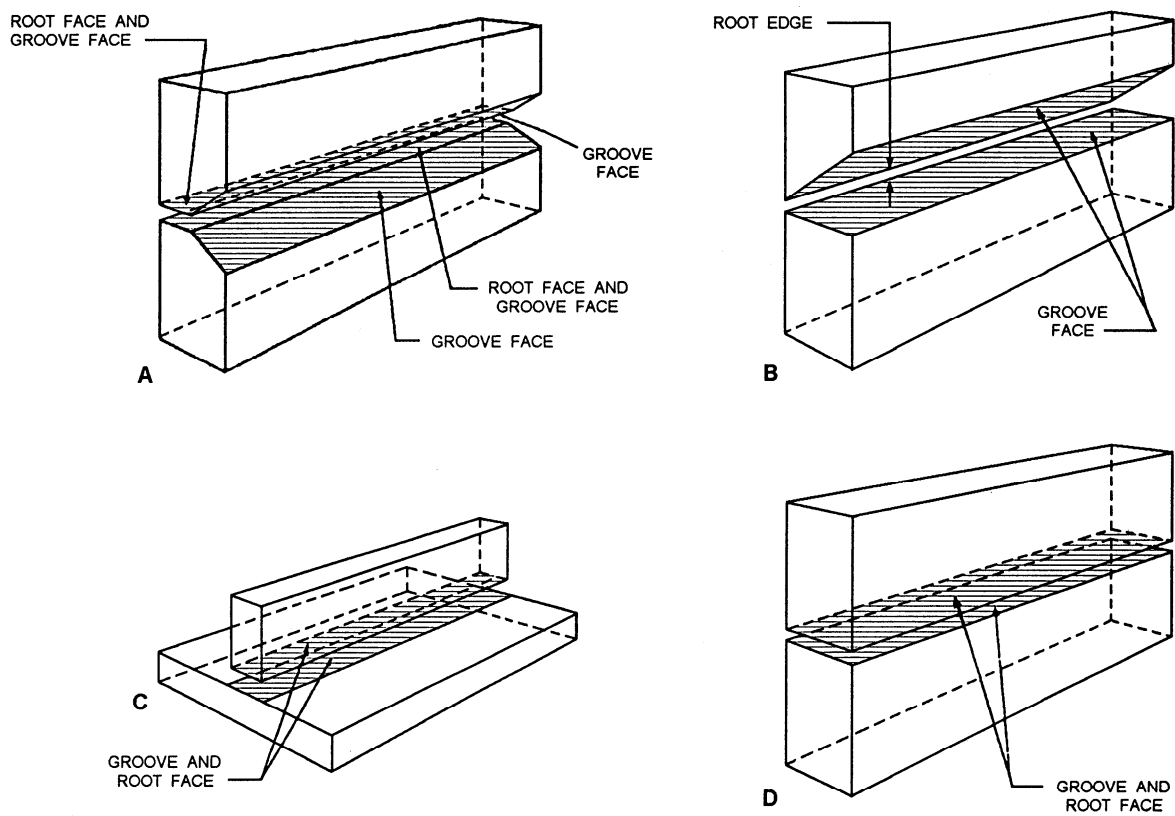


Figure 3-8.—The groove face, root face, and root edge of joints.

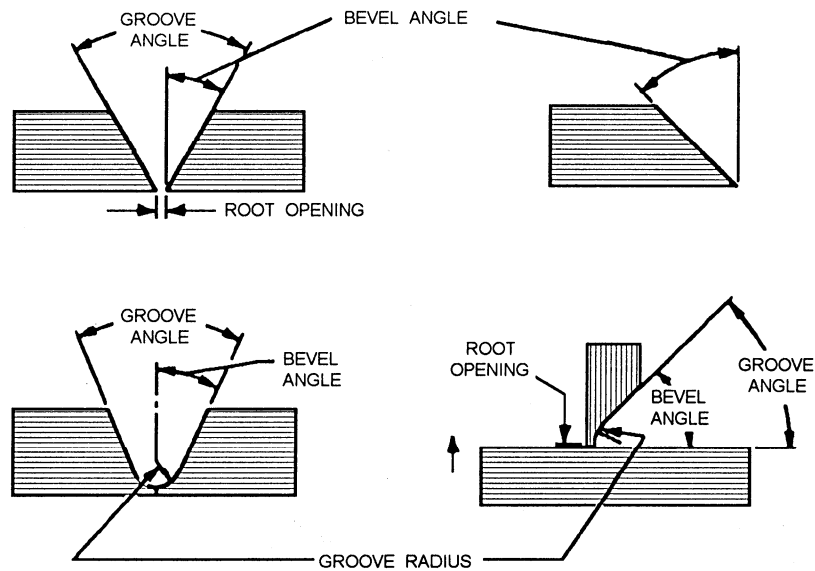


Figure 3-9.—Bevel angle, groove angle, groove radius, and root opening of joints for welding.

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

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

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

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

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

PARTS OF JOINTS

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

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

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

The **groove angle** is the total angle of the groove between the parts to be joined. For example, if the edge of each of two plates were beveled to an angle of 30 degrees, the groove angle would be 60 degrees. This is

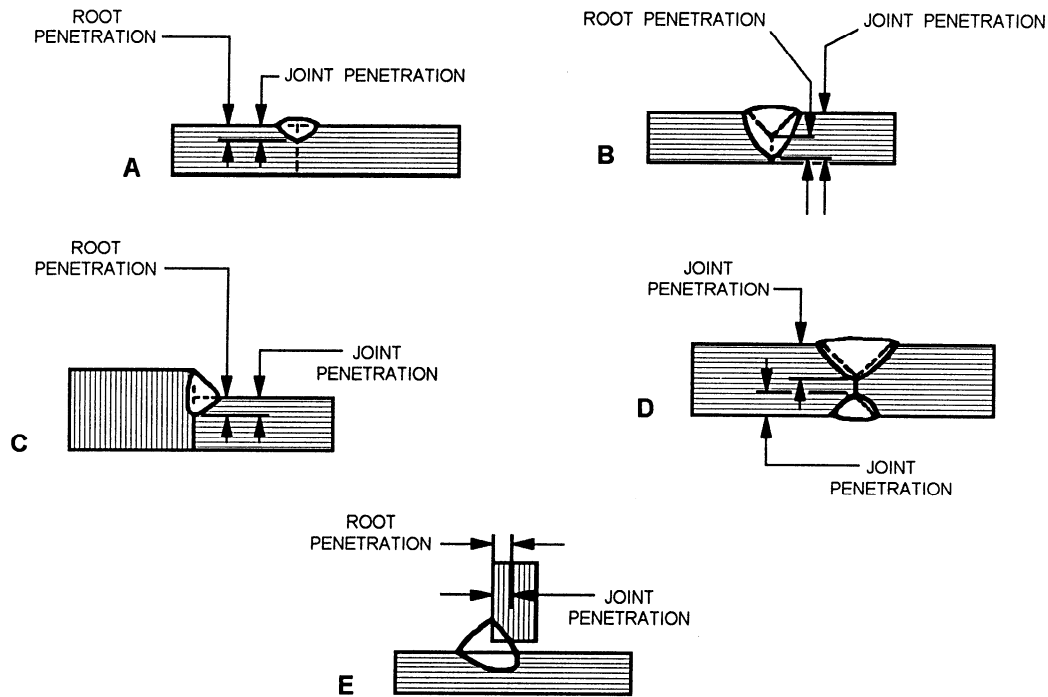


Figure 3-10.—Root penetration and joint penetration of welds.

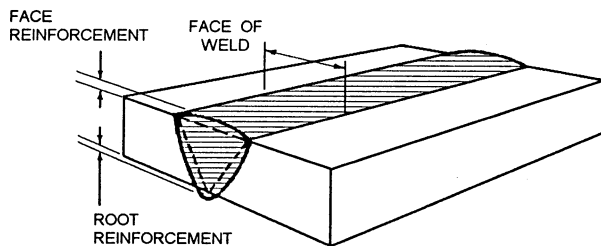


Figure 3-11.—Weld reinforcement.

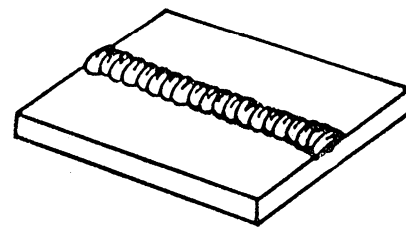


Figure 3-12.—Simple weld bead.

often referred to as the “included angle” between the parts to be joined by a groove weld.

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

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

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

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

Having an adequate root opening is essential for root penetration.

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

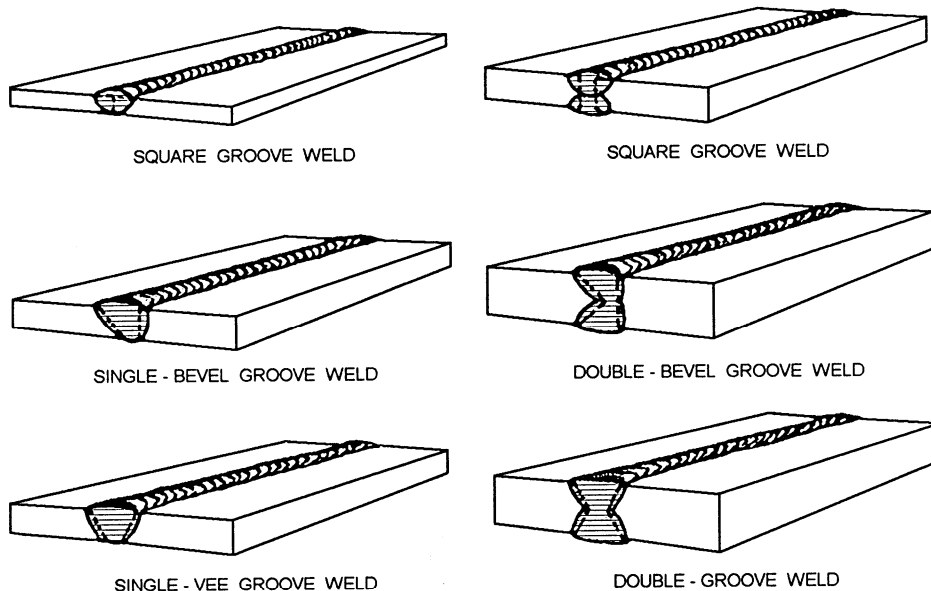


Figure 3-13.—Standard groove welds.

TYPES OF WELDS

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

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

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

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

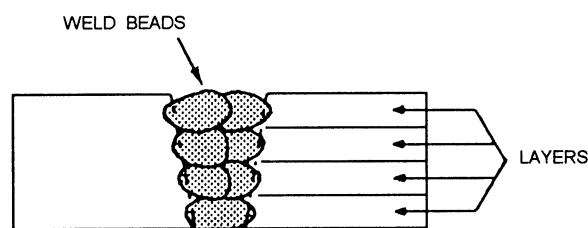


Figure 3-14.—Multiple-pass layers.

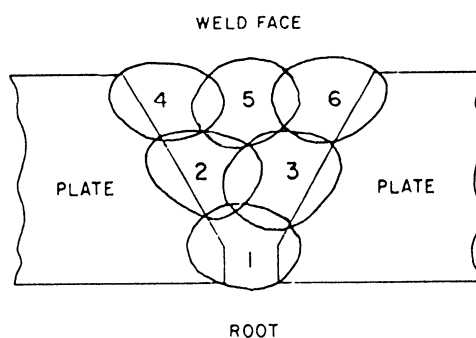


Figure 3-15.—Weld layer sequence.

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

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

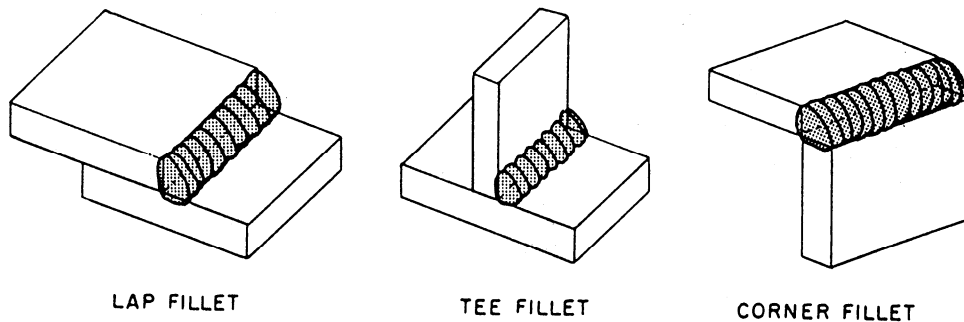


Figure 3-16.—Fillet welds.

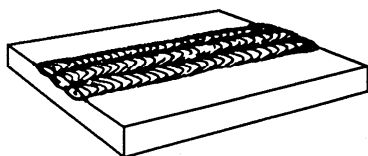


Figure 3-17.—Surfacing welds.

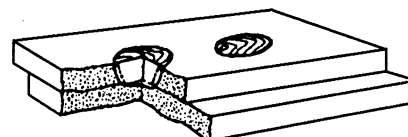
After the effects of heat on metal are discussed, later in the chapter, you will understand the significance of the buildup sequence and the importance of controlling the interpass temperature.

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

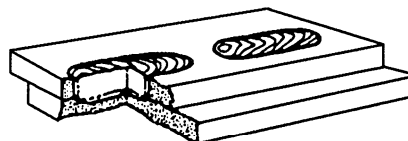
Surfacing is a welding process used to apply a hard, wear-resistant layer of metal to surfaces or edges of worn-out parts. It is one of the most economical methods of conserving and extending the life of machines, tools, and construction equipment. As you can see in figure 3-17, a surfacing weld is composed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

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

Plug and slot welds (fig. 3-18) are welds made through holes or slots in one member of a lap joint. These welds are used to join that member to the surface of another member that has been exposed through the



PLUG WELDS



SLOT WELDS

Figure 3-18.—Plug and slot welds.

hole. The hole may or may not be completely filled with weld metal. These types of welds are often used to join face-hardened plates from the backer soft side, to install liner metals inside tanks, or to fill up holes in a plate.

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

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

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

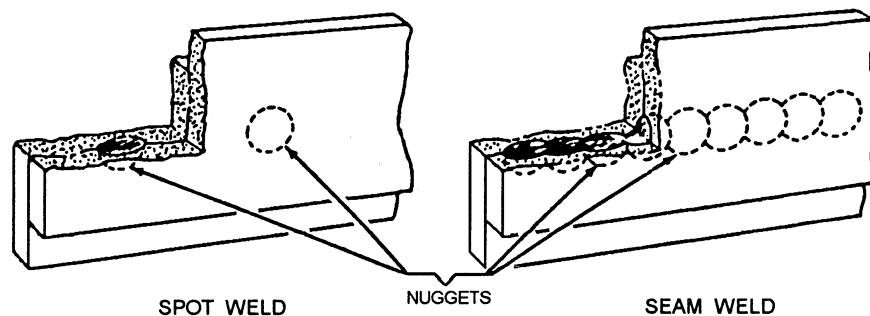


Figure 3-19.—Spot and seam welds.

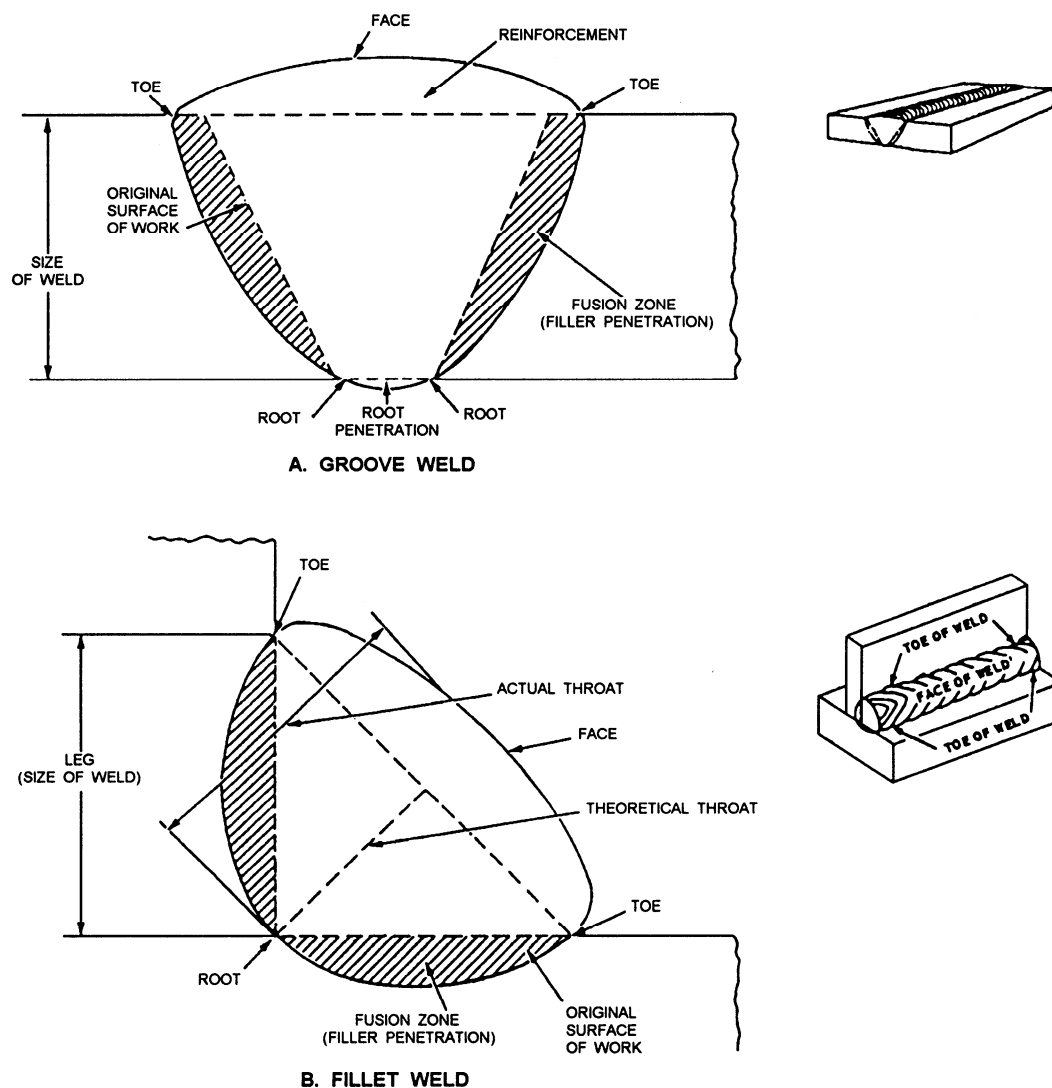


Figure 3-20.—Parts of a groove weld and fillet weld.

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

PARTS OF WELDS

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

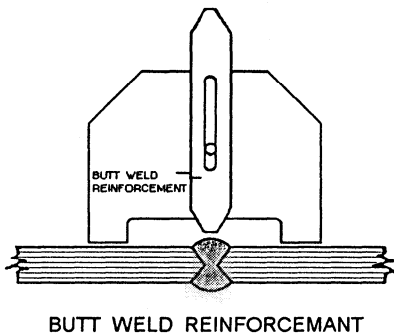
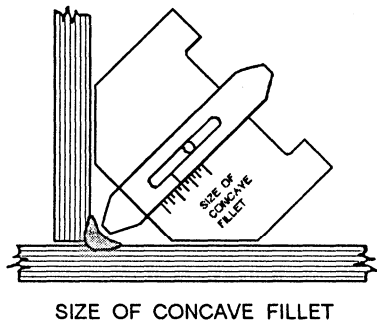
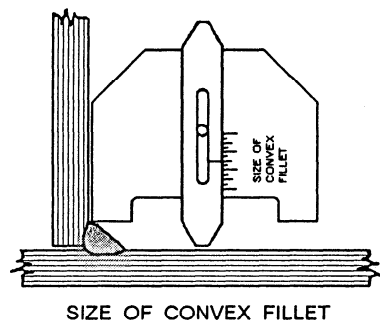


Figure 3-21.—Using a welding micrometer.

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

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

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

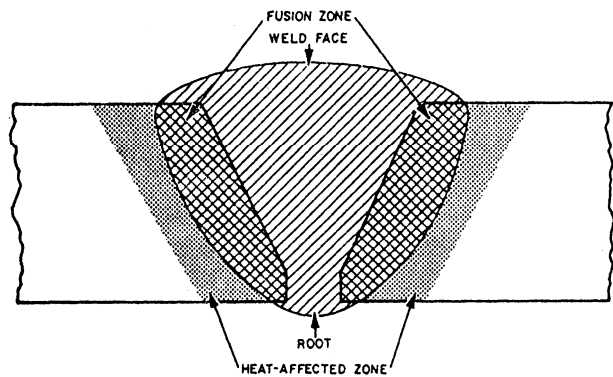


Figure 3-22.—Zones in a weld.

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

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

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

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

WELDED JOINT DESIGN

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

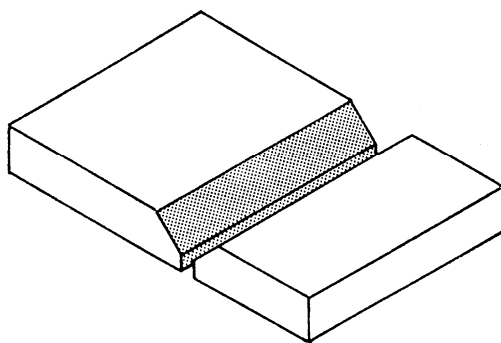
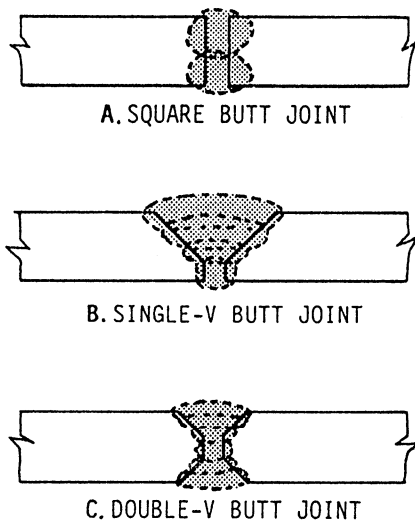


Figure 3-23.—Butt joints.

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

- How a load will be applied; that is, whether the load will be steady, sudden, or variable
- The direction of the load as applied to the joint
- The cost of preparing the joint

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

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

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

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

BUTT JOINTS

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

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

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

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

Remember, to produce good quality welds using the groove joint, you should ensure the fit-up is consistent for the entire length of the joint, use the correct groove

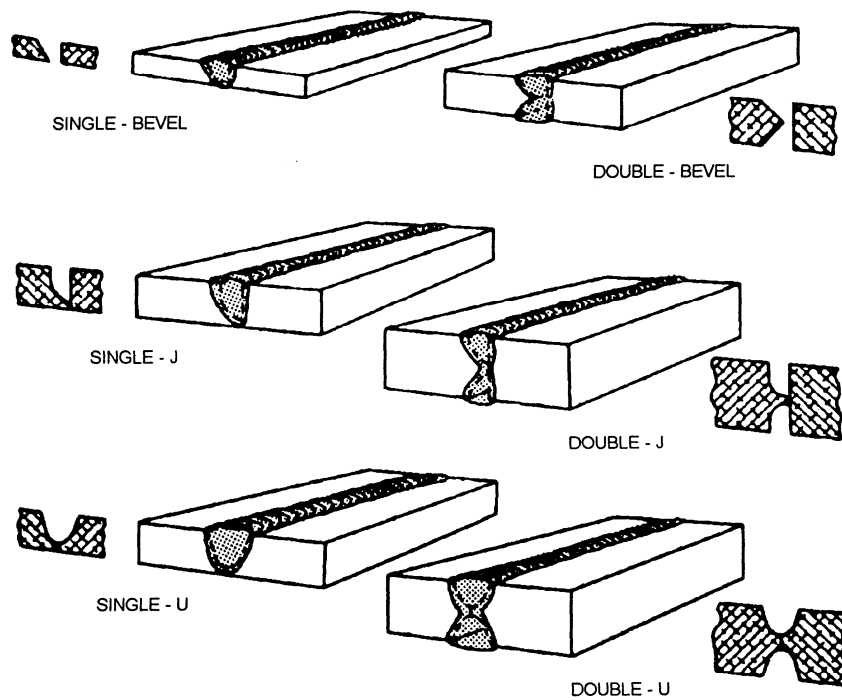


Figure 3-24.—Additional types of groove welds.

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

CORNER JOINTS

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

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

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

TEE JOINTS

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

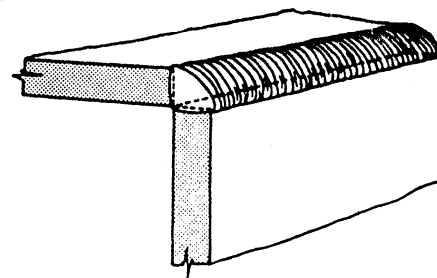
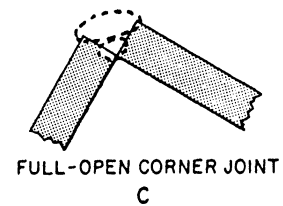
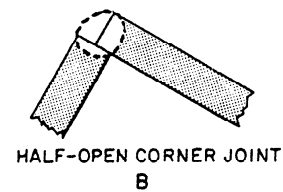
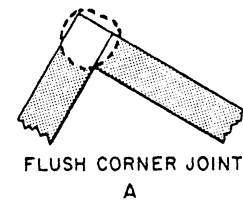


Figure 3-25.—Corner joints.

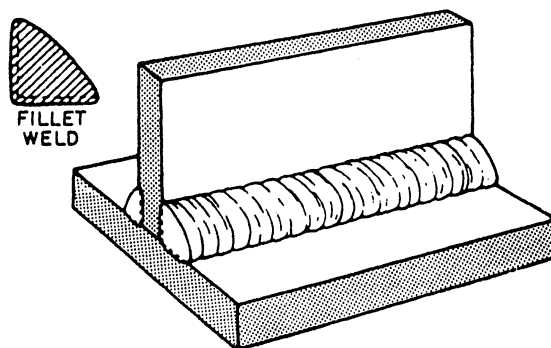
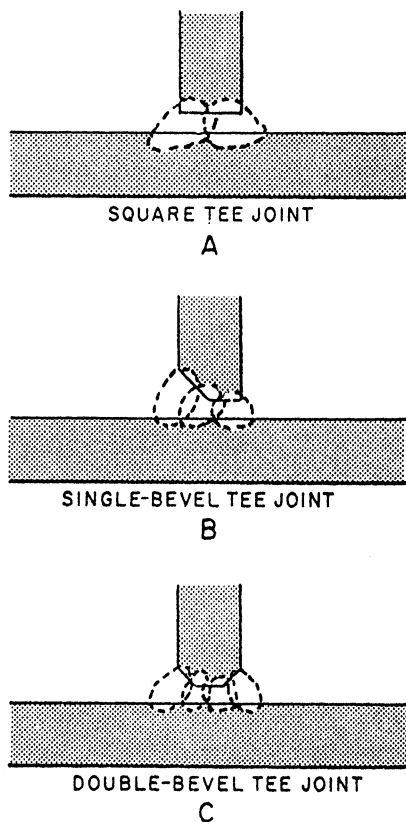


Figure 3-26.—T ee joints.

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

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

LAP JOINTS

The **single-fillet lap joint** (fig. 3-27, view A) is easy to weld, since the filler metal is simply deposited along

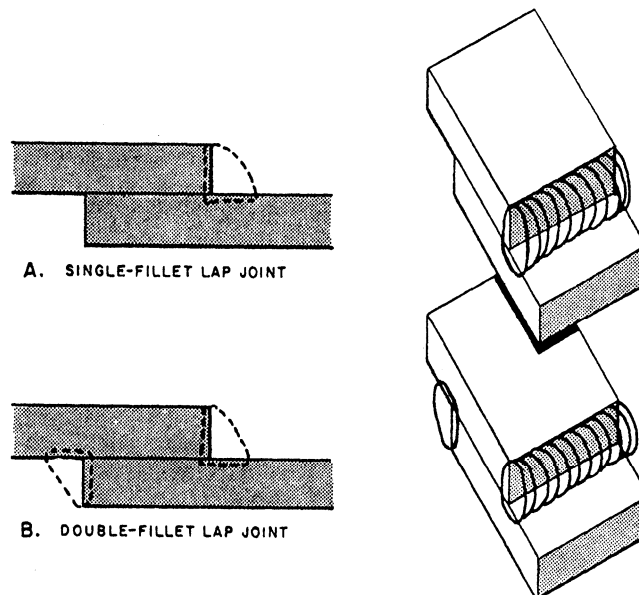


Figure 3-27.—Lap joints,

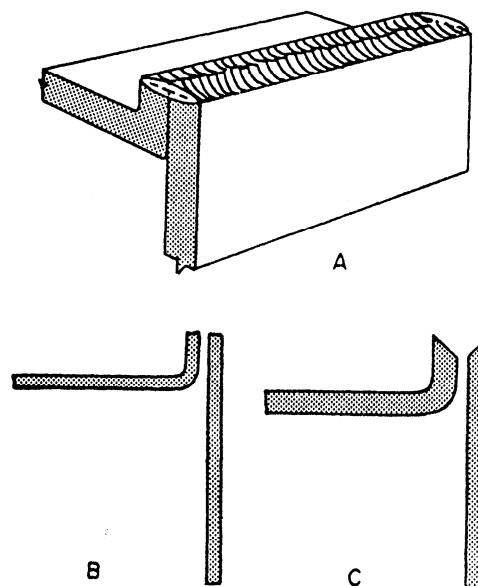


Figure 3-28.—Flanged edge joints.

the seam. The strength of the weld depends on the size of the fillet. Metal up to 1/2 inch in thickness and not subject to heavy loads can be welded using this joint.

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

EDGE JOINTS

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

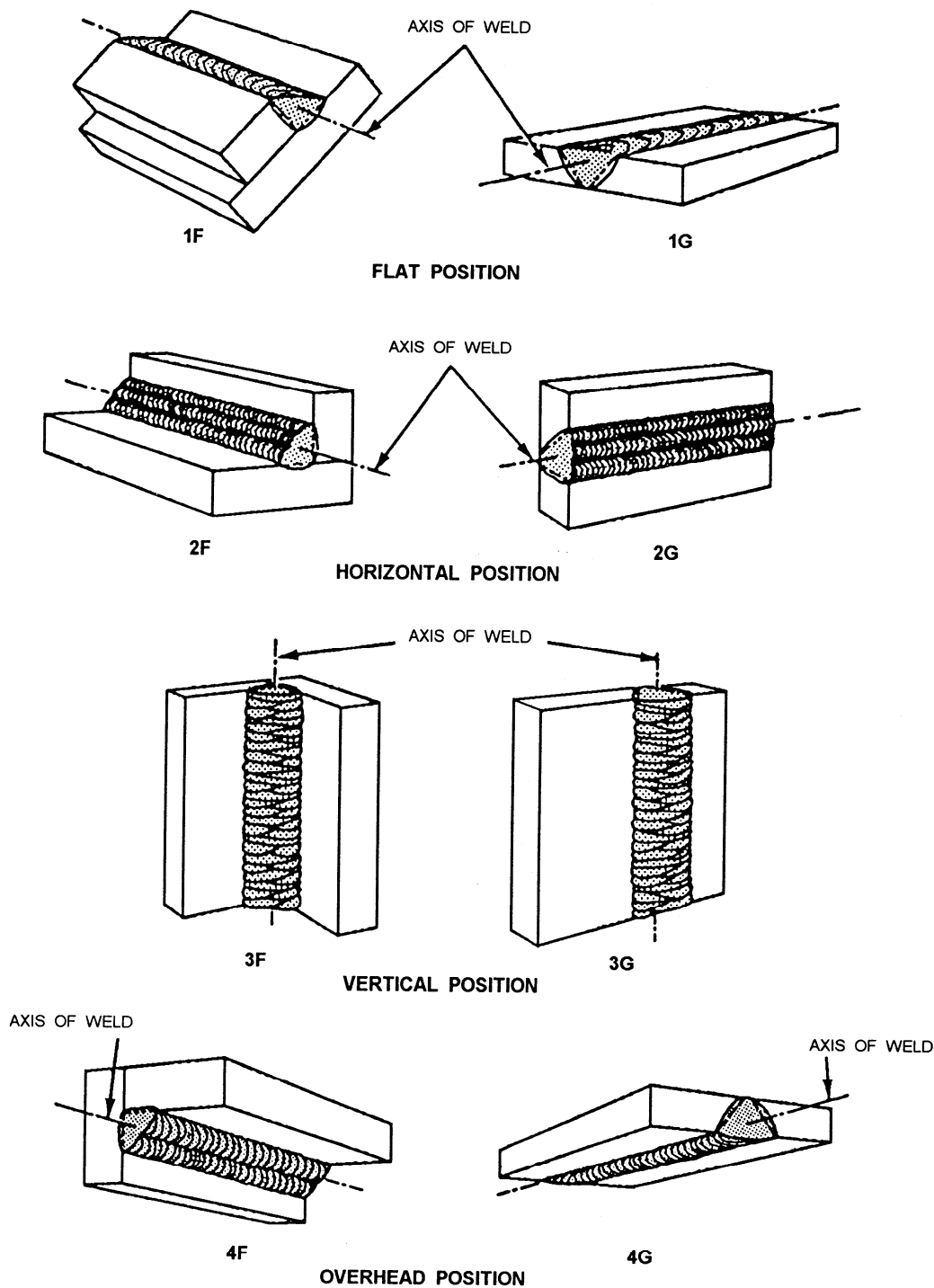


Figure 3-29.—Welding positions—plate.

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

WELDING POSITIONS

All welding is done in one of four positions: (1) flat, (2) horizontal, (3) vertical, or (4) overhead. Fillet or

groove welds can be made in all of these positions. Figure 3-29 shows the various positions used in plate welding. The American Welding Society (AWS) identifies these positions by a number/letter designation; for instance, the 1G position refers to a groove weld that is to be made in the flat position. Here the 1 is used to

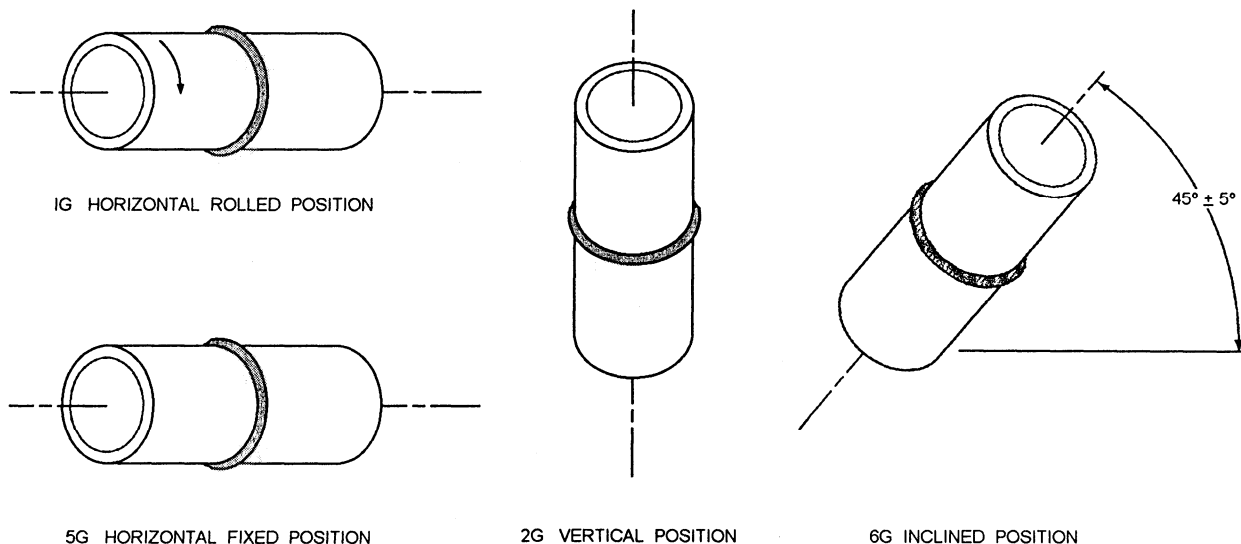


Figure 3-30.—Welding position-pipe.

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

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

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

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

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

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

EXPANSION AND CONTRACTION

When a piece of metal is heated, the metal expands. Upon cooling, the metal contracts and tries to resume its original shape. The effects of this expansion and

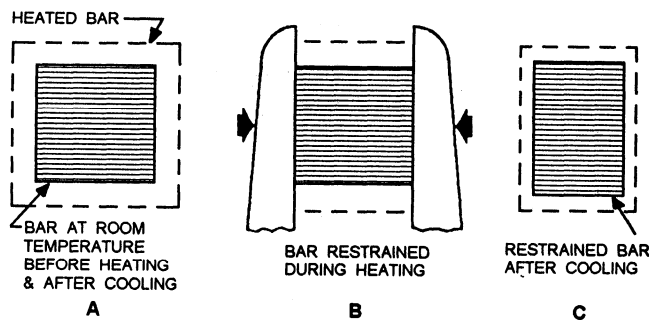


Figure 3-31.—Effects of expansion and contraction.

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

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

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

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

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

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

CONTROLLING DISTORTION

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

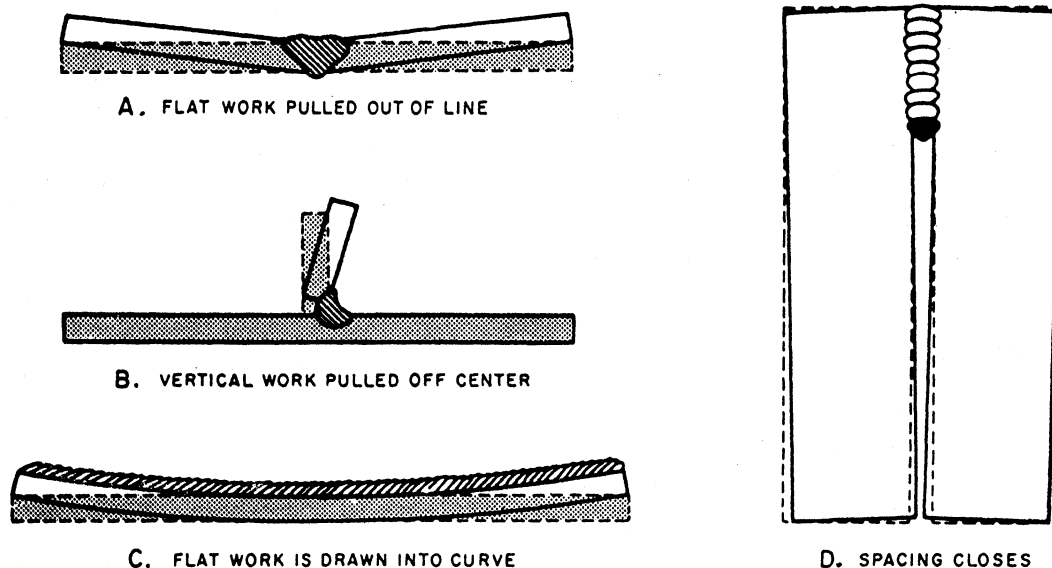
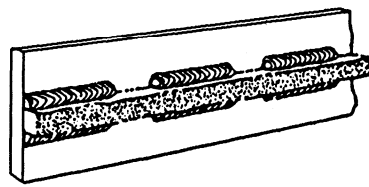
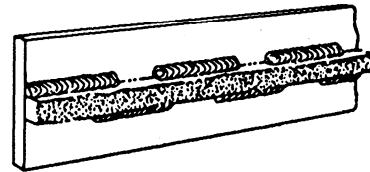


Figure 3-32.—Distortion caused by welding.

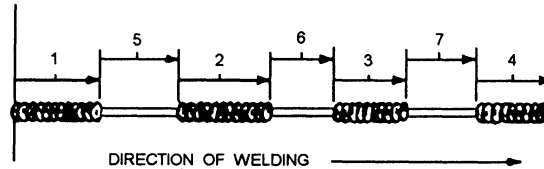


CHAIN INTERMITTENT FILLET WELD



STAGGERED INTERMITTENT FILLET WELD

INTERMITTENT FILLET WELDS



INTERMITTENT BUTT WELD

Figure 3-33.—Intermittent welds.

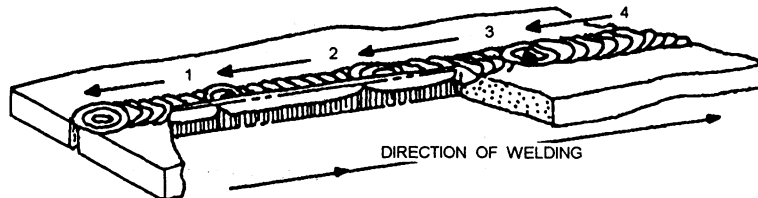


Figure 3-34.—Back-step welding.

Proper Edge Preparation and Fit-up

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

Control the Heat Input

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

Regardless of your experience, it is often necessary to use a welding technique designed to control heat

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

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

Preheat the Metal

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

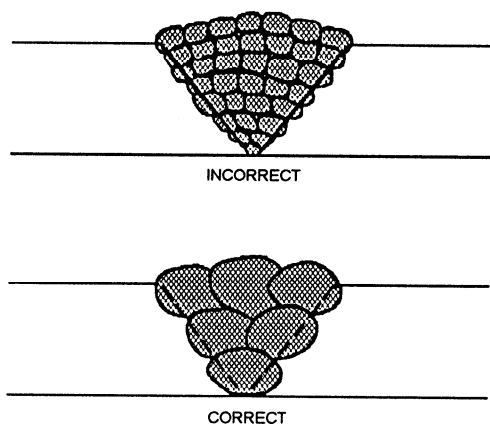


Figure 3-35.—Weld passes.

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

Limit the Number of Weld Passes

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

Use Jigs and Fixtures

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

Allow for Distortion

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

There is more to being a good welder than just being able to lay a good bead. There are many factors that must

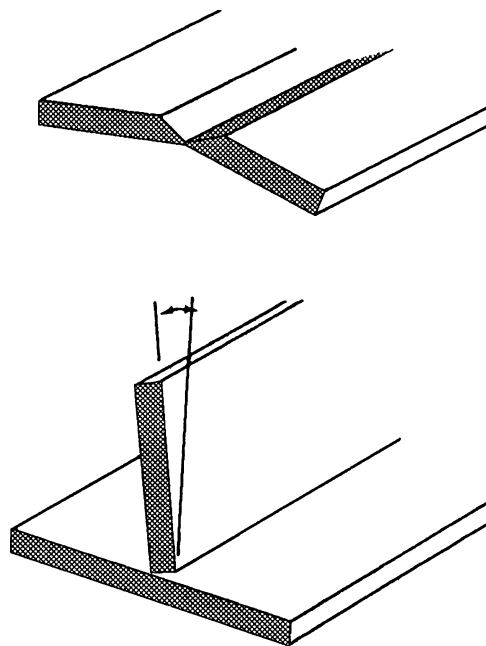


Figure 3-36.—Allowing for distortion.

be considered. Later, we discuss additional techniques that you can apply to specific welding situations.

WELDING PROCEDURES

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

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

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

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

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

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

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

DRAWINGS

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

READING DRAWINGS

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

Lines

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

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

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

QW-482 SUGGESTED FORMAT FOR WELDING PROCEDURE SPECIFICATIONS (WPS)
(See QW-201.1, Section IX, ASME Boiler and Pressure Vessel Code)

Company Name USNAVY By: M. KONSCAK
Welding Procedure Specification No. 1111 Date 4/26/90 Supporting PQR No.(s) 1111-A1
Revision No. N/A Date N/A
Welding Process(es) S.M.A.W. Type(s) MANUAL
(Automatic, Manual, Machine, or Semi-Auto.)

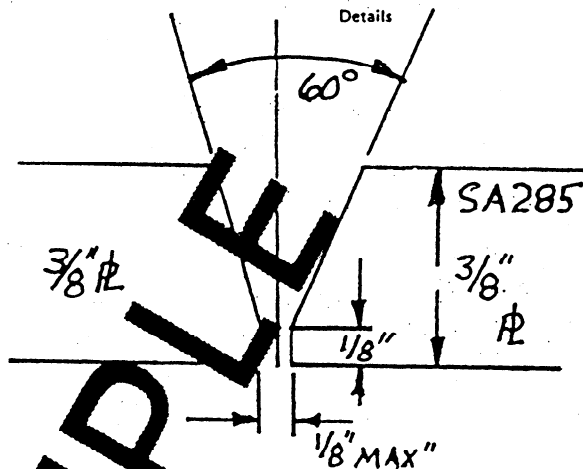
JOINTS (QW-402)

Joint Design BU-1
Backing (Yes) _____ (No) X
Backing Material (Type) N/A
(Refer to both backing and retainers.)

- ☐ Metal ☐ Nonfusing Metal
☐ Nonmetallic ☐ Other

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

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



***BASE METALS (QW-403)**

P-No. 1 Group No. 1 to P-No. 1 Group No. _____
OR
Specification type and grade SA-285-C
to Specification type and grade SA-285-C
OR
Chem. Analysis and Mech. Prop. A-1
to Chem. Analysis and Mech. Prop. A-1
Thickness Range:
Base Metal: Groove 3G Fillet N/A
Pipe Dia. Range: Groove 24" + DTA Fillet N/A
Other _____

***FILLER METALS (QW-404)**

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

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

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

Figure 3-37.—Welding procedure specification.

QW-482 (Back)

WPS No. 1111 Rev. _____

POSITIONS (QW-405) Position(s) of Groove <u>3G</u> Welding Progression: Up <u>X</u> Down _____ Position(s) of Fillet <u>N/A</u>				POSTWELD HEAT TREATMENT (QW-407) Temperature Range <u>WRAP W/ INSULATION</u> Time Range <u>WARM TO TOUCH</u>																																																													
PREHEAT (QW-406) Preheat Temp. Min. <u>200°</u> Interpass Temp. Max. <u>500°</u> Preheat Maintenance <u>CHECK EACH LAYER</u> (Continuous or special heating where applicable should be recorded)				GAS (QW-408) <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th></th> <th style="text-align: center;">Gas(es)</th> <th style="text-align: center;">Percent Composition (Mixture)</th> <th style="text-align: center;">Flow Rate</th> </tr> </thead> <tbody> <tr> <td>Shielding</td> <td><u>N/A</u></td> <td></td> <td></td> </tr> <tr> <td>Trailing</td> <td><u>N/A</u></td> <td></td> <td></td> </tr> <tr> <td>Backing</td> <td><u>N/A</u></td> <td></td> <td></td> </tr> </tbody> </table>					Gas(es)	Percent Composition (Mixture)	Flow Rate	Shielding	<u>N/A</u>			Trailing	<u>N/A</u>			Backing	<u>N/A</u>																																												
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Backing	<u>N/A</u>																																																																
ELECTRICAL CHARACTERISTICS (QW-409) Current AC or DC <u>DC</u> Polarity <u>RP</u> Amps (Range) <u>85-120</u> Volts (Range) <u>19-22</u> (Amps and volts range should be recorded for each electrode size, position, and thickness, etc. This information may be listed in a tabular form similar to that shown below.) Tungsten Electrode Size and Type <u>N/A</u> (Pure Tungsten, 2% Thoriated, etc.) Mode of Metal Transfer for GMAW <u>N/A</u> (Spray arc, shield metal arc, etc.) Electrode Wire feed speed range <u>N/A</u>																																																																	
TECHNIQUE (QW-410) <u>STRINGER AND WEAVE</u> String or Weave Bead _____ Orifice or Gas Cup Size <u>N/A</u> Initial and Interpass Cleaning (Brushing, Grinding, etc.) <u>CLEAN EACH PASS WITH WIRE BRUSH OR BUFFER</u> Method of Back Gouging <u>N/A</u> Oscillation <u>N/A</u> Contact Tube to Work Distance <u>N/A</u> Multiple or Single Pass (per side) <u>MULTIPASS</u> Multiple or Single Electrodes <u>SINGLE</u> Travel Speed (Range) <u>6"-12"</u> Peening <u>N/A</u> Other <u>N/A</u>																																																																	
<table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr> <th rowspan="2">Weld Layer(s)</th> <th rowspan="2">Process</th> <th colspan="2">Filler Metal</th> <th colspan="2">Current</th> <th rowspan="2">Volt Range</th> <th rowspan="2">Travel Speed Range</th> <th rowspan="2">Other (e.g., Remarks, Comments, Hot Wire Addition, Technique, Torch Angle, Etc.)</th> </tr> <tr> <th>Class</th> <th>Dia.</th> <th>Type Polar.</th> <th>Amp. Range</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>SMAW</td> <td>E-6011</td> <td>1/8"</td> <td>DCRP</td> <td>85-120</td> <td>19-22</td> <td>6"-10"</td> <td>N/A</td> </tr> <tr> <td>2</td> <td>SMAW</td> <td>E-7018</td> <td>3/32"</td> <td>DCRP</td> <td>85-120</td> <td>19-22</td> <td>6"-10"</td> <td>N/A</td> </tr> <tr> <td>3</td> <td>SMAW</td> <td>E-7018</td> <td>1/8"</td> <td>DCRP</td> <td>85-120</td> <td>19-22</td> <td>6"-10"</td> <td>N/A</td> </tr> <tr> <td>4</td> <td>SMAW</td> <td>E-7018</td> <td>1/8"</td> <td>DCRP</td> <td>85-120</td> <td>19-22</td> <td>8"-12"</td> <td>N/A</td> </tr> <tr> <td>5</td> <td>SMAW</td> <td>E-7018</td> <td>1/8"</td> <td>DCRP</td> <td>85-120</td> <td>19-22</td> <td>8"-12"</td> <td>N/A</td> </tr> </tbody> </table>								Weld Layer(s)	Process	Filler Metal		Current		Volt Range	Travel Speed Range	Other (e.g., Remarks, Comments, Hot Wire Addition, Technique, Torch Angle, Etc.)	Class	Dia.	Type Polar.	Amp. Range	1	SMAW	E-6011	1/8"	DCRP	85-120	19-22	6"-10"	N/A	2	SMAW	E-7018	3/32"	DCRP	85-120	19-22	6"-10"	N/A	3	SMAW	E-7018	1/8"	DCRP	85-120	19-22	6"-10"	N/A	4	SMAW	E-7018	1/8"	DCRP	85-120	19-22	8"-12"	N/A	5	SMAW	E-7018	1/8"	DCRP	85-120	19-22	8"-12"	N/A
Weld Layer(s)	Process	Filler Metal		Current		Volt Range	Travel Speed Range			Other (e.g., Remarks, Comments, Hot Wire Addition, Technique, Torch Angle, Etc.)																																																							
		Class	Dia.	Type Polar.	Amp. Range																																																												
1	SMAW	E-6011	1/8"	DCRP	85-120	19-22	6"-10"	N/A																																																									
2	SMAW	E-7018	3/32"	DCRP	85-120	19-22	6"-10"	N/A																																																									
3	SMAW	E-7018	1/8"	DCRP	85-120	19-22	6"-10"	N/A																																																									
4	SMAW	E-7018	1/8"	DCRP	85-120	19-22	8"-12"	N/A																																																									
5	SMAW	E-7018	1/8"	DCRP	85-120	19-22	8"-12"	N/A																																																									

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

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

Figure 3-38.—Line characters and uses.

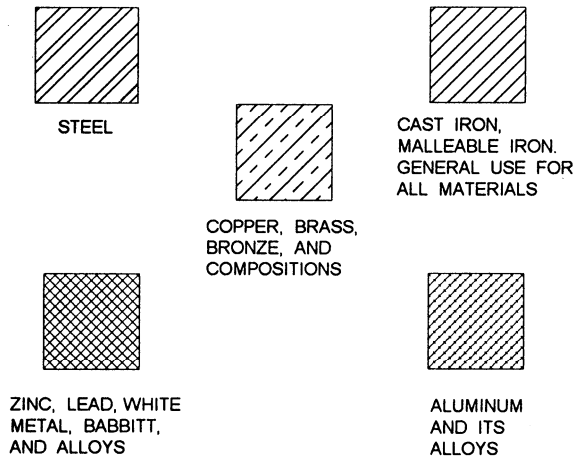


Figure 3-39.—Section lines for various metals.

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

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

Dimensions

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

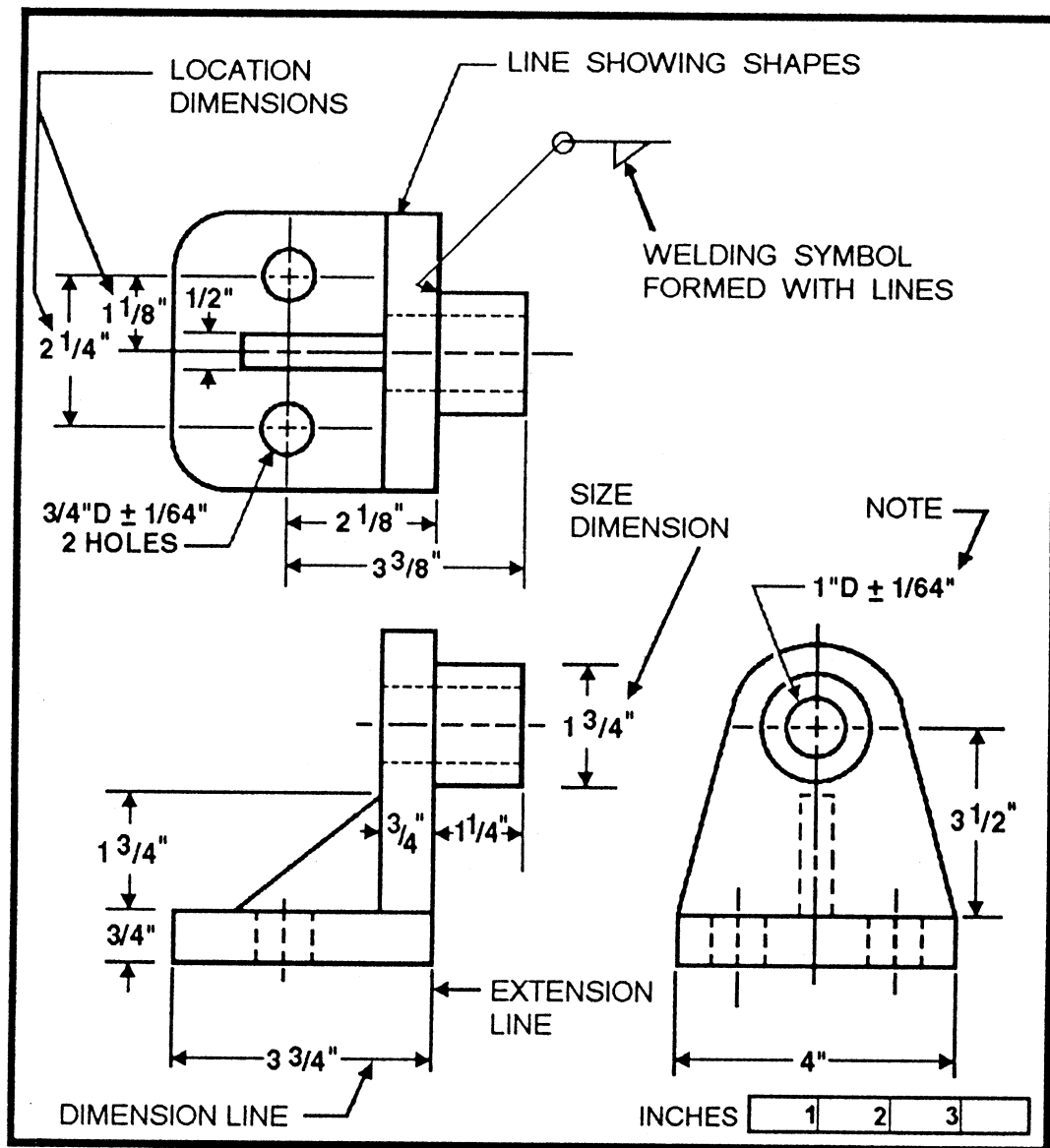


Figure 3-40.—Elements of an orthographic drawing.

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

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

Notes

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

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

Drawing Views

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

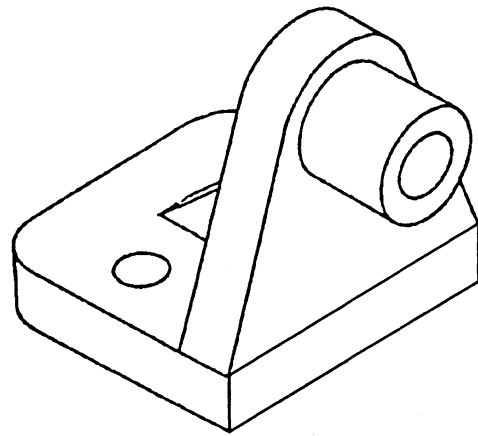


Figure 3-41.—Pictorial drawing of a steel part.

