Chapter 1

Introduction to Types and Identification of Metal

Topics

To hear audio, click on the box.

Overview

In the Seabees, the Steelworker (SW) rating is recognized as the resident expert on the use of metal. SWs lay airfields, erect towers, assemble pontoon causeways, reinforce concrete, and erect buildings. They also use their expertise to fabricate all types of metal objects, repair metal items, and resurface worn machinery parts.

Steelworkers need to know the two basic types of metal and be able to provide initial identification. While they primarily work with the ***ferrous*** metals of iron and steel, they also need to be able to identify and become familiar with the ***nonferrous*** metals coming into more use each day.

In the civilian arena, the term “Steelworker” generally refers to those who make iron and steel in the many steel plants, while the term “Ironworker” refers to those in the construction industry who fabricate and build with iron and steel.

This chapter will present an introductory explanation of the basic types of metal and provide initial instruction on using simple tests to establish their identity. For a more in-depth presentation about the properties and uses of metal, refer to Steelworker Advanced.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Identify the basic metal types.
2. Describe identification procedures associated with basic metals.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	STEELWORKER BASIC
Introduction to Structural Steel	
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas	
Rigging	
Wire rope	
Fiber Line	
Layout and Fabrication of Sheet-Metal and Fiberglass Duct	
Welding Quality Control	
Flux Core Arc Welding-FCAW	
Gas-Metal Arc Welding-GMAW	
Gas-Tungsten Arc Welding-GTAW	
Shielded Metal Arc Welding-SMAW	
Plasma Arc Cutting Operations	
Soldering, Brazing, Braze Welding, Wearfacing	
Gas Welding	
Gas Cutting	
Introduction to Welding	
Basic Heat Treatment	
Introduction to Types and Identification of Metal	

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 BASIC METAL TYPES

Metals can initially be divided into two general classifications, and Steelworkers work with both: ferrous and nonferrous metals.

Ferrous metals are those composed primarily of iron (atomic symbol Fe) and iron alloys.

Nonferrous metals are those composed primarily of some element or elements other than iron, although nonferrous metals or alloys sometimes contain a small amount of iron as an alloying element or as an impurity.

1.1.0 Ferrous Metals

Ferrous metals include all forms of iron and iron-base alloys, with small percentages of carbon (steel, for example), and/or other elements added to achieve desirable properties. Wrought iron, cast iron, carbon steels, alloy steels, and tool steels are just a few examples. Ferrous metals are typically magnetic.

1.1.1 Iron

Iron ores are rocks and minerals from which metallic iron can be economically extracted. The ores are usually rich in iron oxides and vary in color from dark grey, bright yellow, deep purple, to rusty red. Iron ore is the raw material used to make pig iron, which is one of the main raw materials used to make steel. Ninety-eight percent of the mined iron ore is used to make steel.

Iron is produced by converting iron ore to pig iron using a blast furnace. Pig iron is the intermediate product of smelting iron ore with coke, usually with limestone as a flux. Pig iron has very high carbon content, typically 3.5–4.5%, which makes it very brittle and not useful directly as a material except for limited applications.

From pig iron, many other types of iron and steel are produced by the addition or deletion of carbon and alloys. The following briefly presents different types of iron and steel made from iron. Steelworker Advanced will present additional information about their properties.

- Pig Iron **—** comparatively weak and brittle with limited use. Approximately ninety percent is used to produce steel, although cast-iron pipe and some fittings and valves are manufactured from pig iron.
- Wrought Iron — made from pig iron with some slag mixed in during manufacture, it is almost pure iron. Wrought iron usage diminished with the increasing availability of mild steel in the late 19th century. Some items traditionally produced from wrought iron included rivets, nails, chains, railway couplings, water and steam pipes, nuts, bolts, handrails, and ornamental ironworks. Many products still described as wrought iron, such as guardrails and gates, are made of mild steel.
- Cast Iron — any iron containing greater than 2% carbon alloy. It tends to be brittle, except for ***malleable*** cast irons. Cast irons have a wide range of applications, including pipes, machine and automotive industry parts such as cylinder heads, cylinder blocks, and gearbox cases. A malleable cast iron is produced through a prolonged ***annealing*** process.
- ***Ingot*** Iron — a commercially pure iron (99.85% iron). It is easily formed, with properties practically the same as the lowest carbon steel. In iron, the carbon content is considered an impurity; in steel, the carbon content is considered an

alloying element. The primary use for ingot iron is for galvanized and enameled sheet.

1.1.2 Steel

Of all the different metals and materials that Steelworkers use, steel and steel alloys are by far the most used and therefore the most important to study.

The development of the economical ***Bessemer process*** for manufacturing steel revolutionized the American iron industry. *Figure 1-1* shows the container vessel used for the process.

With economical steel 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 and controlled amounts of alloying elements during the molten stage to produce the desired composition.

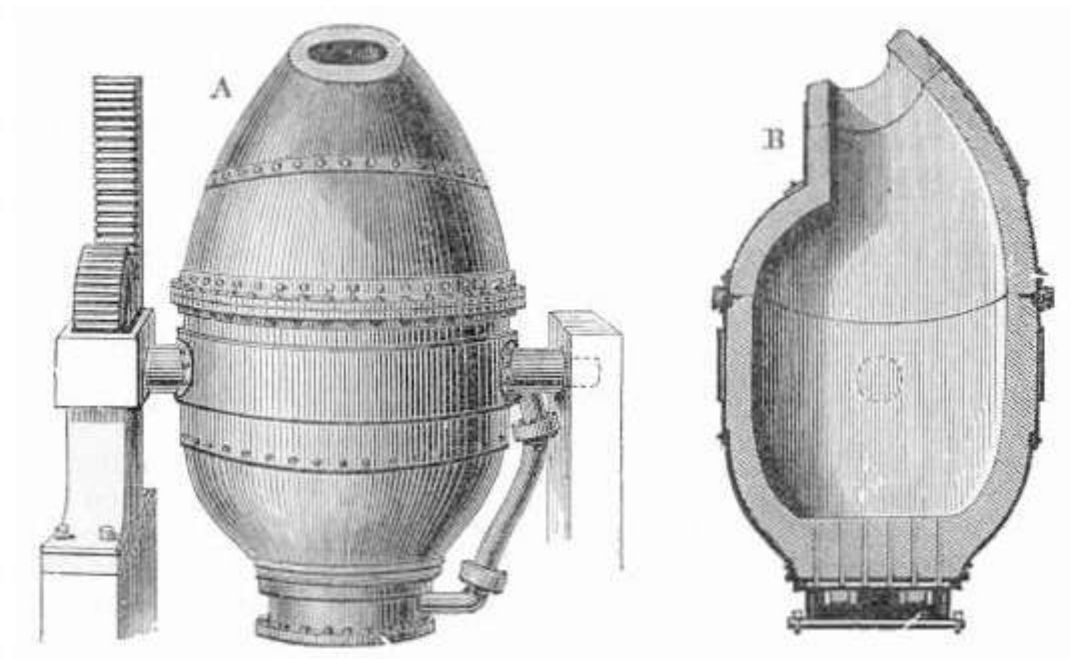

Figure 1-1 — Example of a Bessemer Converter.

The composition of a particular steel is determined by its application and the specifications developed by the following:

- American Society for Testing and Materials (ASTM)
- American Society of Mechanical Engineers (ASME)
- Society of Automotive Engineers (SAE)
- 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 —tough and ductile, easily machined, formed, and welded, but does not respond to any form of heat-treating except case hardening.

- Medium-Carbon Steel — strong and hard but cannot be welded or worked as easily as the low-carbon steels. They are used for crane hooks, axels, shafts, setscrews and so on.
- High-Carbon Steel — responds well to heat treatment and can be welded with special electrodes, but the process must include preheating and stress-relieving procedures to prevent cracks in the weld areas.
- Very High-Carbon Steel — similar to high-carbon, it responds well to heat treatment and can be welded with special electrodes, but the process must include preheating and stress-relieving procedures to prevent cracks in the weld areas. Both steels are used for dies, cutting tools, mill tools, railroad car wheels, chisels, knives, and so on.

High-strength steels are covered by American Society for Testing and Materials (ASTM) specifications.

- Low-Alloy, High-Strength, Tempered Structural Steel — special low carbon steel that contains specific, small amounts of alloying elements. 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. This type of steel is much tougher than low-carbon steels, so the shearing machines must have twice the capacity required for low-carbon steels.

Stainless steels are classified by the American Iron and Steel Institute (AISI) and classified into two general series:

- Stainless Steel 200-300 series — known as ***Austenitic*** [aw-stuh-***nit***-ik]. 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 widely used are the normally nonmagnetic chromium nickel steels.
- Stainless Steel 400 series — further subdivided according to their crystalline structure into two general groups:
    - ***Ferritic*** [fer-***rit***-ik]. Chromium — non-hardenable by heat treatment and normally used in the annealed or soft condition, they are magnetic and frequently used for decorative trim and equipment subjected to high pressures and temperatures.
    - ***Martensitic*** [mahr-tn-***zit***-ik] Chromium — readily hardened by heat treatment, they are magnetic and used where high strength, corrosion resistance, and ductility are required.

Alloy steels derive their properties primarily from the presence of some alloying element other than carbon, but alloy steels always contain traces of other elements as well. 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, and these steels can obtain better physical properties than are possible with hot-rolled carbon steels.

These alloys are used in structures where the strength of material is especially important, for example in bridge members, railroad cars, dump bodies, dozer blades, and crane booms. The following list describes some of the common alloy steels:

- Nickel Steels — used in the manufacture of aircraft parts such as propellers and airframe support members.

- Chromium Steels — used for the races and balls in antifriction bearings; highly resistant to corrosion and to scale.
- Chrome Vanadium Steel — used for crankshafts, gears, axles, and other items that require high strength; also used in the manufacture of high-quality hand tools such as wrenches and sockets.
- Tungsten Steel — expensive to produce, its use is largely restricted to the manufacture of drills, lathe tools, milling cutters, and similar cutting tools.
- Molybdenum — used in place of tungsten to make the cheaper grades of high-speed steel and in carbon molybdenum high-pressure tubing.
- Manganese Steels — use depends upon the properties desired:
  - Small amounts produce strong, free-machining steels.
  - Larger amounts produce a somewhat brittle steel.
  - Still larger amounts produce a steel that is tough and very resistant to wear after proper heat treatment.

1.2.1 Nonferrous Metals

Nonferrous metals contain either no iron or only insignificant amounts used as an alloy, and are nonmagnetic. The following list will introduce you to some of the common nonferrous metals that SWs may encounter and/or work with. Additional information about their properties and usage is available in Steelworker Advanced.

- Copper — one of the most popular commercial metals; used with many alloys; frequently used to give a protective coating to sheets and rods and to make ball floats, containers, and soldering coppers.
- True Brass — an alloy of copper and zinc, sometimes with additional alloys for specific properties; sheets and strips are available in several grades.
- Bronze — a combination of 84% copper and 16% tin, and the best metal available before steel-making techniques were developed; the name bronze is currently applied to any copper-based alloy that looks like bronze.
- Copper-Nickel Alloys — nickel adds resistance to wear and corrosion; some alloys used for saltwater piping systems; other sheet forms used to construct small storage tanks and hot-water reservoirs.
- Lead — a heavy metal, but soft and malleable; surface is grayish in color, but after scratching or scraping it, the actual color of the metal appears white.

CAUTION

When working with lead, take proper precautions!
Lead dust, fumes, or vapors are highly poisonous!

- Zinc — used on iron or steel in the form of a protective coating called galvanizing.
- Tin — used as an important alloy adding resistance to corrosion.
- Aluminum — easy to work with; good appearance; light in weight; needs alloys added to increase strength.

- Duralumin — one of the first strong structural aluminum alloys; now classified in the metal working industries as 2017-T; “T” indicates heat-treated.
- Alclad — a protective covering of a thin sheet of pure aluminum rolled onto the surface of an aluminum alloy during manufacture.
- Monel — an alloy in which nickel is the major element; harder and stronger than either nickel or copper; acceptable substitute for steel in systems where corrosion resistance is the primary concern
- K-Monel — developed for greater strength and hardness than Monel; comparable to heat-treated steel; used for instrument parts that must resist corrosion.
- Inconel — provides good resistance to corrosion and retains its strength at high-operating temperatures; often used in the exhaust systems of aircraft engines.

2.0.0 BASIC METAL IDENTIFICATION

When you are selecting a metal to use in fabrication, to perform a mechanical repair, or even to determine if the metal is weldable, you must be able to identify its basic type.

A number of field identification methods can be used to identify a piece of metal. Some common methods are surface appearance, spark test, chip test, magnet test, and occasionally a hardness test.

2.1.1 Surface Appearance

Sometimes you can identify a metal simply by its surface appearance. *Table 1-1* indicates the surface colors of some of the more common metals.

Table 1-1 — Surface Appearance of Some Common Metals

Metal	Color		Color and Structure
	Unfinished, unbroken surface	**Freshly filed surface**	**Newly fractured surface**
Aluminum	Light gray	White	White: finely crystalline
Brass and Bronze	Reddish-yellow, yellow-green, or brown	Reddish-yellow to yellowish-white	Red to yellow
Copper	Reddish-brown to green	Bright copper color	Bright red
Iron, Cast-gray	Dull gray	Light silvery gray	Dark gray: crystalline
Iron, Cast-white	Dull gray	Silvery white	Silvery white: crystalline
Iron, Malleable	Dull gray	Light silvery gray	Dark gray: finely crystalline
Iron, Wrought	Light gray	Light silvery gray	Bright gray
Lead	White to gray	White	Light gray: crystalline
Monel metals	Dark gray	Light gray	Light gray
Nickel	Dark gray	Bright silvery white	Off-white
Steel, Cast and Steel, Low-carbon	Dark gray	Bright silvery gray	Bright gray
Steel, High-carbon	Dark gray	Bright silvery gray	Light gray
Steel, Stainless	Dark gray	Bright silvery gray	Medium gray

As you can see by studying the table, a metal's surface appearance can help you identify it, and if you are unsure, you can obtain further information by studying a fresh filing or a fresh fracture. If a surface examination does not provide you with enough information for a positive identification, it should give you enough information to place the metal into a class.

In addition to the color of the metal, distinctive marks left from manufacturing also 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.
- High-carbon steel shows either forging or rolling marks.

Inspecting the surface texture by feel may also provide another clue to its identity.

- Stainless steel, in the unfinished state, is slightly rough.
- Wrought iron, copper, brass, bronze, nickel, and Monel are smooth.
- Lead is smooth but has a velvety appearance.

When visual clues from surface appearance, filings, fractures, manufacturing marks, or textural clues from the feel of the surfaces do not give enough information to allow positive identification, other tests become necessary.

Some are complicated and require equipment Seabees do not usually have. However, the following are a few additional simple tests, which are reliable when done by a skilled person: spark test, chip test, magnetic tests, hardness test.

2.2.1 Spark Test

You perform the spark test by holding a sample of the unidentified material against an abrasive wheel and visually inspecting the spark stream. This test is fast, economical, convenient, easily accomplished, and requires no special equipment.

As you become a more experienced Steelworker, you will be able to identify the sample metals with considerable accuracy. You can use this test to identify scrap-salvaged metal, which is particularly important when you are selecting material for cast iron or cast steel heat treatment.

When you hold a piece of iron or steel (ferrous metals) in contact with a high-speed abrasive wheel, small particles of the metal are torn loose so rapidly that they become red-hot. These small particles of metal fly away from the wheel, and glow as they follow a trajectory path called the carrier line, which is easily followed with the eye, especially when observed against a dark background.

The sparks (or lack of sparks) given off can help you identify the metal. Features you should look for include:

- length of the spark stream
- form of the sparks
- color(s) of the sparks

Refer to *Figure 1-2* through *Figure 1-8* for illustrations of the various terms used in referring to the basic spark forms produced during spark testing.

Figure 1-2 — Example of spark testing term-STREAM.

Figure 1-3 — Example of spark testing term-SHAFT.

Figure 1-4 — Example of spark testing term-FORK.

Figure 1-5 — Example of spark testing term-SPRIGS.

Figure 1-6 — Example of spark testing term-DASHES.

Figure 1-7 — Example of spark testing term-APPENDAGES.

Figure 1-8 — Example of spark testing term-BUD BREAK ARROW.

Steels that have the same carbon content but include different alloying elements are difficult to identify; the alloys have an effect on the carrier lines, the bursts themselves, or the forms of the characteristic bursts in the spark picture.

The alloying element may slow or accelerate the carbon spark, or make the carrier line lighter or darker in color. For example:

- Molybdenum — 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, you can identify the nickel spark by tiny blocks of brilliant white light.
- Silicon — suppresses the carbon burst even more than nickel; the carrier line usually ends abruptly in a white flash of light.

You can perform spark testing with either a portable or a stationary grinder, but in either case, the outer rim speed of the wheel should be not less than 4,500 feet per minute with a clean, very hard, rather coarse abrasive wheel. Each point is necessary to produce a true spark

When you conduct a spark test, hold the metal on the abrasive wheel in a position that will allow the carrier line to cross your line of vision. By trial and error, you will soon find what pressure you need in order to get a stream of the proper length without reducing the speed of the grinder. In addition to reducing the grinder's speed, excessive pressure against the wheel can increase the temperature of the spark stream, which in turn increases the temperature of the burst and gives the appearance of a higher carbon content than actually is present.

Use the following technique 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.

An abrasive wheel on a grinder traveling at high speed requires respect, and you need to review some of the safety precautions associated with this tool (*Figure 1-9*).

- Never use a cracked or out of balance wheel.
    - Vibration can cause the wheel to shatter, and when an abrasive wheel shatters, it can be disastrous for personnel standing in line with the wheel.

Figure 1-9 — Example of a grinder's OSHA-designated safety points.

- Always check the wheel for secure mounting and cracks before using.
- When you install a new wheel on a grinder, be sure it is the correct size and designated RPM.
    - As you increase a wheel's radius, the peripheral speed at the rim increases even though the rpms remain the same. Thus, if you use an oversized wheel, there is a distinct danger the peripheral speed can become so great that the consequent centrifugal force can cause the wheel to fly apart. Guards are placed on grinders as protection in case a wheel should shatter, but they cannot provide total protection.
- Never use a grinder when the guards have been removed.
    - When you turn the grinder on, stand to one side; this places you out of line with the wheel's centrifugal force 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 the work rest is adjusted to the minimum clearance for the wheel, and move the work across the entire face of the wheel.
    - This helps eliminate grooving and minimizes the need for wheel dressing, thus prolonging 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.
    - Misuse can clog the pores of the abrasive material with metal buildup, which in turn can cause the wheel to become unbalanced and fly apart.

Grinding wheels require frequent reconditioning.

Dressing is the term you use to describe the cleaning of the working face of an abrasive wheel.

Proper dressing breaks away dull abrasive grains, smoothes the surface, and removes grooves.

The wheel dresser shown in *Figure 1-10* is used for dressing grinding wheels on bench and pedestal grinders.

Figure 1-10 — Typical wheel dresser.

Refer now to *Figure 1-11* through *Figure 1-16* for examples of spark testing results for specific identified material.

Low-carbon steel —

- Spark stream is white.
- Spark stream is about 70 inches long.
- Volume is moderately large.
- A few sparklers may occur at any place and are forked.

Figure 1-11 — Example of low-carbon and cast steel spark stream.

High-carbon steel —

- Spark stream is white.
- Spark stream is about 55 inches long.
- Volume is larger than low-carbon steel.
- Sparklers are small and repeating.

Figure 1-12 — Example of high-carbon spark stream.

Gray cast iron —

- Spark stream near the wheel is red.
- Spark stream in the outer portion is straw colored.
- Spark stream is about 25 inches long.
- Volume is rather small.
- Sparklers are small and repeating.

Figure 1-13 — Example of gray cast iron spark stream.

Monel and Nickel —

- Spark stream is orange.
- Spark stream forms short wavy streaks.
- Volume is small.
- There are no sparklers.

Because of their similar spark pictures, you must use some other method to distinguish monel from nickel.

Figure 1-14 — Example of monel and nickel spark streams.

Stainless steel —

- Spark stream next to the wheel is straw colored.
- Spark stream at the end is white.
- Spark stream is about 50 inches long.
- Volume is moderate with few sparklers.
- Sparklers are forked.

Figure 1-15 — Example of stainless steel spark stream.

Wrought iron —

- Spark stream next to the wheel is straw colored.
- Spark stream at the end is brighter red.
- Spark stream is about 65 inches long.
- Volume is large with few sparklers.
- Sparklers are forked near the end of the stream.

Figure 1-16 — Example of wrought iron spark stream.

One way to become proficient in identifying ferrous metals by spark testing is to practice by testing yourself in the blind. Gather an assortment of known metals for testing. Make individual samples so similar that size and shape will not reveal their identities. Number each sample and prepare a master list of correct names with corresponding numbers.

Then, without looking at the number on the sample, spark test it and call out its name to someone assigned to check your identification against the names and numbers on the list. Repeating this self-testing practice will give you some of the experience you need to become proficient in identifying individual samples.

2.3.0 Chip Test

Another simple field test you can use to identify an unknown piece of metal is the chip test. You perform the chip test by removing a small amount of material from the test piece with a sharp, cold chisel. The material you remove can vary from small, broken fragments to a continuous strip. The chip may have smooth, sharp edges, may be coarse-grained or fine-grained, or may have saw-like edges.

The size of the chip is important in identifying the metal, as well as the ease with which you can accomplish the chipping. Refer to *Table 1-2* for information to help you identify various metals by the chip test.

Table 1-2 — Metal Identification by Chip Test

Metal	Chip Characteristics
Aluminum and Aluminum Alloys	Smooth with saw tooth edges. A chip can be cut as a continuous strip.
Brass and Bronze	Smooth with saw tooth edges. These metals are easily cut, but chips are more brittle than chips of copper. Continuous strip is not easily cut.
Copper	Smooth with saw tooth edges where cut. Metal is easily cut as a continuous strip.
Iron, Cast-white	Small brittle fragments. Chipped surfaces are not smooth.
Iron, Cast-gray	About 1/8 inch in length. Metal is not easily chipped; therefore, chips break off and prevent smooth cut.
Iron, Malleable	Vary from 1/4 to 3/8 inch in length (larger than chips from cast iron). Metal is tough and hard to chip.
Iron, Wrought	Smooth edges. Metal is easily cut or chipped, and a chip can be made as a continuous strip.
Lead	Any shape may be obtained because the metal is so soft that it can be cut with a knife.
Monel	Smooth edges. Continuous strips can be cut. Metal chips easily.
Nickel	Smooth edges. Continuous strips can be cut. Metal chips easily.
Steel, Cast and Steel, Low-carbon	Smooth edges. Metal is easily cut or chipped, and a chip can be taken off as a continuous strip.
Steel, High-carbon	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.

2.4.0 Magnetic Test

A magnet test is another method you can use to aid in a metal's general identification. Remember: ferrous metals are iron-based alloys and normally magnetic; nonferrous metals are nonmagnetic. This test is not 100 percent accurate because some stainless steels are nonmagnetic, but it can aid in the first differentiation of most metals. When dealing with stainless steel, there is no substitute for experience.

2.5.0 Hardness Test

Hardness is the property of a material to resist permanent indentation. One simple way to check for hardness in a piece of metal is to file a small portion of it. If it is soft enough to be machined with regular tooling, the file will cut it. If it is too hard to machine, the file will not cut it. This method will indicate whether the material being tested is softer or harder than the file, but it will not tell exactly how soft or hard it is.

The file can also be used to determine the harder of two pieces of metal; the file will cut the softer metal faster and easier. The file method should be used only in situations when the exact hardness is not required. This test has the added advantage of needing very little in the way of time, equipment, and experience.

Because there are several methods of measuring exact hardness, the hardness of a material is always specified in terms of the particular test 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, and requires a Rockwell hardness testing machine. The basic principle used in the Rockwell test is that a hard material can penetrate a softer one, and the amount of penetration is measured and compared to a scale.

For ferrous metals, usually harder than nonferrous metals, a diamond tip is used for depth penetration measurement and the hardness is indicated by a Rockwell “C” number. On nonferrous metals, which are softer, a metal ball is used for surface indentation measurement and the hardness is indicated by a Rockwell “B” number.

Consider lead and steel for an idea of the property of hardness. Lead can be scratched with a pointed wooden stick, but steel cannot because it is harder than lead.

You can get a more complete explanation of the various methods used to determine the hardness of a material from commercial books or books located in your base library.

Summary

This chapter has introduced you to the basics of the different types of metals and the simple field and shop methods you can use to identify them. From here, you can begin to build on your experiences to become a seasoned Steelworker considered a resident expert on metals. Steelworker Advanced will provide additional, in-depth information about metal properties in their varied compositions and alloys, along with a discussion of additional uses.

Review Questions (Select the Correct Response)

1. What term is used to describe the equivalent of the Steelworker rating in civilian construction?

   A. Steel erector
   B. Iron placer
   C. Steel fabricator
   D. Ironworker

2. A material must be primarily composed of _ to be considered a ferrous metal.

   A. steel
   B. iron
   C. nickel
   D. copper

3. Ferrous metals are typically .

   A. magnetic
   B. nonmagnetic
   C. copper colored
   D. alloy-free

4. Which type of iron is one of the main raw materials used to make steel?

   A. Ingot
   B. Cast
   C. Pig
   D. Wrought

5. What characteristic of pig iron limits its use?

   A. It is comparatively weak and brittle.
   B. It is difficult to remelt.
   C. It cannot be combined with other metals.
   D. It is used exclusively for manufacturing cast-iron pipe.

6. What material do Steelworkers use the most?

   A. Steel
   B. Cast iron
   C. Copper
   D. Wrought iron

7. Cast iron is any iron containing greater than _ alloy.

A. .5%
B. 1%
C. 1.5%
D. 2%

8. What process is used to produce malleability in cast iron?

A. Remelting
B. Annealing
C. Plating
D. Alloying

9. What group of steel is best suited for the manufacture of crane hooks and axles?

A. High carbon
B. Medium carbon
C. Mild carbon
D. Low carbon

10. What group’s specifications cover high-strength steels?

A. American Society for Testing and Materials (ASTM)
B. American Society of Mechanical Engineers (ASME)
C. Society of Automotive Engineers (SAE)
D. American Iron and Steel Institute (AISI)

11. What group’s specifications cover stainless steels?

A. American Society for Testing and Materials (ASTM)
B. American Society of Mechanical Engineers (ASME)
C. Society of Automotive Engineers (SAE)
D. American Iron and Steel Institute (AISI)

12. What stainless steel is normally nonmagnetic?

A. Martensitic-chromium of the 300 series
B. Austenitic chromium-nickel of the 300 series
C. Ferritic-austenite of the 400 series
D. Ferritic-chromium of the 400 series

13. What common alloy steel is used to make high-quality hand tools?

A. Nickel steel
B. Chromium steel
C. Chrome Vanadium steel
D. Tungsten steel

14. Which of the following metals is nonferrous?

    A. Cast iron
    B. Carbon steel
    C. Aluminum
    D. Pig iron

15. What combination of elements in proper proportion make bronze?

    A. Copper-Zinc
    B. Copper-Lead
    C. Copper-Aluminum
    D. Copper-Tin

16. What action does the letter “T” signify when used in conjunction with a numbering system that classifies different aluminum alloys?

    A. The metal has been heat-treated.
    B. The alloying elements have been tempered.
    C. The major alloying element has been tested.
    D. The metal has been covered with a tungsten-rolled cover.

17. What manufacturing marks can you look for when a metal’s color does not provide positive identification?

    A. Evidence of a sand mold
    B. Forging marks
    C. Rolling marks
    D. All of the above

18. When applying the spark test to a metal, you notice the spark stream has white shafts and forks only. What does this condition indicate about the metal under test?

    A. It is a high-carbon steel.
    B. It is a low-carbon steel.
    C. It is a nickel alloy.
    D. It is a molybdenum alloy.

19. What metal produces a spark stream about 25 inches long with small and repeating sparklers of small volume that are initially red in color?

    A. Nickel
    B. Stainless steel
    C. Grey cast iron
    D. Monel metal

20. Which of the following metals produces the shortest length spark stream?

A. High-carbon steel
B. Low-carbon steel
C. White cast iron
D. Nickel

21. You perform the chip test by removing a small amount of material from the test piece with a ______.

A. sharp, cold chisel
B. drill press with ¼ inch bit
C. hack saw
D. cut-off saw

22. **(True or False)** You can depend on a magnetic test for 100% accuracy to determine a ferrous metal.

A. True
B. False

Trade Terms Introduced in this Chapter

Annealing	Subjecting (glass or metal) to a process of heating and slow cooling in order to toughen and reduce brittleness.
Austenitic	Consisting mainly of austenite, which is a nonmagnetic solid solution of ferric carbide, or carbon in iron used in making corrosion-resistant steel.
Bessemer process	Named for Sir Henry Bessemer, an industrial process for the manufacture of steel from molten pig iron. The principle involved is that of oxidation of the impurities in the iron by the oxygen of air that is blown through the molten iron; the heat of oxidation raises the temperature of the mass and keeps it molten during operation.
Ferritic	Consisting of the pure iron constituent of ferrous metals, as distinguished from the iron carbides.
Ferrous	An adjective used to indicate the presence of iron. The word is derived from the Latin word *ferrum* ("iron"). Ferrous metals include steel and pig iron (with a carbon content of a few percent) and alloys of iron with other metals (such as stainless steel).
Ingot	A material, usually metal, that is cast into a shape suitable for further processing. Ingots require a second procedure of shaping, such as cold/hot working, cutting or milling to produce a useful final product.
Malleable	Capable of great deformation without breaking, when subject to compressive stress.
Martensitic	Consisting of a solid solution of iron and up to one percent of carbon, the chief constituent of hardened carbon tool steels.
Nonferrous	The term used to indicate metals other than iron and alloys that do not contain an appreciable amount of iron.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Althouse, Andrew D., Carl H. Turnquist, and William A. Bowditch, *Modern Welding,* Goodheart-Wilcox Co. Inc., 1970.

Giachino and Weeks, *Welding Skills,* American Technical Publishers Inc., 1985.

Welding Theory and Application, TM 9-237, Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1976.

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Chapter 2

Basic Heat Treatment

Topics

To hear audio, click on the box.

Overview

Welding, cutting, or even grinding on metal produces heat, which it turn has an effect on the structure of the metal. As a Steelworker, you need to understand the effect that heat treatment has on metals so you can attain the desired properties for a particular metal. You also need to know what methods can be used to restore a metal to its original condition.

Heat treatment is the process of heating (but never allowing the metal to reach the molten state) and cooling a metal in a series of specific operations which changes or restores its mechanical properties.

Heat treatment makes a metal more useful by making it stronger and more resistant to impact, or alternatively, making it more malleable and ductile.

However, 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, or annealing it may make it too soft.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the heat treatment theory.
2. Identify the stages of heat treatment.
3. Recognize heating colors associated with steel.
4. Describe the different types of heat treatment.
5. Describe the different types of quenching media.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet-Metal and Fiberglass Duct		
Welding Quality Control		
Flux Core Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 HEAT TREATMENT THEORY

All heat-treating processes are similar because they all involve the heating and cooling of metals. However, there are differences in the methods used, such as the heating temperatures, cooling rates, and quenching media necessary to achieve the desired properties.

The heat treatment of ferrous metals (metals with iron) usually consists of annealing, normalizing, hardening, and/or tempering.

Most nonferrous metals can be annealed, but never tempered, normalized, or ***case hardened***.

To successfully heat treat a metal, you need to have the proper equipment with close control over all factors relevant to the heating and cooling. For example, the furnace must be the proper size and type with the temperatures controlled and kept within the prescribed limits for each operation, and you must have the appropriate quenching media to cool the metal at the correct rate.

The furnace atmosphere itself affects the condition of the metal being heat treated. This atmosphere consists of the gases in the furnace's heating chamber that circulate and surround the metal 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 a mixture of gases and air. Air combines with gases released by the fuel's combustion resulting in various proportions of carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H), nitrogen (N), oxygen (O), water vapor (H_2O), and other various hydrocarbons (C_nH_{2n}). When you vary the proportions of air and fuel in a fuel-fired furnace, you can provide three distinct atmospheres: oxidizing, reducing, and neutral.

2.1.1 STAGES of HEAT TREATMENT

You accomplish heat treatment in three major stages:

- Stage l — Heat the metal slowly to ensure a uniform temperature.
- Stage 2 — Soak (hold) the metal at a given temperature for a given time.
- Stage 3 — Cool the metal to room temperature.

2.1.1 Heating Stage

In the heating stage, the primary objective is to heat uniformly, and you attain and maintain uniform temperatures by slow heating. If you heat unevenly, one section can expand faster than another, resulting in a distorted or cracked part.

The appropriate heating rate will depend on several factors.

- The metal's heat conductivity. A metal with a high-heat conductivity heats at a faster rate than one with a low conductivity.
- The metal's condition. The heating rate for hardened (stressed) tools and parts should be slower than the heating rate for unstressed or untreated metals.
- A metal part's size and cross section. To prevent warping or cracking, you need to heat large cross-sectioned parts slowly to allow the interior temperature to remain close to the surface temperature. Parts with uneven cross sections will

naturally tend to heat unevenly, but they are less apt to crack or excessively warp when you keep the heating rate slow.

2.2.0 Soaking Stage

In the soaking stage, the objective is to hold the metal to the proper temperature until the desired internal structural changes take place. “Soaking period” is the term you use for the time the metal is held at the proper temperature. The chemical analysis of the metal and the mass of the part will determine the appropriate soaking period. (Note: For steel parts with uneven cross sections, the largest section determines the soaking period.)

Except for the rare variance, you should not bring the temperature of a metal directly from room temperature to soaking temperature in one operation. Instead, heat the metal slowly to a temperature just below the point at which the internal change occurs and hold it at that temperature until you have equalized the heat throughout. Following this process (called “preheating”), quickly heat the metal to its final required temperature.

When a part has an intricate design, you may have to preheat it to more than one temperature stage to prevent cracking and excessive warping. For example, assume an intricate part needs to be heated to 1500°F for hardening.

You may need to heat this part slowly to a 600°F stage and soak it at this temperature for a defined period, then heat it slowly and soak it at a 1200°F stage, and then heat it quickly to the hardening temperature of 1500°F.

NOTE

Nonferrous metals seldom require preheating; in fact, preheating can cause an increase in their grain size.

2.3.0 Cooling Stage

In the cooling stage, the objective is self-explanatory, but there are different processes to return a metal to room temperature, depending on the type of metal.

To cool the metal and attain the desired properties, you may need to place it in direct contact with a ***cooling medium*** (a gas, liquid, solid, or a combination), and any cooling rate will depend on the metal itself and the chosen medium. Therefore, the choice of a cooling medium has an important influence on the properties desired.

Cooling metal rapidly in air, oil, water, brine, or some other medium is called ***quenching***.

Quenching is usually associated with hardening since most metals that are hardened are cooled rapidly during the process. However, neither quenching nor rapid cooling always results in increased hardness. For example, a water quench is usually used to anneal copper, and some other metals are cooled at a relatively slow rate for hardening, such as air-hardened steels.

Some metals crack or warp during quenching, while others suffer no ill effects; so the quenching medium must fit the metal. Use brine or water for metals that require a rapid cooling rate; use oil mixtures for metals that need a slower cooling rate. Generally, you should water-harden carbon steels, oil-harden alloy steels, and quench nonferrous metals in water.

3.0.0 RECOGNIZING HEAT COLORS for STEEL

"Red-hot" is a term you are probably familiar with as it applies to steel, but steel actually takes on several colors and shades from the time it turns a dull red until it reaches a white heat. *Figure 2-1* shows these approximate colors and their corresponding temperatures.

Figure 2-1 — Example of approximate heat colors for steel.

Steel is heated through various temperatures during hardening, normalizing, or annealing, and each temperature produces a color change; so by observing these changes, you should be able to approximate the temperature of the steel.

As an example, assume you must quench-harden a steel part at 1500°F. You should heat the part slowly and evenly while watching it closely for any change in color. Once the steel begins to redden, carefully note each change in shades of red as you continue to apply heat. When the steel is bright red, or approximately 1500°F, quench the part.

Your judgment, ability to distinguish shades of red, and the accuracy with which you identify each color with its corresponding temperature can determine the success of your heat-treating operation. If you are one of the 5–8 percent of males, or less than 1 percent of females who are color blind in some way or another, your inability to distinguish colors will be problematic.

Refer again to *Figure 2-1* and you will see that you need to observe the colors closely. To accurately judge a steel's temperature, you must be able to tell the difference between faint red and blood red, dark cherry and medium cherry, or cherry red and bright red.

Sometimes in various lightings and work environments, this is a difficult task, and to add to the difficulty, your conception of medium cherry may differ from another's conception. For an actual heat-treating operation, use a printed chart showing the authentic colors of steel at various temperatures. Do not rely on the colors displayed on the monitor you are currently viewing, or on printed versions of this course; there are too many variables in monitors and printers to be able to rely on them for accuracy.

4.0.0 TYPES of HEAT TREATMENT

There are four basic types of heat treatment in use today: annealing, normalizing, hardening, and tempering.

The following sections describe the techniques used in each process and show how they relate to Steelworkers.

4.1.0 Annealing

The objective of annealing is the opposite of hardening. You anneal metals to relieve internal stresses, soften them, make them more ductile, and refine their grain structures. The process includes all three stages of heat treatment already covered (heat the metal to a specific temperature, hold it at a temperature for a set length of time, cool it to room temperature), but the cooling method will depend on the metal and the properties desired.

You may need to furnace-cool some metals or bury others in ashes, lime, or other insulating materials to achieve the appropriate characteristics.

Under certain job conditions, or without proper preheating, welding can produce areas of molten metal adjacent to other areas at room temperature. Given specific conditions, welding can actually weaken a metal, for as a weld cools, internal stresses occur along with hard spots and brittleness.

Annealing is just one method for correcting these problems and relieving the stresses.

4.1.1 Ferrous Metal

To anneal ferrous metals and produce the maximum softness(ductility) in steel, you slowly heat the metal to its proper temperature, soak it, and then let it cool very slowly by burying the hot part in an insulating material, or by shutting off the furnace and allowing the furnace and the part to cool slowly together.

Soaking periods depend on both the type and the mass of the metal involved. *Table 2-1* provides approximate soaking periods for annealing steel of various thicknesses.

Extremely low-carbon steels require the highest annealing temperature, but as steel's carbon content increases, its annealing temperatures decrease.

Table 2-1 — Approximate Soaking Periods for Hardening, Annealing, and Normalizing Steel

Thickness of metal in inches	Time of heating to required temperature in hours	Soaking time in hours
Up to 1	¾	½
1 to 2	1 ¼	½
2 to 3	1 ¾	¾
3 to 4	2 ¼	1
4 to 5	2 ¾	1
5 to 8	3 ½	1 ½

4.1.2 Nonferrous Metal

Annealing nonferrous metals may or may not follow the same process as ferrous metals. For example, copper becomes hard and brittle when mechanically worked, but it can be made soft again by annealing at a temperature between 700°F and 900°F. However, copper may be cooled rapidly (normally associated with hardening) or slowly since the cooling rate has no effect on the heat treatment.

One drawback experienced in annealing copper is the phenomenon called "***hot shortness***." Copper loses its tensile strength at about 900°F and if not properly supported, it could fracture.

Aluminum also has the characteristic of "hot shortness," and reacts similarly to copper when heat treating. With the large number of aluminum alloys in use, you must provide special care while heat treating aluminum to produce the best properties for each alloy.

4.2.0 Normalizing

The intent of normalizing is to remove internal stresses that may have been induced by heat treating, welding, casting, forging, forming, or machining. Uncontrolled stress leads to metal failure; therefore, you should normalize steel before hardening it to ensure maximum results.

Normalizing applies to ferrous metals only, and it differs from annealing; the metal is heated to a higher temperature, but then it is removed from the furnace for air cooling.

Low-carbon steels do not usually require normalizing, but if they are normalized, no harmful effects result.

Castings are usually annealed rather than normalized; however, some castings require the normalizing heat treatment.

Refer again to *Table 2-1* and note the approximate soaking periods for normalizing steel, which varies with the thickness.

Normalized steel has a higher strength than annealed steel; it has a relatively high strength and ductility, much tougher than in any other structural condition. Metal parts that will be subjected to impact and those requiring maximum toughness with resistance to external stress are usually normalized.

In normalizing, since the metal is air cooled, the mass of a metal has a significant influence on the cooling rate and hence on the resulting piece's hardness. With normalizing, thin pieces cool faster in the air and are harder than thick ones, whereas with annealing and its associated furnace cooling, the hardness of the thin and thick pieces is about the same.