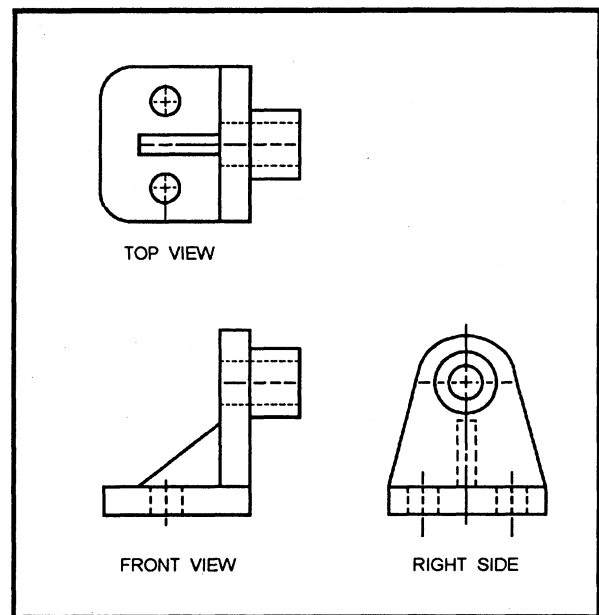


Figure 3-42.—Three-view orthographic drawing of the steel part shown in figure 3-41.

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

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

Handling and Care of Drawings

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

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

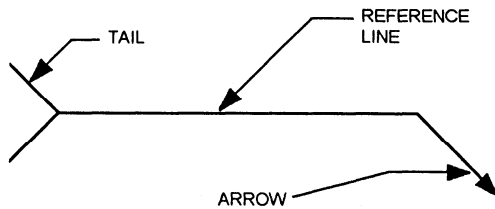


Figure 3-43.—Standard welding symbol.

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

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

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

WELDING SYMBOLS

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

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

Weld Symbols

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

BASIC WELD SYMBOLS									
BEAD	FILLET	PLUG OR SLOT	GROOVE OR BUTT						
			SQUARE	V	BEVEL	U	J	FLARE V	FLARE BEVEL

Figure 3-44.—Basic weld symbols.

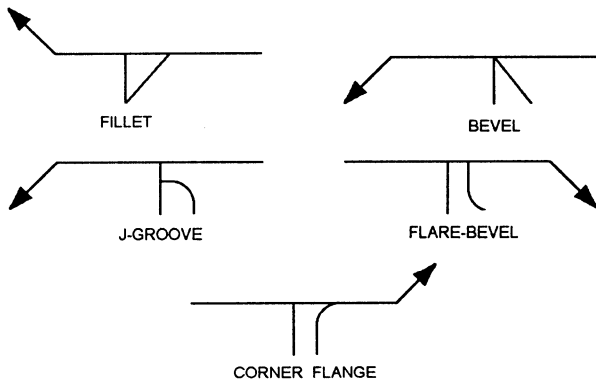


Figure 3-45.—Weld symbols applied to reference line.

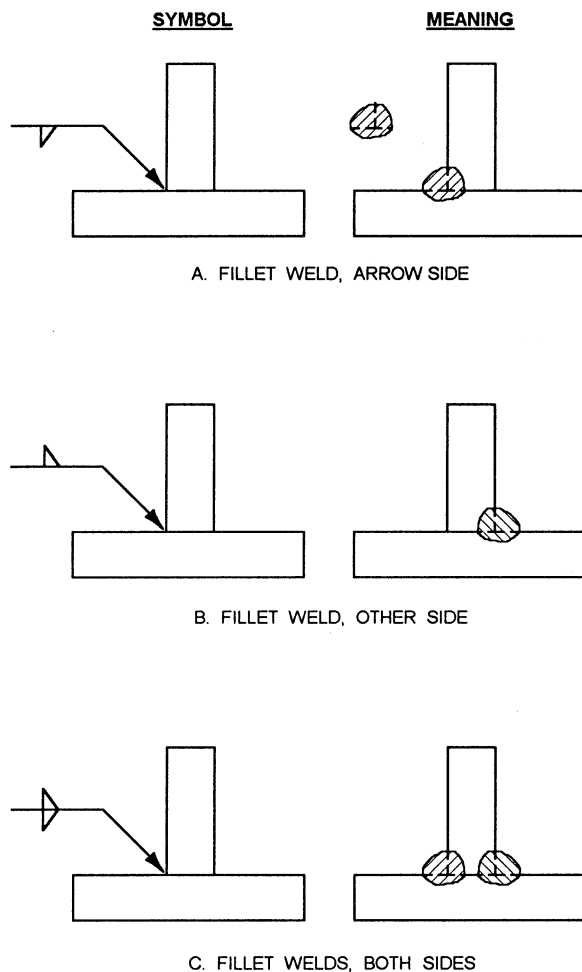


Figure 3-46.—Specifying weld locations.

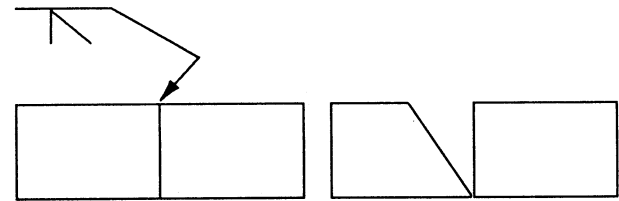


Figure 3-47.—Arrowhead indicates beveled plate.

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

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

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

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

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

Dimensioning

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

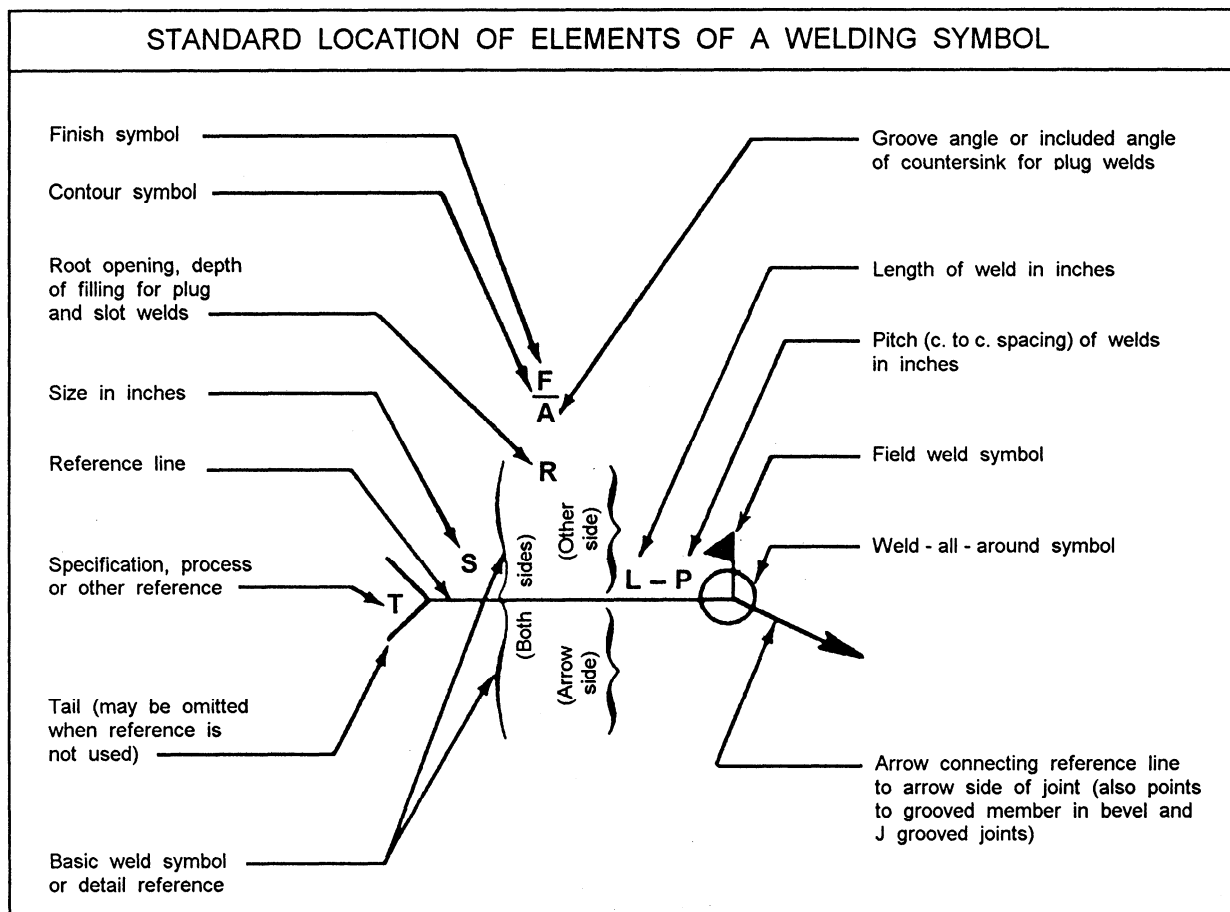


Figure 3-48.—Elements of a welding symbol.

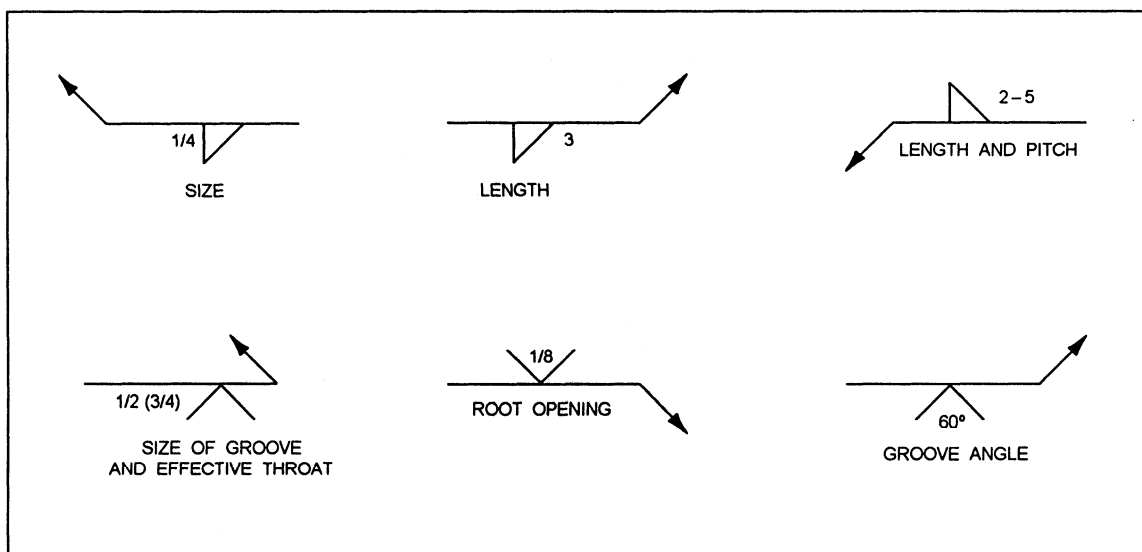


Figure 3-49.—Dimensions applied to weld symbols.

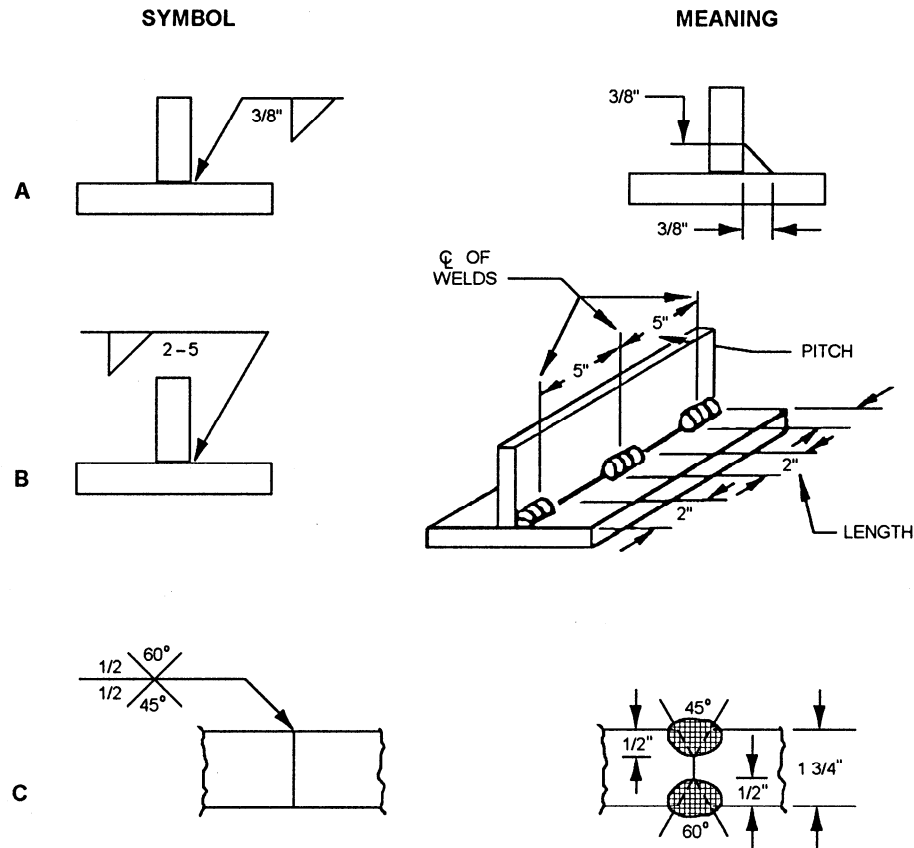


Figure 3-50.—Dimensioning of welds.

CONTOUR		
FLUSH	CONVEX	CONCAVE
WELD-ALL-AROUND	FIELD WELD	

Figure 3-51.—Supplementary symbols.

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

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

Supplementary Symbols

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

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

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

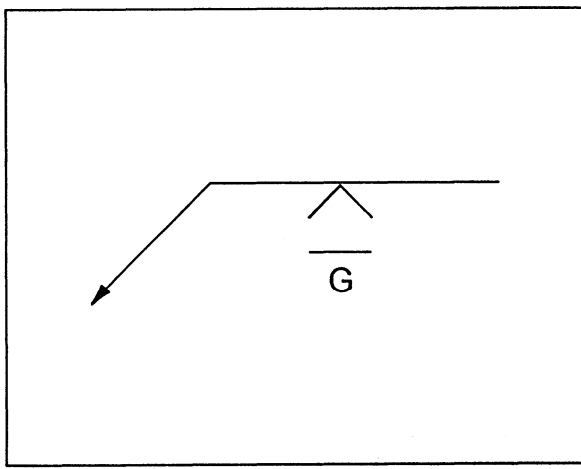


Figure 3-52.—Finish and contour symbols.

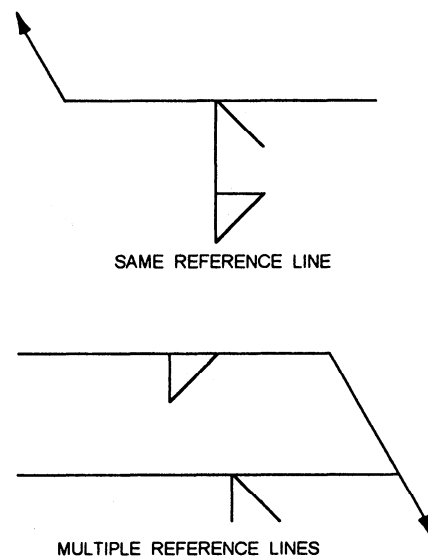


Figure 3-54.—Representing multiple welds.

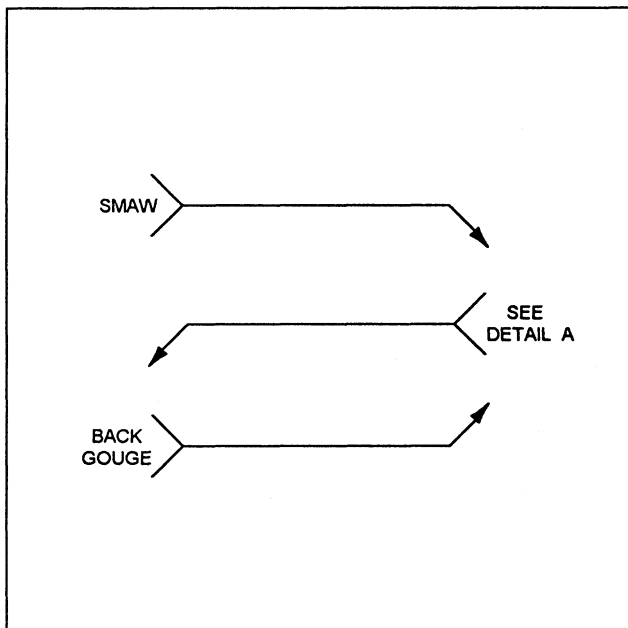


Figure 3-53.—Specifying additional welding information.

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

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

Specifying Additional Information

It is sometimes necessary to specify a certain welding process, a type of electrode, or some type of reference necessary to complete a weld. In this case, a note can be placed in the tail of the reference line. (See

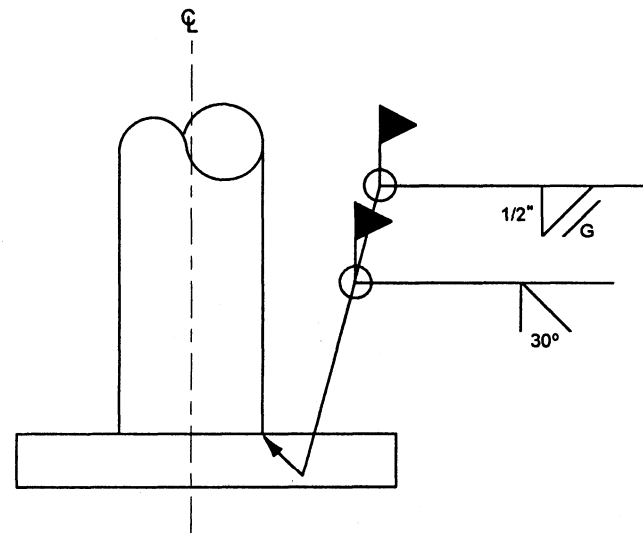


Figure 3-55.—Example of welding symbol in use.

fig. 3-53.) If additional information is not needed, then the tail is omitted.

Multiple-Weld Symbols

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

Applying a Welding Symbol

Figure 3-55 shows an example of how a welding symbol may appear on a drawing. This figure shows a

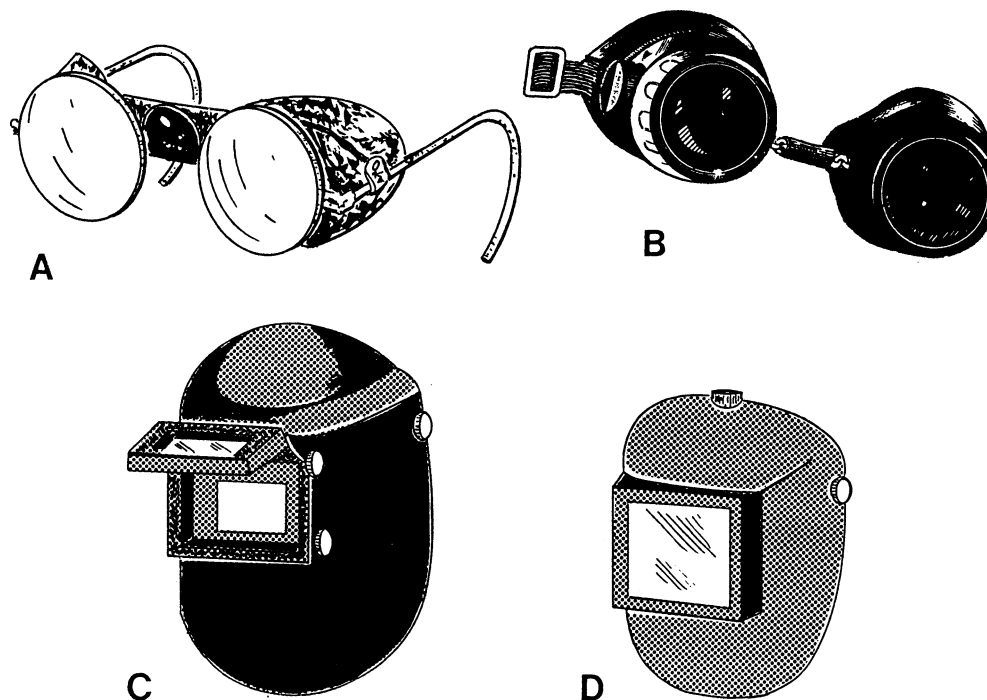


Figure 3-56.—Eye protection devices.

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

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

SAFETY

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

Proper eye protection is of the utmost importance. This covers the welding operator and the other personnel, such as helpers, chippers, or inspectors, who are in

the vicinity of the welding and cutting operations. Eye protection is necessary because of the hazards posed by stray flashes, reflected glare, flying sparks, and globules of molten metal. Devices used for eye protection include helmets and goggles.

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

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

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

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

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

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

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

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

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

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

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

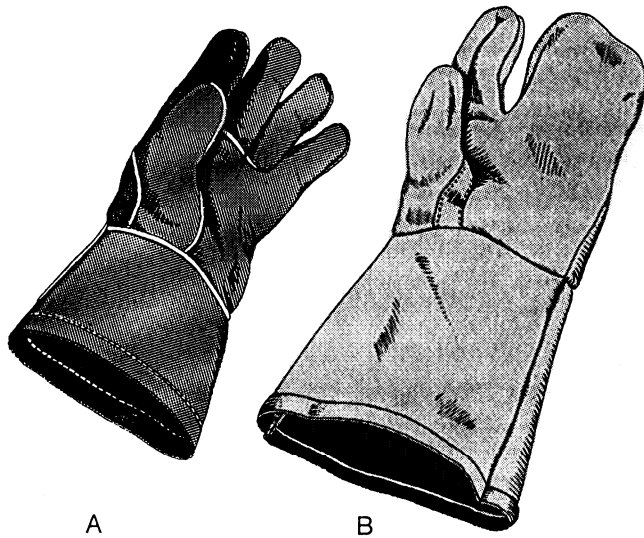
second is to eliminate the harmful infrared and ultraviolet radiations coming from the arc or flame; consequently, the filter lens shade number you select must not vary more than two shades from the numbers recommended in table 3-1.

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

WARNING

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

A variety of special welder's clothing is used to protect parts of the body. The clothing selected varies



A

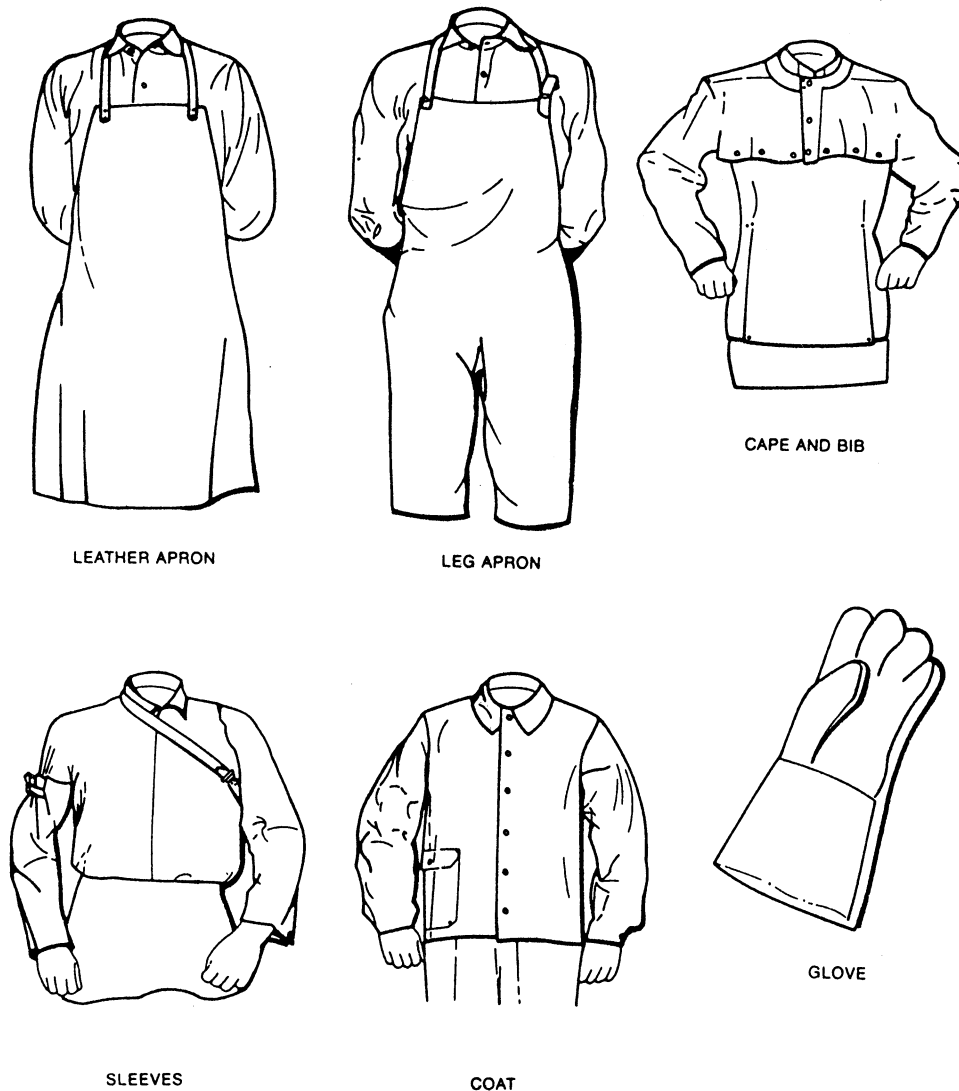
B

Figure 3-57.—Welding gloves and mitts.

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

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

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



LEATHER APRON

LEG APRON

CAPE AND BIB

SLEEVES

COAT

GLOVE

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

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

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

The cape and sleeves are particularly suited for overhead welding, because it protects the back of the neck, top of the shoulders, and the upperpart of the back

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

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

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

CHAPTER 4

GAS CUTTING

The common methods used in cutting metal are oxygas flame cutting, air carbon-arc cutting, and plasma-arc cutting. The method used depends on the type of metal to be cut and the availability of equipment. As a Steelworker, oxygas or air carbon-arc equipment is the most common type of equipment available for your use. Oxygas equipment is explained in this chapter and air carbon-arc cutting is covered in chapter 7.

The oxygas cutting torch has many uses in steelwork. At most naval activities, the Steelworker finds the cutting torch an excellent tool for cutting ferrous metals. This versatile tool is used for operations, such as beveling plate, cutting and beveling pipe, piercing holes in steel plate, and cutting wire rope.

When using the oxygas cutting process, you heat a spot on the metal to the kindling or ignition temperature (between 1400°F and 1600°F for steels). The term for this oxygas flame is the *PREHEATING FLAME*. Next, you direct a jet of pure oxygen at the heated metal by pressing a lever on the cutting torch. The oxygen causes a chemical reaction known as *OXIDATION* to take place rapidly. When oxidation occurs rapidly, it is called *COMBUSTION* or *BURNING*. When it occurs slowly, it is known as *RUSTING*.

When you use the oxygas torch method to cut metal, the oxidation of the metal is extremely rapid and part of the metal actually burns. The heat, liberated by the burning of the iron or steel, melts the iron oxide formed by the chemical reaction and accelerates the preheating of the object you are cutting. The molten material runs off as slag, exposing more iron or steel to the oxygen jet.

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

The walls of the kerf formed by oxygas cutting of ferrous metals should be fairly smooth and parallel to each other. After developing your skills in handling the torch, you can keep the cut within close tolerances; guide the cut along straight, curved, or irregular lines;

and cut bevels or other shapes that require holding the torch at an angle.

Partial oxidation of the metal is a vital part of the oxygas cutting process. Because of this, metals that do not oxidize readily are not suitable for oxygas cutting. Carbon steels are easily cut by the oxygas process, but special techniques (described later in this chapter) are required for the cutting of many other metals.

OXYGAS CUTTING EQUIPMENT

An oxygas cutting outfit usually consists of a cylinder of acetylene or MAPP gas, a cylinder of oxygen, two regulators, two lengths of hose with fittings, and a cutting torch with tips (fig. 4-1). An oxygas cutting outfit also is referred to as a *cutting rig*.

In addition to the basic equipment mentioned above, numerous types of auxiliary equipment are used in oxygas cutting. An important item is the spark igniter that is used to light the torch (fig. 4-2, view A). Another item you use is an apparatus wrench. It is similar in design to the one shown in figure 4-2, view B. The apparatus wrench is sometimes called a *gang wrench* because it fits all the connections on the cutting rig. Note that the wrench shown has a raised opening in the handle that serves as an acetylene tank key.

Other common accessories include tip cleaners, cylinder trucks, clamps, and holding jigs. Personal safety apparel, such as goggles, hand shields, gloves, leather aprons, sleeves, and leggings, are essential and should be worn as required for the job at hand. Information on safety apparel is also contained in chapter 3 of this text.

Oxygas cutting equipment can be stationary or portable. A portable oxygas outfit, such as the one shown in figure 4-3, is an advantage when it is necessary to move the equipment from one job to another.

To conduct your cutting requirements, you must be able to set up the cutting equipment and make the required adjustments needed to perform the cutting operation. For this reason it is important you understand the purpose and function of the basic pieces of equipment that make up the cutting outfit. But, before discussing the equipment, let's look at the gases most often used in cutting: acetylene, MAPP gas, and oxygen.

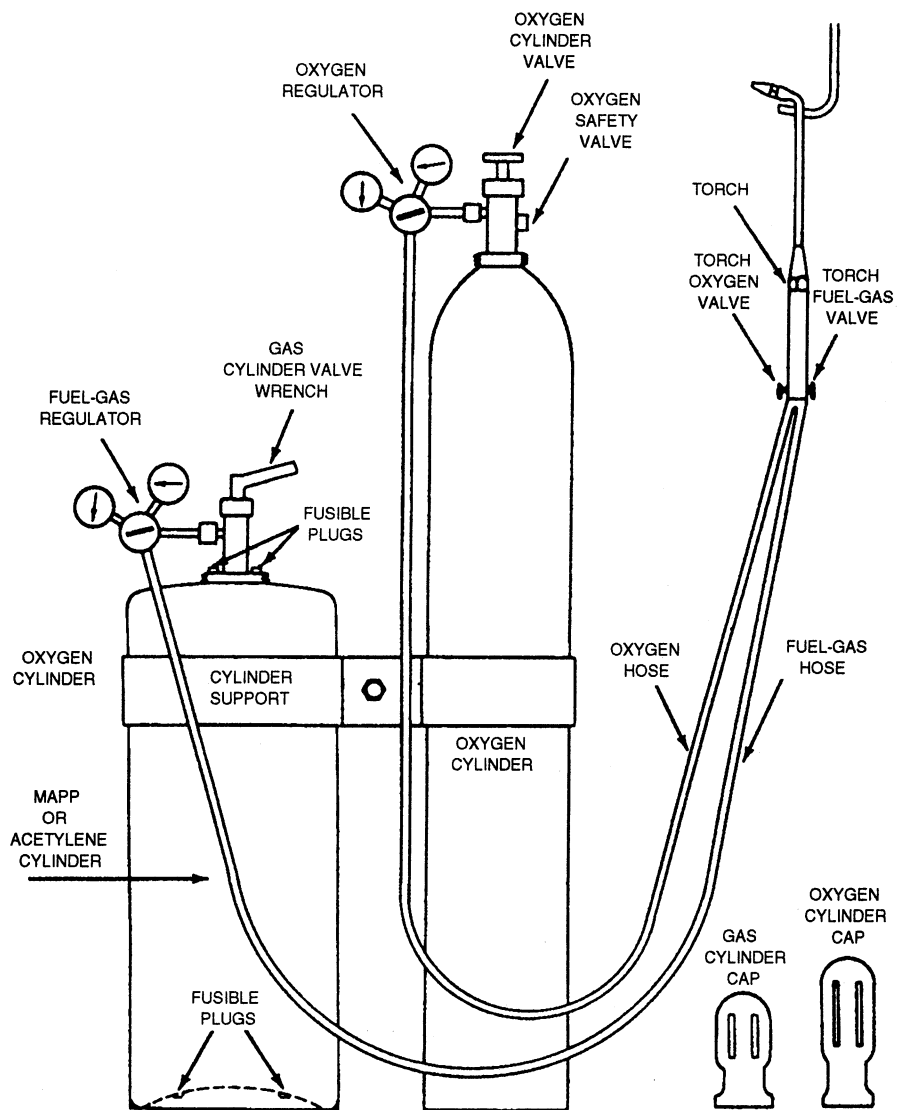


Figure 4-1.—Oxygas cutting outfit.

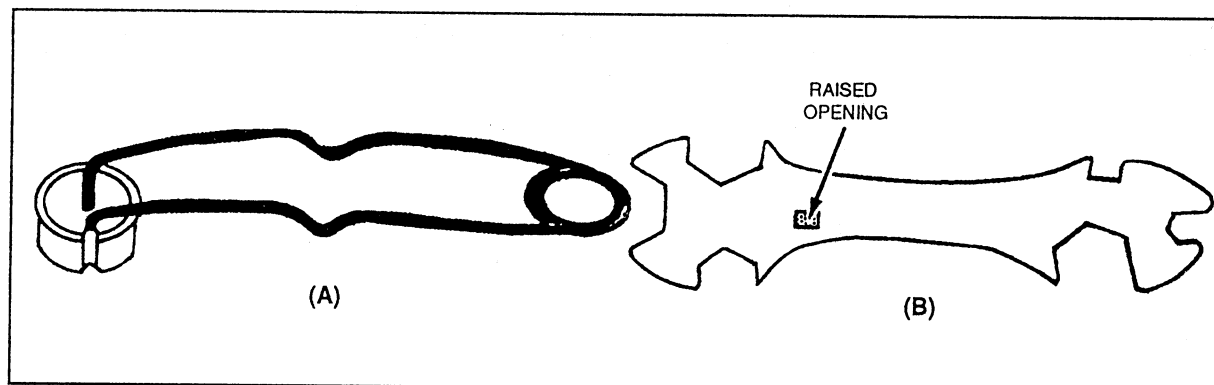


Figure 4-2.—(A) Spark igniter; (B) apparatus wrench.

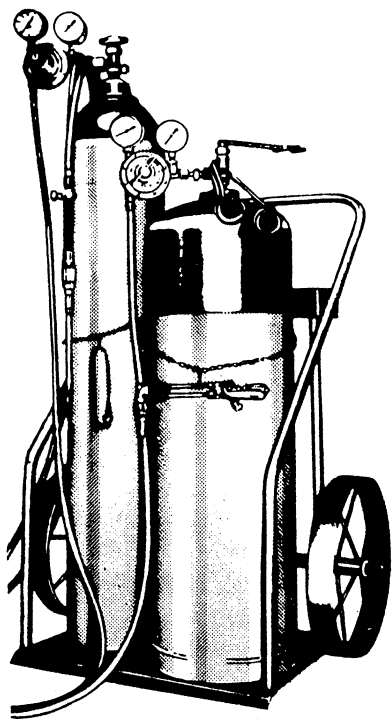


Figure 4-3.—A portable oxygas cutting and welding outfit.

ACETYLENE

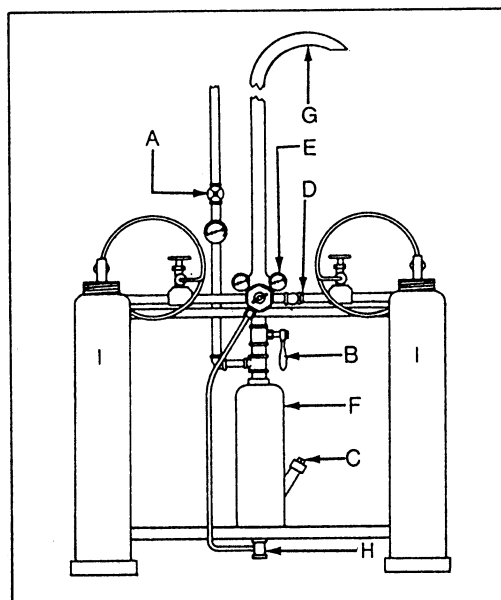
Acetylene is a flammable fuel gas composed of carbon and hydrogen having the chemical formula C_2H_2 . When burned with oxygen, acetylene produces a hot flame, having a temperature between 5700°F and 6300°F. Acetylene is a colorless gas, having a disagreeable odor that is readily detected even when the gas is highly diluted with air. When a portable welding outfit, similar to the one shown in figure 4-3 is used, acetylene is obtained directly from the cylinder. In the case of stationary equipment, similar to the acetylene cylinder bank shown in figure 4-4, the acetylene can be piped to a number of individual cutting stations.

Hazards

Pure acetylene is self-explosive if stored in the free state under a pressure of 29.4 pounds per square inch (psi). A slight shock is likely to cause it to explode.

WARNING

Acetylene becomes extremely dangerous if used above 15 pounds pressure.



- A. Line valve
- B. Release valve
- C. Filler plug
- D. Header pipe
- E. Regulator
- F. Flash arrestor chamber
- G. Escape pipe
- H. Check valve and drain plug
- I. Acetylene cylinders

Figure 4-4.—Stationary acetylene cylinder bank.

Cylinder Design

Acetylene can be safely compressed up to 275 psi when dissolved in acetone and stored in specially designed cylinders filled with porous material, such as balsa wood, charcoal, finely shredded asbestos, corn pith, portland cement, or infusorial earth. These porous filler materials aid in the prevention of high-pressure gas pockets forming in the cylinder.

Acetone is a liquid chemical that dissolves large portions of acetylene under pressure without changing the nature of the gas. Being a liquid, acetone can be drawn from an acetylene cylinder when it is not upright. You should not store acetylene cylinders on their side, but if they are, you must let the cylinder stand upright for a minimum of 2 hours before using. This allows the acetone to settle to the bottom of the cylinder.

NOTE: Acetone contaminates the hoses, regulators, torch, and disrupts the flame.

Acetylene is measured in cubic feet. The most common cylinder sizes are 130-, 290-, and 330-cubic-foot capacity. The standard size cylinder the Navy uses holds

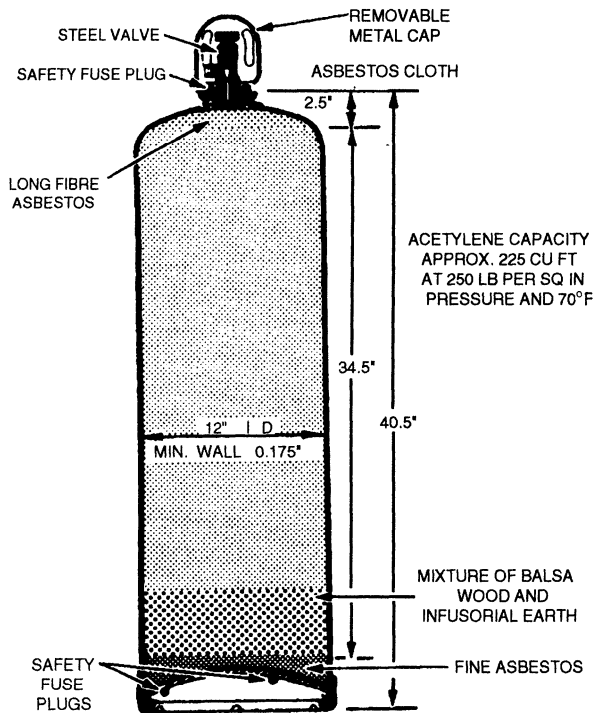


Figure 4-5.—Acetylene cylinder.

225 cubic feet of acetylene. Just because a cylinder has a 225-cubic-foot capacity does not necessarily mean it has 225 cubic feet of acetylene in it. Because it is dissolved in acetone, you cannot judge how much acetylene is left in a cylinder by gauge pressure. The pressure of the acetylene cylinder will remain fairly constant until most of the gas is consumed.

An example of an acetylene cylinder is shown in figure 4-5. These cylinders are equipped with fusible plugs that relieve excess pressure if the cylinder is exposed to undue heat. The standard Navy acetylene cylinder contains 225 cubic feet of acetylene and weighs about 250 pounds. The acetylene cylinder is yellow, and all compressed-gas cylinders are color-coded for identification. More on the color coding of cylinders is covered later in this chapter.

MAPP GAS

MAPP (methylacetylene-propadiene) is an all-purpose industrial fuel having the high-flame temperature of acetylene but has the handling characteristics of propane. Being a liquid, MAPP is sold by the pound, rather than by the cubic foot, as with acetylene. One cylinder containing 70 pounds of MAPP gas can accomplish the work of more than six and one-half 225-cubic-foot acetylene cylinders; therefore, 70 pounds of MAPP gas is equal to 1,500 cubic feet of acetylene.

Cylinder Design

Total weight for a MAPP cylinder, which has the same physical size as a 225-cubic-foot acetylene cylinder, is 120 pounds (70 pounds which is MAPP gas). MAPP cylinders contain only liquid fuel. There is no cylinder packing or acetone to impair fuel withdrawal; therefore, the entire contents of a MAPP cylinder can be used. For heavy-use situations, a MAPP cylinder delivers more than twice as much gas as an acetylene cylinder for the same time period.

MAPP Characteristics

Because of its superior heat transfer characteristics, MAPP produces a flame temperature of 5300°F when burned with oxygen. MAPP equals, or exceeds, the performance of acetylene for cutting, heating, and brazing.

MAPP is not sensitive to shock and is nonflammable in the absence of oxygen. There is no chance of an explosion if a cylinder is bumped, jarred, or dropped. You can store or transport the cylinders in any position with no danger of forming an explosive gas pocket.

The characteristic odor, while harmless, gives warnings of fuel leaks in the equipment long before a dangerous condition can occur. MAPP gas is not restricted to a maximum working pressure of 15 psig, as is acetylene. In jobs requiring higher pressures and gas flows, MAPP can be used safely at the full-cylinder pressure of 95 psig at 70°F. Because of this, MAPP is an excellent gas for underwater work.

Bulk MAPP Gas

Bulk MAPP gas facilities, similar to liquid oxygen stations, are installed at some activities where large supplies of the gas are used. In bulk installations, MAPP gas is delivered through a piping system directly to the user points. Maximum pressure is controlled centrally for efficiency and economy.

Cylinder-filling facilities are also available from bulk installations that allow users to fill their cylinders on site. Filling a 70-pound MAPP cylinder takes one man about 1 minute and is essentially like pumping water from a large tank to a smaller one.

MAPP Gas Safety

MAPP gas vapor is stable up to 600°F and 1,100 psig when exposed to an 825°F probe. The explosive limits of MAPP gas are 3.4 percent to 10.8 percent in air or 2.5 percent to 80 percent in oxygen. As shown in

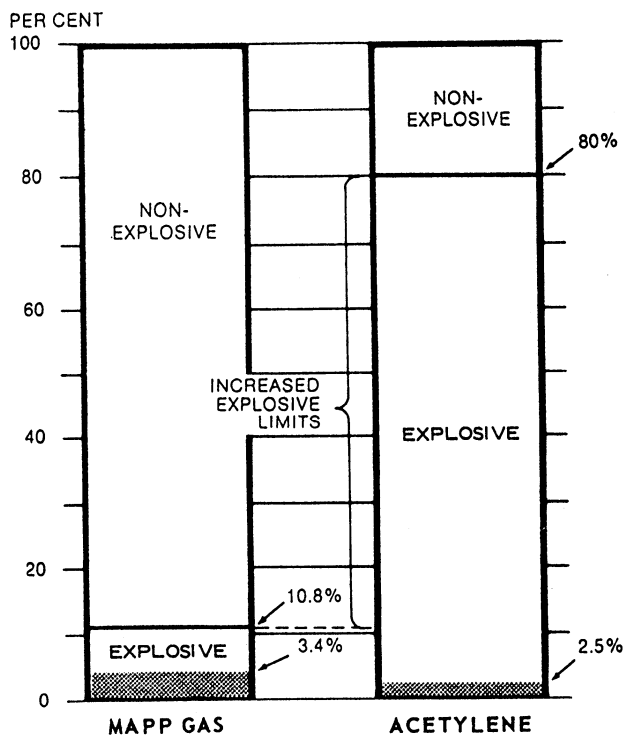


Figure 4-6.—Explosive limits of MAPP and acetylene in air.

figure 4-6, you can see these limits are narrow in comparison with that of acetylene.

MAPP gas has a highly detectable odor. The smell is detectable at 100 ppm, or at a concentration of 1/340th of its lower explosive limit. Small fuel-gas systems may leak 1 or 1 1/2 pounds of fuel or more in an 8-hour shift; bulk systems will leak even more. Fuel-gas leaks are often difficult to find and often go unnoticed; however, a MAPP gas leak is easy to detect and can be repaired before it becomes dangerous.

MAPP toxicity is rated "very slight," but high concentrations (5,000 ppm) may have an anesthetic effect. Local eye or skin contact with MAPP gas vapor causes no adverse effect; however, the liquid fuel can cause dangerous frostlike burns due to the cooling caused by the rapid evaporation of the liquid.

The identification markings on a MAPP cylinder are a yellow body with band "B" colored orange and the top yellow.

OXYGEN

Oxygen is a colorless, tasteless, and odorless gas and is slightly heavier than air. It is nonflammable but supports combustion with other elements. In its free state, oxygen is one of the more common elements. The atmosphere is made up of about 21 parts of oxygen and 78 parts of nitrogen, the remainder being rare gases. Rusting of ferrous metals, discoloration of copper, and

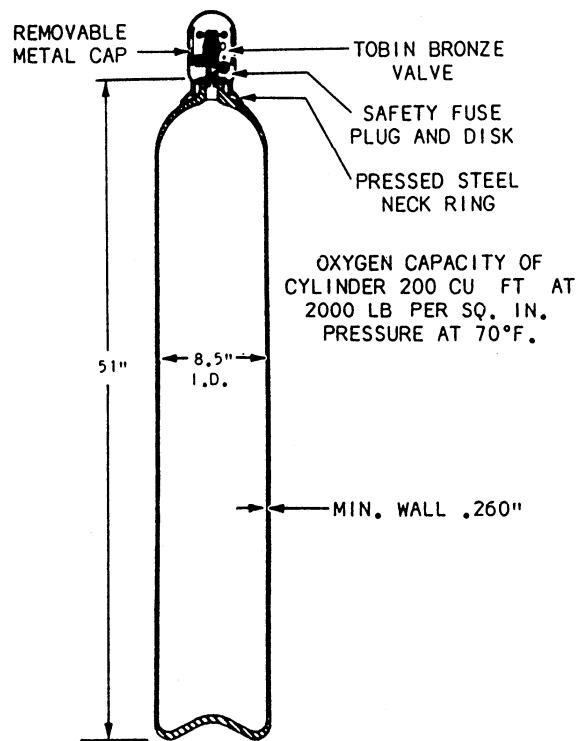


Figure 4-7.—Typical oxygen cylinder.

corrosion of aluminum are all due to the action of atmospheric oxygen. This action is known as *oxidation*.

Oxygen is obtained commercially either by the liquid-air process or by the electrolytic process. In the liquid-air process, the air is compressed and then cooled to a point where the gases become liquid (approximately -375°F). The temperature is then raised to above -321°F , at which point the nitrogen in the air becomes gas again and is removed. When the temperature of the remaining liquid is raised to -297°F , the oxygen forms gas and is drawn off. The oxygen is further purified and compressed into cylinders for use.

The other process by which oxygen is produced—the electrolytic process—consists of running an electrical current through water to which an acid or an alkali has been added. The oxygen collects at the positive terminal and is drawn off through pipes to a container.

Oxygen is supplied for oxyacetylene welding in seamless steel cylinders. A typical oxygen cylinder is shown in figure 4-7. The color of a standard oxygen cylinder used for industrial purposes is solid green. Oxygen cylinders are made in several sizes. The size most often used in welding and cutting is the 244-cubic-foot capacity cylinder. This cylinder is 9 inches in diameter, 51 inches high, and weighs about 145 pounds and is charged to a pressure of 2,200 psi at 70°F .

You can determine the amount of oxygen in a compressed-gas cylinder by reading the volume scale on the high-pressure gauge attached to the regulator.

REGULATORS

You must be able to reduce the high-pressure gas in a cylinder to a working pressure before you can use it. This pressure reduction is done by a regulator or reducing valve. The one basic job of all regulators is to take the high-pressure gas from the cylinder and reduce it to a level that can be safely used. Not only do they control the pressure but they also control the flow (volume of gas per hour).

Regulators come in all sizes and types. Some are designed for high-pressure oxygen cylinders (2,200 psig), while others are designed for low-pressure gases, such as natural gas (5 psig). Some gases like nitrous oxide or carbon dioxide freeze when their pressure is reduced so they require electrically heated regulators.

Most regulators have two gauges: one indicates the cylinder pressure when the valve is opened and the other indicates the pressure of the gas coming out of the regulator. You must open the regulator before you get a reading on the second gauge. This is the delivery pressure of the gas, and you must set the pressure that you need for your particular job.

The pressures that you read on regulator gauges is called gauge pressure. If you are using pounds per square inch, it should be written as *psig* (this acronym means pounds per square inch gauge). When the gauge on a cylinder reads zero, this does not mean that the cylinder is empty. In actuality, the cylinder is still full of gas, but the pressure is equal to the surrounding atmospheric pressure. Remember: no gas cylinder is empty unless it has been pumped out by a vacuum pump.

There are two types of regulators that control the flow of gas from a cylinder. These are either single-stage or double-stage regulators.

Single-Stage Regulators

Regulators are used on both high- and low-pressure systems. Figure 4-8 shows two SINGLE-STAGE regulators: one for acetylene and one for oxygen. The regulator mechanism consists of a nozzle through which the gases pass, a valve seat to close off the nozzle, a diaphragm, and balancing springs. These mechanisms are all enclosed in a suitable housing. Fuel-gas regulators and oxygen regulators are basically the same design. The difference being those designed for fuel gases are

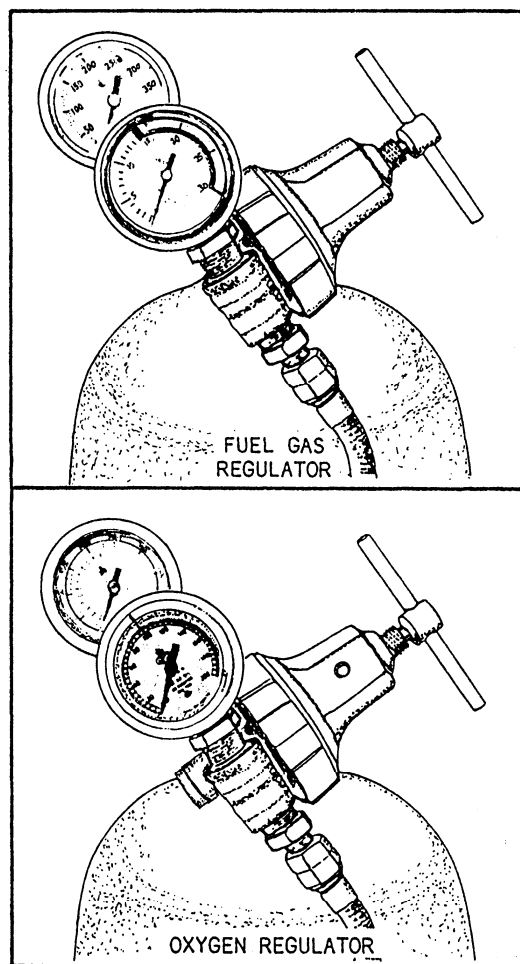


Figure 4-8.—Single-stage regulators.

not made to withstand the high pressures that oxygen regulators are subjected to.

In the oxygen regulator, the oxygen enters through the high-pressure inlet connection and passes through a glass wool filter that removes dust and dirt. Turning the adjusting screw **IN** (clockwise) allows the oxygen to pass from the high-pressure chamber to the low-pressure chamber of the regulator, through the regulator outlet, and through the hose to the torch. Turning the adjusting screw further clockwise increases the working pressure; turning it counterclockwise decreases the working pressure.

The high-pressure gauge on an oxygen regulator is graduated from 0 to 3,000 psig and from 0 to 220 in cubic feet. This allows readings of the gauge to determine cylinder pressure and cubic content. Gauges are calibrated to read correctly at 70°F. The working pressure gauge may be graduated in “psig” from 0 to 150, 0 to 200, or from 0 to 400, depending upon the type of regulator used. For example, on regulators designed for

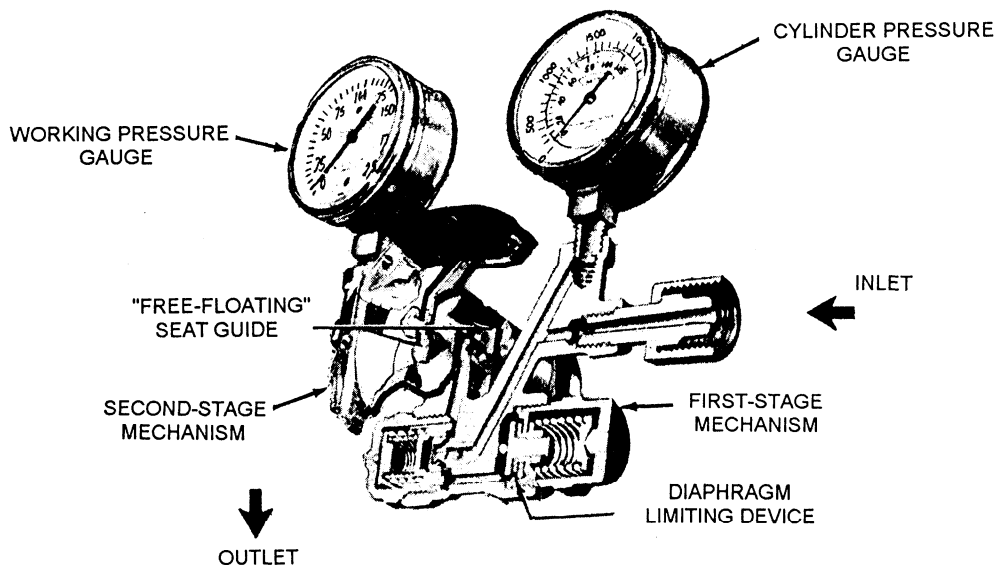


Figure 4-9.—Double-stage regulator.

heavy cutting, the working pressure gauge is graduated from 0 to 400.

The major disadvantage of single-stage regulators is that the working gas pressure you set will decrease as the cylinder pressure decreases; therefore, you must constantly monitor and reset the regulator if you require a fixed pressure and flow rate. Keeping the gas pressure and flow rate constant is too much to expect from a regulator that has to reduce the pressure of a full cylinder from 2,200 psig to 5 psig. This is where double-stage regulators solve the problem.

Double-Stage Regulators

The double-stage regulator is similar in principle to the one-stage regulator. The main difference being that the total pressure drop takes place in two stages instead of one. In the high-pressure stage, the cylinder pressure is reduced to an intermediate pressure that was predetermined by the manufacturer. In the low-pressure stage, the pressure is again reduced from the intermediate pressure to the working pressure you have chosen. A typical double-stage regulator is shown in figure 4-9.

Problems and Safety

Regulators are precise and complicated pieces of equipment. Carelessness can do more to ruin a regulator than any other gas-using equipment. One can easily damage a regulator by simply forgetting to wipe clean the cylinder, regulator, or hose connections. When you open a high-pressure cylinder, the gas can rush into the

regulator at the speed of sound. If there is any dirt present in the connections, it will be blasted into the precision-fitted valve seats, causing them to leak. This results in a condition that is known as *creep*. Creep occurs when you shut off the regulator but not the cylinder and gas pressure is still being delivered to the low-pressure side.

Regulators are built with a minimum of two relief devices that protect you and the equipment in the case of regulator creep or high-pressure gas being released into the regulator all at once. All regulator gauges have blowout backs that release the pressure from the back of the gauge before the gauge glass explodes. Nowadays, most manufacturers use shatterproof plastic instead of glass.

The regulator body is also protected by safety devices. Blowout disks or spring-loaded relief valves are the two most common types of devices used. When a blowout disk ruptures, it sounds like a cannon. Spring-loaded relief valves usually make howling or shrieking like noises. In either case, your first action, after you recover from your initial fright, should be to turn off the cylinder valve. Remove the regulator and tag it for repair or disposal.

When opening a gas cylinder, you should just “crack” the valve a little. This should be done before attaching the regulator and every time thereafter. By opening the cylinder before connecting the regulator, you blow out any dirt or other foreign material that might be in the cylinder nozzle. Also, there is the

possibility of a regulator exploding if the cylinder valve is opened rapidly.