4.3.1 Hardening

The purpose of hardening is not only to harden steel as the name implies, but also to increase its strength. However, there is a trade off; while a hardening heat treatment does increase the hardness and strength of the steel, it also makes it less ductile, and brittleness increases as hardness increases. To remove some of the brittleness, you should temper the steel after hardening.

Many nonferrous metals can also be hardened and their strength increased by controlled heating and rapid cooling, but for nonferrous metals, the same process is called heat treatment rather than hardening.

For most steels, hardening consists of employing the typical first two stages of heat treatment (slowly heat to temperature and soak to time and temperature), but the third stage is dissimilar. With hardening, you rapidly cool the metal by plunging it into oil, water, or brine. (Note: Most steels require rapid cooling [quenching] for hardening, but a few can be air cooled with the same results.)

Refer again briefly to *Table 2-1*, and note that the soaking periods for annealing, normalizing and hardening are all the same. The real difference in each heat treatment process occurs in stage three.

The cooling rate required to produce hardness decreases when alloys are added to steel; this is advantageous since a slower cooling rate also lessens the danger of cracking and warping.

The follow provides hardening characteristics for a few irons and low-carbon steel.

- Pure iron, wrought iron, and extremely low-carbon steels — very little hardening properties; difficult to harden by heat treatment
- Cast iron — limited capabilities for hardening
  - Cooled rapidly, it forms white iron; hard and brittle
  - Cooled slowly, it forms gray iron; soft but brittle under impact
- Plain carbon steel — maximum hardness depends almost entirely on carbon content
  - Hardening ability increases as carbon content increases to a maximum of 0.80 % carbon
  - Increased carbon content beyond 0.80 % increases wear resistance but not hardness
  - Increased wear resistance is due to the formation of hard ***cementite***

Adding an alloy to steel to increase its hardness also increases the carbon's effectiveness to harden and strengthen. Consequently, the carbon content required to produce maximum hardness is lower in alloyed steels than it is for plain carbon steels with the result that alloy steels are usually superior to carbon steels.

When you harden carbon steel, you must cool the steel to below 1000°F in less than one second. When you add alloys to steel and increase the carbon's effectiveness, you also increase the time limit (more than one second to drop below 1000°F). Therefore, you can use a slower quenching medium to produce the desired hardness.

You usually quench carbon steels in brine or water, and alloy steels in oil.

Quenching steel produces extremely high internal stresses. To relieve them, you can temper the steel just before it becomes cold by removing the part from the quenching bath at a temperature of about 200°F and allowing it 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 quenching medium. Further information on tempering follows in another section.

The following presents different commercially used methods of hardening. In the Seabees, a rapid surface hardening compound called *SURFACE-HARDENING (CASE) COMPOUND, NSN: 9GD 6850-00-139-5936 (10 lb. can)* is used, and you can order it through the Navy supply system. More information and three alternative procedures on the use of "Case" are available in the Welding Materials Handbook, P-433.

4.3.1 Case Hardening

The object of case hardening is to produce a hard, wear-resistant surface (case) over a strong, tough core. In case hardening, the surface of the metal is chemically changed by the introduction of a high carbide or nitride content, but the core remains chemically unaffected. When the metal is heat treated, the high-carbon surface responds to hardening and the core toughens.

Case hardening applies only to ferrous metals. It is ideal for parts that must have a wear-resistant surface yet be internally tough enough to withstand heavy loading. Low-carbon and low-alloy series steels are best suited for case hardening. When high-carbon steels are case hardened, the hardness penetrates beyond the surface resulting in brittleness.

There are three principal processes for case hardening: carburizing, cyaniding, and nitriding.

4.3.1.1 Carburizing

Carburizing — a case hardening process by which carbon is added to the surface of low-carbon steel.

When the carburized steel is heat treated, the case becomes hardened and the core remains soft and tough--in other words, it has a high-carbon surface and a low-carbon interior.

There are two methods for carburizing steel:

- Heat the steel in a furnace containing a carbon monoxide atmosphere.
- Place the steel in a container packed with charcoal (or some other carbon-rich material) and heat in a furnace.

The parts can be left in the container and furnace to cool, or they can be removed and air-cooled. In either case, the parts become annealed during the slow cooling. The depth of the carbon penetration depends on the length of the soaking period during heat treatment. Modern methods dictate that carburizing is almost exclusively done by gas atmospheres.

4.3.1.2 Cyaniding

Cyaniding — a case hardening process by which preheated steel is dipped into a heated cyanide bath and allowed to soak.

The part is then removed, quenched, and rinsed to remove any residual cyanide.

This process is fast and efficient. It produces a thin, hard shell, harder than the shell produced by carburizing, and can be completed in 20 to 30 minutes vice several hours. The major drawback is the use of cyanide; cyanide salts are a deadly poison.

4.3.1.3 Nitriding

Nitriding — a case hardening process by which individual parts have been heat treated and tempered *before* being heated in a furnace that has an ammonia gas atmosphere.

This case hardening method produces the hardest surface of any of the hardening processes, and it differs from the other methods in that no quenching is required so there is no worry about warping or other types of distortion.

The nitriding 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.

4.3.2 Flame Hardening

Flame hardening is another process available for hardening the surface of metal parts. In flame hardening, you use an oxyacetylene flame to heat a thin layer of the surface to its critical temperature and then immediately quench it with a water spray. In this case, the cold base metal assists in the quenching since it is not preheated.

Similar to case hardening, this process produces a thin, hardened surface while the internal parts retain their original properties.

The process can be manual or mechanical, but in either case, you must maintain a close watch since an oxyacetylene flame can heat the metal rapidly and temperatures in this method are usually determined visually.

Flame hardening may also be done with automatic equipment.

Figure 2-2 — Typical flame hardening.

Whenever possible, automatic equipment is desirable for more uniform results.

Most automatic machines have variable travel speeds to adapt to parts of various sizes and shapes, and the size and shape of the torch will also depend on the part. (*Figure 2-2*)

A typical flame hardening torch consists of a mixing head, straight extension tube, 90-degree extension head, adjustable yoke, and a water-cooled tip.

Tips are available for hardening flats, rounds, gears, cams, cylinders, and other regular or irregular shapes. Practically any shape or size flame-hardening tip is offered. (*Figure 2-3*)

Figure 2-3 — Typical progressive hardening torch tip.

For hardening localized areas, you can flame harden with a standard hand-held welding torch and the torch flame adjusted to neutral for normal heating. (*Figure 2-4*)

In corners and grooves, however, you should use a slightly oxidizing flame to keep the torch from sputtering, and exercise particular care against overheating.

If dark streaks appear on the metal surface, this is a sign you are overheating, and you need to increase the distance between flame and metal.

Figure 2-4 — Example of carburizing, neutral, and oxidizing flames.

Typically, for the best flame-hardening heating results, you should 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. Occasionally, you may need to change the angle for better results, but you will rarely use a deviation of more than 30°. The speed of torch travel will depend on the type of metal, the mass, the shape of the part, and the depth of hardness desired.

If you have options in selecting the core material for the part to be flame hardened, select the steel according to the properties desired. When surface hardness is the primary factor, select carbon steel; when the physical properties of the core are also factors, select alloy steel.

For good results in flame hardening, plain carbon steels should contain more than 0.35% carbon, and 0.40% to 0.70% is the effective carbon range for water quenching. A carbon content greater than 0.70% is likely to induce surface cracks unless the heating and quenching rate are carefully controlled.

A section that has a flame-hardened surface is equal to a section that was hardened by furnace heating and quenching for the following reasons:

- The decrease in hardness between the case and the core is gradual.
- The core is not affected by flame hardening so there is little danger of ***spalling*** or flaking while the part is in use.

Thus, properly done, flame hardening can produce a hard case that is highly resistant to wear, and a core that retains its original properties.

There are five general methods for flame hardening: stationary, circular band progressive, straight-line progressive, spiral band progressive, and circular band spinning.

- Stationary Method — Torch and metal part are both held stationary.
- Circular Band Progressive Method — Object is rotated in front of a stationary torch at a surface speed of from 3 to 12 inches per minute.
  - Use this method for hardening outside surfaces of round sections.
  - Heating and quenching are done progressively as the part rotates.
  - Hardened band encircles part on one completed rotation.
  - Width of hardened band depends upon the width of the torch tip.
  - To harden the full length of a long section, torch is moved and process repeated until the part is completely hardened.
  - Each torch pass should overlap the previous one.

- Straight-Line Progressive Method — Torch travels along the surface, treating a strip that is about the same width as the torch tip. (*Figure 2-5*)
  - Move the torch and repeat the process to harden a wider area.

Figure 2-5 — Example of progressive hardening.

- Spiral Band Progressive Method — Cylindrical part is mounted between lathe centers; a torch with an adjustable holder is mounted on the lathe carriage.
  - Torch moves parallel to the surface of the part as the part rotates.
  - Travel is synchronized with the part's rotary motion to produce a continuous band of hardness.
  - Heating and quenching occur at the same time.
  - Number of torches required depends on the diameter of the part; seldom more than two.
- Circular Band Spinning Method — Part is mounted between lathe centers and turned at a high rate of speed past a stationary torch.
  - This method provides the best results for hardening cylindrical parts of small or medium diameters.
  - Enough torches are placed side by side to heat the entire part.
  - Part can be quenched by water flowing from the torch tips or in a separate operation. (*Figure 2-6*)

Figure 2-6 — Example of flame hardening with the circular band spinning method.

When heating and quenching are performed as separate operations, the heating tips may be water cooled internally, but no water sprays simultaneously onto the surface of the part.

When you are flame hardening, follow the same safety precautions that apply to welding:

- Guard against holding the flame too close to the surface and overheating the metal.
- When you are judging the temperature of the metal by color, remember the flame makes the metal appear colder than it actually is.

4.4.1 Tempering

After hardening by either case or flame, steel is often harder than needed and too brittle for most practical uses, containing severe internal stresses that were set during the rapid cooling of the process. Following hardening, you need to temper the steel to relieve the internal stresses and reduce brittleness.

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
- Cooling it, usually in still air.

If this sounds familiar, you are correct; it is the same three-stage process as in heat treatment. The difference is in the temperatures used for tempering, which will affect the resultant strength, hardness, and ductility.

You temper a steel part to reduce the brittleness caused by hardening, and develop specific physical properties; it always follows, never precedes hardening. Tempering reduces brittleness, but it also softens the steel, which you cannot avoid. However, the amount of hardness lost is controllable and dependent on the temperature you subject the steel to during the tempering process. That is true of all steels except ***high-speed steel***; tempering increases the hardness of high-speed steel.

The annealing, normalizing, and hardening processes all include steps at temperatures *above the metal's upper critical point*. Tempering is always conducted at temperatures *below the metal's low-critical point*.

When you reheat hardened steel, you begin tempering it at 212°F, and continue as the temperature increases toward the low-critical point. You can predetermine the resulting hardness and strength if you preselect the finite tempering temperature. For planning your tempering time, the minimum should be one hour, or if the part is more than one inch thick, increase the time by one additional hour for each additional inch of thickness.

With most steels, the rate of cooling from the tempering temperature has no effect on the steel. After a steel part is removed from the tempering furnace, it is usually cooled in still air, just like in the normalizing process.

However, there are a few anomalies; a few types of steel must be quenched from the tempering temperature to *prevent* brittleness. Known as blue brittle steels, they can become brittle if heated in certain temperature ranges and cooled slowly. Some nickel chromium steels are subject to this temper brittleness.

Providing there is any hardness to temper, you can temper steel that has been normalized, but you cannot temper annealed steel. What would be the purpose? If you will remember, the purpose of both normalizing (air cooled), and annealing (controlled cooling environment) was to relieve stress, the same as tempering.

Tempering relieves internal stresses from quenching, reduces hardness and brittleness, and may actually increase the tensile strength of hardened steel as it is tempered up to a temperature of about 450°F; above 450°F, tensile strength starts to decrease.

Typically, tempering increases softness, ductility, malleability, and impact resistance, but again, high-speed steel is an exception to the rule. High-speed steel *increases* in hardness on tempering, provided you temper it at a high temperature (about 1150°F). Remember, to temper a part properly, you need to remove it from the quenching bath before it is completely cold and proceed with the tempering process. Failure to temper correctly can result in a quick failure of the hardened part.

Permanent steel magnets are made of hardened and tempered special alloys whose most important properties are stability and hardness. They are tempered at the minimum tempering temperature (212°F) by placing them in boiling water for 2 to 4 hours, and because of this low-tempering temperature, are very hard.

Do not temper case-hardened parts at too high a temperature or they will lose some of their hardness. A temperature range of 212°F — 400°F is high enough to relieve quenching stresses for case-hardened parts. The design of the part can help determine the appropriate tempering temperature, and some metals do not require tempering at all.

Tempering by color range is similar in concept to heat treating by color range, but one of the first things you will notice is the extreme differences in temperature gradations. Instead of the large 750°— 2350° range with color changes in 100° — 150° (+ –) segments for heat treating, the entire range for tempering by color is only about 170° with color changes in 10° — 20° (+ –) segments. (*Figure 2-7*)

In addition, instead of being based on the fundamental metal itself and its alloys as in heat treating, tempering by color is based on surface oxides that change colors as you heat the steel. As you slowly heat a piece of polished hardened steel, you will see the surface turn various colors as the surface temperature changes; this indicates you are making structural changes within the metal.

Once the preplanned color appears, rapidly quench the part to prevent further structural change. The part may be heated by torch, furnace, hot plate, or radiation, but in all circumstances, it must be smooth and free of oil for true indication of color.

Figure 2-7 — Example of oxide colors for tempering steel.

Cold chisels and similar tools must have hard cutting edges with softer bodies and heads. The heads must be tough but not brittle to prevent shattering when struck, the cutting edge must be twice as hard (or more) as the head, and the zone separating the two must blend the two extremes without a line of demarcation that would encourage breakage.

One method frequently used for tempering chisels and similar tools is one in which the cutting end is heated and tempered by the residual heat of the opposite end of the same tool.

To simultaneously harden and temper a cold chisel by this method:

- Heat the tool to the proper hardening temperature.
- 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 (normalizing) while rapidly quenching the cutting edge (hardening).

The result is a tough head, a fully hardened cutting edge, and a properly blended structure.

Figure 2-8 — Typical cold chisel tempering areas.

When the cutting end has cooled:

- Remove the chisel from the bath.
- Quickly polish the cutting end with a buff stick (emery).
- Watch the polished surface for heat from the opposite end feeding back into the quenched end.
  - Oxide colors will appear on the hardened end as the temperature increases, progressing from pale yellow, to a straw color, and finally to blue colors.

As soon as the correct shade of blue appears:

- Quench the entire chisel to prevent further softening of the cutting edge.
  - Temper the hardened end as soon as the proper oxide color appears; quenching merely prevents further tempering by halting the process.
  - This final quench has no effect on the body and the head of the chisel. Their temperatures will have dropped below the critical point by the time the proper oxide color appears on the cutting edge.

By completing this described process, you will have hardened and tempered the chisel, and it only needs grinding.

The oxide color at which you quench the steel during tempering will vary with the properties you want to attain in the part. Refer again to *Figure 2-7.* To see the colors clearly, turn the part from side to side under good lighting conditions. While hand tempering can produce the same result as furnace tempering, there is a greater possibility for error, so the slower you perform the operations the more accurate your results will be.

Test your Knowledge (Select the Correct Response)

1. **(True or False)** To make a metal more useful, heat treating can make it stronger, more resistant to impact, malleable, and ductile with one process.

   A. True
   B. False

5.1.1 QUENCHING MEDIA

The rate at which you can cool an object will depend on several factors:

- Size of the part
  - The mass of the part will affect quenching; the greater the mass, the greater the time required for complete cooling.
- Configuration of the part
  - Parts may be of the same size, but those containing holes or recesses cool more rapidly than solid objects.
- Composition of the part
  - The composition of a metal will determine the maximum cooling rate possible without the danger of cracking or warping.
- Initial temperature of the part
  - Different steels and steel alloys require a wide range of temperatures for heat treatment.
- Final properties desired
  - The medium must cool the metal at the rate you need (rapidly or slowly) to produce the results you want.

Each is a factor in deciding which quenching medium you should use.

The value of any quenching medium's cooling rate upon a quenched part will vary with the medium's temperature; therefore, to get uniform results, you must keep the medium's temperature within prescribed limits.

The quenching medium's absorption of heat will also depend on the circulation of the medium or the movement of the part; agitating the liquid or the part breaks up gas that forms an insulating blanket between the part and the liquid, hence increasing the time element to cool to a given temperature.

Normally, when you quench a metal, hardening occurs and the metal's composition will determine the type of quench to use to achieve the desired hardness.

For example, shallow-hardened, low-alloy, and carbon steels require more severe quenching than deep-hardened alloy steels with large quantities of nickel, manganese, or other elements. Therefore, the shallow-hardening steels are usually quenched in water or brine while the deep-hardening steels are usually quenched in oil.

Sometimes it is necessary to use a combination quench (starting with brine or water and finishing with oil), for in addition to producing the desired hardness, the quench must minimize cracking, warping, and soft spots.

The quenching liquid's volume needs to be large enough to absorb all the heat during a normal quenching operation.

As you quench more metals, the medium's temperature will rise as the liquid absorbs the heat.

This temperature rise will cause a decrease in the cooling rate, which in turn will negatively affect your efforts to harden the metal.

Some tanks use mechanical means to keep temperatures at prescribed levels during continuous operations, such as the heat exchanger shown in *Figure 2-9*.

Figure 2-9 — Example of a controlled temperature quench tank.

5.1.1 Liquid Quenching

There are two methods for liquid quenching:

- Still-bath
    - Metal is cooled in a tank of liquid; only movement of the liquid is caused by movement of the hot metal.
- Flush quenching
    - Liquid is sprayed onto the surface and into every cavity at the same time to ensure uniform cooling; used for parts with recesses or cavities not quenchable by ordinary methods; assures a thorough and uniform quench; reduces the possibilities of distortion.

As already mentioned, for satisfactory heat treating results, quenching liquids must be maintained at uniform temperatures; this is particularly true for oil. Many commercial operations that use oil-quenching tanks maintain the oil bath at their proper temperature by circulating the oil medium through coils that themselves are water cooled. Self-contained coolers are an integral part of large quench tanks.

Quenching tanks have a wide range of capabilities, from the large commercial polymer-quenching tank shown in *Figure 2-10 View A*, to the small portable water- and oil-quenching tank that may be available to the Seabees, shown in *Figure 2-10 View B*.

Figure 2-10 — Examples of the wide range of quenching tanks.

The typical portable quenching tank shown in *Figure 2-10 View B* can be moved to various parts of the Steelworker shop for heat treating as needed. These portable tanks may have just one compartment, but typically, they have compartments for containing water in one segment and oil in another, with a liquid-tight partition 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. In addition, shops can attach a portable electric pump or a mechanical agitation mixer to the rim of the tank for liquid circulation to aid in uniform cooling.

5.1.1 Water

You can use water to quench some forms of steel, but water is not recommended for ***tool steel*** or other alloy steels. Water absorbs large quantities of atmospheric gases, which have a tendency to form bubbles on the metal's surface when you quench a hot piece. The bubbles tend to collect in holes or recesses causing soft spots that can lead to cracking or warping.

For any given part to be treated, the quench tank must meet the following criteria:

- Large enough to hold the part being treated
- Adequate circulation and temperature control
- Water temperature not exceeding 65°F

- Water volume large enough to prevent a temperature rise of more than 20°F during a single operation
    - Temperature rise may exceed 20°F for heavy-sectioned parts but should be kept as low as possible,
    - For wrought products, temperature should be about 65°F and never exceed 100°F before the piece enters the liquid,
- Water changed daily; more often if required

When you quench aluminum alloys and other nonferrous metals, always quench them in clean water.

5.1.2 Brine

You prepare brine by dissolving common rock salt in water. The brine solution should contain from 7% to 10% salt by weight or three-fourths pound of salt for each gallon of water. Brine reduces the water's absorption of atmospheric gases, thus reducing the amount of bubbles and allowing greater surface contact to cool the part more rapidly than water. The correct temperature range for a brine solution is 65°F to 100°F.

You can quench low-alloy and carbon steels in brine solutions, but brine is not recommended for high-carbon or low-alloy steels with uneven cross sections; the rapid cooling rate of brine can cause cracking or stress in the latter.

In addition to rapid and uniform cooling, a brine medium removes a large percentage of any scale that may be present, but do not quench nonferrous metals in brine due to the corrosive action brine has on these metals.

5.1.3 Oil

Use oil to quench high-speed and oil-hardened steels and preferably all other steels if you can obtain the required hardness. Practically any type of obtainable oil is acceptable as quenching oil, including the various animal oils, fish oils, vegetable oils, and mineral oils.

Oil is classed as an intermediate quench; its cooling rate is slower than brine or water but faster than air. Keep the quenching oil's temperature within a range of 80°F to 150°F.

In small amounts, the water that usually collects in the bottom of a quenching oil tank is not harmful, but in large quantity it can interfere with the quenching operations. For example, if the end of a long piece extends through the oil into the water at the bottom of the tank, the more rapid cooling action of the water can cause the piece to crack.

Nonferrous metals are not routinely oil quenched unless called for in the specifications.

Table 2-2 provides the properties and average cooling rates of various quenching oils relative to water.

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

Quenching Media	Cooling Rate Compared to Water	Flash Point (°F)	Fire Point (°F)
Caustic Soda (Sodium Hydroxide) (10%)	2.06		
Brine (10%) at 65°	1.96		
Water at 65°	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		

5.1.4 Caustic Soda

Only use ***caustic soda*** for specific types of steel that require extremely rapid cooling. Refer to *Table 2-2*. Like brine, a solution of water and caustic soda (10% caustic soda by weight) has a higher cooling rate than water. However, caustic soda (note the name “caustic”) requires special attention.

CAUTION

Never quench nonferrous metals in caustic soda

Caustic Soda requires special handling because of its harmful effects on skin and clothing

5.2.0 Dry Quenching

As the term implies, when you dry quench, you are using materials other than liquids and in most cases only to slow the cooling rate to prevent warping or cracking.

5.2.1 Air

You use air quenching for cooling some highly alloyed steels. If you use still air, place each tool or part on a suitable rack so air can reach all sections of the piece.

If you use circulated air, place them in the same manner in a suitable rack, but ensure that the circulated air from the source reaches the parts equally for uniform cooling.

You can use compressed air to concentrate cooling on specific areas of a part, but to prevent cracking the metal you must first ensure that the air lines are dry and free of the moisture that typically builds in compression tanks and lines.

To quench nonferrous metals, you should use water, but when necessary, you can use forced-air drafts to cool pieces too large to fit into the quench tank. However, you should only use an air quench for nonferrous metal 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 air quench.

5.2.2 Solids

The solids you can use for cooling steel parts include cast iron chips, lime, sand, and ashes. Generally, you would use them to slow the rate of cooling; for example, you might place a cast iron part in a lime box after welding to prevent cracking and warping. Regardless of which solid you select, it must be free of moisture to prevent uneven cooling.

Summary

This chapter has covered just a few elements of the heat treating theory and explained how you can change the properties of a metal. The heat treatment you apply as a Steelworker can, if done properly, extend the service life of appropriate TOA parts and equipment. Conversely, if done improperly, you could shorten the service life.

To recognize the appropriate treatment for achieving the desired properties for a selected metal is your challenge. However, you should now be able to recognize a reference chart for color temperature, and be able to select a suitable general method of heat treatment with the correct quenching medium to achieve the targeted properties. You may not achieve the ultimate properties on the first try, but repeated practice and experimentation will improve your ability in this set of skills.

Review Questions (Select the Correct Response)

1. What process consists of tempering, normalizing, hardening, and annealing?

   A. Cold forming of metals
   B. Heat treatment of nonferrous metals
   C. Heat treatment of ferrous metal
   D. Quenching of austenitic materials

2. **(True or False)** Most nonferrous metals can be normalized and case hardened but not annealed.

   A. True
   B. False

3. Which of the following conditions is required for the successful heat treatment of metals?

   A. Proper size of furnace
   B. Proper furnace atmosphere
   C. Suitable quenching medium
   D. All of the above

4. What type of furnace produces an atmosphere consisting of a gas/air combustion product?

   A. Oil-fired only
   B. Both gas-fired and electric
   C. Both oil-fired and gas-fired
   D. Both oil-fired and electric

5. Which of these gas mixtures are constituents of a fuel-fired furnace atmosphere?

   A. Carbon dioxide, hydrogen, oxygen, and nitrogen
   B. Carbon monoxide, nitrogen, argon, and radon
   C. Hydrogen, bromine, oxygen, and chlorine
   D. Hydrogen, oxygen, argon, and radon

6. What allows you to provide an oxidizing, reducing, or neutral atmosphere in a fuel fired furnace?

   A. Varying the type of fuel
   B. Construction of the furnace
   C. Varying the proportion of air to fuel
   D. All of the above

7. What type of furnace(s) allows the atmosphere to consist of air only?

   A. Oil-fired
   B. Electric
   C. Both oil-fired and gas-fired
   D. Both oil-fired and electric

8. What is the primary cause of distortion and cracking of the heat-treated part?

   A. Heating the part too slowly
   B. Increasing the soaking temperature too slowly
   C. Uneven expansion due to carbon deposits in the part
   D. Heating one section of the part more rapidly than other parts

9. How do you determine the soaking period when parts are uneven in cross section?

   A. By the total weight
   B. By the largest section
   C. By the lightest section
   D. By the number of parts

10. What type of medium is normally used to quench nonferrous metals?

   A. Oil
   B. Brine
   C. Air
   D. Water

11. What effect is produced when steel is cooled very slowly in a medium that does NOT conduct heat easily?

   A. Maximum softness
   B. Maximum hardness
   C. Maximum ductility
   D. Minimum ductility

12. Copper becomes hard and brittle when mechanically worked, but it can be made soft again by annealing. Within what temperature range must you heat it to anneal it?

   A. 500°F to 600°F
   B. 600°F to 700°F
   C. 700°F to 900°F
   D. 900°F to 1100°F

13. **(True or False)** Normalizing is a form of heat treatment applicable to nonferrous metals only.

   A. True
   B. False

14. Which of these metals are difficult to harden by heat treatment?

    A. Wrought irons
    B. Pure irons
    C. Extremely low-carbon steels
    D. All of the above

15. What factor almost completely determines the maximum obtainable hardness in plain carbon steel?

    A. The carbon content of the steel
    B. The thickness of the steel
    C. The heating time
    D. The temperature to which it was heated

16. What case-hardening method produces the hardest surface of any of the hardening processes?

    A. Nitriding
    B. Cyaniding
    C. Carburizing
    D. Halogenizing

17. If the steel parts are placed in a container packed with charcoal and heated in a furnace, what case-hardening process is being used?

    A. Cementation
    B. Pack hardening
    C. Carburizing
    D. Atmospheric cementation

18. On what areas of a part being flame hardened should a slightly oxidizing flame be used?

    A. Flat surfaces
    B. Corners and grooves
    C. Rounded surfaces
    D. Edges and elongated sections

19. Which of these factors determines the rate at which you move the welding torch when flame hardening a steel part?

    A. Mass of the part
    B. Shape of the part
    C. Depth of the hardness desired
    D. All of the above

20. **(True or False)** Flame hardening can produce a hard case that resists wear while the core retains the metal's original properties.

    A. True
    B. False

21. What term is used to describe the process of heating steel to a specific temperature (below its hardening temperature), holding this temperature for a certain length of time, and then cooling the steel in still air to room temperature?

    A. Annealing
    B. Hardening
    C. Tempering
    D. Case hardening

22. **(True or False)** Steel can be tempered provided some hardness remains after it has been normalized.

    A. True
    B. False

23. In which of the following metals are the softness, ductility, and resistance to impact NOT increased?

    A. Aluminum
    B. High-speed steel
    C. Low-carbon steel
    D. Already hardened steel

24. What are the most important properties to be obtained in tempering permanent steel magnets?

    A. Stability and malleability
    B. Softness and malleability
    C. Hardness and stability
    D. Ductility and resistance to wear

25. Why should you agitate the part or the quenching medium when cooling a part?

    A. To break up gases that form
    B. To induce oxidation
    C. To reduce the cooling rate
    D. To raise the temperature of the liquid

26. For which of the following reasons is the flush method of quenching better than other quenching methods for parts having cavities or recesses?

    A. It enables formation of gases that enhance the hardening process.
    B. It introduces oxygen into the process to increase the temperature.
    C. It ensures a thorough uniform quench as liquid is sprayed all over the parts.
    D. It facilitates the formation of gases that help reduce the temperature.

27. What temperature should water not exceed when used as a quenching medium?

    A. 65°F
    B. 75°F
    C. 85°F
    D. 95°F

28. Which of these quenching media has the highest cooling rate compared to water?

    A. Fuel oil
    B. Prepared oil
    C. Brine, 10% solution at 65°F
    D. Caustic soda (sodium hydroxide), 10% solution

29. What is the correct solution for a brine quench medium?

    A. 3.8% salt for every 3 gallons of water at 65°F
    B. 3/4 pound of salt per gallon of water at 65°F to 100°F
    C. 20% salt solution for the entire mix
    D. 3/4 pound of salt per 100 gallons of water

30. **(True or False)** Caustic soda requires special handling because of its harmful effects on skin and clothing.

    A. True
    B. False

31. **(True or False)** Air quenching should only be used for nonferrous metals

    A. True
    B. False

Trade Terms Introduced in this Chapter

Case hardened	Case hardening or surface hardening is the process of hardening the surface of a metal, often a low-carbon steel, by infusing elements into the material's surface, forming a thin layer of a harder alloy. Case hardening is usually done after the part in question has been formed into its final shape.
Caustic Soda	Sodium hydroxide (NaOH), also known as lye and caustic soda, is a caustic metallic base. It is used in many industries, mostly as a strong chemical base in the manufacture of pulp and paper, textiles, drinking water, soaps and detergents, and as a drain cleaner.
Cementite	Hard, brittle iron carbide (Fe_3C) in steel, cast iron, and iron-carbon alloys.
Cooling medium	Any gas, liquid, solid, or combination used specifically to cool a metal to room temperature during a heat-treating process.
High-speed steel	High-speed steel is a general name for high alloy steels that retain their hardness at very high temperatures and are used for metal-cutting tools. All high-speed steels are based on either tungsten or molybdenum (or both) as the primary heat-resisting alloying element. These steels require a special heat so that their unique properties can be fully realized. The manufacturing process consists of heating the steel to a temperature of 2,150°F to 2,400°F (1,175°C to 1,315°C) to obtain solution of a substantial percentage of the alloy carbides, quenching to room temperature, tempering at 1,000°F to 1,150°F (535°C to 620°C), and again cooling to room temperature.
Hot-shortness	Brittleness in metals during high temperature deformation.
Quenching	Quench hardening is a mechanical process in which steel and cast iron alloys are strengthened and hardened. This is done by heating the material to a certain temperature, differing upon material, and then rapidly cooling the material. This produces a harder material by either surface hardening or through-hardening, varying according to the rate at which the material is cooled. The material is then often tempered to reduce the brittleness that may increase from the quench- hardening process.
Spalling	To break up into chips or fragments; to chip or crumble.

Tool steel	A variety of carbon and alloy steels particularly well suited for making into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, ability to hold a cutting edge, and/or resistance to deformation at elevated temperatures (red-hardness). Tool steel is generally used in a heat-treated state. With a carbon content between 0.7% and 1.4%, tool steels are manufactured under carefully controlled conditions to produce the required quality and are made to a number of grades for different applications.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Althouse, Andrew D., Carl H. Turnquist, and William A. Bowditch, *Modern Welding, 10th Edition,* Goodheart-Wilcox Co. Inc., 2004.

Fundamentals of Machine Tools, *Training Circular Number 9-524 (TC 9-524)*, Headquarters, Department of the Army, Washington D.C., 1976

Giachino and Weeks, *Welding Skills, 5th Edition,* American Technical Publishers Inc., Chicago, IL., 1985.

Naval Construction Force Welding Materials Handbook, P-433, Naval Facilities Engineering Command, Department of the Navy, Washington D. C., 1991.

Operator's Manual for Welding Theory and Application, Training Manual 9-237 (TM 9-237), Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1976.

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Chapter 3

Introduction to Welding

Topics

To hear audio, click on the box.

Overview

Welding is a fabrication or sculptural process that joins materials (usually metals or thermoplastics) by causing coalescence, often by melting the work-pieces and adding a filler material to form a pool of molten material (the *weld pool*) that cools to become a strong joint.

Welding is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the workpieces to form a bond between them, without melting the workpieces.

Of the many methods for joining metals, welding is one of the most convenient and rapid, as well as one of the most permanent. Welding has been used since ancient times through the process of forge welding where two pieces were heated to near melting temperature and hammered together. The roots of modern welding began in the late 19th century and progressed rapidly through two World Wars.

Today's welding techniques and processes continue to develop to fit various needs, from simple steel brackets to nuclear reactors. For the Navy, commercial enterprises, governmental agencies, and many other institutions around the world, welding is a widely accepted technique for the fabrication, maintenance, and repair of parts and structures.

As with all the Seabee rating skills, you cannot become a proficient welder by reading a book, you need practice to build experience. However, you can gain a great deal of knowledge through study. For instance, by learning the correct equipment setting, set up method, or procedure from a book, you may eliminate many mistakes that otherwise would occur through trial and error.

This chapter will provide a background of basic information applicable to welding in general. Later chapters will provide more detailed information on various welding methods.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the welding processes.
2. Define welding terminology.
3. Describe the different types of welded joint designs.
4. Describe the different welding positions.
5. Describe procedures associated with expansion and contraction.
6. Describe procedures associated with the welding process.
7. Interpret the different types of diagrams associated with welding.
8. State the safety precautions associated with welding.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet-Metal and Fiberglass Duct		
Welding Quality Control		
Flux Core Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 WELDING PROCESSES

Forge welding, the earliest known form of welding, dates back to 2000 B.C.

A primitive process, forge welding joins metals by heating and hammering until the metals are fused together (*Figure 3-1*).

Forge welding still exists, but it is mainly limited to the blacksmith trade and to the artisans recreating replicas of historical metal implements and weapons.

Figure 3-1 — Example of forge welding process.

Today, there are multitudes of welding processes available. This course will cover only a few, but they are the most common of the welding applications.

Figure 3-2 provides a list of processes used in modern metal fabrication and repair. Published by the American Welding Society (AWS), this list shows the official abbreviations for each process; for example, RSW stands for resistance spot welding and SMAW stands for shielded metal arc welding. The primary differences between the various welding processes are the methods by which heat is generated to melt the metal.

Arc welding is a process that fuses metal by heating it to a melting temperature with an electric arc created between an electrode and the metals being joined. The carbon arc welding (CAW) process is the oldest of all the arc-welding processes and is considered the beginning of arc welding. The Welding Society defines carbon arc welding as *"an arc welding process which produces coalescence of metals by heating them with an arc between a carbon electrode and the work-piece. No shielding is used. Pressure and filler metal may or may not be used."* It has limited applications today, but a variation called twin carbon arc welding is more popular, while yet another variation uses compressed air for cutting.

Carbon arc welding has developed into the currently popular shielded metal arc welding (SMAW) process defined as *"an arc welding process which produces coalescence of metals by heating them with an arc between a covered metal electrode and the work-piece. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode."*

The most common types of welding are resistance welding (RW), oxyfuel gas welding (OFW), and arc welding (AW). Of the welding processes listed in *Figure 3-2*, shielded metal arc welding, also called stick welding, is the most common welding process. Your primary concern as a Steelworker will be gas and arc welding, the difference being in the method you use to generate the heat. Once you understand the theory of welding, you can apply it to most welding processes.

Figure 3-2 — Example of the multitude of welding processes.

1.1.0 Gas Welding

The oxyfuel gas welding process (OFW), shown in *Figure 3-3*, is one of the most popular welding methods. Heat is produced by mixing and burning oxygen with a combustible gas such as acetylene or MAPP (methylacetylene-propadiene).

Gas welding is widely used for maintenance and repair work because of the ease in transporting oxygen and fuel cylinders. Once you learn the basics and begin to practice OFW, you will find the process is adaptable to brazing, cutting, and heat treating.

Figure 3-3 — Example of oxyfuel gas welding (OFW).

1.1.1 OXYFUEL GAS Welding (OFW) 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 with a temperature between 5700°F and 6300°F. Acetylene is a colorless gas, but has a disagreeable odor that is readily detected even when the gas is highly diluted with air.

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.

WARNING

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 h ours before using. This allows the acetone t o se ttle to t he bottom o f t he cylinder. A cetone c ontaminates t he hoses, regulators, and torch, and disrupts the flame.

Acetylene is measured in cubic feet. The most common cylinder sizes are 130-, 290-, and 330-cubic-foot capacity. A common standard size cylinder holds 225 cubic feet of acetylene.

1.1.2 OXYFUEL GAS Welding (OFW) MAPPGAS

MAPP (methylacetylene-propadiene) is an all-purpose industrial fuel having the high-flame temperature of acetylene but the handling characteristics of propane. MAPP is a liquid 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.

The total weight for a MAPP cylinder, which has the same physical size as a 225-cubic-foot acetylene cylinder, is 120 pounds (70 pounds of which is MAPP gas). MAPP cylinders contain only liquid fuel, with 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 period.

MAPP produces a flame temperature of 5300°F when burned with oxygen, 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.

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. This characteristic allows MAPP to be excellent for underwater work.

1.2.0 Arc Welding

The arc welding process uses an electric arc to join the metals being welded. This allows concentrated heat on the work material, a distinct advantage of arc welding over gas welding.

In gas welding the flame spreads over a large area, sometimes causing heat distortion. Concentrated heat, characteristic of arc welding, is an advantage because less heat spreads to the rest of the work material. While buckling and warping can still be a problem with both processes if unattended, they are less so with arc welding.

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, particularly as the work material depth increases.

1.2.1 ommon Arc Welding Processes

All arc-welding processes have three things in common: a heat source, filler metal, and shielding. In arc welding, you produce heat by arcing an electrical current between two contacts. The power source for the electrical current’s arc is a welding machine, or more commonly called a welder. This is also the same term for the person performing the operation, so do not confuse the two when communicating: “When a welder is welding, he or she is using the welder.” The welder (welding machine) can be either plug-in electric or motor-powered to produce the electricity. As a member of the Naval Construction Force (NCF), you need to become familiar with the two main types of arc-welding processes: shielded metal arc welding (SMAW) and gas shielded arc welding (a generic term that covers a number of specific processes).

1.2.1.1 Shielded Metal Arc Welding (SMAW)

You perform shielded metal arc welding (*Figure 3-4*) with an arc between a coated metal electrode and the base metal. Once you establish the arc (called striking the arc), the molten metal from the tip of the electrode flows together with the molten metal from the base metal to form a sound joint. This process is known as ***fusion*****.**

The coating from the electrode melts and forms a covering over the weld deposit, shielding it from contamination; hence, the name shielded metal arc welding**.** SMAW’s advantages are: 1) high-quality welds 2) made rapidly 3) at low cost. Additional information about shielded metal arc welding will be presented later in this course.

Figure 3-4 — Example of shielded metal arc welding (SMAW).

1.2.1.2 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. Gas shielded arc welding is extremely useful because it can be used to weld all types of ferrous and nonferrous metals of all thicknesses.

1.2.1.2.1 Gas Tungsten Arc Welding (GTAW)

GTAW or “TIG” (*Figure 3*-5) is one gas shielded arc welding process. Features of TIG include:

- Uses a non-consumable tungsten electrode during the welding process
- Uses a number of shielding gases including helium (He) and argon (Ar)
- Is easily applied to thin materials
- Produces very high-quality, superior welds
- Allows welds to be made with or without filler metal
- Provides precise control of welding variables (i.e., heat)
- Yields low distortion welding
- Leaves no ***slag*** or splatter

Figure 3-5 — Example of tungsten metal arc welding (GTAW) (TIG).

1.2.1.2.2 Gas Metal Arc Welding (GMAW)

GMAW or “MIG” (*Figure 3*-6) is a second gas shielded arc welding process. Features of MIG include:

- Uses a consumable wire electrode during the welding process that is fed from a spool
- Provides a uniform weld bead
- Produces a slag-free weld bead
- Uses a shielding gas, usually argon, argon with 1 to 5% oxygen, argon with 3 to 25% $CO_{2,}$ or a combination argon/helium gas
- Is considered a semi-automatic welding process
- Allows welding in all positions
- Requires less operator skill than TIG welding
- Allows long welds to be made without starts or stops
- Needs little cleanup

Figure 3-6 — Example of gas metal arc welding (GMAW) (MIG).

1.2.1.2.3 Flux Core Arc Welding (FCAW)

FCAW (*Figure 3*-7) is a third gas shielded arc welding process. Features of FCAW include:

- Can be a semi-automatic or automatic process
- Uses a continuously fed consumable tubular electrode containing a flux
- Is widely used in construction because of its high welding speed and portability

Figure 3-7 — Example of flux core arc welding (FCAW).

- One type of FCAW requires no shielding gas
  - The flux core in the tubular consumable electrode core contains more than just flux; it also contains various ingredients that when exposed to the high temperatures of welding generate a shielding gas for protecting the arc.
  - This type of FCAW is attractive because it is portable and generally has good penetration into the base metal. In addition, windy conditions are not as much of a factor as much for the process requiring shielding gas.
  - There are some disadvantages. This process can produce excessive, noxious smoke (making it difficult to see the weld pool); under some conditions, it can produce welds with inferior mechanical properties; the slag is often difficult and time-consuming to remove, and operator skill can be a major factor.

- Another type of FCAW uses a shielding gas that must be supplied by an external supply.
  - This is known informally as "dual shield" welding. This type of FCAW was developed primarily for welding structural steels. In fact, since it uses both a flux-cored electrode and an external shielding gas, one might say that it is a combination of gas metal (GMAW) and flux-cored arc welding (FCAW). This particular style of FCAW is preferable for welding thicker and out-of-position metals. The slag created by the flux is also easy to remove.
  - The main advantages of this process is that in a closed shop environment, it generally produces welds of better and more consistent mechanical properties, with fewer weld defects, than either the SMAW or GMAW processes. In practice, it also allows a higher production rate, since the operator does not need to stop periodically to apply a new electrode, as is the case in SMAW.
  - Some disadvantages: like GMAW, it cannot be used in a windy environment, as the loss of the shielding gas from air flow will produce visible porosity (small craters) on the surface of the weld.

1.2.1.3 Resistance Spot Welding

Spot welding (*Figure 3-8*) is a process in which contacting metal surfaces are joined by heat resistance to electric current flow. Work-pieces are held together under pressure by two shaped copper alloy electrodes. They simultaneously clamp and concentrate a welding current into a small "spot." Forcing a large current through the spot melts the metal (typically 0.5-3.0 mm thickness range) to form the weld without a filler metal.

Figure 3-8 — Example of resistance spot welding (RSW) equipment.

Which one is the right one for your project? There are no fixed rules. In general, the controlling factors are these:

- Types of metal you are joining
- Nature of the products you are fabricating
- Techniques you use to fabricate them
- Cost involved

Oxyfuel Gas welding (OFW) is widely used for maintenance and repair work in the field because of its flexibility and mobility. On the other hand, if you are tasked with repairing a critical piece of equipment made from aluminum or stainless steel, you should probably choose one of the gas shielded metal arc welding processes.

No matter which process you use, there is some basic information you need to know since it applies to all the processes. The remainder of this chapter is devoted to this type of information. Study this information carefully; knowing it will allow you to follow welding instructions, read welding symbols, and weld various types of joints using the proper welding techniques.

Test your Knowledge (Select the Correct Response)

1. **(True or False)** Welding is similar to soldering and brazing, in that you form a bond between materials by melting the workpieces.

   A. True
   B. False

2.0.0 WELDING TERMINOLOGY

To become a skilled welder, the first thing you need to learn is the technical vocabulary of welding. The next sections will present some of the basic welding terms. Once you understand the language of welding, you will be prepared to interpret and communicate welding information accurately.

2.1.0 Filler Metals

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

Figure 3-9 — Typical use of welding rod (filler rod).

Welding rod (*Figure 3-9)*, 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.

Electrode refers to the component in electric arc welding that conducts the current from the electrode holder to the metal being welded. Electrodes are classified into two groups: consumable and non-consumable.

Consumable electrodes not only provide a path for the current, they also supply the filler metal to the joint.

The electrode used in shielded metal arc welding is an example (*Figure 3-10*).

Figure 3-10 — Example of consumable electrode.

Non-consumable electrodes are used only as a conductor for the electrical current.

The electrode in gas tungsten arc welding is an example (*Figure 3-11*).

The filler metal for gas tungsten arc welding is a hand-fed consumable welding rod.

Figure 3-11 — Example of non-consumable electrode.

You will find additional information about filler rods and electrodes in other chapters of this course, which cover specific welding processes.

2.2.1 Fluxes

Flux is a chemical cleaning agent that facilitates soldering, brazing, and welding by removing oxidation from the surface of metals to be joined. In high-temperature metal joining processes, the primary purpose of flux is to prevent oxidation of the base and filler materials.

Before performing any of the welding processes, you must ensure the base metal is clean. No matter how much the base metal is physically cleaned, it is not chemically clean; it still contains impurities called oxides, the result of oxygen combining with the metal and other contaminants within the base metal. Unless you remove these oxides with a proper flux, your weld may be faulty.

Flux is the material used to dissolve oxides and release trapped gases and impurities from the base metal. Thus, the reason flux is thought of as a cleaning agent is that it allows the filler metal and the base metal to be fused.

Different types of metals require different types of fluxes; therefore, you need to select a flux formulated for a specific base metal. Beyond that, you need to select a flux based on the expected temperature if you are soldering, brazing, or welding.

When you are brazing, for example, you should select a flux that becomes liquid at the correct brazing temperature, so when it melts, you 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.

Table 3-1 — Typical Flux Selection Chart (Example)

Flux Name	Base Metal	Recommended Filler Metal	Form	Applications / Description	ActiveTemp	Specification
Flux17	Stainless Steels, High Chrome Alloy And Carbides	Nickel Silver, Brass And Bronze, Low Silver Alloys	Powder	Carbide Tools, Restaurant Appliance Mining Tools	1400-2200° F	AWS Type 3D
Flux11	Cast And Malleable Iron	Low Fuming Bronze	Paste	Maintenance, Marine Engines	1500-2000° F	Mil-F-16136B
Flux800	Cast Iron	Cast Iron	Powder	All Cast To Cast Iron Joining	950-1300° F	N/A

Fluxes are available in many different forms. Fluxes for oxyfuel gas applications, such as brazing and soldering, can be a paste, liquid, or powder. Paste and liquid fluxes can be applied to the filler rod and to the base metal with a brush. Powders can be sprinkled on the base metal, or the filler rod can be heated and dipped into the powder.

For shielded metal arc welding, the flux is a coating on the exterior of the electrode. In this case, as the electrode applies the filler metal, 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.

Because of the wide variety of metal properties and different melting temperatures, no single flux is satisfactory for universal use; however, there are many 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, and remember: **ALL welding operations require adequate ventilation whether a flux is used or not.**

2.3.0 Weld Joints

The weld joint is where two or more metal parts are joined by welding. The five basic types of weld joints are butt, corner, tee, lap, and edge.

A butt joint is used to join two members aligned in the same plane (*Figure 3-12*).

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 presented later in this chapter.

Figure 3-12 — Example of a butt joint.

Corner joints (*Figure 3-13 View A*) and tee joints (*Figure 3-13 View B*) are used to join two members located at right angles.

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.

Figure 3-13 — Examples of a corner joint and a tee joint.

Commonly used with torch brazing and spot welding applications, a lap joint, as the name implies, is made by lapping one piece of metal over another (*Figure 3-14*).

This is one of the strongest types of joints; however, for maximum joint efficiency, you should overlap the metals a minimum of three times the thickness of the thinnest member you are joining.

Figure 3-14 — Example of a lap joint.

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 3-15*.

This type has some applications in plate work, but is more useful in sheet metal work. An edge joint should only be used for joining metals 1/4 inch thick or less that are not subjected to heavy loads.

Figure 3-15 — Example of an edge joint.

While there are five basic types of joints, there are many possible variations and combinations of the five, some of which will be presented later in this chapter.

2.4.1 Parts of Joints

There are many joint variations, but the parts of a joint are described by standard terms.

Figure 3-16 — Examples of the root of a joint.

The root of a joint is that portion of the joint where the metals are closest to each other. As shown in *Figure 3-16*, the root may be a point, a line, or an area when viewed in cross section.

The groove of a joint 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; see *Figure 3-17 View A*.

Figure 3-17 — Examples of groove face, root face, and root edge of joints.

A given joint may have a root face or a root edge.

The root face (refer again to *Figure 3-17 View A*), is that portion of the prepared edge of a part to be joined by a groove weld that has not been grooved; the root face has relatively small dimensions.

Essentially, a root edge is a root face of zero width; see *Figure 3-17 View B*.

Now look at *Figures 3-17 Views C* and *D*. In some joints, the groove face and the root face are the same metal surfaces.

The specified requirements for a particular joint are expressed in such terms as bevel angle, groove angle, groove radius, and root opening.

The bevel angle is the angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member (*Figure 3-18*).

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

Figure 3-18 — Examples of bevel angle and groove angle.

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 (*Figure 3-19*).

The root opening refers to the separation between the parts to be joined at the root of the joint, sometimes called the root gap.

Figure 3-19 — Examples of groove radius and root opening.

To determine the bevel angle, groove angle, and root opening for a joint, you must consider these factors:

- Thickness of the weld material
- Type of joint to be made
- Welding process to be used

As a 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.

Figure 3-20 illustrates the terms root penetration and joint penetration of welds.

Figure 3-20 — Examples of root penetration and joint penetration of welds.

Root penetration refers to the depth that a weld extends into the root of the joint. Root penetration is measured on the centerline 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.

Observe *Views A, C,* and *E*. Often, the terms root penetration and joint penetration both refer to the same dimension. Notice *View B*, however; it 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 (*Figure 3-21*).

Figure 3-21 — Example of face reinforcement and root reinforcement.

2.5.1 Types of Welds

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

The first type of weld you will learn to produce is called a weld bead, also referred to simply as a bead (*Figure 3-22*).

A weld bead is merely a weld deposit produced by a single pass with one of the welding processes.

It may be narrow or wide, depending on the amount of transverse oscillation (side-to-side movement) you use.

If you use a great deal of oscillation, the bead is wide; if you use little or no oscillation, the bead is narrow.

Figure 3-22 — Example of weld bead.

A narrow weld bead made without much weaving motion is often referred to as a stringer bead; a weld bead made with side-to-side oscillation is called a weave bead.

Groove welds (*Figure 3-23*) are made in the groove between two members of a work-piece and are adaptable to a variety of butt joints of varying thicknesses.

Figure 3-23 — Examples of standard groove welds on varying thicknesses.

If two or more beads are deposited in the groove, the weld is made with multiple-pass layers, as shown in *Figure 3-24*.

As a rule, a multiple-pass layer is made with stringer beads (narrow) in manual operations.

As a Steelworker, if you are assigned welding tasks, you will frequently use groove welds in both single and multiple passes.

Figure 3-24 — Example of multiple pass layers.

Buildup sequence is another term you need to be familiar with when making a multiple-pass weld.

Buildup sequence refers to the order in which you deposit the beads in the joint of a multiple-pass weld (*Figure 3-25*).

Interpass temperature is another term you need to know. Often, welding instructions will specify an interpass temperature.

This term refers to the temperature you must allow the previous pass to lower to before applying the next pass.

Figure 3-25 — Example of weld layer sequence.

When the effect of heat on metal is addressed later in this chapter, you will be able to appreciate the significance of buildup sequence and the importance of controlling the interpass temperature.

A fillet weld is used to join two surfaces at approximately right angles to each other in a lap, tee, or corner joint. The shape of a fillet weld’s cross-sectional view is triangular (*Figure 3-26*).

Figure 3-26 — Examples of fillet welds.

Surfacing is a welding process used to apply a hard, wear-resistant layer of metal to surfaces or edges of parts as either a preventative to wear, or a remedy for already worn parts (*Figure 3-27*).

It is one of the most economical methods of conserving and extending the life of machines, tools, and construction equipment.

Sometimes known as hardfacing or wearfacing, a surfacing weld is composed of one or more stringer or weaves beads.

Figure 3-27 — Example of surfacing (hardfacing/wearfacing) welds.

A tack weld is a temporary weld made to hold parts of an assembly in proper alignment until the final welds are made (*Figure 3-28*).

Although the sizes of tack welds are not specified, they are normally between 1/2 to 3/4 inch in length, but never more than 1 inch in length.

In determining the size and number of tack welds you need for a specific project, you need to consider the thicknesses of the metals being joined and the complexity of the object being assembled.

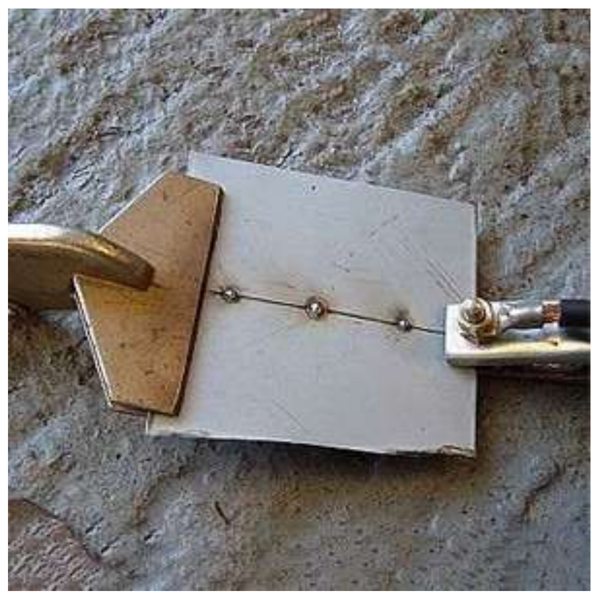

Figure 3-28 — Example of tack welds.

Plug welds and slot welds are welds made through holes or slots in one member of a lap joint (*Figure 3-29*).

These welds are used to join the member with holes to the surface of another member exposed through the hole.

The hole may or may not be completely filled with weld metal.

These types of welds are often used to:

- join face-hardened plates from the backer soft side
- install liner metals inside tanks
- fill up holes in a plate

Figure 3-29 — Examples of plug welds and slot welds.

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 (*Figure 3-30*).

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 either manually or automatically to weld the pieces together.

Figure 3-30 — Example of the resistance weld process.

Resistance Spot Welding (RSW) and Resistance Seam Welding (RSEW) are two of the most common types of resistance welding processes (*Figure 3-31*).

Resistance spot welding is probably the most common. The material to be joined is placed between two electrodes and pressure is applied, with a charge of electricity sent from one electrode through the material to the other electrode.

Spot welding is applicable to light gauge material; it is especially useful in fabricating sheet metal parts.

Figure 3-31 — Examples of resistance spot welds and seam welds.

Resistance seam welding is similar to spot welding except the spot welds overlap to make a continuous weld seam (*Figure 3-31*).

Seabees do not normally use seam welding. This type of welding is most often used in the commercial area of industrial manufacturing.

In this process, the metal pieces pass between two roller-style electrodes (*Figure 3-32*).

As the electrodes (usually a copper alloy wheel) revolve, the current is automatically turned on and off at the speed the parts are set to move.

Figure 3-32 — Example of the commercial resistance seam welding (RSEW) process.

2.6.0 Parts of Welds

For you to produce welds that meet the job requirements, you need to be familiar with the terms used to describe a weld. Some terms may apply to multiple joint assemblies; some will be unique. Refer to both *Figure 3-33* and *Figure 3-34* for the weld terms.

Figure 3-33 — Terminology of a groove weld.

Face — the exposed surface of a weld on the side from which the weld was made.

Toe — the junction between the face of the weld and the base metal.

Root — the points at which the back of the weld intersects the base metal surfaces.

Leg — the portion of the weld from the toe to the root when looking at a triangular cross section of a fillet weld.

Throat — 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.

Figure 3-34 — Terminology of a fillet weld.

In determining the size of a groove weld (*Figure 3-33*), you must consider such factors as the depth of the groove, root opening, and groove angle.

The size of a fillet weld (*Figure 3-34*) refers to the length of the legs of the weld. Unless specified otherwise, assume the legs are equal in size.

There are multiple styles and types of welding gauges available to measure and prepare material for welding, as well as gauges to check the parts of the completed weld as described in welding terminology. *Figure 3-35* shows a few.

Figure 3-35 — Examples of various welding gauges.

A welding micrometer is a gauge used for determining the size of a weld.

Figure 3-36 shows how the welding micrometer is used to determine the various dimensions of a weld.

Figure 3-36 — Examples of using a welding micrometer.

You need to be familiar with still more terms that are used to describe areas or zones of welds. As previously covered, fusion is the melting together of base and/or filler metal. Refer to *Figure 3-37*.

The fusion zone 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.

The heat-affected zone is another zone of interest to the welder.

This zone is that portion of the base metal that has not been melted, but where the structural or mechanical properties of the metal have been altered by the welding heat.

Figure 3-37 — Examples of zone terminology in a weld.

Welding heat affects the mechanical properties of the base metal; therefore, it is very important for you to learn techniques to control this heat. For example, the intermittent weld is one technique often used to minimize heat input.

This technique and others will be presented as you progress through this chapter. However, first consider some of the factors that affect the welded joint design.

Test your Knowledge (Select the Correct Response)

2. To become a skilled welder, the first thing you need to learn is ______.

   A. which size of welding rod to use
   B. how to set up a cutting rig
   C. which gas to use with TIG or MIG welding
   D. the technical vocabulary of welding

3.1.1 WELDED JOINT DESIGN

The welded joint design is the term that includes all of the details of a joint, including the geometry and the required dimensions. The type of joint design best suited for a particular job will depend on many factors.

Welded joints are designed primarily to meet strength and safety requirements, but you must also consider such questions as the following.

- Will the load be in tension or compression?
- Will bending, fatigue, or impact stresses be applied?
- How will a load be applied--steady, sudden, variable?
- From what direction will the load be applied relative to the weld joint?
- What is the cost of preparing the joint?

Another factor you must consider is joint efficiency; in welding, this is the ratio of the strength of a joint to the strength of the base metal expressed in percent. An efficient joint is one that is just as strong as the base metal, or 100 percent.

Normally, a designer or engineer determines the joint design and includes it in the project plans and specifications. Your understanding of how to interpret the joint design information is what will enable you to produce proper welds.

Earlier, this chapter presented the five basic types of welded joints—butt, corner, tee, lap, and edge, and stated that every joint you weld would be some variation of them.

Now consider some of the variations of these welded joint designs and note the characteristics, efficiencies, and basis for a particular design.

3.1.1 Butt Joints

Square butt joint — *Figure 3-38*

- Used primarily for metals 3/16 inch or less in thickness.
- Reasonably strong, but not recommended when metals are subject to fatigue or impact loads.
- Preparation is simple, requiring only matching the edges of the plates together.
- Must be fitted together correctly for the entire length of the joint.
- Must allow enough root opening for the joint.

Figure 3-38 — Example of a square butt joint.

When you weld metals thicker than 3/16 inch, often it is necessary to use a grooved butt joint. The purpose of grooving is to give the joint the required strength. When you use a grooved joint, the groove angle must be adequate to allow the electrode into the joint; otherwise, the weld will lack penetration and may crack.

On the other hand, you also need to avoid excess beveling, as this wastes both weld filler metal and time. Depending on the thickness of the base metal, the joint design will call for either a single-groove (grooved on one side only) or double-groove (grooved on both sides) weld.

As a welder, you primarily use the single-V and double-V grooved joints.

Single-V butt joint — *Figure 3-39*

- For use on plates ¼ to ¾ inch in thickness.
- Each member beveled so included angle is approximately 60 degrees for plate and 75 degrees for pipe.
- Preparation requires a special beveling machine (or cutting torch).
- Requires more filler material than square joint but is stronger.
- Not recommended when subjected to bending at the root of the weld.

Figure 3-39 — Example of a single-V butt joint.

Double-V butt joint — *Figure 3-40*

- Excellent joint for all load conditions.
- Primary use is for metals thicker than 3/4 inch but usable on thinner plate where strength is critical.
- Preparation time is greater than for single-V joint but less filler metal is used because of narrower included angle.
- Weld deposit sides must be alternated to reduce heat and minimize warpage.

Figure 3-40 — Example of a double-V butt joint.

To produce good quality welds using the groove joint you must:

- Ensure the fit-up is consistent for the entire length of the joint.
- Use the correct groove angle.
- Use the correct root opening.
- Use the correct root face for the joint.

When you follow these principles, you will produce better welds every time.

Other standard but less often used grooved butt joint designs include the bevel groove, J-groove, and U-groove, as shown in *Figure 3-41*.

Figure 3-41 — Examples of additional grooved butt joint designs.

3.2.0 Corner Joints

Figure 3-42 — Examples of corner joints.

The flush corner joint (*Figure 3-42 View A*) is designed primarily for welding 12-gauge or thinner sheet metal. 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 (*Figure 3-42 View B*) is used for welding materials heavier than 12-gauge. Penetration is better than in the flush corner joint, but its use is recommended only for moderate loads.

The full-open corner joint (*Figure 3-42 View C*) produces a strong joint, especially when welded on both sides. It is useful for welding plates of all thicknesses.

3.3.0 Tee Joints

Figure 3-43 — Examples of tee joints.

The square tee joint (*Figure 3-43 View A*) requires a fillet weld that can be made on one or both sides. It can be used for light or marginally thick materials. For maximum strength, place considerable weld metal on each side of the vertical plate.

The single-bevel tee joint (*Figure 3-43 View B*) can withstand more severe loadings than the square tee joint because of better stress distribution. It is generally used on plates ½ inch thick or less, and where welding can be done from only one side.

The double-bevel tee joint (*Figure 3-43 View C*) is for use where heavy loads are applied and the welding can be done on both sides of the vertical plate.

3.4.0 Lap Joints

The single-fillet lap joint (*Figure 3-44 View A*) is easy to weld and the filler metal is simply deposited along the seam, but the strength of the weld depends on the size of the fillet.

It can be used for metal up to ½ inch thick that will not be subject to heavy loads

The double-fillet lap joint (*Figure 3-44 View B*) should be used when the joint will be subjected to heavy loads.

When welded properly, the strength of this joint is very close to the strength of the base metal.

Figure 3-44 — Examples of lap joints.

3.5.0 Edge Joints

The flanged edge joint (*Figure 3-45 View A*) is suitable for plate ¼ inch thick or less and can sustain only light loads.

Depending on the thickness of the work-pieces, you can prepare for this joint as shown in either *Figure 3-45 View B* or *C*.

Figure 3-45 — Examples of edge joints.

Test your Knowledge (Select the Correct Response)

3. Welded joints are designed primarily to meet ________.

   A. the cost of preparing the joint
   B. tension or compression requirements
   C. strength and safety requirements
   D. bending, fatigue, or impact stresses

4.0.0 WELDING POSITIONS

You will do all your welding in one of four positions: (1) flat, (2) horizontal, (3) vertical, or (4) overhead. A fully qualified welder can make either fillet or groove welds in all of these positions. *Figure 3-46* shows the various American Welding Society (AWS) positions used in plate welding.

Figure 3-46 — American Welding Society's welding positions for plate.

The AWS uses a number/letter designation to identify the positions. For instance, the number designation indicates the position, or axis, of the weld, while the letter F indicates a fillet weld and the letter G indicates a groove weld. Thus, the 1G position refers to a groove weld in the flat position.

These number/letter designations refer to test positions, the positions a welder demonstrates a proficiency in to become certified during a welding qualification test.

As a Steelworker, whether for your own professional development or for a project you are assigned to, there is a good possibility you will need 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.

It is important to note, however, that you do not have to qualify in all the positions initially. Qualifying in the various positions with different welding processes is a matter of steps. *Figure 3-47* shows an example of a certification and a guide to its interpretation.

Figure 3-47 — AWS guide for interpreting certified welder card abbreviations.

Gravity will affect the flow of molten filler metal in any of the positions, so use the flat position, if possible.

- In the flat position, gravity will draw the molten metal downward into the joint, making the welding faster and easier.
- Horizontal welding is a little more difficult; the molten metal will tend 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; the weld metal flows downward. This position requires considerable practice 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.

Figure 3-48 shows the four basic test positions used in pipe welding. Notice that the position refers to the position of the pipe, not the position of welding.

Figure 3-48 — American Welding Society's welding positions for pipe.

Test position 1G — the pipe is in the horizontal position. In this position, the pipe is rolled so that the welding is actually done in the flat position with the pipe rotating under the arc. This position is the most advantageous of all the pipe welding positions.

Test position 2G — the pipe is in the vertical position. The welding is then done in the fixed horizontal position.

Test position 5G — the pipe is in the horizontal position. However, unlike position 1G, in the 5G position, the pipe is not turned or rolled during the welding operation; thus the welding is more difficult.

Test position 6G — the pipe is at a 45-degree angle with the horizontal and the pipe is not rolled (*Figure 3-49*).

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.

Figure 3-49 — Typical 6G certification test with GTAW (TIG).

NOTE

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

Test your Knowledge (Select the Correct Response)

4. **(True or False)** A fully qualified welder can make fillet or groove welds in four different positions.

    A. True
    B. False

5.0.0 EXPANSION and CONTRACTION

One of the physical properties of a metal is its characteristic expansion when heated, and its contraction back to room temperature size when allowed to cool.

While some metals expand more readily than others, typically upon cooling, a metal contracts and tries to resume its original shape.

Figure 3-50 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.

Figure 3-50 — Example of unrestrained expansion/contraction with heating/cooling.

Figure 3-51 shows the results of heating and cooling metal under restraint.

When the bar is clamped in a vise and heated, expansion is limited to the unrestricted sides of the bar, in this instance vertically.

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.

Figure 3-51 — Example of restrained expansion/contraction with heating/cooling.

Expansion and contraction forces act on the weld metal and base metal of a welded joint in the same way, although metal thicknesses will either exaggerate or diminish the effect.

However, when two pieces of metal are welded together, expansion and contraction are unlikely to be uniform throughout due to the difference in 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 3-52 shows some of the most common difficulties you are likely to encounter if no controls are put in place during the weld preparation.

Figure 3-52 — Examples of distortion caused by welding.

Refer to *Figure 3-52 View A*. When you weld a single-V butt joint, the highest temperature is at the surface of the molten puddle; this is where expansion and contraction are greatest. The temperature decreases as you move toward the root of the weld and travel away from the weld. Since the surface of the weld joint was the highest temperature, it contracts the most when the weld begins to cool, thus causing warpage or distortion.

Refer to *Figure 3-52 View B.* For a tee joint, the same principle applies with similar results but in a different axis orientation.

Refer to *Figure 3-52 View C.* Welding a bead on one side of a plate can warp it into a curve.

Refer to *Figure 3-52 View D*. Welding two plates together without proper tack welds can result in closed spacing and a loss of overall dimension.

When you expose a work-piece to heat buildup during welding, it will expand in the direction of least resistance. Conversely, when it cools, it will contract 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.

5.1.0 Controlling Distortion

You can control the metal's tendency to distort by expansion and contraction during welding by following some simple procedures.

5.1.1 Preparation and Fit-up

To make good quality welds, proper edge preparation and fit-up are essential.

- Make certain the edges are properly beveled and spacing is adequate.
- Use tack welds, especially on long joint.

- Space at least 12 inches apart.
- Run approximately twice as long as the thickness of the weld.

5.1.2 Heat Input

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 minimize the heat by simply speeding up the welding process.

Often, regardless of your experience, you will need to use a welding technique designed to control heat input. An intermittent weld (sometimes called a skip weld) is one such technique you can use in lieu of one continuous weld.

To make an intermittent weld:

- Make a short weld at the beginning of the joint.
- Skip to the center and weld a few inches.
- Weld at the other end of the joint.
- Return to the end of the first weld and repeat the cycle until the weld is finished.

Figure 3-53 shows examples of intermittent weld techniques.

Figure 3-53 — Examples of intermittent weld techniques.

Another technique to control the heat input is the back-step method (*Figure 3-54*).

When you use this technique, deposit short weld beads from right to left along the seam.

Then move ahead and finish where you left off on the previous strip.

Figure 3-54 — Example of back-step welding techniques.

5.1.3 Preheat

As previously covered, expansion and contraction rates are not uniform in a structure during welding because of the differences in temperature throughout the metal.

To control the differences in temperature, and thus the forces of expansion and contraction, you can preheat the entire structure before welding, and then following the welding, postheat to allow the structure to cool evenly and slowly. More about preheating and postheating will be presented later.

5.1.4 Number of Weld Passes

Keep distortion to a minimum by using as few weld passes as possible.

Limit the number of weld passes to the number necessary to meet the requirements of the job (*Figure 3-55*).

Figure 3-55 — Example of limiting the number of weld passes.

5.1.5 Jigs and Fixtures

Holding the metal in a fixed position will prevent excessive movement from its tendency to expand and contract, so using 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 (*Figure 3-56*).

Jigs can be temporarily developed for a unique part, or they can be an adjustable worktable that allows for various preparation positions.

Figure 3-56 — Example of a welding jig.

5.1.6 Allow for Distortion

Another alternative to adjust for distortion caused by expansion and contraction requires a certain level of experience and practice, but may be the simplest; just allow for it during fit-up.

To reduce distortion, angle the parts to be welded slightly in the opposite direction in which the contraction will take place.

When the metal cools, contraction forces pull the pieces back into position.

Figure 3-57 shows how distortion can be overcome in both the butt and tee joints.

Figure 3-57 — Examples of allowing for distortion for a butt and tee joint.

To be a good welder, you have to know more than how to do preparation, and be able to do more than lay a good bead. Many other factors must be considered, proper procedures being one of them. Later, additional techniques will be presented that you can apply to specific welding situations.

Test your Knowledge (Select the Correct Response)

5. Typically, upon cooling, a metal tries to ________.

   A. maintain its heated shape
   B. resume its original shape
   C. deform from gravity
   D. compress smaller than it original shape

6.1.1 WELDING PROCEDURES

Many factors are involved in the preparation of any welded joint. A ***welding procedure*** addresses those factors by providing the detailed methods and practices to prepare and perform a particular weldment. It identifies all the welding variables pertinent to a particular job or project.

Generally, these variables include:

- Welding process
- Type of base metal
- Joint design
- Welding position
- Type of shielding
- Preheating
- Postheating
- Welding machine setting
- Testing requirements

6.1.0 American Welding Society

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. It also publishes a number of other books specific to welding techniques for other metals.

As published, the AWS's mission statement is: *"The mission of the American Welding Society is to advance the science, technology and application of welding and allied joining and cutting processes, including brazing, soldering and thermal spraying."*

6.2.0 American Society of Mechanical Engineers

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 also provide a standardized guide of proven welding practices and procedures.

As published, the ASME's mission statement is: *"To serve our diverse global communities by advancing, disseminating and applying engineering knowledge for improving the quality of life; and communicating the excitement of engineering."*

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, a Naval Construction Force unit is assigned to a project with the usual accompanying set of drawings and specifications, and welding is required. Those specifications will normally require the welding to be accomplished according to a specific code requirement, commonly one of AWS's codes.

If your unit is tasked to fabricate a welded steel structure, for instance, 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.

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

Once a welding procedure specification has been developed and qualified, the project's welders are required to perform a Welding Performance Qualification test to meet the procedures. The weld specimens are then tested according to the requirements of the Welding Procedure Specification using either destructive or nondestructive tests. One destructive test is the *guided-bend* test; a nondestructive test would be an X-ray test.

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 you can receive the training needed to perform the required welds.

As shown in *Figures 3-58* and *3-59*, a welding procedure specification is simply a document that provides details of the required variables for a specific welding application. ASME provides a suggested format with form QW-482.

Figure 3-58 — Example of welding procedure specification (QW-482 Front).

Figure 3-59 — Example of welding procedure specification (QW-482 Back).

Test Your Knowledge (Select the Correct Response)

6. What organization produces the *Structural Welding Code* that is used for the design and construction of steel structures?

   A. Occupational Safety and Health Administration (OSHA)
   B. American Society of Mechanical Engineers (ASME)
   C. American Institute of Steel Construction (AISC)
   D. American Welding Society (AWS)

7.0.0 DRAWINGS

An engineer uses drawings or sketches to convey ideas 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 designs them.

7.1.0 Reading Drawings

To read the drawings or sketches, you must know how engineers use lines, dimensions, notes, and views to communicate their ideas. This section will briefly cover each of these drawing elements. For more in depth information, refer to publications such as *Blueprint Reading and Sketching,* NAVEDTRA 10077-F1 or to *Engineering Aid Basic.*

7.1.1 Lines

Refer to *Figure 3-60*, which shows many of the different types of lines used in engineering drawings; each line has a specific meaning you must understand to interpret a drawing correctly.

Visible line (object line) — used to show the edges of objects visible to the viewer.

- Look at one of the walls of the room you are in; you can see the outline of the walls, doors, and windows. These visible outlines or edges would be shown using visible lines drawn as described in *Figure 3-60*.

Hidden line — used to show the edges of objects concealed from the viewer.

- Look at the wall again. Assuming the wall is wood frame, you know there are studs or framing members inside the wall that you cannot see. These invisible outlines or edges would be shown using hidden lines drawn as described in *Figure 3-60*.

The wall may also contain other items you cannot see, such as water pipes and electrical conduit, so as you can imagine, the more hidden lines there are, the more difficult it becomes to decipher what the hidden lines mean. However, there is another way these studs and other items can be “seen.”

Cutting or Viewing plane — used to reveal the edges of objects concealed from the viewer after an imaginary removal of layers causing the concealment.

- Imagine you “cut away” the wallboard covering and replace it with a sheet of clear plastic 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.

Sectional view — the view as seen at the cutting plane.

Section drawing — used to reveal an object or view at the point of the cutting plane.

- Section drawings are commonly used to show the internal components of a complicated object.

Section lines — used to show different types of materials.

- These are drawn on the visible surfaces of a section drawing. Some types of section lines you are likely to encounter as a welder will indicate a metal type.

Figure 3-60 — Example of engineering drawing’s line characters and uses.

7.1.2 Dimensions

Engineers use lines to describe the shape (form) of an object and use dimensions to provide a complete size description. Two types of dimensions are used on drawings: size and location; their purposes are self-explanatory. Refer to *Figure 6-61* for examples.

Figure 3-61 — Examples of using location dimension and size dimension in an orthographic drawing.

For obvious reasons, large objects are not 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 the 1/2"= 1'-0" noted here, or a graphic scale, such as the one shown in *Figure 3-61*. In the Navy, both numerical and graphic scales are usually shown on construction drawings.

Never measure the dimension of an object directly from the drawing. These measurements are frequently inaccurate; a change in atmospheric conditions causes drawing paper to shrink or expand, and copying processes may render them inaccurate as well. To ensure accuracy, always use the size and location dimensions shown on the drawing. If a needed dimension is not shown on the drawing, check the graphic scale for accuracy, since it will always shrink or expand at the same rate as the drawing paper.

7.1.3 Notes

Drawing notes are used for different purposes and are either specific or general in nature.

Refer again to *Figure 3-61* for an example of how specific notes are used. Two notes give the inside diameters of the holes, and they are used for size dimensioning. They are specific in that, by using a leader line, each note is referred to a specific hole or set of holes.

A general note provides additional information that does not apply to any one particular part or feature of the drawing. For example, the *Figure 3-61* drawing could contain a general note saying: “All holes shall be reamed using a tolerance of ± 1/64 inch.” General notes often appear in the corners of drawings, so always remain alert for them.

7.1.4 Views

Look at the drawing shown in *Figure 3-62.* This type of drawing is called a pictorial drawing. These drawings are frequently used to show, in a three-dimensional view, 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, but for complex objects, such as shown in *Figure 3-62*, it becomes too difficult to provide a complete description in a pictorial drawing.

Common practice for complex objects is to prepare orthographic drawings to describe the object fully.

Assume you are holding the object shown in *Figure 3-62* so you are looking directly down 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.

Figure 3-62 — Example of a pictorial drawing of a steel part.

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, but an extremely complex object may require as many as six views (top, front, left side, right side, back, and bottom).

Typically though, most objects, such as the steel part shown in *Figure 3-62*, can be sufficiently described using three views: top, front, and right side.

Figure 3-63 is a typical orthographic drawing of the object in *Figure 3-62* showing top, front, and right-side views.

Notice the placement of the views; this is a standard practice 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.

Figure 3-63 — Example of orthographic views of pictorial viewed steel part.

Placement of the back view is somewhat flexible, but it is usually drawn to the left of the left-side view.

When reading and understanding the different orthographic views, sometimes you will find it helpful to prepare your own pictorial sketch. You can find information on sketching in *Blueprint Reading and Sketching,* NAVEDTRA 10077-F1.

Drawings are a form of communication that saves many words of explanation. Done properly, they help you understand all the necessary information you need to fabricate and assemble an object regardless of the complexity. It is important that you, as a Steelworker, learn to read drawings and become accustomed to their meanings.

7.1.5 ndling and Care

Exercise special care when handling drawings. When they are in use, keep them on a rack or in another assigned storage place. Drawings are valuable, and they may be difficult or impossible to replace if lost or damaged.

7.2.0 Welding Symbol

Drawings contain special symbols to specify the weld location, type of joint, and size and amount of weld metal to be deposited in the joint. The American Welding Society (AWS) has standardized them. You will see them whenever you do a welding job from a set of prints, so you need to be familiar with all the elements of a standard welding symbol, and the location and meaning of the basic weld symbols.

A standard *welding symbol* is: reference line + arrow + tail (*Figure 3-64*).

The reference line is the foundation. Weld symbols, dimensions, and other data are applied to it.

The arrow 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 process, specification, or other reference information

Figure 3-64 — Standard welding symbol.

7.2.1 Type of Weld (Weld Symbols)

Weld symbols refer to the symbols for a specific type of weld, such as fillet, groove, butt, surfacing, plug, or slot.

The weld symbol is only part of the information required in the welding symbol.

When used to disseminate information, the term *welding symbol* refers to the total symbol, which includes all the *weld symbols* needed to specify the weld(s) required

Figure 3-65 — Standard weld symbols.

Figure 3-66 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 or curved leg of the symbol.

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 3-66 — Example of weld symbols applied to a reference line.

Figure 3-67 shows the significance of the weld symbol's position on the reference line.

View A — fillet weld symbol on lower side of reference line (termed the *arrow side*) **Weld on arrow side.**	View B — fillet weld symbol on upper side of reference line (termed the *other side*) **Weld on other side.**	View C — fillet weld symbols on both sides of reference line **Weld on both sides.**

Figure 3-67 — Example of specifying weld location.

When only one edge of a joint is to be beveled, it is necessary to show which member is to be beveled (*Figure 3-68*).

When such a joint is specified, the arrow of the welding symbol points with a definite break toward the member to be beveled.

Other weld symbols may be added to a welding symbol as necessary to communicate all the information needed for the weld.

However, regardless of the direction of the arrow, all information applied to the reference line on a welding symbol is read from left to right. (See *Figure 3-69*.)

Figure 3-68 — Example of arrowhead indicating bevel plate.

7.2.2 Dimensioning

Notice in *Figure 3-69* that some specified information has designated locations.

Figure 3-69 — Example of locations for specific elements of a welding symbol.

The size, length, pitch (center-to-center spacing), groove angle, and root opening of a weld all have designated locations.

These locations are determined by the side of the reference line on which the weld symbol is placed.

Figure 3-70 shows how dimensions are applied to weld symbols.

Figure 3-70 — Example of dimensions applied to weld symbols.

Figure 3-71 shows the meaning of various welding dimension symbols.

Figure 3-71 — Example of dimensioning welds and their meanings.

Refer to *Figure 3-71 View A.*

- The left side specifies a tee joint with the size of the weld on a fillet weld symbol.
- The right side shows the length and pitch of the indicated fillet weld. (Note that both legs are equal unless specified otherwise.)

Refer to *Figure 3-71 View B.*

- The left side specifies a tee joint with 2-inch intermittent fillet welds that are 5 inches apart, on center.
- The right side shows a pictorial view of the meaning of the welding symbol

Refer to *Figure 3-71 View C.*

- The left side specifies a butt weld with a ½-inch, V groove weld on both sides but of different angles, a 60° and a 45°.
- The right side shows the results, 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. This is consistent with the standard locations of weld symbols, but can be confusing to the beginning welder.

7.2.3 Supplementary

Besides the basic weld symbols, the welding symbol may include supplementary symbols. *Figure 3-72* shows some of the most common. Contour symbols show how the face is to be formed; finish symbols indicate the method to use to form the contour.

Figure 3-72 — Supplementary symbols.

Figure 3-73 — Finish symbol.

A finish symbol (when used) shows the method of finish, C represents chipping, M means machining, and G indicates grinding, not the degree of finish.

Figure 3-73 shows how contour and finish symbols are applied to a welding symbol. This symbol indicates 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.

Refer again to *Figure 3-72*. Another supplementary symbol shown is the weld-all-around symbol. When this symbol is placed on a welding symbol, welds are to continue all around the joint.

Yet another symbol on *Figure 3-72* is the field weld symbol, a black flag that points toward the tail of the welding symbol. For welds that cannot be made in the shop, for size, transportation, constructability, or other reasons, this symbol directs the welder to make the weld in the field, which could be “in situ” or on site.

7.2.4 Additional Information

If additional information is unnecessary, the welding symbol will not have a tail.