WARNING

Oil or other petroleum products must never be used around oxygen regulators because these products will either cause a regulator explosion or fire.

HOSES

The hoses used to make the connections between the torch and the regulators must be strong, nonporous, light, and flexible enough to make torch movements easy. They must be made to withstand internal pressures that can reach as high as 100 psig. The rubber used in hose manufacture is specially treated to remove the sulfur that could cause spontaneous combustion.

Welding hose is available in single- and double-hose lengths. Size is determined by the inside diameter, and the proper size to use depends on the type of work for which it is intended. Hose used for light work has a 3/16 or 1/4 inch inside diameter and one or two plies of fabric. For heavy-duty welding and cutting operations, use a hose with an inside diameter of 5/16 inch and three to five plies of fabric. Single hose is available in the standard sizes as well as 1/2-, 3/4-, and 1-inch sizes. These larger sizes are for heavy-duty heating and for use on large cutting machines.

The most common type of cutting and welding hose is the twin or double hose that consists of the fuel hose and the oxygen hose joined together side by side. They are joined together by either a special rib (fig. 4-10, view A) or by clamps (fig. 4-10, view B). Because they are joined together, the hoses are less likely to become tangled and are easier to move from place.

The length of hose you use is important. The delivery pressure at the torch varies with the length of the hose. A 20-foot, 3/16-inch hose maybe adequate for a job, but if the same hose was 50 feet long, the pressure drop would result in insufficient gas flow to the torch. Longer hoses require larger inside diameters to ensure the correct flow of gas to the torch. When you are having problems welding or cutting, this is one area to check

The hoses used for fuel gas and oxygen are identical in construction, but they differ in color. The oxygen hose cover is GREEN, and the fuel-gas hose cover is RED. This color coding aids in the prevention of mishaps that could lead to dangerous accidents.

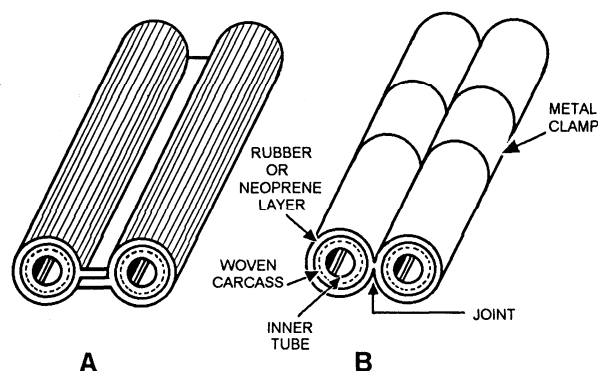


Figure 4-10.—Types of twin welding hose.

All connections for welding and cutting hoses have been standardized by the *Compressed Gas Association*. Letter grades A, B, C, D, and E plus the type of gas used correspond directly with the connections on the regulators. A, B, and C are the most common size connections. A-size is for low-flow rates; B-size for medium-flow rates; and C-size is for heavy-flow rates. D and E sizes are for large cutting and heating torches.

When ordering connections, you must specify the type of gas the hose will be carrying. This is because the connections will be threaded differently for different types of gas. Fuel gases use left-hand threads, while oxygen uses right-hand threads. The reason for this is to prevent the accidental hookup of a fuel gas to a life-support oxygen system or vice versa.

The basic hose connection consists of a nut and gland. The nut has threads on the inside that match up with the male inlet and outlet on the torch and regulator. The gland slides inside the hose and is held in place by a ferrule that has been crimped. The nut is loose and can be turned by hand or a wrench to tighten the threaded nut onto the equipment.

Another important item that is often overlooked are check valves. These inexpensive valves prevent personal injuries and save valuable equipment from flashbacks. When ordering, make sure you specify the type of gas, connection size, and thread design. The check valves should be installed between the torch connection and the hose.

CUTTING TORCHES

The equipment and accessories for oxygas cutting are the same as for oxygas welding except that you use a cutting torch or a cutting attachment instead of a welding torch. The main difference between the cutting torch and the welding torch is that the cutting torch has

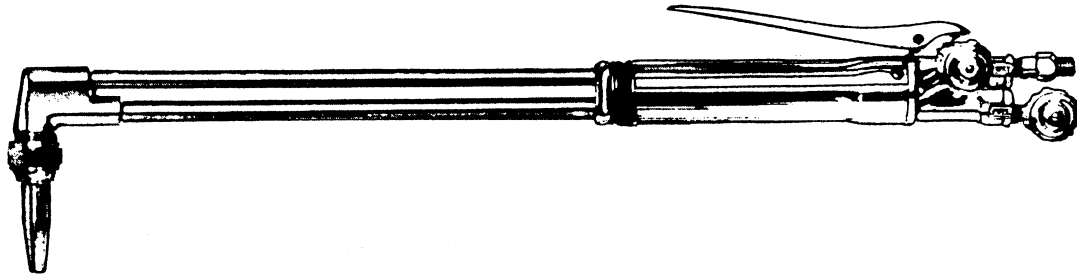


Figure 4-11.—One piece oxygas cutting torch.

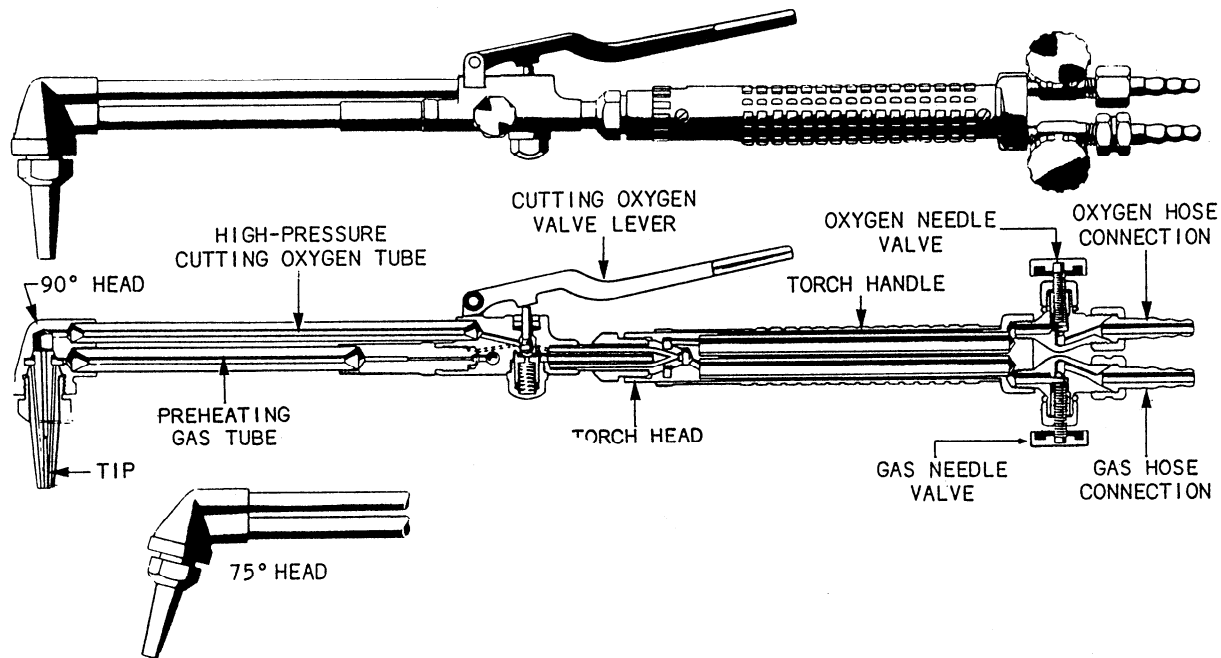


Figure 4-12.—Cutting attachment for combination torch.

an additional tube for high-pressure cutting oxygen. The flow of high-pressure oxygen is controlled from a valve on the handle of the cutting torch. In the standard cutting torch, the valve may be in the form of a trigger assembly like the one in figure 4-11. On most torches, the cutting oxygen mechanism is designed so the cutting oxygen can be turned on gradually. The gradual opening of the cutting oxygen valve is particularly helpful in operations, such as hole piercing and rivet cutting.

Torch Body

Most welding torches are designed so the body of the torch can accept either welding tips or a cutting attachment. This type of torch is called a combination torch. The advantage of this type of torch is the ease in changing from the welding mode to the cutting mode. There is no need to disconnect the hoses; you just

unscrew the welding tip and then screw on the cutting attachment. The high-pressure cutting oxygen is controlled by a lever on the torch handle, as shown in figure 4-12.

Cutting Torch Tips

As in welding, you must use the proper size cutting tip if quality work is to be done. The preheat flames must furnish just the right amount of heat, and the oxygen jet orifice must deliver the correct amount of oxygen at just the right pressure and velocity to produce a clean cut. All of this must be done with a minimum consumption of oxygen and fuel gases. Careless workers and workers not acquainted with the correct procedures waste both oxygen and fuel gas. This does not seem important when you are working in a shop, but if you are deployed, it

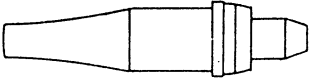
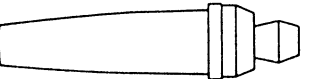
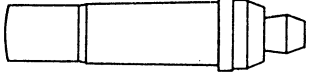
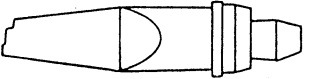
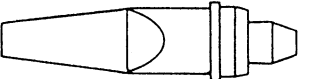
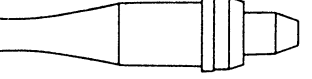
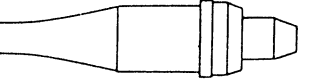
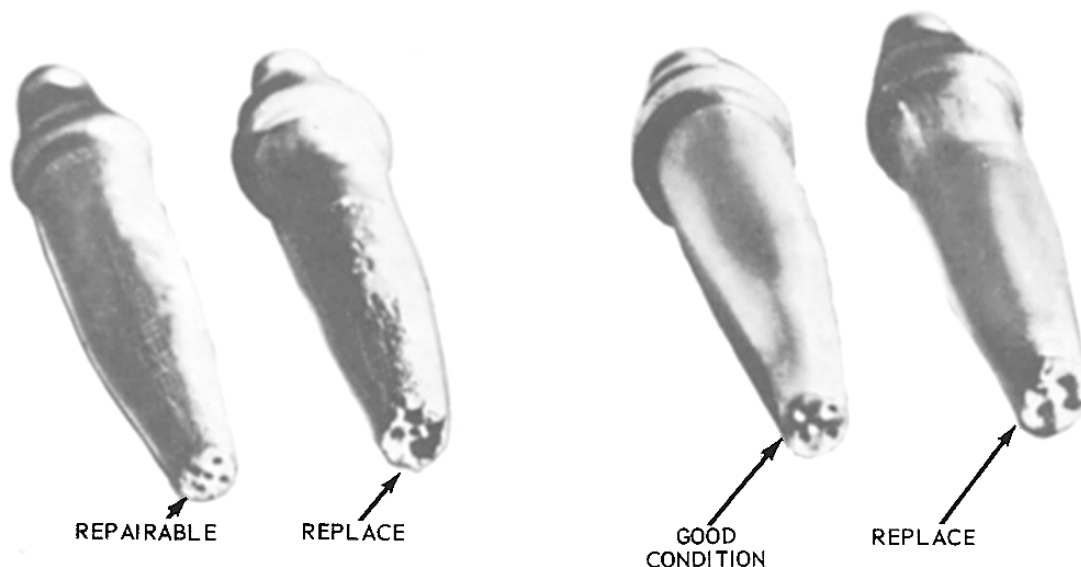
STYLE	PREHEAT	DESCRIPTION	SIZE	TYPE
	 Medium	MAPP* GAS — One-Piece Preheat: Medium. Typical use: Hand and machine cutting.	00-6	1-303M
	 Medium	MAPP* GAS — One-Piece Preheat: Medium. Typical use: Cutting close to bulkheads, hand cutting of rivet heads, machine cutting 35° with torch perpendicular.	1,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

Figure 4-13.—Common cutting torch tips and their uses.

becomes critical due to the long lead time between resupply.

Each manufacturer makes many different types of cutting tips. Although the orifice arrangements and the tip material are much the same among the manufacturers, the part of the tip that fits into the torch head often differs in design. Because of the way the Navy pur-

chases its cutting and welding equipment, there is the possibility of having two or three different types of cutting torches in your kits. Make sure that the cutting tips match the cutting attachment and ensure that the cutting attachment matches the torch body. Figure 4-13 shows the different styles of tips, their orifice arrangements, and their uses. The tips and seats are designed to



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Figure 4-14.—Four cutting-tip conditions.

produce a even flow of gas and to keep themselves as cool as possible. The seats must produce leakproof joints. If the joints leak, the preheat gases could mix with the cutting oxygen or escape to the atmosphere, resulting in poor cuts or the possibility of flashbacks.

To make clean and economical cuts, you must keep the tip orifices and passages clean and free of burrs and slag. If the tips become dirty or misshapened, they should be put aside for restoration. Figure 4-14 shows four tips: one that is repairable, two that need replacing, and one in good condition. Since it is extremely important that the sealing surfaces be clean and free of scratches or burrs, store the tips in a container that cannot scratch the seats. Aluminum racks, plastic racks, and wood racks or boxes make ideal storage containers.

TIP MAINTENANCE.— In cutting operations, the stream of cutting oxygen sometimes blows slag and molten metal into the tip orifices which partially clogs them. When this happens, you should clean the orifices thoroughly before you use the tip again. A small amount of slag or metal in an orifice will seriously interfere with the cutting operation. You should follow the recommendations of the torch manufacturer as to the size of drill or tip cleaner to use for cleaning the orifices. If you do not have a tip cleaner or drill, you may use a piece of soft copper wire. Do not use twist drills, nails, or welding rods for cleaning tips because these items are likely to enlarge and distort the orifices.

Clean the orifices of the cutting torch tip in the same manner as the single orifice of the welding torch tip. Remember: the proper technique for cleaning the

tips is to push the cleaner straight in and out of the orifice. Be careful not to turn or twist the cleaning wire. Figure 4-15 shows a typical set of tip cleaners.

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

After reconditioning a tip, you may test it by lighting the torch and observing the preheating flames. If the

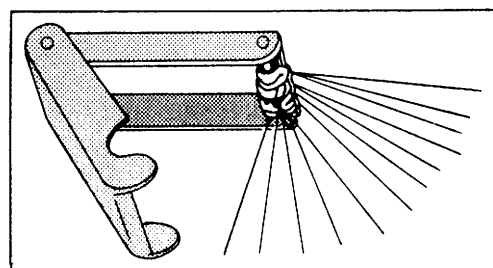


Figure 4-15.—Tip cleaners.

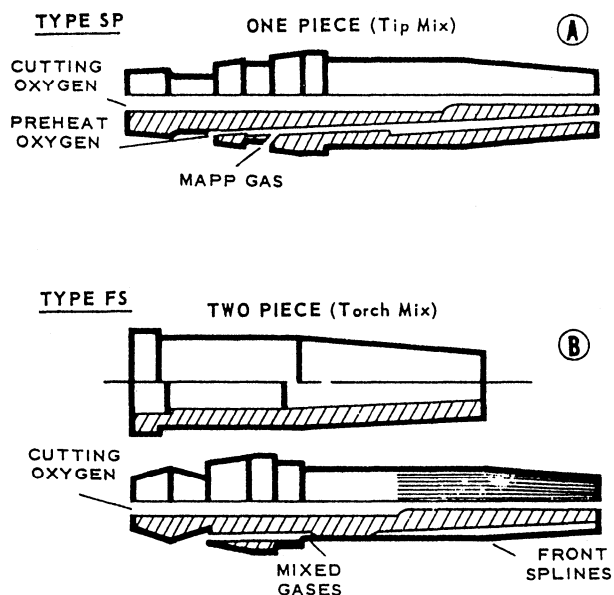


Figure 4-16.—MAPP gas cutting tips.

flames are too short, the orifices are still partially blocked. If the flames snap out when you close the valves, the orifices are still distorted.

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

MAPP GAS CUTTING TIPS.— Four basic types of MAPP gas cutting tips are used: two are for use with standard pressures and normal cutting speeds, and two are for use with high pressures and high cutting speeds. Only the standard pressure tips, types *SP* and *FS*, will be covered here since they are the ones that Steelworkers will most likely use. *SP* stands for standard pressure and *FS* for fine standard.

The *SP* tip (fig. 4-16, view A) is a one-piece standard pressure tip. It is used for cutting by hand, especially by welders who are accustomed to one-piece tips. *SP* tips are more likely to be used in situations where MAPP gas is replacing acetylene as the fuel gas.

The *FS* tip (fig. 4-16, view B) is a two-piece, fine spline, standard pressure tip. It is used for cutting by hand as well as by machine. Welders accustomed to two-piece cutting tips will use them in hand cutting, especially when MAPP gas is replacing natural gas or propane as the fuel gas. The *FS* tips will produce heavier preheating flames and faster starts than the *SP* tips; however, two-piece tips will not take as much thermal or physical abuse as one-piece tips. But in the hands of skilled Steelworkers, they should last as long as one-piece tips.

Recommended tip sizes and gas pressures for use in cutting different thicknesses of steel using MAPP gas as a fuel are given in table 4-1.

Table 4-1.—Recommended MAPP Gas Tip Sizes and Oxyfuel Pressures

Material Thickness inches (millimeters)	Cutting Tip Number	Oxygen Cutting Pressure (psig)	MAPP Gas Pressure (psig)
1/8 (3)	75	40-50	2-10
3/16 (4.8)	72		
1/4 (6.4)	68		
1/2 (12.7)	61		
3/4 (19)	56		
1 (25.4)			
1 1/4 (31.8)	54	50-60	
1 1/2 (38)			
2 (50.8)			
2 1/2 (63.5)			
3 (76)			
4 (101)	46	60-70	

OXYGAS CUTTING OPERATIONS

Before you begin a cutting operation with an oxygas cutting torch, make a thorough inspection of the area. Ensure that there are no combustible materials in the area that could be ignited by the sparks or slag produced by the cutting operation. If you are burning into a wall, inspect the opposite side of the wall, and post a fire watch as required.

EQUIPMENT SETUP

Setting up the oxygas equipment and preparing for cutting must be done carefully and systematically to avoid costly mistakes. To ensure your own safety, as well as the safety of your coworkers and equipment, make sure the following steps are taken before any attempt is made to light the torch:

- Secure the cylinders so they cannot be accidentally knocked over. A good way to do this is to either put them in a corner or next to a vertical column and then secure them with a piece of line. After securing the cylinders, remove the protective caps. Cylinders should never be secured to a structural member of a building that is a current conductor.

- Standing to one side, crack each cylinder valve slightly and then immediately close the valve again. This blows any dirt or other foreign matter out of the cylinder valve nozzle. Do not bleed fuel gas into a confined area because it may ignite. Ensure the valves are closed and wipe the connections with a clean cloth.

- Connect the fuel-gas regulator to the fuel-gas cylinder and the oxygen regulator to the oxygen cylinder. Using a gang wrench, snug the connection nuts sufficiently to avoid leaks.

- Back off the regulator screws to prevent damage to the regulators and gauges and open the cylinder valves slowly. Open the fuel-gas valve only one-half turn and the oxygen valve all the way. Some fuel-gas cylinders have a handwheel for opening the fuel-gas valve while others require the use of a gang wrench or T-handle wrench. Leave the wrench in place while the cylinder is in use so the fuel-gas bottle can be turned off quickly in an emergency. Read the high-pressure gauge to check the contents in each cylinder.

- Connect the RED hose to the fuel-gas regulator and the GREEN hose to the oxygen regulator. Notice the left-hand threads on the fuel-gas connection.

- To blow out the oxygen hose, turn the regulator screw in (clockwise) and adjust the pressure between 2

and 5 psig. After the hose has been purged, turn the screw back out again (counterclockwise) to shutoff the oxygen. Do the same for the fuel-gas hose, but do it ONLY in a well-ventilated place that is free from sparks, flames, or other possible sources of ignition.

- Connect the hoses to the torch. The RED (fuel-gas) hose is connected to the connection gland with the needle valve marked "FUEL." The GREEN (oxygen) hose is connected to the connection gland with the needle valve marked "OXY."

- With the torch valves closed, turn both regulator screws clockwise to test the hose connections for leaks. If none are found, turn the regulator screws counterclockwise and drain the hose by opening the torch valves.

- Select the correct cutting tip and install it in the cutting torch head. Tighten the assembly by hand, and then tighten with your gang wrench.

- Adjust the working pressures. The fuel-gas pressure is adjusted by opening the torch needle valve and turning the fuel-gas regulator screw clockwise. Adjust the regulator to the working pressure needed for the particular tip size, and then close the torch needle valve. To adjust MAPP gas, you should set the gauge pressure with the torch valves closed. To adjust the oxygen working pressure, you should open the oxygen torch needle valve and proceed in the same manner as in adjusting the fuel-gas pressure.

In lighting the torch and adjusting the flame, always follow the manufacturer's directions for the particular model of torch being used. This is necessary because the procedure varies somewhat with different types of torches and, in some cases, even with different models made by the same manufacturer.

In general, the procedure used for lighting a torch is to first open the torch oxygen needle valve a small amount and the torch fuel-gas needle valve slightly more, depending upon the type of torch. The mixture of oxygen and fuel gas coming from the torch tip is then lighted by means of a spark igniter or stationary pilot flame.

CAUTION

NEVER use matches to light the torch; their length requires bringing the hand too close to the tip. Accumulated gas may envelop the hand and, upon igniting, result in a severe burn. Also, never light the torch from hot metal.

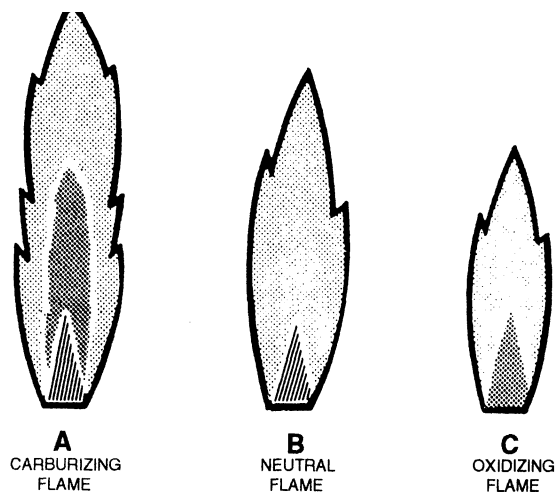


Figure 4-17.—MAPP-gas flames.

After checking the fuel-gas adjustment, you can adjust the oxygas flame to obtain the desired characteristics for the work at hand, by further manipulating the oxygen and fuel-gas needle valves according to the torch manufacturer's direction.

There are three types of gas flames commonly used for all oxygas processes. They are carburizing, neutral, and oxidizing. To ensure proper flame adjustment, you should know the characteristics of each of these three types of flame. Figure 4-17 shows how the three different flames look when using MAPP gas as the fuel.

A pure fuel-gas flame is long and bushy and has a yellowish color. It takes the oxygen it needs for combustion from the surrounding air. The oxygen available is not sufficient enough to burn the fuel gas completely; therefore, the flame is smokey and consists of soot. This flame is not suitable for use. You need to increase the amount of oxygen by opening the oxygen needle valve until the flame takes on a bluish white color, with a bright inner cone surrounded by a flame envelope of a darker hue. It is the inner cone that develops the required operating temperature.

CARBURIZING FLAME.— The carburizing flame always shows distinct colors; the inner cone is bluish white, the intermediate cone is white, the outer envelope flame is light blue, and the feather at the tip of the inner cone is greenish. The length of the feather can be used as a basis for judging the degree of carburization. The highly carburizing flame is longer with yellow or white feathers on the inner cone, while the slightly carburizing flame has a shorter feather on the inner cone and becomes more white. The temperature of carburizing flames is about 5400°F.

Strongly carburizing flames are not used in cutting low-carbon steels because the additional carbon they add causes embrittlement and hardness. These flames are ideal for cutting cast iron because the additional carbon poses no problems and the flame adds more heat to the metal because of its size.

Slightly carburizing flames are ideal for cutting steels and other ferrous metals that produce a large amount of slag. Although a neutral flame is best for most cutting, a slightly carburizing flame is ideal for producing a lot of heat down inside the kerf. It makes fairly smooth cuts and reduces the amount of slag clinging to the bottom of the cut.

NEUTRAL FLAME.— The most common preheat flame for oxygas cutting is the neutral flame. When you increase the oxygen, the carburizing flame becomes neutral. The feather will disappear from the inner flame cone and all that will be left is the dark blue inner flame and the lighter blue outer cone. The temperature is about 5600°F.

The neutral flame will not oxidize or add carbon to the metal you are cutting. In actuality, a neutral flame acts like the inert gases that are used in TIG and MIG welding to protect the weld from the atmosphere. When you hold a neutral preheat flame on one spot on the metal until it melts, the molten puddle that forms looks clear and lies very quietly under the flame.

OXIDIZING FLAME.— When you add a little more oxygen to the preheat flame, it will quickly become shorter. The flame will start to neck down at the base, next to the flame ports. The inner flame cone changes from dark blue to light blue. Oxidizing flames are much easier to look at because they are less radiant than neutral flames. The temperature is about 6000°F.

The oxidizing flame is rarely used for conventional cutting because it produces excessive slag and does not leave square-cut edges. Oxidizing flames are used in conjunction with cutting machines that have a high-low oxygen valve. The machine starts the cut with an oxidizing flame then automatically reverts to a neutral flame. The oxidizing flame gives you fast starts when using high-speed cutting machines and is ideal for piercing holes in plate. Highly oxidizing flames are only used in cutting metal underwater where the only source of oxygen for the torch is supplied from the surface.

CUTTING MILD-CARBON STEEL

To cut mild-carbon steel with the oxygas cutting torch, you should adjust the preheating flames to neutral.

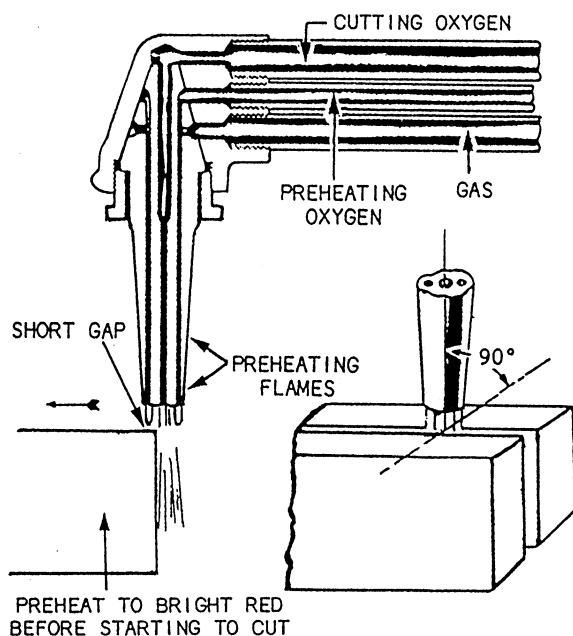


Figure 4-18.—Position of torch tip for starting a cut.

Hold the torch perpendicular to the work, with the inner cones of the preheating flames about 1/16 inch above the end of the line to be cut (fig. 4-18). Hold the torch in this position until the spot you are heating is a bright red. Open the cutting oxygen valve slowly but steadily by pressing down on the cutting valve lever.

When the cut is started correctly, a shower of sparks will fall from the opposite side of the work, indicating that the flame has pierced the metal. Move the cutting torch forward along the line just fast enough for the flame to continue to penetrate the work completely. If you have made the cut properly, you will get a clean, narrow cut that looks almost like it was made by a saw. When cutting round bars or heavy sections, you can save preheating time by raising a small burr with a chisel where the cut is to begin. This small raised portion will heat quickly, allowing you to start cutting immediately.

Once you start the cut, you should move the torch slowly along the cutting mark or guide. As you move the torch along, watch the cut so you can tell how it is progressing. Adjust the torch as necessary. You must move the torch at the correct speed, not too fast and not too slow. If you go too slowly, the preheating flame melts the top edges along the cut and could weld them back together again. If you go too rapidly, the flame will not penetrate completely, as shown in figure 4-19. When this happens, sparks and slag will blow back towards you. If you have to restart the cut, make sure there is no slag on the opposite side.

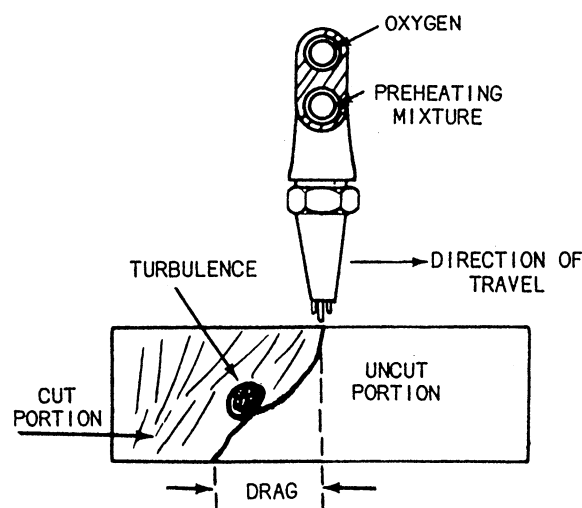


Figure 4-19.—The effect of moving a cutting torch too rapidly across the work.

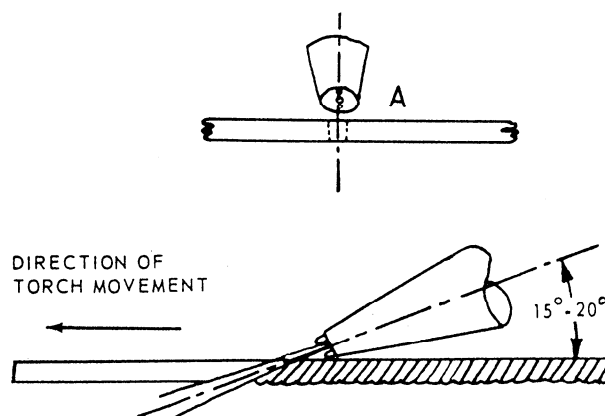


Figure 4-20.—Recommended procedure for cutting thin steel. Notice that the two preheat flames are in line with the cut (kerf).

Cutting Thin Steel

When cutting steel 1/8 inch or less in thickness, use the smallest cutting tip available. In addition, point the tip in the direction the torch is traveling. By tilting the tip, you give the preheating flames a chance to heat the metal ahead of the oxygen jet, as shown in figure 4-20. If you hold the tip perpendicular to the surface, you decrease the amount of preheated metal and the adjacent metal could cool the cut enough to prevent smooth cutting action. Many Steelworkers actually rest the edge of the tip on the metal during this process. If you use this method, be careful to keep the end of the preheating flame inner cone just above the metal.

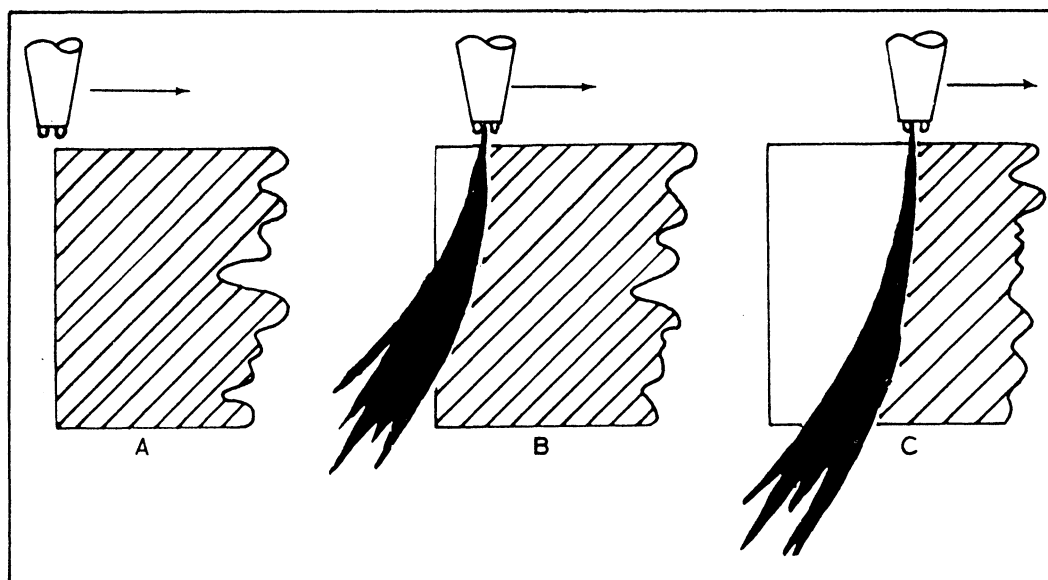


Figure 4-21.—Progress of a cut in thick steel. A. Preheat flames are 1/16 to 1/8 inch from the metal surface. Hold the torch in this spot until the metal becomes cherry red. B. Move the torch slowly to maintain the rapid oxidation, even though the cut is only partially through the metal. C. The cut is made through the entire thickness; the bottom of the kerf lags behind the top edge slightly.

Cutting Thick Steel

Steel, that is greater than 1/8 inch thick, can be cut by holding the torch so the tip is almost vertical to the surface of the metal. If you are right-handed, one method to cut steel is to start at the edge of the plate and move from right to left. Left-handed people tend to cut left to right. Either direction is correct and you may cut in the direction that is most comfortable for you. Figure 4-21 shows the progress of a cut in thick steel.

After heating the edge of the steel to a dull cherry red, open the oxygen jet all the way by pressing on the cutting lever. As soon as the cutting action starts, move the torch tip at a even rate. Avoid unsteady movement of the torch to prevent irregular cuts and premature stopping of the cutting action.

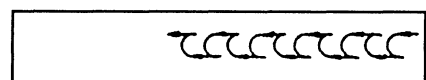
To start a cut quicker in thick plate, you should start at the edge of the metal with the torch angled in the opposite direction of travel. When the edge starts to cut, bring the torch to a vertical position to complete the cut through the total thickness of the metal. As soon as the cut is through the metal, start moving the torch in the direction of travel.

Two other methods for starting cuts are used. In the first method, you nick the edge of the metal with a cold chisel at the point where the cut is to start. The sharp edges of the metal upset by the chisel will preheat and oxidize rapidly under the cutting torch, allowing you to

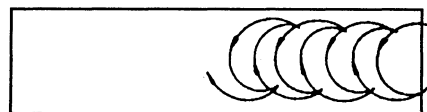
start the cut without preheating the entire edge of the plate. In the second method, you place an iron filler rod at the edge of a thick plate. As you apply the preheat flames to the edge of the plate, the filler rod rapidly reaches the cherry red temperature. At this point, turn the cutting oxygen on and the rod will oxidize and cause the thicker plate to start oxidizing.

CUTTING CAST IRON

It is more difficult to cut cast iron than steel because the iron oxides in cast iron melt at a higher temperature than the cast iron itself. Before you cut cast iron, it is best to preheat the whole casting to prevent stress fractures. Do not heat the casting to a temperature that is too high, as this will oxidize the surface and make cutting



A. TORCH MOVEMENT FOR CUTTING THIN SECTIONS OF CAST IRON



B. TORCH MOVEMENT FOR CUTTING HEAVY SECTIONS OF CAST IRON

Figure 4-22.—Torch movements for cutting cast iron.

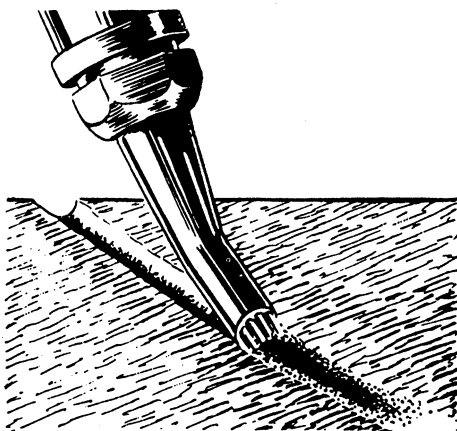


Figure 4-23.—Typical gouging operation using a low-velocity cutting jet for better control of depth and width.

more difficult. A preheat temperature of about 500°F is normally satisfactory.

When cutting cast iron, adjust the preheating flame of the torch to a carburizing flame. This prevents the formation of oxides on the surface and provides better preheat. The cast-iron kerf is always wider than a steel kerf due to the presence of oxides and the torch movement. The torch movement is similar to scribing semi-circles along the cutting line (fig. 4-22). As the metal becomes molten, trigger the cutting oxygen and use its force to jet the molten metal out of the kerf. Repeat this action until the cut is complete.

Because of the difficulty in cutting cast iron with the usual oxygas cutting torch, other methods of cutting were developed. These include the oxygen lance, carbon-arc powder, inert-gas cutting, and plasma-arc methods.

GOUGING MILD STEEL

Cutting curved grooves on the edge or surface of a plate and removing faulty welds for rewelding are additional uses for the cutting torch. The gist of groove cutting or gouging is based on the use of a large orifice, low-velocity jet of oxygen instead of a high-velocity jet. The low-velocity jet oxidizes the surface metal only and gives better control for more accurate gouging. By varying the travel speed, oxygen pressure, and the angle between the tip and plate, you can make a variety of gouge contours.

A gouging tip usually has five or six preheat orifices that provide a more even preheat distribution. Automatic machines can cut grooves to exact depths, remove bad

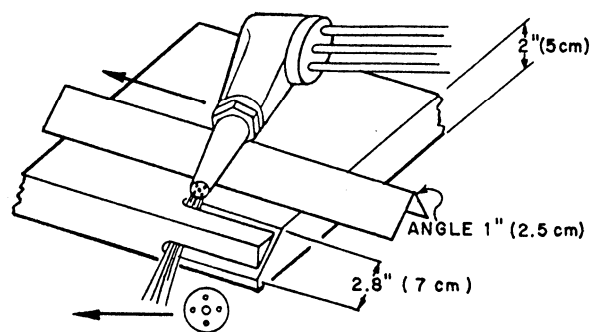


Figure 4-24.—Using angle iron to cut bevels on steel plate.

spots, and rapidly prepare metal edges for welding. Figure 4-23 shows a typical gouging operation.

If the gouging cut is not started properly, it is possible to cut accidentally through the entire thickness of the plate. If you cut too shallow, you can cause the operation to stop. The travel speed of the torch along the gouge line is important. Moving too fast creates a narrow, shallow gouge and moving too slow creates the opposite; a deep, wide gouge.

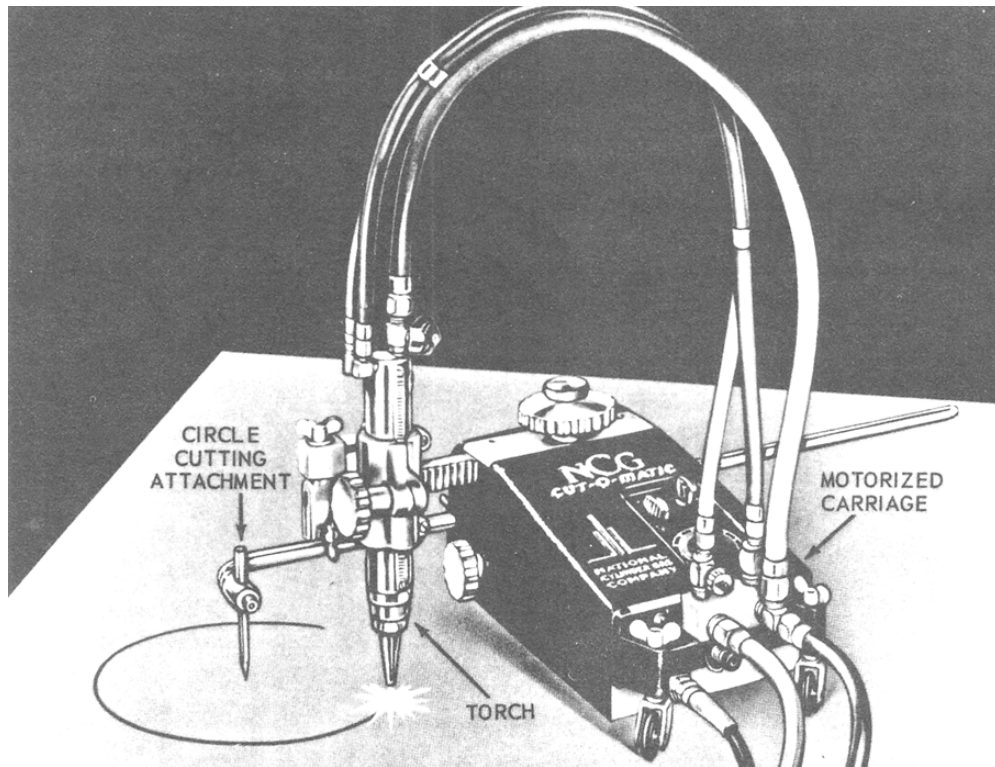
BEVELING MILD STEEL

Frequently, you must cut bevels on plate or pipe to form joints for welding. The flame must actually cut through 2.8 inches of metal to make a bevel cut of 45 degrees on a 2-inch steel plate. You must take this into consideration when selecting the tip and adjusting the pressures. You use more pressure and less speed for a bevel cut than for a straight cut.

When bevel cutting, you adjust the tip so the preheating orifices straddle the cut. A piece of 1-inch angle iron, with the angle up, makes an excellent guide for beveling straight edges. To keep the angle iron in place while cutting, you should use a heavy piece of scrap, or tack-weld the angle to the plate being cut. Move the torch along this guide, as shown in figure 4-24.

ELECTRIC DRIVE CUTTING TORCH CARRIAGE

An improvement over mechanical guides is an electric motor-driven cutting torch carriage. The speed of the motor can be varied allowing the welder to cut to dimensions and to cut at a specific speed. A typical motor driven carriage has four wheels: one driven by a reduction gear, two on swivels (castor style), and one freewheeling. The torch is mounted on the side of the carriage and is adjusted up and down by a gear and rack



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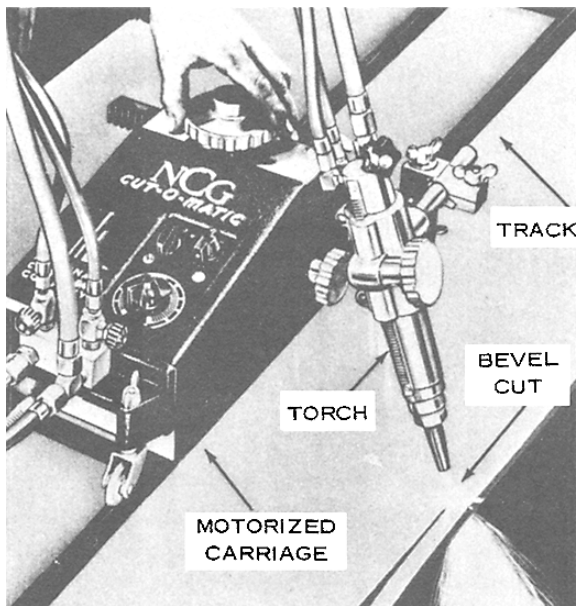
Figure 4-25.—Electric motor-driven carriage being used to cut a circle in steel plate.

The rack is a part of the special torch. The torch also can be tilted for bevel cuts. This machine comes with a straight two-groove track and has a radial bar for use in cutting circles and arcs. A motor-driven cutting torch cutting a circle is shown in figure 4-25. The carriage is

equipped with an off-and-on switch, a reversing switch, a clutch, and a speed-adjusting dial that is calibrated in feet per minute.

Figure 4-26 shows an electric drive carriage on a straight track being used for plate beveling. The operator must ensure that the electric cord and gas hoses do not become entangled on anything during the cutting operation. The best way to check for hose, electric cord, and torch clearance is to freewheel the carriage the full length of the track by hand.

You will find that the torch carriage is a valuable asset during deployment. This is especially true if your shop is called upon to produce a number of identical parts in quantity. Such an assignment might involve the fabrication of a large supply of handhole covers for runway fixtures, or another assignment might be the production of a large quantity of thick base plates for vertical columns. When using the torch carriage, you should lay the track in a straight line along a line parallel to the edge of the plate you are going to cut. Next, you light the torch and adjust the flame for the metal you are cutting. Move the carriage so the torch flame preheats the edge of the plate and then open the cutting oxygen valve and turn on the carriage motor. The machine begins moving along the track and continues to cut automatically until the end of the cut is reached. When the cut is complete,



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Figure 4-26.—Electric motor-driven carriage being used on straight track to cut a beveled edge on steel plate.

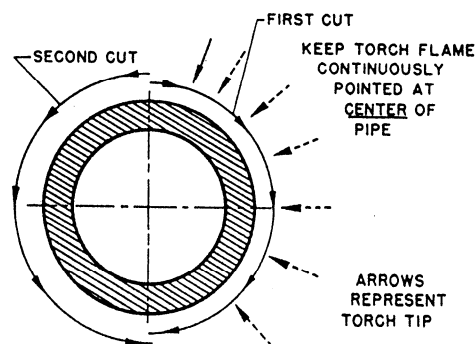


Figure 4-27.—Cutting pipe with an oxygas cutting torch.

you should do the following: promptly turn off the cutting oxygen, turn off the current, and extinguish the flame—in that order. The cutting speed depends upon the thickness of the steel being cut.

CUTTING AND BEVELING PIPE

Pipe cutting with a cutting torch requires a steady hand to obtain a good bevel cut that is smooth and true. Do not attempt to cut and bevel a heavy pipe in one operation until you have developed considerable skill. First, you should cut the pipe off square, and ensure all the slag is removed from the inside of the pipe. Next, you should bevel the pipe. This procedure produces a cleaner and better job; it is ideal for use by an inexperienced Steelworker.

When cutting a piece of pipe, you should keep the torch pointed toward the center line of the pipe. Start the cut at the top and cut down one side. Then begin at the top again and cut down the other side, finishing at the bottom of the pipe. This procedure is shown in figure 4-27.

When you make T and Y fittings from pipe, the cutting torch is a valuable tool. The usual procedure for fabricating pipe fittings is to develop a pattern like the one shown in figure 4-28, view A-1.

After you develop the pattern, wrap it around the pipe, as shown in figure 4-28, view A-2. Be sure to leave enough material so the ends overlap. Trace around the pattern with soapstone or a scribe. It is a good idea to mark the outline with a prick punch at 1/4-inch intervals. During the cutting procedure, as the metal is heated, the punch marks stand out and make it easier to follow the line of cut. Place the punch marks so the cutting action will remove them. If punch marks are left on the pipe, they could provide notches from which cracking may start.

An experienced Steelworker can cut and bevel pipe at a 45-degree angle in a single operation. A person with little cutting experience should do the job in two steps.

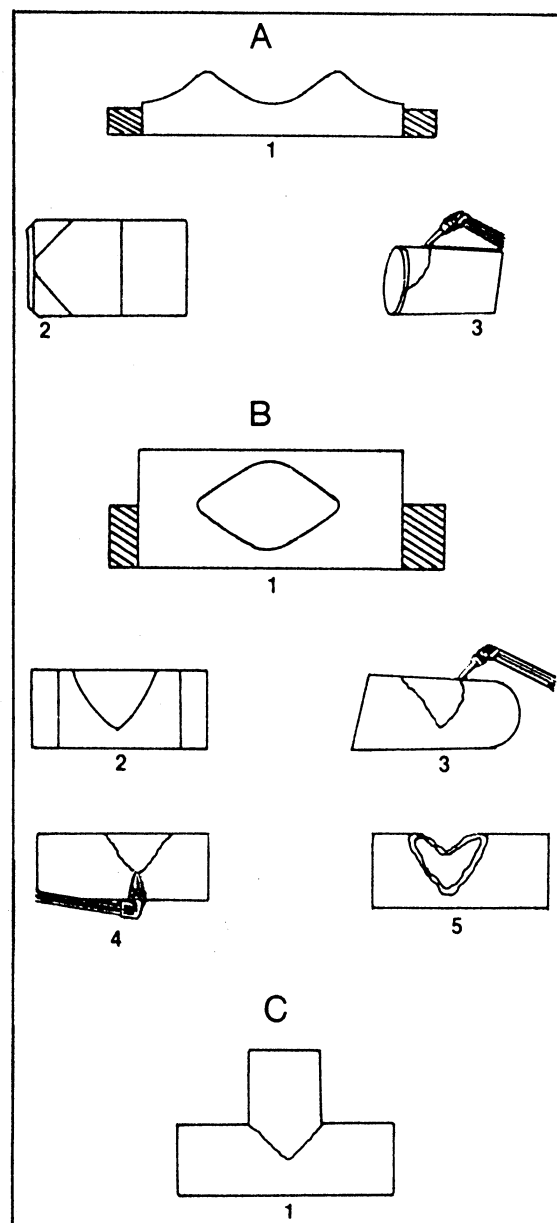


Figure 4-28.—Fabricating a T.

In that case, the first step involves cutting the pipe at a 90-degree angle. In the second step, you bevel the edge of the cut to a 45-degree angle. With the two-step procedure, you must mark an additional line on the pipe. This second line follows the contour of the line traced around the pattern, but it is drawn away from the original pattern line at a distance equal to the thickness of the pipe wall. The first (90-degree) cut in the two-step procedure is made along the second line. The second (45-degree) cut is made along the original pattern line. The primary disadvantage of the two-step procedure is it is time consuming and uneconomical in oxygen and gas consumption.

The one-step method of cutting and beveling pipe is not difficult, but it does require a steady hand and a

great deal of experience to turn out a first-class job. An example of this method for fabricating a T is shown in figure 4-28. View A of figure 4-28 outlines the step-by-step procedures for fabricating the branch; view B shows the steps for preparing the main section of the T; and view C shows the assembled T, tack-welded and ready for final welding.

Step 3 of view A shows the procedure for cutting the miter on the branch. You should begin the cut at the end of the pipe and work around until one half of one side is cut. The torch is at a 45-degree angle to the surface of the pipe along the line of cut. While the tip is at a 45-degree angle, you should move the torch steadily forward, and at the same time, swing the butt of the torch upward through an arc. This torch manipulation is necessary to keep the cut progressing in the proper direction with a bevel of 45 degrees at all points on the miter. Cut the second portion of the miter in the same reamer as the first.

The torch manipulation necessary for cutting the run of the T is shown in Steps 3 and 4 of view B in figure 4-28. Step 3 shows the torch angle for the starting cut and Step 4 shows the cut at the lowest point on the pipe. Here you change the angle to get around the sharp curve and start the cut in an upward direction. The completed cut for the run is shown in Step 5 (fig. 4-28, view B).

Before final assembly and tack welding of any of the parts of a fabricated fitting, you must clean the slag from the inner pipe wall and check the fit of the joint. The bevels must be smooth and have complete fusion when you weld the joint.

PIERCING HOLES

The cutting torch is a valuable tool for piercing holes in steel plate. Figure 4-29 shows the steps you should use to pierce holes in steel plate. First, lay the

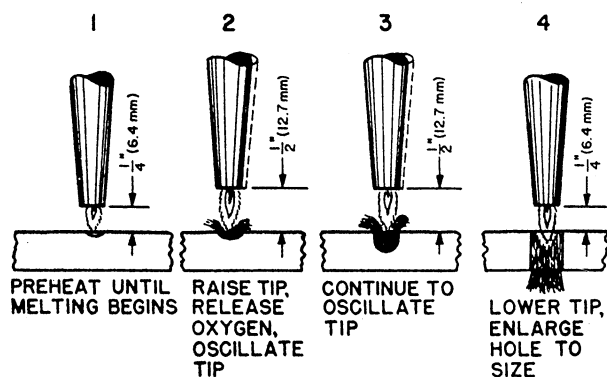


Figure 4-29.—Piercing a hole with an oxygas cutting torch.

plate out on firebricks or other suitable material so the flame does not damage anything when it burns through the plate. Next, hold the torch over the hole location with the tips of the inner cone of the preheating flames about 1/4 inch above the surface of the plate. Continue to hold the torch in this position until a small spot has been heated to a bright red. Then open the cutting oxygen valve gradually, and at the same time, raise the nozzle slightly away from the plate. As you start raising the torch and opening the oxygen valve, rotate the torch with a slow spiral motion. This causes the molten slag to be blown out of the hole. The hot slag may fly around, so BE SURE that your goggles are tightly fitted to your face, and avoid placing your head directly above the cut.

If you need a larger hole, outline the edge of the hole with a piece of soapstone, and follow the procedure indicated above. Begin the cut from the hole you pierced by moving the preheating flames to the normal distance from the plate and follow the line drawn on the plate. Round holes are made easily by using a cutting torch with a radius bar attachment.

CUTTING RIVETS

The cutting torch is an excellent tool for removing rivets from structures to be disassembled. Rivet cutting procedures are shown in figure 4-30. The basic method is to heat the head of the rivet to cutting temperature by using the preheating flames of the cutting torch. When the rivet head is at the proper temperature, turn on the oxygen and wash it off. The remaining portion of the rivet can then be punched out with light hammer blows. The step-by-step procedure is as follows:

1. Use the size of tip and the oxygen pressure required for the size and type of rivet you are going to cut.
2. Heat a spot on the rivet head until it is bright red.
3. Move the tip to a position parallel with the surface of the plate and turn on the cutting oxygen slowly.
4. Cut a slot in the rivet head like the screwdriver slot in a roundhead screw. When the cut nears the plate, draw the nozzle back at least 1 1/2 inches from the rivet so you do not cut through the plate.
5. When cutting the slot through to the plate, you should swing the tip through a small arc. This slices half of the rivet head off.
6. Swing the tip in an arc in the other direction to slice the other half of the rivet head off.

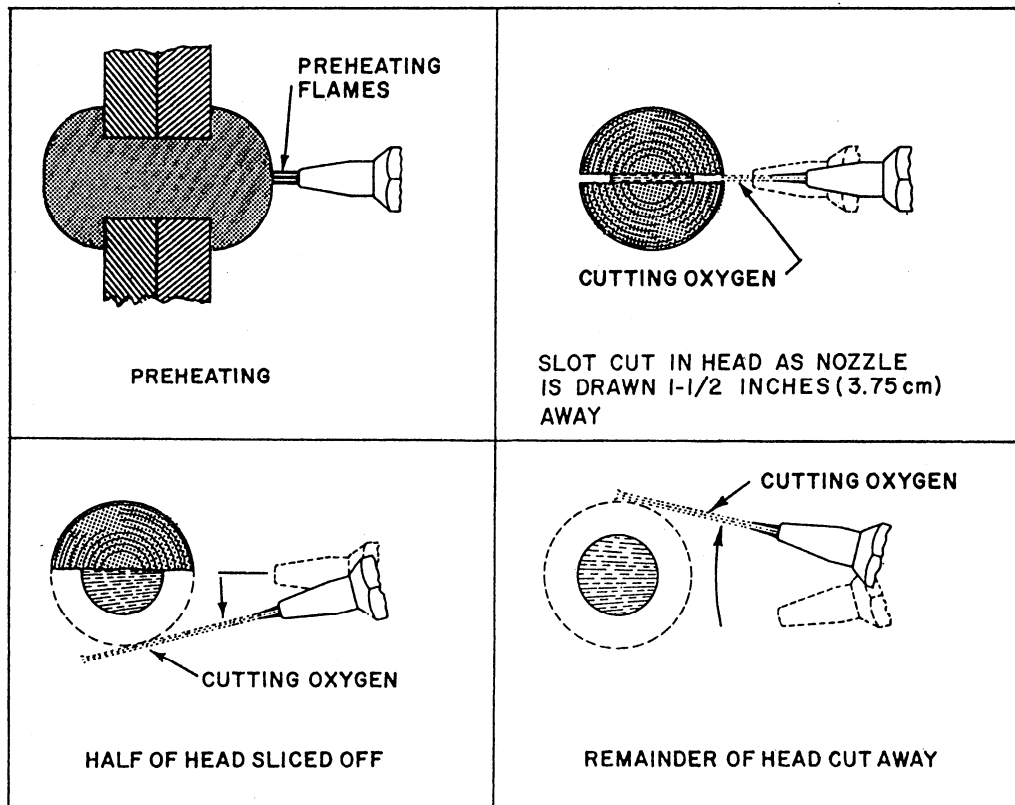


Figure 4-30.—Using a cutting torch to remove a rivet head,

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

A low-velocity cutting tip is best for cutting button-head rivets and for removing countersunk rivets. A low-velocity cutting tip has a cutting oxygen orifice with a large diameter. Above this orifice are three preheating orifices. Always place a low-velocity cutting tip in the torch so the heating orifices are above the cutting orifice when the torch is held in the rivet cutting position.