However, when additional information is needed to specify a certain welding process, a type of electrode, or some other type of reference necessary to direct the weld process, the tail is added and the information is placed there (*Figure 3-74*).

Figure 3-74 — Examples of a welding symbol tail with additional information.

7.2.5 Multiple-Weld

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.

Figure 3-75 shows two methods of illustrating these weld symbols, either on the same reference line or on multiple reference lines.

Note that in both welding symbol examples of the same information, the bevel groove weld (closest to the arrowhead) is to be completed first, followed by the fillet weld.

Figure 3-75 — Examples of symbols indicating multiple welds.

7.2.6 Application of Symbol

Figure 3-76 is an example of how a welding symbol may appear on a drawing. How would you interpret it?

This figure shows a steel pipe column to be welded to a baseplate.

- The pipe is to be beveled at a 30-degree angle followed by a bevel groove weld all around.
- A 1/2-inch fillet weld follows, also welded all around.
- The fillet weld is to be finished by grinding flush.
- Both welds are to be done in the field.

How did you do?

Figure 3-76 — Example of a typical welding symbol in use on a project.

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

Test your Knowledge (Select the Correct Response)

7. **(True or False)** As a welder, your only obligation is to know how to read weld symbols and you need not concern yourself with drawings.

   A. True
   B. False

8.0.0 SAFETY

Mishaps of varying degrees of severity can occur in welding operations, in part because of the nature of the work with metal, heat, confined vision, and construction in general. In some 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/or the misuse of available equipment.

Precautions applying to specific equipment are pointed out in the chapter covering that equipment. This section will cover topics such as protective clothing, eye protection devices, and practices applicable to the personal safety of the operator and personnel working nearby.

8.1.0 Eye Protection

Proper eye protection is of the utmost importance! This strong statement applies to the welding operator, helpers, chippers, inspectors, or any other personnel who are in the proximity 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 goggles and helmets.

NOTE

In addition to providing eye protection, helmets also provide a shield for the entire face and neck against sparks, flying metal and ultraviolet rays.

Flash goggles (*Figure 3-77*) 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.

Figure 3-77 — Example of flash goggles with side shields.

Eyecup or cover type of goggles (*Figure 3-78*) is 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.

Figure 3-78 — Example of eyecup goggles for fuel-gas operations.

NOTE

DO NOT substitute eyecup or cover type of goggles for an arc-welding helmet.

8.2.0 Welding Helmet

For electric arc-welding and arc-cutting operations, you must use a helmet with a suitable filter lens (*Figure 3-79*). This helmet serves three functions: 1) as eye protection, and as protection from 2) ultraviolet rays and 3) flying metal.

One helmet has an opening, called a window, for a flip-up filter lens 2 by 4 1/4 inches in size. When flipped up, another clear or light shaded lens provides additional eye protection from chipping or grinding operations.

Another helmet has a 4 1/2- by 5 1/4-inch window. The larger window affords a wider view and is especially useful when you are working in a confined place where head and body movement is restricted.

Figure 3-79 — Examples of welding helmets.

When welding in locations where other welders are working, you should wear flash goggles beneath your helmet to provide protection from the flashes caused by the other welders' arcs. In addition, if you are not using the flip-up style of helmet, the flash goggles will serve as eye protection when chipping the slag from a previous weld deposit.

Welding goggles and helmets are made from nonflammable insulating material, with an exchangeable shaded filter lens and a protective 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. You should replace the clear lens when it impairs vision.

Filter lenses are available in a variety of shades designated by number; the lower the number, the lighter the shade; the higher the number, the darker the shade.

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.

1. To diminish the intensity of the visible light to a point where there is no glare and the welding area can be clearly seen.

2 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 3-2*.

Table 3-2 — 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.

Rule of thumb: when selecting the proper shade of filter lens for an electric arc welding helmet, place the lens in the helmet, look through it at an exposed bare light bulb, and see if you can distinguish its outline. If you can, use the next darker shade lens and repeat the test. When you no longer see the outline of the bulb, the lens is of the proper shade.

Remember, you should perform this rule of thumb test in the same lighting conditions as the welding operation will be performed. Welding in a shop may require a shade lighter lens than if you are going to do the same in bright daylight, perhaps on the work site. When testing for the proper lens shade to work in field operations, look 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.

8.3.1 Protective Clothing

A variety of special welder’s clothing is available to protect parts of the body.

Figure 3-80 — Examples of welding gloves and mitts.

The clothing selected varies with the size, location, and nature of the work you need to perform. During any welding or cutting operation, you should always wear flameproof gauntlets, that is, five-finger gloves for gas welding and cutting, or two-finger gloves (or mitts) for electric arc welding. Both types of gloves protect your hands from heat and metal spatter (*Figure 3-80*).

The two-finger gloves have an advantage over the five-finger gloves: they reduce the danger of weld spatter and sparks lodging between the fingers. They also reduce finger chafing from the inside seams, 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 goggles. Nevertheless, even in these taskings, it is essential you wear your work clothes properly. Sparks seem to have an affinity for and are very likely to lodge in pockets, rolled-up sleeves, and cuffs of trousers or overalls.

You should leave your sleeves rolled down and buttoned, as well as your shirt collar. Do not cuff your trousers on the outside, and eliminate any pockets from the front of overalls and aprons that do not have button-down flaps. Be sure all your clothing is free of oil and grease. Wear high-top safety shoes; low-cut shoes are a hazard. Sparks and molten metal can lodge in them, especially when you are sitting down.

Figure 3-81 — Examples of welder's protective clothing.

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 (*Figure 3-81*).

This clothing is designed to protect you against radiated heat, splashes of hot metal, or sparks. They afford a choice of protection depending upon the specific nature of the particular welding or cutting job

This clothing consists of aprons, sleeves, combination sleeves and bib, jackets, and overalls.

- Aprons and overalls provide protection to the legs and are suited for welding operations on the floor.
- Sleeves provide satisfactory protection for welding operations at floor or bench level.
- The cape and sleeves are particularly suited for overhead welding; they protect the back of the neck, top of the shoulders, and the upper part of the back and chest.
- The bib, in combination with the cape and sleeves, gives added protection to the chest and abdomen.
- Wear the jacket when there is a need for complete all-around protection to the upper part of the body. This is especially true when several welders are working in close proximity to one another.
- During overhead welding operations, and again especially when several welders are working in close proximity, you should wear leather or flameproof caps under your helmet to prevent head burns.
- Wear earplugs to keep sparks or splatter from entering and burning the ears.
- If you will be exposed to falling or sharp objects, wear the combination welding helmet/hard hats.
- For very heavy work, wear fire-resistant leggings or high boots; do not wear shoes or boots with exposed nail heads or rivets.
- Never wear any oilskins or plastic clothing for any welding operation.

NOTE

If leather protective clothing is not available, wear woolen clothing instead of cotton. Woolen clothing is not as flammable and helps protect you from the changes in temperature caused by welding. If cotton clothing is unavoidable, it should be chemically treated to reduce its flammability.

8.4.0 Area Awareness

Area awareness can also be termed situational awareness. It really is a matter of staying attentive and cognizant of your surroundings. That includes remaining alert to those working around you whether you are in the shop or in the field.

Welding by its very nature is a narrowly focused task, and when the welding helmet is down you have no peripheral vision. Before you drop the hood, know what is going on in the immediate area and always have an alternate position to which you can move. If the tasking does not allow this, a welder’s helper can assist with an overall view of any changing conditions around you until the confined tasking is completed. Know your surrounding at all times.

Summary

Modern welding is just over 100 years old. The continuing changes in equipment and technologies have advanced from the beginnings of carbon arc to the multiple processes available today. As a Steelworker, you are, or will be, the resident expert on metals regardless of which billet assignment or tour you are in. Learning to weld, practicing, and becoming proficient at it will serve you well in both your Naval service and in the civilian community when you eventually transition. Certified welders are always in demand on multitudes of projects. The key word is “certified”; that means 1) in the positions 2) with the equipment 3) with plate and pipe. Practicing for proficiency and applying your ability as often as possible will improve your skills and opportunities.

Review Questions (Select the Correct Response)

1. **(True or False)** The source of heat for the forge welding process is a flow of electricity between two contacts.

   A. True
   B. False

2. In welding terms, RSW means   .

   A. round sheet welding
   B. resident shop welds
   C. resistance spot welding
   D. resistant spot welds

3. The source of heat for electric arc welding is   .

   A. a flow of electricity between two contacts
   B. the resistance of a metal to the flow of an electric current
   C. the bombardment of a metal with electrons
   D. a furnace

4. **(True or False)** The primary advantage of using shielded metal-arc welding is that it produces high-quality welds rapidly at a low cost.

   A. True
   B. False

5. What is the primary purpose of the gas in gas shielded arc welding?

   A. To provide a more even flow to the weld.
   B. To increase the overall temperature of the weld.
   C. To prevent atmospheric contamination.
   D. To minimize the amount of rod needed.

6. When welding two pieces of metal together, you will often need to leave a space to be filled in. What material is added during the welding phase?

   A. Filler metal
   B. Electrodes
   C. Flux
   D. Fusion gas

7. **(True or False)** The two types of filler metals commonly used in welding are welding rods and welding electrodes.

   A. True
   B. False

8. **(True or False)** A common property of a welding rod and a welding electrode is that both are used to conduct electricity.

   A. True
   B. False

9. Into what categories are electrodes classified when they are divided into groups?

   A. Consumable or nonconsumable
   B. Conductive or nonconductive
   C. Electric-arc or gas
   D. Metallic or nonmetallic

10. What term refers to materials that are used to dissolve or facilitate the removal of oxides and other undesirable substances formed during welding?

   A. Alloys
   B. Peroxides
   C. Fluxes
   D. Distillates

11. A good flux does NOT have to ______.

   A. remove oxides from joint surfaces
   B. be active at the melting point of the filler metal
   C. mix well with the base metal alloys in order to lower the base metal melting temperature
   D. be easily removed after the joint is welded

12. In which of the following forms are fluxes produced?

   A. Paste
   B. Powder
   C. Liquid
   D. All of the above

13. What are the five fundamental types of joints?

   A. Fillet, groove, bead, stringer, and tack
   B. Lap, corner, tee, butt, and edge
   C. Lap, flanged, tee, butt, and bead
   D. Lap, flanged, tee, butt, and stringer

14. What type(s) of welded joint should you use when two members are at right angles to each other?

   A. Lap only
   B. Edge only
   C. Tee or corner
   D. Butt or edge

Refer to the figure below for questions 15-17.

15. What location(s) indicate(s) a corner joint?

    A. B only
    B. A and C only
    C. A, B, and C only
    D. A, B, C, and E

16. What location(s) indicate(s) a tee joint?

    A. B
    B. A and C
    C. E
    D. D and F

17. What type of joint is E?

    A. Butt
    B. Lap
    C. Edge
    D. Tee

18. How large, in degrees, is the groove angle when the edges of each of two joints that are to be joined are beveled to an angle of 45 degrees?

    A. 30
    B. 45
    C. 60
    D. 90

19. Which factors must you consider to determine the bevel angle, groove angle, and root opening for a weld joint?

    A. Type of weld joint and electrode composition
    B. Kind of joint, welding process, and thickness of the base metal or material to be welded
    C. Amount of weld joint penetrator required to produce a sound weld
    D. Thickness of the base metal and diameter of the electrode to be used

20. What term refers to the depth that a groove weld extends into the root of a joint?

    A. Reinforcement factor
    B. Joint penetration
    C. Root opening
    D. Root penetration

21. What type of weld bead is made by using a side-to-side oscillation?

    A. Stringer
    B. Filler
    C. Weave
    D. Buildup

22. What factor in the welding process does the term “buildup sequence” refer to?

    A. Frequency of oscillation required to fill in a groove
    B. Order in which the beads of a multipass weld are deposited
    C. Number of filler layers required
    D. Thickness of the metal that is to be welded

23. What type of weld has a triangular cross section?

    A. Surface
    B. Plug
    C. Root
    D. Fillet

24. What type of weld has a circular cross section made by applying filler metal through a prepunched or precut hole?

    A. Surface
    B. Plug
    C. Spot
    D. Fillet

25. What type of weld is used to apply a hard wear-resistant layer of metal to surfaces or edges of worn-out parts?

    A. Surface
    B. Plug
    C. Spot
    D. Fillet

26. What type of weld should you use temporarily to hold two parts in proper alignment for the final weld?

   A. Fillet
   B. Tack
   C. Plug
   D. Slot

27. The junction between the face of the weld and the base is known as the ______.

   A. face
   B. root
   C. toe
   D. leg

28. The exposed surface on the side from which the weld is made is known as the ______.

   A. face
   B. root
   C. toe
   D. leg

29. The portion of the weld from the toe to the root is known as the ______.

   A. face
   B. root
   C. toe
   D. leg

30. Why is the term “heat-affected zone” important to a welder?

   A. It is the zone only where melting (fusion) occurs.
   B. It is the zone that includes a portion of the base metal that has not been melted but where the structural and mechanical properties have been altered by weld heat.
   C. It is the amount of heat applied after weld completion to return it to its original condition.
   D. It is the type of heating gases produced during welding.

31. What term is used to describe the details of a joint that includes both geometry and required dimensions?

   A. Joint efficiency
   B. Joint design
   C. Joint shape
   D. Joint description

32. What butt joint is NOT recommended when metals are subject to fatigue or impact loads?

A. Single-V butt joint
B. Double-V butt joint
C. Square butt joint
D. Single-bevel butt joint

33. Which of these butt joints is recommended as an excellent joint for all load conditions?

A. Single V
B. Double V
C. Square
D. Single bevel

34. What corner joint is used primarily for welding 12-gauge or lighter sheet metal?

A. Full open
B. Flush
C. Half open
D. Double fillet lap

35. What tee joint is used in locations where heavy loads are applied?

A. Single bevel
B. Double bevel
C. Square
D. Full open

36. What factor determines the strength of a single-fillet lap joint?

A. Depth of weld penetration
B. Strength of the base metals
C. Size of the fillet
D. Filler metal

37. **(True or False)** All welding is done in one or more of four positions.

A. True
B. False

38. The American Welding Society (AWS) number/letter designation 1F indicates a _____.

A. vertical weave bead
B. horizontal stringer bead
C. fillet weld in the overhead position
D. fillet weld in a flat position

39. What welding position should a welder use anytime conditions allow, due to the effects of gravity on welding?

    A. Flat
    B. Vertical
    C. Horizontal
    D. Overhead

40. **(True or False)** In pipe welding there are four basic test positions that refer to the position of the pipe and not to the position of the welding.

    A. True
    B. False

41. What welding position(s) do you use for pipe welding when welding in the 6G position?

    A. Horizontal only
    B. Vertical only
    C. Overhead and vertical
    D. All positions

42. What factor causes internal stresses, distortion, and warpage when two pieces of metal are welded together?

    A. The difference in temperature from the actual joint of the weld out to the edges of the joint
    B. The structural weakness of the metal
    C. An incorrect flame adjustment
    D. A high concentration of heat in one area

43. **(True or False)** When exposed to the heat buildup of welding, all metals expand in the path of least resistance.

    A. True
    B. False

44. You should space tack welds at least 12 inches apart and _ to aid in controlling distortion.

    A. the thickness of the metal
    B. twice the thickness of the metal
    C. the thickness of the weld
    D. twice the thickness of the weld

45. Why is an intermittent weld (often referred to as a skip weld) used?

    A. To control heat input
    B. To ensure spacing between the metals being welded
    C. To allow you to check weld penetration
    D. To satisfy the job requirement

46. **(True or False)** To control the forces of expansion and contraction during welding operations, you can heat the entire structure before welding.

A. True
B. False

47. What devices should you use to prevent excessive movement of metal parts during a welding operation?

A. Clamps and tape
B. Tape and glue
C. Fixtures and springs
D. Welding clamps and jigs

48. Which of these variables must be considered when identifying the correct welding procedure?

A. Type of base metal
B. Testing requirement
C. Joint design
D. All of the above

49. When assigned a welding job, you should make a thorough examination of the drawings and specifications. In what section of the specifications should you look for welding codes?

A. Section 2
B. Section 3
C. Section 4
D. Section 5

50. What type of line is used to show the edges of an object that are visible to a viewer?

A. Hidden
B. Visible
C. Viewing plane
D. Section lines

51. What type of line is used on a drawing to show the edges of concealed studs, pipes, and electrical conduit?

A. Hidden
B. Visible
C. Viewing plane
D. Section drawing

52. What type of line is used on a drawing to show different types of materials?

A. Hidden
B. Visible
C. Viewing plane
D. Section lines

53. Which of these drawings is used to show internal components?

A. Cutting plane
B. Hidden
C. Section
D. Internal

54. **(True or False)** A general note is used to provide additional information that applies to one particular part or feature of a drawing.

A. True
B. False

55. **(True or False)** The dimensions of an object should be measured (scaled) directly from the drawing.

A. True
B. False

56. What do you call a drawing that shows how an object will appear after being manufactured?

A. Orthographic
B. Pictorial
C. Sectional
D. Dimensional

57. What type of drawing is used to show a complex object completely?

A. Orthographic
B. Pictorial
C. Sectional
D. Dimensional

58. Which of these features make(s) up the standard welding symbols of the American Welding Society (AWS)?

A. A reference line
B. An arrow
C. A tail
D. All of the above

59. **(True or False)** The term “welding symbol” refers to the total symbol, which includes all the information needed to specify the weld(s) required.

A. True
B. False

60. What type of symbols is used with weld symbols to show how the face of the weld is to be formed?

A. Finish
B. Contour
C. Completion
D. Detail

61. What type of symbol is used to indicate the method to use for forming the contour of the weld?

A. Finish
B. Contour
C. Completion
D. Detail

62. What eye protection device is designed for wear under the welder’s helmet?

A. Eyecup or cover goggles
B. Flash goggles with side shields
C. Dark lens plastic full-face shield
D. Commercial sunglasses

63. For which of the following reasons is a welding helmet worn?

A. To provide eye protection
B. To shield against flying metal
C. To protect against ultraviolet rays
D. All of the above

64. When you are welding with a current of 300 amperes, what lens filter is best for eye protection?

A. No. 06
B. No. 08
C. No. 10
D. No. 12

65. Which of these indications can determine whether the lens is the proper shade when using a light bulb to test a filter lens?

A. You can see a distinct outline of the bulb.
B. The light from the bulb becomes a sharp point of light.
C. You can no longer see the outline of the bulb.
D. The light becomes blue and scattered.

66. What type of leather gauntlets is recommended for arc welding?

A. Two finger
B. Three finger
C. Four finger
D. Five finger

67. What items of safety gear are best suited for overhead welding?

A. Cape and sleeves
B. Apron and overalls
C. Jacket and leggings
D. Bib and leggings

68. Which of the following clothing materials is least likely to catch fire from welding sparks?

A. Oilskin
B. Wool
C. Plastic
D. Cotton

Trade Terms Introduced in this Chapter

Fuse	To become liquid under the action of heat; melt, to become united or blended.
Slag	The vitreous mass left as a residue by the smelting of metallic ore.
Weldment	A unit composed of an assemblage of pieces welded together.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

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Chapter 4

Gas Cutting

Topics

To hear audio, click on the box.

Overview

As a Steelworker, the methods you might use in cutting metal are oxygas flame, air carbon-arc, and plasma-arc. The method you will actually make use will depend on the type of metal to be cut and the local availability of equipment.

Either oxygas flame or air carbon-arc equipment will be the most common type of equipment available, and the former is probably the method you will use most often. This chapter will cover oxygas equipment; plasma-arc and carbon-arc cutting will be presented in later chapters.

The oxygas cutting torch has many uses in steelwork. It is the most readily available equipment at naval activities, it is accessible from outside resources in most locations, and it is portable enough to be taken to the work site. You will find it an excellent tool for cutting ferrous metals.

This versatile tool is used for a variety of operations such as cutting reinforcing iron, beveling plate, cutting and beveling pipe, piercing holes in steel plate, cutting wire rope, and, when properly adjusted, preheating metal prior to welding.

Once you are familiar with the equipment and procedures, you should be able to make a quality cut with oxygas equipment in a safe and professional tradesman-like manner.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the purpose and components of the OXYGAS cutting equipment.
2. Describe the procedures utilized in OXYGAS cutting operations.
3. Identify the methods of judging cutting quality.
4. State the safety precautions associated with gas cutting.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet-Metal and Fiberglass Duct		
Welding Quality Control		
Flux Core Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.1.1 OXYGAS CUTTING EQUIPMENT

For a typical oxygas cutting outfit, also referred to as a *cutting rig* (*Figure 4-1*), you need:

- a cylinder of acetylene or MAPP gas
- a cylinder of oxygen
- two regulators
- two lengths of hose (usually joined) with fittings
- a cutting torch with tips

Figure 4-1 — Typical oxygas cutting outfit (cutting rig).

Numerous types of additional auxiliary equipment are available to improve the overall cutting operation; two of the most important are the spark igniter (commonly called a striker) and an apparatus wrench (commonly called a gang wrench) that fits all the connections on the cutting rig. The gang wrench has a raised opening in the handle that serves as an acetylene tank key (*Figure 4-2*).

Figure 4-2 — Typical apparatus wrench (gang wrench) and spark igniter (striker).

Some other common accessories include tip cleaner, tip drill set, hose connectors, extra striker and refill flints, extra cutting tip, hose repair kit, and a cylinder truck (*Figure 4-3*).

Figure 4-3 — Typical oxygas accessories for cutting rig.

Personal safety apparel, such as goggles, hand shields, gloves, leather aprons, sleeves, and leggings, is essential and should be worn as required for the job at hand (*Figure 4-4*).

You can find additional information about safety apparel in the Introduction to Welding chapter.

Figure 4-4 — Typical personal safety apparel for oxygas cutting operations.

Oxygas cutting equipment can be stationary or portable.

A portable oxygas outfit, such as the one shown in *Figure 4-5*, is particularly advantageous when you need to move the equipment from one shop cutting project to another.

When working on a project field site, though, a cart with a larger set of wheels has a distinct advantage in moving over rough terrain, as in foundation work.

In fact, building a cart with spoked metal wheels can be a shop-welding project with excellent field application later.

Figure 4-5 — Typical portable cutting rig.

Proficient cutting, like proficient welding, cannot be learned from reading text; it takes hands-on practice to be an accomplished Steelworker or Ironworker (civilian term) who can cut a smooth-edged bevel on a pipe to prepare it for welding. However, what text can give you is the foundation of how to set up the equipment and how it functions to best advantage.

You must be able to set up the cutting equipment and make the necessary adjustments to be able to perform your cutting tasks. Therefore, you need to know and understand the purpose and function of the basic equipment making up the cutting rig.

However, before learning about the equipment, you must be familiar with the gases most often used to fuel the cutting equipment: acetylene, MAPP gas, oxygen.

1.1.0 Acetylene

Acetylene (C_2H_2) is a fuel gas made up of carbon and hydrogen. It is manufactured by the chemical reaction between calcium carbide, a gray stone-like substance, and water in a generating unit. Acetylene is colorless, but it has a distinctive odor (strong garlic) that can be easily detected. Mixtures of acetylene and air that contain from 2 to 80 percent of acetylene by volume will explode when ignited.

However, with suitable equipment and proper precautions, acetylene can be safely burned with oxygen for welding and cutting purposes. When burned with oxygen, acetylene produces a very hot flame that has a temperature between 5,700°F and 6,300°F. Acetylene is obtained directly from the cylinder when a portable cutting outfit is used, as shown in *Figure 4-5*.

However, for stationary equipment and larger operations as might be found in large shops, acetylene can be piped to a number of individual cutting stations from a manifold configuration similar to the acetylene cylinder bank shown in *Figure 4-6*.

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

Figure 4-6 — Example of a stationary acetylene cylinder bank.

1.1.1 Hazards

Acetylene stored in a free state under pressure greater than 15 psi can be made to break down by heat or shock and possibly explode. Under pressure of 29.4 psi, acetylene becomes self-explosive, and a slight shock will cause it to explode spontaneously. However, when dissolved in acetone, it can be compressed into cylinders at higher pressures.

WARNING

Acetylene becomes extremely dangerous if used above 15 pounds pressure.

1.1.2 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*** (in-fyoo-sawr-ee-uh l), ***earth***. These porous filler materials help prevent high-pressure gas pockets from forming in the cylinder.

Acetone [$OC(CH_3)_2$] is a liquid chemical that dissolves large portions of acetylene under pressure without changing the nature of the gas. Since it is a liquid, acetone can be drawn from an acetylene cylinder when it is not upright.

Do not store acetylene cylinders on their sides. However, if they have been, you must let the cylinder stand upright for a minimum of 2 hours before using to allow the acetone to settle to the bottom of the cylinder.

WARNING

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

Acetylene is measured in cubic feet. Of the wide variety available, the Navy typically uses the standard size 225 cubic feet cylinders (*Figure 4-7).*

Figure 4-7 — Example of the variety of acetylene cylinder sizes available.

However, just because a cylinder has a 225-cubic-foot capacity does not necessarily mean it has 225 cubic feet of acetylene in it. Because the acetylene 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 comparatively constant until most of the gas is consumed.

Figure 4-8 is an example of an acetylene cylinder. These cylinders are equipped with fusible plugs that relieve excess pressure if the cylinder is exposed to undue heat.

The standard Navy acetylene cylinder of 225 cubic feet weighs about 250 pounds.

Compressed-gas cylinders are color-coded for identification, but the color identifications are not standardized among all commercial-owned sources.

Navy-owned acetylene cylinders are designated yellow, but typical commercial-owned acetylene cylinder colors may be black or red, unless you use a European outsourcing supply system while deployed; then maroon is the standardize EEU color.

Figure 4-8 — Cut detail of an acetylene cylinder.

To quote from MIL-STD-101B, 3 DECEMBER 1970 — *5.2.5.1 "Commercial-owned cylinders are those not owned by or procured for the U.S. Government. Commercial-owned cylinders are contractor-owned or supplier-owned cylinders in which compressed gas is supplied to the Government. When Department of Defense activities procure compressed gases in commercial-owned cylinders, it is not mandatory that the cylinders be color coded in accordance with this standard."*

1.2.0 MAPP Gas

As presented in the Introduction to Welding Chapter, MAPP (C_3H_4 methylacetylene-propadiene) is an all-purpose industrial fuel with the high-flame temperature of acetylene and the handling characteristics of propane. MAPP is sold by the pound as a liquid instead of by the cubic foot, as with acetylene. One 70-pound MAPP cylinder can accomplish the work of more than six and one-half 225-cubic-foot acetylene cylinders, making it equal to 1,500 cubic feet of acetylene.

1.2.1 Cylinder Design

A full MAPP cylinder (about the same physical size as a 225-cubic-foot acetylene cylinder) is 120 pounds (70 pounds is MAPP gas). MAPP cylinders contain only the liquid fuel with no packing or acetone to impair fuel withdrawal, so the entire contents of a MAPP cylinder is usable. For heavy-use situations, a MAPP cylinder delivers more than twice as much gas as an equivalent acetylene cylinder for the same time period. A typical MAPP cylinder is canary yellow and, as is common to propane-type gas cylinders, it has a protective collar around the valve.

1.2.2 MAPP Characteristics

The BTU value of MAPP gas makes it an excellent fuel gas for preheating and stress relieving metals. MAPP produces a flame temperature of 5300°F when burned with oxygen and equals or exceeds the performance of acetylene for cutting, heating, and brazing. However, like all of the liquefied petroleum gases, MAPP is not appropriate for welding steel due to the high concentration of hydrogen in the flame. The hydrogen infuses into the molten steel and renders the welds brittle.

MAPP is nonflammable in the absence of oxygen and not sensitive to shock, so if a cylinder is bumped, jarred, or dropped, there is no chance of an explosion. You can store or transport MAPP cylinders in any position with no danger of forming an explosive gas pocket. It has a harmless but characteristic odor to give warning 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; it can be used safely at the full-cylinder pressure of 95 psig at 70°F on jobs requiring higher pressures and gas flows. Hence, MAPP is an excellent gas for underwater work.

1.2.3 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 person about 1 minute and is essentially like pumping water from a large tank to a smaller one.

1.2.4 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, whereas acetylene’s explosive limits are 2.5 percent to 80 percent.

As *Figure 4-9* shows, MAPP’s limits are narrow compared to those of acetylene.

Figure 4-9 — Example of explosive limits of MAPP and acetylene in air.

MAPP's garlicky odor 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 1½ pounds of fuel or more in an 8-hour shift, bulk systems even more. Often, fuel-gas leaks are difficult to find and go unnoticed; however, a MAPP gas leak is easily detectable and repairable before becoming dangerous.

MAPP toxicity is rated "very slight," but high concentrations (5,000 ppm) may have an anesthetic effect.

MAPP gas vapor causes no adverse effects in local contact with eyes or skin, but the liquid fuel can cause dangerous frostlike burns due to the liquid's rapid evaporation.

The Navy-owned MAPP cylinders are identified by a yellow body with an orange band "B" and yellow cap/top.

1.3.1 Oxygen

Oxygen (O) is a colorless, tasteless, and odorless gas slightly heavier than air. It is nonflammable in its pure state, but vigorously supports combustion with other elements. In its free state, oxygen is the third most common element, with the atmosphere made up of about 21 parts of oxygen and 78 parts of nitrogen, the remainder being rare gases.

Working with metals, Steelworkers soon become very familiar with atmospheric oxygen in the form of oxidation, the results of which include rusting ferrous metals, discolored copper, and aluminum corrosion, to name a few.

The commercial processes for extracting oxygen are liquid-air and electrolytic.

- Liquid-air process
  - Air is compressed and cooled to a point where gases become liquid (approximately –375°F).
  - Temperature is raised to above –321°F where nitrogen becomes gas again and is removed.
  - Temperature of remaining liquid is raised to –297°F where oxygen forms gas again and is drawn off.
  - Oxygen is further purified and compressed into cylinders for use.
- Electrolytic process
  - An electrical current is run through water to which an acid or an alkali has been added.
  - Oxygen collects at a positive terminal and is drawn off through pipes to a container.

Figure 4-10 shows the components of a typical oxygen cylinder.

Oxygen is supplied for oxyacetylene welding in seamless steel cylinders.

The Navy-owned oxygen cylinders for industrial use are designated as solid green with a green cap/top.

Figure 4-10 — Example of a typical oxygen cylinder.

Oxygen cylinders are available in several sizes (*Figure 4-11*). The size the Navy uses most often for welding and cutting is the 244-cubic-foot capacity cylinder. This cylinder is 9 inches in diameter and 51 inches high, weighs about 145 pounds, and is charged to a pressure of 2,200 psi at 70°F.

Figure 4-11 — Example of the variety of oxygen cylinder sizes available.

To determine the amount of oxygen remaining in a compressed-gas cylinder, you read the volume scale on the non-adjustable high-pressure gauge attached to the regulator.

1.4.0 Regulators

Regulators reduce the high-pressure gas in a cylinder to a working pressure you can safely use. That is their one basic job, but in addition, they control the flow (volume of gas per hour).

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

Most regulators have two gauges: one indicates the cylinder pressure when the valve is open, and the other indicates the pressure of the gas coming out of the regulator.

The regulator must be open to get a reading on the second gauge, but before opening the cylinder valve, be sure to lower the regulator setting (back-off counter clockwise) to avoid damage from a sudden rush of pressure from the high pressure cylinder.

The reading on the regulator setting is the delivery pressure of the gas, and you set the pressure for your particular job.

Figure 4-12 — Example of the variety of regulators for different gases.

The pressures you read on regulator gauges are called gauge pressures. If you are using pounds per square inch (psi), it should be written as psig (pounds per square inch gauge). A zero reading gauge does not mean the cylinder is empty. To the contrary, the cylinder is still full of gas but the cylinder pressure is equal to the surrounding atmospheric pressure, which at sea level is 14.7 psi.

CAUTION

No gas cylinder is empty unless it has been pumped out by a vacuum pump.

Two types of regulators are used to control the flow of gas from a cylinder: single-stage regulators and double-stage regulators.

1.4.1 Single-Stage Regulators

Single-stage regulators are used on both high- and low-pressure systems. *Figure 4-13* shows two single-stage regulators: one for acetylene and one for oxygen, along with a diagram of their interior functioning.

The regulator mechanism consists of:

- a nozzle through which the gases pass
- a valve seat to close off the nozzle
- a diaphragm
- balancing springs

These mechanisms are all enclosed in a suitable housing.

Fuel-gas regulators and oxygen regulators are the same basic design.

The difference is in the pressures (high/low) for which they were designed.

Figure 4-13 — Example of single-stage regulator functioning.

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 4,000 psig. 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 0 to 400, depending upon the type of regulator used. For example, on regulators designed for heavy cutting, the working pressure gauge is graduated from 0 to 400.

The single-stage regulator's major disadvantage is that you must constantly monitor and reset the regulator if you require a fixed pressure and flow rate. With a single-stage regulator, the pressure you set will decrease as the cylinder pressure decreases. 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 down to cutting pressures or all the way down to 5 psig for welding. Double-stage regulators solve this problem.

1.4.2 Double-Stage Regulators

The double-stage regulator is similar in principle to the one-stage regulator. The main difference is that the total pressure drop takes place in two stages instead of one.

Figure 4-14 shows two double-stage regulators: one for acetylene and one for oxygen, along with a diagram of their interior functioning.

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 select.

Figure 4-14 — Example of double-stage regulator functioning.

1.4.3 Problems and Safety

The interior workings of regulators are precise pieces of equipment; carelessness usually does more to damage a regulator than any other gas-using equipment. You can damage a regulator by simply forgetting to clean wherever there will be gas flow: the cylinder connection, the regulator inlet, the hose connection threads.

When you open a high-pressure cylinder, the gas can rush into the regulator at the speed of sound. Any dirt particles present in the connections will be blasted into the precision-fitted valve seats, causing them to leak and resulting in a condition known as creep*.* When you shut the regulator off but not the cylinder, and gas pressure is still being delivered to the low-pressure side because of dirt in a valve--that is creep.

Manufacturers build regulators with a minimum of two relief devices, which are designed to protect you and the equipment in case of a regulator creep or a high-pressure rush of gas into the regulator. All regulator gauges have blowout backs to release the pressure from the back of the gauge before the gauge face (usually made of plastic) explodes.

The body of the regulator is also protected by safety devices. Blowout disks or spring-loaded relief valves are the two most common types of devices used. When they function for safety, the blowout disk sounds like a cannon, and the spring-loaded relief valves make howling or shrieking noises.

In either case, after you recover from your initial surprise, your first action is to close the cylinder valve, followed by removing the regulator and tagging it for repair or disposal.

Before connecting a regulator, you should always “crack” and close the valve a little. This helps protect the regulator by blowing out any dirt or other foreign material that might be in the cylinder nozzle. Then, back-off the regulator a little, connect the regulator to the cylinder, slowly crack open the cylinder valve, adjust the regulator to the desired setting, and go to work.

WARNING

Never use oil or other petroleum products around oxygen regulators. These products will cause either a regulator explosion or fire.

1.5.0 Hoses

The connection between the torch and the regulators is made with hoses that must be strong, nonporous, light, and flexible enough to make torch movements easy yet able to withstand internal pressures as high as 100 psig. The rubber used is specially treated to remove sulfur that could cause spontaneous combustion. Welding hose is available in single- and double-hose design. The proper size to use will depend on the type of work for which it is intended.

Figure 4-15 — Example of hose diameters.

Hose intended for light work has a 3/16-in. or 1/4-in. inside diameter and one or two plies of fabric (*Figure 4-15*).

For heavy-duty welding and cutting operations, use a hose with an inside diameter of 5/16-in. or 3/8-in. and three to five plies of fabric. Single hose is available in the standard sizes as well as in 1/2-, 3/4-, and 1-in. sizes for heavy-duty heating and use on large cutting machines.

The most common type of cutting and welding hose is the double hose with the fuel hose and the oxygen hose joined side by side by a slight melding together of the hoses in the manufacturing process (*Figure 4-16*).

This can be augmented by clamps, particularly at the split when separated to connect to the regulators.

Because they are joined together, the hoses are less likely to become tangled and are easier to move.

Figure 4-16 — Example of hose design.

The length of hose for a particular task is also important. Delivery pressure at the torch will vary with the length of the hose. A 3/16-inch hose that is adequate for one job at a 20-foot length may not be appropriate for another if it is extended to 50 feet; 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. If you are having volume flow problems when welding or cutting, this is one area to check

The fuel gas and oxygen hoses are identical in construction but differ in color; oxygen is green and fuel-gas is red to help prevent mishaps that could lead to dangerous accidents.

The Compressed Gas Association (CGA) has standardized connections for welding and cutting hose fittings. Connections on the regulators must correspond to identifying letter grades A, B, C, D, and E, plus the type of gas.

A, B, and C are the most common size connections: A- for low-flow rates; B- for medium-flow rates; and C- 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 carry because connections are threaded differently for different types of gases. The threadings for fuel gases and oxygen fittings are not compatible (fuel uses left-hand threads, oxygen uses right-hand threads) to prevent the accidental hookup of a fuel gas to a life-support oxygen system or vice versa.

Figure 4-17 — Examples of nut and gland (A) and check valves (B).

The basic hose connection consists of a nut and gland (*Figure 4-17 View A*). The nut has threads on the inside that match up with the male inlet and outlet on the torch and regulator. The left-hand threaded nuts have a distinguishing mark on the exterior as well. The gland slides inside the hose and is held in place by a ferrule that is crimped over the hose. The nut remains loose so it can be turned by hand and gently tightened with a wrench.

Two often overlooked but important items are the check valves (*Figure 4-17 View B*). These inexpensive valves prevent personal injuries and save valuable equipment from flashbacks. The check valves should be installed between the torch connection and the hose.

When ordering, you must specify the type of gas, connection size, and thread design.

1.6.0 Cutting Torches

The basic equipment and accessories for oxygas cutting are the same you would use for oxygas welding. The singular difference is you use a cutting torch, or cutting attachment, instead of a welding torch. The most characteristic difference between the cutting torch and the welding torch is the additional oxygen tube the cutting torch has for high-pressure cutting. You control the high-pressure oxygen flow with a levered 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 one of those shown in *Figure 4-18*.

Figure 4-18 — Examples of cutting torches with different trigger locations.

On most torches, the cutting oxygen mechanism is designed so you can turn on the cutting oxygen gradually. This is particularly helpful in close operations, such as hole piercing and rivet cutting.

1.6.1 Torch Body

While cutting torches are designed for singular purpose, most welding torches are designed so the body can accept a welding tip, heating tip (rosebud), or cutting attachment. This type of torch is called a combination torch. The advantage of this type of torch is the ease in changing from one mode to another (*Figure 4-19*).

Figure 4-19 — Example of a combination torch.

With a combination torch, you do not need to disconnect the hoses; you just unscrew the welding tip and screw on the heating tip or cutting attachment, which has the high-pressure oxygen-cutting lever on the now-attached torch handle.

1.6.2 Cutting Torch Tips

To do quality work and produce a clean cut, in cutting, as in welding, you must use the proper size tip for the appropriate fuel gas. The preheat flames must furnish the right amount of heat, and the oxygen jet orifice must deliver the correct amount of oxygen at the right pressure and velocity.

To add to this, you must also operate with a minimum consumption of oxygen and fuel gas. Inattentive workers or workers unfamiliar with correct procedures can waste both oxygen and fuel gas. This may not seem important in homeport working in a shop, but on deployment with long supply lead times, it can become critical to a project.

Manufacturers make many different types of cutting tips to serve multiple purposes and service the use of different gases. While orifice arrangements are relatively common based on the best configuration for a particular gas, and tip material is much the same among the manufacturers, the part of the tip that fits into the torch head often differs in design.

Although some tip designs may appear similar to others, there are two distinct areas to watch for if a manufacture's name is not apparent. Be sure the tip fits snugly into the torch head nut. The tip should fit smoothly into the nut without any undue movement. Secondly, be sure the tip "seats" correctly into the bevels of the torch head, again without any undue movement. Do **not** try to insert the tip and tighten the nut to see it will "seat"; this will damage the torch head beyond repair.

Because of the way the Navy supply system purchases cutting and welding equipment, there is a distinct possibility you may have two or three different manufacturers' brands of cutting torches in your kits. Make sure that the cutting tips match the cutting attachment and the cutting attachment matches the torch body. Again, this is particularly critical in deployment scenarios. See *Figure 4-20* for an example of different manufacturers' cutting tips.

The tips and seats are designed to produce an even flow of gas and keep themselves as cool as possible. The seats must seal tightly to develop leak-proof joints. If the joints leak, the preheat gases could mix with the cutting oxygen or escape to the atmosphere, resulting in poor quality 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 tips become dirty or misshapen, put them aside for restoration. Since it is extremely important that the sealing surfaces be kept clean and free of scratches or burrs, store the tips in a container that cannot scratch the seats.