CUTTING WIRE ROPE

You can use a cutting torch to cut wire rope. Wire rope consists of many strands, and since these strands do not form one solid piece of metal, you could experience difficulty in making the cut. To prevent the wire

rope strands from unlaying during cutting, seize the wire rope on each side of the place where you intend to cut.

Adjust the torch to a neutral flame and make the cut between the seizings. If the wire rope is going to go through sheaves, then you should fuse the strand wires together and point the end. This makes reeving the block much easier, particularly when you are working with a large-diameter wire rope and when reeving blocks that are close together. To fuse and point wire rope, adjust the torch to a neutral flame; then close the oxygen valve until you get a carburizing flame. With proper torch manipulation, fuse the wires together and point the wire rope at the same time.

Wire rope is lubricated during fabrication and is lubricated routinely during its service life. Ensure that all excess lubricant is wiped off the wire rope before you begin to cut it with the oxygas torch.

CUTTING ON CONTAINERS

Never perform cutting or welding on containers that have held a flammable substance until they have been cleaned thoroughly and safeguarded. Cutting, welding, or other work involving heat or sparks on used barrels,

drums, tanks, or other containers is extremely dangerous and could lead to property damage or loss of life.

Whenever available, use steam to remove materials that are easily volatile. Washing the containers with a strong solution of caustic soda or a similar chemical will remove heavier oils.

Even after thorough cleansing, the container should be further safeguarded by filling it with water before any cutting, welding, or other hot work is done. In almost every situation, it is possible to position the container so it can be kept filled with water while cutting or other hot work is being done. Always ensure there is a vent or opening in the container for the release of the heated vapor inside the container. This can be done by opening the bung, handhole, or other fitting that is above water level.

When it is practical to fill the container with water, you also should use carbon dioxide or nitrogen in the vessel for added protection. From time to time, examine the gas content of the container to ensure the concentration of carbon dioxide or nitrogen is high enough to prevent a flammable or explosive mixture. The air-gas mixture inside any container can be tested with a suitable gas detector.

The carbon dioxide concentration should be at least 50 percent of the air space inside the container, and 80 percent or more when the presence of hydrogen or carbon monoxide is detected. When using nitrogen, you must ensure the concentration is at least 10 percent higher than that specified for carbon dioxide.

Carbon dioxide or nitrogen is used in apparently clean containers because there may still be traces of oil or grease under the seams, even though the vessel was cleaned and flushed with a caustic soda solution. The heat from the cutting or welding operation could cause the trapped oil or grease to release flammable vapors that form an explosive mixture inside the container.

A metal part that is suspiciously light maybe hollow inside; therefore, you should vent the part by drilling a hole in it before heating. Remember: air or any other gas that is confined inside a hollow part will expand when heated. The internal pressure created may be enough to cause the part to burst. Before you do any hot work, take every possible precaution to vent the air confined in jacketed vessels, tanks, or containers.

JUDGING CUTTING QUALITY

To know how good of a cutting job you are doing, you must understand what constitutes a good

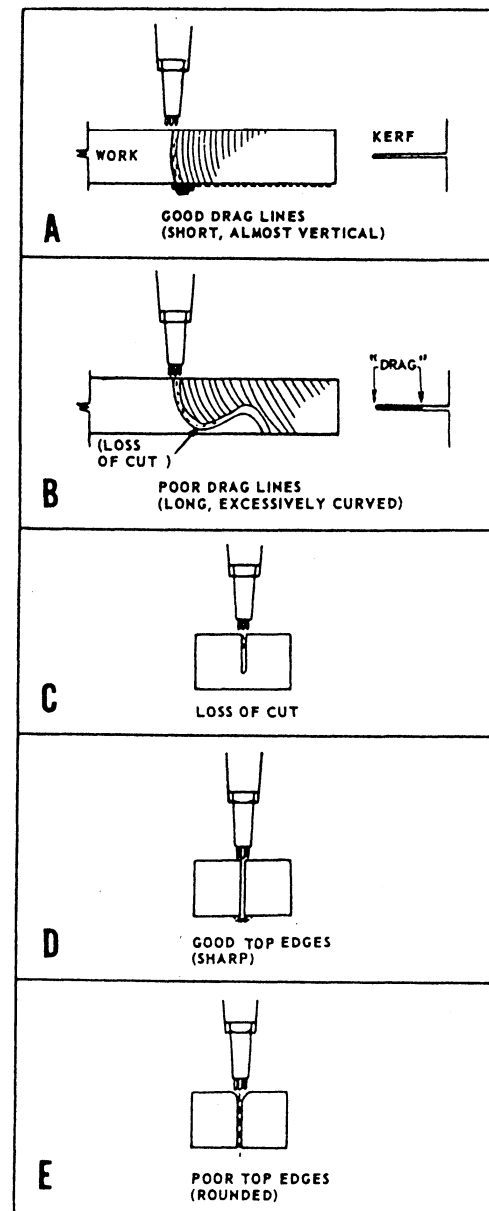


Figure 4-31.—Effects of correct and incorrect cutting procedures.

oxygas cut. In general, the quality of an oxygas cut is judged by four characteristics:

1. The shape and length of the draglines
2. The smoothness of the sides
3. The sharpness of the top edges
4. The amount of slag adhering to the metal

DRAG LINES

Drag lines are line markings that show on the surface of the cut. Good drag lines are almost straight up and down, as shown in figure 4-31, view A. Poor drag

lines, as shown in figure 4-31, view B, are long and irregular or curved excessively. Drag lines of this type indicate a poor cutting procedure that could result in the loss of the cut (fig. 4-31, views B and C). Draglines are the best single indication of the quality of the cut made with an oxygas torch. When the draglines are short and almost vertical, the sides smooth, and the top edges sharp, you can be assured that the slag conditions are satisfactory.

SIDE SMOOTHNESS

A satisfactory oxygas cut shows smooth sides. A grooved, fluted, or ragged cut surface is a sign of poor quality.

TOP EDGE SHARPNESS

The top edges resulting from an oxygas cut should be sharp and square (fig. 4-31, view D). Rounded top edges, such as those shown in view E of figure 4-31, are not satisfactory. The melting of the top edges may result from incorrect preheating procedures or from moving the torch too slowly.

SLAG CONDITIONS

An oxygas cut is not satisfactory when slag adheres so tightly to the metal that it is difficult to remove.

SAFETY PRECAUTIONS

In all cutting operations, you must ensure that hot slag does not come in contact with combustible material. Globules of hot slag can roll along the deck for long distances. Do not cut within 30 to 40 feet of unprotected combustible materials. If you cannot remove the combustible materials, cover them with sheet metal or other flameproof guards. Keep the fuel gas and oxygen cylinders far enough away from the work so hot slag does not fall on the cylinders or hoses.

Many of the safety precautions discussed in chapters 5 through 8 of this manual apply to cutting as well as to welding. Be sure you are completely familiar with all the appropriate safety precautions before attempting oxygas cutting operations.

BACKFIRE AND FLASHBACK

Improper operation of the oxygas torch can cause the flame to go out with a loud snap or pop. This is called a "backfire." Close the torch valves, check the connections, and review your operational techniques before relighting the torch. You may have caused the backfire by touching the tip against the work, by overheating the tip, or by operating the torch with incorrect gas pressures. A backfire also may be caused by a loose tip or head or by dirt on the seat.

A flashback occurs when the flame burns back inside the torch, usually with a shrill hissing or squealing noise. You should close the torch oxygen valve that controls the flame to stop the flashback at once. Then you should close the gas valve and the oxygen and gas regulators. Be sure you allow the torch to cool before relighting it. Also, blow oxygen through the cutting tip for a few seconds to clear out soot that may have accumulated in the passages. Flashbacks may extend back into the hose or regulators. Flashbacks indicate that something is wrong, either with the torch or with the way it is being operated. Every flashback should be investigated to determine its cause before the torch is relighted. A clogged orifice or incorrect oxygen and gas pressures are often responsible. Avoid using gas pressures higher than those recommended by the manufacturer.

CYLINDERS

Gas cylinders are made of high-quality steel. High-pressure gases, such as oxygen, hydrogen, nitrogen, and compressed air, are stored in cylinders of seamless construction. Only nonshatterable high-pressure gas cylinders may be used by ships or activities operating outside the continental United States. Cylinders for low-pressure gases, such as acetylene, may be welded or brazed. Cylinders are carefully tested, either by the factory or by a designated processing station, at pressures above the maximum permissible charging pressure.

Identification of Cylinders

Color warnings provide an effective means for marking physical hazards and for indicating the location of safety equipment. Uniform colors are used for marking compressed-gas cylinders, pipelines carrying hazardous materials, and fire protection equipment.

Five classes of material have been selected to represent the general hazards for dangerous materials,

Table 4-2.—Standard Colors

Class	Standard Color	Class of Material
a	Yellow, No. 13655	FLAMMABLE MATERIALS. All materials known ordinarily as flammables or combustibles. Of the chromatic colors, it has the highest coefficient of reflection under white light and can be recognized under the poorest conditions of illumination.
b	Brown, No. 10080	TOXIC AND POISONOUS MATERIALS. All materials extremely hazardous to life or health under normal conditions as toxics or poisons.
c	Blue, No. 15102	ANESTHETICS AND HARMFUL MATERIALS. All materials productive of anesthetic vapors and all liquid chemicals and compounds hazardous to life and property but not normally productive of dangerous quantities of fumes or vapors.
d	Green, No. 14260	OXIDIZING MATERIALS. All materials which readily furnish oxygen for combustion and fire producers which react explosively or with the evolution of heat in contact with many other materials.
e	Gray, No. 16187	PHYSICALLY DANGEROUS MATERIALS. All materials, not dangerous in themselves, which are asphyxiating in confined areas or which are generally handled in a dangerous physical state of pressure or temperature.
f	Red, No. 11105	FIRE PROTECTION MATERIALS. All materials provided in piping systems or in compressed-gas cylinders exclusively for use in fire protection.

TITLE	LOCATION ON CYLINDER			
	TOP A	BAND B	BAND C	BODY
ACETYLENE	YELLOW	YELLOW	YELLOW	YELLOW
ARGON, OIL-FREE	GRAY	WHITE	GRAY	GRAY
CARBON DIOXIDE	GRAY	GRAY	GRAY	GRAY
CARBON DIOXIDE (<i>Fire only</i>)	RED	RED	RED	RED
HELIUM, OIL-TOLERANT	GRAY	ORANGE	GRAY	GRAY
METHYLE ACETYLENE PROPADIENE (MAPP) MIXTURE	YELLOW	ORANGE	YELLOW	YELLOW
OXYGEN	GREEN	GREEN	GREEN	GREEN

Figure 4-32.—Titles and color codes for compressed-gas cylinders.

while a sixth class has been reserved for fire protection equipment. A standard color has been chosen to represent each of these classes and is shown in table 4-2.

Since you work with fuel gas and oxygen, you must become familiar with the colors of the cylinders in which these gases are contained. The fuel-gas cylinder is yellow, and the oxygen cylinder is green.

In addition to color coding, the exact identification of the material contained in a compressed-gas cylinder must be indicated by a written title that appears in two locations—diametrically opposite and parallel to the longitudinal axis of the cylinder. Cylinders, having a background color of yellow, orange, or buff have the title painted black. Cylinders, having a background color of red, brown, black, blue, gray, or green, have the title painted white.

COLOR WARNINGS.— The appearance on the body, top, or as a band(s) on compressed-gas cylinders of the six colors specified should provide a warning of danger from the hazard involved.

CYLINDER COLOR BANDS.— Cylinder color bands appear upon the cylinder body and serve as color warnings when they are yellow, brown, blue, green, or gray. The bands also provide color combinations to separate and distinguish cylinders for convenience in handling, storage, and shipping. Color bands for segregation purposes will not be specified for new materials not presently covered by MIL-STD-101B.

DECALS.— Two decals may be applied on the shoulder of each cylinder. They should be diametrically opposite and at right angles to the titles. They should indicate the name of the gas, precautions for handling, and use. A background color corresponding to the primary warning color of the contents should be used.

SHATTERPROOF CYLINDERS.— A shatter-proof cylinder should be stenciled with the phrase “NON-SHAT” longitudinally 90 degrees from the titles. Letters must be black or white and approximately 1 inch in size.

SERVICE OWNERSHIP.— On cylinders owned by or procured for the Department of Defense, the bottom and the lower portion of the cylinder body opposite the valve end may be used for service ownership titles.

The six colors identified in table 4-2 are used on the body and top of, or as a band on, a compressed-gas cylinder to serve as a warning of the hazard involved in handling the type of material contained in the cylinder.

Figure 4-32 shows titles and color codes for compressed-gas cylinders most often found in a construction

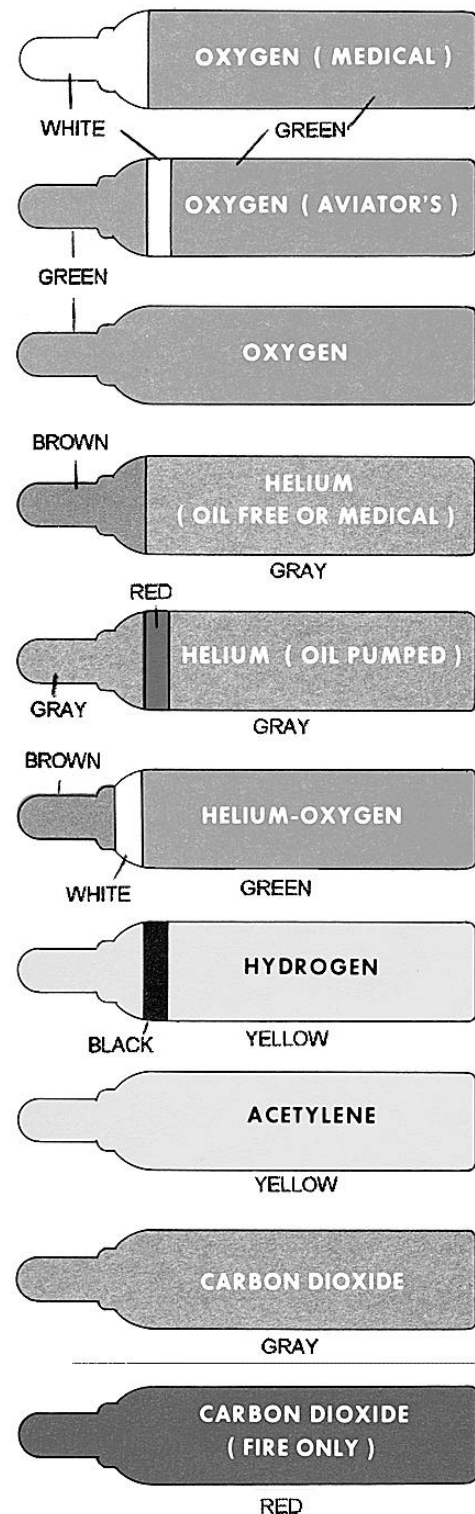


Figure 4-33.—Identifying color patterns for gas cylinders.

battalion or in a public works department where Seabee personnel are working. Figure 4-33 shows how cylinders are identified by the overall painted color code and

by the stenciled name of the gas. For a complete listing of compressed-gas cylinders, refer to MIL-STD 101B, “Color Code for Pipelines and for Compressed-Gas Cylinders.”

NOTE: Ensure you have a manual with the latest up-to-date changes inserted, as changes may occur in MIL-STD 101B after this manual is published. It should be noted that the color code of cylinders shown in figure 4-32 is military only; the commercial industry does not necessarily comply with these color codes.

Handling and Storing Gas Cylinders

Each compressed-gas cylinder carries markings indicating compliance with Interstate Commerce Commission (ICC) requirements. When the cylinders are at your work site, they become your responsibility. There are several things you should not do when handling and storing compressed-gas cylinders.

- Never fill your own cylinders. It requires special training and special equipment.

- Never alter or fix the safety devices on a cylinder. It is illegal and also stupid. The only personnel permitted to work on cylinder safety devices are the cylinder owners and suppliers.

- Never store cylinders near a heat source or in direct sunlight. Heat causes the gas inside a cylinder to expand. This could result in cylinder failure or fire.

- Never store cylinders in a closed or unventilated space. If one of the cylinders were to leak, it could cause an explosion or asphyxiate someone entering the space. Store cylinders in protected, well-ventilated, and dry

spaces. Protect the cylinder valves and safety devices from ice and snow. A safety device may not work if it is frozen.

- Never store fuel cylinders and oxidizers within the same space. Oxidizers must be stored at least 50 feet from fuel cylinders. Use fire-resistant partitions between cylinder storage areas.

- Never mix empty cylinders with full cylinders. Do not mix cylinders that contain different gases. Always replace the cylinder cap and mark the cylinder “Empty” or “MT.” Store the cylinders in a cool, dry place ready for pickup by the supplier. Even in storage, chain the cylinders when they are stored in the upright position.

- Never drag a cylinder to move it. When available, use a cylinder truck. If at all possible, leave the cylinders on the hand truck and operate them from there; otherwise, tilt the cylinder slightly and roll it on the bottom edge. Always install the cylinder cap before moving the cylinder. Never use slings or magnets to carry cylinders. If you lift a cylinder upright by the cap, make sure that it is screwed on tightly. If the cylinder cap comes off, the cylinder could fall and either crush your foot or snap the valve off. If a cylinder is dropped and the valve breaks, it could launch itself like a rocket.

When cylinders have been stored outside in freezing weather, they sometimes become frozen to the ground or to each other. This is true particularly in the antarctic and arctic areas. To free the cylinders, you can pour warm water (not boiling) over the frozen or icy areas. As a last resort, you can pry them loose with a prybar. If you use a prybar, never pry or lift under the valve cap or valve.

GAS WELDING

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

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

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

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

OXYGAS WELDING EQUIPMENT

An oxygas welding outfit is basically the same as an oxygas cutting outfit with the exception of the torch. The welding outfit usually consists of a cylinder of acetylene or MAPP gas, a cylinder of oxygen, two regulators, two lengths of hose with fittings, and a

welding torch with tips (fig. 5-1). An oxygas welding outfit also is called a welding rig.

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

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

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

WELDING TORCHES

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

Two general types of welding torches are used:

- Low pressure
- Medium pressure

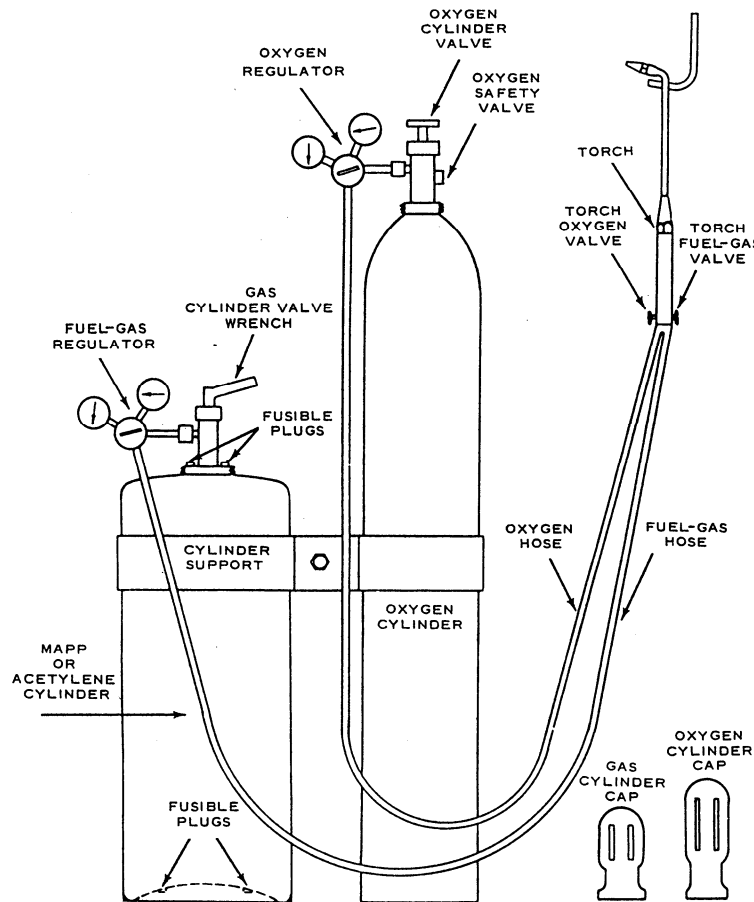


Figure 5-1.—An oxygas welding outfit.

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

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

DANGER

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

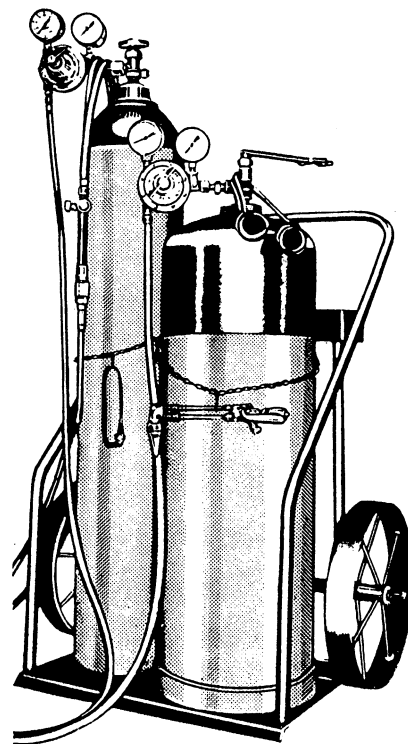


Figure 5-2.—A portable oxygas welding and cutting outfit,

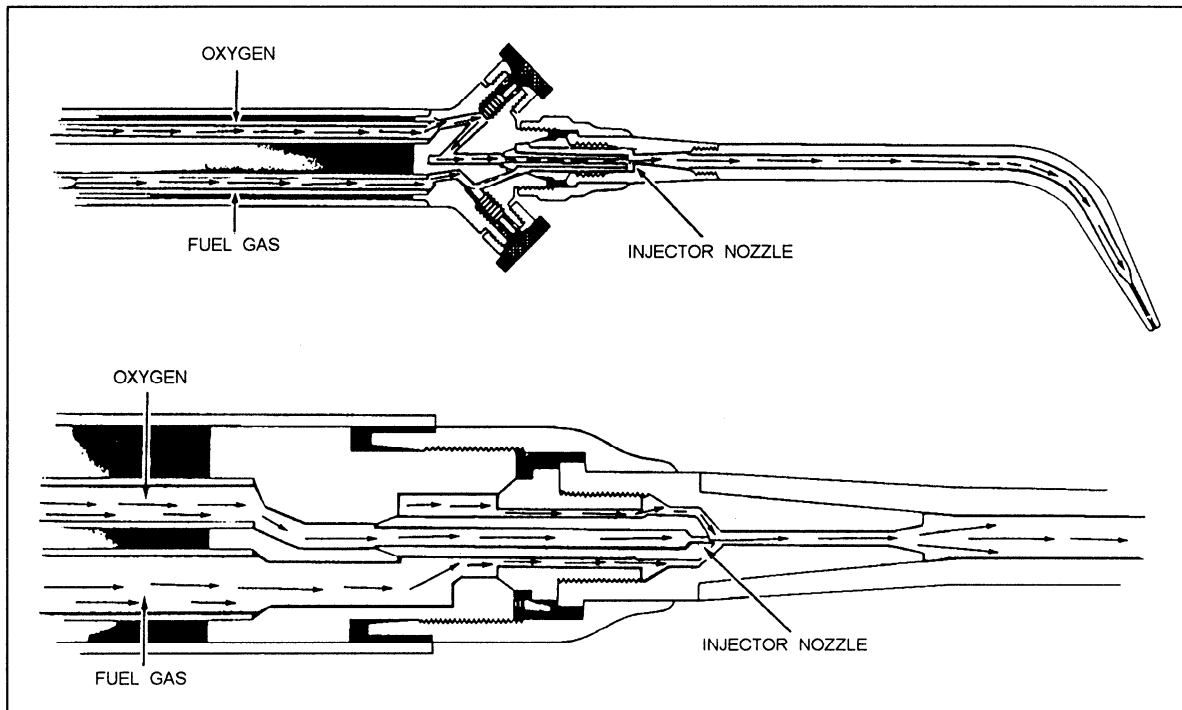


Figure 5-3.—Mixing head for the low-pressure torch.

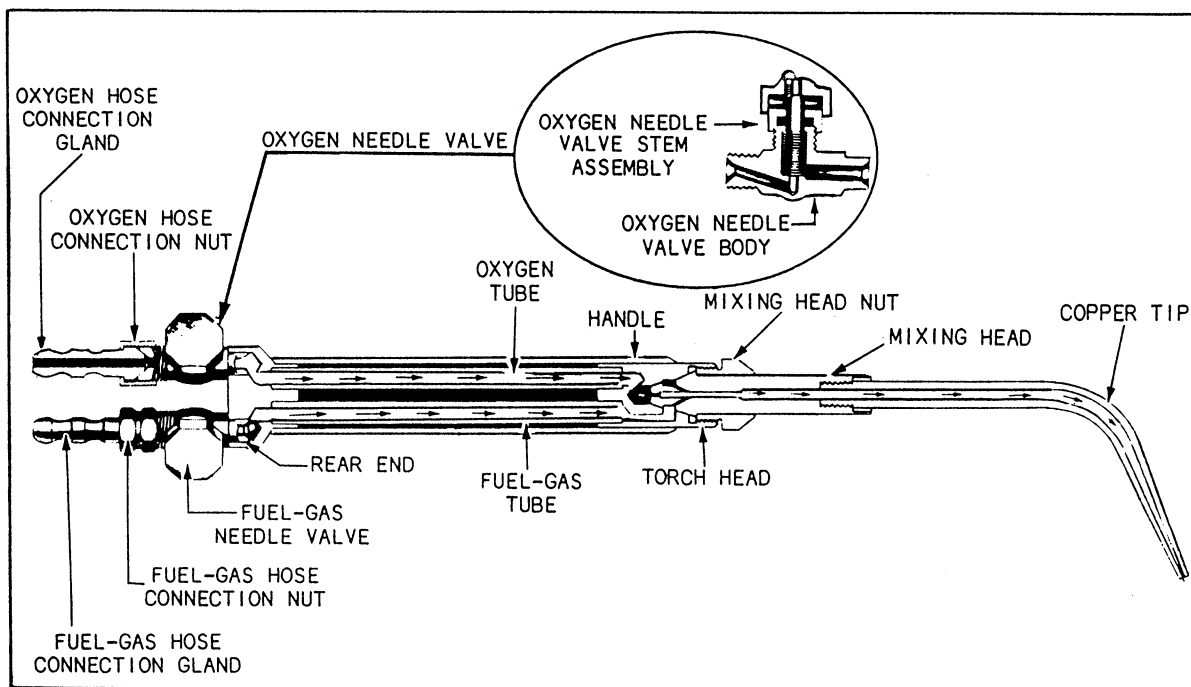


Figure 5-4.—Equal-pressure welding torch.

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

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

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

FILLER RODS

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

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

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

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

OPERATION AND MAINTENANCE OF OXYGEN EQUIPMENT

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

SELECTING THE WELDING TORCH TIP SIZE

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

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

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

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

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

EQUIPMENT SETUP

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

TORCH LIGHTING AND FLAME ADJUSTMENT

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

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

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

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

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

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

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

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

MAINTAINING THE EQUIPMENT

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

types of maintenance duties that you will be required to perform,

Torch Gas Leaks

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

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

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

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

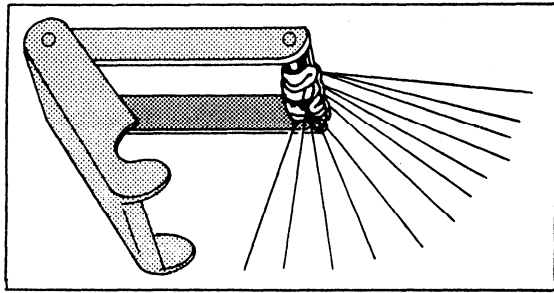


Figure 5-5.—Welding tip orifice cleaner.

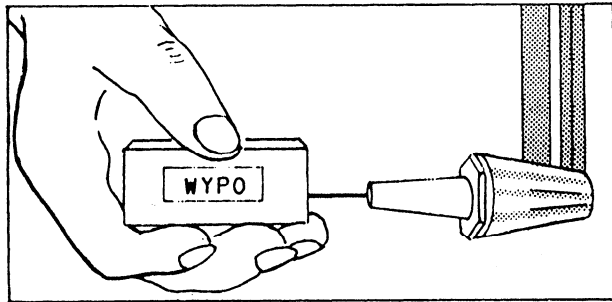


Figure 5-6.—A welding tip cleaner in use.

Welding Torch Tips

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

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

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

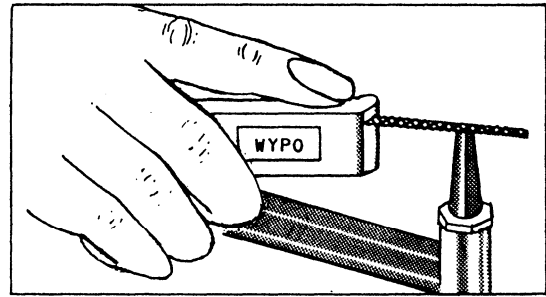


Figure 5-7.—Reconditioning the orifice end of a torch tip.

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

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

Regulator Leaks

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

OXYGEN WELDING TECHNIQUES

Oxygen welding may be done using either the forehand or the backhand method. Each of these techniques has special advantages and you should become skillful with both. The deciding factor that determines whether a technique is considered forehand or backhand is the relative position of the torch and rod during welding, not

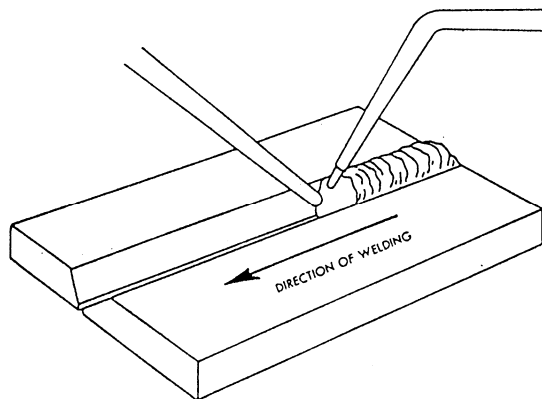


Figure 5-8.—Forehand welding.

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

FOREHAND WELDING

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

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

BACKHAND WELDING

In backhand welding (fig. 5-9), the torch tip pre-cedes the rod in the direction of welding and the flame points back at the molten puddle and completed weld. The welding tip should make an angle of about 60 degrees with the plates or joint being welded. The end of the welding rod is placed between the torch tip and the molten puddle.

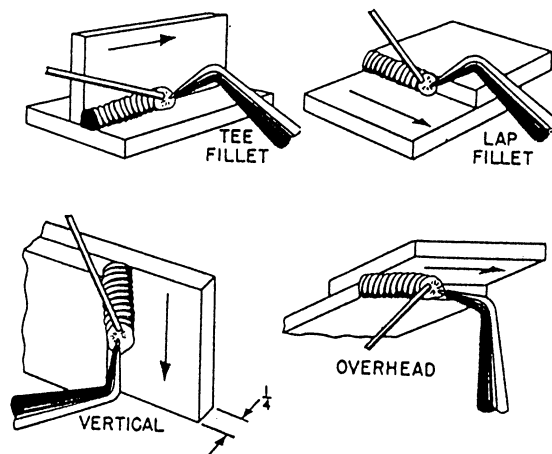


Figure 5-9.—Backhand welding.

Less motion is used in the backhand method than in the forehand method. If you use a straight welding rod, you should rotate it so the end rolls from side to side and melts off evenly. You might have to bend the rod when working in confined spaces. If you do, it becomes difficult to roll a bent rod, and to compensate, you have to move the rod and torch back and forth at a rather rapid rate. When making a large weld, you should move the rod so it makes complete circles in the molten puddle. The torch is moved back and forth across the weld while it is advanced slowly and uniformly in the direction of the welding.

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

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

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

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

JOINT EDGE PREPARATION

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

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

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

OXYGAS WELDING OF FERROUS METALS

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

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

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

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

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

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

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

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

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

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

OXYGAS WELDING OF NONFERROUS METALS

Although brazing and braze welding are used extensively to make joints in nonferrous metals, there are many situations in which oxygas welding is just as suitable. The joint designs are the same for nonferrous

metals as for ferrous metals in most cases. Oxygas welding of nonferrous metals usually requires mechanical cleaning of the surfaces before welding and the use of flux during welding. Filler metals must be suitable for the base metal being welded. A separate section on aluminum and aluminum alloys is included as part of this chapter since you may need more detailed instructions in welding these materials.

Copper

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

Copper-Zinc Alloy (Brasses)

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

Copper-Silicon Alloy (Silicon Bronze)

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

Copper-Nickel Alloy

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

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

Nickel and High-Nickel Alloys

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

Lead

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

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

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

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

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

WARNING

LEAD FUMES ARE POISONOUS.

Aluminum and Aluminum Alloys

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

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

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

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

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

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

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

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

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

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

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

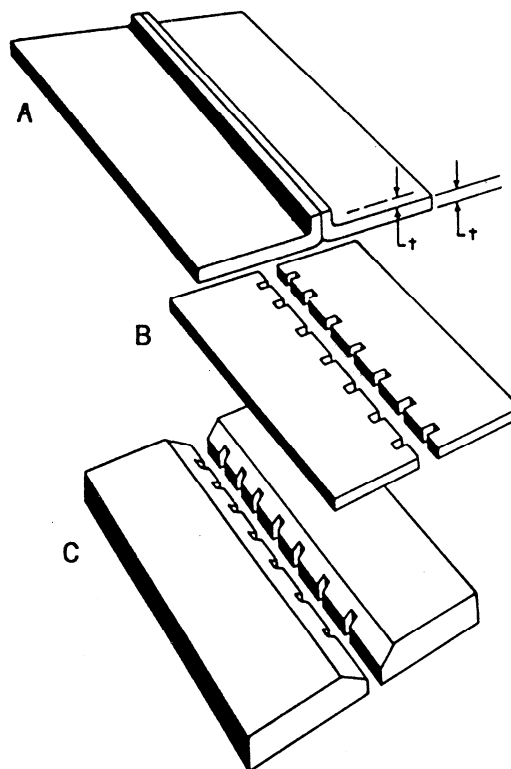


Figure 5-10.—Edge preparation for gas-welding aluminum.

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

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

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

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

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

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

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

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

When welding aluminum alloys up to 0.188 of an inch thick, you have little need to impart any motion to the torch other than moving it forward. On flanged

material, care must be taken to break the oxide film as the flange melts down. This may be done by stirring the melted flange with a puddling rod. A puddling rod is essentially a paddle flattened and shaped from a 1/4-inch stainless steel welding rod.

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

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

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

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

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

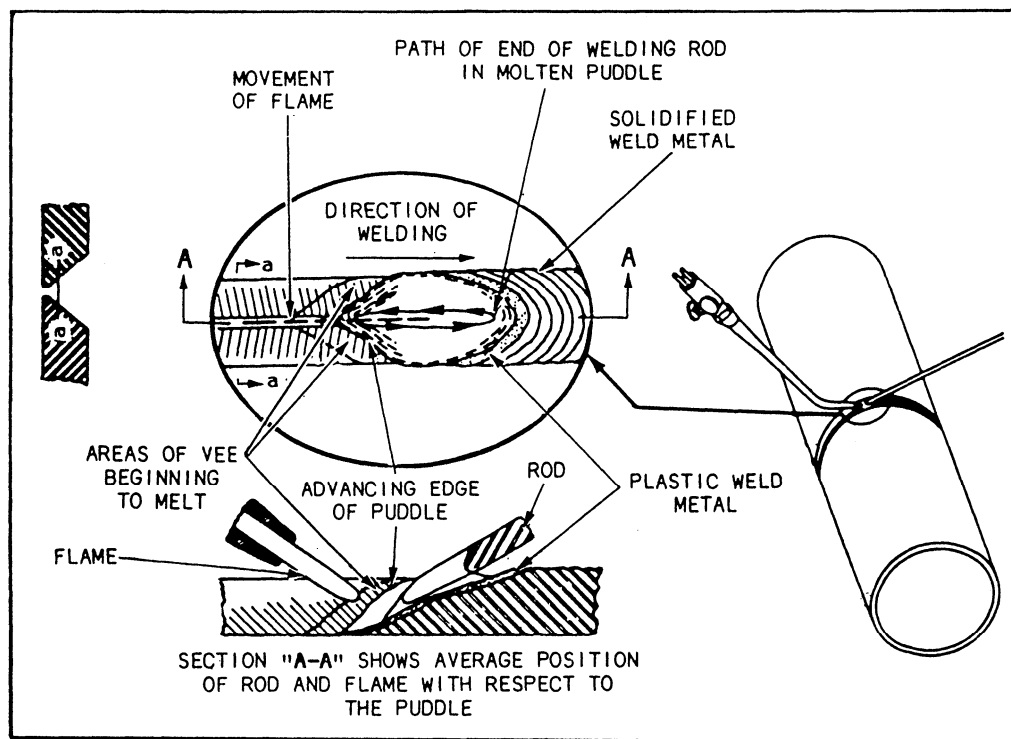


Figure 5-11.—Welding operation with backhand technique.

FUSION WELDING PIPE

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

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

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

The cohesiveness of the molten metal, the pressure of the flame, the support of the weld metal already deposited, and the manipulation of the rod all combine

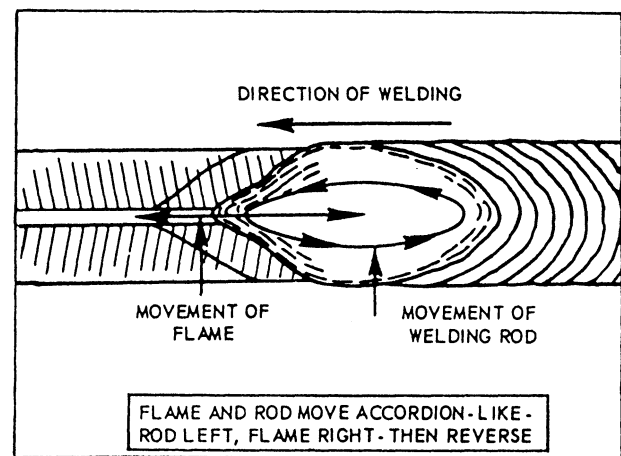


Figure 5-12.—Flame and rod motion with backhand technique.

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

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

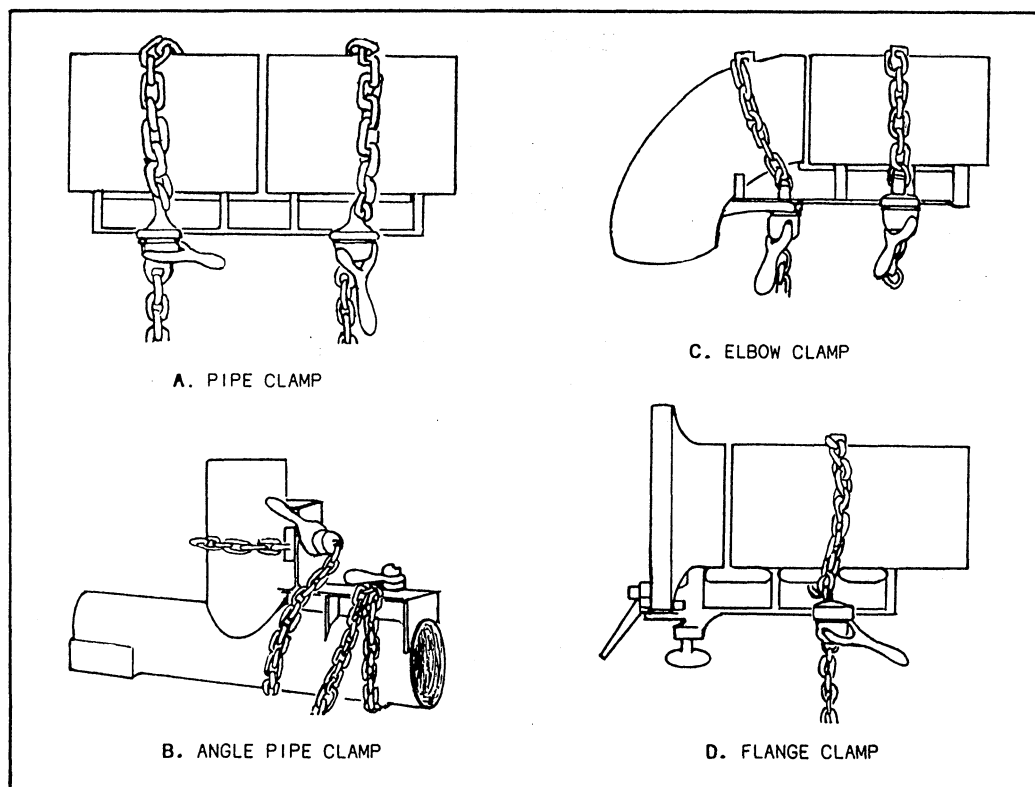


Figure 5-13.—Chain clamps quickly align pipe fittings of any description.

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

1. Use an excess fuel-gas flame.
2. Use a welding rod containing deoxidizing agents.
3. Use the backhand welding technique.

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

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

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

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

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

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

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

CHAPTER 6

SOLDERING, BRAZING, BRAZE WELDING, AND WEARFACING

The information presented in chapter 5 covered the joining of metal parts by the process of fusion welding. In this chapter, procedures that do not require fusion are addressed. These procedures are as follows: soldering, brazing, braze welding, and wearfacing. These procedures allow the joining of dissimilar metals and produce high-strength joints. Additionally, they have the important advantages of not affecting the heat treatment or warping the original metal as much as conventional welding.

SOLDERING

Soldering is a method of using a filler metal (commonly known as solder) for joining two metals without heating them to their melting points. Soldering is valuable to the Steelworker because it is a simple and fast means for joining sheet metal, making electrical connections, and sealing seams against leakage. Additionally, it is used to join iron, nickel, lead, tin, copper, zinc, aluminum, and many other alloys.

Soldering is not classified as a welding or brazing process, because the melting temperature of solder is below 800°F. Welding and brazing usually take place above 800°F. The one exception is lead welding that occurs at 621°F. Do not confuse the process of SILVER SOLDERING with soldering, for this process is

actually a form of brazing, because the temperature used is above 800°F.

This chapter describes the following: equipment and materials required for soldering, the basic methods used to make soldered joints, and the special techniques required to solder aluminum alloys.

EQUIPMENT

Soldering requires very little equipment. For most soldering jobs, you only need a heat source, a soldering copper or iron, solder, and flux.

Sources of Heat

The sources of heat used for soldering vary according to the method used and the equipment available. Welding torches, blow-torches, forges, and furnaces are some of the sources of heat used. Normally, these heating devices are used to heat the soldering coppers that supply the heat to the metal surfaces and thus melt the solder. Sometimes, the heating devices are used to heat the metal directly. When this is done, you must be careful to prevent heat damage to the metal and the surrounding material.

SOLDERING COPPERS.— A soldering copper (usually called a soldering iron) consists of a forged copper head and an iron rod with a handle. (See fig. 6-1.)

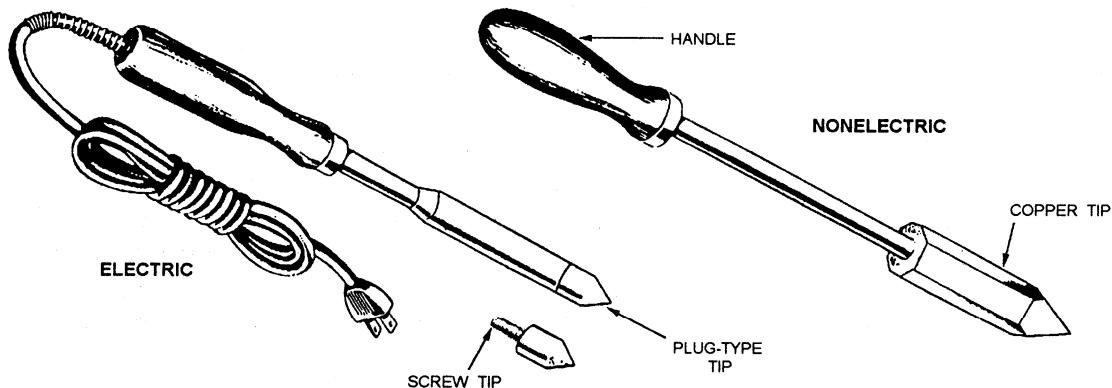


Figure 6-1.—Soldering irons.

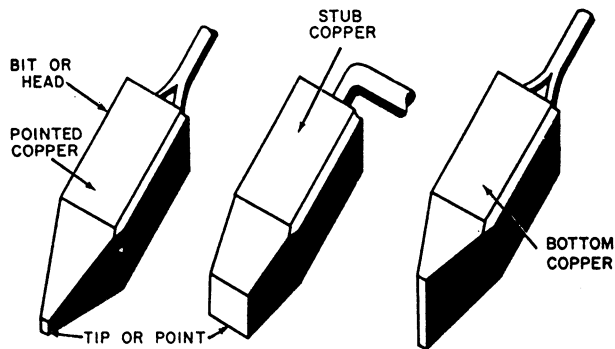


Figure 6-2.—Soldering copper heads.

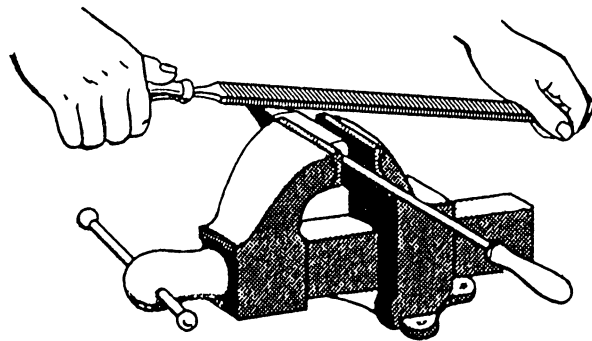


Figure 6-3.—Filing a soldering copper.

The handle, which may be wood or fiber, is either forced or screwed onto the rod.

Soldering heads are available in various shapes. Figure 6-2 shows three of the more commonly used types. The pointed copper is for general soldering work. The stub copper is used for soldering flat seams that need a considerable amount of heat. The bottom copper is used for soldering seams that are hard to reach, such as those found in pails, pans, trays, and other similar objects.

Nonelectrical coppers are supplied in pairs. This is done so one copper can be used as the other is being heated. The size designation of coppers refers to the weight (in pounds) of TWO copperheads; thus a reference to a pair of 4-pound coppers means that each copper head weighs 2 pounds. Pairs of coppers are usually supplied in 1-pound, 1 1/2-pound, 3-pound, 4-pound, and 6-pound sizes. Heavy coppers are designed for soldering heavy gauge metals, and light coppers are for thinner metals. Using the incorrect size of copper usually results in either poorly soldered joints or overheating.

Filing and Tinning Coppers.— New soldering coppers must be tinned (coated with solder) before use.

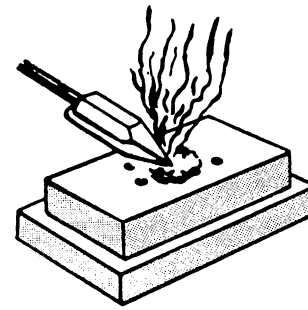


Figure 6-4.—Tinning a copper (solder placed on cake of sal ammoniac).

Also, coppers must be filed and retinned after overheating or for any other reason that caused the loss of their solder coating. The procedure for filing and tinning a copper is as follows:

1. Heat the copper to a cherry red.
2. Clamp the copper in a vise, as shown in figure 6-3.

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

CAUTION

Remember that the copper is hot! Do not touch it with your bare hands.

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

5. Reheat the copper until it is hot enough to melt the solder.

6. Rub each filed side of the copper back and forth across a cake of sal ammoniac, as shown in figure 6-4.

7. Apply solder to the copper until it is tinned. You may rub the solder directly onto the copper, or place it on the cake of sal ammoniac. Do not push the iron into the cake of sal ammoniac, because this can split the cake.

When sal ammoniac is not available, use powdered rosin instead. In this instance, place the powdered rosin on top of a brick. Rub the copper back and forth to pick up the rosin and then place the solder directly onto the copper. (See fig. 6-5.)

Commercially prepared soldering salts are also used in tinning soldering coppers. These salts are available in

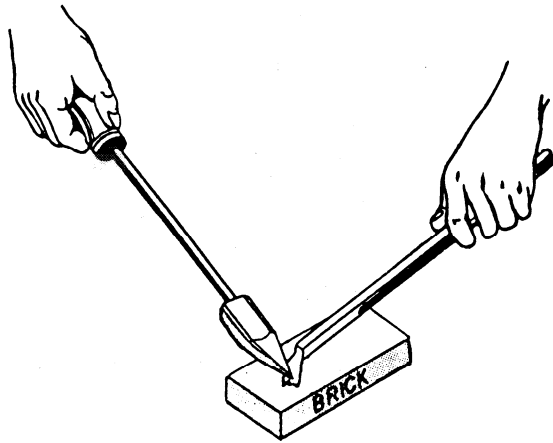


Figure 6-5.—Tinning a copper (solder placed directly on copper).

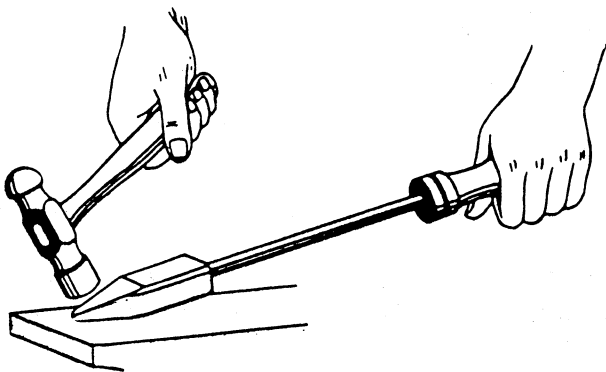


Figure 6-6.—Forging a soldering copper.

powder form. Dissolve the powder in water according to the directions and dip the soldering copper into the solution and then apply the solder.

Forging Soldering Coppers.— Soldering coppers may be reshaped by forging when they become blunt or otherwise deformed. The procedure for forging a copper is as follows:

1. File the copper to remove all old tinning and to smooth the surfaces.
2. Heat the copper to a bright red.
3. Hold the copper on an anvil and forge it to the required shape by striking it with a hammer. (See fig. 6-6.) As you reshape the copper, a hollow will appear at the point. Keep this hollow to a minimum by striking the end of the copper. Do not shape too long a taper or sharp point, because this causes the copper to cool too rapidly. Turn the copper often to produce the necessary squared-off sides and reheat the copper as often as necessary during this part of the forging.

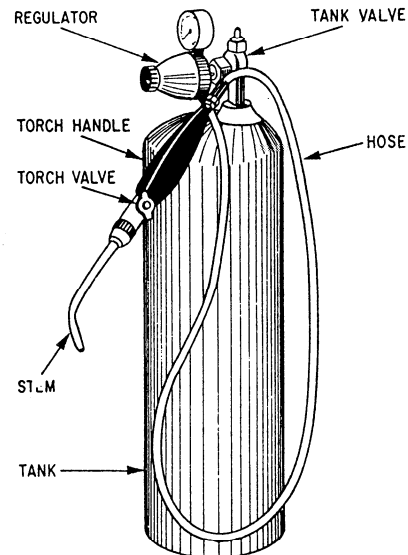


Figure 6-7.—Presto-lite heating unit.

4. Reheat the copper to a bright red, and use a flat-faced hammer to remove as many hollows as possible.

5. File and tin the copper using the previously described procedure.

ELECTRIC SOLDERING COPPERS.— Electric soldering coppers, or soldering irons, as they sometimes are called, are built with internal heating coils. The soldering heads are removable and interchangeable. Tinning is basically the same with the exception that the tip usually does not become cherry red. Forging or reshaping is not necessary, because the heads are easily replaced.

Electric soldering irons are usually used for electrical work or other small jobs. They are especially suited for this type of work, because they do not require auxiliary heating and they can be manufactured as small as a pencil.

GAS TORCHES.— Gas torches can be used in combination with soldering head attachments or as a direct heat source. The Presto-lite heating unit is ideal for soft soldering, because it delivers a small controllable flame. It also may be used effectively to heat soldering coppers. As figure 6-7 shows, this heating unit includes a fuel tank regulator, hose, and torch. It burns acetylene or MAPP gas as fuel in the presence of oxygen. The torch tip (stem) is interchangeable with other tips that come with the unit.

Soft Solder

There are many different types of solder being used by industry. Solders are available in various forms that include bars, wires, ingots, and powders. Wire solders are available with or without a flux core. Because of the many types of solder available, this chapter only covers the solders most commonly used by Steelworkers.

TIN-LEAD SOLDER.— The largest portion of all solders in use is solders of the tin-lead alloy group. They have good corrosion resistance and can be used for joining most metals. Their compatibility with soldering processes, cleaning, and most types of flux is excellent. In describing solders, it is the custom of industry to state the tin content first; for example, a 40/60 solder means to have 40% tin and 60% lead.

Tin-lead alloy melting characteristics depend upon the ratio of tin to lead. The higher the tin content, the lower the melting temperature. Tin also increases the wetting ability and lowers the cracking potential of the solder.

The behavior of tin-lead solder is shown by the diagram in figure 6-8. This diagram shows that 100% lead melts at 621°F and 100% tin melts at 450°F. Solders that contain 19.5% to 97.5% tin remain a solid until they exceed 360°F. The eutectic composition for tin-lead solder is about 63% tin and 37% lead. ("Eutectic" means the point in an alloy system that all the parts melt at the same temperature.) A 63/37 solder becomes completely liquid at 361°F. Other compositions do not. Instead, they remain in the pasty stage until the temperature increases to the melting point of the other alloy. For instance, 50/50 solder has a solid temperature of 361°F and a liquid temperature range of 417°F. The pasty temperature range is 56°F—the difference between the solid and the liquid.

Solders with lower tin content are less expensive and primarily used for sheet metal products and other high-volume solder requirements. High tin solders are extensively used in electrical work. Solders with 60% tin or more are called fine solders and are used in instrument soldering where temperatures are critical.

TIN-ANTIMONY-LEAD SOLDER.— Antimony is added to a tin-lead solder as a substitute for some of the tin. The antimony, up to 6%, increases the strength and mechanical properties of the solder. A word of caution, solders having a high antimony content should not be used on aluminum, zinc, or zinc-coated materials. They form an intermetallic compound of zinc and antimony that causes the solder to become very brittle.

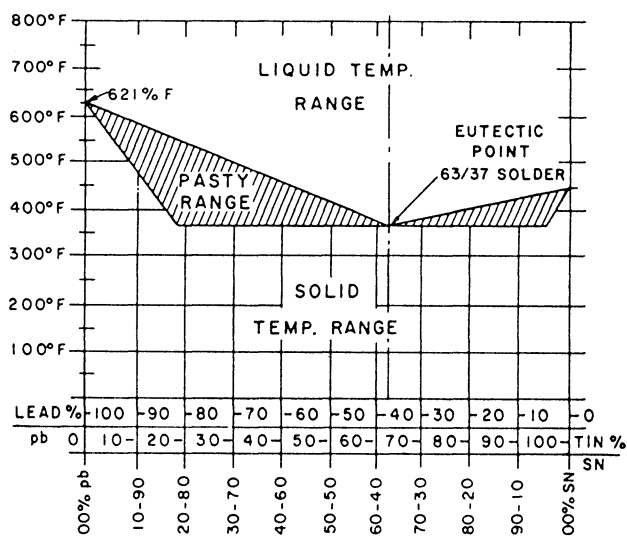


Figure 6-8.—Tin-lead alloy constitutional diagram.

TIN-ZINC SOLDER.— Several tin-zinc solders have come into use for the joining of aluminum alloys. The 91/9 and 60/40 tin-zinc solders are for higher temperature ranges (above 300°F), and the 80/20 and 70/30 tin-zinc alloys are normally used as precoating solders.

LEAD-SILVER SOLDER.— Lead-silver solders are useful where strength at moderately high temperatures is required. The reason lead by itself cannot be used is that it does not normally wet steel, cast iron, or copper and its alloys. Adding silver to lead results in alloys that more readily wet steel and copper. Flow characteristics for straight lead-silver solders are rather poor, and these solders are susceptible to humidity and corrosion during storage. The wetting and flow characteristics can be enhanced as well as an increased resistance to corrosion by introducing a tin content of 1%.

Lead-silver solders require higher soldering temperatures and special fluxing techniques. The use of a zinc-chloride base flux or uncoated metals is recommended, because rosin fluxes decompose rapidly at high temperatures.

TIN-ANTIMONY SOLDER.— Tin-antimony solders are used for refrigeration work or for joining copper to cast-iron joints. The most common one is the 95/5 solder.

TIN-SILVER SOLDER.— Tin-silver solder (96/4) is used for food or beverage containers that must be cadmium and lead-free. It also can be used as a replacement for tin-antimony solder (95/5) for refrigeration work.

Table 6-1.—Fluxes Used for Soldering Some Common Metals

Metals	Fluxes
Brass, copper, tin	Rosin
Lead	Tallow, rosin
Iron, steel	Borax sal ammoniac
Stainless steel and other nickel alloys	Phosphenic acid
Galvanized iron	Zinc chloride
Zinc	Zinc chloride
Aluminum	Stearine, special flux

These solders and the procedures for their use are also listed in the *Welding Materials Handbook*, NAVFAC, P-433.

Fluxes

Scale, rust, and oxides form on most metal surfaces when exposed to air, and heating accelerates this formation. Solder will not adhere to or wet the metal unless these pollutants are removed. Fluxes are chemical compounds used to clean and maintain the metal surfaces during the soldering process. They also decrease the surface tension of the solder, making it a better wetting agent. Fluxes are manufactured in cake, paste, liquid, or powder form and are classified as either noncorrosive or corrosive. Table 6-1 shows the fluxes that are normally used for soldering common metals.

NONCORROSIVE FLUXES.— Noncorrosive fluxes are for soldering electrical connections and for other work that must be free of any trace of corrosive residue. Rosin is the most commonly used noncorrosive flux. In the solid state, rosin is inactive and noncorrosive. When heated, it melts and provides some fluxing action. Rosin is available in powder, paste, or liquid form.

Rosin fluxes frequently leave a brown residue. This residue is nonconductive and sometimes difficult to remove. The removal problem can be reduced by adding a small amount of turpentine to the rosin. Glycerine is added to the rosin to make the flux more effective.

CORROSIVE FLUXES.— Corrosive fluxes have the most effective cleaning action, but any trace of corrosive flux that remains on the work can cause corrosion later. For this reason, corrosive fluxes are not used on electrical connections or other work where corrosion would cause a serious problem.

The most commonly used corrosive fluxes are sal ammoniac (ammonium chloride) and zinc chloride. These fluxes are frequently used in either solution or in paste form. The solvent, if present, evaporates as the work heats, leaving a layer of solid flux on the work. When the metal reaches the soldering temperature, this layer of flux melts, partially decomposes, and liberates hydrochloric acid. The hydrochloric acid dissolves the oxides from the work surfaces and the solder, making them ready for soldering.

Zinc chloride (sometimes called **CUT ACID** or **KILLED ACID**) can be made in the shop as long as safety precautions are followed. To prepare zinc chloride, pour a small amount of muriatic acid (the commercial form of hydrochloric acid) into a glass or acid-resistant container and then add small pieces of zinc. As you add the zinc, the acid boils and bubbles as a result of a chemical reaction that produces zinc chloride and hydrogen gas. Keep adding small pieces of zinc to the mixture until the liquid no longer boils and bubbles. At this point, the reaction is complete and you then dilute the liquid in the container with an equal amount of water. Make only enough as required and strain it before use. If any is leftover, store it in a tightly sealed glass container.

WARNING

When diluting the acid, you always add the acid to the water. Adding water to acid can result in an explosive reaction, resulting in serious injuries.

Specific precautions must be taken when preparing zinc chloride. Rubber gloves, a full-face visor, and an apron are required. The fumes given off by muriatic acid or by the mixture of muriatic acid and zinc are a health

hazard as well as an explosive. Prepare zinc chloride under a ventilation hood, out in the open, or near openings to the outside to reduce inhalation of the fumes or the danger of explosion. It is essential that precautions be taken to prevent flames or sparks from coming in contact with the liberated hydrogen.

Another type of corrosive flux in use is known as **SOLDERING SALTS**. Commercially prepared soldering salts are normally manufactured in a powder form that is water soluble that allows you to mix only the amount needed.

After a corrosive flux has been used for soldering, you should remove as much of the flux residue as possible from the work. Most corrosive fluxes are water soluble; therefore, washing the work with soap and water and then rinsing thoroughly with clear water usually removes the corrosive residue. To lessen damage, you should ensure the work is cleaned immediately after the soldering.

SOLDERING TECHNIQUES

The two soldering methods most often used are soldering with coppers or torch soldering. The considerations that apply to these methods of soldering are as follows:

1. Clean all surfaces of oxides, dirt, grease, and other foreign matter.
2. Use the proper flux for the particular job. Some work requires the use of corrosive fluxes, while other work requires the use of noncorrosive fluxes. Remember, the melting point of the flux must be **BELOW** the melting point of the solder you are going to use.
3. Heat the surfaces just enough to melt the solder. Solder does not stick to unheated surfaces; however, you should be very careful not to overheat the solder, the soldering coppers, or the surfaces to be joined. Heating solder above the work temperature increases the rate of oxidation and changes the proportions of tin and lead.
4. After making a soldered joint, you should remove as much of the corrosive flux as possible.

Sweat Soldering

Sweat soldering is used when you need to make a joint and not have the solder exposed. You can use this process on electrical and pipe connections. To make a sweated joint, you should clean, flux, and tin each adjoining surface. Hold the pieces firmly together and

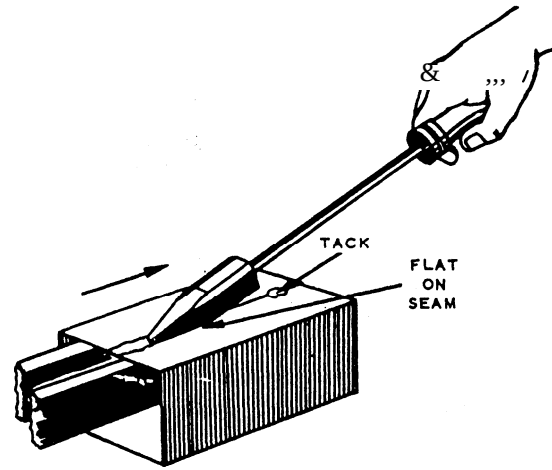


Figure 6-9.—Soldering a seam.

heat the joint with a soldering copper or a torch until the solder melts and joins the pieces together. Remove the source of heat and keep the parts firmly in position until the solder has completely hardened. Cleaning any residue from the soldered area completes the job.

Seam Soldering

Seam soldering involves running a layer of solder along the edges of a joint. Solder seam joints on the inside whenever possible. The best method to use for this process is soldering coppers, because they provide better control of heat and cause less distortion.

Clean and flux the areas to be soldered. If the seam is not already tacked, grooved, riveted, or otherwise held together, tack the pieces so the work stays in position. Position the piece so the seam does not rest directly on the support. This is necessary to prevent loss of heat to the support. After you have firmly fastened the pieces together, solder the seam.

Heat the area by holding the copper against the work. The metal must absorb enough heat from the copper to melt the solder, or the solder will not adhere. Hold the copper so one tapered side of the head is flat against the seam, as shown in figure 6-9. When the solder begins to flow freely into the seam, draw the copper along the seam with a slow, steady motion. Add as much solder as necessary without raising the copper from the work. When the copper becomes cold, you should use the other copper and reheat the first one. Change coppers as often as necessary. Remember, the best soldered seams are made without lifting the copper from the work and without retracing completed work. Allow the joint to cool and the solder to set before

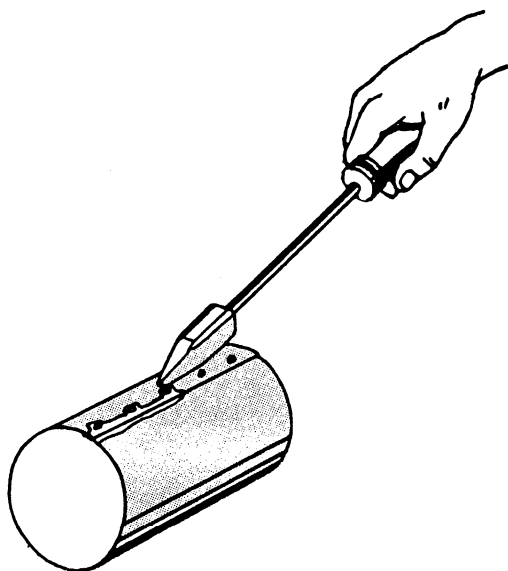


Figure 6-10.—Soldering a riveted seam.

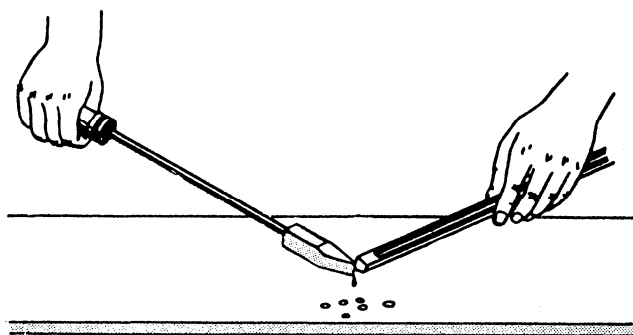


Figure 6-11.—Making solder beads.

moving the joint. When you use a corrosive flux, clean the joint by rinsing it with water and then brushing or wiping it with a clean, damp cloth.

Riveted seams are often soldered to make them watertight. Figure 6-10 shows the procedure for soldering a riveted seam.

Solder beads, or solder shots, are sometimes used for soldering square, rectangular, or cylindrical bottoms. To make the solder beads, hold the solder against a hot copper and allow the beads to drop onto a clean surface, as shown in figure 6-11.

To solder a bottom seam with solder beads, you should first flux the seam before dropping one of the cold beads of solder into the container. Place the hot soldering copper against the seam, as shown in figure

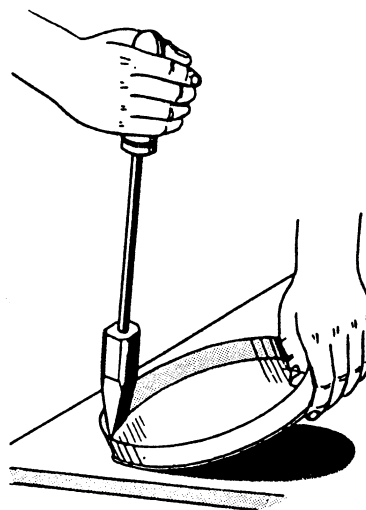


Figure 6-12.—Soldering a bottom seam.

6-12. Hold the copper in one position until the solder starts to flow freely into the seam. Draw the copper slowly along the seam, turning the work as you go. Add more beads as you need them and reheat the copper as necessary.

To heat an electric soldering copper, you merely plug it in. Otherwise, the procedure is much the same as that just described. Be very careful not to let an electric soldering copper overheat. Overheating can burn out the electrical element as well as damage the copper and tinning.

Soldering Aluminum Alloys

Soldering aluminum alloys is more difficult than soldering many other metals. The difficulty arises primarily from the layer of oxide that always covers aluminum alloys. The thickness of the layer depends on the type of alloy and the exposure conditions.

Using the proper techniques, many of the aluminum alloys can be successfully soldered. Wrought aluminum alloys are usually easier to solder than cast aluminum alloys. Heat-treated aluminum alloys are extremely difficult to solder, as are aluminum alloys containing more than 1% magnesium.

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

The first step in soldering aluminum is to clean the surfaces and remove the layer of oxide. If a thick layer of oxide is present, you should remove the main part of it mechanically by filing, scraping, sanding, or wire brushing. A thin layer of oxide can often be removed by using a corrosive flux. Remember, remove any residual flux from the joint after the soldering is finished.

After cleaning and fluxing the surfaces, you should tin the surfaces with aluminum solder. Apply flux to the work surfaces and to the solder. You can tin the surfaces with a soldering copper or with a torch. If you use a torch, do not apply heat directly to the work surfaces, to the solder, or to the flux. Instead, play the torch on a nearby part of the work and let the heat conduct through the metal to the work area. Do not use more heat than is necessary to melt the solder and tin the surfaces. Work the aluminum solder well into the surfaces. After tinning the surfaces, the parts may be sweated together.

Another procedure you can use for soldering aluminum alloys is to tin the surfaces with an aluminum solder and then use a regular tin-lead solder to join the tinned surfaces. This procedure can be used when the shape of the parts prevents the use of the sweating method or demands a large amount of solder. When using tin-lead solder with aluminum solder, you do not have to use flux.

After soldering is complete, you should clean the joints with a wire brush, soap and water, or emery cloth. Ensure that you remove all the flux from the joint since any flux left will cause corrosion.

BRAZING

Brazing is the process of joining metal by heating the base metal to a temperature above 800°F and adding a nonferrous filler metal that melts below the base metal. Brazing should not be confused with braze welding, even though these two terms are often interchanged. In brazing, the filler metal is drawn into the joint by capillary action and in braze welding it is distributed by tinning. Brazing is sometimes called hard soldering or silver soldering because the filler metals are either hard solders or silver-based alloys. Both processes require distinct joint designs.

Brazing offers important advantages over other metal-joining processes. It does not affect the heat treatment of the original metal as much as welding does, nor does it warp the metal as much. The primary advantage of brazing is that it allows you to join dissimilar metals.

EQUIPMENT

Brazing requires three basic items. You need a source of heat, filler metals, and flux. In the following paragraphs these items are discussed.

Heating Devices

The source of heat depends on the type and amount of brazing required. If you are doing production work and the pieces are small enough, they can be put into a furnace and brazed all at once. Individual torches can be mounted in groups for assembly line work, or you can use individual oxyacetylene or Mapp-oxygen torches to braze individual items.

Filler Metals

Filler metals used in brazing are nonferrous metals or alloys that have a melting temperature below the adjoining base metal, but above 800°F. Filler metals must have the ability to wet and bond with the base metal, have stability, and not be excessively volatile. The most commonly used filler metals are the silver-based alloys. Brazing filler metal is available in rod, wire, preformed, and powder form.

Brazing filler metals include the following eight groups:

1. Silver-base alloys
2. Aluminum-silicon alloys
3. Copper
4. Copper-zinc (brass) alloys
5. Copper-phosphorus alloys
6. Gold alloys
7. Nickel alloys
8. Magnesium alloys

Fluxes

Brazing processes require the use of a flux. Flux is the substance added to the metal surface to stop the formation of any oxides or similar contaminants that are formed during the brazing process. The flux increases both the flow of the brazing filler metal and its ability to stick to the base metal. It forms a strong joint by bringing the brazing filler metal into immediate contact with the

adjoining base metals and permits the filler to penetrate the pores of the metal.

You should carefully select the flux for each brazing operation. Usually the manufacturer's label specifies the type of metal to be brazed with the flux. The following factors must be considered when you are using a flux:

- Base metal or metals used
- Brazing filler metal used
- Source of heat used

Flux is available in powder, liquid, and paste form. One method of applying the flux in powdered form is to dip the heated end of a brazing rod into the container of the powdered flux, allowing the flux to stick to the brazing rod. Another method is to heat the base metal slightly and sprinkle the powdered flux over the joint, allowing the flux to partly melt and stick to the base metal. Sometimes, it is desirable to mix powdered flux with clean water (distilled water) to form a paste.

Flux in either the paste or liquid form can be applied with a brush to the joint. Better results occur when the filler metal is also given a coat.

The most common type of flux used is borax or a mixture of borax with other chemicals. Some of the commercial fluxes contain small amounts of phosphorus and halogen salts of either iodine, bromine, fluorine, chlorine, or astatine. When a prepared flux is not available, a mixture of 12 parts of borax and 1 part boric acid may be used.

WARNING

Nearly all fluxes give off fumes that may be toxic. Use them only in WELL-VENTILATED spaces.

JOINT DESIGN

In brazing, the filler metal is distributed by capillary action. This requires the joints to have close tolerances and a good fit to produce a strong bond. Brazing has three basic joint designs (fig. 6-13): lap, butt, and scarf. These joints can be found in flat, round, tubular, or irregular shapes.

Lap Joints

The lap joint is one of the strongest and most frequently used joint in brazing, especially in pipe work. The primary disadvantage of the lap joint is the increase

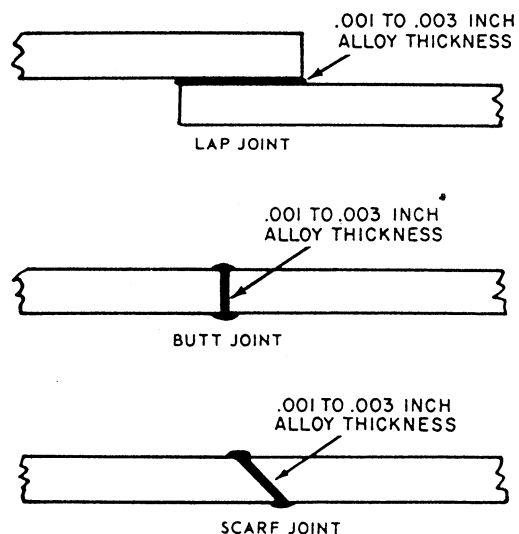


Figure 6-13.—Three types of common joint designs for brazing.

in thickness of the final product. For maximum strength, the overlap should be at least three times the thickness of the metal. A 0.001-inch to 0.003-inch clearance between the joint members provides the greatest strength with silver-based brazing filler metals. You should take precautions to prevent heat expansion from closing joints that have initial close tolerances.

Butt Joints

Butt joints are limited in size to that of the thinnest section so maximum joint strength is impossible. Butt joint strength can be maximized by maintaining a joint clearance of 0.001 to 0.003 of an inch in the finished braze. The edges of the joint must be perfectly square to maintain a uniform clearance between all parts of the joint. Butt joints are usually used where the double thickness of a lap joint is undesirable. When double-metal thickness is objectionable and you need more strength, the scarf joint is a good choice.

Scarf Joints

A scarf joint provides an increased area of bond without increasing the thickness of the joint. The area of bond depends on the scarf angle cut for the joint. Usually, an area of bond two to three times that of a butt joint is desirable. A scarf angle of 30 degrees gives a bond area twice that of a 90-degree butt joint, and an angle of 19 1/2 degrees increases the bond area three times.

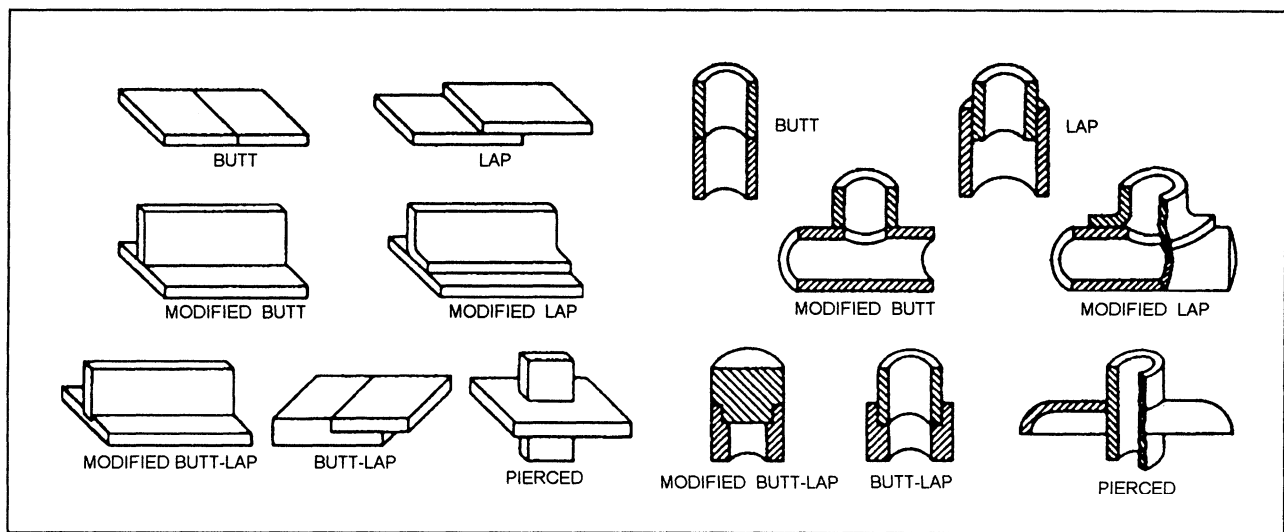


Figure 6-14.—Joints designed to produce good brazing results.

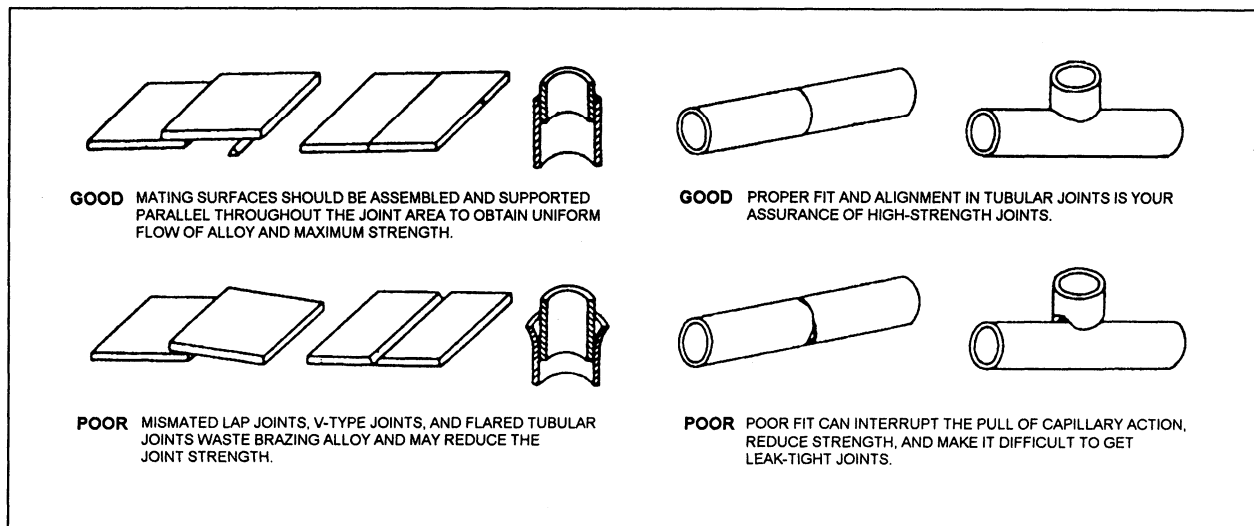


Figure 6-15.—Some well-designed joints that have been prepared for brazing, and some poorly designed joints shown for comparison

Figure 6-14 shows some variations of butt and lap joints designed to produce good brazing results. A comparison of good and bad designed joints is shown in figure 6-15.

BRAZING PROCEDURES

The procedure for brazing is very similar to braze and oxyacetylene welding. The metal needs to be cleaned by either mechanical, chemical, or a combination of both methods to ensure good bonding. The two pieces must be fitted properly and supported to prevent

voids in the joint or accidental movement during brazing and cooling operations.

Surface Preparation

The surfaces of the metal must be cleaned for capillary action to take place. When necessary, chemically clean the surface by dipping it in acid. Remove the acid by washing the surface with warm water. For mechanical cleaning, you can use steel wool, a file, or abrasive paper. Do not use an emery wheel or emery cloth,

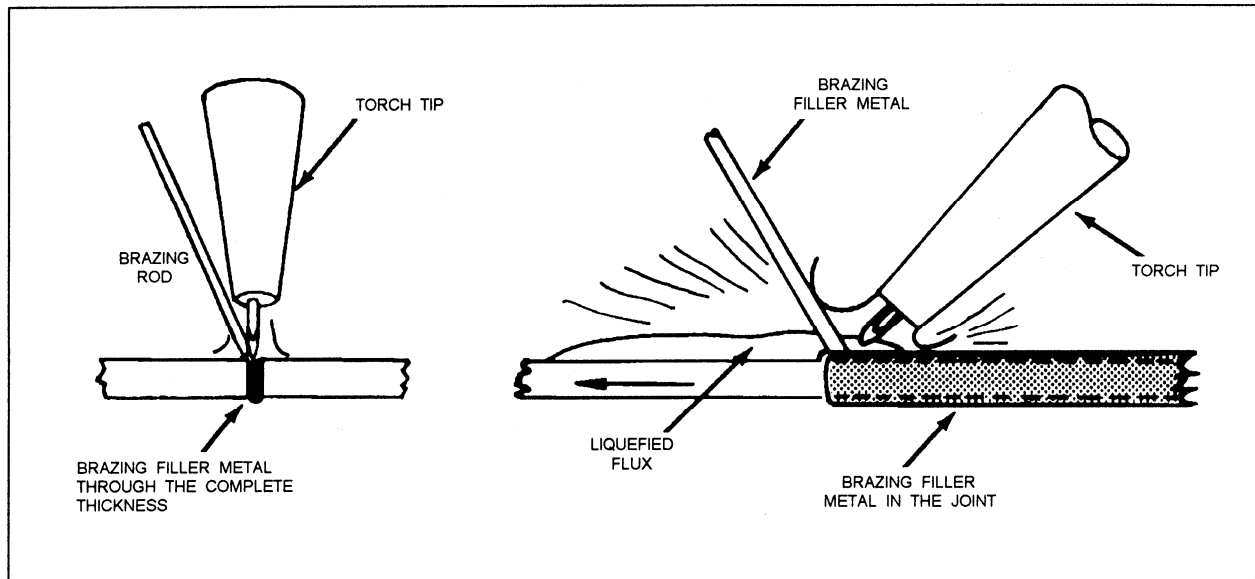


Figure 6-16.—Brazing a butt joint.

because abrasive particles or oil might become embedded in the metal.

Work Support

Mount the work in position on firebricks or other suitable means of support, and if necessary, clamp it. This is important because if the joint moves during the brazing process, the finished bond will be weak and subject to failure.

Fluxing

The method of application varies, depending upon the form of flux being used and the type of metal you are brazing. Refer to the material on fluxes previously described. It is extremely important that the flux is suitable for your job.

Brazing

The next step is to heat the parts to the correct brazing temperature. Adjust the torch flame (oxygen) to a neutral flame because this flame gives the best results under normal conditions. A reducing flame produces an exceptionally neat-looking joint, but strength is sacrificed. An oxidizing flame will produce a strong joint but it has a rough-looking surface.

The best way to determine the temperature of the joint, as you heat it, is by watching the behavior of the flux. The flux first dries out as the moisture (water) boils off at 212°F. Then the flux turns milky in color and starts to bubble at about 600°F. Finally, it turns into a clear liquid at about 1100°F. That is just short of the brazing temperature. The clear appearance of the flux indicates that it is time to start adding the filler metal. The heat of the joint, not the flame, should melt the filler metal. When the temperature and alignment are proper, the filler metal spreads over the metal surface and into the joint by capillary attraction. For good bonding, ensure the filler metal penetrates the complete thickness of the metal. Figure 6-16 shows a good position for the torch and filler metal when brazing a butt joint.

Stop heating as soon as the filler metal has completely covered the surface of the joint, and let the joint cool slowly. Do not remove the supports or clamps or move the joint in any way until the surface is cool and the filler metal has completely solidified.

Finally, clean the joint after it has cooled sufficiently. This can be done with hot water. Be sure to remove all traces of the flux because it can corrode the metal. Excess metal left on the joint can be filed smooth.

The above described procedure is a general one, but it applies to the three major types of brazing: silver, copper alloy, and aluminum. The differences being the base metals joined and the composition of the filler metals.

Table 6-2.—Silver Brazing Filler Metal Alloys

ASTM Spec #B-73-29	Percent				Melts°F	Flows°F	Color
	Silver	Copper	Zinc	Cadmium			
1	9	53	38		1450	1565	
	10	52		.05	1510	1600	Yellow
	*15	80		(5% Phos)	1185	1300	Gray
2	20	45	35	.05	1430	1500	Yellow
3	20	45	30	.05	1430	1500	Yellow
	30	38	32		1370	1410	
	**35	26	21	18	1125	1295	Almost white
	40				1135	1205	Almost white
4	45	30	25		1250	1370	Almost white
	**45	15	16	24	1125	1145	Almost white
5	50	34	16		1280	1425	Almost white
	**50	15.5	16.5	18	1160	1175	Almost white
	**50	15.5	15.5	16 (3% Ni)	1195	1270	White
6	65	20	15		1280	1325	White
7	70	20	10		1335	1390	White
8	80	16	4		1360	1490	White

*—A special alloy containing phosphorus and used only on nonferrous metals
 **—Some special alloys of silver using a fairly high cadmium content

Silver Brazing

Often, you will be called on to do a silver brazing job. Table 6-2 lists different types of silver brazing alloys and their characteristics. A popular way to apply silver brazing metal on a tubing is to use silver alloy rings, as shown in figure 6-17. This is a practical and economical way to add silver alloy when using a production line system. Another method of brazing by using preplaced brazing shims is shown in figure 6-18. The requirements of each job varies; however, through experience you can become capable of selecting the proper procedure to produce quality brazing.

BRAZE WELDING

Braze welding is a procedure used to join two pieces of metal. It is very similar to fusion welding with the exception that the base metal is not melted. The filler metal is distributed onto the metal surfaces by tinning. Braze welding often produces bonds that are

comparable to those made by fusion welding without the destruction of the base metal characteristics. Braze welding is also called bronze welding.

Braze welding has many advantages over fusion welding. It allows you to join dissimilar metals, to minimize heat distortion, and to reduce extensive preheating. Another side effect of braze welding is the elimination of stored-up stresses that are often present in fusion welding. This is extremely important in the repair of large castings. The disadvantages are the loss of strength when subjected to high temperatures and the inability to withstand high stresses.

EQUIPMENT

The equipment needed for braze welding is basically identical to the equipment used in brazing. Since braze welding usually requires more heat than brazing, an oxyacetylene or oxy-mapp torch is recommended.

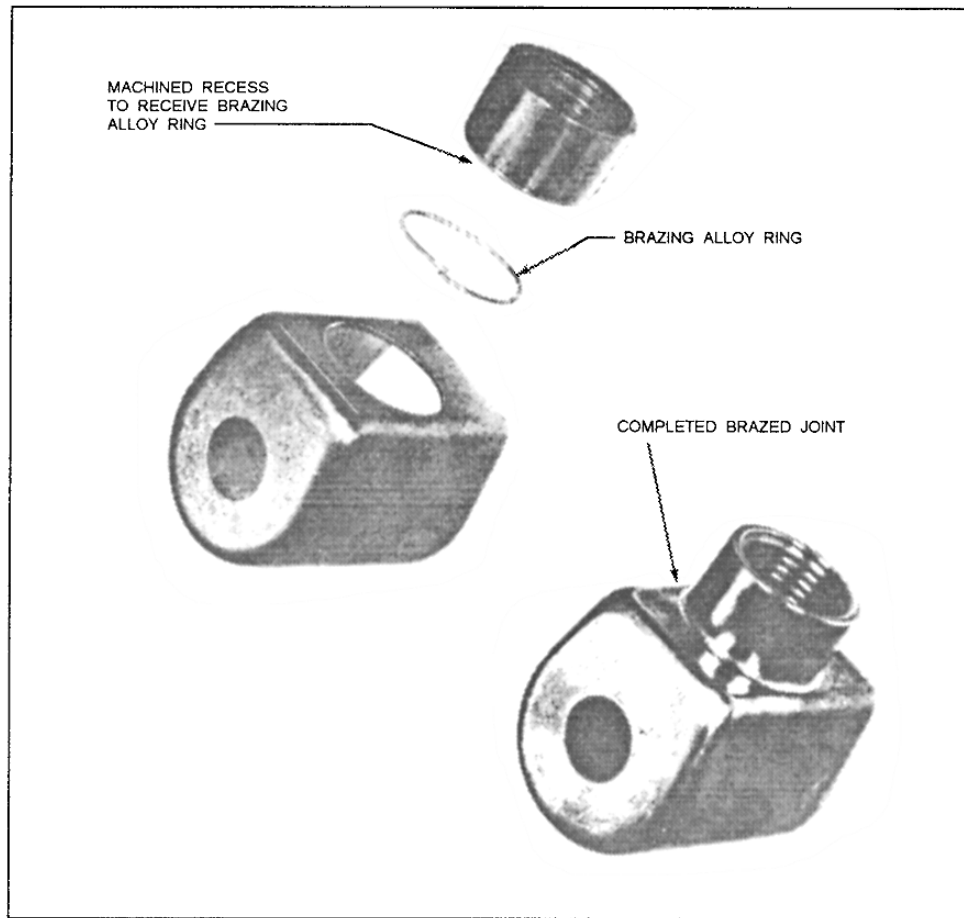


Figure 6-17.—Silver-brazed joints designed to use preplaced silver alloy rings. The alloy forms almost perfect fillets, and no further finishing is necessary.

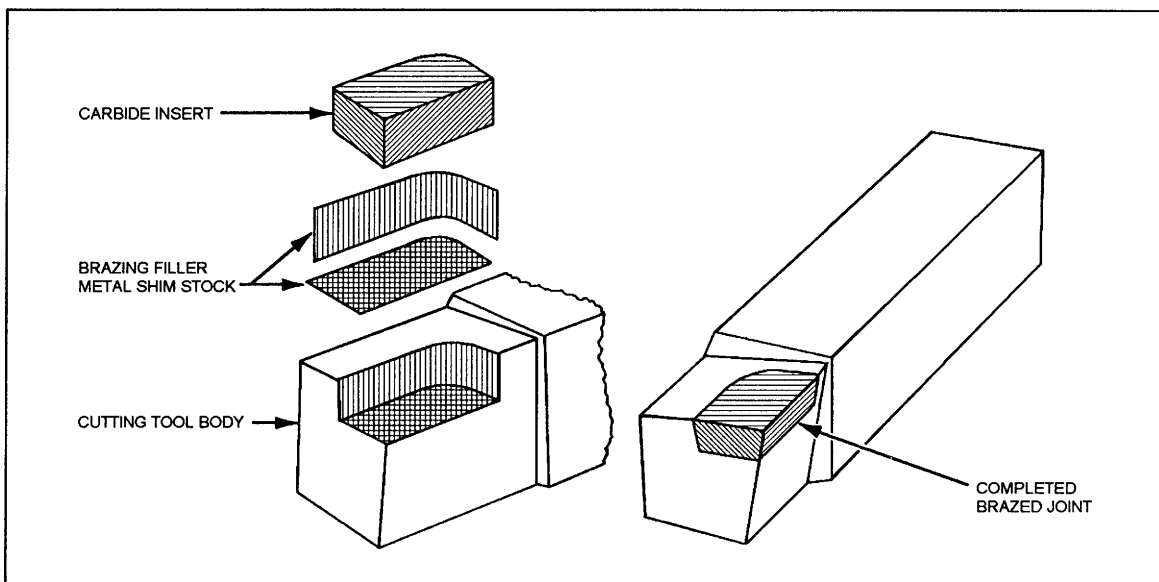


Figure 6-18.—A machining tool bit showing how the carbide insert is brazed to the tool bit body using preplaced brazing filler metal shims.

Table 6-3.—Copper Alloy Brazing Filler Metals

	Copper %	Zinc %	Tin %	Fe %	Mn %	Si %	Ni %	P %	Use	Melting Temp °F	Flow Temp °F
Brass Brazing Alloy	60	40							Copper, Nickel, Alloy, Steel	1650	1660
Naval Brass	60	39.25	.75						Copper, Steel, Nickel Alloys	1630	1650
Tobin Bronze	59	40.5	.50						Steel, Cast Iron	1625	
Manganese Bronze	58.5	39.25	1.0	1.0	.25				Steel	1590	1630
Low Fuming Bronze	57.5 52 50	40.48 48 50	.9	1.0	.03	.09			Cast Iron, Steel	1598 1570 1585	1595 1610
Nickel Silver	55-65 48	27-17 42					18 10		Steel, Nickel Alloys, Cast Iron Steel, Nickel Alloys	1690	1715
Copper Silicon	98.25				.25	1.5			Steel to Copper	1981	
Phosphor Bronze	98.2		1.5					.3	Copper Alloys	1922	

Filler Metal

The primary elements of a braze welding rod are copper and zinc. These elements improve ductility and high strength. Small amounts of iron, tin, aluminum, manganese, chromium, lead, nickel, and silicon are also added to improve the welding characteristics of the rod. They aid in deoxidizing the weld metal, increasing flow action, and decreasing the chances of fuming. Table 6-3 lists some copper alloy brazing filler metals and their use. The most commonly used are brass brazing alloy and naval brass. The selection of the proper brazing filler metal depends on the types of base metals.

Flux

Proper fluxing is essential in braze welding. If the surface of the metal is not clean, the filler metal will not flow smoothly and evenly over the weld area. Even after mechanical cleaning, certain oxides often remain and interfere with the flow of the filler metal. The use of the correct flux eliminates these oxides.

Flux may be applied directly to the weld area, or it can be applied by dipping the heated end of the rod into the flux. Once the flux sticks to the rod, it then can be transferred to the weld area. A prefluxed braze welding rod is also available, and this eliminates the need to add flux during welding.

BRAZE WELDING PROCEDURES

Edge preparation is essential in braze welding. The edges of the thick parts can be beveled by grinding, machining, or filing. It is not necessary to bevel the thin parts (one-fourth inch or less). The metal must be bright and clean on the underside as well as on the top of the joint. Cleaning with a file, steel wool, or abrasive paper removes most foreign matter such as oil, greases, and oxides. The use of the proper flux completes the process and permits the tinning to occur.

After you prepare the edges, the parts need to be aligned and held in position for the braze welding process. This can be done with clamps, tack welds, or a combination of both. The next step is to preheat the assembly to reduce expansion and contraction of the metals during welding. The method you use depends upon the size of the casting or assembly.

Once preheating is completed, you can start the tinning process. Adjust the flame of the torch to a slightly oxidizing flame and flux the joint. Through experience, you will find that the use of more flux during the tinning process produces stronger welds. Apply heat to the base metal until the metal begins to turn red. Melt some of the brazing rod onto the surface and allow it to spread along the entire joint. You may have to add more filler metal to complete the tinning. Figure 6-19 shows

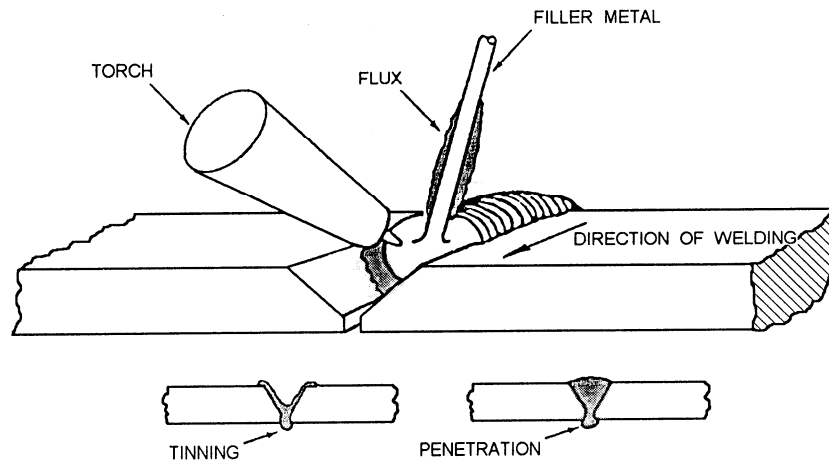


Figure 6-19.—Braze welding cast iron, using the backhand method.

an example of tinning being used with the backhand method of welding.

Temperature control is very important. If the base metal is too hot, the filler metal bubbles or runs around like beads of water on a hot pan. If the filler metal forms little balls and runs off the metal, then the base metal is too cold.

After the base metal is tinned, you can start adding beads of filler metal to the joint. Use a slight circular motion with the torch and run the beads as you would in regular fusion welding. As you progress, keep adding flux to the weld. If the weld requires several passes, be sure that each layer is fused into the previous one.

After you have completed the braze welding operation, heat the area around the joint on both sides for several inches. This ensures an even rate of cooling. When the joint is cold, remove any excess flux or any other particles with a stiff wire brush or steel wool.

WEARFACING

WEARFACING is the process you use to apply an overlay of special ferrous or nonferrous alloy to the surface of new or old parts. The purpose is to increase their resistance to abrasion, impact, corrosion, erosion, or to obtain other properties. Also, wearfacing also can be used to build up undersized parts. It is often called hard-surfacing, resurfacing, surfacing, or hardfacing.

As a Steelworker, there are times when you are required to build up and wear-face metal parts from various types of construction equipment. These parts include the cutting edges of scraper or dozer blades, sprocket gears, and shovel or clamshell teeth. You may even wear-face new blades or shovel teeth before they

are put into service for the first time. There are several different methods of wearfacing; however, in this discussion we only cover the oxygas process of wearfacing.

Wearfacing provides a means of maintaining sharp cutting edges and can reduce wear between metal parts. It is an excellent means for reducing maintenance costs and downtime. These and other advantages of wearfacing add up to increased service life and high efficiency of equipment.

Wearfacing with the oxygas flame is, in many respects, similar to braze welding. The wearfacing metals generally consist of high-carbon filler rods, such as high chromium or a Cr-Co-W alloy, but, in some instances, special surfacing alloys are required. In either event, wearfacing is a process in which a layer of metal of one composition is bonded to the surface of a metal of another composition.

The process of hard-surfacing is suitable to all low-carbon alloy and stainless steels as well as Monel and cast iron. It is not intended for aluminum, copper, brass, or bronze, as the melting point of these materials prohibits the use of the hard-surfacing process. It is possible to increase the hardness of aluminum by applying a zinc-aluminum solder to the surface. Copper, brass, and bronze can be improved in their wear ability by the overlay of work-hardening bronze. Carbon and alloy tool steels can be surface-hardened, but they offer difficulties due to the frequent development of shrinkage and strain cracks. If you do surface these materials, they should be in an annealed, and not a hardened condition. When necessary, heat treating and hardening can be accomplished after the surfacing operation. Quench the part in oil, not water.

WEARFACING MATERIALS

A surfacing operation using a copper-base alloy filler metal produces a relatively soft surface. Work-hardening bronzes are soft when applied and give excellent resistance against frictional wear. Other types of alloys are available that produce a surface that is corrosion and wear resistant at high temperatures. Wearfacing materials are produced by many different manufacturers; therefore, be sure that the filler alloys you select for a particular surfacing job meet Navy specifications.

Two types of hard-surfacing materials in general use in the Navy are iron-base alloys and tungsten carbide.

Iron-Base Alloys

These materials contain nickel, chromium, manganese, carbon, and other hardening elements. They are used for a number of applications requiring varying degrees of hardness. A Steelworker frequently works with iron-base alloys when he builds up and resurfaces parts of construction equipment.

Tungsten Carbide

You use this for building up wear-resistant surfaces on steel parts. Tungsten carbide is one of the hardest substances known to man. Tungsten carbide can be applied in the form of inserts or of composite rod. Inserts are not melted but are welded or brazed to the base metal, as shown in figure 6-18. The rod is applied with the same surfacing technique as that used for oxygas welding; a slightly carburizing flame adjustment is necessary.

WEARFACING PROCEDURES

Proper preparation of the metal surfaces is an important part of wearfacing operations. Make sure that scale, rust, and foreign matter are removed from the metal surfaces. You can clean the metal surfaces by grinding, machining, or chipping. The edges of grooves, corners, or recesses should be well rounded to prevent base metal overheating and to provide a good cushion for the wearfacing material.

Wearfacing material is applied so it forms a thin layer over the base metal. The thickness of the deposit is usually from one sixteenth to one eighth of an inch and is seldom over one fourth of an inch. It is generally deposited in a single pass. Where wear is extensive, it may become necessary to use a buildup rod before

wearfacing. If in doubt as to when to use a buildup rod, you should check with your leading petty officer.

Preheating

Most parts that require wearfacing can be preheated with a neutral welding flame before surfacing. You should use a neutral flame of about 800°F. Do not preheat to a temperature higher than the critical temperature of the metal or to a temperature that can cause the formation of scale.

Application

In general, the torch manipulations and the wearfacing procedures are similar to brazing techniques. However, higher temperatures (about 2200°F) are necessary for wearfacing, and tips of one or two sizes larger than normal are used.

To begin, you heat a small area of the part with a sweeping torch movement until the surface of the base metal takes on a sweating or wet appearance. When the surface of the base metal is in this condition, bring the end of the surfacing alloy into the flame and allow it to melt. Do not stir or puddle the alloy; let it flow. When the surface area has been properly sweated, the alloy flows freely over the surface of the base metal.

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

When you heat steel with a carburizing flame, it first becomes red. As heating continues, the color becomes lighter and lighter until a bright whiteness is attained. At this point, a thin film of liquid, carburized metal appears on the surface. Surfacing alloy added at this time flows over the sweated surface and absorbs the film of carburized metal. This surface condition is not difficult to recognize, but you should make several practice passes before you try wearfacing for the first time.

When you use an oxygas torch for surfacing with chromium cobalt, the torch flame should have an excess fuel-gas feather about three times as long as the inner

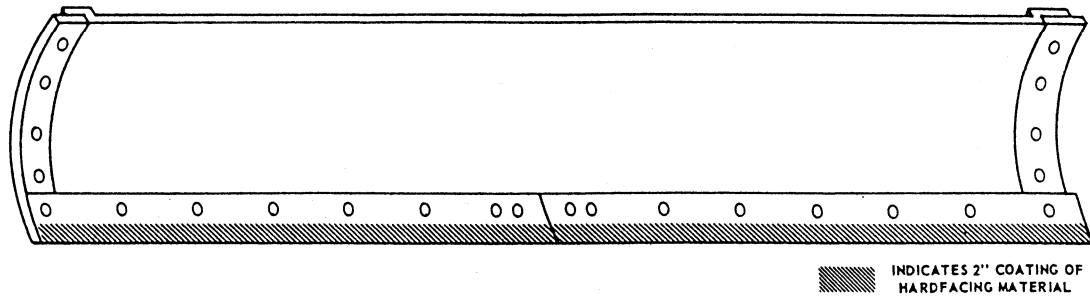


Figure 6-20.—Grader blade with hardfacing material applied to cutting edge.

cone. Unless the excess fuel-gas flame is used, the proper base metal surface condition cannot be developed. Without this condition, the surfacing alloy does not spread over the surface of the part.

Figure 6-20 shows a grader blade with a deposit of hardfacing material applied along the cutting edge. A

grader blade is usually wearfaced by the electric arc process. If the electric arc process is not available, you may use the oxygas torch.

Welding Materials Handbook, NAVFAC P-433, is an excellent source of information for wearfacing construction equipment.

SHIELDED METAL-ARC WELDING AND WEARFACING

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

MANUAL SHIELDED METAL-ARC WELDING

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

ARC-WELDING EQUIPMENT

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

The basic parts of a typical shielded metal-arc welding outfit include a welding machine, cables, electrode holder (stinger), and electrodes. The Steelworker also

requires a number of accessories that include a combination chipping hammer and wire brush, welding table (for shopwork), C-clamps, and protective apparel.

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

Electrical Terms

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

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

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

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

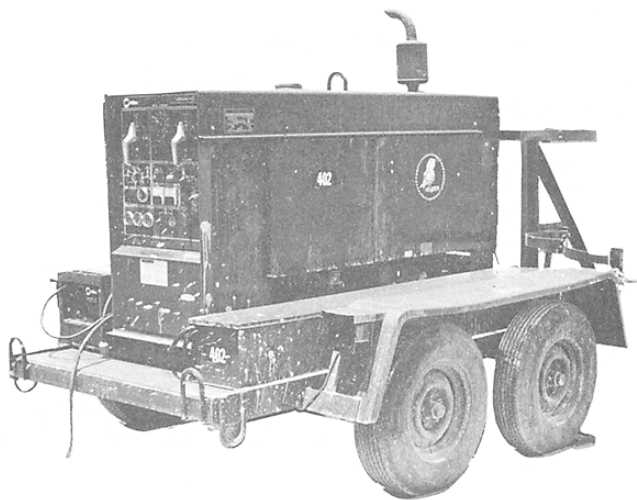
CURRENT.— Current is the movement or flow of an electrical charge through a conductor.

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

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

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

RESISTANCE.— Resistance is the opposition of the conductor to the flow of current. Resistance causes electrical energy to be changed into heat.



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Figure 7-1.—A 300 amp ac/dc portable welding machine.

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

Power Source

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

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

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

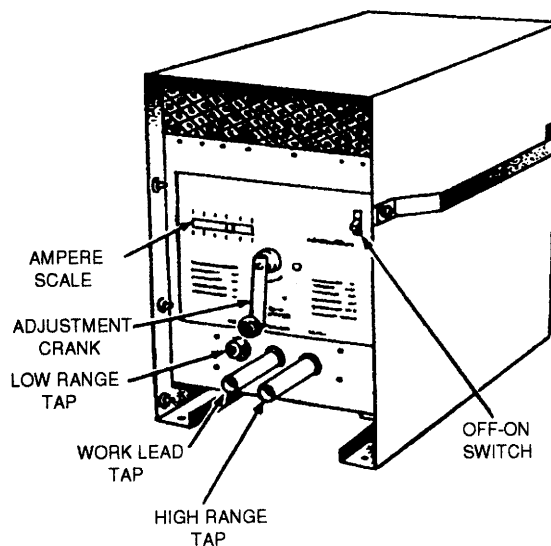


Figure 7-2.—An ac arc-welding transformer.

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

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

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

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

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

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

Table 7-1.—Cable Size Selection Guide

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

Based on a 4-Volt Drop

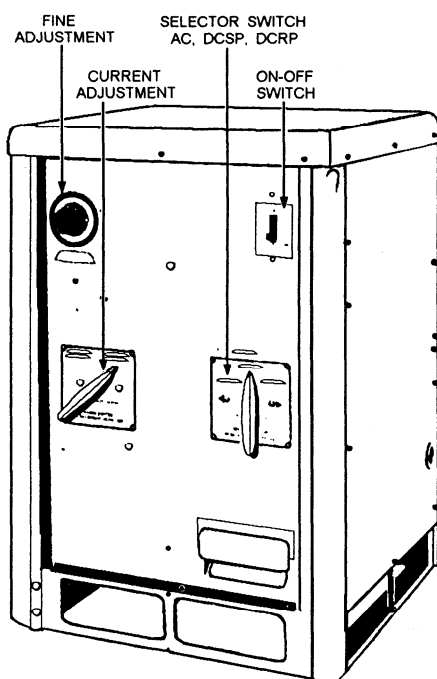


Figure 7-3.—Combination ac, dc transformer-rectifier arc welder.

RECTIFIER WELDING MACHINES.— Rectifier welders are single-phase or three-phase transformers that have selenium or silicon rectifiers added to rectify (change) the output current from alternating to direct current. Most of these machines have the capability of producing either ac or dc straight or reverse

polarity current. By flicking a switch, the welder can select the current that best suits the job. Figure 7-3 shows an example of a combination ac/dc rectifier.

Cables

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

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

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

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

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

Electrode Holder

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

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

Ground Clamps

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

Cleaning Equipment

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

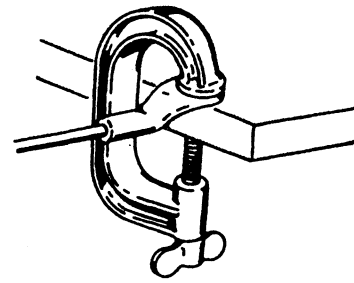


Figure 7-4.—C-clamped ground cable.

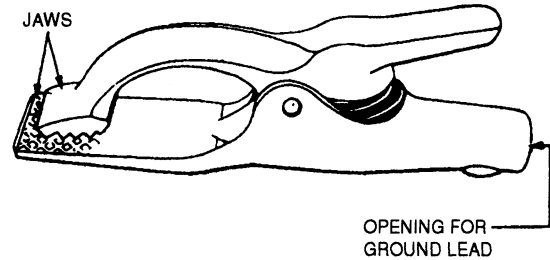


Figure 7-5.—A spring-loaded ground clamp for the ground lead.

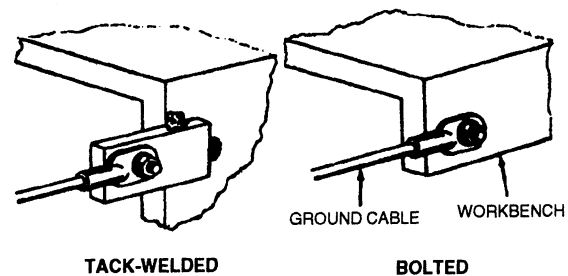


Figure 7-6.—Bolted and tack-welded ground clamps.

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

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

Safety Equipment

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

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

WARNING

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

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

EQUIPMENT OPERATION AND MAINTENANCE

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

WELDING AREA REQUIREMENTS

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

WELDING MACHINE OPERATION AND MAINTENANCE

You should become familiar with the welding machine that you will be using. Study the manufacturer's

literature and check with your senior petty officer or chief on the items that you do not understand. Machine setup involves selecting current type, polarity, and current settings. The current selection depends on the size and type of electrode used, position of the weld, and the properties of the base metal.

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

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

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

SHIELDED-METAL ARC WELDING

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

- Clear the welding area of all debris and clutter.
- Do not use gloves or clothing that contains oil or grease.
- Check that all wiring and cables are installed properly.
- Ensure that the machine is grounded and dry.
- Follow all manufacturer's directions on operating the welding machine.
- Have on hand a protective screen to protect others in the welding area from FLASH burns.
- Always keep fire-fighting equipment on hand.
- Clean rust, scale, paint, or dirt from the joints that are to be welded.

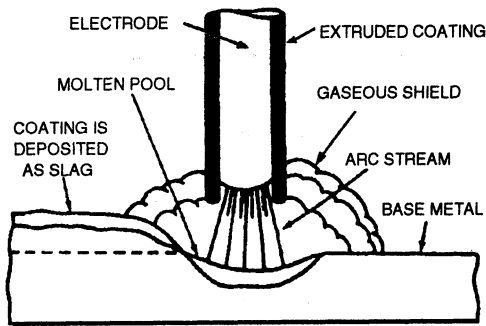


Figure 7-7.—Electrode covering and gaseous shield that protects weld metal from the atmosphere.

ELECTRODES

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

1. Mild steel
2. High-carbon steel
3. Special alloy steel
4. Cast iron
5. Nonferrous

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

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

Types of Electrodes

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

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

All mild steel and low-alloy electrodes are classified with a 4 or 5 digit number prefixed by "E."

Prefix "E" = Electrode

First two (or three) digits = Tensile strength (psi) (stress relieved or as welded)

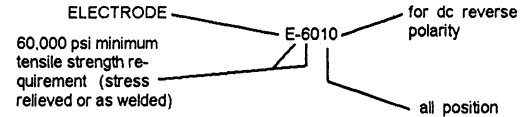
Third (or fourth) digit = Position of welding

1 = all positions (flat, horizontal, vertical, overhead)

2 = horizontal and flat positions only

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

EXAMPLE



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

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

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

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

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

Electrode Identification

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

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

Table 7-2.—Electrode Selection Guide

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

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

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

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

Electrode Selection

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

current types and welding positions for the most common electrodes.

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

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

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

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

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

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

Another group of electrodes are the low-hydrogen type that were developed for welding high-sulfur and high-carbon steel. These electrodes produce X-ray

quality deposits by reducing the absorption of hydrogen that causes porosity and cracks under the weld bead.

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

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

Electrode Storage

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

Polarity

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

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

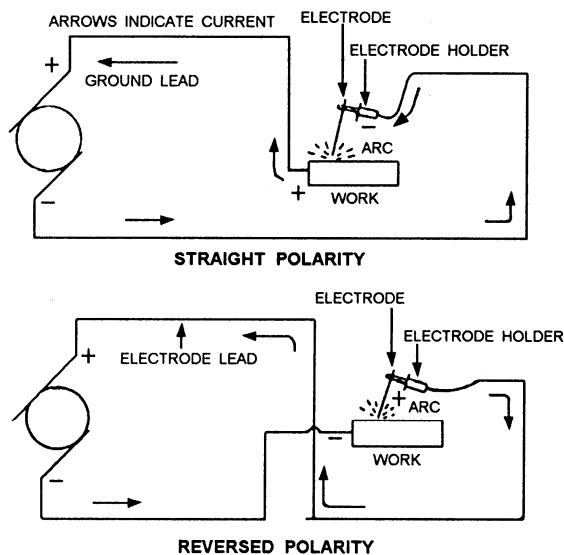


Figure 7-9.—Straight and reverse polarity in electric welding.

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

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

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

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

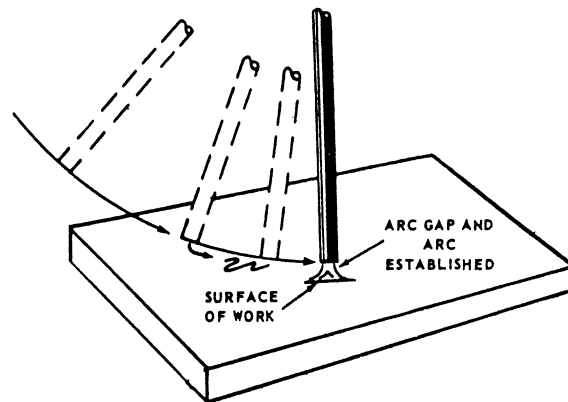


Figure 7-10.—Striking or brushing method of starting the arc.

opposite is true and the greatest heat is produced on the negative side. Electrode coatings affect the heat conditions differently. One type of heavy coating may provide the most desirable heat balance with straight polarity, while another type of coating on the same electrode may provide a more desirable heat balance with reverse polarity.