Aluminum racks, plastic racks, or wooden racks and boxes make ideal storage containers.

Figure 4-20 — Example of manufacturers' differing cutting torch seating designs.

1.6.2.1 Acetylene Tip Maintenance

When you are cutting, sometimes the stream of cutting oxygen blows slag and molten metal into the tip orifices instead of away from the workpiece. When this happens, it can clog one or more of the tip orifices and you need to clean it before you use the tip again. A small amount of slag or metal in an orifice will seriously interfere with the cutting operation. *Figure 4-21* shows four tips: one is repairable, two need replacing, and one is in good condition.

Figure 4-21 — Examples of repairable and non-repairable acetylene tips.

Follow the torch manufacturer's recommendations for the size of the tip drill or tip cleaner to use for cleaning the orifices. If you do not have a tip drill or cleaner, you may use a piece of soft copper wire. Do **not** use twist drills, nails, or welding rods for cleaning tips; these are likely to enlarge and distort the orifices.

Figure 4-22 shows a typical set of tip cleaners.

Clean the orifices of the cutting torch tip in the same manner as the single orifice of the welding torch tip; push the cleaner straight in and out of the orifice.

Be careful not to turn or twist the cleaning wire.

Figure 4-22 — Typical tip cleaner.

Occasionally, even when you use the proper tip cleaners, the orifices become enlarged and/or distorted. When this happens, you will get shorter and thicker preheating flames and the jet of cutting oxygen can spread, instead of leaving the torch in a long, thin stream.

If the orifices become slightly belled, sometimes you can 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.

The action serves the same purpose as the file provided with some tip cleaning tools, but if you use this file, exercise caution: the file is typically a much harder metal than the tip. These procedures, of course, will not work if the damage is great or if the belling is extensive.

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

1.6.2.2 MAPP Tip Maintenance

MAPP gas cutting tips are available in four basic types: two for use with standard pressures and normal cutting speeds; two for use with high pressures and high cutting speeds.

Only standard pressure tips, types *SP* and *FS,* will be presented, as they are the ones that Steelworkers are likely use. SP stands for standard pressure and FS stands for fine standard.

The SP tip (*Figure 4-23 View A*) is a one-piece standard pressure tip 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. Notice the MAPP tip has 8 fuel orifices versus acetylene’s typical 4 or 6.

The FS tip (*Figure 4-23 View B*) is a two-piece, splined, standard pressure tip 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.

Figure 4-23 — Examples of MAPP cutting tips.

FS two-piece tips produce heavier preheating flames and faster starts than the SP tips, but they will not take as much thermal or physical abuse as SP one-piece tips. However, in the hands of skilled Steelworkers and in a shop atmosphere where cleaning slag from the splines is more available, they can last as long as one-piece tips.

Table 4-1 provides recommended tip sizes and gas pressures when using MAPP to cut different steel thicknesses.

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

<table>
<tr><th>Material Thickness inches (millimeters)</th><th>Cutting Tip Number</th><th>Oxygen Cutting Pressure (psig)</th><th>MAPP Gas Pressure (psig)</th></tr>
<tr><td>1/8 (3)</td><td>75</td><td rowspan="6">40-50</td><td rowspan="9">2-10</td></tr>
<tr><td>3/16 (4.8)</td><td>72</td></tr>
<tr><td>1/4 (6.4)</td><td>68</td></tr>
<tr><td>1/2 (12.7)</td><td>61</td></tr>
<tr><td>3/4 (19)</td><td rowspan="2">56</td></tr>
<tr><td>1 (25.4)</td></tr>
<tr><td>1 1/4 (31.8)</td><td rowspan="2">54</td><td rowspan="5">50-60</td></tr>
<tr><td>1 1/2 (38)</td></tr>
<tr><td>2 (50.8)</td><td>52</td></tr>
<tr><td>2 1/2 (63.5)</td><td rowspan="2">48</td><td rowspan="3">6-10</td></tr>
<tr><td>3 (76)</td></tr>
<tr><td>4 (101)</td><td>46</td><td>60-70</td></tr>
</table>

Test your Knowledge (Select the Correct Response)

1. As a Steelworker, what method are you most likely to use for cutting metal plate?

   A. Oxygas flame
   B. Air carbon-arc
   C. Plasma-arc
   D. Oxygen lance

2.1.1 OXYGAS CUTTING OPERATIONS

CAUTION

Before you begin any cutting operation, make a thorough inspection of the area for any combustible materials that could be ignited by sparks or slag. If you are burning into a wall, inspect the opposite side and post a fire watch as required.

When you use the oxygas cutting process, proceed as follows:

- Heat a spot on the metal to kindling or ignition temperature (1400°F to 1600°F for steels).
  - The term for this oxygas flame is the *preheating flame.*
- Press the lever on the cutting torch to direct a jet of pure oxygen at the heated metal.
  - The oxygen causes a rapid chemical reaction known as *oxidation.*

This rapid oxidation is called *combustion* or *burning.* Slow oxidation is known as *rusting.*

When you use an oxygas torch to cut metal, the oxidation of the metal is extremely rapid and part of the metal actually burns. 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. The molten material runs off as slag, exposing more iron or steel to the oxygen jet.

In oxygas cutting, only the metal in the direct path of the oxygen jet is oxidized, and the narrow slit formed 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 is molten metal blown out of the kerf by the force of the oxygen jet.

Figure 4-24 — Example of a quality oxygas cut.

A quality cut leaves the kerf walls fairly smooth and parallel with no excess of slag (*Figure 4-24*). When you develop your torch handling skills, you should be able to 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 is a vital part of the oxygas cutting process. Hence, metals that do not oxidize readily are not suitable for oxygas cutting.

Carbon steels are easily cut by the oxygas process, but special techniques are required for cutting many other metals.

2.1.1 Equipment Setup

To avoid costly mistakes and avoid injury to yourself and others, set up the oxygas equipment and prepare for cutting in a careful and systematic manner.

Take the following steps before attempting to light the torch:

- Secure cylinders so they cannot be knocked over.
  - Place in a corner or next to a vertical column; secure with a piece of line.
  - Never secure to a structural member that is a current conductor.
- Remove protective caps.
- Stand to one side, crack each cylinder valve slightly, and immediately reclose valve.
  - This blows dirt and other foreign matter out of cylinder valve nozzle.
  - Do not bleed fuel gas into a confined area; it may ignite.
- Wipe connections with a clean cloth.
- Connect fuel-gas regulator to fuel-gas cylinder and oxygen regulator to oxygen cylinder.

- Snug connection nuts sufficiently with gang wrench to avoid leaks.
- Back off regulator screws to prevent damage to regulators and gauges.
- Open cylinder valves slowly.
    - Open fuel-gas valve only one-half turn.
    - Open oxygen valve all the way.

Note: Some fuel-gas cylinders have a hand wheel for opening the fuel-gas valve; others require using a gang wrench or T-handle wrench. Leave any wrench in place while the cylinder is in use so the fuel-gas bottle can be turned off quickly in an emergency.

- Read high-pressure gauge to check contents in each cylinder.
- Connect red hose to fuel-gas regulator (left-hand threads) and green hose to oxygen regulator.
- Purge oxygen hose by turning regulator screw in (clockwise) to between 2 and 5 psig; turn screw out (counterclockwise) to shutoff oxygen.
- Repeat for fuel-gas hose ONLY in a well-ventilated place free from sparks, flames, or possible sources of ignition.
- Connect hoses to torch, red (left-threaded) to fuel, green to oxy.
- With torch valves closed, turn both regulator screws clockwise to test hose connections for leaks.
- If no leaks are found, turn regulator screws counterclockwise to close.
- Open torch valves to drain hose.
- Install correct cutting tip in cutting torch head.
    - Tighten assembly by hand; snug tighten with gang wrench.
- Adjust working pressures.
    - Adjust fuel-gas pressure by opening torch needle valve and turning fuel-gas regulator screw clockwise. Adjust regulator to working pressure needed for particular tip size; close torch needle valve.

      - Adjust MAPP gas pressure with torch valves closed.
    - Adjust oxygen pressure by opening torch needle valve and proceed as with fuel-gas.

To light the torch and adjust the flame, always follow the manufacturer’s directions for that particular model of torch. Procedures vary somewhat with different types and, in some cases, even with different models of torches made by the same manufacturer.

In general, the procedure is to open the torch oxygen needle valve a small amount, followed by opening the torch fuel-gas needle valve slightly more. Then use a spark igniter or stationary pilot flame to light the mixture.

CAUTION

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

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.

A pure fuel-gas flame is long and bushy with a yellowish color. It takes the oxygen it needs for combustion from the surrounding air and there is not enough oxygen available to burn the fuel gas completely. Consequently, the flame is smoky, sooty, and unsuitable for use.

To set the flame appropriately, 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. The inner cone is the portion of the flame that develops the required operating temperature.

All oxygas processes commonly use one of three types of preheat flames: carburizing, neutral, or oxidizing.

You need to know their characteristics to ensure proper flame adjustment.

Figure 4-25 shows how the three different flames look.

Figure 4-25 — Example of carburizing, neutral, and oxidizing flames.

2.1.1 burizing Flame

The temperature of a carburizing flame is about 5400°F. It 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; the slightly carburizing flame has a shorter feather on the inner cone and becomes whiter.

Strongly carburizing flames are not used in cutting low-carbon steels because the additional carbon they add causes brittleness and hardness. However, these flames are ideal for cutting cast iron; the additional carbon poses no problem, 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 reasonably smooth cuts and reduces the amount of slag clinging to the bottom of the cut.

2.1.2 Neutral Flame

The temperature of a neutral flame is about 5600°F. It is the most common preheat flame for oxygas cutting. The carburizing flame becomes neutral when you add additional oxygen. 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 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 focus a neutral preheat flame on a single spot on the metal until it melts, it forms a clear-looking molten puddle that lies very quietly under the flame.

2.1.3 Oxidizing Flame

The temperature of an oxidizing flame is about 6000°F. 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 port, and 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 oxidizing flame is rarely used for conventional cutting since 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. They are used also in cutting metal underwater where the only source of oxygen for the torch is supplied from the surface.

2.2.0 Cutting Mild-Carbon Steel

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

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 (*Figure 4-26*).

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.

Figure 4-26 — Typical position to start a cut.

Move the cutting torch forward along your proposed cut line just fast enough for the cutting oxygen flame to continue to penetrate the work completely. If you make the cut properly, you will get a clean, narrow cut that looks almost like it was made by a saw.

When cutting round bar or heavy sections, you can save preheating time by raising a small burr with a chisel where you will begin the cut. This small raised portion will heat quickly, allowing you to start cutting immediately.

Once you start the cut, move the torch slowly along the cutting mark or guide; watch the cut to observe progress and adjust as necessary. You need to move the torch at the correct speed.

Too slow — the preheating flame melts the top edges along the cut and they may weld back together again behind the cut. Too fast — the oxidizing flame will not penetrate completely, as shown in *Figure 4-27*.

Figure 4-27 — Example of moving too rapidly across the work.

When this happens, sparks and slag will blow back towards you. Make sure there is no slag on the opposite side if you have to restart the cut.

2.2.1 Cutting Thin Steel

When you cut steel 1/8-inch thick or less, use the smallest cutting tip available and angle the tip in the direction of travel to give the preheating flames a chance to heat the metal ahead of the oxygen jet (*Figure 4-28*).

For thin metals, holding the tip perpendicular decreases the amount of preheated metal and the adjacent metal cools the cut enough to prevent smooth cutting action.

You can actually rest the edge of the tip on the metal during this process. If you do so, be sure to keep the end of the preheating flame inner cone just above the metal.

Figure 4-28 — Example of method for cutting thin metal.

2.2.2 Cutting Thick Steel

For steel thicker than 1/8-inch, hold the torch so the tip is almost vertical to the surface. One method, if you are right-handed, is to start at the right edge and move to left. Left-handed people tend to cut left to right but either direction is correct, and if conditions permit, cut in the direction that is most comfortable for you. *Figure 4-29* shows the progress of a cut in thick steel.

Figure 4-29 — Example of progress cutting mild steel thicker than 1/8-inch.

- A. Hold the preheat flame 1/16 to 1/8 inch from surface until the metal becomes cherry red.
- B. Press the cutting oxygen valve and move the torch at an even rate to maintain rapid oxidation even though the cut is only partially through the metal.
- C. The cutting oxygen cuts through the entire thickness as the bottom of the kerf lags slightly behind the top edge.

Avoid unsteady movement of the torch; a smooth movement helps prevent irregular cuts and premature stopping of the cutting action.

There are three methods to starting a cut quicker in thick plate.

1. Start at the edge with the torch angled in the opposite direction of travel. When the edge starts to cut with the cutting oxygen, bring the torch to a vertical position to 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.
2. Nick the edge 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, allowing you to start the cut without preheating the entire edge of the plate.
3. 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; the rod will oxidize and cause the thicker plate to start oxidizing.

Table 4-2 provides recommended tip sizes and gas pressures when using Acetylene to cut different steel thicknesses.

Table 4-2 Acetylene cutting tip chart.

Metal Thickness	Tip Size	Cutting Oxygen		Pre-heat Oxygen PSIG	Acetylene		Speed IPM	Kerf Width
		Pressure PSIG	Flow SCFH		Pressure PSIG	Flow SCFH		
1/8"	000	20-25	20-25	3-5	3-5	6-11	20-30	.04
1/4"	00	20-25	30-35	3-5	3-5	6-11	20-28	.05
3/8"	0	25-30	55-60	3-5	3-5	6-11	18-26	.06
1/2"	0	30-35	60-65	3-6	3-5	9-16	16-22	.06
3/4"	1	30-35	80-85	4-7	3-5	8-13	15-20	.07
1"	2	35-40	140-160	4-8	3-6	10-18	13-18	.09
2"	3	40-45	210-240	5-10	4-8	14-24	10-12	.11
3"	4	40-50	280-320	5-10	5-11	18-28	10-12	.12
4"	5	45-55	390-450	6-12	6-13	22-30	6-9	.15

2.3.0 Cutting Cast Iron

The iron oxides in cast iron melt at a higher temperature than the cast iron itself. This makes cutting cast iron more difficult than cutting steel. Before you cut cast iron, preheat the whole casting to prevent stress fractures, but do not heat it to too high a temperature; that will oxidize the surface and make cutting more difficult. A preheat temperature of about 500°F is normally satisfactory.

Use a carburizing flame when you cut cast iron. This prevents the formation of oxides on the surface and provides better preheat.

A cast-iron kerf is always wider than a steel kerf due to the presence of oxides and the torch movement.

Use a torch movement similar to scribing semicircles along the cutting line (*Figure 4-30*).

As the metal becomes molten, trigger the cutting oxygen and use its force to jet the molten metal out of the kerf.

The difficulty in cutting cast iron with the usual oxygas cutting torch has led to the development of other processes such as the oxygen lance, carbon-arc powder, inert-gas cutting, and plasma-arc methods.

Figure 4-30 — Example of torch movement for cast iron.

2.4.0 Gouging Mild Steel

A cutting torch can also be used to cut curved grooves on the edge or surface of a plate or to remove faulty welds for rewelding. Typically, for gouging you use an angled tip with a large orifice and a low-velocity jet of oxygen instead of a high-velocity jet. The low-velocity jet oxidizes only the surface of the metal and gives you better control for more accurate gouging. By varying travel speed, oxygen pressure, and tip to plate angle, 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. *Figure 4-31* shows the variety of gouging tips available and an example of a typical gouging operation. Note the large cutting oxygen orifice typical of gouging tips.

Figure 4-31 — Typical gouging tips and the gouging process.

You must start the gouging operation properly (not too deep) or you can unintentionally cut through the entire thickness of the plate. Alternately, if you cut too shallow, you can cause the operation to stop.

The travel speed of the torch along the gouge line is important as well; moving too fast creates a narrow, shallow gouge, and moving too slow creates the opposite, a deep, wide gouge.

2.5.0 Beveling Mild Steel

Often, Steelworkers must cut plate or pipe on a bevel to meet a joint design for welding. To make a 45° bevel cut on a 2-inch steel plate, you will actually have to cut through 2.8 inches of metal and need to consider this when you select a tip and adjust the pressures. You must use more pressure and less speed for a bevel cut than for a straight cut.

When you make a bevel cut, adjust the tip so the preheating orifices straddle the cut.

To help maintain the proper angle and travel speed, use a piece of 1-inch angle iron with the angle up as a guide for beveling straight edges.

You can keep the angle iron in place by using a heavy piece of scrap angle, clamping a lighter angle down, or tack welding the angle to the plate being cut.

Then move the torch along your guide, as shown in *Figure 4-32*.

Figure 4-32 — Example of using angle iron to assist in a bevel cut.

2.6.1 Electric Drive Cutting Torch Carriage

One improvement over a mechanical guide is an electric motor-driven cutting torch carriage. With this tool, you can vary the speed of the motor to cut to dimensions 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 adjusted up and down by a gear and rack.

This machine comes with a radial bar for use in cutting circles and arcs (*Figure 4-33*).

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

Figure 4-33 — Example of using a cutting torch carriage to cut a circle.

This machine comes with a straight two-groove rack.

The rack is a part of the special torch. The torch also can be tilted for bevel cuts.

Figure 4-34 shows an electric drive carriage on a straight track being used for cutting a plate straight edge to size.

Figure 4-34 — Example of using a cutting torch carriage on track to cut a straight edge.

Figure 4-35 — Example of using a cutting torch carriage to bevel a pipe.

Still other specialty carriages are used in commercial and industrial projects to prepare pipe for welding

Figure 4-35 shows a cutting torch carriage being used to bevel a large diameter pipe.

Regardless of which automatic carriage is available, 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 free-wheel the carriage the full length of the track by hand.

On deployment, you may find the torch carriage a valuable asset, especially if your shop is tasked with producing a quantity of identical parts, such as handhole covers for runway fixtures or thick base plates for vertical columns.

When you use the torch carriage, perform the following steps in order.

- Lay the track in a straight line along a line parallel to the edge of the plate you are going to cut.
- Perform the freewheeling exercise to check for hose and cord travel.
- Light the torch and adjust the flame for the metal and thickness you are cutting.
- Move the carriage so the torch flame preheats the edge of the plate.
- Open the cutting oxygen valve and turn on the carriage motor.

The machine will begin to move along the track and continue to cut automatically until it reaches the end of the track. The cutting speed will depend on the thickness of the steel you are cutting.

When the cut is complete, perform these steps in order:

- Promptly turn off the cutting oxygen.
- Turn off the current.
- Extinguish the flame.

2.7.1 Cutting and Beveling Pipe

You need practice, experience, and a steady hand to cut pipe in a smooth, true bevel. Do not attempt to cut and bevel a heavy pipe in one operation until you have developed that considerable skill.

Instead, until you develop the single step skills, cut the pipe off square, remove all the slag from the inside of the pipe, then bevel the pipe.

For the inexperienced Steelworker, this procedure will produce a cleaner and better job.

When you cut pipe, keep the torch pointed toward the centerline of the pipe.

Start at the top and cut down one side; then begin at the top again and cut down the other side, finishing at the bottom, as shown in *Figure 4-36*.

Figure 4-36 — Example of cutting pipe.

The cutting torch is a valuable tool when you need to make T and Y fittings from pipe. The usual procedure for fabricating pipefittings is to develop patterns like those shown in *Figure 4-37 Views A-1* and *B-1*. Be sure to leave enough material so the ends overlap.

After you develop the patterns, wrap them around the pipe, as shown in *Figure 4-37 Views A-2* and *B-2*, and trace around the pattern with soapstone or a scribe.

Figure 4-37 — Example of fabricating a pipe "T" section.

It is also a good idea to mark the outline with a prick punch at 1/4-inch intervals. Place the punch marks so the cutting action will remove them. If you leave them on the pipe, they could provide notches where cracking could start. During the cutting procedure, as the metal is heated, the punch marks stand out and make it easier to follow the line of cut.

As already mentioned, an experienced Steelworker can cut and bevel pipe at a 45° angle in a single operation, but a person with little cutting experience should cut the pipe at a 90° angle then bevel the edge of the cut to a 45° angle.

With the two-step procedure, you need to mark an additional line on the pipe. Draw the second line parallel to the line traced around the pattern, but draw it on the waste area away from the original pattern line at a distance equal to the thickness of the pipe wall. Make your first (90°) cut along the second line in the waste area. Make your second (45°) cut along the original pattern line.

The disadvantages of the two-step procedure are the time expended and the consumption of oxygen and gas, but it is better than a wasted attempt if the single cut effort damages the pipe. When deployed at the end of a long resupply, you will need to weigh the risks.

The one-step method, while not particularly difficult, does require a steady hand and a great deal of experience to turn out a first-class job.

Refer again to *Figure 4-37* for an example of the one-step method for fabricating a T.

- View A shows the steps for preparing the branch of the T.
- View B shows the steps for preparing the main section of the T
- View C shows the assembled T, tack-welded and ready for final welding.

View A, Step 3 shows the procedure for cutting the miter on the branch. Begin the cut at the end of the pipe and work around until the one-half of one side is cut. Keep the torch at a 45-degree angle to the surface of the pipe along the punched cut line. While the tip is at a 45-degree angle, move the torch steadily forward, and at the same time, keep swinging the butt of the torch upward through an arc, always angling the tip towards the centerline of the pipe. 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 manner as the first.

View B, Steps 3 and 4 show the torch manipulation necessary to cut the run in the main branch of the T. 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.

View B, Step 5 shows the completed cut for the run. The bevels must be smooth and obtain complete fusion when you weld the joint. Of course you will check the fit of your cut pieces, but before you do your final assembly and tack weld for a fabricated fitting, you must clean all the slag from the inner pipe wall.

2.8.1 Piercing Holes

The cutting torch is also valuable for piercing holes in steel plate. *Figure 4-38* shows the steps to use.

- Lay plate on firebricks or other suitable material so no damage occurs at burn through.
- Hold torch over location with tip of preheating flame's inner cone about 1/4 inch above surface.
- Hold until small spot has heated to a bright red.
- Open cutting oxygen valve gradually and raise nozzle slightly away at the same time.
- Rotate torch with slow spiral motion.
- At burn through, lower tip and oscillate to enlarge.

Figure 4-38 — Typical steps in piercing a hole with a cutting torch.

The molten slag will blow out of the hole and fly around, so BE SURE 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. You can make round holes easily by using a radius bar attachment with the cutting torch.

2.9 0 Cutting Rivets

The cutting torch is a proven and excellent tool for removing rivets from structures to be disassembled. The basic method is to heat the head of the rivet to cutting temperature with the preheating flames and turn on the cutting oxygen to wash it off. The remaining portion of the rivet can then be punched out with light hammer blows. The key is to avoid gouging the surface metal. *Figure 39* shows the rivet cutting procedures.

- Use tip size and oxygen pressure required for size and type of rivet.
- Heat a spot on rivet head until bright red.
- Move tip to position parallel with surface and slowly turn on cutting oxygen.
- Cut slot in rivet head; when cut nears plate, draw nozzle back at least 1½ inches from rivet.
- Swing tip in an arc slicing off half of rivet
- Swing tip in an arc slicing off other half of rivet.

Figure 4-39 — Example of rivet cutting steps.

By the time you cut the slot, the rest of the rivet head is at cutting temperature. Just before you get through the slot, draw the torch tip back the 1½ inches to allow the cutting oxygen to scatter slightly. This keeps the torch from breaking through the ever present layer of scale between rivet head and plate and allows you to cut the rivet head 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.

Figure 4-40 — Example of a rivet cutting tip.

Figure 4-40 shows a typical rivet cutting tip. Use this type whenever it is available.

For buttonhead and countersunk rivets, a low-velocity cutting tip is better. This tip has a large diameter cutting oxygen orifice similar to the gouging tip shown in *Figure 4-31*. It has three preheating orifices above the oxygen orifice. Always place a low-velocity rivet cutting tip in the torch so the heating orifices are above the cutting orifice when it is in the cutting position.

2.10.0 Cutting Wire Rope

You can use a cutting torch to cut wire rope. Wire rope is constructed by wrapping multiple strands around a core, and since these strands do not form one solid piece of metal, you could have trouble in making the cut. When you cut wire rope, you need to focus the torch on one strand at a time working your way through the layers. *Figure 4-41* is an example of wire rope construction.

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 cut the strands one at a time between the seizings.

If the wire rope is going to go through sheaves, 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 are close together.

To fuse and point wire rope, adjust the torch to a neutral flame; then close the oxygen needle valve until you get a carburizing flame.

Figure 4-41 — Typical wire rope construction.

Manipulate the torch in an in-and-out and oscillating manner to fuse the wires together and point the wire rope at the same time.

Wire rope is lubricated during fabrication and lubricated routinely during its service life.

Some lubrication burning is likely to occur, so ensure that excess lubricant is wiped off before you begin to cut it with the oxygas torch.

2.11.0 Cutting on Containers

WARNING

Never cut or weld 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 can lead to property damage or loss of life.

Whenever available, use steam to remove volatile materials. 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 doing any cutting, welding, or other hot work. In almost every situation, it is possible to position the container so it can be kept filled with water during these operations.

Always ensure there is a vent or opening in the container to release the heated vapor that builds inside. You can do this by opening the bung, handhole, or other fitting above the 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, and examine the gas content of the container periodically to ensure the concentration of carbon dioxide (CO_2) or nitrogen (N) is high enough to prevent a flammable or explosive mixture. You can test the air-gas mixture inside any container 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 you detect the presence of hydrogen (H) or carbon monoxide (CO). If you use nitrogen, ensure the concentration is at least 10 percent higher than that specified for carbon dioxide.

Even in apparently clean containers, you should use carbon dioxide or nitrogen because there may still be traces of oil or grease under the seams. Although the vessel was cleaned and flushed with a caustic soda solution, heat from the cutting or welding operation could cause the trapped oil or grease to release enough flammable vapors to form an explosive mixture inside the container.

A suspiciously light metal part may be hollow inside; therefore, you should vent the part by drilling a hole in it before heating. Remember: air or any other gases confined inside a hollow part will expand when heated and 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 any air confined in jacketed vessels, tanks, or containers.

Test your Knowledge (Select the Correct Response)

2. What is the kindling temperature for steels?

   A. 1000°F to 1200°F
   B. 1200°F to 1400°F
   C. 1400°F to 1600°F
   D. 1600°F to 1800°F

3.1.1 JUDGING CUTTING QUALITY

How good a cutting job are you doing? Refer to *Figure 4-42*.

To know how good a cut you are making, you need to know what constitutes a good oxygas cut.

The quality of an oxygas cut is judged generally 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

Figure 4-42 — Typical effects of correct and incorrect cutting procedures.

3.1.0 Drag Lines

Drag lines show on the face of the cut. Good drag lines are almost straight up and down (*Figure 4-42 View A*). Poor drag lines are long and irregular or excessively curved (*Figure 4-42 View B*). Poor drag lines indicate you are using a poor cutting procedure, which could result in the loss of the cut (*Figure 4-42 Views B and C*).

3.2.0 Side Smoothness

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

3.3.0 Top Edge Sharpness

The top edges should be sharp and square (*Figure 4-42 View D*). Rounded top edges (*Figure 4-42 View E*) are unsatisfactory. The top edges melting may be a result of incorrect preheating procedures or of moving the torch too slowly.

3.4.0 Slag Conditions

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

Overall, draglines are the best single indication of the quality of your cut with an oxygas torch. When the draglines you make are short and almost vertical, the sides smooth, and the top edges sharp, you can be assured that the slag conditions are satisfactory.

4.0.0 SAFETY PRECAUTIONS

In all cutting operations, you must ensure that hot slag is not exposed to combustible material. Globules of hot slag can roll along the deck for long distances, so do not cut within 30 to 40 feet of unprotected combustible materials. If you cannot remove combustible materials, cover them with sheet metal or some 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 the welding chapters of this course 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.

4.1.0 Backfire and Flashback

Backfire is the result of improperly operating the oxygas torch and the flame goes out with a loud snap or pop. If this happens, 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. It may also be caused by a loose tip or head, or by dirt on the seat.

Flashback occurs when the flame burns back inside the torch, typically with a shrill hissing or squealing noise. If this happens, close the torch oxygen valve at once to stop the flashback; then close the gas valve and the oxygen and gas regulators.

Flashbacks may extend back into the hose or regulators. They indicate that something is wrong either with the torch or with the way you are using it. Investigate every flashback to determine the cause before you relight the torch. Allow the torch to cool before relighting it and blow oxygen through the cutting tip for a few seconds to clear out soot that may have accumulated in the passages.

A clogged orifice or incorrect oxygen and gas pressures are often responsible for flashbacks. Avoid using gas pressures higher than manufacturers' recommendations.

4.2.0 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.

4.2.1 Identification of Cylinders

Color warnings provide an effective means for marking physical hazards and for indicating the location of safety equipment. The Navy uses uniform color codes 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, while a sixth class has been reserved for fire protection equipment. *Table 4-3* shows the colors that represent the six classes.

Table 4-3 — Standard Colors for General Hazards

Class	Standard Color	Class of Material
a	Yellow, No. 13655	**FLAMMABLE** — All materials known ordinarily as flammables or combustibles.
b	Brown, No. 10080	**TOXIC AND POISONOUS** — All materials extremely hazardous to life or health under normal conditions as toxics or poisons.
c	Blue, No.15102	**ANESTHETICS AND HARMFUL** — 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** — 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** — 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** — All materials provided in piping systems or in compressed-gas cylinders exclusively for use in fire protection.

Since you work with fuel gas and oxygen, you must become familiar with the Navy's designated colors for the cylinders containing these gases; the fuel-gas cylinder is yellow, the oxygen cylinder is green.

In further compliance with the Navy's system, 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 with a background color of yellow, orange, or buff have the title painted in black lettering. Cylinders with a background color of red, brown, black, blue, gray, or green have the title painted in white lettering.

4.2.1.1 Color Warnings

A compressed-gas cylinder with one of the specified six colors appearing on the body or top, or as a band or bands should provide you with a warning of danger from the hazard involved.

4.2.1.2 1.2 Cylinder Color Bands

Cylinder color bands appear upon the cylinder body and serve as color warnings when they identify one of the general hazards by being 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 any new materials not presently covered by MIL-STD-101B.

4.2.1.3 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, and precautions for handling and use. A background color should correspond to the primary warning color of the contents.

4.2.1.4 Shatterproof Cylinders

A shatterproof cylinder should be stenciled with the phrase “NONSHAT’’ longitudinally 90 degrees from the titles. Letters must be black or white as appropriate to the background color and approximately 1 inch in size.

4.2.1.5 Service Ownership

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

Table 4-3 identifies the six colors used on a compressed-gas cylinder’s body and cap (top), or as a band, to serve as a warning of the hazard involved in handling the type of material the cylinder.

Figure 4-43 shows DOD titles and color codes for compressed-gas cylinders most often found in a construction battalion or in a public works department where Seabee personnel are working.

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 (fire only)	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 4-43 — Typical DOD titles and colors found in Seabee working areas.

Figure 4-44 shows how DOD cylinders are identified by:

- Class of material body color codes
- Additional color codes for top and/or cap as appropriate
- Additional identifying color code bands as appropriate
- Stenciled name of the gas in contrasting black or white

Refer to MIL-STD 101B, *Color Code for Pipelines and for Compressed-Gas Cylinders.* Dec 1970, for a complete listing of compressed-gas cylinder and piping identification requirements.

NOTE

Ensure you have a manual with the latest up-to-date changes inserted, as changes may occur in MIL-STD 101B after this course is published.

NOTE

The color codes of cylinders shown in *Figure 4-44* are military only; the commercial industry does not comply with these color codes.

4.2.2 Handling and Storing Gas Cylinders

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

- 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 as well as stupid. Cylinder owners and suppliers are the only personnel permitted to work on cylinder safety devices.
- Never store cylinders near a heat source or in direct sunlight.
    - Heat causes the gas inside a cylinder to expand, which 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.

Figure 4-44 — Typical cylinder identifying color patterns.

- Store cylinders in protected, well-ventilated, 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.
  - Chain the cylinders when they are stored in the upright position.
- Never drag a cylinder to move it.
  - Use a cylinder hand truck whenever available; leave the cylinders on the hand truck and operate them from there as much as possible. Alternatively, 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.
  - Avoid lifting a cylinder upright by the cap; make sure that it is screwed on tightly. A cylinder cap suddenly releasing can be hazardous to your teeth, and/or the cylinder can fall and either crush your foot or snap the valve off.
  - A dropped pressurized cylinder with a sudden valve break can 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 pry bar. If you use a pry bar, never pry or lift under the valve cap or valve.

Summary

This chapter has presented information on the different types of gases and equipment available and necessary to perform quality oxygas cutting on metals. It has also identified the operational steps you should take to prepare the material and adjust the equipment to the characteristics of the metal. However, it takes hands–on practice and experience to develop the skills and steady hand to make good quality cuts. Your tasking is to practice your cutting techniques, judge your work by the criteria presented here, and do so in a manner that is safe for you and those around you in both the shop and field working environments.

Review Questions (Select the Correct Response)

1. What portion, if any, of a ferrous metal becomes oxidized during the oxygas cutting process?

   A. Portion directly in the path of the preheating flame
   B. Portion directly in the path of the oxygen jet
   C. Portion previously cut
   D. None

2. **(True or False)** Metals that oxidize readily are best suited for oxygas cutting.

   A. True
   B. False

3. **(True or False)** The principal difference between a standard cutting torch and an oxygas welding torch is that the cutting torch has an extra tube for high-pressure oxygen.

   A. True
   B. False

4. What type of problem(s) can occur during their use if the cutting torch tips and seats are not properly matched and assembled?

   A. Improper cooling
   B. Improper gas flow
   C. Leakage
   D. All of the above

5. What action should you take to keep cutting tips in proper working order when they are not in use?

   A. Place them in kits.
   B. Store them in toolboxes20-foot.
   C. Store them in a container equipped with a wooden rack.
   D. Store them in a mount-out box.

6. Which of these basic types of MAPP tips do Steelworkers often use?

   A. High pressure only
   B. Standard pressure only
   C. High pressure and normal cutting
   D. Standard pressure and high cutting

Refer to the figure below when answering questions 7-9.

7. Which cutting torch tip is a low-velocity tip?

   A. 1
   B. 2
   C. 3
   D. 4

8. What cutting torch tip is a MAPP gas two-piece tip?

   A. 1
   B. 2
   C. 3
   D. 4

9. Which cutting torch tip is specially designed for cutting rivets?

   A. 1
   B. 2
   C. 3
   D. 4

10. **(True or False)** The FS type of MAPP gas-cutting tip can be used for machine cutting.

   A. True
   B. False

11. What can you use as a tool to clean torch tip orifices when a tip cleaner is not available?

    A. Nail
    B. Welding rod
    C. Soft cooper wire
    D. Twist drill

12. **(True or False)** When cleaning the orifices of a tip with a cleaner, you should push the cleaner straight into the orifices and pull it straight out without twisting.

    A. True
    B. False

13. With which of these tools can you correct slightly belled orifices by wearing down the end of the tip?

    A. Grinding tool
    B. Wire brush
    C. Emery cloth
    D. Rasp file

14. **(True or False)** Before starting to cut with a torch, you should inspect the working area and adjacent areas for combustibles that must be removed or covered to keep sparks or slag from igniting them.

    A. True
    B. False

Refer to the table below when answering question 15.

<table>
<tr><th>Material Thickness inches (millimeters)</th><th>Cutting Tip Number</th><th>Oxygen Cutting Pressure (psig)</th><th>MAPP Gas Pressure (psig)</th></tr>
<tr><td>1/8 (3)</td><td>75</td><td rowspan="6">40-50</td><td rowspan="9">2-10</td></tr>
<tr><td>3/16 (4.8)</td><td>72</td></tr>
<tr><td>1/4 (6.4)</td><td>68</td></tr>
<tr><td>1/2 (12.7)</td><td>61</td></tr>
<tr><td>3/4 (19)</td><td rowspan="2">56</td></tr>
<tr><td>1 (25.4)</td></tr>
<tr><td>1 1/4 (31.8)</td><td rowspan="2">54</td><td rowspan="5">50-60</td></tr>
<tr><td>1 1/2 (38)</td></tr>
<tr><td>2 (50.8)</td><td>52</td></tr>
<tr><td>2 1/2 (63.5)</td><td rowspan="2">48</td><td rowspan="3">6-10</td></tr>
<tr><td>3 (76)</td></tr>
<tr><td>4 (101)</td><td>46</td><td>60-70</td></tr>
</table>

15. What thickness material can you cut when using a Number 54 tip and setting the oxygen cutting pressure between 50 to 60 psig?

    A. 1 1/4 inches only
    B. 1 1/4 or 1 1/2 inches
    C. 1 1/2 or 2 inches
    D. 2 inches only

16. What device is used to ignite a cutting torch?

    A. Safety match
    B. Open flame
    C. Spark igniter
    D. Butane lighter

17. What type of flame should you use to cut steels that produce a lot of slag?

    A. Oxidizing
    B. Neutral
    C. Carburizing
    D. Cyanizing

18. What distance in inches should you maintain between the preheating flame and the surface of the metal when using the cutting torch to preheat a mild-carbon steel plate?

    A. 1/32
    B. 1/16
    C. 1/8
    D. 3/16

19. How should the shower of sparks fall when you have started a cut properly and the cut is going all the way through the material?

    A. Over both sides of the material
    B. From the top of the material
    C. Over one side of the material
    D. From the bottom of the material

20. Which of the following actions can save time when you need to cut a round piece of metal stock with a cutting torch?

    A. Using a one-piece standard pressure tip
    B. Using a two-piece, fine spline, standard pressure tip
    C. Chiseling a small burr at the starting point on the stock
    D. Punching a small dent in the stock at the starting point

21. What type of flame is best for piercing holes in plate?

    A. Oxidizing
    B. Neutral
    C. Carburizing
    D. Cyanizing

22. One 70-pound MAPP cylinder can accomplish the work of more than _ 225-cubic-foot acetylene cylinders.

    A. three
    B. four and one-half
    C. six and one-half
    D. eight

23. What error are you making when cutting metal plate with an oxygas torch and you cause the top surfaces of the kerf to fuse?

    A. Using too much oxygen pressure
    B. Advancing the torch too slowly
    C. Holding the torch tip too close to the line of cut
    D. Advancing the torch too rapidly

24. What effect does moving the cutting torch too fast have on the material during the cutting process?

    A. An incomplete cut
    B. Slag buildup on the cutting side
    C. Penetration by the cutting oxygen
    D. All of the above

25. What results when you cut thin steel by holding the torch vertical to the metal surfaces?

A. A smooth cutting action
B. An irregular cutting action
C. Accelerated flame penetration
D. Slow flame penetration

26. When, if ever, can you place your cutting torch almost vertical to the surface for cutting?

A. Cutting steel that is less than 1/8 inch thick
B. Cutting pipe that is over 1/4 inch thick
C. Cutting steel that is over 1/8 inch thick
D. Never

27. When cutting steel greater than 1/8 inch thick, you position the torch so the preheat flames are from 1/16 to 1/8 inch from the plate. You then hold the flame at this position until the steel becomes _______ red.

A. bright
B. cherry
C. light
D. dark

28. **(True or False)** To start a cut quickly in thick plate, you should hold the cutting torch so it slants toward the direction of travel.

A. True
B. False

29. **(True or False)** One way you can commence a starting cut is to place an iron filler rod at the edge of a thick metal plate and begin preheating it.

A. True
B. False

30. When cast iron is being cut, what is the preheating temperature?

A. 200°F
B. 300°F
C. 400°F
D. 500°F

31. Which of these tasks are you accomplishing by varying the speed of travel, the oxygen pressure, and the angle of a large orifice, and by using a low-velocity-jet cutting tip on the surface of a metal plate?

A. Creating gouged contours
B. Beveling
C. Chamfering
D. All of the above

32. Which of these actions using a cutting torch can result in a deep, wide gouge on a metal plate?

A. Applying too much cutting oxygen
B. Moving the torch too fast in the cut
C. Moving the torch too slow in the cut
D. All of the above

33. When cutting bevels on a plate instead of cutting straight through on the same plate, you must use (a)_____ oxygen pressure and (b)_____ cutting speed.

A. (a) more (b) slower
B. (a) more (b) faster
C. (a) less (b) slower
D. (a) less (b) faster

34. By what component(s) do you adjust a motor-driven cutting torch up and down?

A. Hand wheel only
B. Radial bar only
C. Reduction gear assembly and the hand wheel
D. Gear and rack assembly

35. By performing which of the following actions can you check the clearance of the torch before cutting when using an electric drive carriage on a straight track?

A. Releasing the clutch and pushing the carriage an arms-length in either direction on the track
B. Releasing the clutch and freewheeling the carriage the full length of the track by hand
C. Releasing the clutch, opening the oxygen torch valve, and measuring the flame distance between the torch and material
D. Turning on the current and making a dry pass with the torch

36. In what sequence should you secure the machine after the desired cut with the motor-driven cutting torch is completed?

A. Extinguish the flame, turn off the cutting oxygen, then turn off the electric current.
B. Turn off the cutting oxygen, extinguish the flame, then turn off the electric current.
C. Turn off the cutting oxygen, turn off the electric current, then extinguish the flame.
D. There is no specific sequence to follow.

37. Which of the following actions should an inexperienced operator perform to obtain a smooth bevel on heavy pipe with an oxygas cutting torch?

A. Cut the pipe off square, then cut the bevel.
B. Cut the pipe off square, then cut the bevel with a bench grinder.
C. Use a small cutting tip, one that is easy to manipulate.
D. Use a length of angle iron to guide the torch along the line of cut.

38. **(True or False)** When cutting pipe, you should always keep the torch pointed toward the centerline of the pipe.

A. True
B. False

39. What condition can develop if you do not cut out the punch marks used to mark an outline when fabricating a T-fitting from pipe?

A. Slag buildup
B. Enlarged kerf
C. Irregular bevel
D. Cracking

Refer to the figure below when answering questions 40-41.

40. What step shows the procedure for cutting the miter on the branch of the pipe?

A. Step 1, part B
B. Step 2, part A
C. Step 3, part A
D. Step 1, part C

41. What step shows the completed cut for the run?

A. Step 1, part C
B. Step 2, part B
C. Step 3, part A
D. Step 5, part B

42. What is the desired distance relative to the preheating cones and the metal surfaces when you use the cutting torch to pierce holes in a steel plate?

A. The inner preheating cones contact the metal surface.
B. The outer preheating cones are about 1/16 inch above the metal surface.
C. The inner preheating cones are about 1/8 inch above the metal surface.
D. The inner preheating cones are about 1/4 inch above the metal surface.

43. What procedural step should you take just before slicing off a portion of the head when removing a rivet from a plate with a cutting torch?

A. Heat the entire rivet and surrounding plate to cutting temperature.
B. Change the torch tip from preheating to cutting.
C. Remove the layer of scale between the rivet head and the plate.
D. Cut a slot in the rivet head.

44. What type of cutting tip with a large diameter cutting oxygen orifice is considered best suited for cutting buttonhead rivets and removing countersunk rivets?

A. Low velocity
B. High velocity
C. Fast cut
D. Low speed

45. How can you prevent the strands of rope from unlaying when cutting wire rope with a torch?

A. Clamp the wire rope with c-clamps on each side where the cut is to be made.
B. Wrap the wire rope with seizing wire on each side where the cut is to be made.
C. Place the wire rope in a riggers vise.
D. Heat the ends of the wire rope until the strands fuse together.

46. What action should you take before cutting a wire rope with an oxygas cutting torch?

A. Remove excess lubricant.
B. Remove the outer layer of strands.
C. Coat the rope with a special flux material in the area to be cut.
D. Fuse the ends of the strands to prevent unlaying of the wire rope.

47. Acetylene is extremely dangerous if used above _______ pounds pressure.

A. 8
B. 10
C. 12
D. 15

48. What element in an acetylene cylinder can contaminate cutting torch equipment if the cylinder is not upright when in use?

A. Ketone
B. Acetone
C. Methyl acetate
D. Naphtha

49. Under what conditions, if any, can you actually rest the cutting tip on the metal you are cutting?

A. When cutting cast iron
B. When the fuel-gas pressure is low
C. When cutting thin metal
D. Never

50. A cast iron kerf is always _______ than a steel kerf due to the presence of oxides and the torch movement.

A. narrower
B. wider
C. deeper
D. shallower

51. On which metal do you use a reciprocating torch movement to cut?

A. Copper
B. Aluminum
C. Stainless steel
D. Cast iron

52. **(True or False)** A single-stage regulator's pressure will decrease as the cylinder pressure decreases.

A. True
B. False

53. Which characteristic indicates a good cutting job with an oxygas torch?

A. Smooth at the sides
B. Sharp and square at the top
C. Free of slag
D. All of the above

54. Which characteristics of a drag line indicates proper cutting procedures were followed?

A. Long and irregular
B. Long and vertical
C. Short and vertical
D. Short and irregular

55. What minimum distance in feet is permitted between unprotected combustibles and oxygas cutting equipment that is being used?

A. 10
B. 20
C. 30
D. 40

56. Under which of these circumstances can a backfire occur during the operation of an oxygas cutting torch?

A. Overheating of the cutting tip
B. Dirt on the tip seat
C. Incorrect gas pressure
D. All of the above

57. What action, if any, should you take to stop a flashback safely with an oxygas cutting torch?

A. Close off the gas value first.
B. Close off the oxygen valve first.
C. Close off both valves simultaneously.
D. None

58. What component(s) of an oxygas cutting torch unit is/are usually responsible for a flashback?

A. Loose tip or head
B. Clogged valves
C. Clogged orifices
D. Dirt in the seating

59. When, if ever, should you weld or cut a container that once held a flammable substance?

A. After cleaning
B. After filling with water
C. After cleaning and filling with water
D. Never

60. What percentage of air space inside a water-filled container should carbon dioxide occupy when it is used in a vessel for additional protection?

A. 40
B. 50
C. 60
D. 80

61. What additional safety precaution should you take when doing any hot work on water-filled tanks or containers?

A. Vent them.
B. Stem them.
C. Wash them chemically.
D. Seal them.

Trade Terms Introduced in this Chapter

Infusorial earth	Another name for diatomaceous earth (light soil consisting of siliceous diatom remains [microscopic shells] often used as a filtering material).
psig	Pound-force per square inch gauge - a unit of pressure relative to the surrounding atmosphere.
ppm	Parts per million - used especially in science and engineering to denote relative proportions in measured quantities, particularly in low-value (high-ratio) proportions at the parts-per-million (**ppm**).

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Althouse, Andrew D., Carl H. Turnquist, and William A. Bowditch, *Modern Welding,* Goodheart-Wilcox Co. Inc., 1970.

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Smith, David, *Welding Skills and Technology,* Gregg Division, McGraw-Hill, 1984.

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Chapter 5

Gas Welding

Topics

To hear audio, click on the box.

Overview

Welding (also called fusion welding) is the process of heating two or more materials (usually metals) to a melting point where they can coalesce, sometimes with additional material (a third metal) called filler. When the heating is provided by gas, naturally, the term used is "gas welding." Oxyacetylene and oxy-MAPP (methylacetylenepropadiene) welding are two types of gas-welding processes. Both require a gas-fueled torch to raise the temperature of two similar pieces of metal to the fusion point that allows them to flow together. A filler rod is used to deposit additional metal as necessary to merge the two base materials. The gas and oxygen must be mixed to correct proportion and pressure in the torch, and you can adjust the torch to produce the type of flames appropriate for the metal being welded.

This chapter presents information on the equipment and materials used in gas welding, as well guidance on the operation and maintenance of oxyacetylene and oxy-MAPP equipment. In addition, it will recommend welding techniques for both ferrous and nonferrous metals.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the purpose and components of the OXYGAS welding equipment.
2. Describe the operation and maintenance of OXYGAS welding operations.
3. Identify the different types OXYGAS welding techniques.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	STEELWORKER BASIC
Introduction to Structural Steel	
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas	
Rigging	
Wire rope	
Fiber Line	
Layout and Fabrication of Sheet-Metal and Fiberglass Duct	
Welding Quality Control	
Flux Core Arc Welding-FCAW	
Gas-Metal Arc Welding-GMAW	
Gas-Tungsten Arc Welding-GTAW	
Shielded Metal Arc Welding-SMAW	
Plasma Arc Cutting Operations	
Soldering, Brazing, Braze Welding, Wearfacing	
Gas Welding	
Gas Cutting	
Introduction to Welding	
Basic Heat Treatment	
Introduction to Types and Identification of Metal	

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.1.1 OXYGAS WELDING EQUIPMENT

Fundamentally, an oxygas welding outfit is the same as an oxygas cutting outfit; the only exception is the torch, or in some combination torches, only the torch head. An oxygas welding outfit is also called a welding rig (*Figure 5-1*).

Like the cutting outfit, the minimum welding outfit consists of the following parts:

- Cylinder of acetylene or MAPP gas
- Cylinder of oxygen
- Two regulators
- Two lengths of hose with fittings
- Torch with welding tips

Figure 5-1 — Typical oxygas welding rig similar to oxygas cutting rig.

In addition to the basic equipment shown, you also will use much of the same auxiliary equipment as presented in Chapter 4 Gas Cutting, and the same safety equipment identified in Chapter 3 Introduction to Welding, for example, tip cleaners, cylinder trucks, clamps, strikers, gang wrench, and holding jigs. Safety apparel such as goggles, gloves, as well as leather aprons, sleeves, and leggings are essential, and you should wear them as appropriate for the work being performed (*Figure 5-2*).

Figure 5-2 — Examples of common auxiliary and safety equipment for oxygas welding and oxygas cutting.

Like oxygas cutting equipment, a welding rig may be stationary or portable.

Figure 5-3 shows the setup of a portable oxygas welding or cutting rig. This portable setup is very advantageous when it is necessary to move the equipment, particularly on a project site with rough terrain since the metal wheels will not go flat.

To perform your gas welding duties, you must be able to set up and adjust the equipment, so you must understand the purpose and function of the basic pieces.

The gases, cylinders, regulators, hoses, and safety equipment are covered in Chapter 4. If you have any questions, review Chapter 4 before continuing.

Figure 5-3 — Typical setup of a portable welding or cutting rig.

1.1.1 Welding Torches

A properly adjusted oxygas welding torch mixes oxygen and the selected fuel-gas in the proper proportion and delivers a controlled amount of the mixture to burn at the welding tip. An oxygas welding torch has the following basic parts:

- Handle (body) with two tubes (one for oxygen/ one for fuel) and two needle valves
    - One valve for adjusting oxygen flow
    - One valve for adjusting fuel-gas flow
- Mixing head
- Tip

Welding tips are made from a special copper alloy available in a wide range of styles, configurations, and sizes to accommodate for various plate thicknesses, and to meet welders' needs ranging from industrial manufacturers to the individual hobby shop user (*Figure 5-4*).

Some manufacturers' models are designed as tubes, silver-brazed to the head with rear-end forgings fitted into the handle.

Other manufacturers have welding tips with flexible tubes.

Figure 5-4 — Examples of the variety of oxygas welding tips available.

There are two general types of welding torches:

- Low pressure
- Medium pressure

The low-pressure torch is also known as an injector torch. The injector torch uses fuel-gas pressure at about 1 psig (pound per square inch gauge) or less, with oxygen pressure ranges set between 10 to 40 pounds, depending on the size of the torch tip. The flow of relatively high-pressure oxygen produces the suction (***venturi effect***) necessary to draw the low-pressure fuel-gas into the mixing head. The welding tips may or may not have separate injectors in the tip. *Figure 5-5* shows a typical mixing head for a low-pressure (injector) torch.

Figure 5-5 — Mixing head for a low-pressure (injector) torch.

Medium-pressure torches are also known as balanced-pressure or equal-pressure torches. While overall operating pressures will vary depending on the size and type of tip necessary for the thickness of the material, these torches operate with the fuel-gas and oxygen pressure relatively equal.

Figure 5-6 shows a typical equal-pressure (general-purpose) welding torch. A medium-pressure torch is easier to adjust than a low-pressure torch and, since you are using equal oxygen and fuel-gas pressures, you are less likely to get a flashback. (Refer to Chapter 4 for information on flashbacks.)

Figure 5-6 — Typical equal-pressure (general-purpose) welding torch mixing head.

WARNING

If you use acetylene as the fuel-gas, never allow the pressure to exceed 15 psig; acetylene becomes very dangerous at 15 psig and is self-explosive at 29.4 psi.

Welding mixers and tips are designed in several ways.

Some torch designs have a separate mixing head or mixer for each tip size (*Figure 5-7, View A*). 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 (*Figure 5-7, View B*).

When used with an extension tube, removable tips are made of hard copper, brass, or bronze.

Figure 5-7 — Examples of fixed and removable tips.

Each manufacturer assigns its own arrangement for classifying tip sizes, but typically they are designated by a number system which corresponds to the diameter of the hole in the tip.

1.2.0 Filler Rods

The term *filler rod* refers to the filler metal you use in gas welding, brazing, and certain electric welding processes such as gas tungsten arc welding or TIG, where the filler metal is not a part of the electrical circuit. As its name implies, filler rod supplies the filler metal to the joint. Depending on the characteristics and thickness of the metal, a weld design's required gaps and bevels may vary widely, so filler rod comes in a variety of sizes and in wire or rod form to accommodate a project's needs.

Most rods are available in 36-inch lengths and a wide variety of diameters, ranging from 1/32 to 3/8 inch. The thickness of the base metal will determine which diameter you need to use.

Rods for welding cast iron vary from 12 to 24 inches in length and are frequently square, rather than round.

Figure 5-8 — Typical filler rod and packaging.

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 (*Figure 5-8*).

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.

You select the proper filler rod based on the specifications (specs) of the metal being joined, and there are federal, military, or Navy specs for filler rods that identify which filler rod may be used with which metal. This means the specs apply to all federal agencies, the military establishment, or the Navy, respectively.

Presently, one or more of these three types of specifications cover filler metals, but eventually all Navy specifications will be rewritten as military (MIL) specifications. Therefore, some of the specifications presented in this section may subsequently be published as military rather than Navy specifications.

Test Your Knowledge (Select the Correct Response)

1. Fundamentally, an oxygas welding outfit is the same as an oxygas cutting outfit.

    A. True
    B. False

2.0.0 OPERATION and MAINTENANCE of OXYGAS EQUIPMENT

This section presents the basic procedures involved in setting up oxygas equipment, securing the equipment, lighting it off, and adjusting the flame. It also provides information on the maintenance of oxygas welding equipment.

2.1.1 Operation

A properly made gas weld has a consistent appearance that shows a uniform deposit of weld metal and complete fusion of the sidewalls forming a good joint (*Figure 5-9*).

You must consider some of the following factors when making a gas weld:

- Edge preparation
- Spacing and alignment of parts
- Temperature control before, during, and after the welding
- Size of torch tip
- Size and type of filler rod
- Flame adjustment
- Rod and torch manipulation

Figure 5-9 — Example of consistent appearance and uniform deposit.

In some cases, you need to use fluxes to remove oxides and slag from the molten metal and to protect the puddle from atmospheric contamination.

When you join sections of sheet and thin plate by gas welding, you need to melt the edges uniformly with the heat from the torch. When you weld heavier plate, you need to use filler metals to accommodate the designed gaps and beveled edges required to permit heat and weld penetration to reach the base of the joint. You melt the filler metal along with the base metals, and as they mix and solidify, they form a continuous piece.

Usually, you do not need filler metal for light sheet metal, and the edges of light sheet metal are flanged at the joint so they flow together to form one solid piece when you melt them.

2.1.1 Selecting the Welding Torch Tip Size

The size of a welding tip is designated by a number stamped on the tip, and the tip size is determined by the size of the orifice (*Figure 5-10*).

Figure 5-10 — Welding tip orifices.

The various manufacturers do not use a common system of identifying welding tip sizes; each has its own part number identification system.

This course will refer to tip size by using the number drill for the orifice size.

Once you are familiar with a specific manufacturer's torch and tip numbering system, referring to the tip by the orifice's number drill size will become unnecessary.

Number drills consist of a series of 80 drills, numbered 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. *Table 5-1* shows the full range of number drill sizes.

NOTE: The higher the number of the drill, the smaller the size the drill.

Table 5-1 — Number Drill Bit Conversion Table

gauge	inches	mm	gauge	inches	mm	gauge	inches	mm
80	0.0135	0.343	53	0.0595	1.511	26	0.147	3.734
79	0.0145	0.368	52	0.0635	1.613	25	0.1495	3.797
78	0.016	0.406	51	0.067	1.702	24	0.152	3.861
77	0.018	0.457	50	0.07	1.778	23	0.154	3.912
76	0.02	0.508	49	0.073	1.854	22	0.157	3.988
75	0.021	0.533	48	0.076	1.93	21	0.159	4.039
74	0.0225	0.572	47	0.0785	1.994	20	0.161	4.089
73	0.024	0.61	46	0.081	2.057	19	0.166	4.216
72	0.025	0.635	45	0.082	2.083	18	0.1695	4.305
71	0.026	0.66	44	0.086	2.184	17	0.173	4.394
70	0.028	0.711	43	0.089	2.261	16	0.177	4.496
69	0.0292	0.742	42	0.0935	2.375	15	0.18	4.572
68	0.031	0.787	41	0.096	2.438	14	0.182	4.623
67	0.032	0.813	40	0.098	2.489	13	0.185	4.699
66	0.033	0.838	39	0.0995	2.527	12	0.189	4.801
65	0.035	0.889	38	0.1015	2.578	11	0.191	4.851
64	0.036	0.914	37	0.104	2.642	10	0.1935	4.915
63	0.037	0.94	36	0.1065	2.705	9	0.196	4.978
62	0.038	0.965	35	0.11	2.794	8	0.199	5.055
61	0.039	0.991	34	0.111	2.819	7	0.201	5.105
60	0.04	1.016	33	0.113	2.87	6	0.204	5.182
59	0.041	1.041	32	0.116	2.946	5	0.2055	5.22
58	0.042	1.067	31	0.12	3.048	4	0.209	5.309
57	0.043	1.092	30	0.1285	3.264	3	0.213	5.41
56	0.0465	1.181	29	0.136	3.454	2	0.221	5.613
55	0.052	1.321	28	0.1405	3.569	1	0.228	5.791
54	0.055	1.397	27	0.144	3.658			

Orifice size will determine the quantity of fuel-gas and oxygen fed to the flame, and by extension, it determines the amount of heat the torch tip can produce: the larger the orifice, the greater the heat.

If you use a torch tip with too small an orifice, you will not be able to generate enough heat to bring the metal to its fusion temperature.

If you use a torch tip with too large an orifice, you are likely to produce poor welds for these reasons:

1) The weld is made too fast.

2) You have difficulty controlling the melting of the filler rod.

3) You cannot control the appearance.

Therefore, the quality of the weld is unsatisfactory.

For practice purposes, use an equal-pressure torch with the filler welding rod sizes and the tip sizes shown in *Table 5-2*; they should give you satisfactory results as you develop your hands-on skills.

Table 5-2 — Welding Rod Sizes and Tip Sizes Used to Weld Various Thickness of Metal

Metal Thickness	Diameter Welding Rod*	Tip Drill Size	Pressures Oxygen	Pressures 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 size tip and welding rod. When welding larger pieces, use the larger size tip and welding rod.

2.1.2 Equipment Setup

Except for the selection of the torch, or just the welding tip in the case of a combination torch, you set up the oxygas equipment and prepare for welding the same way you set it up for oxygas cutting. Review Chapter 4 Gas Cutting if you need a refresher.

Select the correct tip and mixing head (depending on the torch manufacturer), and connect them to the torch body. Tighten the assembly snugly by hand, adjust the tip to the proper working angle, and then tighten the tip. Depending on the manufacturer and model, you tighten some equipment with a wrench (those with nut ends), while others you only hand tighten (those with knurled ends).

2.1.3 Torch Lighting and Flame Adjustment

Light the torch and adjust the flame by following the manufacturer's directions for the particular model of torch you are using. Procedures vary with different manufacturers' torches and, in some cases, even with different models made by the same manufacturer, so always use their guidance for lighting.

After lighting, adjust the flame according to the type of metal being welded: carburizing, neutral, or oxidizing. Again, review Chapter 4 Gas Cutting if you need more in-depth coverage of the different types of flames.

- Always adjust the welding flame to neutral before setting it to work at either the oxidizing or carburizing flame mixture.
- A neutral flame is correct for welding most metals. When you weld steel with this flame, the puddle of molten metal is quiet and clear, and the metal flows without boiling, foaming, or sparking.
- The carburizing flame is best used for welding high-carbon steels, hardfacing, and welding nonferrous alloys such as Monel.

- The oxidizing flame has a limited use and is harmful to many metals. When you apply an oxidizing flame to steel, it causes the molten metal to foam and spark. You use a slightly oxidizing flame to braze steel and cast iron. You use a stronger oxidizing flame to fusion weld brass and bronze.

2.2.0 Maintaining the Equipment

Like any other equipment, you must perform minor upkeep and proper maintenance for welding equipment to operate at peak efficiency, give useful service, and be readily available when you need it. You are not required (or authorized) to make major repairs; however, when major repairs are indicated, you need to remove the equipment from service and turn it in for repair. This section presents some of the common types of maintenance duties you will need to perform.

2.2.1 Torch Gas Leaks

Occasionally, the torch head's needle valves may fail to shut off when hand tightened in the normal manner. If this occurs, do not use a wrench to tighten the valve stem. Instead, use the following procedures:

- Open the valve and try to blow the foreign matter off the valve seat by using increased working gas pressure in the hose. (Do not exceed 15 psig for acetylene.)
- If this fails, remove the stem assembly and wipe the needle valve and seat clean. Reassemble the valve and try closing it tightly by hand several times.
- If these measures fail to stop the leak, have the parts replaced or the valve body reseated. Only a qualified person should make this repair.

When there is leakage around the torch valve stem, you can tighten the packing nut or repack it if necessary. For repacking, use only the packing recommended by the torch's manufacturer. **DO NOT USE ANY OIL.** While it is disassembled for repacking, observe the valve stem, and if bent or badly worn, replace it.

Before you use a new torch for the first time, check the packing nut on the valves to make sure they are tight; some manufacturers ship torches with these nuts loose.

Leaks in a torch's mixing-head seat will cause the oxygen and fuel-gas to leak between the inlet orifices leading to the mixing head; this causes improper gas mixing and flashbacks. You can correct this problem by sending the equipment to the manufacturer for repair by having the seat in the torch head reamed and the mixing-head seat trued.

2.2.2 Welding Torch Tips

Welding tips are subject to considerable abuse just by the nature of their working environment. The tip may be damaged if you allow it to contact the welding work, bench, or firebricks. This damage roughens the end of the tip and causes the flame to burn with a "fishtail." In addition, you must avoid dropping a tip because that may damage the seat that seals the joint with the mixing chamber.

For a welding tip to perform satisfactorily, you must:

- Keep the orifice smooth and clean.
- Maintain a flat and smooth face.
- Remove carbon deposits and slag regularly.

Exercise care when you clean a welding tip; do not enlarge or scar the orifice.

Special welding/cutting tip cleaners are available to help remove carbon or slag from the tip orifice (*Figure 5-11)*.

The cleaner set contains a series of ***broach*** wires that correspond to the diameter of the tip orifices.

These wires are packaged in a holder, which makes their use safe and convenient.

Figure 5-11 — Typical welding/cutting tip cleaner.

Figure 5-12, View A 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 (*Figure 5-12, View B)*.

A number drill must be used carefully so the orifice is not enlarged, bell-mouthed, reamed out of round, or otherwise deformed.

Refer to *Table 5-1* for number drill sizes.

Figure 5-12 — Typical welding/cutting tip cleaner in use.

Recondition the tip face if it becomes rough, pitted, or the orifice is bell-mouthed.

To ensure a properly shaped flame, the face end of the tip must be clean, smooth, and at right angles to the centerline of the tip orifice.

Some tip cleaner sets contain a small file for maintaining the tip face (*Figure 5-13, View A*).

As an alternative, you can use a 4-inch mill file (*Figure 5-13, View B*) to recondition the surface provided you exercise extreme care not to over-file the surface of the much softer copper.

Figure 5-13 — Reconditioning the face of a welding/cutting tip.

Another easy method involves a piece of emery cloth. Place it grit side up on a flat surface; hold the tip face 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.

2.2.3 Regulator Leaks

Regulator creep, that is, gas leakage between the regulator seat and the nozzle, is the most common type of trouble with regulators.

The most obvious indicator of this problem is the gradual rise of working-gauge pressure without having moved the adjusting screw. This trouble can be caused by worn or cracked seats, but it is due more often simply to foreign matter lodged between the seat and the nozzle.

You need to remove leaking regulators from service at once, and then send them for repair to prevent possible injury to personnel or additional equipment damage, particularly with faulty fuel-gas regulators. Fuel-gas under pressure in a hose becomes an explosive hazard, and remember, acetylene is over-pressured and dangerous at just 15 psig. To ensure the safety of personnel and equipment, ensure that regulators with such leaks are removed from service and turned in for repair.

Test Your Knowledge (Select the Correct Response)

2. What characteristics indicate a properly made gas weld?

   A. Complete fusion of the sidewalls
   B. Uniform deposit of weld metal
   C. Consistent appearance
   D. All of the above

3.0.0 OXYGAS WELDING TECHNIQUES

You can use the forehand or backhand method to weld with oxygas. Each technique has its advantages, particularly in different positions, so you need to become skillful with both; it is the relative position of the torch and rod that determines whether you consider a technique forehand or backhand, not the direction of welding. Under any circumstances, you need to use the method considered best, but the best method will depend upon a combination of factors: type of joint, joint position, joint design, and heat control on the parts.

3.1.0 Forehand Welding

In forehand welding, also called *puddle* or *ripple welding*, you point the flame in the direction of travel. You hold the tip at an angle of about 45 degrees to the working surfaces and keep the rod ahead of the flame in the direction in which you are making the weld (*Figure 5-14*).

This flame position preheats the edges you are welding just ahead of the molten puddle.

While moving with the torch tip, rotate the tip and welding rod back and forth in opposite, semicircular paths to 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.

Figure 5-14 — Example of forehand welding.

Forehand is ideal for thin plate; it permits better control of a small puddle and results in a smoother weld.

You can use the forehand technique in all positions for sheet and light plate up to 1/8 inch thick. However, it is not the recommend method for heavy plate because it lacks sufficient base metal penetration.

3.2.0 Backhand Welding

In backhand welding, you point the flame away from the direction of travel and back at the molten puddle and completed weld (*Figure 5-15*).

Hold the welding tip at an angle of about 60 degrees with the plates or joint being welded, and place the welding rod between the torch tip and the molten puddle.

You use less motion in the backhand method than in the forehand method.

If you use a straight welding rod, rotate it so the end rolls from side to side and melts off evenly.

You may, however, need to bend the rod when working in confined spaces.

Figure 5-15 — Examples of backhand welding.

If you have to bend the rod, it becomes difficult to roll, so to compensate, move the rod and torch back and forth at a rather rapid rate.

When you make a large weld, move the rod so it makes complete circles in the molten puddle, and move back and forth across the weld while advancing slowly and uniformly in the direction of the welding.

Backhand welding is best suited for material more than 1/8 of an inch thick. You can use a narrower vee at the joint than is possible with forehand welding, and an included angle of 60 degrees is sufficient to get good joint penetration. In addition, the backhand method requires less welding rod or puddling than the forehand method.

By using the backhand technique on heavier material, you can increase your welding speed, exercise better control of the larger puddle, and have more complete fusion at the weld root. Also, if you use a slightly reducing flame (carburizing), you melt a smaller amount of base metal while still welding the joint.

When you weld steel with a backhand technique and a slightly reducing flame, a thin surface layer of metal absorbs carbon and reduces the melting point of the steel, thus speeding up the welding operation. You can also use this technique in surfacing with chromium-cobalt alloys.

3.3.0 Multilayer Welding

You use multilayer welding with gas welding for the same reason you do with arc welding: to avoid carrying large, difficult-to-control puddles when working on thick plate and pipe (*Figure 5-16*).

Instead, 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.

Generally, you can easily control the final layer to get a smooth surface.

Figure 5-16 — Example of multilayer welding sequence.

Multilayer welding has an added advantage: you are refining the previous layer as you make the succeeding layer. In effect, you heat-treat the weld metal by allowing one layer to cool to a black heat before you reheat it, thus improving the ductility of the weld metal. If you need to develop this added ductility in the last layer, you can deposit an additional or succeeding layer and then machine it off.

3.4.1 Joint Edge Preparation

You can easily melt sheet metal and it does not require special edge preparation. However, for a welding operation involving plate, you must prepare the joint edges and provide for proper spacing. The plate's thickness will determine the required amount of edge preparation.

- Up to 3/16 inch thick — Butt the faces of square edges together and weld.
- 3/16 to 1/4 inch thick — Provide a slight root opening between parts for complete penetration.
- More than 1/4 inch thick — Use beveled edges and a root opening of 1/16 inch.
  - Bevel each edge at an angle of 30° to 45° making the groove-included angle from 60° to 90 °.
  - Prepare by flame cutting, shearing, flame grooving, machining, chipping, or grinding.
  - Ensure edge surfaces are free of oxides, scale, dirt, grease, or other foreign matter.

You can weld plate 3/8 to ½ inch thick from one side only, but you should prepare and weld thicker sections on both sides. Generally, butt joints prepared on both sides permit easier welding, produce less distortion, and ensure better weld qualities.

Only use oxygas welding for heavy steel plate when all other types of welding equipment are unavailable. It is not cost effective due to the quantity of gases and the amount time needed to complete a weld. Instead, use a form of electric arc welding; you can weld the joint faster and cheaper, with less heat distortion.

3.5.1 Ferrous Metals

The oxygas process easily welds low-carbon steel, low-alloy steel, cast steel, and wrought iron. These metals have oxides that melt at a lower temperature than the base metal, so you do not need to use flux.

During the welding process, enclose the molten puddle with the flame envelope. This is to ensure the molten metal does not contact the air and begin to oxidize rapidly. However, you need to reach a balance and avoid overheating the metal as well.

To make a good weld, you need a properly adjusted flame.

- Adjust to neutral or slightly reducing (carburizing) flame.
    - Do not use oxidizing flame.
- Manipulate torch and rod with tip of oxygas cone about 1/16 to 1/8 inch from the work surface.
- Melt filler rod in the puddle, not with the flame.

There are no special problems involved in welding low-carbon steels and cast steels other than selecting the proper filler rod.

Low-alloy steels usually require both pre- and post-welding heat treatment. This relieves the stresses developed during welding and produces the desired physical properties of the metal.

With steels, as carbon content increases, welding difficulty increases. Use a slightly carburizing flame to weld steels with carbon content in the 0.3-percent to 0.5-percent range, and these low-carbon steels require post-welding heat treatment to develop their best physical properties.

High-carbon steel and tool steel require a slightly different technique.

- Protect parts from drafts and slowly preheat to about 1000°F.
- Complete weld as rapidly as possible with carburizing flame and no flux.
- Do not manipulate either rod or torch.
- Add filler metal in small amounts as needed.
- Use smaller flame and lower gas pressure than used for low-carbon steel.
    - This is to ensure you do not overheat the steel.

After welding, you must heat-treat high-carbon steels and tool steels to develop the physical properties required.

You use the same procedure for oxygas welding WROUGHT IRON as you do for low-carbon or mild steel; however, you need to keep several points in mind (*Figure 5-17*).

Figure 5-17 — Example of wrought iron oxygas weld.

- Wrought iron contains slag incorporated during manufacturing.
- Slag gives the molten puddle's surface a greasy appearance.
- Do not confuse greasy appearance with appearance of actual fusion.
- Continue heating until sidewalls of joint break down into puddle.

You obtain the best results with wrought iron when you mix the filler metal (usually mild steel) and base metal in the molten puddle with a minimum of agitation.

Oxygas welding CAST IRON is not difficult, but it does require a modification of the procedure used with steel. *Figure 5-18* shows some cast iron welding opportunities.

For metal:

- Not exceeding 3/16 inch thick — no V-groove required.
- 3/16 inch to 3/8 inch thick — use a single V-butt joint with a 60° included angle.
- Over 3/8 inch thick — use a double V-butt joint with 60° included angles.

- Preheat entire weldment to between 750°F and 900°F.
- Use neutral flame and backhand method.
- Use cast-iron filler metal.
- Use appropriate flux but sparingly.
- Add filler metal by directing inner cone of flame against rod.
- Do not dip rod into puddle.
- Deposit filler metal in layers not exceeding 1/8 inch thick.

Figure 5-18 — Examples of potential oxygas cast iron welding projects.

After you complete a cast iron weld, you must stress relieve the weldment by heating it to between 1100°F and 1150°F and cooling it slowly.

Oxygas welding cast iron will provide a good color match and good machinability, but if color match is not essential, you can use braze welding to make an easier and more economical cast iron repair.

You can use oxygas welding for some CHROMIUM- NICKEL STEELS (STAINLESS STEELS), but usually only for light sheet; typically, you join heavier pieces with one of the electric arc welding processes.

On material 20 gauge (0.040 of an inch) or less thick, you can make the weld on a turned up flange (equal to the metal's thickness) without filler metal using the following steps.

- Clean joint surfaces with sandpaper or other abrasives.
- Apply stainless steel flux.
- Use torch tip one or two sizes smaller than used for mild steel of same thickness.
- Use carburizing flame, as seen through goggles, with excess fuel-gas feather extending about 1/16 inch beyond tip of inner cone.
- Angle flame at an 80° angle to surface with cone tip almost, but not quite, touching molten metal.
- Weld in one pass using forehand technique.
    - Do not puddle or retrace.

For welding light-gauge stainless steel, you need to use a uniform speed; if you find it necessary to stop welding or reweld a section, wait until the entire weld has cooled.

3.6.0 Nonferrous Metals

Brazing and braze welding are the more common methods of joining nonferrous metals, but oxygas welding is just as suitable in many situations. In most cases, joint designs are the same for nonferrous metals as for ferrous metals, but welding nonferrous metals usually requires you to clean the surfaces mechanically and also to use flux. Of course, you must use filler metals suitable for the base metal as well.

3.6.1 Copper

You can oxygas weld pure copper, but where high-joint strength is a requirement, use DEOXIDIZED copper (copper that contains no oxygen). Use the following guidance.

- Use neutral flame.
- Use flux.
- Preheat to 500°F to 800°F.
- Use larger size tip for welding.
    - A larger tip supplies more heat to maintain the required temperature at the joint.
- Post-welding, cool slowly.

Other than the extra volume of heat required, the technique for welding deoxidized copper is the same as for steel.

3.6.2 Copper-Zinc Alloy (Brasses)

You can weld copper-zinc alloys (brasses) using the same methods as for deoxidized copper. However, for welding brasses you use a silicon-copper rod, which is usually already flux-coated so you do not need additional flux. The preheat temperature for brass is 200°F to 300°F.

3.6.3 Copper-Silicon Alloy (Silicon Bronze)

Welding copper-silicon alloy (silicon bronze) requires a different technique than for pure copper and brass. Use the following guidance.

- Use slightly oxidizing flame.
- Use flux with high boric acid content.
- Use filler metal of same composition as base metal.
- As weld progresses, dip rod tip under viscous film covering puddle.
- Keep puddle small so weld solidifies quickly.

CAUTION

Safeguard against zinc poisoning by doing welding outdoors or by wearing a respirator, or by both, depending on the situation.

3.6.4 Copper-Nickel Alloy

To oxygas weld copper-nickel alloys, you must prepare the surface and preheat the material. Use the following guidance.

- Apply flux (a thin paste) by brush to all parts of joint and rod.
- Use slightly carburizing flame.
- Hold flame so inner cone’s tip just contacts base metal.
  - Do not melt the base metal more than necessary to ensure good fusion.
- Keep end of filler rod within protective envelope of flame.
- Add filler metal without disturbing molten pool.
- If possible, run weld from one end of joint to other without stopping.
- After completion, cool slowly.
- Remove remaining traces of flux with warm water.

3.6.5 Nickel and High-Nickel Alloys

You can oxygas weld nickel and high-nickel alloys similar to the methods you use for copper-nickel alloys.

- Mechanically clean joint surfaces.
- Use joint designs similar to steel thickness.
  - For V-butt welds, use included angle of 75°.
- Apply flux (a thin paste) with a brush to both sides of seam, top and bottom, and to filler rod.
  - Plain nickel does not require flux.

    - High-nickel alloys require special boron-free and borax-free flux.
- Use very slightly carburizing flame.
- Use same size or one size larger tip as used for steel of same thickness.
- Keep flame soft and cone’s tip in contact with molten pool.
- Use suitable rod and keep it well within protective envelope of flame.
- After completion, postheat and cool slowly.
- Remove flux with warm water.

3.6.6 Lead

To oxygas weld lead, you need to use special tools and special techniques.

When you weld lead or lead alloys, wear a respirator approved for protection against lead fumes.

WARNING

LEAD FUMES ARE POISONOUS.

Flux is not required, but you must ensure the metal in the joint area is scrupulously clean by shaving the joint surfaces with a scraper and wire brushing them to remove all oxides and foreign matter.

You can use a square butt joint if you are welding in the flat position, but for all other positions, you need to use a lap joint with edges overlapping from ½ to 2 inches, depending upon the thickness.

- Use special lightweight fingertip torch, with tips ranging from 68 to 78 in drill size.
- Use neutral flame with gas pressure ranging from 1½ to 5 psig, depending on thickness.
    - Flame length will vary from 1½ to 4 inches depending upon gas pressures.
- Use soft, bushy flame when welding in horizontal and flat positions.
- Use more pointed flame when welding in vertical and overhead positions.
- Ensure filler metal is same composition as base metal.
- Manipulate flame in semicircular or V-shaped pattern to control and distribute molten puddle.
- Make separate, individual, tiny segment welds.
    - Flick torch away upon completion of each semicircular or V-shaped movement.
- Make joints in thin layers.
- Do not add filler metal on first pass; add on all subsequent passes.

3.6.7 Aluminum and Aluminum Alloys

If you are assigned to work with nonferrous metals, you can expect to do projects that involve welding aluminum and aluminum alloys. Pure aluminum has a specific gravity of 2.70 and a melting point of 1210°F, but pure aluminum is seldom used; it is soft, not hard enough or strong enough for structural purposes. However, manufactured aluminum is strengthened significantly with the addition of other elements to form aluminum alloys.

Pure aluminum has only about ¼ the strength of steel, and the alloys are usually about 90 percent pure. Yet, when elements such as silicon, magnesium, copper, nickel, and/or manganese are added to aluminum, the aluminum alloy is stronger than mild steel.

A considerable number of aluminum alloys are available and used to manufacture many everyday items (*Figure 5-19*).

You may need to use some aluminum alloys in sheet form to make and/or repair lockers, shelves, boxes, trays, and other containers, or you may need to repair chairs, tables, and other items of furniture.

Typically, oxygas welding aluminum alloy is confined to materials from 0.031 to 0.125 inch thick, but you can weld thicker material if necessary.

On the other hand, thinner material is usually spot or seam welded.

Figure 5-19 — Examples of potential oxygas aluminum alloy welding projects.

3.6.7.1 Melting Characteristics

Before you attempt to weld aluminum alloy for the first time, you need to be familiar with how it reacts under the welding flame. You can practice using the following guidance.

- Place a small piece of sheet aluminum on the welding table.
- Use a neutral flame.
- Hold the flame perpendicular to the surface and bring the tip of the inner cone almost in contact.
    - Observe — almost without warning, the metal suddenly melts and runs away, leaving a hole.
- Repeat with the torch held at about 30° angle to the plane of the surface.
- Move the flame slowly along the surface, melting a small puddle.
    - Observe —the puddle quickly solidifies when you remove the flame.

Continue this practice until you are able to control the melting. With a little practice, you will be able to melt the surface metal without forming a hole.

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, then try using a welding rod with thin sheet, and then with castings.

3.6.7.2 WELDING RODS

There are two types of welding rods available for gas welding aluminum alloys.

1100

- For welding 1100 and 3003 type aluminum alloys only.
- Provides maximum resistance to corrosion.
- Offers high ductility.

4043

- For all other wrought aluminum alloys and castings.
- Provides greater strength.
- Minimizes tendency for cracking.

3.6.7.3 Welding Fluxes

It is extremely important to use the proper flux when welding aluminum. Aluminum welding flux is designed to remove the aluminum oxide by combining with it chemically. In gas welding, oxide forms rapidly in the molten metal and must be removed or your weld will be defective. To ensure proper flux distribution and minimize the oxide, paint the flux on the welding rod as well as the surface to be welded.

Aluminum flux usually comes in powder form and you mix it with water to form a paste. Keep the prepared paste in an aluminum, glass, or earthenware container; steel or copper containers will contaminate the mixture.

For flanged joints where you do not use filler rod, it is essential that you apply plenty of flux to the edges of both the bottom and top sides in the area of the weld.

On the other hand, after you finish welding, you must remove all traces of flux with a brush and hot water; if you leave aluminum flux on the weld, it will corrode the metal.

3.6.7.4 Welding Preparation

The thickness of the aluminum will determine how you need to prepare edges.

On material up to 0.062 inch thick, form a 90° flange with the height of the flange about the same height, or a little higher, as the thickness of the material (*Figure 5-20*).

The flange edges must be straight and square.

You can use flange joints for material up to 0.125 (1/8) inch thick.