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

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

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

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

STARTING THE ARC

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

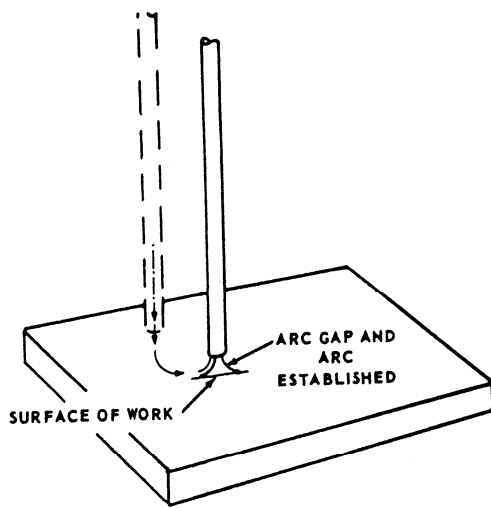


Figure 7-11.—Tapping method of starting the arc.

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

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

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

CAUTION

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

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

Setting the Current

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

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

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

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

When the electrode, current, and polarity are correct, a good arc produces a sharp, crackling sound. When any of these conditions are incorrect, the arc produces a steady, hissing sound, such as steam escaping.

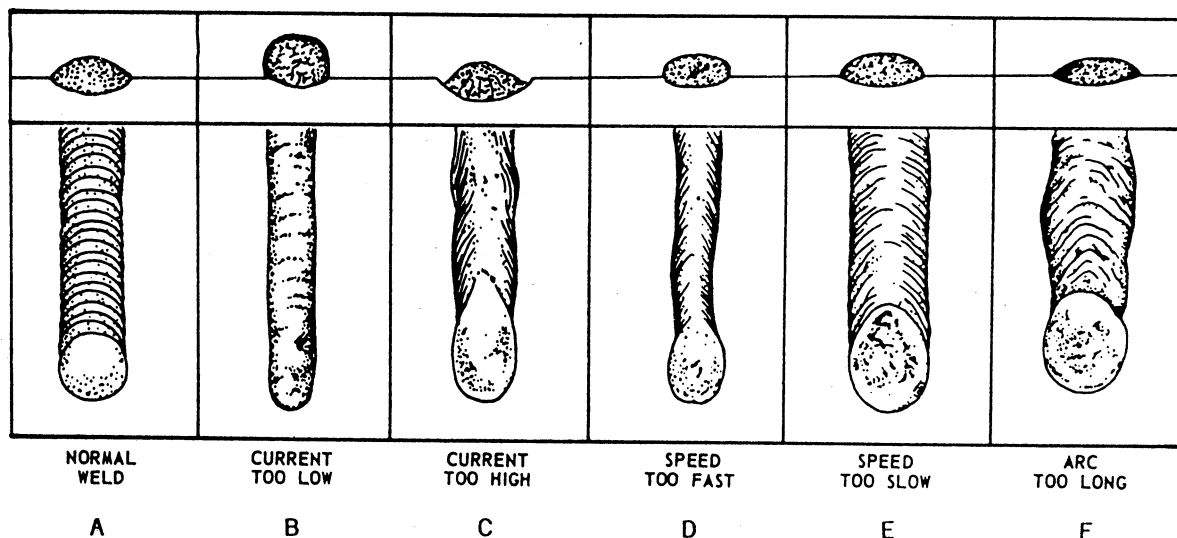


Figure 7-12.—Comparison chart of welds.

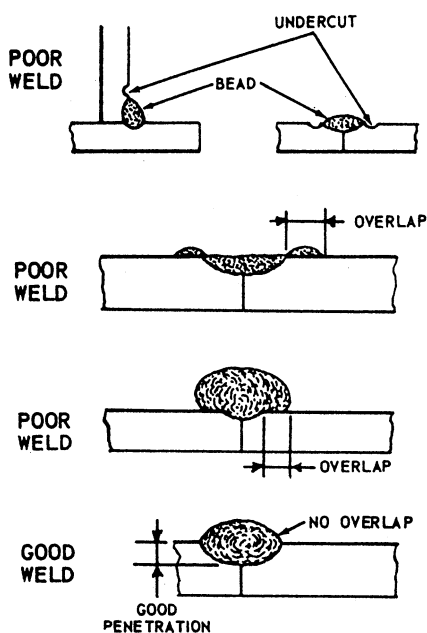


Figure 7-13.—Undercuts and overlaps in welding.

Length of Arc

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

When an arc is too short, it fails to generate enough heat to melt the base metal properly, causes the electrode

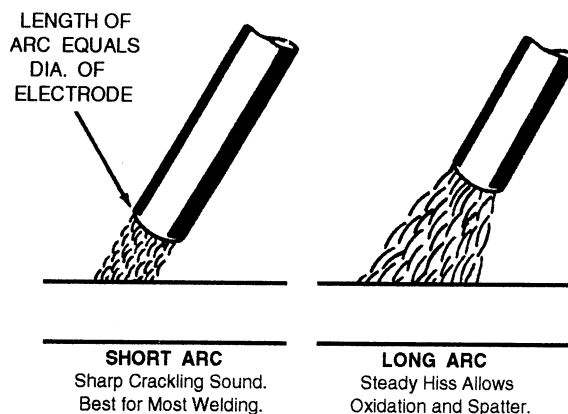


Figure 7-14.—Setting the length of an arc.

to stick frequently to the base metal, and produces uneven deposits with irregular ripples. The recommended length of the arc is equal to the diameter of the bare end of the electrode, as shown in figure 7-14.

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

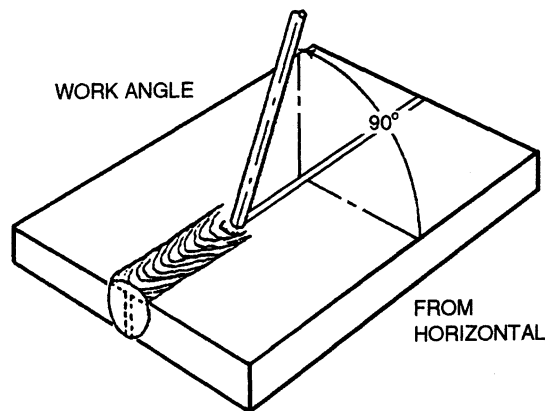


Figure 7-15.—Work angle.

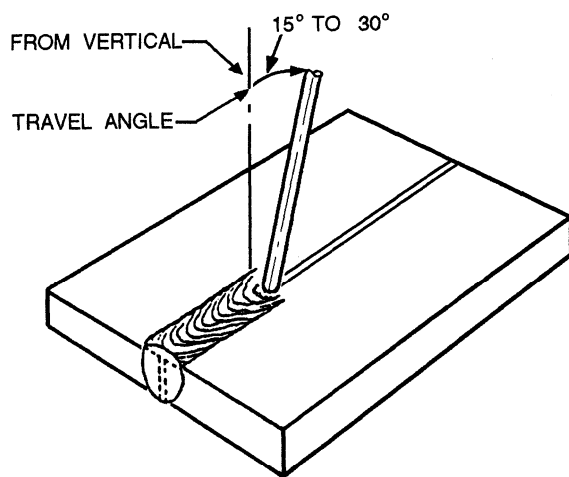


Figure 7-16.—Travel angle.

Electrode Angle

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

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

Travel Speed

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

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

Breaking the Arc

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

Reestablishing the Arc

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

Peening

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

ARC WELDING POSITIONS

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

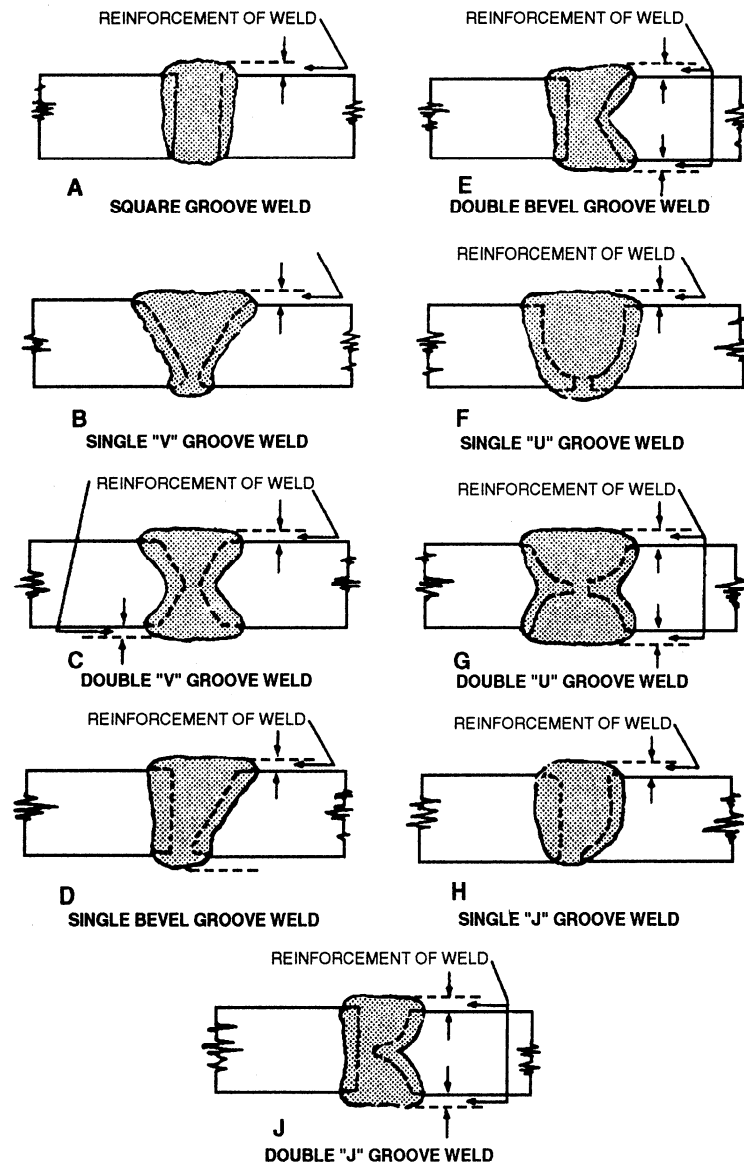


Figure 7-17.—Butt joints in the flat position.

FLAT-POSITION WELDING

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

Joint Type

Butt joints are the primary type of joints used in the flat position of welding; however, flat-position welding

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

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

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

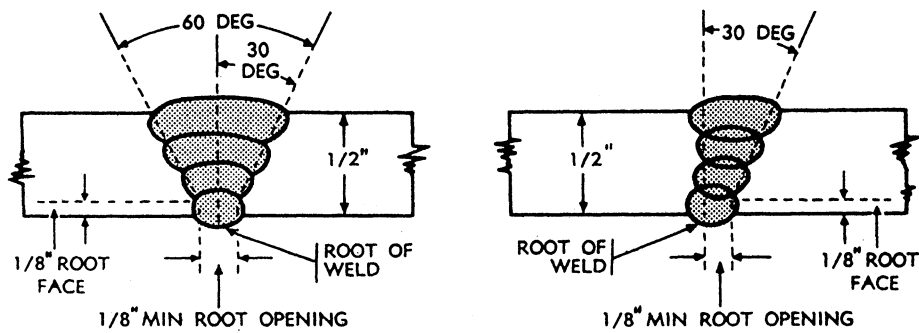


Figure 7-18.—Butt welds with multipass beads.

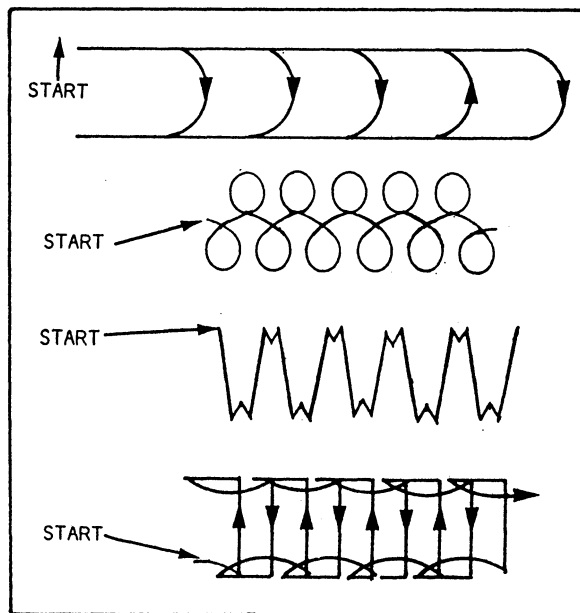


Figure 7-19.—Weave motions used in manual shielded arc welding.

Tack welds should be used to keep the plates aligned for welding. The electrode motion is the same as that used in making a bead weld.

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

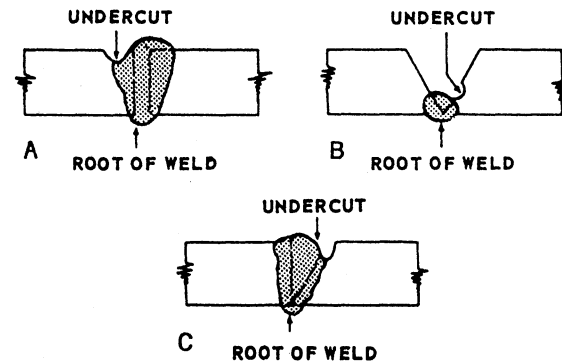


Figure 7-20.—Undercutting in butt joint welds.

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

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

BUTT JOINTS WITH BACKING STRIPS.—

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

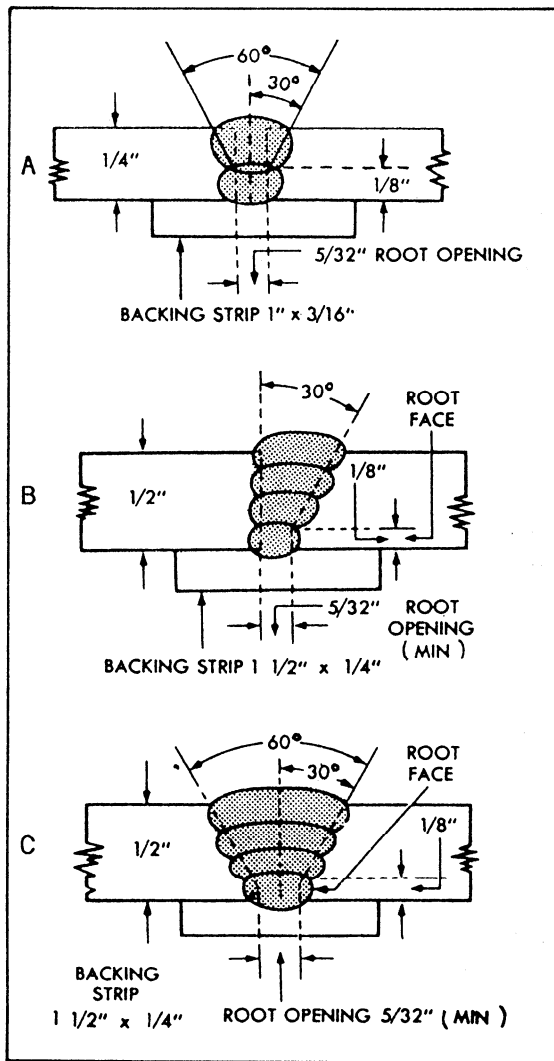


Figure 7-21.—Use of backing strips in welding butt joints.

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

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

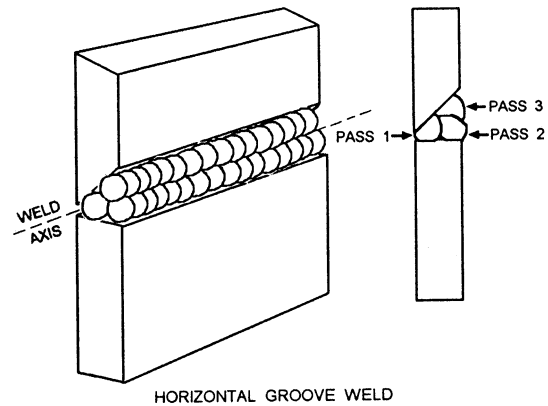


Figure 7-22.—Horizontal groove weld.

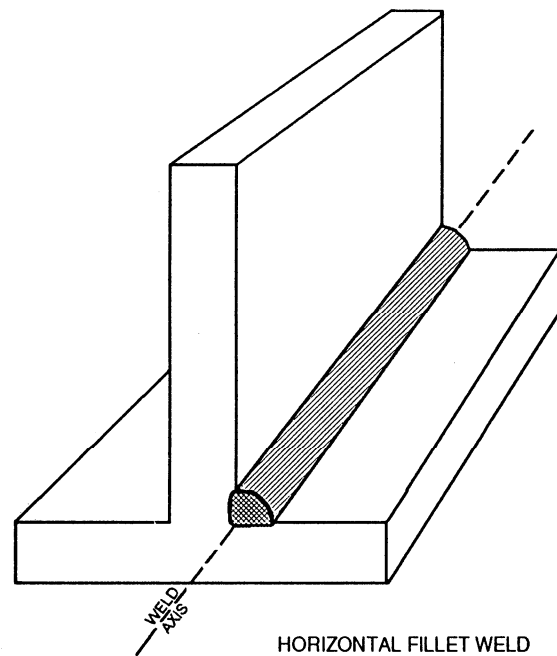


Figure 7-23.—Horizontal fillet weld,

HORIZONTAL-POSITION WELDING

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

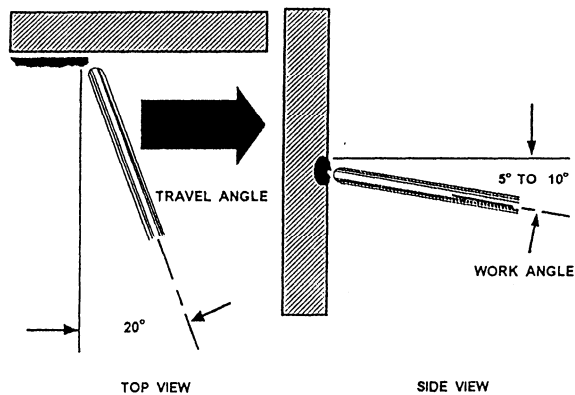


Figure 7-24.—Horizontal welding angles.

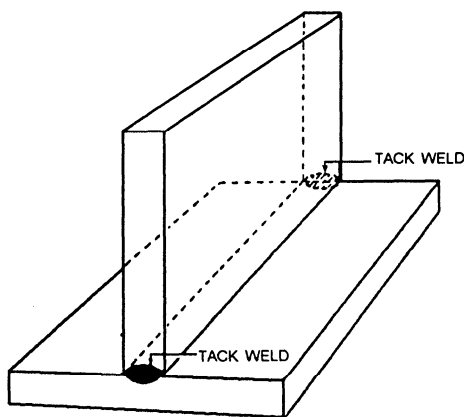


Figure 7-25.—Tack-weld to hold the tee joint elements in place.

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

Electrode Movement

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

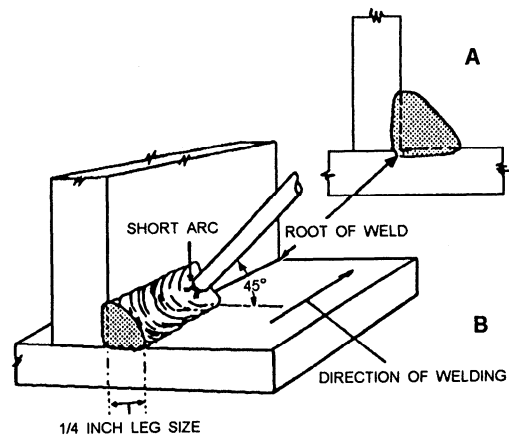


Figure 7-26.—Position of electrode and fusion area of fillet weld on a tee joint.

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

Joint Type

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

TEE JOINTS.— When you make tee joints in the horizontal position, the two plates are at right angles to each other in the form of an inverted T. The edge of the vertical plate may be tack-welded to the surface of the horizontal plate, as shown in figure 7-25.

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

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

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

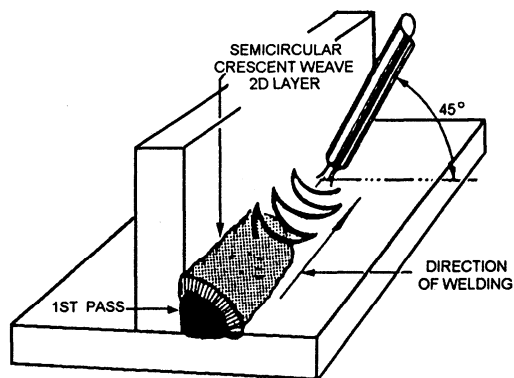


Figure 7-27.—Weave motion for multipass fillet weld.

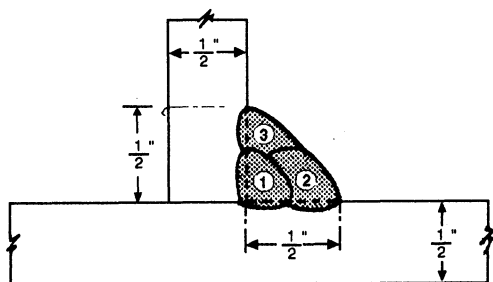


Figure 7-28.—Order of making string beads for a tee joint in heavy plate.

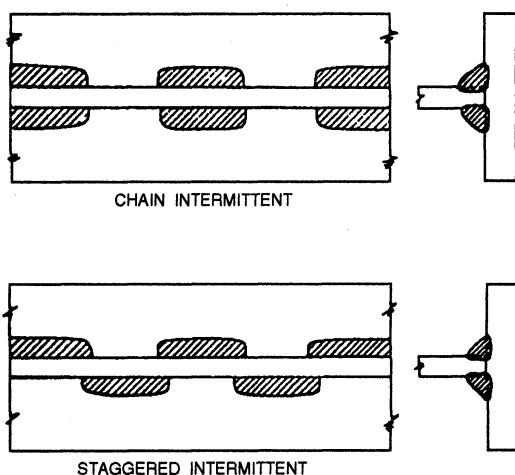


Figure 7-29.—Intermittent fillet welds.

Chain-intermittent or staggered-intermittent fillet welds, as shown in figure 7-29, are used on long tee joints. Fillet welds of these types are for joints where high weld strength is not required; however, the short welds are arranged so the finished joint is equal in

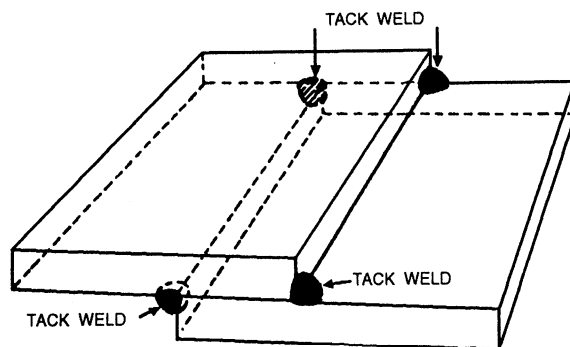


Figure 7-30.—Tack welding a lap joint.

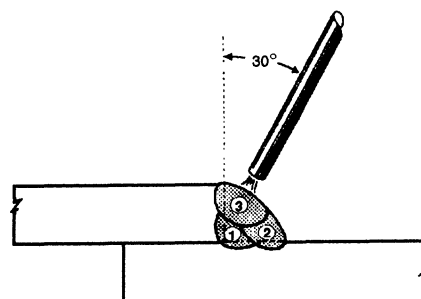


Figure 7-31.—Position of electrode on a lap joint.

strength to that of a joint that has a fillet weld along the entire length of one side. Intermittent welds also have the advantage of reduced warpage and distortion.

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

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

In making lap joints on plates of different thickness, you should hold the electrode so that it forms an angle of between 20 and 30 degrees from the vertical

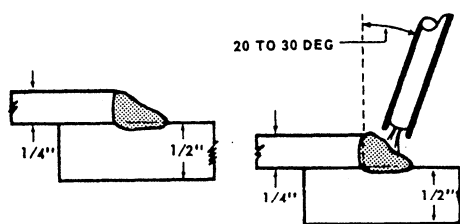


Figure 7-32.—Lap joints on plates of different thickness.

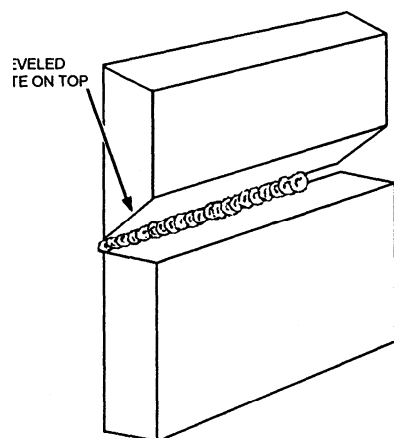


Figure 7-33.—Horizontal butt joint.

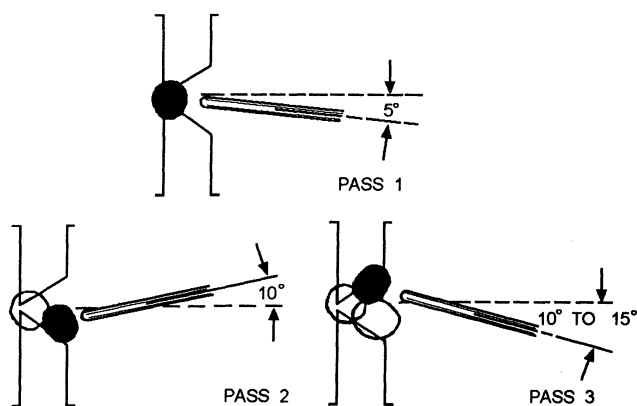


Figure 7-34.—Multiple passes.

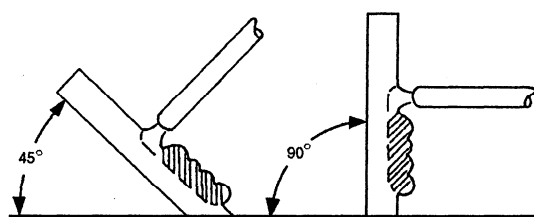


Figure 7-35.—Vertical weld plate positions.

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

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

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

VERTICAL-POSITION WELDING

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

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

Current Settings and Electrode Movement

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

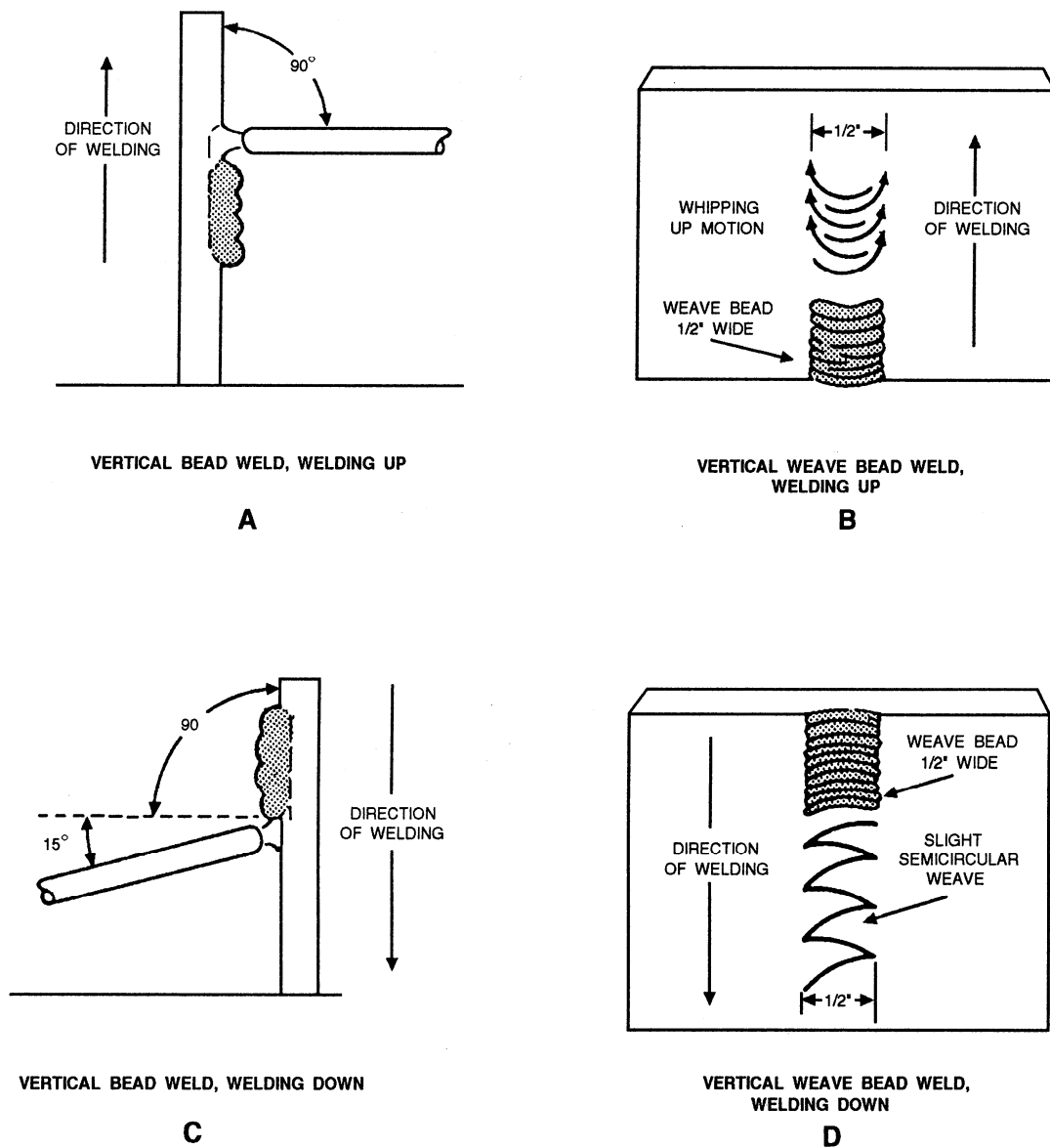


Figure 7-36.—Bead welding in the vertical position.

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

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

Joint Type

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

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

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

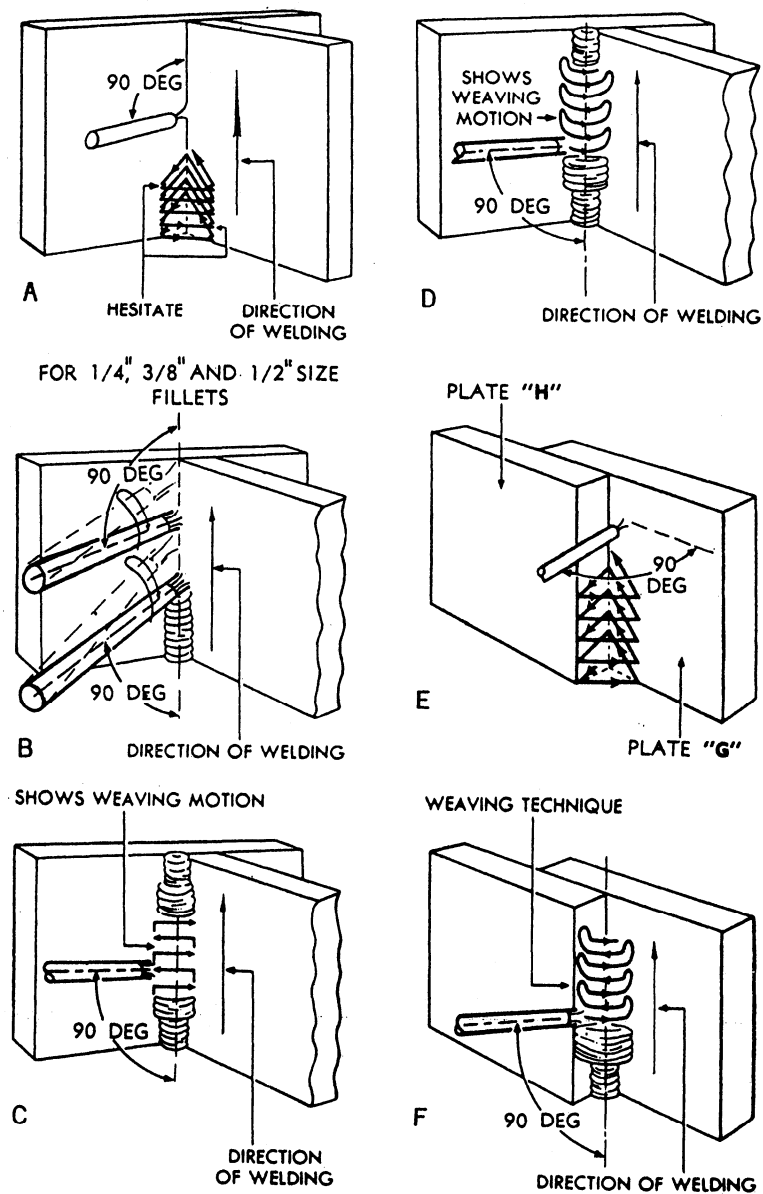


Figure 7-37.—Fillet welds in the vertical position.

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

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

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

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

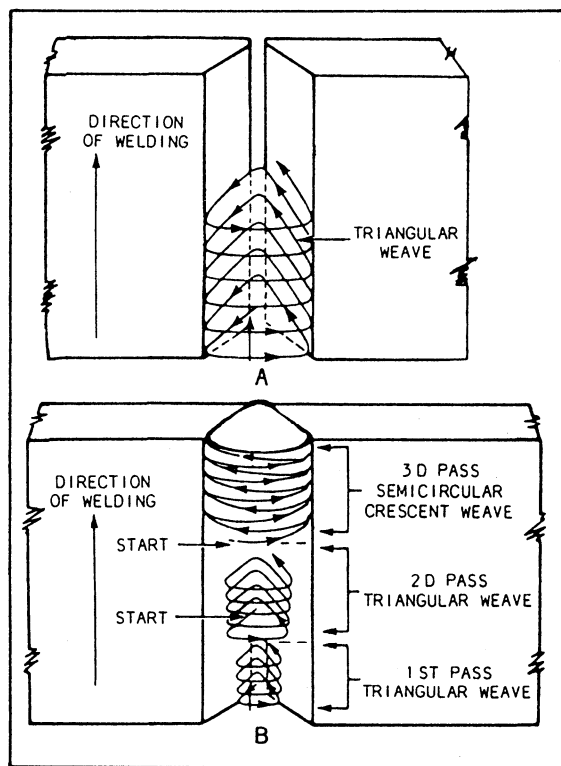


Figure 7-38.—Butt joint welding in the vertical position.

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

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

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

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

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

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

E-7018 Electrode Welding Technique

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

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

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

OVERHEAD-POSITION WELDING

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

Current Settings and Electrode Movement

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

One of the problems encountered in overhead welding is the weight of the cable. To reduce arm and wrist fatigue, drape the cable over your shoulder when welding in the standing position. When sitting, place the

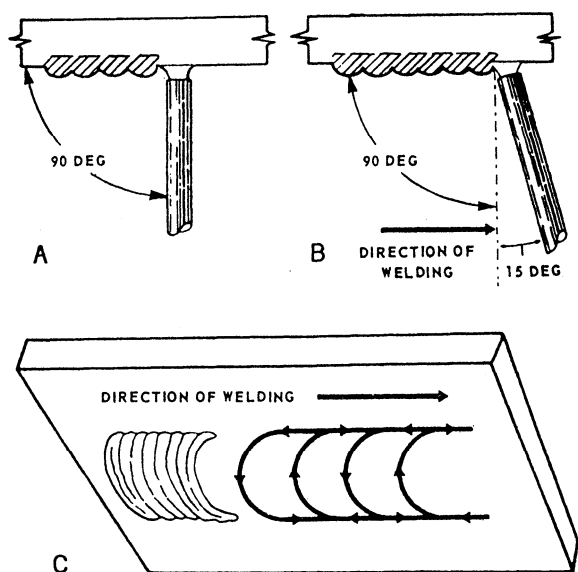


Figure 7-39.—Position of electrode and weave motion in the overhead position.

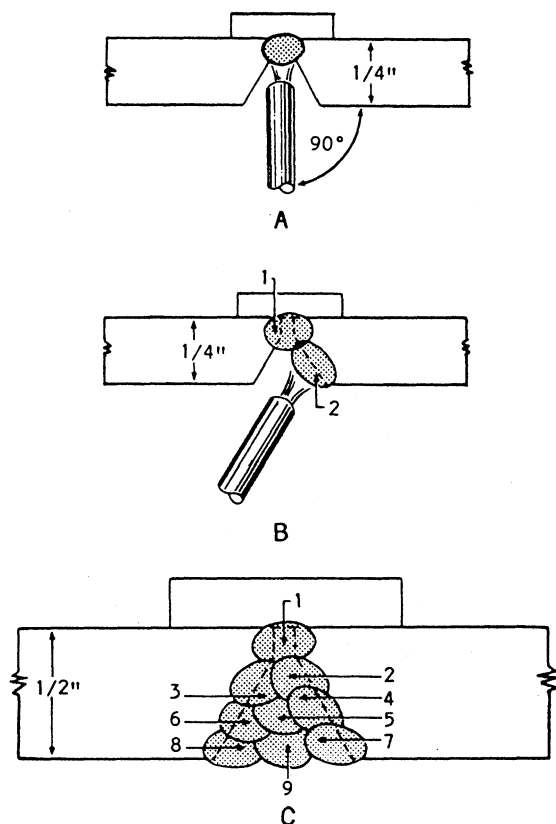


Figure 7-40.—Multipass butt joint in the overhead position.

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

WARNING

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

Type of Welds

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

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

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

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

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

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

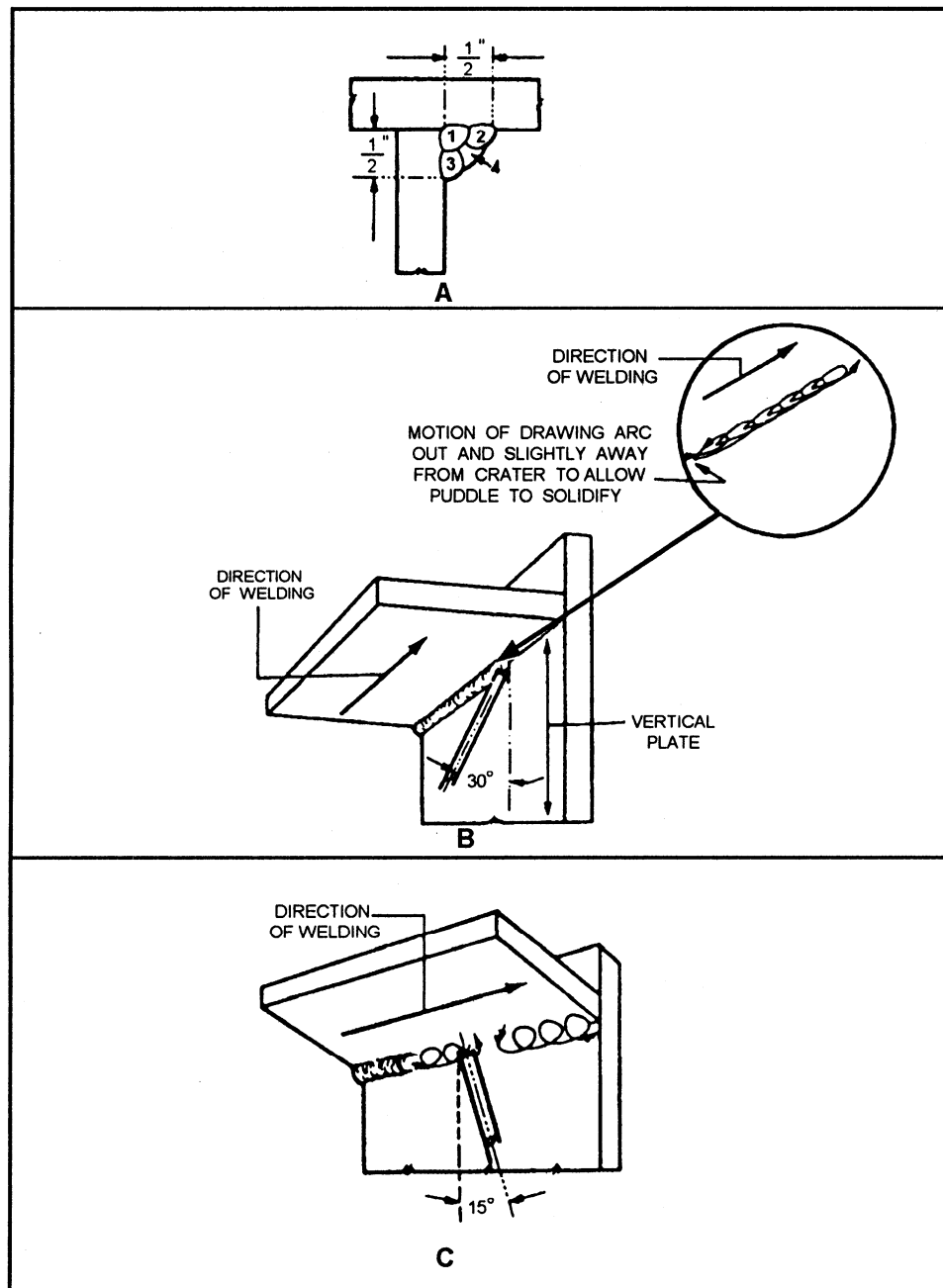


Figure 7-41.—Fillet welding in the overhead position.

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

the arc and allow the metal to solidify. Immediately return the electrode to the crater and continue welding.

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

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

porous welds WHY 1. Short arc with exception of low hydrogen and stainless 2. Insufficient puddling time 3. Impaired base metal 4. Poor electrode 5. Improper shield coverage WHAT TO DO 1. Check impurities in base metal 2. Allow sufficient puddling time for gases to escape 3. Use proper current 4. Weave your weld to eliminate pin holes 5. Use proper electrode for job 6. Hold longer arc 7. Check shield gas	cracked welds WHY 1. Wrong electrode 2. Weld and parts sizes unbalanced 3. Faulty welds 4. Faulty preparation 5. Rigid joint WHAT TO DO 1. Design structure to eliminate rigid joints 2. Heat parts before welding 3. Avoid welds in string beads 4. Keep ends free to move as long as possible 5. Make sound welds of good fusion 6. Adjust weld size to parts size 7. Allow joints a proper and uniform gap 8. Work with amperage as low as possible
poor penetration WHY 1. Speed too fast 2. Electrode too large 3. Current too low 4. Faulty preparation WHAT TO DO 1. Use enough current to obtain desired penetration—weld slowly 2. Select electrode according to welding groove size 3. Leave proper gap at bottom of weld	poor appearance WHY 1. Faulty electrode 2. Overhang 3. Improper use of electrode 4. Wrong arc voltage and current WHAT TO DO 1. Use a proper welding technique 2. Avoid overheating 3. Use a uniform weave 4. Avoid overly high current
warping WHY 1. Shrinkage of weld metal 2. Faulty clamping of parts 3. Faulty preparation 4. Overheating at joint WHAT TO DO 1. Peen joint edges before welding 2. Weld more rapidly 3. Avoid excessive space between parts 4. Preform parts before welding 5. Use proper sequence 6. Clamp or tack parts properly—back-up to cool 7. Adopt a proper welding procedure 8. Use high speed, moderate penetration process	poor fusion WHY 1. Wrong speed 2. Current improperly adjusted 3. Faulty preparation 4. Improper electrode size WHAT TO DO 1. Adjust electrode to match joint 2. Weave must be sufficient to melt sides of joint 3. Select proper current and voltage 4. Keep weld metal from flowing away from plates
undercutting WHY 1. Faulty electrode or gun manipulation 2. Faulty electrode usage 3. Current too high WHAT TO DO 1. Use a uniform weave in butt welding 2. Avoid using an overly large electrode 3. Avoid excessive weaving 4. Use moderate current, weld slowly 5. Hold electrode at safe distance from vertical plane in making horizontal fillet weld	brittle welds WHY 1. Wrong electrode 2. Faulty preheating 3. Metal hardened by air WHAT TO DO 1. Preheat at 300° to 500° F. if welding on medium carbon steel or certain alloy steels 2. Make multiple layer welds 3. Stress relieving after welding 4. Use low hydrogen processes for increased weld ductility
spatter WHY 1. Arc blow 2. Current too high 3. Arc too long 4. Faulty electrodes WHAT TO DO 1. Clean parts in weld area 2. Adjust current properly 3. Adjust voltage 4. Pick suitable electrode	magnetic blow WHY 1. Magnetic fields cause the arc to deviate from its intended course WHAT TO DO 1. Use steel blocks to alter magnetic path around arc 2. Divide the ground into parts 3. Weld in same direction the arc blows 4. Use a short arc length 5. Locate the ground properly on the work 6. Use A-C welding

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

WELDING DIFFICULTIES

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

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

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

1. Use only high-quality welding machines, electrodes, and welding accessories.
2. Know the base material that you are working on.
3. Select the proper welding process that gives the highest quality welds for the base material used.
4. Select the proper welding procedure that meets the service requirement of the finished weldment.
5. Select the correct electrode for the job in question.
6. When preheating is specified or required make sure you meet the temperature requirements. In any case, do not weld on material that is below 32°F without first preheating.
7. Clean the base metal of all slag, paint, grease, oil, moisture, or any other foreign materials.
8. Remove weld slag and thoroughly clean each bead before making the next bead or pass.
9. Do not weld over cracks or porous tack welds. Remove defective tack welds before welding.
10. Be particularly alert to obtain root fusion on the first pass of fillet and groove welds.
11. When groove weld root gaps are excessive, build up one side of the joint before welding the pieces together.
12. When fillet weld root gaps are excessive, be sure you increase the size of the fillet weld to the size of

the root gap to maintain the strength requirement. In some cases, it is advantageous to make a groove weld to avoid extremely large fillet welds.

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

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

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

PIPE WELDING

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

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

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

PIPE WELDING POSITIONS

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

PIPE WELDING PROCEDURES

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

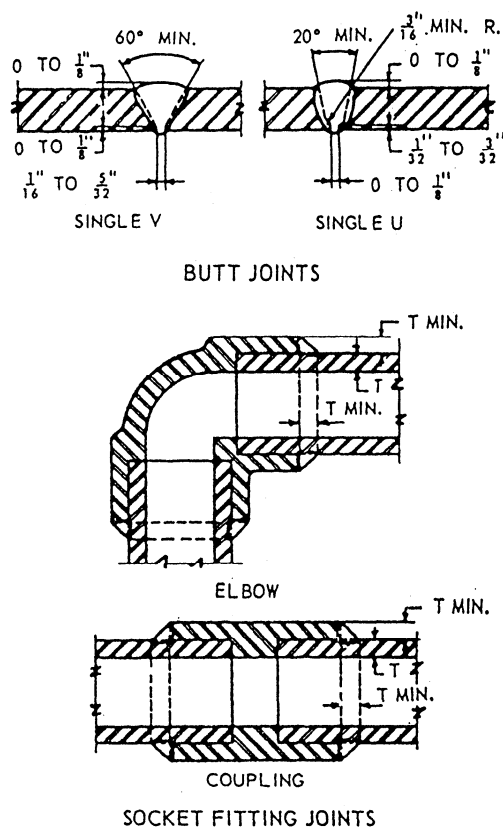


Figure 7-42.—Butt joints and socket fitting joints.

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

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

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

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

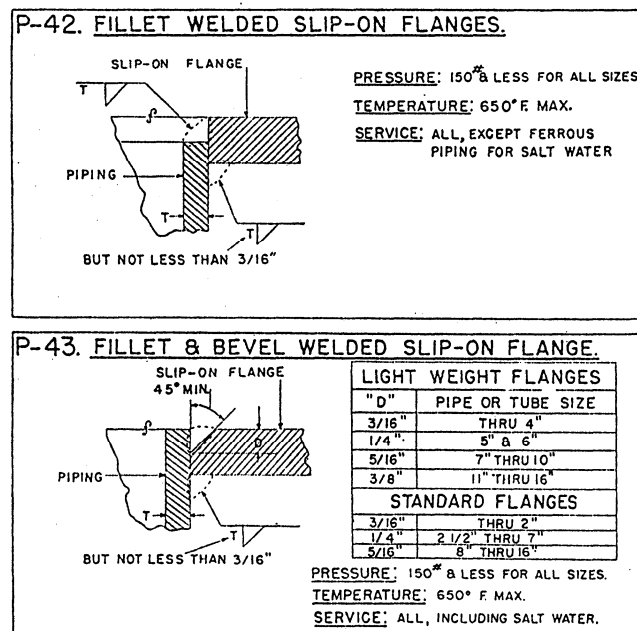


Figure 7-43.—Flange connections.

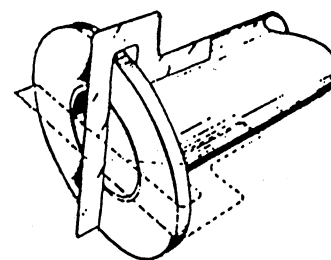


Figure 7-44.—Flange alignment.

JOINT PREPARATION AND FIT-UP

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

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

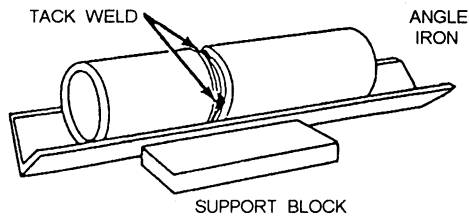


Figure 7-45.—Angle iron jig.

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

TACK WELDING

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

SPACERS

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

ELECTRODE SELECTION

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

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

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

WEATHER CONDITIONS

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

- When the atmospheric temperature is less than 0°F
- When the surfaces are wet
- When rain or snow is falling, or moisture is condensing on the weld surfaces
- During periods of high wind

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

WEARFACING

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

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

WORKPIECE PREPARATION

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

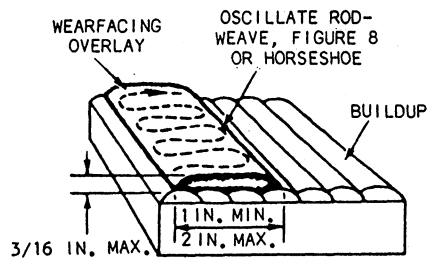


Figure 7-46.—Wearfacing techniques.

PREHEATING

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

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

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

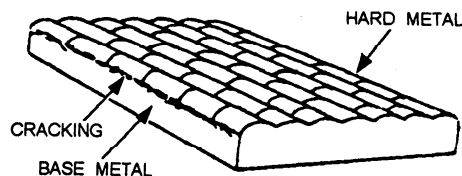
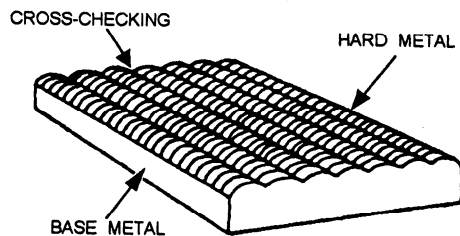


Figure 7-47.—Comparison between cross-checking and cracking.

TECHNIQUES

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

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

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

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

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

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

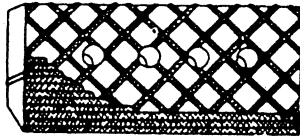


Figure 7-48.—Wearfacing bulldozer end bits.

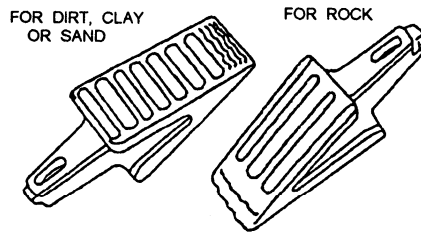


Figure 7-49.—Wearfacing shovel teeth.

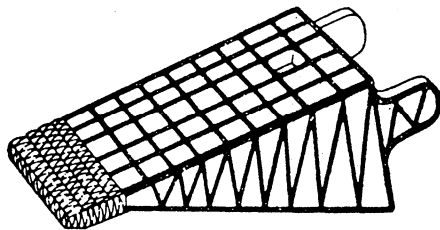


Figure 7-50.—Waffle or crosshatching.

(locked-in) stresses. Without checking, the combination of residual stresses and service stresses may exceed tensile strength and cause deep cracks or **spalling** (fig. 7-47). Be sure to induce checking if it does not occur

naturally or if it is unlikely to occur, as in large parts where heat builds up. You can bring on checking by sponging the deposit with a wet cloth or by spraying it with a fine mist of water. Also you can speed up checking by occasionally striking it with a hammer while it is cooling. When a check-free deposit is required, use a softer alloy and adjust preheating and postheating requirements.

Bulldozer Blades

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

Shovel teeth

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

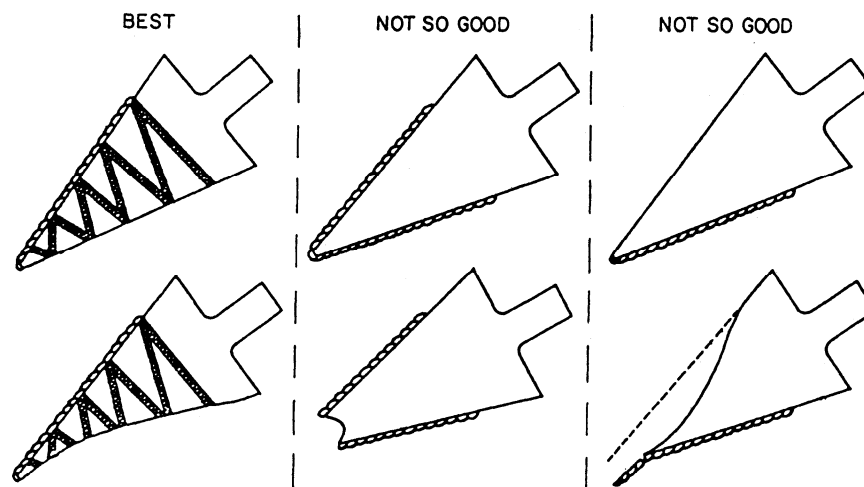


Figure 7-51.—Comparison of wearfacing patterns for shovel teeth.

Table 7-4.—Table of Recommended Electrode Sizes, Current Settings, and Cutting Speeds for Carbon-Arc Cutting Different Thicknesses of Steel Plate

THICKNESS OF PLATE INCHES	CURRENT SETTING AND CARBON DIA.			
	300 AMPS. 1/2 IN. DIA.	500 AMPS. 5/8 IN. DIA.	700 AMPS. 3/4 IN. DIA.	1000 AMPS. 1 IN. DIA.
	SPEED OF CUTTING IN MINUTE PER FOOT			
1/2	3.5	2.0	1.5	1.0
3/4	4.7	3.0	2.0	1.4
1	6.8	4.1	2.9	2.0
1-1/4	9.8	5.6	4.0	2.9
1-1/2	...	8.0	5.8	4.0
1-3/4	...	...	8.0	5.3
2	...	...	...	7.0

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

CARBON-ARC CUTTING

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

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

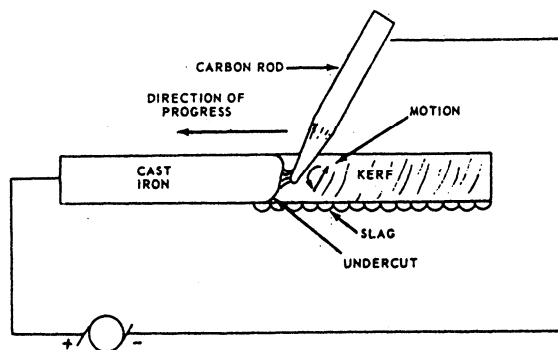


Figure 7-52.—Carbon-arc cutting on cast iron.

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

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

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

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

AIR CARBON-ARC CUTTING

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

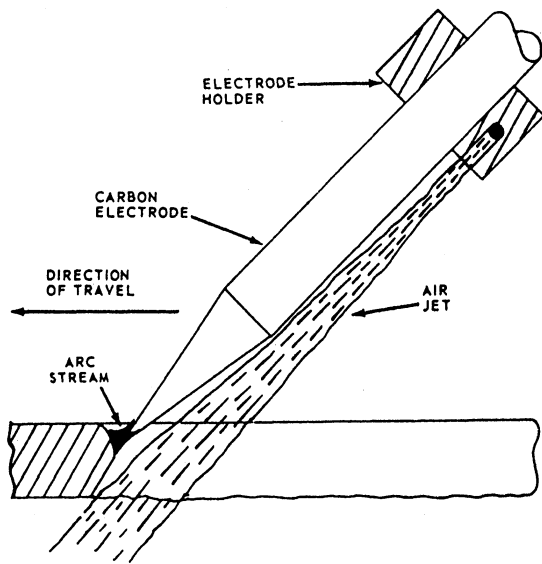


Figure 7-53.—Air carbon-arc cutting.

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

The air jet blows the molten metal away and usually leaves a surface that needs no further preparation for

welding. The electrode holder operates at air pressures varying between 60 and 100 psig.

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

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

- Adjust the machine to the correct current for electrode diameter.
- Start the air compressor and adjust the regulator to the correct air pressure. Use the lowest air pressure possible—just enough pressure to blow away the molten metal.
- Insert the electrode in the holder. Extend the carbon electrode 6 inches beyond the holder. Ensure that the electrode point is properly shaped.
- Strike the arc; then open the air-jet valve. The air-jet disc can swivel, and the V-groove in the disc automatically aligns the air jets along the electrode. The electrode is adjusted relative to the holder.
- Control the arc and the speed of travel according to the shape and the condition of the cut desired.

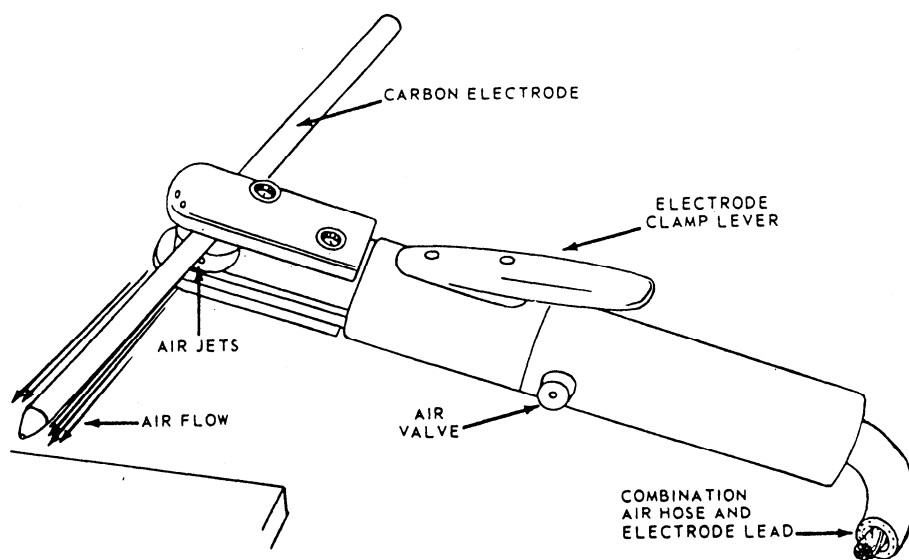


Figure 7-54.—Air carbon-arc electrode holder with carbon electrode installed.

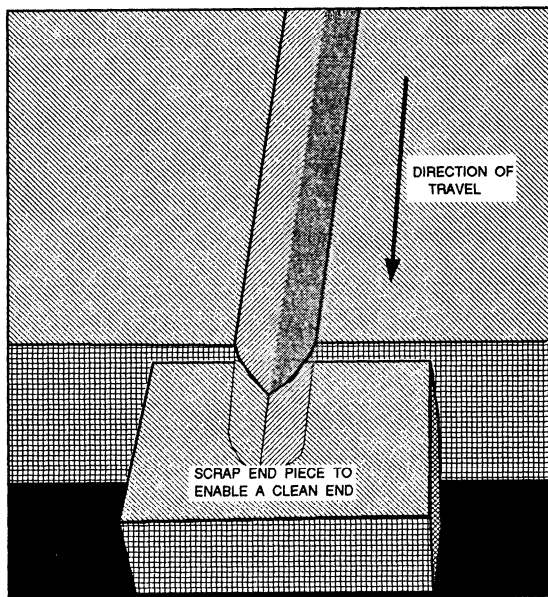


Figure 7-55.—V-groove gouge in 2-inch-thick carbon steel.

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

AIR CARBON-ARC GOUGING

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

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

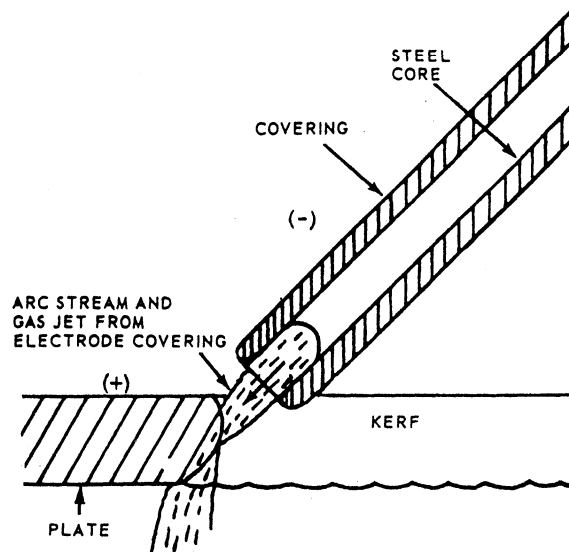


Figure 7-56.—Steel electrode being used to cut plate.

METAL ELECTRODE ARC CUTTING

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

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

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

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

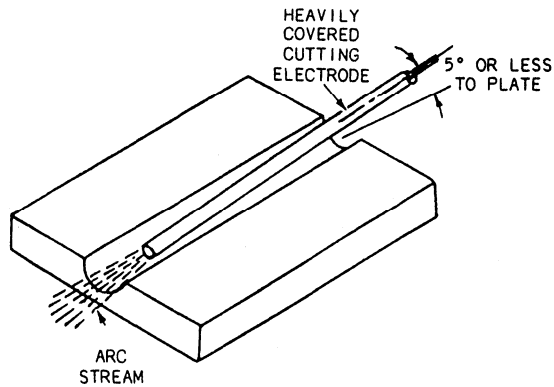


Figure 7-57.—Gouge-cutting operation using a solid core arc-cutting electrode.

WELDING QUALITY CONTROL

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

NONDESTRUCTIVE TESTING

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

Visual Inspection

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

Magnetic Particle Inspection

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

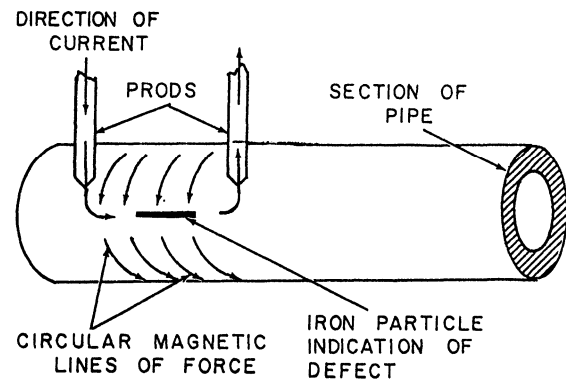


Figure 7-58.—Circular magnetization (prod method).

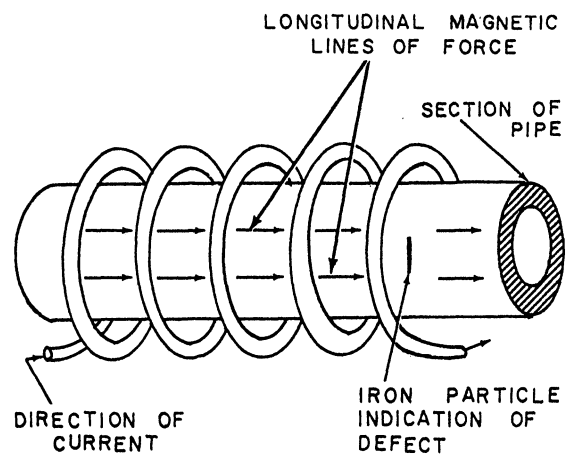


Figure 7-59.—Longitudinal magnetization (coil method).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Demagnetization can be accomplished with the portable unit if a special demagnetizer is not available. To demagnetize with the portable unit, form a coil of flexible cable around the workpiece. Ensure that the cable is plugged into the unit for the delivery of

alternating current. Set the current regulator to deliver a current identical to that used for the inspection and turn on the unit. Gradually decrease the current until the ammeter indicates zero. On large pieces, it may be necessary to demagnetize a small portion of the work at a time.

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

Liquid Penetrant Inspection

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

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

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

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

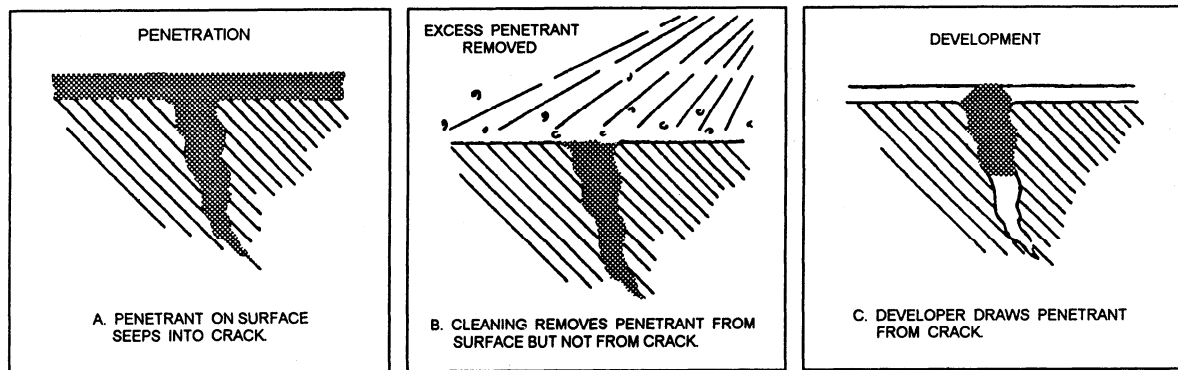


Figure 7-60.—Liquid penetrant inspection.

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

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

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

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

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

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

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

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

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

Radiographic Inspection

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

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

Ultrasonic Inspection

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

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

Eddy Current Testing

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

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

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

DESTRUCTIVE TESTING

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

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

Free-Bend Test

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

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

The next step in the free-bend test is to scribe two lines on the face of the filler deposit. Locate these lines

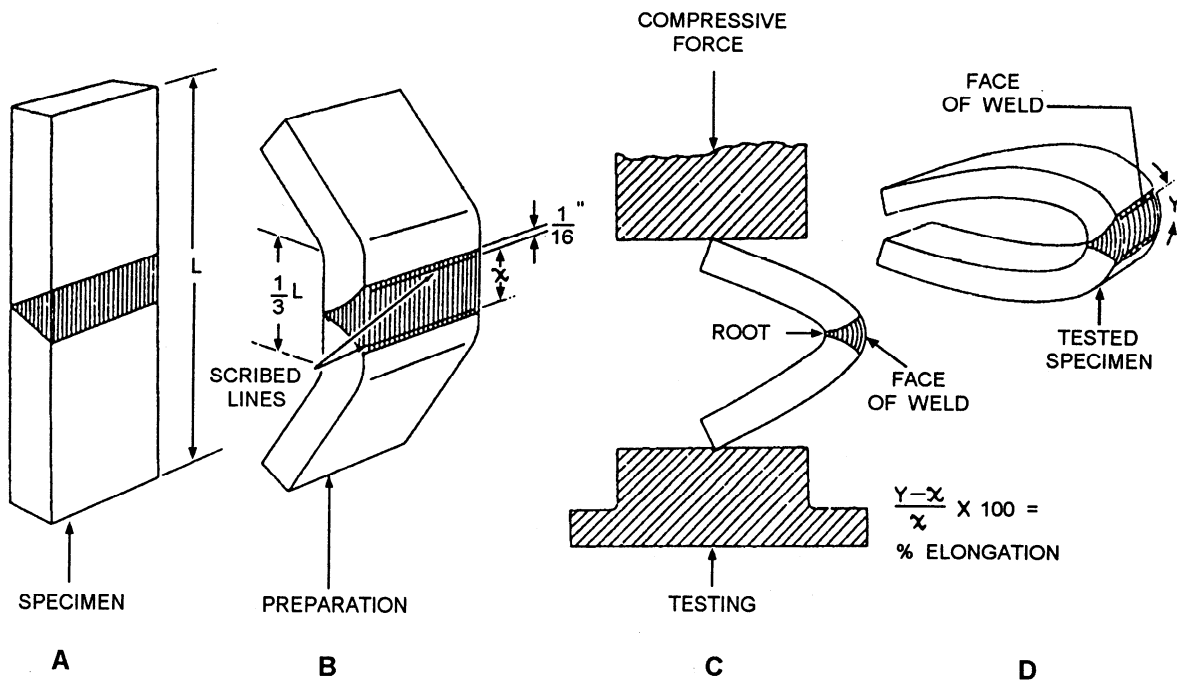


Figure 7-61.—Free-bend test

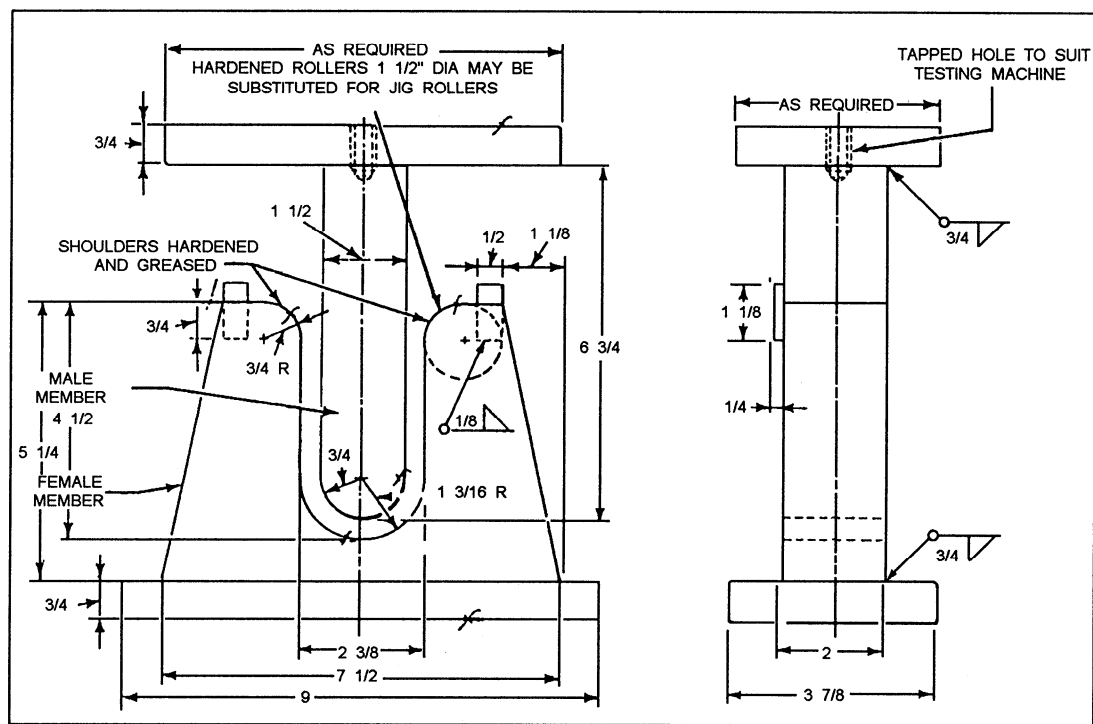


Figure 7-62.—Guided-bend test jig.

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

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

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

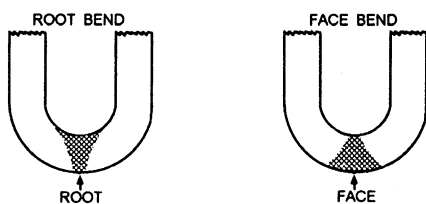


Figure 7-63.—Guided-bend test specimens.

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

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

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

Guided-Bend Test

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

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

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

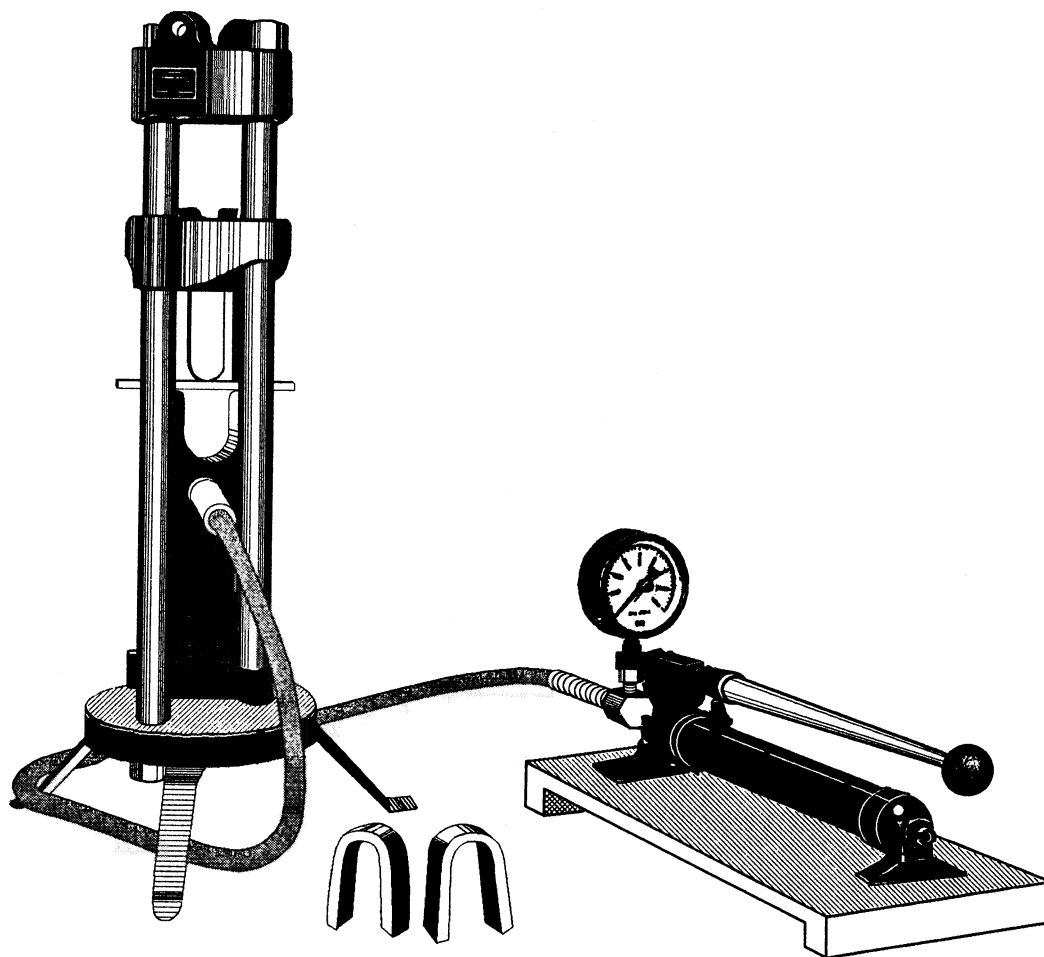


Figure 7-64.—Testing machine for making guided-bend tests.

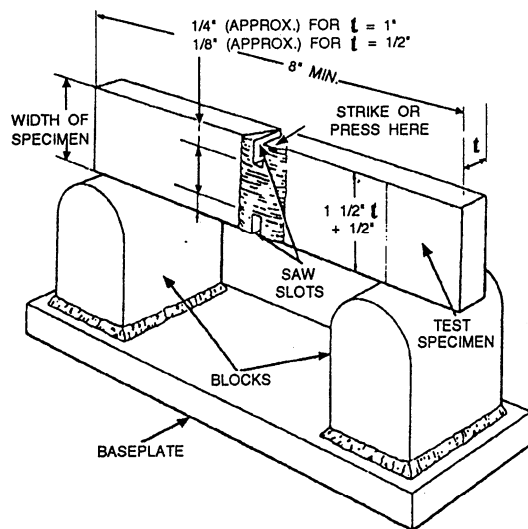


Figure 7-65.—Nick-break test of a butt weld.

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

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

Nick-Break Test

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

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

Impact Test

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

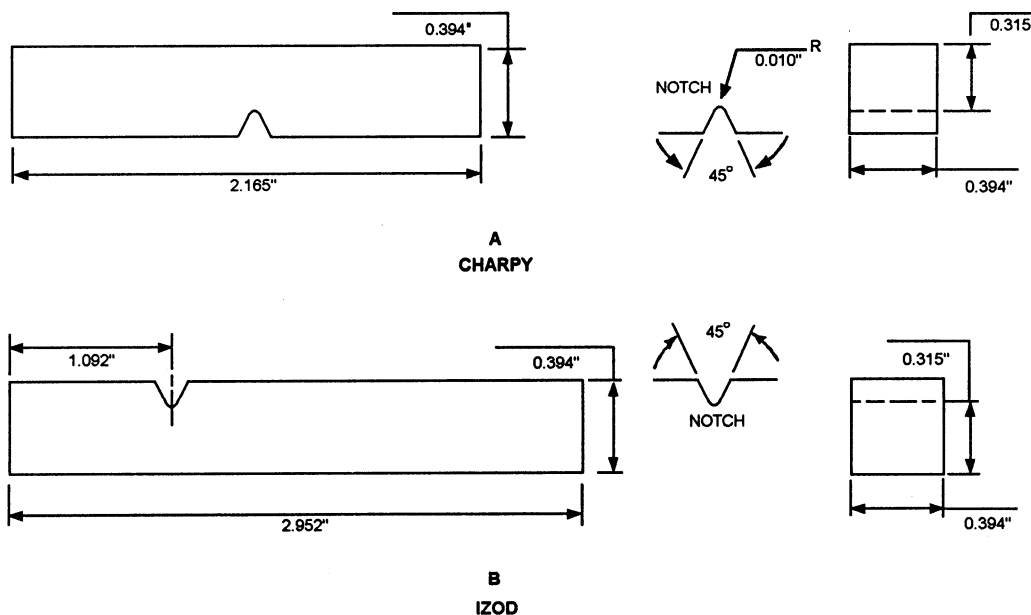


Figure 7-66.—Test pieces for impact testing.

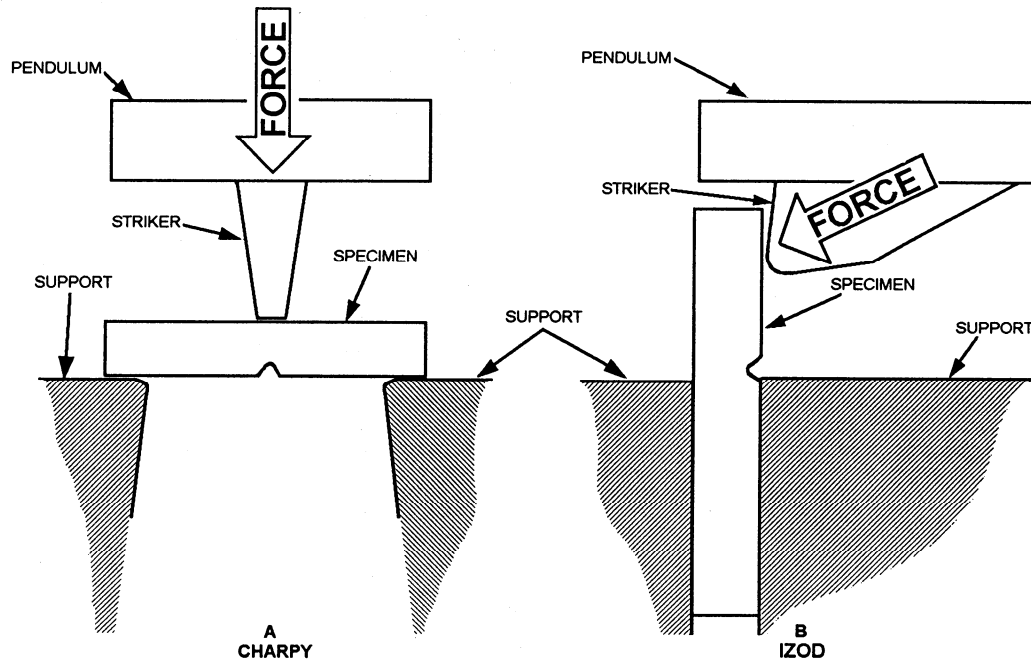


Figure 7-67.—Performing impact test.

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

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

Fillet-Welded Joint Test

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

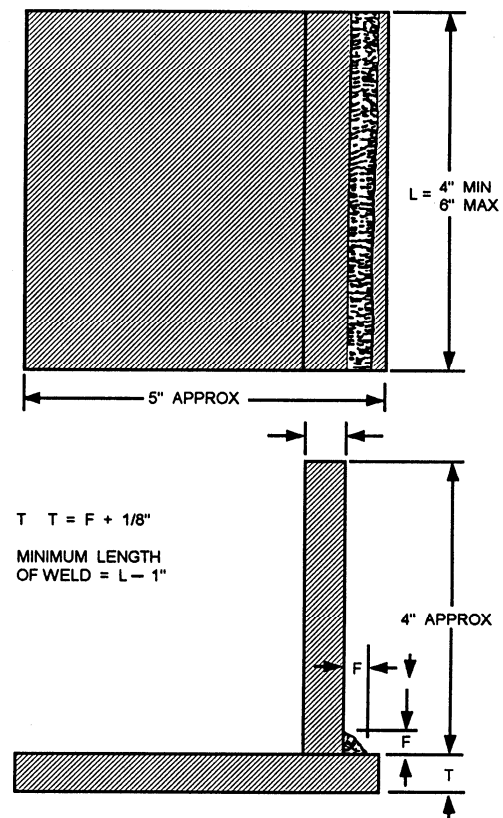


Figure 7-68.—Test plate for fillet weld test.

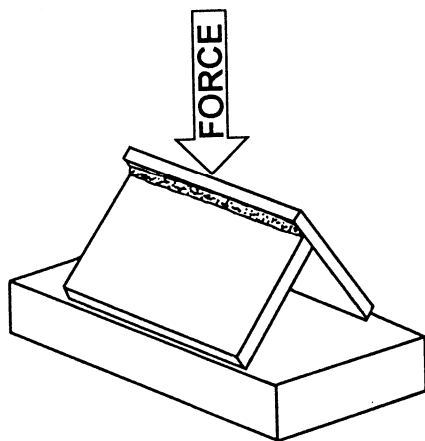


Figure 7-69.—Rupturing fillet weld test plate.

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

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

Etching Test

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

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

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

Tensile Strength Test

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

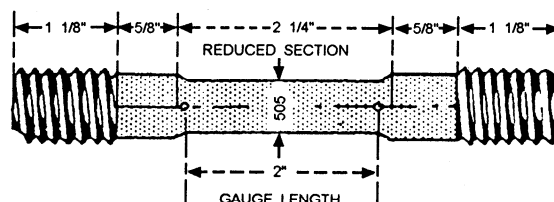


Figure 7-70.—Standard tensile test specimen.

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

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

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

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

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

SAFETY REGULATIONS

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

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

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

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

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

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

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

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

GAS SHIELDED-ARC WELDING

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

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

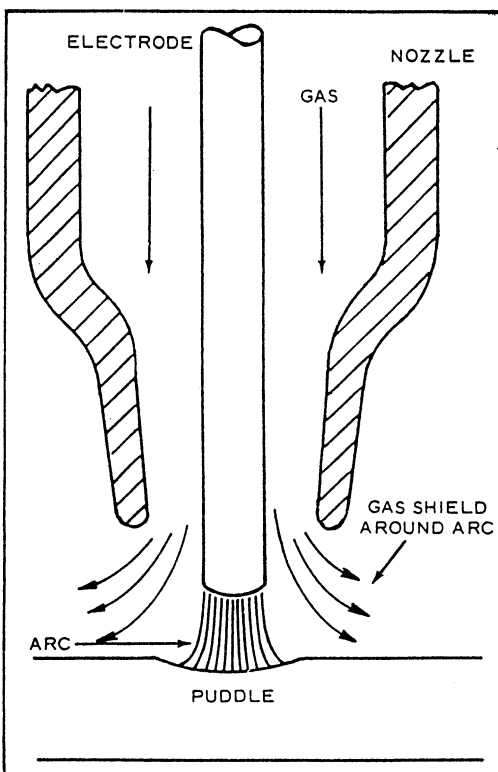


Figure 8-1.—Gas shielded-arc welding principle.

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

GAS TUNGSTEN-ARC WELDING—GTAW

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

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

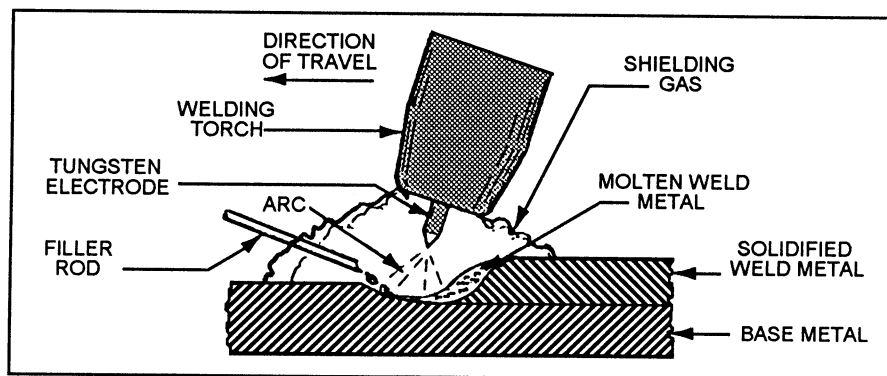


Figure 8-2.—GTA welding process.

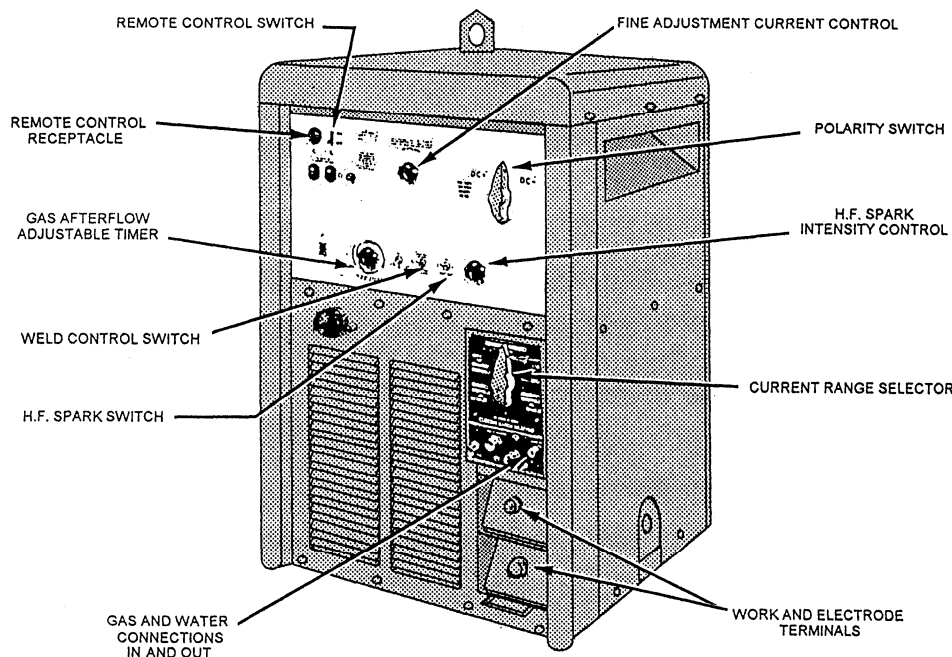


Figure 8-3.—Power supply unit specifically designed for gas tungsten-arc welding.

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

Specific advantages of gas tungsten-arc welding include the following:

- Welding can be done in all positions.
- The weld is usually equal to the base metal in composition.
- Flux is not used; therefore, finished welds do not require cleaning of corrosive residue.
- Smoke or fumes are not present to obscure vision; therefore, you can easily see the welding process.
- Distortion of the base metal is minimal because the heat is concentrated in a small area.
- No splatter is produced because metal is not transferred across the arc.

GTA WELDING EQUIPMENT AND SUPPLIES

The equipment and supplies required for gas tungsten-arc welding consist of an electric power unit, shielding gas, a pressure-reducing regulator and flowmeter, an electrode holder (commonly called a torch), nonconsumable tungsten electrodes, filler rods, a supply of cooling water (when required), and personal protective gear.

Electric Power Unit

Most welding power sources can provide the current needed for GTA welding. The common welding machines, whether alternating current (ac) or direct current (dc), have their advantages in certain welding applications; however, they can be cumbersome and their hose and cable connections can create difficulties. Because of this, specially designed machines with all the necessary controls are available for gas tungsten-arc welding (fig. 8-3).

GTA power units are equipped with solenoid valves that turn the flow of shielding gas and cooling water on and off. They are also equipped with a hand- or foot-operated remote-control switch that turns the water and gas on and off. Some of these remote-control devices

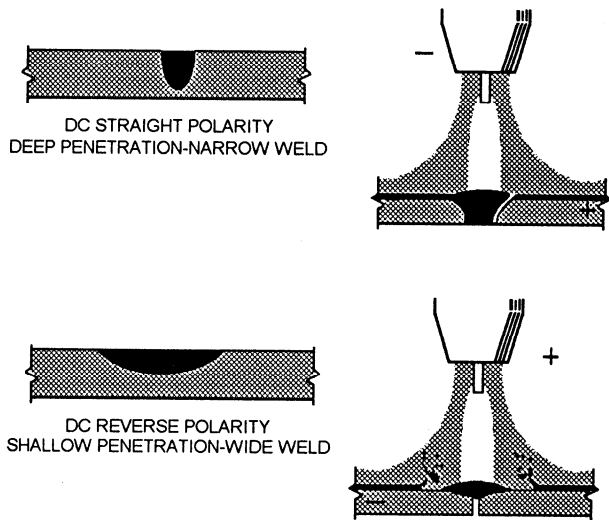


Figure 8-4.—Effects of polarity on the weld.

also turn the main welding current on and off at the same time. This not only allows the operator to start and stop without leaving the work but also to adjust the current while welding.

Most of these welding machines can produce both ac and dc current. The choice of ac or dc depends on the welding characteristics required.

DIRECT CURRENT.— As you learned in chapter 7, a direct-current welding circuit may be either straight or reverse polarity. When the machine is set on straight polarity, the electrons flow from the electrode to the plate, concentrating most of the heat on the work. With reverse polarity, the flow of electrons is from the plate to the electrode, thus causing a greater concentration of heat at the electrode. Because of this intense heat, the electrode tends to melt off; therefore, direct-current reverse polarity (DCRP) requires a larger diameter electrode than direct-current straight polarity (DCSP).

The effects of polarity on the weld are shown in figure 8-4. Notice that DCSP produces a narrow, deep weld. Since the heat is concentrated on the work, the welding process is more rapid and there is less distortion of the base metal. Overall, straight polarity is preferred over reverse polarity because you can achieve better welds.

DCRP forms a wide and shallow weld and is rarely used in the GTAW process. The exception to this is when it is used to weld sections of aluminum or magnesium. DCRP has excellent cleaning power that results from the

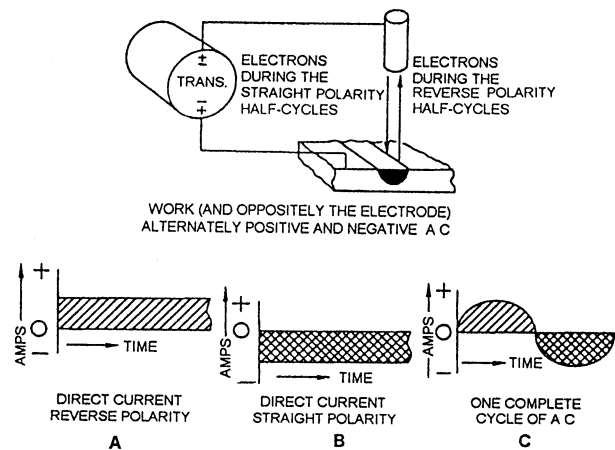


Figure 8-5.—The ac welding cycle.

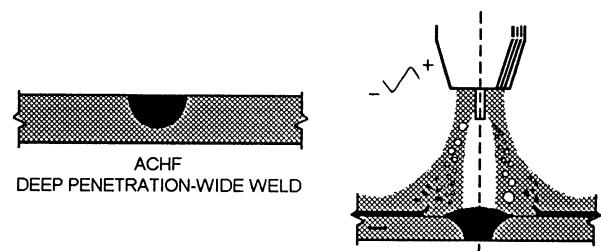


Figure 8-6.—ACHF combines the desired cleaning action of DCRP with the good penetration of DCSP.

action of positive-charged gas ions. When these gas ions strike the metal, they pierce the oxide film and form a path for the welding current to follow. This same cleaning action occurs in the reverse polarity half of an alternating-current welding cycle.

ALTERNATING CURRENT.— As shown in figure 8-5, ac welding is actually a combination of DCSP and DCRP; however, the electrical characteristics of the oxides on the metal often prevent the current from flowing smoothly in the reverse polarity half of the cycle. This partial or complete stoppage of current flow (*rectification*) causes the arc to be unstable and sometimes go out. Ac welding machines were developed with a high-frequency current flow unit to prevent this rectification. The high-frequency current pierces the oxide film and forms a path for the welding current to follow. The effects of alternating current high-frequency (ACHF) are shown in figure 8-6. Notice that ACHF offers both the advantages of DCRP and DCSP. ACHF is excellent for welding aluminum.

Table 8-1.—Current Selection Guide for GTA Welding of Common Metals

Material	Alternating Current With High-Frequency Stabilization	With High-Frequency Starting Current	
		Straight Polarity	Reverse Polarity
Aluminum-up to 3/32 inch thick	1	2	N.R.
Aluminum-over 3/32 inch thick	1	N.R.	N.R.
Aluminum castings	1	N.R.	N.R.
Brass alloys	2	1	N.R.
Silcon copper	N.R.	1	N.R.
Monel	2	1	N.R.
Stainless steel	2	1	N.R.
Hard-surfacing alloys	2	1	N.R.
Key: 1. Excellent Results 2. Good Results N.R. Not Recommended			

You can use table 8-1 as a guide for selecting the current for welding some of the more common metals. For more specific information, refer to the operator's manual for the specific machine you are using.

Torches

GTA welding torches are designed to conduct both welding current and inert gas to the weld zone. The torches can be either air or water cooled, depending on the welding current. Air-cooled torches are used for welding light-gauge materials at relatively low-current settings. Water-cooled torches are recommended for currents above 200 amperes. A sectional view of a GTA water-cooled torch is shown in figure 8-7. When you are using this type of torch, a circulating stream of water flows around the torch to keep it from overheating.

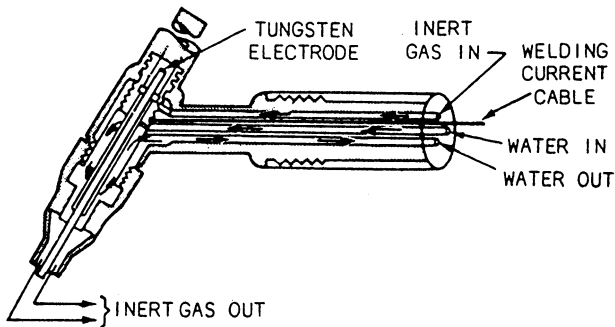


Figure 8-7.—GTA water-cooled torch.

NOTE: To avoid torch overheating caused by clogging and flow restrictions, you must keep the water clean.

The GTA welding torch carries the welding current and directs the gas to the weld area. The torch must have

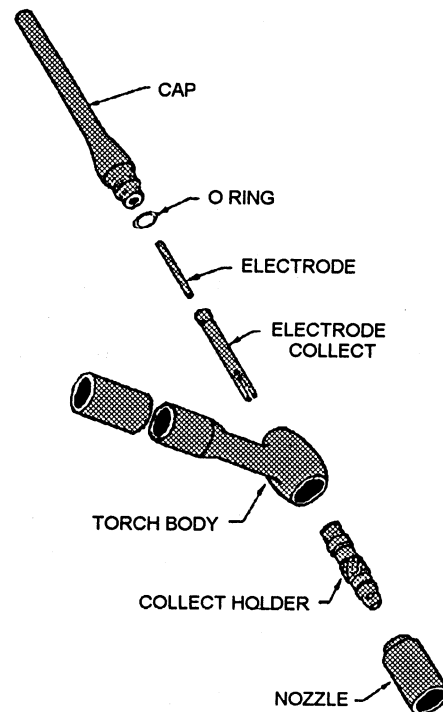


Figure 8-8.—GTA torch parts.

Table 8-2.—Approximate Cup Size for GTA Welding

TUNGSTEN ELECTRODE diameter (inches)	CUP ORIFICE diameter (inches)
1/16	1/4-3/8
3/32	3/8-7/16
1/8	7/16-1/2
3/16	1/2-3/4

Table 8-3.—Approximate Current Ranges for Tungsten Electrodes

Electrode Diameter Inches	Current, Amperes	
	Standard Tungsten Electrodes	Thoriated Tungsten Electrodes
0.04	10-60	15-80
1/16	40-120	60-150
3/32	100-160	140-250
1/8	150-210	225-350
5/32	190-275	300-450
3/16	250-350	400-550
1/4	300-490	500-800
5/16	450-600	

the proper insulation for the maximum current ranges to ensure 'operational safety. Current is transmitted from the weld-rig machine through the power cable to a collet holding the tungsten electrode. A variety of collet sizes are available, depending on the diameter of the electrode. Figure 8-8 shows the various parts of a typical GTA torch.

Gas is fed to the welding zone through the torch nozzle that consists of a ceramic cup. Nozzles also are made of steel (chrome plated), plastic, and glass (Pyrex) materials. These nozzles (gas cups) vary in size, depending upon the type and size of torch and the diameter of the electrode. See table 8-2 for sizes.

Electrodes

The electrode should extend beyond the end of the gas cup a distance equal to its diameter for butt welding and slightly further for fillet welding. Selecting the right size electrode for each job is important to prevent electrode damage and poor welds caused by too high or too low a current. Excessive current causes tungsten particles to transfer to the weld, while not enough current allows the arc to wander emetically over the end of the electrode.

The diameter of the electrode selected for GTA welding is governed by the amount of welding current used. Remember: DCRP requires larger electrodes than DCSP. Recommended electrode sizes for various ranges of welding current are shown in table 8-3. These current ranges are broad. You should refer to the manufacturer's recommendations for specific current ranges and electrode sizes based on the type of material you are welding.

Basic diameters of nonconsumable electrodes are .040, 1/16, 3/32, and 1/8 of an inch. They are either pure tungsten or alloyed tungsten. The alloyed electrodes are of three types: 1% thorium alloy, 2% thorium alloy, and zirconium alloy. Pure tungsten is routinely used with ac welding and is sufficient for most GTA welding operations. The thoriated types are normally used for DCSP welding. These electrodes give slightly better penetration and arc-starting characteristics over a wider range of current settings. The zirconium alloy is excellent for ac welding and has high resistance to contamination. The electrodes alloyed with thorium and zirconium are primarily used for critical weldments in the aircraft and missile industries.

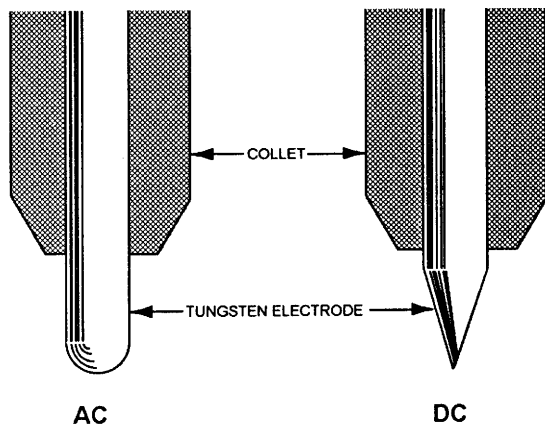


Figure 8-9.—Tungsten electrode shapes for ac and dc welding.

Tungsten electrodes are usually color-coded at one end. A green color indicates that the rod is pure tungsten; yellow indicates a 1-percent thoriated tungsten rod; red indicates a 2-percent thoriated tungsten rod; and brown indicates that the rod is alloyed with zirconium.

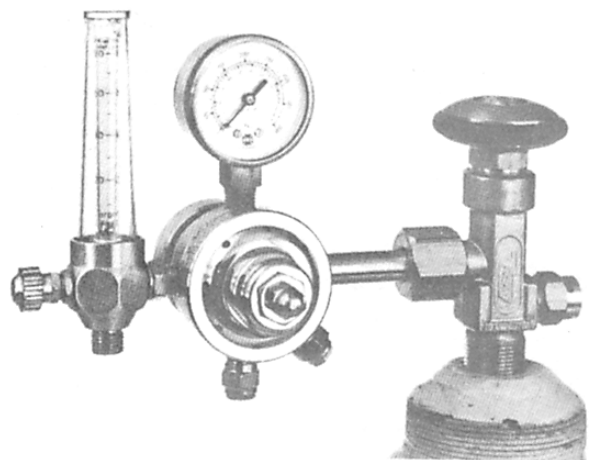
To produce good quality welds with the GTA process, you must shape the electrode properly. The general practice is to use a pointed electrode with dc welding and a spherical end with ac welding (fig. 8-9).

Shielding Gas

Shielding gas for GTA welding can be argon, helium, or a mixture of argon and helium. Argon is by far the most popular. When compared to helium, argon has greater cleaning action and provides a more stable arc. Argon is heavier than air; therefore, it provides a blanket over the weld that protects it from contaminants. Helium, being lighter than air, requires a higher gas flow than argon and is therefore more expensive to use. However, as a shielding gas, helium - allows greater penetration and faster welding speeds because the arc is hotter in the helium atmosphere than in the argon atmosphere. The opposite is true for GMA welding; therefore, a mixture of argon and helium is sometimes used in welding metals that require a higher heat input. Table 8-4 lists a selection of shielding gases recommended for various metals for both the GTA and GMA welding processes. Notice that for most GTA welding operations, you use pure argon.

Regulators

The primary difference between the regulators used for oxyfuel welding and for GTA/GMA welding is that the working pressure on the oxyfuel regulators is shown in pounds per square inch (psi) while the regulators used



127.286

Figure 8-10.—Combination regulator and flowmeter.

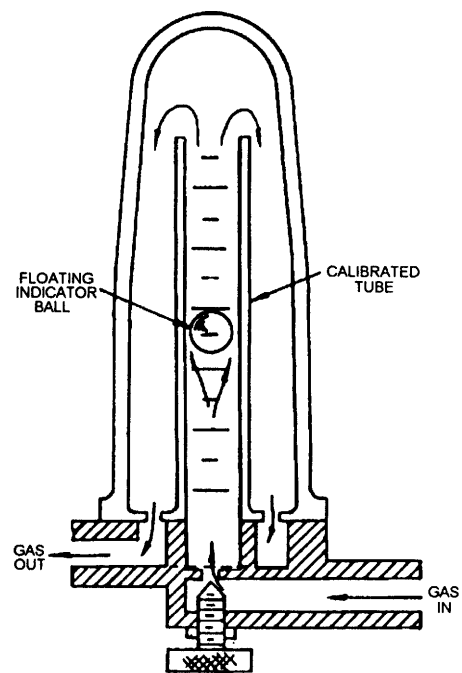


Figure 8-11.—Cross section of flowmeter.

for GMA/GTA show the flow of shielding gas in cubic feet per hour (cfh) or liters per minute (lpm). Regulators used for GMA/GTA welding have a flowmeter instead of a working pressure gauge along with the cylinder pressure gauge. See figure 8-10.

The flowmeter consists of a plastic or glass tube that contains a loosely fitting ball. As the gas flows up the tube, it passes around the ball and lifts it up. The more

Table 8-4.—Selection of Shielding Gases for Various GMAW and GTAW Applications

METALS	ARGON	HELIUM	CO ₂	O ₂	H ₂	N ₂	METHOD		POLARITY
							(GTAW)	(GMAW)	
Aluminum Alloys	100							*	DCRP
	100						*		ACHF
		100					*		DCSP
	25	75						*	
Aluminum Bronze	100						*	*	DCSP
Copper	25	75					*	*	DCSP
	100							*	
		100					*		
	95					5			
Magnesium	100							*	DCRP
	100						*		ACHF
Nickel	100						*	*	ACHF
	20	80							
		100					*A		DCSP
Silicon Bronze	100						*	*	ACHF
	100							*	
Steel mild	100						*		DCSP
	75		25					*	DCRP
		100					*A		
			100					*	
	98			2				*	
Low alloy	97			3				*	DCRP
	95			5				*	
	80				20				
	80		20						
Stainless	99			1				*	DCRP
	95			5				*	DCSP
	80				20		*		
	100						*		
		100					*A		
Titanium	100							*	DCSP
	100						*		
		100					*A		
Dissimilar Metals Backup Gas	100						*		DCSP
					5	80			

gas that moves up the tube, the higher the ball is lifted. Figure 8-11 shows a cross section of the flowmeter.

The shielding gas regulator has a constant outlet pressure to the flowmeter of about 50 psig. This is important because the flowmeter scales are accurate only if the gas entering them is at that approximate

pressure. If you use higher inlet pressures, the gas flow rate will be higher than the actual reading. The reverse is true if the inlet pressure is lower than 50 psig; therefore, it is important to use accurately adjusted regulators. With an accurate flowmeter, these regulators can deliver inert gas flows up to 60 cfh. You should read the scale by aligning the top of the ball with the cfh desired.

Table 8-5.—Suggested Inert Gas Flow Rates for Various Metals

METAL		GAS FLOW CU. FT./HR. (CFH)		
KIND	THICKNESS	ARGON	HELIUM	*CO ₂
Steel	.035-3/32	8-10	20-30	8-10
Cast Iron	1/4	16	40	---
Stainless Steel	1/16-1/8	11	30	---
Stainless Steel	3/16-1/4	13	32	---
Copper	1/16-1/4	15	38	---
Magnesium	1/16-1/8	10	25	---
* Pure CO ₂ is currently used exclusively on steel.				

To obtain an accurate reading, you must mount the meter in a vertical position. Any slant will create an off-center gas flow and result in an inaccurate reading. Also, because gas densities vary, you should use different flowmeters for different gases.

The flow of gas necessary for good GTA welding depends primarily on the thickness of the material. Other factors include the following: welding current, size of nozzle, joint design, speed of welding, and a draft-free area in the location the welding is done. This last factor can affect gas coverage and use considerably. Table 8-5 shows the approximate gas flow rates for various types of metals.

Filler Rods

Normally you do not require filler metal when GTA welding light-gauge materials since they tend to flow together easily. Thick material and thin material that needs reinforcing should be welded using a filler metal.

Special filler rods are available for GTA welding; therefore, you should not use welding rods designed for oxyfuel welding because they can contaminate the tungsten electrode. You should use filler rods that have the same composition as the base metal; for example, use mild steel rods to weld low-carbon steel and aluminum rods for welding aluminum. Additionally, there are many different compositions of the same metal; therefore, you should select a filler metal of the same composition as the metal you are welding.

Personal Protective Equipment

A welding hood like the one used in shielded metal-arc welding should be used for gas tungsten-arc

welding. The correct shade of lens depends on the intensity of the arc. Chapter 3 provides a chart of recommended lens shades based on the current setting of the machine. For normal GTA welding at current ranges of 76 to 200 amperes, a shade No. 10 lens is satisfactory. Eye fatigue indicates you should use a different shade of lens or there is leakage around the protective filter glass.

In addition to the welding hood, protective clothing, such as gloves and an apron, should be worn. Bare skin should never be exposed to the rays of the welding arc because painful burns may result.

GTA WELDING PREPARATION

Although it can produce outstanding results, GTA welding can be expensive. The equipment, electrodes, and shielding gas are costly and the material you weld is usually much more expensive than the material welded by other welding processes. To avoid costly mistakes, you should take the time to prepare for each welding operation fully. Preparation is the key to producing quality weldments.

Specific information on the different manufacturers of GTA welding equipment is not provided in this training manual. You should read the manufacturer's instructional pamphlets for specific information on your machine. The following suggestions are considered general and you can apply them to any GTA welding operation:

- Prepare the joint according to the welding procedure you are performing. Refer to chapter 3 of this training manual for specific information about joint preparation.

- Clean the metal of all oxidation, scale, oil, dirt, or other foreign matter. Regardless of the type of joint used, proper cleaning of the metal is essential. For best results, use a stainless steel wire brush.
- Check all electrical circuit connections to make sure they are properly connected and all fittings are tight.
- Be sure the torch is the right type and capacity for the current at which most of the welding will be done. Some manufacturers offer different torches for different ranges of welding current.
- Check the size, appearance, and position of the tungsten electrode in the torch. Ensure that the electrode diameter and nozzle size meet the manufacturer's recommendations. The tip should be properly shaped as discussed earlier (refer to figure 8-9). The electrode should extend beyond the end of the gas cup a distance ranging from 1/8 to 3/16 of an inch for butt welding and 1/4 to 3/8 of an inch for fillet welding. Check the electrode for positioning and good electrical contact. The electrode should be clean and silvery. A dirty tungsten electrode can usually be cleaned satisfactorily with a fine emery cloth. If severely contaminated, the electrode should be replaced or the tip broken off and dressed on a grinding wheel. A contaminated tungsten electrode and a good tungsten electrode are shown in figure 8-12.
- Check the ground cable connections to the workpiece. The connections should be periodically checked after welding begins because they tend to work loose. When this happens, the welding current varies.
- Set the machine for the correct welding amperage. (Follow manufacturer's recommendations.)
- Open the cylinder valve and adjust the gas flow. Before welding, check the connections on the gas supply for leaks with soapy water.
- If using a water-cooled torch, turn on the water. Be sure the water pressure is not higher than recommended by the torch manufacturer.

GTA WELDING PROCEDURES

As we discussed in chapter 3, the detailed methods and practices used to prepare a particular weldment are called the *welding procedure*. We also said that the

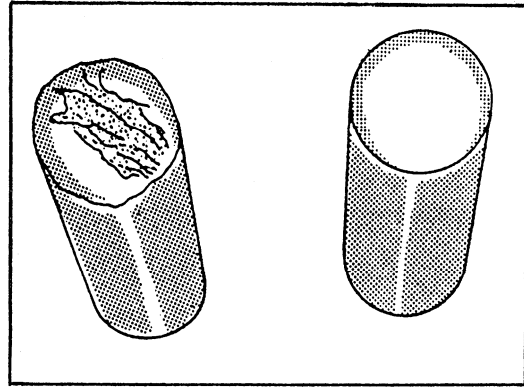


Figure 8-12.—Contaminated and good tungsten electrode.

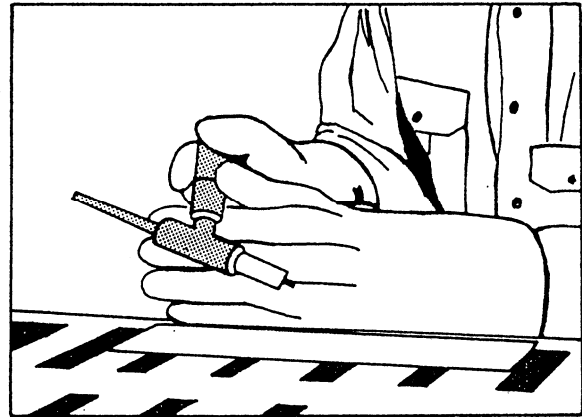


Figure 8-13.—Torch position for the starting swing to strike the arc.

procedure for a particular welded joint includes many variables. The same variables that must be considered for other welding processes also must be considered for gas shielded-arc welding. Some of the variables that you must consider include the following: type of base metal, the joint design, the welding position, the type of shielding gas, and the welding machine setting.

Starting the Arc

Before starting the arc, you should form a ball on the end of the electrode for ac welding. To do this, simply set the current to DCRP and strike an arc for a moment on a piece of carbon or a piece of copper. The ball diameter should be only slightly larger than the original diameter of the tungsten electrode.

When starting the arc with an ac high-frequency current, you do not have to bring the electrode into contact with the workpiece. To strike the arc, you must hold the torch in a horizontal position about 2 inches above the work surface, as shown in figure 8-13. Then

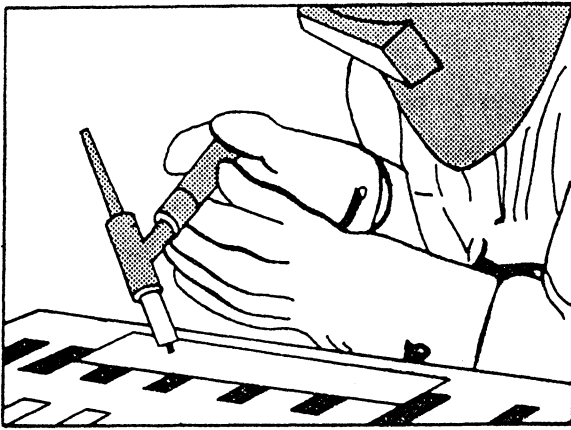


Figure 8-14.—Torch position at the end of the swing when the arc strikes.