No filler rod is necessary for welding flange joints.

Figure 5-20 — Example of aluminum alloy flanged edge preparation.

On material 0.062 to 0.188 inch thick, you can make unbeveled butt welds, but notch the edges with a saw or cold chisel similar to that shown in *Figure 5-21*.

When you edge notch aluminum welding, it aids in getting full penetration and preventing local distortion.

All butt welds made in material over 0.125-inch thick are usually notched in some manner.

Figure 5-21 — Example of aluminum alloy notched edge preparation.

To weld aluminum alloy more than 0.188 inch thick, both bevel the edges and notch them as shown in *Figure 5-22*, with the included angle of bevel from 90° to 120°.

Figure 5-22 — Example of aluminum alloy notched and beveled edge preparation.

After you properly prepare the edges, clean the surfaces you will be welding. Use a stainless steel wire brush to remove any heavy oxide, or a solvent-soaked rag to wipe off any dirt, grease, or oil.

If you are welding aluminum plate 0.250-inch thick or greater, preheat it to 500°F to 700°F; this aids in avoiding heat stresses. Preheating also reduces fuel and oxygen requirements for the actual welding.

Do not exceed 700°F during your preheating operation or you may severely weaken the alloy; high temperatures can cause large aluminum parts to collapse under their own weight. Also, warm thin material with the torch before welding; this slight preheat helps prevent cracking.

3.6.7.5 Welding Techniques

After preparing and fluxing the aluminum alloy pieces for welding, use the following guidance to weld.

- Pass flame in small circles over starting point until flux melts.
- Keep flame’s inner cone off of flux to avoid burning it.
    - If the flame’s inner cone burns the flux, it must be cleaned and reapplied.
- Scrape rod over surface at 3- to 4-second intervals; let rod clear flame each time.
    - A rod in the flame too long melts before the base metal melts.

  - Scraping action identifies softness and indicates when you can start welding without overheating.
- Maintain cycle throughout welding except allow rod to remain under flame long enough to melt amount of filler metal needed.

With practice, you can easily master the rod and flame movement.

Generally, you should use the forehand method for welding aluminum alloys; the flame points away from the completed weld, preheating the edges to be welded, which helps prevent too rapid a melting as you progress.

- For thin material, hold torch at a low angle.
- For material 0.188-inch thick and above, increase torch angle to near vertical.
  - Changing the torch angle according to the thickness minimizes burning through sheet.

When you weld aluminum alloys up to 0.188-inch thick, you do not need to add any motion to the torch other than forward, but on flanged material, you must break the oxide film as the flange melts down. You can do this by stirring the melted flange with a puddling rod, which is essentially a paddle flattened and shaped from a ¼- inch stainless steel welding rod.

When you weld aluminum alloys above 0.188 inch thick, give the torch a uniform lateral motion to distribute the weld metal over the entire width of the weld. Also, use a slight back-and-forth motion to assist the flux in removing oxides. Dip the filler rod in the weld puddle with a forward motion.

Your welding speed will be directly related to the torch's angle; instead of having to lift the flame to avoid melting holes, hold the torch at a flatter angle to the work. Never let the flame's inner cone contact the molten metal; keep it about 1/8-inch away from the metal, and as you approach the end of the sheet, increase your welding speed.

If you are welding in the vertical position, give the torch an up-and down motion, rather than a rotating one. If you are in the overhead position, give the torch a light back-and-forth motion as in flat welding.

Whenever possible, hold heat-treatable alloys in a jig for welding to help eliminate cracking. You can also reduce the likelihood of cracking by using the 4043 filler rod. 4043 rod has a lower melting range than the alloy being joined, thus permitting the base metal to solidify before the weld puddle freezes.

The weld is the last area to solidify, so all of the contraction strains are in the weld bead rather than throughout the base metal. To reduce cracking further, tack weld parts while in the jig and then loosen the clamps and complete the work

As soon as the weld is complete and the work has cooled, thoroughly wash the weld by scrubbing it vigorously with a stiff brush as hot water runs over it. Continue until you have removed all traces of flux; if any flux is left on the weld, it can corrode the metal. If hot water is unavailable, use a diluted solution of 10 percent sulfuric acid, then wash the acid solution off with cold, fresh water.

3.7.1 Welding Pipe

In considering oxygas welding for pipe, many tests have proven that properly made fusion-welded pipe joints are as strong as the pipe itself.

There are three essential requirements to meet for successful oxygas welding of pipe.

1) You must have a convenient source of controlled heat available to produce rapid, localized melting of the metal.
2) You must remove the oxides present on the surface or edges of the joints.
3) You must make a metal-to-metal union between the edges or surfaces by means of molten metal.

Refer to *Figure 5-23*. It shows a welding operation at the top of a joint on a (assumed) horizontal pipe. For certification welding test purposes, if the pipe is rolled, the test would be to qualify the welder in the 1G position; if stationary, the test would be in the 5G position.

Figure 5-23 — Example of a pipe welding operation using the backhand technique.

Now refer to *Figure 5-24*.

This figure shows a detail of the flame and rod motions used to weld the pipe with the backhand technique.

The rod and flame are moved alternately toward and away from each other in an accordion motion.

Figure 5-24 — Example of the flame and rod motion performed on a pipe with the backhand technique.

An experienced welder can make full-strength oxygas welds in any physical welding position, and on a stationary pipe, most positions will be used.

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

The soundness and strength of your welds will depend heavily on the quality of the welding rod you use. If you have any doubt about the quality of the rods available, or you are unsure of which type to use, contact the rod manufacturer or one of the distributors. If your rod was supplied through the federal stock system, supply personnel should be able to look up the information you need based on the federal stock number.

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

- Use an excess fuel-gas (carburizing) flame.
- Use a welding rod containing deoxidizing agents.
- Use the backhand welding technique.

The following is a brief explanation:

- Excess Fuel-Gas Flame — As the base metal surface reaches white heat, it absorbs carbon from the excess fuel-gas flame. This lowers the melting point of steel; hence, the surface melts faster and speeds up the welding.
- Special Deoxidizing Welding Rod — Deoxidizing agents in the recommended rod eliminate impurities and prevent excess oxidation of carbon.

- Considerable carbon, the most valuable strengthening element of steel, would be lost were it not for this action. Thus, even with high-carbon, high-strength pipe, the weld metal is as strong as or stronger than the pipe material.

- Backhand Technique — This technique produces faster melting of the base metal surfaces, and you can use a smaller bevel, resulting 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 5-25* shows four different variations of using chain clamps for pipe welding setup.

Figure 5-25 — Examples of typical chain clamps aligning various pipefittings.

If these clamps are unavailable, you can fabricate your own by welding two C-clamps to a piece of heavy angle iron; a piece of 4” x 4” x 3/8-inch angle iron about 12 inches long is usually suitable. When you are butt-welding a small-diameter pipe, you can lay it in a piece of channel iron to obtain true alignment, or when you are working on a large diameter pipe, you can use a wide flange beam for alignment.

Summary

Gas welding is just one of many skills you need to practice and become proficient in as a Steelworker. Depending on the characteristics and thickness of the material you have for an assigned task, you may determine that gas welding is the preferred method for either repair or fabrication. This chapter presented information about the necessary equipment and identified how similar it is to gas cutting equipment in setup, use, and the gases utilized. It also provided instructions on how to operate and maintain the equipment in good working order with proper tip cleaning tools. Lastly, it offered gas welding techniques with recommendations about when to use the forehand or backhand technique relative to type of weld and specific metal. With this guidance, you should be able to set up the equipment, adjust the pressures, select the appropriate filler metal to match the base metal, and practice/practice/practice until you can demonstrate your capabilities and proficiencies in gas welding to yourself and your supervisors.

Review Questions (Select the Correct Response)

1. Which factor should you consider when considering gas welding?

    A. Edge prep, spacing, and joint alignment
    B. Flame adjustment and rod and torch manipulation
    C. Temperature control, before, during, and after the welding process
    D. All of the above

2. From what special type of alloy(s) are welding tips made?

    A. Carbon and zinc
    B. Tin and iron
    C. Titanium
    D. Copper

3. In a low-pressure torch, the fuel pressure in pounds per square inch (psig) is _____.

    A. 1 psig or less
    B. 2 to 3 psig
    C. a constant 5 psig
    D. greater than 7 psig

4. What device(s) control(s) the volume of oxygen and fuel-gas burned at the torch tip?

    A. One needle valve at the torch mixing head
    B. Two needle valves at the torch mixing head
    C. One separate mixing head for each gas
    D. Two different size tips

5. In a low-pressure welding torch, the fuel-gas enters as a result of suction created in the torch by a jet of higher-pressure _____.

    A. nitrogen
    B. gasoline
    C. oxygen
    D. helium

6. **(True or False)** In a medium-pressure welding torch, the working pressure of oxygen and fuel-gas is equal.

    A. True
    B. False

7. What primary function do filler rods serve in oxygas welding?

   A. As an electrical connection between the torch and the workpiece
   B. As a source of metal to fill the weld joint
   C. As a surface for braze welding
   D. As a heat conductor

8. The copper coating on steel filler rods enables the rods to _.

   A. melt at a higher temperature
   B. melt at a lower temperature
   C. clean the weld joint of impurities
   D. resist corrosion during storage

9. Which factor determines the proper diameter of filler rod to use for gas welding two steel plates?

   A. Type of steel that the plates are made of
   B. Thickness of the metal
   C. Job specifications
   D. Type of welding torch

10. Which factor determines the type of filler rods to use in oxygas welding?

   A. Specifications of the metal being joined
   B. Composition of the rod coatings
   C. Length and shape of available rods
   D. Type of welding position required

11. **(True or False)** Welding tip sizes are standardized among manufacturers.

   A. True
   B. False

12. What mistake have you most likely made when you have difficulty controlling the melting of the welding rod, the welds are being made too fast, and their appearance and quality are unsatisfactory?

   A. Used a welding rod that is too small
   B. Used incorrect polarity
   C. Used an incorrect “dragging” technique
   D. Used a welding tip that is too large

13. What factor dictates the adjustment you must make to the flame after igniting a welding torch?

   A. Thickness of the metal
   B. Type of filler rod used
   C. Type of metal being welded
   D. Polarity being used

14. What type of flame is best used for welding high-carbon steels, nonferrous metals, and hardfacing?

    A. Neutral
    B. Carburizing
    C. Oxidizing
    D. Normalizing

15. What type of flame is correct for use on most metals?

    A. Neutral
    B. Carburizing
    C. Oxidizing
    D. Normalizing

16. What flame is limited in use and harmful to many metals?

    A. Neutral
    B. Carburizing
    C. Oxidizing
    D. Normalizing

17. What is the first corrective step you should take when needle valves fail to shut off when hand tightened in the usual manner?

    A. Use a wrench to tighten it.
    B. Open the valve and using the working gas pressure blow out any foreign matter.
    C. Remove the stem assembly and wipe the seat clean.
    D. Have the parts replaced by qualified personnel.

18. When there is a leak around the torch valve stem, you should tighten the packing nut or repack it if necessary. For repacking, NEVER use oil. Instead, you should use only _.

    A. dry packing
    B. the packing recommended by the manufacturer
    C. heavy-weight packing
    D. granulated packing

19. You must remove deposits of _ regularly to ensure good performance of welding tips.

    A. copper and zinc oxide
    B. sodium carbide and phosphorus
    C. ferrous oxide and sodium phosphate
    D. slag and carbon

20. What procedure should you follow to recondition the end of a torch tip that has become rough and pitted?

    A. Insert a drill one size larger than the orifice opening into the tip end.
    B. Insert a tip drill into the seat opening and twist until penetration can be made at the tip-end opening.
    C. Place emery cloth, grit side up, on a flat surface and rub the tip end over it until the tip is back to its original condition.
    D. Use a bench grinder to square off the end of the tip, then drill out the orifice.

21. What type of file is commonly used to recondition a welding tip?

    A. Mill
    B. Pillar
    C. Square
    D. Taper

22. When forehand welding, you point the flame in the direction of travel and hold the tip at about a _ angle.

    A. 15°
    B. 30°
    C. 45°
    D. 60°

23. The forehand method is best for welding .

    A. heavy plate that is between 1 to 3 inches thick
    B. sheet and light plate up to 1/8 of an inch thick
    C. sheet plate that is between 1 to 2 inches thick
    D. any type of metal

24. When backhand welding, you point the flame away from the direction of travel and hold the tip at about a _ angle.

    A. 15°
    B. 30°
    C. 45°
    D. 60°

25. For which of the following reasons should you use the backhand method instead of the forehand method when welding plates thicker than 1/8 inch?

    A. It uses less welding rod and results in less puddling of molten metal.
    B. It requires less motion of the rod and torch tip and increases welding speed.
    C. It results in better control of large puddles of molten metal and achieves more complete fusion at the root of the weld.
    D. All of the above

26. For which reason is it possible to weld steel plates faster by using the backhand technique and a reducing flame rather than the forehand technique and a neutral flame?

    A. More of the base metal is melted during the welding operation.
    B. It is not necessary to control the heat on the plate.
    C. A thin surface layer of steel absorbs carbon and reduces the melting point of steel.
    D. All of the above

27. Which factor is an advantage of using multilayer welding instead of single layer when welding thick plate and pipe?

    A. The final layer is easier to control to get a smooth surface.
    B. Ductility of the weld metal is improved since one layer cools before being reheated when an additional layer is made.
    C. There is better control over each layer since carrying large puddles of molten metal is avoided.
    D. All of the above

28. **(True or False)** Sheet metal melts easily and does not require special edge preparation.

    A. True
    B. False

29. On what thickness of plate do you begin to make a slight root opening between the parts to get complete penetration?

    A. 1/16 to 1/8 inch
    B. 3/16 to 1/4 inch
    C. 1/4 to 3/8 inch
    D. 3/8 to ½ inch

30. What size plate requires beveled edges 30 degrees to 45 degrees and a root opening of 1/16 inch?

    A. 1/8 inch and greater
    B. 3/16 inch and greater
    C. 1/4 inch and greater
    D. ½ inch and greater

31. What action must you take to relieve stresses developed when oxygas welding low-alloy steels?

    A. Chip and peen after welding
    B. Quench after welding
    C. Heat-treat before and after welding
    D. Use special flux in the welding process

32. What causes the surface of the molten puddle to appear greasy when welding wrought iron?

    A. High carbon content of the wrought iron
    B. Slag used in manufacturing the wrought iron
    C. Use of mild steel as a filler metal
    D. Failure to use a special flux

33. **(True or False)** When you oxygas weld cast iron, you must preheat the entire weldment to between 750°F and 900°F. After completing the weld, you must postheat the weldment to between 1100°F to 1150°F to relieve stresses.

    A. True
    B. False

34. Which characteristics apply to the method of joining a light stainless steel sheet by oxygas welding?

    A. No flux, a carburizing flame, no puddle, and a relatively small torch tip
    B. No flux, an oxidizing flame, puddle, and a relatively large torch tip
    C. Flux, an oxidizing flame, no puddle, and a relatively small torch tip
    D. Flux, a carburizing flame, no puddle, and a relatively small torch tip

35. To what temperature range should you preheat the joint area when you oxygas weld deoxidized copper?

    A. 100°F to 300°F
    B. 300°F to 500°F
    C. 500°F to 800°F
    D. 800°F to 900°F

36. Assuming the same welding process and same part thickness, compared with the technique for joining steel parts, the technique for joining deoxidized copper calls for the use of a/an ______.

    A. smaller torch tip and no preheating
    B. larger torch tip and more preheating
    C. oxidizing flame and no flux
    D. carburizing flame and oxygas brass flux

37. What type of rod is used for welding brass by the oxygas process?

    A. Lead
    B. Steel
    C. Silicon-copper
    D. Silicon-bronze

38. Which action should you take when oxygas welding copper-nickel alloys?

A. Adjust the flame to a slightly oxidizing flame.
B. Agitate the molten puddle when adding filler metal.
C. Keep the welding rod end outside the protective envelope of the flame.
D. Remove all traces of flux with warm water after welding is completed and the part has been cooled slowly.

39. You must wear a respirator to guard against poisonous fumes when you weld _____.

A. silver
B. aluminum
C. lead
D. brass

40. What type of welding rod should you use to minimize cracking when gas welding wrought aluminum alloys?

A. 1100
B. 3003
C. 4043
D. 5511

41. Pure aluminum is one fourth as strong as _____.

A. steel
B. iron
C. copper
D. titanium

42. For which reason do you use a flux when welding aluminum alloy?

A. To preserve the luster of the metal
B. To reduce the tendency of the metal to crack
C. To remove the aluminum oxide formed during the welding process
D. To lower the melting point of aluminum

43. Edge notching is a recommended procedure for oxygas butt welding aluminum plate because it _____.

A. gives a clear view of the weld area
B. aids in getting full penetration and prevents distortion
C. allows the torch flame to cover a greater area
D. allows the welder to use either the forehand or backhand method

44. What temperature should you not exceed when preheating aluminum alloys?

    A. 300°F
    B. 500°F
    C. 700°F
    D. 900°F

45. **(True or False)** The forehand method of welding is preferred for aluminum alloys.

    A. True
    B. False

46. What action should you take to reduce the possibility of heat-treatable aluminum alloys cracking during the welding process?

    A. Secure them in a jig.
    B. Use 4043 filler rod.
    C. Tack the work while clamped in a jig, then loosen before completing the seam.
    D. All of the above

47. Which requirement must be met to complete a successful weld when oxygas welding pipe?

    A. A controlled heat source localized to produce rapid melting
    B. Elimination of surface oxides
    C. Union of edges or surfaces by means of molten metal
    D. All of the above

48. **(True or False)** For welding pipe, the backhand technique is preferred because it produces faster melting of the base metal surfaces, allows a smaller bevel to be used, and results in a savings of 20% to 30% in welding time, rods, and gases.

    A. True
    B. False

Trade Terms Introduced in This Chapter

Venturi effect	The reduction in fluid pressure that results when a fluid flows through a constricted section of pipe.
Broach	In machinery, an elongated, tapered, serrated cutting tool for shaping and enlarging holes.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

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Chapter 6

Soldering, Brazing, Braze Welding, Wearfacing

Topics

To hear audio, click on the box.

Overview

Chapters 3 and 5, Introduction to Welding and Gas Welding, addressed two processes for joining metals by fusion welding, the first by electricity and the second by heated gases.

This chapter also presents procedures for joining metals, but without fusion. These procedures, which include soldering, brazing, braze welding, and wearfacing, allow you to join dissimilar metals and produce high-strength joints while not affecting the heat treatment of the base metal or warping it as much as conventional welding may do with the requisite high temperatures.

A Steelworker functioning at the civilian journeyman level is expected to be capable, if not proficient, in each of these four methods of non-fusion metal joining. They are part of the total package of skills you need to develop for your professional skills tool kit.

Working with metal, whether stock material or parts, you will encounter situations where you must determine whether the tasking is a permanent or expedient effort, and what is the best method of fabrication or repair given the tools and assets available.

With the capability to join metals by both fusion and non-fusion methods in your skills inventory, you increase your value to yourself and the Seabees while upholding the "Can Do" spirit.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the procedures utilized in soldering operations.
2. Describe the procedures utilized in brazing operations.
3. Identify the equipment and procedures for braze welding.
4. Describe the materials and procedures for wearfacing.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet-Metal and Fiberglass Duct		
Welding Quality Control		
Flux Core Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 SOLDERING

Soldering is a simple and fast means for joining sheet metal, making electrical connections, and sealing seams against leakage. Like welding, soldering uses a filler metal (commonly called solder) to join two metals. However, unlike welding, soldering joins the two metals without heating them to their melting points. In addition, you can also use soldering to join dissimilar metals such as iron, nickel, lead, tin, copper, zinc, aluminum, and many other alloys.

800°F is a key determining temperature. Because solder's melting temperature is below 800°F, it is not classified as a welding or brazing process. Welding and brazing usually take place above 800°F, the one exception being lead welding, which occurs at 621°F.

Do not confuse "silver soldering" with soldering. The silver soldering process is a form of brazing because it uses a temperature above 800°F.

1.1.0 Equipment

Soldering requires very little equipment. Typically, you only need a heat source, a soldering copper or iron, solder, and flux.

1.1.1 Sources of Heat

Heat sources can vary according to the **a**vailable equipment and the method you need to use. Some common sources are welding torches, blowtorches, forges, and furnaces, all of which heat the soldering coppers that secondarily supply the direct heat to the metal surfaces, thus melting the solder. Occasionally you may opt to use a heat source directly to heat the metal, but if or when you do this, you must be careful not to damage the metal or the surrounding material.

1.1.1.1 Soldering Coppers

Externally heated soldering coppers (soldering irons) consist of a forged copper head, an iron rod, and a handle, usually wood or fiber either screwed or forced on. Other soldering irons are electrically heated (*Figure 6-1*).

Figure 6-1 — Examples of soldering coppers (soldering irons).

Soldering heads are available in various shapes. *Figure 6-2* shows three of the more commonly used types.

Pointed copper — for general soldering work.

Stub copper — for soldering flat seams needing a considerable amount of heat.

Bottom copper — for soldering hard to reach seams, such as those in pails, pans, trays, and similar objects.

Figure 6-2 — Common soldering copper heads.

Nonelectrical coppers come in pairs so you can use one copper as the other is heating. When coppers are referred to by size designation, they are referred to by weight (in pounds) of the pair, so a reference to a pair of 4-pound coppers means each copper head weighs 2 pounds.

Pairs of coppers are usually available in 1-pound, 1 1/2-pound, 3-pound, 4-pound, and 6-pound sizes. As you would expect, because of their differing heat transfer ranges, heavy coppers are designed for soldering heavy gauge metals, while light coppers are for thinner metals, and using the incorrect size of copper usually results in poorly soldered joints from problems caused by not enough steady heat or by overheating.

1.1.1.1.1 Filing and Tinning Coppers

Before you can use new soldering coppers, you must tin them (coat with solder). In addition, you must file and re-tin them if they overheat or lose their solder coating for any reason.

Use the following procedure for filing and tinning a copper (*Figure 6-3*).

- Heat to cherry red.
- Clamp in vise.
- File with single-cut bastard file.
    - Bear down on forward stroke.
    - Release pressure on return stroke.
    - Do not rock file.
    - Continue filing tapered sides until bright and smooth.

CAUTION

Remember, the copper is hot! Do not touch it with your bare hands!

- Smooth off point and any sharp edges.
- Reheat until hot enough to melt solder.
- Rub each filed side back and forth across cake of sal ammoniac.
- Apply solder to copper until tinned.
  - Rub solder directly on copper, or place solder on a cake of sal ammoniac.
  - Do not push copper into cake; this can split the cake.

Figure 6-3 — Filing and tinning a soldering copper head with solder on a cake of sal ammoniac.

Figure 6-4 — Tinning with rosin on a brick and direct solder application.

If sal ammoniac is unavailable, you can use powdered rosin (*Figure 6-4*).

- Place powdered rosin on a brick.
- Rub copper back and forth to pick up rosin.
- Place solder directly onto copper.

Commercially prepared soldering salts (in powder form) are also used to tin soldering coppers.

Dissolve the powder in water according to the directions, dip the soldering copper into the solution, and apply the solder.

1.1.1.1.2 Forging Soldering Coppers

When nonelectric soldering coppers become blunt or deformed, you can reshape them by a forging process. Use the following procedures (*Figure 6-5*).

- File to remove all old tinning and smooth surfaces.
- Heat to bright red.
- Hold on an anvil and forge to required shape by striking with a hammer.

NOTE

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. These shapes cause the copper to cool too rapidly when in use.

Turn it often to produce the necessary squared-off sides and reheat as often as necessary during this part of the forging.

- Reheat to a bright red
- Use a flat-faced hammer to remove as many hollows as possible.
- File and tin per previous guidance.

Figure 6-5 — Forging a soldering copper head.

1.1.1.2 Electric Soldering Coppers

Electric soldering coppers (usually called soldering irons) use internal heating coils to heat the head, and the heads are removable and interchangeable.

Tinning is the same with the exception that the tip usually does not become cherry red as the internal coils have limiting resistors.

Forging or reshaping is not necessary since the heads are easily replaced.

Electric soldering irons are especially suited for, and usually used for, electrical work or other small jobs (*Figure 6-6*).

They do not require auxiliary heating and can be as small as a pencil.

Figure 6-6 — Typical electric soldering iron with replaceable heads.

1.1.1.3 Gas Torches

You can use a gas torch in combination with soldering head attachments (*Figure 6-7, View A*) or as a direct heat source.

Figure 6-7 — Examples of using a gas torch as a heat source.

A Prest-O-Lite heating unit (*Figure 6-7, View B*) delivers a small controllable flame and is ideal for soft soldering, or you can use it effectively to heat soldering coppers. The unit includes a fuel tank regulator, hose, torch, interchangeable tips, and burns either acetylene or MAPP gas in the presence of oxygen.

1.1.2 Soft Solder

Commercial industry uses many different types of solders, and they are available in various forms including bar, ingot, powder, and wire, which is available with or without a flux core. Because there are so many types of solders available, this chapter will cover only solders that Steelworkers would most commonly use.

1.1.2.1 Tin-Lead Solder

The atomic symbol for tin is Sn; the symbol for lead is Pb. Occasionally, you may see these symbols used as Sn-Pb instead of the term tin-lead but they have equal meaning.

The tin-lead alloy group of solders is the largest group used. You can use them for joining most metals, they have good corrosion resistance, and they have excellent compatibility with soldering processes, most types of flux, and cleaning.

Industry custom is to state the tin content first when describing solders, so a 40/60 solder has a content of 40% tin and 60% lead.

The melting characteristics of any tin-lead alloy will depend on 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 solder’s cracking potential.

Figure 6-8 shows the behavior of a 63/37 tin-lead solder.

Note that 100% lead melts at 621°F and 100% tin melts at 450°F.

Also, solders containing 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.

The eutectic point is the point in an alloy system when all the elements of the alloy melt at the same but lower temperature than any other composition.

A 63/37 solder becomes liquid at 361°F.

Figure 6-8 — Tin-lead alloy constitutional diagram.

Other compositions do not. Instead, they remain in the pasty stage until the temperature increases to the melting point of the other alloy. For an example, refer to *Figure 6-8* again.

- As already stated, tin solders containing 19.5% to 97.5% tin remain a solid until they exceed 360°F.
- Therefore, a 50/50 solder with a solid temperature of 360°F and a liquid temperature range of 417°F has a pasty temperature range of 57°F—the difference between the solid and the liquid temperatures.

The less expensive solders with lower tin content are used primarily for sheet metal products and other high-volume solder requirements. The solders with higher tin content are used extensively in electrical work, and the solders with 60% tin or more (fine solders) are used in instrument soldering where temperatures are critical.

1.1.2.2 Tin-Antimony-Lead Solder

Antimony (an'-*tuh-moh-nee*), symbol Sb, is added up to 6% to a tin-lead solder as a substitute for some of the tin. It increases the solder’s strength and mechanical properties.

CAUTION

Do not use solders with high antimony content on aluminum, zinc, or zinc-coated materials. They form an intermetallic compound of zinc and antimony that causes the solder to become very brittle.

1.1.2.3 Tin-Zinc Solder

There are several tin-zinc solders available for joining aluminum alloys. The 91/9 and 60/40 are used for higher temperature ranges (above 300°F), and normally the 80/20 and 70/30 are used as precoating solders.

1.1.2.4 Tin-Antimony Solder

Tin-antimony solders are used for refrigeration work or for joining copper to cast iron joints. The 95/5 is the most common.

1.1.2.5 Tin-Silver Solder

Tin-silver solder (96/4) is used for food or beverage containers that must be cadmium- and lead-free. The 95/5 tin-silver can also be used as a replacement for the 95/5 tin-antimony solder for refrigeration work.

1.1.2.6 Lead-Silver Solder

Lead-silver solders are useful where the requirement is for strength at moderately high temperatures.

Lead by itself cannot be used since it does not normally wet steel, cast iron, or copper and its alloys, so adding silver results in alloys that wet steel and copper more readily.

However, flow characteristics for straight lead-silver solders are rather poor, and they are susceptible to humidity and corrosion during storage. By adding a tin content of 1%, manufacturers enhance the wetting and flow characteristics, and increase resistance to corrosion.

Lead-silver solders require higher soldering temperatures and special fluxing techniques such as using a zinc-chloride-based flux (an acid flux) on uncoated metals because rosin-based fluxes decompose rapidly at high temperatures.

You can find more information about these solders and the procedures for their use in the NAVFAC *Welding Materials Handbook* P-433, 1991.

1.1.3 Fluxes

Most metal surfaces form scale, rust, and oxides when exposed to air, and heating accelerates their formation.

Solder will not adhere to or wet metal with these pollutants.

Fluxes are chemical compounds you use to clean and maintain the metal surfaces during the soldering process (*Figure 6-9).*

They also decrease the surface tension of the solder, making it a better wetting agent.

Fluxes are available in cake, paste, liquid, or powder form and are classified as either noncorrosive or corrosive for situational application with specific metals.

Figure 6-9 — Flux action during soldering.

Table 6-1 shows fluxes you would normally use for soldering common metals.

Table 6-1 — Fluxes Used for Soldering Common Metals

Metals	Fluxes
Aluminum	Stearine, special flux
Brass, copper, tin	Rosin
Galvanized iron	Zinc chloride
Iron, steel	Borax sal ammoniac
Lead	Tallow, rosin
Stainless steel and other nickel alloys	Phosphenic acid
Zinc	Zinc chloride

1.1.3.1 Noncorrosive Fluxes

For soldering electrical connections or other work that must be free of any trace of corrosive residue, you need to use a noncorrosive flux. Rosin is the most commonly used noncorrosive flux. In the solid state, it is inactive and noncorrosive; when heated, it melts and provides some fluxing action.

Available in powder, paste, or liquid form, rosin fluxes frequently leave a nonconductive brown residue that is sometimes difficult to remove since it is made of purified pine sap.

You can reduce the removal problem by adding a small amount of turpentine to the (pine sap) rosin, and you can add glycerin to it to make it more effective.

1.1.3.2 Corrosive Fluxes

Corrosive fluxes provide the most effective cleaning action, but since any trace of corrosive flux remaining on the work can cause corrosion later, do not use corrosive fluxes on electrical connections or other work where corrosion would cause a problem.

Sal ammoniac (ammonium chloride) and zinc chloride, in either solution or paste form, are the most common and frequently used corrosive fluxes.

If present, any solvent evaporates as the work heats, leaving a layer of solid flux on the metal. When the metal heats further to soldering temperature, this layer of solid flux melts, partially decomposes, and liberates hydrochloric acid. Then the hydrochloric acid dissolves the oxides from the work surfaces and filler metal (solder) if applied, thus providing a clean surface for the solder process to bond (refer again to *Figure 6-9*).

You can make zinc chloride (also called cut acid or killed acid**)** in the shop as long as you follow specific safety precautions.

You must use rubber gloves, a full-face visor, and an apron. Fumes given off by muriatic acid or the mixture of muriatic acid and zinc are explosive and a health hazard as well.

Prepare zinc chloride under a ventilation hood, out in the open, or near openings to the outside to reduce the danger of explosion or inhalation, and take precaution to prevent flames or sparks from coming in contact with the liberated hydrogen gas.

To prepare zinc chloride:

- Pour small amount of muriatic acid (commercial form of hydrochloric acid) into glass or acid-resistant container.
- Add small pieces of zinc.
    - As you add the zinc, the muriatic acid boils and bubbles (a chemical reaction), producing zinc chloride and hydrogen gas.
- Keep adding small pieces of zinc until liquid no longer boils and bubbles.
    - At this point, the reaction is complete.
- Dilute liquid in container with an equal amount of water.

WARNING

Always add acid to water when diluting. Adding water to acid can result in an explosive reaction, resulting in serious injuries.

- Make only enough as required and strain it before use; store any leftover in a tightly sealed glass container.

Soldering salts are another type of corrosive flux. Commercial soldering salts are normally manufactured in a water-soluble, powder form that allows you to mix only the amount needed.

If you use a corrosive flux for soldering, upon completion, remove as much of the residue as possible. Most corrosive fluxes are water-soluble, so you can wash the work with soap and water and rinse it thoroughly with clear water to remove the corrosive residue. To minimize potential damage, clean the work immediately after soldering.

1.2.1 Soldering Techniques

Soldering with coppers and torch soldering are the two most common methods of soldering, and the same considerations apply to both methods.

- Clean all surfaces of oxides, dirt, grease, and other foreign matter.
- Use proper flux for particular job.
  - Some work requires corrosive fluxes; other work requires noncorrosive fluxes.
  - The melting point of the flux must be BELOW the melting point of the solder.
- Heat surfaces just enough to melt solder.
  - Solder does not stick to unheated surfaces, but be very careful not to overheat the solder, the soldering coppers, or the base metals.
  - Heating solder above the work temperature increases the rate of oxidation and changes the proportions of tin and lead.
- Remove as much corrosive flux as possible after soldering.

1.2.1 Sweat Soldering

Use sweat soldering when you need to make a joint but do not want the solder exposed.

You can use this process on electrical and pipe connections (*Figure 6-10)*.

To make a sweated joint:

- Clean, flux, and tin each adjoining surface.
- Hold pieces firmly together; heat with soldering copper or torch until solder melts and pieces join.
- Remove source of heat; keep parts firmly in position until solder completely hardens.
- Clean any residue from soldered area.

Figure 6-10 — Common application of sweat soldering technique.

1.2.2 Seam Soldering

Seam soldering involves running a layer of solder along the edges of a joint (*Figure 6-11),* on the inside whenever possible. Soldering with coppers is the best method for seam soldering; they provide better heat control and cause less distortion.

Figure 6-11 — Common application of seam soldering technique.

To seam solder:

- Clean and flux areas.
- Tack pieces so work stays in position (if not already riveted or grooved).
- Position piece so seam does not rest directly on support (prevents loss of heat to support).
- Solder seam.

- Heat area by holding copper against work.
    - o The work must absorb enough heat from the copper so the work melts the solder.
- Hold copper so one tapered side is flat against seam (*Figure 6-12*).
- When solder begins to flow freely into seam, draw copper along seam with slow, steady motion.
- Add solder as necessary without raising copper from work.

Figure 6-12 — Example of soldering a seam.

- When copper becomes cold, use other copper and reheat first one.
    - o Change the coppers as often as necessary.
    - o The best-soldered seams are made without lifting the copper from the work and without retracing the completed work.
- Allow joint to cool and solder to set before moving.
- If corrosive flux was used, rinse with water and brush or wipe with clean, damp cloth.

Figure 6-13 — Example of soldering a riveted seam.

Riveted seams are often soldered to make them watertight.

Figure 6-13 shows the procedure for soldering a riveted seam.

Solder beads, or solder shots, are sometimes used for soldering the bottom of square, rectangular, or cylindrical vessels.

To make solder beads, simply hold the solder against a hot copper and allow the melted beads to drop onto a clean surface (*Figure 6-14*).

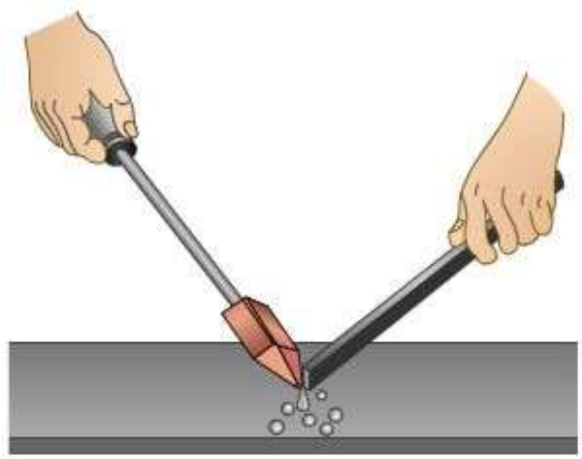

Figure 6-14 — Example of making solder beads.

To solder a bottom seam with solder beads:

- Flux seam.
- Drop cold bead of solder into container.
- Place hot soldering copper against seam (*Figure 6-15*).
- Hold copper in position until solder starts to flow freely into seam.
- Draw copper slowly along seam, turning work as you go.
- Add beads and reheat copper as necessary.

Figure 6-15 — Example of soldering a bottom seam.

To heat and use an electric soldering copper (electric iron), you merely plug it in; otherwise, the procedure is much the same as that just described. Although electric irons have built-in resistors to prevent it, be careful not to let an electric unit overheat. Overheating can burn out the electrical element as well as damage the copper and tinning.

1.3.1 Soldering Aluminum Alloys

Soldering is more difficult on aluminum alloys than on many other metals because of the layer of oxide that always covers them, and the thickness of the layer will depend on the type of alloy and the exposure conditions.

Wrought aluminum alloys are usually easier to solder than cast aluminum alloys, while heat-treated aluminum alloys are extremely difficult to solder, as are aluminum alloys containing more than 1% magnesium. However, you can still successfully solder many aluminum alloys by using proper techniques.

Aluminum alloys usually require tin-zinc or tin-cadmium solder alloys, generally called the aluminum solders. Most of these solders have higher melting points than the tin-lead solders used for ordinary soldering, and both corrosive and noncorrosive fluxes are used for soldering aluminum depending on a given situation.

To solder an aluminum alloy:

- Clean surfaces and remove layer of oxide.
    - Thick layer — remove mechanically by filing, scraping, sanding, or wire brushing.
    - Thin layer —remove by using corrosive flux.
- Apply flux to work and solder.
- Tin surfaces with aluminum solder.
    - Use either a soldering copper or torch.

      - If you use a torch, do not apply heat directly to the work surfaces, solder, or flux. Instead, play the torch on a nearby unsoldered part of the work and let the heat conduct through the metal to the work area.
      - Do not use any more heat than necessary to melt the solder and tin the surfaces.
- Work aluminum solder well onto surfaces.
- Sweat parts together.

For an alternate procedure to solder an aluminum alloy:

- Tin surfaces with aluminum solder.
- Use regular tin-lead solder to join aluminum solder-tinned surfaces.
   - No need to use flux when using tin-lead solder with aluminum solder.
      - You can use this procedure when the shape of the parts prevents you from using the sweat method or the task demands a large amount of solder.

For both methods, after you complete the soldering, clean with a wire brush, soap and water, or emery cloth to ensure you remove all the flux from the joint; any flux left will cause corrosion.

Test Your Knowledge (Select the Correct Response)

1. **(True or False)** Like welding, soldering joins two metals by heating them to their melting points.

   A. True
   B. False

2.0.0 BRAZING

Do you remember the key determining temperature of 800°F?

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's temperature. Sometimes brazing is called hard soldering or silver soldering because the filler metals are either hard solders or silver-based alloys.

Do not confuse brazing with braze welding, though the two terms are often interchanged. In brazing, the filler metal is drawn into the joint by capillary action; in braze welding the filler metal is distributed by tinning. Both processes require distinct joint designs.

Like soldering, brazing offers important advantages over some other metal-joining processes such as oxygas welding. It does not affect the heat treatment of the original metal as much as welding, does not warp the metal as much, and allows you to join dissimilar metals.

2.1.0 Equipment

Brazing requires three basic items: a heat source, filler metal, and flux.

2.1.1 Heating Devices

The source of heat depends on the type and amount of brazing required. If you were doing production work and the pieces were small enough, you could put them into a furnace and braze them all at once. Alternatively, you could mount individual torches in groups for assembly line work, or you could use an individual oxyacetylene or MAPP-oxygen torch to braze an individual item.

2.1.2 Filler Metals

Brazing filler metals are nonferrous metals or alloys with a melting temperature below the base metal, but above 800°F. They must have the ability to wet and bond with the base metal, be stable, and not be excessively volatile.

The most commonly used filler metals for brazing are the silver-based alloys available in rod, wire, powder, and preformed form.

Brazing filler metals include the following groups:

Aluminum-silicon alloys	Gold alloys
Copper	Magnesium alloys
Copper-phosphorus alloys	Nickel alloys
Copper-zinc (brass) alloys	Silver-based alloys

2.1.3 Fluxes

Brazing requires flux to stop any oxides or similar contaminants from forming during the process, and flux increases both the flow of the filler metal and its ability to stick to the base metal. Flux helps form a strong joint by bringing the filler metal into immediate contact with the adjoining base metals and permitting the filler to penetrate the pores of the metal.

Carefully select the flux for each brazing operation; read the manufacturer's label for the type of metal than can be brazed with the flux. Consider the following three factors:

Base metal or metals — Brazing filler metal — Source of heat

Flux is available in powder, liquid, and paste form. You can apply the powdered form of flux by dipping the heated end of the brazing rod into the container, allowing the flux to stick to it. Alternatively, you can heat the base metal slightly and sprinkle the powdered flux over the joint, allowing the flux to partly melt and stick. Sometimes you may find it desirable to mix the powdered flux with distilled water to form a paste.