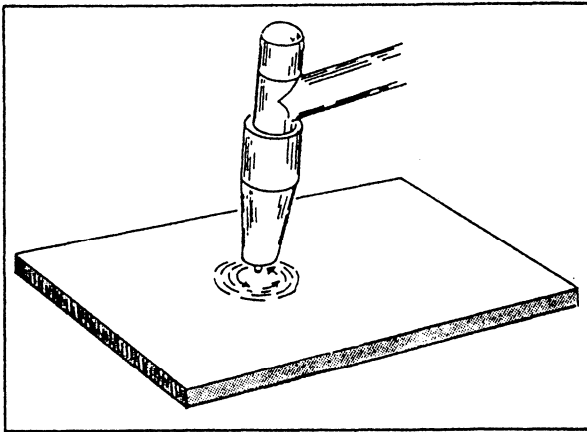


Figure 8-15.—Forming a molten puddle with a GTA torch.

rapidly swing the electrode end of the torch down to within 1/8 of an inch of the work surface. The high-frequency arc will then jump the gap between the electrode and the plate, establishing the arc. Figure 8-14 shows the torch position at the time the arc strikes.

If you are using a dc machine, hold the torch in the same position, but touch the plate to start the arc. When the arc is struck withdraw the electrode so it is about 1/8 of an inch above the plate.

To stop the arc, quickly swing the electrode back to the horizontal position. If the machine has a foot pedal, gradually decrease the current before stopping the arc.

Welded Joints

In the following paragraphs the different types of joints and the procedures used to weld them is discussed.

BUTT JOINTS.— After you strike the arc, hold the torch at a 90-degree angle to the workpiece surface, and

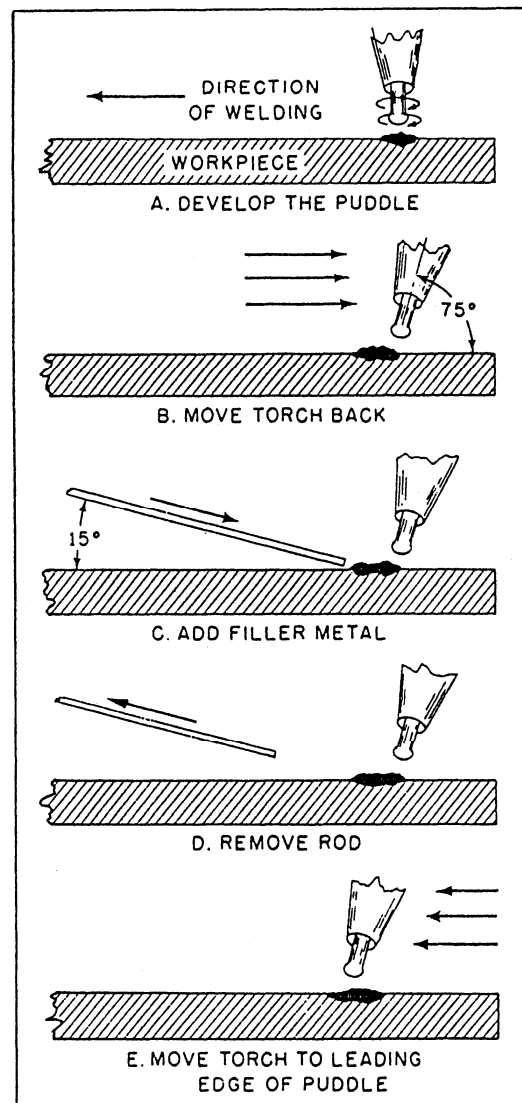


Figure 8-16.—Addition of filler metal in the flat position.

with small circular motions, as shown in figure 8-15, form a molten puddle. After you form the molten puddle, hold the torch at a 75-degree angle to the work surface and move it slowly and steadily along the joint at a speed that produces a bead of uniform width. Move the torch slowly enough to keep the puddle bright and fluid. No oscillating or other movement of the torch is necessary except the steady forward movement.

When you must use a filler metal, form the molten puddle as described previously. When the puddle becomes bright and fluid, you should move the arc to the rear of the puddle and add the filler metal by quickly touching the rod to the front edge of the puddle. Hold the rod at about a 15-degree angle from the work. Because the electrode is pointing toward the filler metal or pushing it, it is known as the *push angle*. Remove the

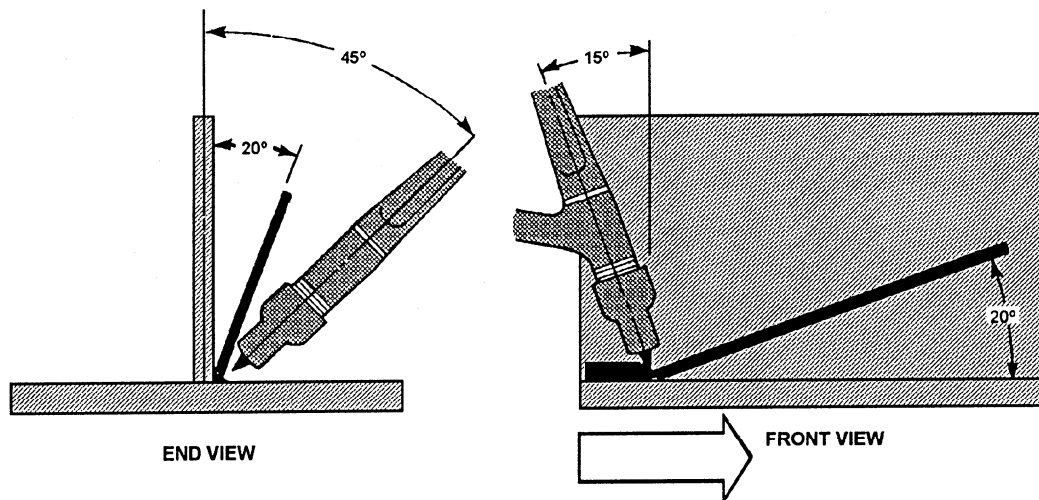


Figure 8-17.—GTA welding a tee joint.

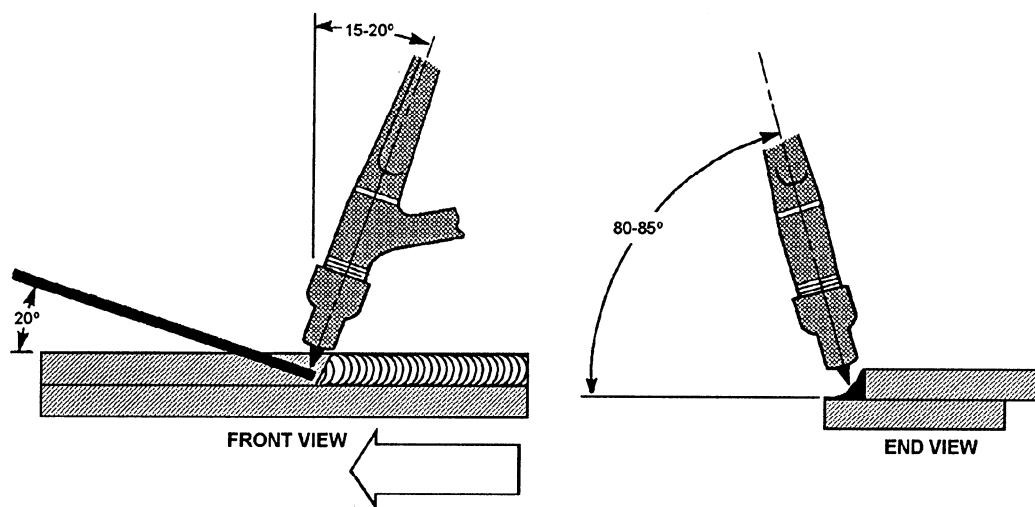


Figure 8-18.—GTA welding a lap joint.

filler rod and bring the arc back to the front edge of the puddle. When the puddle becomes bright and fluid again, you should repeat the steps as described before. Figure 8-16 shows the correct procedures for adding filler metal. Continue this sequence until the weld joint has been completed. The width and height of the weld bead is determined by the speed of travel, by the movement of the torch, and by the amount of filler metal added.

In welding practice, it is again stressed that good (GTA welding depends on following this definite procedure—form the molten pool and then feed filler rod intermittently to the leading edge of the pool as you move the torch forward. DO NOT feed the filler rod into

the arc. You should practice making single-pass butt welds until you can produce satisfactory welds.

LAP AND TEE JOINTS.— In chapter 3, we said that lap and tee joints are welded using the fillet weld. Fillet welds are slightly awkward to make using the GTA welding process because of the gas nozzle. Once you establish the arc, you should pay close attention to the molten puddle. Figures 8-17 and 8-18 show the correct torch and rod angles for the tee and lap joints.

In welding a tee or lap joint, the puddle forms a V-shape. The center of the V is called a *notch*, and the speed at which you fill the notch governs how fast you should move the torch. Do NOT get ahead of the notch. If you do, the joint will have insufficient fusion and penetration. As you weld along the joint, dip the rod in

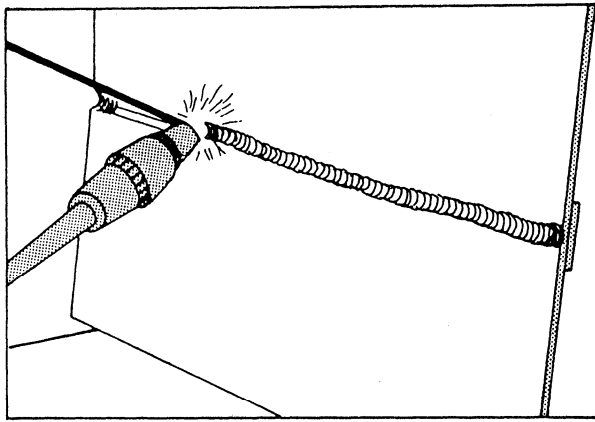


Figure 8-19.—GTA welding in the horizontal position.

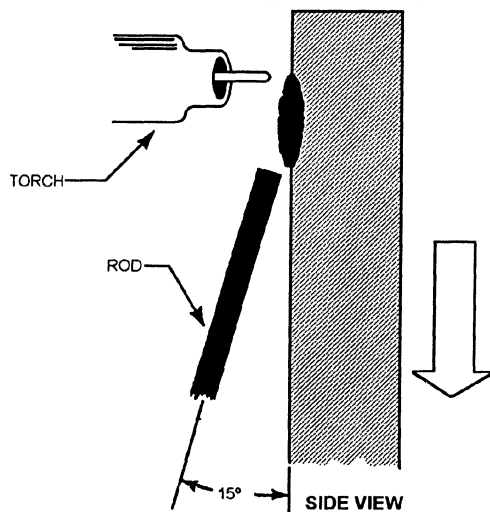


Figure 8-20.—GTA welding vertical downward.

and out of the puddle about every 1/4 of an inch of travel. If you add the filler rod to the molten puddle at just the right time uniform welds result every time.

Out-of-Position Welding

Rules for quality welding in the flat position also must be followed for out-of-position GTA welding. Cleanliness, good joint fit-up, preheat, sufficient shielding gas, and correct welding current are important. In addition, you should not use high welding current or deposit large weld beads. Direct the arc so there is no overheating at anyone area that could cause sagging or undercutting. The adding of filler metal, bead size, and sequence must be done correctly to ensure complete fusion between passes.

HORIZONTAL WELDING.— When welding in the horizontal position, start the arc on the edge of the

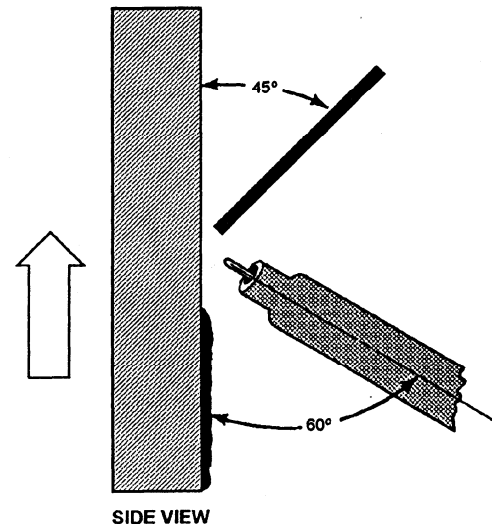


Figure 8-21.—GTA welding vertical upward.

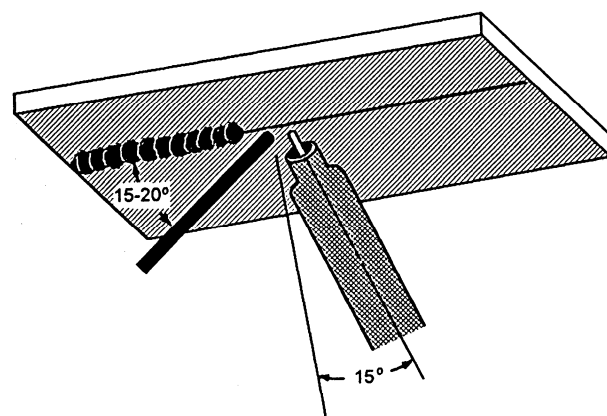


Figure 8-22.—GTA welding overhead.

joint. Then hold the torch at a work angle of 15 degrees and a push angle of 15 degrees. After you establish the puddle, dip the rod into the front edge of the puddle on the high side as you move the torch along the joint (fig. 8-19). Maintain an arc length as close as possible to the diameter of the electrode. Correct arc length coupled with the correct speed of travel helps prevent undercutting and permits complete penetration.

VERTICAL WELDING.— When welding thin material with the GTA welding process, you should weld from the top, moving downward (fig. 8-20). This helps you produce an adequate weld without burning through the metal. Filler material is not normally needed for welding downward.

On heavier materials, you should weld from the bottom, upwards (fig. 8-21). This enables you to achieve adequate penetration. When welding upward, you normally need to use a filler rod.

OVERHEAD WELDING.— When GTA welding in the overhead position, you should lower the welding current by 5 to 10 percent of what normally is used for flat welding. This reduced welding current enables you to maintain better control of the welding puddle. Conversely, you need a higher flow of shielding gas. Hold the torch and the rod as you do for flat welding (fig. 8-22). You should try to maintain a small weld puddle to avoid the effects of gravity. Most inexperienced welders find overhead welding awkward; therefore, try to get in as comfortable and relaxed a position as possible when welding. This helps you to maintain steady, even torch and filler rod manipulation.

GTA WELDING COMMON METALS

The actual welding technique for gas tungsten-arc welding common metals is virtually the same; however, each of the metals that we discuss has its own unique welding characteristics. In this section we discuss some of those characteristics. It is not the scope of this training manual to provide you with an in depth study of the welding procedures required to weld all types of metals. This chapter is merely an introduction to gas shielded-arc welding. For more information, refer to the manufacturer's literature for the specific welding equipment you use or any of the references listed in this book.

Aluminum

Steelworkers use the gas tungsten-arc welding procedure more for aluminum than for any other metal. Aluminum is available in a variety of compositions. Series 1000, 3000, and 5000 aluminum alloys are considered nonheat-treatable and are easily weldable. The heat-treatable alloys in the series 2000, 6000, and 7000 also can be welded; however, higher welding temperatures and speed are needed.

You can weld aluminum in all positions, but better welds are normally produced in the flat position. You should also use copper backup blocks whenever possible, especially on thin material. For best results use ACHF current and argon for shielding gas.

Stainless Steel

In GTA welding of stainless steel, the welding techniques used are similar to those used with aluminum. The major differences are in the selection of the welding current and the type of tungsten electrode used. To get the best results in welding stainless steel, you should use DCSP welding current; however, ACHF can be used. The forehand welding technique should be used.

The amperage settings for GTA welding stainless steel are higher than for aluminum. The amperage used for different thicknesses of stainless should be according to the recommended settings that you can find in the manufacturer's technical manual or the information pamphlets provided with the equipment.

Copper and Its Alloys

Pure copper is easily welded; however, as with any of the other metals we have discussed, it must be thoroughly cleaned before to welding. The GTA weldability of each copper-alloy group depends largely upon the alloying elements. Copper-silicon and copper-nickel alloys are weldable using the GTA process. Copper-zinc, copper-tin, and copper-lead alloys are difficult or impossible to weld by the GTA process. Plates up to 1/4 of an inch thick are generally prepared with a square edge. The forehand welding technique with DCSP is recommended for materials thicker than 0.050 of an inch. On lighter material, ACHF also can be used.

Cast Iron

You can make sound welds using the GTA welding process in three principal grades of cast iron: gray, white, and malleable. Cast-iron parts must always be preheated before to welding. Gray cast iron should be preheated to a temperature ranging between 500°F to 1250°F. The required temperature depends on the size and shape of the workpiece.

In either GTA or GMA welding, you should allow the workpiece to cool slowly after welding. You can accomplish this by covering the workpiece in a bed of lime or ashes. This slow cooling prevents cracking and residual stresses.

Magnesium

The welding characteristics of magnesium are comparable to those of aluminum. Both have high-heat conductivity, a low-melting point, high-thermal expansion, and both oxidize rapidly. Both DCRP and ac provide excellent cleaning action to the weld metal. DCRP can be used with helium gas to produce wide weld deposits, high heat, and shallow penetration. ACHF with helium, argon, or a mixture of the gases can be used to join metals ranging from 0.20 to over 0.25 of an inch. DCSP with helium produces deep penetration but no surface cleaning.

Most satisfactory results on magnesium are obtained by using the electrode in as nearly a vertical

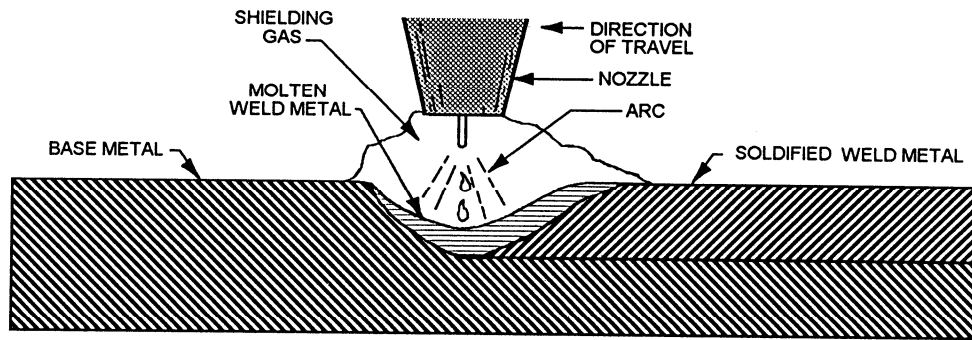


Figure 8-23.—GMA welding process.

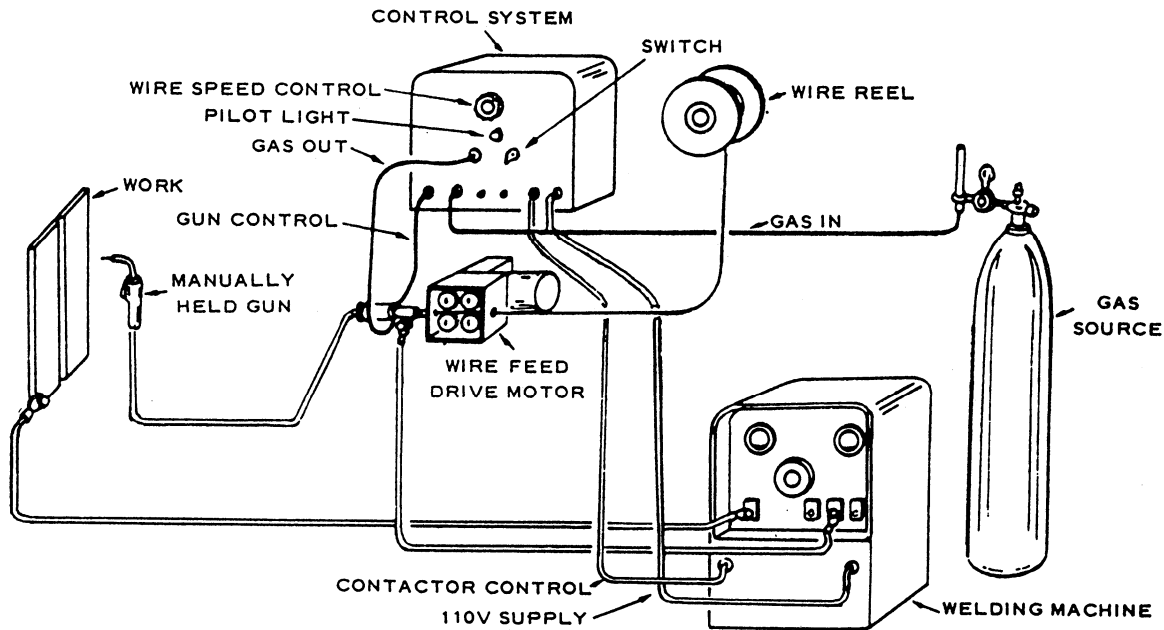


Figure 8-24.—Diagram of GMA welding equipment.

position as possible. The electrode is advanced along the line of weld, using the forehand technique.

CAUTION

Always be sure there is good ventilation when welding. The fumes from some of these metals are highly toxic; therefore, a good ventilating system is essential.

GAS METAL-ARC WELDING-GMAW

The gas metal-arc welding process (GMAW), often called *MIG*, has revolutionized arc welding. In this process, a consumable electrode (in the form of wire) is fed from a spool through the torch (welding gun) at a

preset controlled speed. As the wire passes through the contact tube of the gun, it picks up the welding current. The consumable wire electrode serves two functions: it maintains the arc and provides filler metal to the joint. The method of delivery of the filler metal allows GMAW welding to be basically a one-handed operation which does not require the same degree of skill as GTAW. Figure 8-23 shows the basic principle of gas metal-arc welding.

An important factor in the GMA welding process is the high rate at which metal can be deposited. This high rate of metal deposition and high speed of welding results in minimum distortion and a narrow heat-affected zone. When you are deciding whether to use GTA or GMA welding, the thickness of the material should

be a deciding factor. GMAW is often chosen for welding thicker material.

Like GTA welding, gas metal-arc welding also uses a shielding gas to protect the weld zone during welding. The inert gas is fed through the gun into the weld zone and prevents atmospheric contamination.

GMAW offers many of the advantages of GTAW. Since there is no flux, GMA welds are clean and there is no slag to remove. GMAW enables you to produce sound welds in all positions quickly. Now let's take a look at the equipment you will use for GMA welding.

GMA WELDING EQUIPMENT AND SUPPLIES

Gas metal-arc welding equipment basically consists of four units: the power supply, the wire feeding mechanism, the welding gun (also referred to as the torch), and the gas supply. Figure 8-24 shows atypical GMA welding outfit.

Welding Machine

When you use a conventional type of welding machine for GMA welding, the voltage varies depending on the length of the arc. Whenever the nozzle-to-work distance changes, the arc length and the voltage changes. The only way to produce uniform welds with this type of power source is to maintain the arc length and voltage at a constant value. Besides producing nonuniform welds, this inconsistent voltage can cause the wire to burn back to the nozzle.

A *constant voltage (CV)* power source was developed to overcome the inconsistent voltage characteristics of a conventional welding machine, (See fig. 8-25). It can be either a dc rectifier or motor generator that supplies current with normal limits of 200 to 250 amperes.

The CV type power source has a nearly flat voltam-pere characteristic. This means that the machine maintains the same voltage regardless of the amount of current used. With this type of power source, you can change the wire-feed speed over a considerable range without causing the wire to burn back to the nozzle. When the wire-feed speed is set at a specific rate, a proportionate amount of current is automatically drawn. In other words, the current selection is based on the wire-feed speed. When the wire is fed faster, the current increases; when it is fed slower, the current decreases. With this type of power supply, variations in

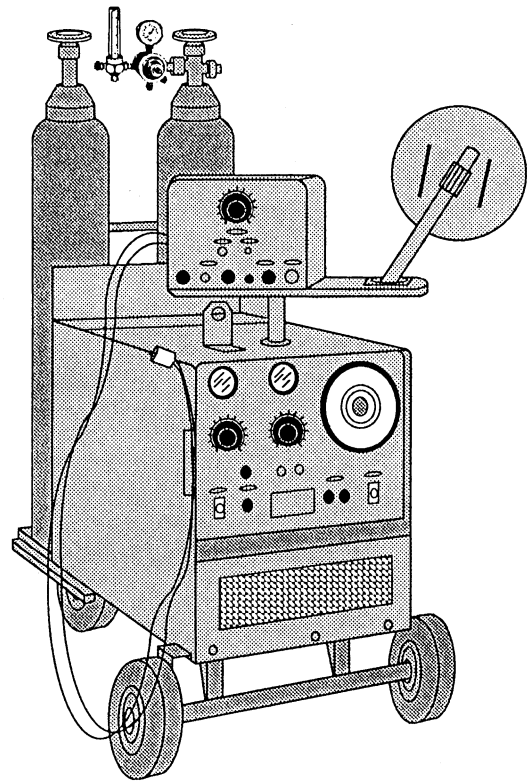


Figure 8-25.—Constant voltage (CV) power unit.

the nozzle-to-work distance will not change the arc length and burn back is virtually eliminated.

In gas metal-arc welding, direct-current reverse polarity (DCRP) is recommended. You should recall from the previous section that DCRP produces excellent cleaning action and allows for deeper penetration.

Wire Feed Drive Motor

The wire feed drive motor is used to automatically drive the electrode wire from the wire spool through the gun up to the arc point. You can vary the speed of the wire feed by adjusting the controls on the wire-feed control panel. The wire feeder can be mounted on the power unit or it can be separate from the welding machine.

Welding Gun

The function of the welding gun is to carry the electrode wire, the welding current, and the shielding gas to the arc area. The gun has a trigger switch that controls the wire feed and arc as well as the shielding gas. The welding operator directs the arc and controls the weld with the welding gun. GMA welding guns are available in many different styles, some of which are

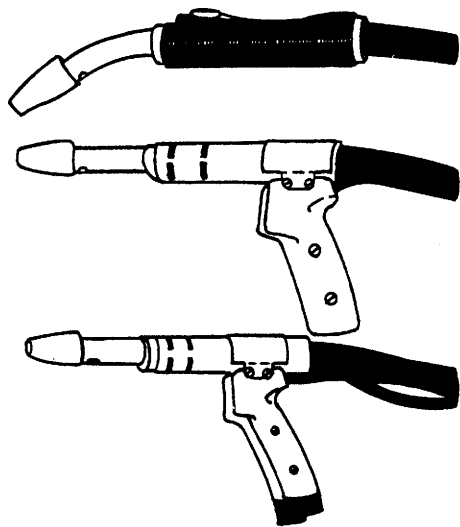


Figure 8-26.—GMA welding guns.

shown in figure 8-26. When using these guns, the wire is fed to the torch by an automatic wire feeding machine which pushes the wire through a flexible tube to the arc point.

Figure 8-27 shows another type of GMA welding gun that Steelworkers could use. This model incorporates the drive motor and a small spool of wire inside the gun. This type of gun is attached directly to the welding unit and gas supply, eliminating the need for a separate control unit and wire drive assembly.

As with the GTA welding torch, the torch nozzle must be kept clean at all times. Also, you should clean the tube through which the electrode wire passes each time the electrode reel is changed.

Shielding Gas

In gas metal-arc welding, as with gas tungsten-arc welding, the shielding gas can have a major effect on the properties of the base metal. Some of the shielding gases commonly used with the GMA process are pure argon, argon-helium, argon-oxygen, argon-carbon dioxide, and carbon dioxide. Refer to table 8-4 for a selection of shielding gases recommended for various metals for both the GMA and GTA welding processes. The smoothness of operation, weld appearance, weld quality, and welding speeds are affected in different ways with each type of metal, thickness, and gas mixture.

ARGON.— Earlier in this chapter, we said that argon provides greater cleaning action than other gases. Because it is heavier than air, argon blankets the weld from contamination. Also, when you are using argon as a shielding gas, the welding arc tends to be more stable. For this reason, argon is often used in combination with



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Figure 8-27.—GMA welding torch with wire feed motor and wire spool inside.

other gases for arc shielding. Argon reduces spatter by producing a quiet arc and reducing arc voltage that results in lower power in the arc and thus lower penetration. The combination of lower penetration and reduced spatter makes argon desirable when welding sheet metal.

Pure argon is seldom used for arc shielding except in welding such metals as aluminum, copper, nickel, and titanium. The use of pure argon to weld steel usually results in undercutting, poor bead contour, and the penetration is somewhat shallow.

ARGON-OXYGEN.— Small amounts of oxygen added to argon can produce excellent results. Normally oxygen is added in amounts of 1, 2, or 5 percent. When oxygen is added to argon, it improves the penetration pattern. It also improves the bead contour and eliminates the undercut at the edge of the weld. You use argon-oxygen mixtures in welding alloy steels, carbon steels, and stainless steel.

HELIUM.— Helium, like argon, is an inert gas. But there are few similarities between the two gases. Argon is heavier than air and helium is lighter than air. Helium has a high-voltage change as the arc length changes. When you use helium for GMA welding, more arc energy is lost in the arc itself and is not transmitted to the work. In the section on GTA welding, we said that helium produces good penetration and fast welding speeds. For GMA welding, the opposite is true. In GMA welding, helium produces a broader weld bead, but shallower penetration.

Because of its high cost, helium is primarily used for special welding tasks and for welding nonferrous metals, such as aluminum, magnesium, and copper. It is also used in combination with other gases.

CARBON DIOXIDE (CO₂).— Argon and helium gases are composed of single atoms. Carbon dioxide, on the other hand, consists of molecules. Each molecule contains one carbon atom and two oxygen atoms. At

Table 8-6.—Recommended Wire Diameters for GMA Welding Using Welding Grade CO₂ and a Wire Stick-out of 1/4 to 3/8 of an Inch

(Manual travel, single pass, flat fillet welds)					
MATERIAL THICKNESS (inches)	ELECTRODE SIZE	WELDING DCRO (arc volts)	CONDITIONS (amperes)	GAS FLOW (cfh)	TRAVEL SPEED (ipm)
0.025	0.030	15-17	30-50	15-20	15-20
.031	.030	15-17	40-60	15-20	18-22
.037	.035	15-17	65-85	15-20	35-40
.050	.035	17-19	80-100	15-20	35-40
.062	.035	17-19	90-110	20-25	30-35
.078	.035	18-20	110-130	20-25	25-30
.125	.035	19-21	140-160	20-25	20-25
.125	.045	20-23	180-200	20-25	27-32
.187	.035	19-21	140-160	20-25	14-19
.187	.045	20-23	180-200	20-25	18-22
.250	.035	19-21	140-160	20-25	10-15
.250	.045	20-23	180-200	20-25	12-18

normal temperatures carbon dioxide is essentially an inert gas; however, at high temperatures it decomposes into carbon monoxide (CO) and oxygen (O₂). Because the excess oxygen atoms can combine with carbon or iron in the weld metal, wires used with this gas must contain *deoxidizing* elements. A deoxidizing element has a great affinity for the oxygen and readily combines with it. Some of the more common deoxidizers used in wire electrodes are manganese, silicon, and aluminum.

Carbon dioxide is used primarily for the GMA welding of mild steel. Because of its low cost, CO₂ is often used in combination with other shielding gases for welding different types of metals. Direct-current reverse polarity (DCRP) is generally used with CO₂. The current setting is about 25 percent higher with CO₂ than with other shielding gases.

Carbon dioxide produces abroad, deep penetration pattern. It also produces good bead contour and there is no tendency toward undercutting. The only problem with CO₂ gas is the tendency for the arc to be violent. This can lead to spatter problems; however, for most applications this is not a problem and the advantages of CO₂ far outweigh the disadvantages.

Regulators

You should use the same type of regulator and flowmeter for gas metal-arc welding that you use for gas tungsten-arc welding. The gas flow rates vary, depending on the types and thicknesses of the material and the joint design. At times it is necessary to connect two or

more gas cylinders (manifold) together to maintain higher gas flow.

For most welding conditions, the gas flow rate is approximately 35 cubic feet per hour (cfh). This flow rate may be increased or decreased, depending upon the particular welding application. Final adjustments usually are made on a trial-and-error basis. The proper amount of gas shielding results in a rapidly crackling or sizzling arc sound. Inadequate gas shielding produces a popping arc sound and results in weld discoloration, porosity, and spatter.

Filler Wires

The composition of the filler wire used for GMA welding must match the base metal. For mild steel, you should select mild steel wire; for aluminum, you should select aluminum wire. Additionally, you should try to select electrode wire that matches the composition of the various metals you are welding. For instance, when you are welding Type 308 aluminum, you should use an ER-308L filler wire.

Wires are available in spools of several different sizes. The wire varies in diameter from .020 to 1/8 of an inch. You should select the proper diameter of wire based on the thickness of the metal you are welding as well as the position in which you are welding. Wires of 0.020, 0.030, and 0.035 of an inch are generally used for welding thin materials. You also can use them for welding low- and medium-carbon steels and low-alloy/high-strength steels of medium thicknesses. (See table 8-6.) Medium thicknesses of metals are normally welded with

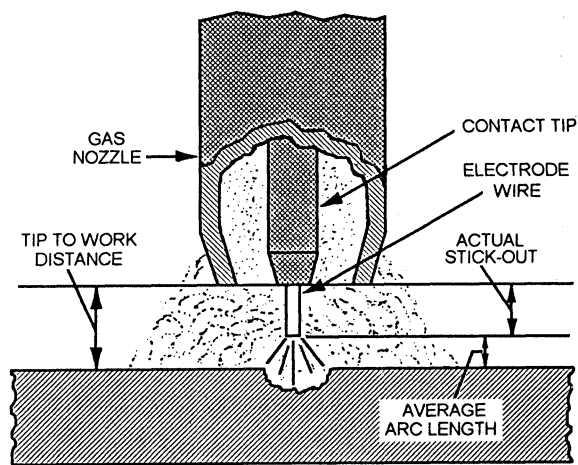


Figure 8-28.—Correct wire stick-out.

0.045-inch or 1/16-inch diameter wires. For thicker metals, larger diameter electrodes may be required.

As you learned earlier, the position of welding is a factor that must be considered. For instance, when you are welding in the vertical or overhead positions, you normally use smaller diameter electrodes.

Special attention must be given to ensure the wire is clean. Unsound welds result from the use of wire that is contaminated by oil, grease, dust, or shop fumes. You can obtain the best welding results with wire that has just been taken out of its carton. Wire should be stored in a hot locker or in a warm dry area, and should be kept covered. If welding is stopped for a long period of time, you should remove the wire and place it in its original carton to prevent contamination.

WIRE STICK-OUT.— In gas metal-arc welding, *wire stick-out* refers to the distance the wire extends from the nozzle of the gun (fig. 8-28). The correct amount of wire stick-out is important because it influences the welding current of the power source. Since the power source is self-regulating, the current output is automatically decreased when the wire stick-out increases. Conversely, when the stick-out decreases, the power source is forced to furnish more current. Too little stickout causes the wire to fuse to the nozzle tip, which decreases the tip life.

For most GMA welding, the wire stickout should measure from 3/8 to 3/4 of an inch. For smaller (micro) wires, the stick-out should be between 1/4 and 3/8 of an inch.

WIRE-FEED SPEED.— As we stated earlier, you can adjust the wire-feed drive motor to vary the

wire-feed speed. This adjustment is limited to a definite range, depending on the welding current used. (See table 8-6). The wire-feed speed is measured in inches per minute (ipm). For a specific amperage setting, a high wire-feed speed results in a short arc, whereas a low speed produces a long arc. You use higher speeds for overhead welding than with flat-position welding.

Personal Protective Equipment

As with any other welding process, SAFETY is extremely important. A welding hood like the one used in shielded metal-arc welding should be used for gas metal-arc welding. The correct shade of lens depends on the intensity of the arc. Chapter 3 provides a chart of recommended lens shades based on the current setting of the machine. Eye fatigue indicates you should use a different shade of lens or there is leakage around the protective filter glass.

In addition to the welding hood, protective clothing, such as gloves and an apron, should be worn. Bare skin should never be exposed to the rays of the welding arc because it could result in painful burns.

TYPES OF GMA WELDING

When using the GMA welding process, metal is transferred by one of three methods: spray transfer, globular transfer, or short-circuiting transfer. The type of metal transfer depends on the arc voltage, current setting, electrode wire size, and shielding gas.

Spray-Arc Welding

Spray-arc transfer is a high-current range method that produces a rapid disposition of weld metal. This type of transfer is effective for welding heavy-gauge metals because it produces deep weld penetration. The use of argon or a mixture of argon and oxygen are necessary for spray transfer. Argon produces a pinching effect on the molten tip of the electrode, permitting only small droplets to form and transfer during the welding process. Spray transfer is useful when welding aluminum; however, it is not practical for welding light-gauge metal.

Globular Transfer

Globular transfer occurs when the welding current is low. Because of the low current, only a few drops are

transferred per second, whereas many small drops are transferred with a higher current setting. In this type of transfer, the ball at the tip of the electrode grows in size before it is transferred to the workpiece. This globule tends to reconnect with the electrode and the workpiece, causing the arc to go out periodically. This results in poor arc stability, poor penetration, and excessive spatter.

Globular transfer is not effective for GMA welding. When it is used, it is generally restricted to thin materials where low heat input is desired.

Short-Circuiting Arc Transfer

Short-circuiting arc transfer is also known as *short arc*. Short arc was developed to eliminate distortion, burn-through, and spatter when welding thin-gauge metals. It can be used for welding in all positions, especially vertical and overhead where puddle control is more difficult. In most cases, it is used with current levels below 200 amperes and wire of 0.045 of an inch or less in diameter. Small wire produces weld puddles that are small and easily manageable.

The shielding gas mixture for short-arc welding is 75% carbon dioxide and 25% argon. The carbon dioxide provides for increased heat and higher speeds, while the argon controls the spatter. Straight CO₂ is now being used for short-arc welding; however, it does not produce the excellent bead contour that the argon mixture does.

GMA WELDING PREPARATION

Preparation is the key to producing quality weldments with the gas metal-arc welding process. As in GTA welding, the equipment is expensive; therefore, you should make every effort to follow the manufacturer's instruction manuals when preparing to use GMA welding equipment.

Joints

For the most part, the same joint designs recommended for other arc welding processes can be used for gas metal-arc welding (refer to chapter 3). There are some minor modifications that should be considered due to the welding characteristics of the GMA process. Since the arc in GMA welding is more penetrating and narrower than the arc for shielded metal-arc welding, groove joints can have smaller root faces and root openings. Also, since the nozzle does not have to be placed within the groove, less beveling of the plates is required.

GMA welding can actually lower material costs, since you use less weld metal in the joint.

Equipment

The following suggestions are general and can be applied to any GMA welding operation:

- Check all hose and cable connections to make sure they are in good condition and are properly connected.
- Check to see that the nozzle is clean and the correct size for the particular wire diameter used.
- Make sure that the guide tube is clean and that the wire is properly threaded through the gun.
- Determine the correct wire-feed speed and adjust the feeder control accordingly. During welding, the wire-speed rate may have to be varied to correct for too little or too much heat input.
- Make sure the shielding gas and water coolant sources are on and adjusted properly.
- Check the wire stick-out.

GMA WELDING PROCEDURES

As with any other type of welding, the GMA welding procedure consists of certain variables that you must understand and follow. Many of the variables have already been discussed. This section applies some of these variables to the actual welding procedure.

Starting the Arc

For a good arc start, the electrode must make good electrical contact with the work. For the best results, you should clean the metal of all impurities. The wire stick-out must be set correctly because as the wire stick-out increases, the arc initiation becomes increasingly difficult.

When preparing to start the arc, hold the torch at an angle between 5 and 20 degrees. Support the weight of the welding cable and gas hose across your shoulder to ensure free movement of the welding torch. Hold the torch close to, but not touching, the workpiece. Lower your helmet and squeeze the torch trigger. Squeezing the trigger starts the flow of shielding gas and energizes the welding circuit. The wire-feed motor does not energize until the wire electrode comes in contact with the workpiece. Move the torch toward the work, touching the wire electrode to the work with a sideways scratching

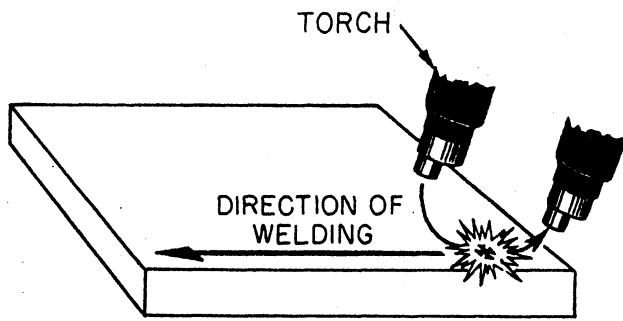


Figure 8-29.—Striking the arc (GMAW).

motion, as shown in figure 8-29. To prevent sticking, you should pull the torch back quickly, about 1/2 of an inch—the instant contact is made between the wire electrode and the workpiece. The arc strikes as soon as contact is made and the wire-feed motor feeds the wire automatically as long as the trigger is held.

A properly established arc has a soft, sizzling sound. Adjustment of the wire-feed control dial or the welding machine itself is necessary when the arc does not sound right. For example, a loud, crackling sound indicates that the arc is too short and that the wire-feed speed is too fast. You may correct this problem by moving the

wire-feed dial slightly counterclockwise. This decreases the wire-feed speed and increases the arc length. A clockwise movement of the dial has the opposite effect. With experience, you can recognize the sound of the proper length of arc to use.

To break the arc, you simply release the trigger. This breaks the welding circuit and de-energizes the wire-feed motor. Should the wire electrode stick to the work when striking the arc or during welding, release the trigger and clip the wire with a pair of side cutters.

Welding Positions

In gas metal-arc welding, the proper position of the welding torch and weldment are important. The position of the torch in relation to the plate is called the work and travel angle. Work and travel angles are shown in figure 8-30. If the parts are equal in thickness, the work angle should normally be on the center line of the joint; however, if the pieces are unequal in thickness, the torch should angle toward the thicker piece.

The travel angle refers to the angle in which welding takes place. This angle should be between 5 and 25 degrees. The travel angle may be either a push angle or a drag angle, depending on the position of the torch.

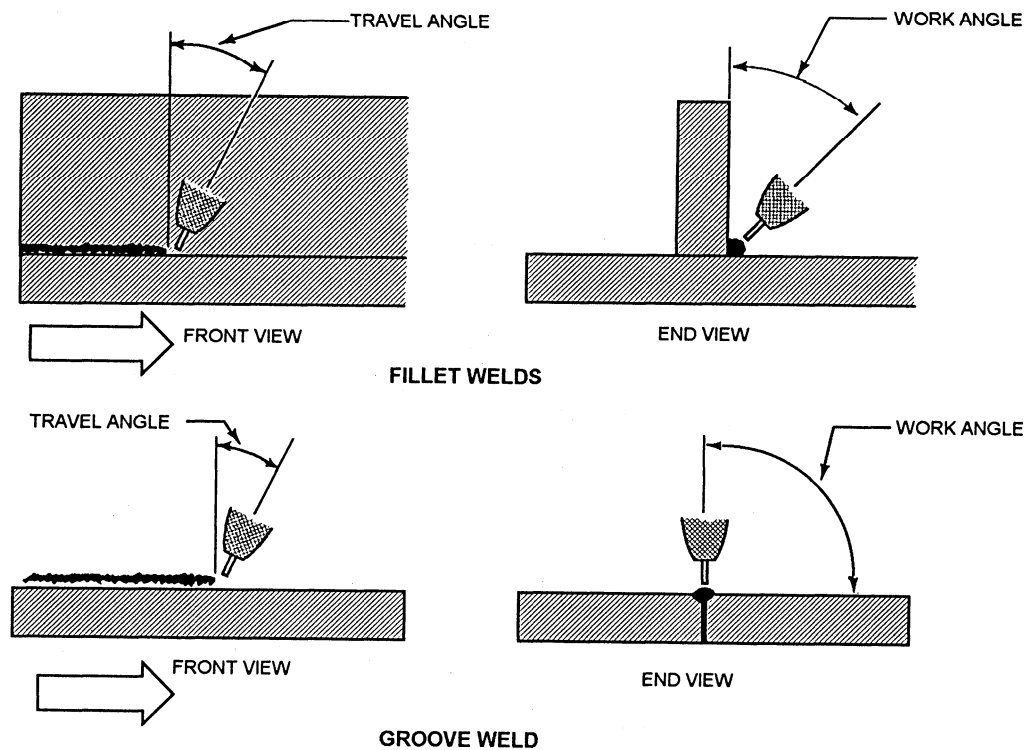


Figure 8-30.—Travel and work angle for GMA welding.

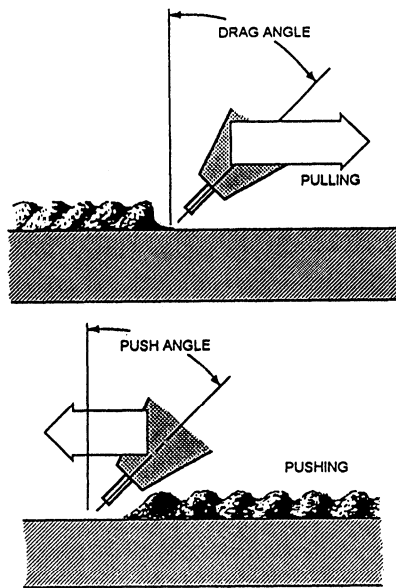


Figure 8-31.—Pulling and pushing travel angle techniques.

When the torch is ahead of the weld, it is known as pulling (or dragging) the weld. When the torch is behind the weld, it is referred to as pushing the metal (fig. 8-31).

The pulling or drag technique is for heavy-gauge metals. Usually the drag technique produces greater penetration than the pushing technique. Also, since the welder can see the weld crater more easily, better quality welds can consistently be made. The pushing technique is normally used for light-gauge metals. Welds made with this technique are less penetrating and wider because the welding speed is faster.

For the best results, you should position the weldment in the flat position. This position improves the molten metal flow, bead contour, and gives better shielding gas protection.

After you have learned to weld in the flat position, you should be able to use your acquired skill and knowledge to weld out of position. These positions include horizontal, vertical-up, vertical-down, and overhead welds. The only difference in welding out of position from the flat position is a 10-percent reduction in amperage.

When welding heavier thicknesses of metal with the GMA welding process, you should use the multipass technique (discussed in chapter 3). This is accomplished by overlapping single small beads or making larger beads, using the weaving technique. Various multipass welding sequences are shown in figure 8-32. The numbers refer to the sequences in which you make the passes.

Common Weld Defects

Once you get the feel of welding with GMA equipment, you will probably find that the techniques are less difficult to master than many of the other welding processes; however, as with any other welding process, GMA welding does have some pitfalls. To produce good quality welds, you must learn to recognize and correct possible welding defects. The following are a few of the more common defects you may encounter along with corrective actions that you can take.

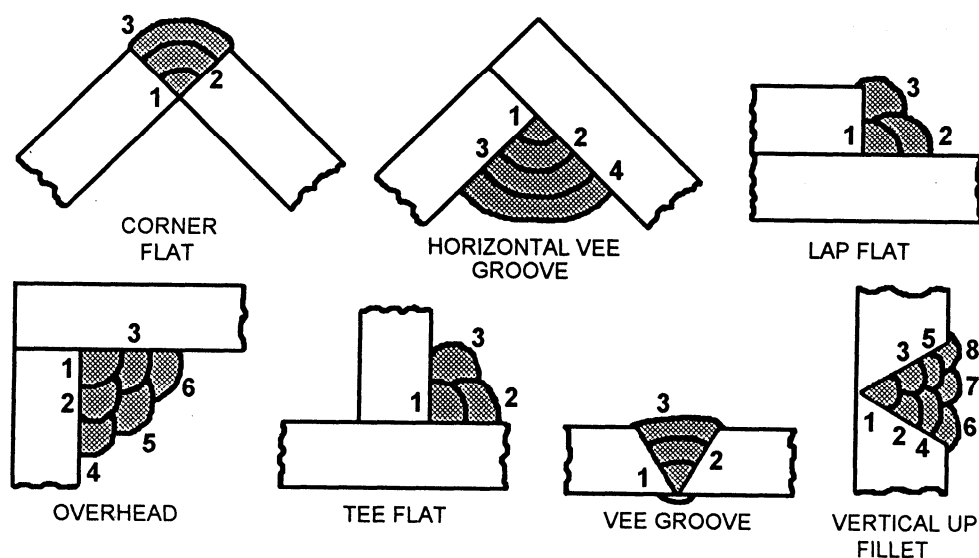


Figure 8-32.—Multipass welding.

SURFACE POROSITY.— Surface porosity usually results from atmospheric contamination. It can be caused by a clogged nozzle, shielding gas set too low or too high, or welding in a windy area. To avoid surface porosity, you should keep the nozzle clean of spatter, use the correct gas pressure, and use a protective wind shield when welding in a windy area.

CRATER POROSITY.— Crater porosity usually results from pulling the torch and gas shield away before the crater has solidified. To correct this problem, you should reduce the travel speed at the end of the joint. You also may try reducing the tip-to-work distance.

COLD LAP.— Cold laps often result when the arc does not melt the base metal sufficiently. When cold lap occurs, the molten puddle flows into an unwelded base metal. Often this results when the puddle is allowed to become too large. To correct this problem, you should keep the arc at the leading edge of the puddle. Also, reduce the size of the puddle by increasing the travel speed or reducing the wire-feed speed. You also may use a slight whip motion.

LACK OF PENETRATION.— Lack of penetration usually results from too little heat input in the weld zone. If the heat input is too low, increase the wire-feed speed to get a higher amperage. Also, you may try reducing the wire stick-out.

BURN-THROUGH.— Burn-through (too much penetration) is caused by having too much heat input in the weld zone. You can correct this problem by reducing the wire-feed speed, which, in turn lowers the welding amperage. Also you can increase the travel speed. Burn-through can also result from having an excessive amount of root opening. To correct this problem, you increase the wire stick-out and oscillate the torch slightly.

WHISKERS.— Whiskers are short pieces of electrode wire sticking through the root side of the weld joint. This is caused by pushing the wire past the leading edge of the weld puddle. To prevent this problem, you should cut off the ball on the end of the wire with side cutters before pulling the trigger. Also, reduce the travel speed and, if necessary, use a whipping motion.

GMA WELDING COMMON METALS

You can use the welding equipment and techniques for gas metal-arc welding to join all types of metals; however, as we discussed in the GTAW process, each of the metals requires a unique welding method. In this

section, we discuss some of the welding methods associated with a few of the more commonly welded metals.

Carbon Steels

The majority of welding by all methods is done on carbon steels. When you are using GMA to weld carbon steels, both the spray-arc and short-arc methods may be applied. For spray-arc welding, a mixture of 5-percent oxygen with argon is recommended. As we mentioned earlier, this mixture provides a more stable arc. Also you may use a mixture of argon and CO₂ or straight CO₂. Straight CO₂ is often used for high-speed production welding; however, with CO₂ the arc is not a true spray arc. For short-arc welding, a 25-percent CO₂ and 75-percent argon mixture is preferred.

For GMA welding of thin materials (0.035 inch to 1/8 inch), no edge preparation is needed and a root opening of 1/16 of an inch or less is recommended. For production of adequate welds on thicker material, some beveling is normally required. When welding plates 1/4 of an inch or greater in thickness, you should prepare a single or double-V groove with 50- to 60-degree included angle(s).

Aluminum

The joint design for aluminum is similar to that of steel; however, aluminum requires a narrower joint spacing and lower welding current setting.

The short-arc welding method is normally used for out-of-position welding or when welding thin materials because short-arc produces a cooler arc than the spray type arc. When welding thinner material (up to 1 inch in thickness), you should use pure argon.

The spray-arc welding method is recommended for welding thicker materials. With spray arc, more heat is produced to melt the wire and base metal. When you are welding thicker material (between 1 and 2 inches) a mixture of 90-percent argon and 10-percent helium is recommended. The helium provides more heat input and the argon provides good cleaning action.

Stainless Steel

DCRP with a 1- or 2-percent oxygen with argon mixture is recommended for most stainless steel welding. In general, you weld stainless steel with the spray-arc welding method and a pushing technique. When welding stainless steel up to 1/16 of an inch in thickness, you should use a copper backup strip. For welding thin materials in the overhead or vertical positions, the short-arc method produces better results.

APPENDIX I

GLOSSARY

ACC— Air carbon arc cutting.

ARC BLOW— The tendency for an arc to wander or whip from its normal course during arc welding.

ASME— American Society of Mechanical Engineers.

AWS— American Welding Society.

BACKFIRE— Momentary burning back of the flame into the torch tip during welding or cutting.

BACKHAND WELDING— Welding in the direction opposite the direction the gas flame is pointing.

BURR— The sharp edge remaining on metal after cutting.

CARBURIZING FLAME— Produced by burning an excess of fuel gas.

CHAMFER— Bevel angling the metal edge where welding is to take place.

COMPRESSION STRESSES— The stresses developed within a material when forces tend to compress or crush the material.

DCRP— Direct current reverse polarity.

DCSP— Direct current straight polarity.

DISTORTION— The warping of a structure.

DUCTILITY— The property that enables a material to withstand extensive permanent deformation due to tension.

ELASTICITY— The ability of a material to return to its original form after deformation.

FATIGUE— The tendency of a material to fail after repeated stressing at the same point.

FATIGUE STRENGTH— The ability of a material to resist various kinds of rapidly alternating stresses.

FERROUS— Denotes the family of metals in which iron is the major ingredient.

FLASHBACK— The flame burning in or beyond the torch mixing chamber during welding or cutting.

FLUX— A chemical used to promote fusion of metals during the welding process.

FOREHAND WELDING— Welding in the same direction as the torch flame points.

FUSION— The melting together of metals.

GMAW— Gas metal arc welding.

GTAW— Gas tungsten arc welding.

IMPACT STRENGTH— The ability of a metal to resist suddenly applied loads; measured in foot-pounds of force.

KERF— The narrow slit formed in metal as cutting progresses.

LAYOUT— The process of measuring and marking materials for cutting, bending, drilling, or welding.

MALLEABILITY— The property that enables a material to withstand permanent deformation caused by compression.

MAPP— A stabilized methyl acetylene-propadiene fuel gas. A Dow Chemical Company product.

METALLOID— A nonmetal that can combine with a metal to form an alloy.

METALLURGY— The science and technology of metals.

MIG— A term used to describe gas metal arc welding (metal inert gas).

NEUTRAL FLAME— Produced when equal amounts of oxygen and fuel gas are burned.

NORMALIZING— A heat-treating operation involving the heating of an iron-base alloy above its critical temperature range and cooling it in still air for the purpose of removing stresses.

NONFERROUS— Metals containing no iron.

OFW— Oxyfuel welding.

OXIDIZING FLAME— Produced by burning about twice as much oxygen as fuel gas.

PASS— A single progression of a welding operation along a joint or weld deposit. The result of a pass is a weld bead.

PLASTICITY— The ability of a material to permanently deform without breaking or rupturing.

POROSITY— The presence of gas pockets or voids in metal.

QUENCHING— The process of rapid cooling from an elevated temperature by contact with fluids or gases.

QUENCHING MEDIUM— The oil, water, brine, or other medium used for rapid cooling.

RSW— Resistance spot welding.

RW— Resistance welding.

SEIZE— To bind securely the end of a wire rope or strand with seizing wire.

SHEARING STRESSES— The stresses developed within a material when external forces are applied along parallel lines in opposite directions.

SMAW— Shielded metal arc welding.

SOAKING— Holding a metal at a required temperature for a specified time to obtain even temperature throughout the section.

STINGER— An electrode holder; a clamping device for holding the electrode securely in any position.

STRESS— External or internal force applied to an object.

TENSILE STRENGTH— The resistance to being pulled apart.

TENSION STRESSES— The stresses developed when a material is subjected to a pulling load.

TIG— A term used to describe gas tungsten arc welding (tungsten inert gas).

TINNING— A term applied to soldering where the metals to be soldered together are first given a coat of the soldering metal.

WELD— To join metals by heating them to a melting temperature and causing the molten metal to flow together.

WELDMENT— An assembly whose parts are joined by welding.

ULTIMATE STRENGTH— The maximum strain that a material is capable of withstanding.

APPENDIX II

REFERENCES USED TO DEVELOP THE TRAMAN

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