You can apply flux with a brush in either the paste or liquid form, but in either case, you will achieve better results if you give the filler metal a coat also.

The most common type of flux for brazing is borax or a mixture of borax with other chemicals, while some commercial fluxes contain small amounts of phosphorus and halogen salts of iodine, bromine, fluorine, chlorine, or astatine.

When a prepared flux is not available, you can use a mixture of 12 parts borax and 1 part boric acid.

WARNING

Nearly all fluxes give off fumes that may be toxic. Use them only in WELL VENTILATED spaces.

2.2.0 Joint Design

In brazing, the filler metal is distributed by capillary action.

Therefore, the joints must have close tolerances and a good fit prior to brazing in order to produce a strong bond.

Brazing has three basic joint designs: lap, butt, and scarf (*Figure 6-16*), but they can be found in flat, round, tubular, or irregular shapes.

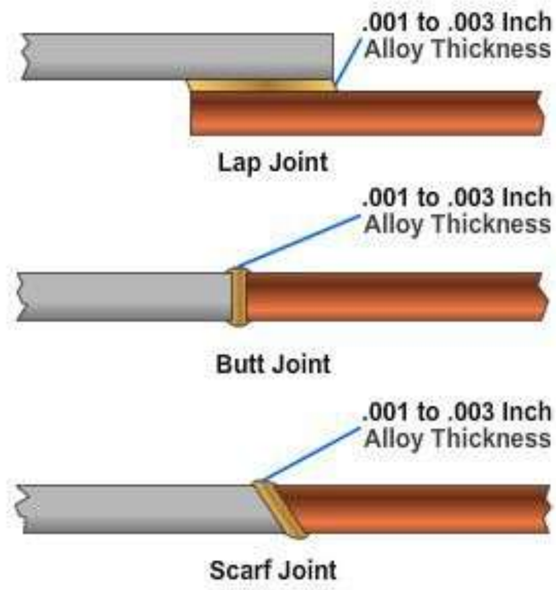

Figure 6-16 — Examples of three types of brazing joint designs.

2.2.1 Lap Joints

The lap joint is one of the strongest and most frequently used joint in brazing, especially in pipe work. Its primary disadvantage is the increased 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 joint members provides the greatest strength with a silver-based filler metal. With such close tolerances for pipefittings, you need to take precautions to prevent heat expansion from closing joints before the capillary action.

2.2.2 Butt Joints

The size of a butt joint is limited to the thinnest section, so maximum joint strength is impossible, but you can maximize the available butt joint strength by maintaining a 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 that uniform clearance between all parts of the joint. Butt joints are usually used where it is undesirable to have double thickness.

2.2.3 Scarf Joints

When double metal thickness is objectionable but you still need more strength, the scarf joint is a good choice. A scarf joint provides an increased bond area without increasing the thickness of the joint. The amount of bond area depends on the angle the scarf is cut; usually, an area two to three times the butt joint area is desirable. A 30° scarf angle gives a bond area twice that of a 90° butt joint, and a 19½° scarf angle increases the bond area three times.

Figure 6-17 shows some variations of butt and lap joints designed to produce good brazing results.

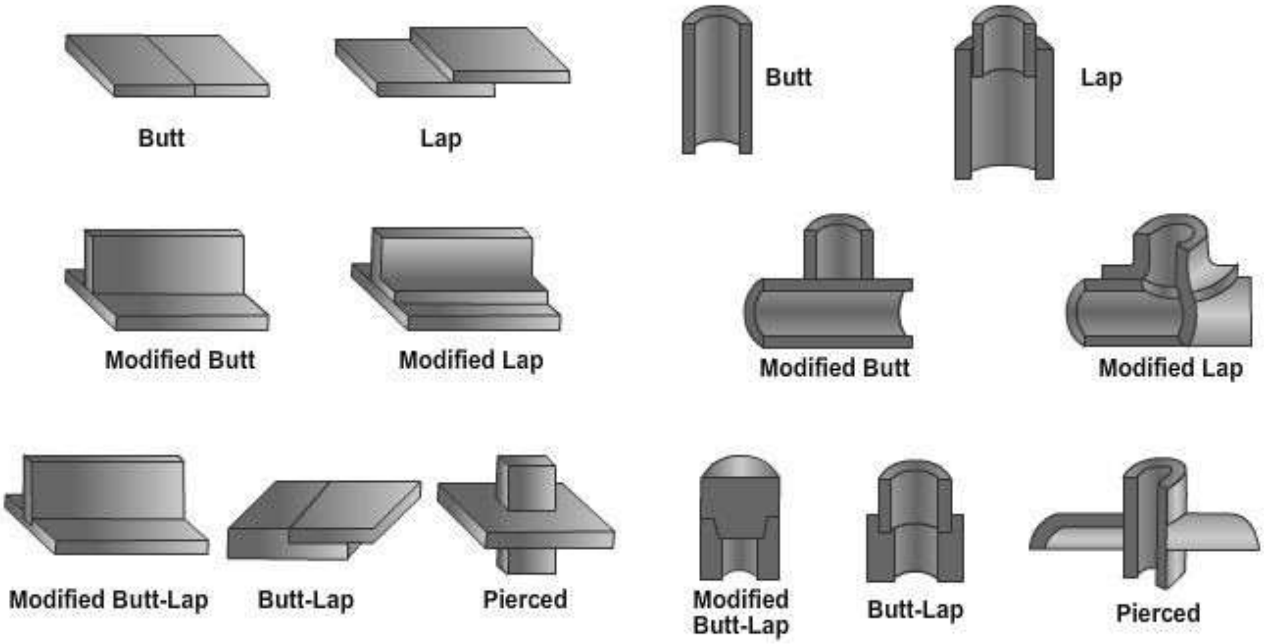

Figure 6-17 — Joints designed to produce good brazing results.

Figure 6-18 shows a comparison of some good and bad brazing joint designs and preparations.

Figure 6-18 — Comparison of some well designed joints prepared for brazing and some poorly designed/prepared joints.

2.3.0 Brazing Procedures

The procedure for brazing is very similar to braze welding and oxyacetylene welding. You must clean the metal mechanically, chemically, or with a combination of both to ensure good bonding, fit the two pieces properly, and support them to prevent voids in the joint or accidental movement during your brazing and cooling operations.

2.3.1 Surface Preparation

Clean the work. The metal surfaces must be clean for capillary action to take place. When necessary and practical, you can chemically clean the surface by dipping it in acid, then remove the acid by washing the surface with warm water. You can use steel wool, a file, or abrasive paper for mechanical cleaning, but do not use an emery wheel or emery cloth; abrasive particles or oil might become embedded in the metal.

2.3.2 Work Support

Support the work. If the joint moves during the brazing process, the finished bond will be weak and subject to failure, so mount the work in position on firebricks or other suitable means of support, and if necessary, clamp it.

2.3.3 Fluxing

Flux the work (and filler rod). Flux application varies depending on the form of flux you are using and the type of metal you are brazing, but the flux must be suitable for the job. Refer to the previously described material on fluxes and always refer to the manufacturer's information.

2.3.4 Brazing

Heat the work. The next step is to heat the parts to the correct brazing temperature. Use a neutral flame; it gives the best results under normal conditions. A reducing flame produces an exceptionally neat-looking joint, but you sacrifice strength; an oxidizing flame produces a strong joint, but you get a rough-looking surface.

Watch the behavior of the flux as you heat it to determine the temperature of the joint. First, the flux dries out as the moisture (water) boils off at 212°F, then it turns milky in color and starts to bubble at about 600°F, and finally it turns into a clear liquid at about 1100°F, just short of brazing temperature.

When the flux appears clear, it is time to start adding the filler metal with the heat of the joint, not the flame, melting the filler metal.

If you have properly aligned the parts and applied the temperature, the filler metal will spread 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 6-19 shows a good position for the torch and filler metal when brazing a butt joint. Note the position is the forehand method, so you are heating the metal ahead of applying the filler metal to the joint.

Figure 6-19 — Example of good torch and filler metal position when brazing a butt joint.

Stop heating the work. As soon as the filler metal has completely covered the surface of the joint, turn off the torch 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 solidified completely.

Clean the work. Finally, after the joint has cooled sufficiently, clean it; you can do this with hot water. Be sure you remove all traces of flux since it can corrode the metal, and you can file off any excess metal left on the joint.

The procedure described is a general one, but it applies to the three major types of brazing: silver, copper alloy, and aluminum, where the differences lay in the type of base metal, composition of filler metal, and appropriate flux, not in the procedure.

2.3.5 Silver Brazing

You may be called upon often to do a silver brazing job. For many years, the primary reference standard for silver solders was the American Society for Testing and Materials' standard ASTM B73-29 *Specification for Silver Solders*. In 1952, that standard was withdrawn and replaced by ASTM B260-62 *Specification for Brazing Filler Metal*. However, in 1968 the B260-62 standard was once again withdrawn, this time with no replacement.

Currently, the primary source to access standards for silver-based brazing alloys is the American Welding Society standard AWS 5.8 (*Tables 6-2* and *6-3*).

Table 6-2 — Standard AWS Silver-Based Brazing Alloys

Composition									
AWS 5.8 Specs	Silver	Copper	Zinc	Others	AWS 5.8 Specs	Silver	Copper	Zinc	Others
BAg-1	44.0-46.0	14.0-16.0	14.0-18.0	23.0-25.0 Cd **	BAg-8	71.0-73.0	Remainder		
BAg-1a	49.0-51.0	14.5-16.5	14.5-18.5	17.0-19.0 Cd	BAg-8a	71.0-73.0	Remainder		
BAg-2	34.0-36.0	25.0-27.0	19.0-23.0	17.0-19.0 Cd	BAg-13	53.0-55.0	Remainder	4.0-6.0	0.5-1.5 Ni
BAg-2a	29.0-31.0	26.0-28.0	21.0-25.0	19.0-21.0 Cd	BAg-13a	55.0-57.0	Remainder		1.5-2.5 Ni
BAg-3	49.0-51.0	14.5-16.5	13.5-17.5	16 Cd, 3N*	BAg-18	59.0-61.0	Remainder		10Sn. 0.125 max. P
BAg-4	39.0-41.0	29.0-31.0	26.0-30.0	1.5-2.5 Ni	BAg-19	92.0-93.0	Remainder		0.15-0.30 Li
BAg-5	44.0-46.0	29.0-31.0	23.0-27.0		BAg-20	29.0-31.0	37.0-39.0	30.0-34.0	
BAg-6	49.0-51.0	33.0-35.0	14.0-18.0		BAg-21	62.0-64.0	27.5-29.5		6 Sn, 2.5 Ni
BAg-7	55.0-57.0	21.0-23.0	15.0-19.0	4.5-5.5 Sn					

*Total maximum allowable impurities is 0.15%. Cd=cadmium Sn=tin P=phosphorus Ni=nickel Li=lithium

Table 6-3 — Standard AWS Brazing Alloy Usage Temperatures

	Brazing Temperature			Brazing Temperature	
AWS 5.8 Specs	°F	°C	AWS 5.8 Specs	°F	°C
BAg-1	1145-1400	618-760	BAg-8	1435-1650	779-899
BAg-1a	1175-1400	635-760	BAg-8a	1435-1650	779-899
BAg-2	1295-1550	702-843	BAg-13	1575-1775	857-968
BAg-2a	1310-1550	710-843	BAg-13a	1600-1800	871-982
BAg-3	1270-1500	688-816	BAg-18	1325-1550	718-843
BAg-4	1435-1650	779-899	BAg-19	1610-1800	877-982
BAg-5	1370-1550	743-843	BAg-20	1410-1600	766-871
BAg-6	1425-1600	774-871	BAg-21	1475-1650	802-899
BAg-7	1205-1400	652-760			

Figure 6-20 shows a common and popular way to apply silver brazing metal on tubing, by using silver alloy rings. This is a practical and economical way to add silver alloy when using a production line system.

Figure 6-20 — Silver-brazed joints designed to use silver alloy rings.

Figure 6-21 shows another method of brazing, by using preplaced brazing shims.

Figure 6-21 — A machining tool bit with preplaced brazing filler metal shims.

Jobs will vary according to the metal and the dictates of the task, but the experiences will help you become capable of selecting the proper procedure to produce quality brazing.

Test Your Knowledge (Select the Correct Response)

2. **(True or False)** Brazing is the process of joining metal by heating the base metal to a temperature below 800°F and adding a nonferrous filler metal that melts below the base metal's temperature.

    A. True
    B. False

3.1.1 BRAZE WELDING

Braze welding (also called bronze welding) is another procedure you can use to join two pieces of metal. It is very similar to fusion welding except you do not melt the base metal and you distribute the filler metal onto the metal surfaces by tinning. Braze welding can produce bonds comparable to those made by fusion welding without the destruction of the base metal characteristics.

Advantages of braze welding over fusion welding:

- Allows the joining of dissimilar metals
- Minimizes heat distortion
- Reduces extensive preheating
- Eliminates stored-up stresses often present in fusion welding (extremely important in repairing large castings)

Disadvantages of braze welding compared to fusion welding:

- Loss of strength when subjected to high temperatures
- Inability to withstand high stresses

3.1.0 EQUIPMENT

The equipment you need for braze welding is essentially identical to the equipment you need for brazing. However, braze welding usually requires more heat than brazing, so you should definitely use an oxyacetylene or oxy-MAPP torch for braze welding.

3.1.1 Filler Metal

Copper and zinc are the primary elements of a braze-welding rod; they provide ductility and high strength. Iron, tin, aluminum, manganese, chromium, lead, nickel, and silicon are also added in small amounts to improve the rod's welding characteristics.

These elements aid in deoxidizing the weld metal, increasing flow action, and decreasing the chances of fuming.

Table 6-4 lists some copper alloy brazing filler metals and their uses. Brass brazing alloy and naval brass are the most commonly used filler rods, but the selection of the proper brazing filler metal always depends on the types of base metals you need to join.

Table 6-4 — Copper Alloy Brazing Filler Metals

	% Cu	% Zn	% Sn	% Fe	% Mn	% Si	% Ni	% P	Use	Melting °F	Flow °F
Brass Brazing Alloy	60	40							Copper, Nickel Alloys, Steel	1650	1660
Naval Brass	60	39.25	.75						Copper, Steel, Nickel Alloys	1630	1650
Tobin Brass	59	40.5	.50						Steel, Cast Iron	1625	
Manganese Bronze	58.5	39.25	1.0	1.0	.25				Steel	1590	1630
Low Fuming Brass	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 28	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	
Phosphorus Bronze	98.2		1.5					.3	Copper Alloys	1922	

Copper-Cu Zinc-Zn Tin-Sn Iron-Fe Manganese-Mn Silicon-Si Nickel-Ni Phosphorous-P

3.1.2 Flux

Proper fluxing is as essential in braze welding as it is in the other processes; if the surface of the metal is not clean, the filler metal will not flow smoothly and evenly over the weld area. Even after you have mechanically cleaned the workpiece, certain oxides often remain and interfere with the flow of the filler metal, so always use the correct flux to eliminate them.

You can apply flux directly to the weld area, or you can apply it by dipping the heated end of the rod into the flux; once the flux sticks to the rod, you can transfer it to the weld area. Some braze welding rod is also available in a prefluxed form; this eliminates the need to add flux during welding.

3.2.1 Braze Welding Procedures

Edge preparation is essential in braze welding. You can bevel the edges of thick parts by grinding, machining, or filing, but it is not necessary to bevel thin parts (1/4-inch or less). You need to make the piece bright and clean on the underside as well as on the top of the joint. If you clean with a file, steel wool, or abrasive paper, it will remove most of the foreign matter such as oils, greases, and oxides, and using the proper flux will complete the process to permit the tinning to bond.

After you prepare the work's edges, use the following steps to braze weld:

- Align parts and hold in position with clamps, tack welds, or both.
- Preheat assembly to reduce expansion and contraction during welding.
  - Preheat method depends on the size of the casting or assembly.
- Adjust flame to slightly oxidizing flame.
- Flux joint.
  - Note: More flux during the tinning process produces stronger welds.
- Apply heat to base metal until it begins to turn red.

- Melt some brazing rod onto surface and allow spreading along entire joint.
  - Note: You may have to add more filler metal to complete the tinning.
  - Note: Temperature control is critical.
    - Base metal too hot — filler metal bubbles or runs around like beads of water on a hot pan.
    - Base metal too cold — filler metal forms little balls that run off the metal.
- Complete tinning entire joint.

See *Figure 6-22* for an example of tinning and welding with the backhand method.

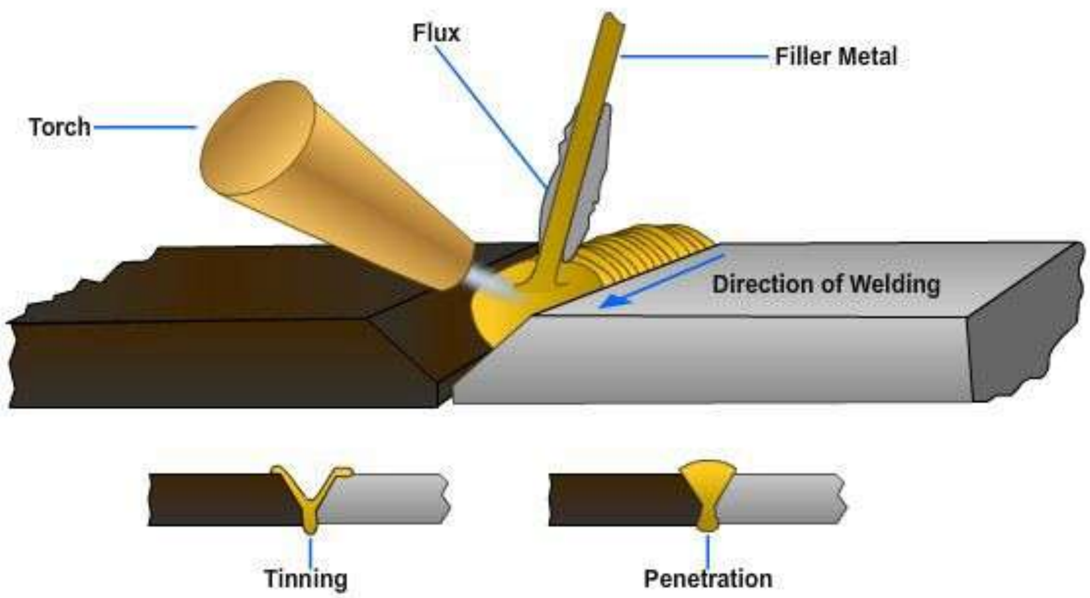

Figure 6-22 — Braze welding cast iron and nickel alloy using the backhand method.

- Begin adding beads of filler metal to fill joint.
  - Use a slight circular motion with the torch and run the beads as in regular fusion welding.
  - Continue adding flux.
  - If the weld requires several passes, ensure each layer fuses with the previous one.
- Upon completion of fill, heat area around joint on both sides for several inches to ensure even rate of cooling.
- When joint is cold, remove any excess flux or other particles with stiff wire brush or steel wool.

Test Your Knowledge (Select the Correct Response)

3. Braze welding is also called ______.

   A. silver brazing
   B. hard soldering
   C. brazing
   D. bronze welding

4.0.0 WEARFACING

Wearfacing (also called hardfacing, hard-surfacing, resurfacing, or surfacing) is the process you use to apply an overlay to the surface of new or old parts to increase their resistance to abrasion, impact, corrosion, and erosion, or to obtain other properties. It can be used also to build up undersized parts.

The goal of wearfacing is to provide an additional means of maintaining sharp cutting edges and reduce wear between metal parts. It is an excellent means for reducing maintenance costs and downtime, thus improving productivity, profitability, efficiency, and longevity of equipment (*Figure 6-23*).

Figure 6-23 — Example of wearfacing (hardfacing) on a loader bucket.

Various types of construction equipment use repair and maintenance hardfacing on their leading or wearing edges, and as a Steelworker and one of the Battalion's metal experts, there will be times when you need to build up and wearface some of that equipment. It could be the cutting edges of scraper or dozer blades, sprocket gears, or shovel and clamshell teeth. You may even get an opportunity to wearface new blades or shovel teeth before they are put into service for the first time.

You can wearface using several different methods (typically it is done by arc welding), but this presentation will cover only the oxygas process of wearfacing. Wearfacing with an oxygas flame is, in many respects, similar to braze welding. The wearfacing metals generally consist of high-carbon filler rods, such as high chromium (Cr) or a chromium-cobalt-tungsten (Cr-Co-W) alloy, but in some instances you may need to use special surfacing alloys. In any of the methods, wearfacing is a process in which a layer of metal of one composition is bonded to the surface of a metal of another composition.

Hardfacing is suitable for all low-carbon alloys and stainless steels as well as Monel and cast iron, although it is not appropriate for aluminum, copper, brass, or bronze, as their lower melting points prohibit using the hard-surfacing process.

You can increase the hardness of aluminum by applying a zinc-aluminum solder to the surface, and you can improve the wear strength of copper, brass, and bronze with an overlay of work-hardening bronze.

You can surface-hardened carbon and alloy tool steels also, but with difficulty due to the frequent development of shrinkage and strain cracks. If you do surface these materials, do so when they are in an annealed condition, not a hardened condition. When necessary, you can heat treat and harden after the surfacing operation, but quench the part in oil, not water.

4.1.0 Wearfacing Materials

Using a copper-base alloy filler metal will produce a relatively soft surface. Work hardening bronzes are soft when applied and give excellent resistance against frictional wear. Other types of alloys produce a corrosion- and wear-resistant surface at high temperatures.

Many different manufacturers produce wearfacing materials, so be sure the filler alloys you select for a particular hardfacing job meet Navy specs.

The Navy uses two general types of hard-surfacing materials: iron-base alloys and tungsten carbide.

4.1.1 Iron-Base Alloys

Iron-base alloys are used for a number of applications requiring varying degrees of hardness. They contain nickel, chromium, manganese, carbon, and other hardening elements. Steelworkers frequently work with iron-base alloys when building up and resurfacing parts of construction equipment.

4.1.2 Tungsten Carbide

Tungsten carbide is one of the hardest substances known to man. You use it to build up wear-resistant surfaces on steel parts. You can apply tungsten carbide in the form of inserts or composite rod. When applied as inserts, they are not melted; instead, they are welded or brazed to the base metal as you saw in *Figure 6-21* with the brazing shims. When you apply it as a rod, you use the same surfacing technique as you use for oxygas welding, but with a slightly carburizing flame.

4.2.1 Wearfacing Procedures

Like all work with metal, proper surface preparation is an important part of wearfacing operations.

- Remove all scale, rust, and foreign matter by grinding, machining, or chipping.
- Round edges of grooves, corners, or recesses to a) prevent base metal from overheating and b) provide a good cushion for wearfacing material.
- Apply wearfacing material so it forms a thin layer over the base metal.
    - Thickness is usually 1/16- to 1/8- inches thick, seldom over ¼-inch thick.
    - Deposit in a single pass.

If wear is extensive, you may need to use a buildup rod before adding the wearfacing material. Check with your leading petty officer if you are in doubt about when to use a buildup rod.

4.2.1 Preheating

Most parts that require wearfacing can be preheated with a neutral welding flame of about 800°F before surfacing. Do not preheat to a temperature higher than the critical temperature of the metal, or to a temperature that can cause scale to form.

4.2.2 Application

In general, for wearfacing you manipulate the torch similar to the technique for brazing but you need higher temperatures (about 2200°F) for wearfacing, so use tips one to two sizes larger than normal and adjust the torch to a carburizing flame.

- Heat small area with sweeping movement until surface of base metal appears sweating or wet.
    - The ability to recognize a sweated surface is essential for surfacing.
- Bring end of surfacing alloy into flame and allow melting.
    - 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.

When you heat steel with a carburizing flame, it turns red first, but as you continue to add heat, the color becomes lighter and lighter until the metal attains a bright whiteness. Sweating occurs when you heat the steel with a carburizing flame to this white heat temperature. It 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, and as a result, it becomes a liquid, while the underlying metal remains a solid. This thin liquid film provides the medium to flow the filler metal over the surface of the base metal. It is similar to, and serves the same purpose as, a tinned surface in soldering and braze welding.

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 your first wearfacing.

If you use an oxygas torch for surfacing with chromium cobalt (Cr-Co), you need to adjust the torch flame to have an excess fuel-gas feather (carburizing flame) about three times as long as the inner cone. If you do not use a carburizing flame, you will not be able to develop the base metal surface properly to a condition that will allow the surfacing alloy to spread over the surface of the part.

Hardfacing, whether applied by oxygas or arc welding, can include a number of configurations depending on the environmental conditions the equipment is expected to work in. *Figure 6-24* shows a few standard patterns along with their intended working environments.

Figure 6-24 — Hardfacing patterns for specific working environments.

For further information about wearfacing construction equipment, from dozers to crusher rollers, and the appropriate pattern to use, from ripper teeth to drive sprockets, refer to Section 2 of NAVFAC *Welding Materials Handbook*, P-433.

Summary

This chapter presented information on four processes for joining metals without fusion: soldering, brazing, braze welding, and wearfacing. Each method has its own unique application depending on the metal and the task. Your responsibility as one of the unit's metal experts will be to know which process will best accomplish the given task, and then be able to apply the process. Take whatever opportunities you can to practice these (as well as other) processes to develop your "hands-on" skills; a well rounded Steelworker/Ironworker is a valued asset in both the military and civilian labor force.

Review Questions (Select the Correct Response)

1. **(True or False)** The soldering, brazing, braze welding, and wearfacing processes allow the joining of dissimilar metals, produce high strength joints, and do not affect heat treatment or warp the original metal as much as conventional fusion welding.

   A. True
   B. False

2. Below what temperature does the soldering process join metals by melting filler metal?

   A. 800°F
   B. 850°F
   C. 900°F
   D. 950°F

3. Which type of soldering coppers (irons) is used for soldering flat seams requiring considerable heat?

   A. Pointed
   B. Stub
   C. Bottom
   D. Top

4. The size designation of soldering coppers refers to the weight of two copper heads in _____.

   A. kilograms
   B. pounds
   C. grams
   D. ounces

5. A pair of coppers has a weight designation of 3 pounds. This designation indicates that each individual copper weighs _____.

   A. 1 1/2 kilograms
   B. 1 1/2 pounds
   C. 10 grams
   D. 16 ounces

6. What type of file should you use to file a soldering copper head during the filing and tinning process?

   A. Rasp
   B. Half round
   C. Single cut
   D. Double cut

7. What should you do to carry out the preliminary steps in filing a cold, but once overheated soldering copper head?

   A. Without clamping it in a vise, heat the copper head, but not hot enough to melt the solder.
   B. Without clamping the copper head in a vise, heat the copper head until it is hot enough to melt the solder.
   C. Clamp the copper in a vise, then heat the copper head until it is cherry red.
   D. Heat the copper until it is cherry red, then clamp the copper in a vise.

8. What technique should you use to manipulate a file?

   A. On each forward stroke, bear down and rock the file, and on each return stroke, let up on the file.
   B. On both forward and return strokes, bear down and rock the file.
   C. On each forward stroke, bear down on the file without rocking it; on each return stroke, let up on the file.
   D. On both strokes, bear down on the file without rocking it.

9. **(True or False)** In the forging process of reshaping a copper, you should ensure a sharp point and a long taper are created.

   A. True
   B. False

10. Most solder alloys consist of ______.

   A. lead and tin
   B. cadmium and aluminum
   C. tin, lead, and zinc
   D. tin, lead, and bismuth

11. Which solder has the lowest melting point?

   A. 30/70
   B. 40/60
   C. 50/50
   D. 60/40

12. What term describes the point in an alloy system when all the elements of the alloy melt at the same temperature?

   A. Constitutional range
   B. Eutectic
   C. Liquidus/solidus
   D. Temperature differential

13. What solder composition is best for joining aluminum alloys?

    A. 50% tin, 45% lead, and 5% antimony
    B. 63% tin and 37% lead
    C. 60% tin and 40% zinc
    D. 86% tin, 12% lead, and 2% zinc

14. Which purpose does flux serve?

    A. To clean the metal during the soldering process
    B. To harden the solder
    C. To soften the metal to be joined
    D. To increase the ductility of solder

15. Which flux is used to solder galvanized iron?

    A. Borax
    B. Rosin
    C. Sal ammoniac
    D. Zinc chloride

16. What is the most commonly used noncorrosive flux?

    A. Rosin
    B. Zinc chloride
    C. Soldering salts
    D. Sal ammoniac

17. Which action should you make a practice when heating solder or surfaces to be soldered?

    A. Heat the surfaces to cherry red.
    B. Heat just enough to melt the solder.
    C. Overheat the solder, then allow it to cool slightly to the working temperature.
    D. Heat the surfaces until scum forms, then skim it off and discard.

18. Heating solder to a temperature higher than its working temperature increases oxidation and changes the proportions of tin and ________.

    A. lead
    B. copper
    C. aluminum
    D. silver

19. What action should you take immediately after finishing the soldering when you use a corrosive flux?

    A. Sprinkle the joint with a powdered noncorrosive flux.
    B. Remove all the traces of flux or as much as possible.
    C. Clean the joint with powdered rosin.
    D. Clean the joint with a solution of sal ammoniac and water.

20. How should you manipulate the copper when soldering seams that are held together by rivets or other fasteners?

    A. Keep it in contact with the work.
    B. Raise it at regular intervals and retrace the work.
    C. Raise it at intermittent intervals.
    D. Hold it slightly above the work as you go.

21. Which action should you take when soldering a bottom seam using solder beads?

    A. Hold the copper in one position until the solder flows freely into the seam.
    B. Draw the copper along the seam.
    C. Turn the work as you go.
    D. All of the above

22. Which action should you take before soldering an aluminum alloy?

    A. Coat the alloy with noncorrosive flux.
    B. Remove the oxide that covers the alloy.
    C. Coat the alloy with a thin layer of tin-lead solder.
    D. Dip the alloy in a solution of turpentine and powdered rosin.

23. A thick layer of oxides is present on the piece of aluminum you are going to solder. Which cleaning method can you use to remove the oxides?

    A. Filing
    B. Sanding
    C. Wire brushing
    D. All of the above

24. Toward what location should you direct the torch flame when soldering aluminum with a torch?

    A. Solder
    B. Flux
    C. Work surface
    D. Metal near the work

25. What type of solder does NOT require the use of flux when you are using it in combination with aluminum solder?

    A. Tin and lead
    B. Tin and zinc
    C. Tin and silver
    D. Tin and antimony

26. What type of solder is recommended for food containers?

    A. 50% tin and 50% lead
    B. 50% tin, 45% antimony, and 2% lead
    C. 96% tin and 4% silver
    D. 95% tin and 5% antimony

27. What process is used to join two base metals together by using a filler metal such as a hard solder?

    A. Braze welding
    B. Bronze welding
    C. Brazing
    D. Soldering

28. What action in brazing distributes the filler metal to the joint?

    A. Oxidation
    B. Fusion
    C. Reduction
    D. Capillary

29. **(True or False)** One of the advantages that brazing or braze welding has over oxygas welding is that you can use it to join dissimilar metals.

    A. True
    B. False

30. Which function is NOT served by the use of flux in brazing operations?

    A. Increasing the flow of brazing filler material
    B. Oxidizing the metal surface
    C. Permitting the molten filler metal to penetrate the pores of the metal
    D. Bringing the brazing filler metal into contact with the metals to be joined

31. What type of application should be used with paste or solution fluxes to ensure a uniform coating on metals to be brazed?

    A. Spray gun
    B. Brush
    C. Cloth
    D. Putty knife

32. What chemical mixture should you use for brazing when a prepared flux is not available?

    A. Tallow and water
    B. Copper sulfate and ammonia
    C. Borax and boric acid
    D. Muriatic acid and water

33. For which reason should you maintain a clearance of 0.001 inch to 0.003 inch when lap joining two base metals with silver-based brazing filler metal?

    A. To improve durability
    B. To produce a finished braze
    C. To extend the bonding area
    D. To increase strength

34. A scarf of 19 1/2° produces a bond area ______ times greater than that of a 90° butt joint.

    A. 2
    B. 3
    C. 4
    D. 5

35. What condition will result if there is any movement of the base metal while you are brazing?

    A. Weakness in the joint
    B. Thickened joint
    C. Over-oxidized surface
    D. Loss of ductility

36. To what temperature do you heat two pieces of base metal before adding the filler metal when brazing or braze welding?

    A. A temperature slightly below the melting temperature of the brazing filler metal
    B. A temperature at the melting point of the brazing filler metal
    C. The temperature at which the flux turns milky
    D. The temperature at which the flux turns clear

37. With what kind of flame from an oxygas torch should you obtain the heat needed to braze or braze weld?

    A. Carburizing
    B. Oxidizing
    C. Neutral
    D. Reducing

38. Which tool should NOT be used to clean base metals mechanically before brazing or braze welding?

    A. Any type of file
    B. A piece of emery cloth
    C. A piece of steel wool
    D. Abrasive paper

39. What is the primary reason you must remove all traces of flux after brazing?

    A. It will corrode the metal.
    B. It will weaken the metal.
    C. It will cause distortion in the pieces brazed.
    D. It will reduce bonding strength.

40. **(True or False)** Braze welding often produces bonds that are comparable to those made by fusion welding without the destruction of the base metal characteristics.

    A. True
    B. False

41. What type of welding has the disadvantages of loss of strength when subjected to high temperatures and an inability to withstand high stresses?

    A. Braze
    B. MIG
    C. TIG
    D. Arc

42. You can braze tubing by using a filler-metal rod or what type of rings?

    A. Brazing alloy
    B. Silver shim
    C. Copper alloy
    D. Silver alloy

43. What is the next step in braze welding after you have cleaned, aligned, clamped, or tack-welded the base metals?

    A. Tinning
    B. Fluxing
    C. Preheating
    D. Applying filler metal

44. **(True or False)** When using a prefluxed braze welding rod, you do NOT have to add flux during welding.

    A. True
    B. False

45. What condition has developed in braze welding if the filler metal forms little balls and runs off the metal?

    A. The joint is not clean enough.
    B. The wrong flux was used.
    C. The metal is too hot.
    D. The metal is too cold.

46. Which is NOT a purpose of wearfacing?

    A. To increase resistance to abrasion
    B. To build up undersized parts
    C. To stop corrosion and erosion
    D. To increase ductility

47. The two types of hard-surfacing materials in general use by the Navy are ______.

    A. iron-base alloys and low-carbon alloys
    B. iron-base alloys and tungsten carbide
    C. stainless steel and copper-base alloys
    D. stainless steel and low-carbon alloys

48. **(True or False)** Before commencing wearfacing procedures, you must remove scale, rust, and foreign matter from the metal surfaces.

    A. True
    B. False

49. With (a) what type of flame and (b) at what temperature do you preheat parts that require wearfacing?

    A. (a) oxidizing (b) 800°
    B. (a) carburizing (b) 700°
    C. (a) neutral (b) 800°
    D. (a) neutral (b) 700°

50. What type of flame do you use in wearfacing to heat the steel to a white heat temperature for sweating?

    A. Oxidizing
    B. Carburizing
    C. Neutral
    D. Normalizing

Trade Terms Introduced in this Chapter

Wetting	Solder wetting pertains to the formation of a relatively uniform, smooth, and unbroken film of solder that exhibits excellent adherence on the soldered surface. Non-wetting is the condition wherein the solder coating contacted the surface but did not adhere completely to it, causing the surface or a part thereof to be exposed. Dewetting is the condition wherein the solder recedes after coating a surface, creating irregular mounds of solder, but leaving behind no exposed areas.
Eutectic	A eutectic system is an alloy system that has a single chemical composition that solidifies at a lower temperature than any other composition. This composition is known as the eutectic composition and the temperature is known as the eutectic temperature.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Giachino and Weeks, Welding Skills, American Technical Publishers Inc., 1985.

Naval Construction Force Welding Materials Handbook, P-433, Naval Facilities Engineering Command, Department of the Navy, Washington D. C., 1991.

Smith, David, Welding Skills and Technology, Gregg Division, McGraw-Hill, 1984.

The Oxy-Acetylene Handbook, 2d ed., Linde Company, Union Carbide Corporation, 270 Park Avenue, New York, 1960.

Welding Theory and Application, TM 9-237, Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1976.

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Chapter 7

Plasma Arc Cutting Operations

Topics

To hear audio, click on the box.

Overview

As a Steelworker, you will be expected to become familiar with the Plasma Arc Cutting (PAC) process. To achieve optimum performance of your plasma cutting system, first you must know what plasma is and understand the basic plasma cutting process.

Plasma is a physical state of matter. In fact, plasma is the most abundant form of matter in the universe. Physical matter may be found in four states: solid, liquid, gas, or plasma. Changes from one physical state to another occur by either adding or removing energy. Plasma looks and behaves like a high temperature gas, but with an important difference: it conducts electricity. Lightning is a naturally occurring example of plasma.

A plasma arc is created by electrically heating a gas to a very high temperature; this ***ionizes*** the atoms, which enables the gas to conduct electricity. This is the major difference between a neutral gas and plasma; the particles in plasma can exert electromagnetic forces on one another.

This chapter will present an introductory explanation of plasma arc cutting. Since the Navy supply system purchases equipment from different manufacturers, always refer to the manufacturer's manuals for specific operating and maintenance instructions.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the Plasma Arc Cutting process.
2. Describe plasma arc equipment and consumables.
3. Identify the plasma cutting and gouging sequence.
4. Describe the steps in arc gouging.
5. Identify the steps of a quality plasma cut.
6. Describe the safety procedures for plasma arc processes.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet-Metal and Fiberglass Duct		
Welding Quality Control		
Flux Cored Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 PLASMA ARC CUTTING PROCESS

Plasma arc cutting is such a simple process you could almost take it out of the box and start using it. However, as with any piece of equipment you need to know how and why it does what it does and the necessary precautions to do the job safely.

1.1.0 Description

Materials in nature exist in one of four different states: solid, liquid, gas, or plasma. Plasma is very rare on Earth because of its very high temperature; however, most of the matter in the universe is plasma. The Sun, stars, and galaxies are made of plasma. On Earth, you will find naturally occurring plasma in lightning and a few other places (*Figure 7-1*). Neon tubes and florescent lights generate low-temperature plasma. It is the energy from ionization that you are actually seeing.

Figure 7-1 — Naturally occurring plasma.

Experiments with plasma arcs date back to early in the twentieth century but it was in the 1950s when PAC torches were patented. The equipment was large and bulky and used a variety of cutting and cooling gases. Today, the introduction of cutting with clean, compressed air or nitrogen is replacing many other types of cutting equipment.

Temperature makes the difference between water ice, liquid water, and water vapor. In each of these states, temperature energy pushes the molecules of water away from each other to change the water's state. At very high temperature and pressure, the water molecules themselves break apart and the atoms begin to ionize.

Normal atoms consist of protons and neutrons in a nucleus surrounded by a cloud of electrons. In plasma, the negatively charged electrons separate from the nucleus leaving behind their positively charged nuclei known as ions. When the fast-moving electrons collide with other electrons and ions, they release vast amounts of energy. This energy is what gives plasma its cutting

Figure 7-2 — Plasma arc.

power. Plasma cutters work by electrically charging a gas within a ***plenum*** (chamber) that surrounds the electrode (*Figure 7-2*). This charge superheats and ionizes the gas, which is now a greatly expanded (in volume and pressure) plasma gas. The electrically charged plasma then exits the torch nozzle through a constricting orifice and arcs to the surface of the grounded workpiece, creating a stream of directed plasma, approximately 30,000° F (16,649° C) moving at approximately 20,000 feet per second (6,096 m/sec), reducing metal to molten slag. The plasma itself conducts electrical current. The cycle of creating the arc is continuous as long as power is supplied to the electrode and the plasma stays in contact with the grounded metal being cut.

The PAC process uses this high temperature, high velocity jet of ***ionized*** gas (exiting from the constricting orifice of the torch tip) to melt a localized area, and removes the molten material by the force of the plasma jet. The force of the arc pushes the molten metal through the workpiece and severs the material (*Figure 7-3*). You can make extremely clean and accurate cuts with PAC, and because of the tightly focused heat energy, there is very little warping, even when cutting thin sheet metal. PAC also offers quality gouging and piercing capabilities.

Figure 7-3 — PAC torch cut-away.

1.2.1 Plasma vs. Oxy-Fuel Cutting

Before the PAC process became commonplace, if you wanted to cut carbon steel, stainless steel, or aluminum, chances were you would be using several means or methods of cutting. Perhaps you would use oxy-fuel gas flame cutting for steel, but that process is not recommended for cutting stainless steel and aluminum due to the formation of an oxide that prevents ***oxidation*** from fully occurring. You could use bandsaws, shears, abrasive cut-off wheels, or power hacksaws, but you would need special blades to cut the stainless steels and alloy steels.

With engineering advances in PAC equipment, all metals that conduct electricity, whether they are common or exotic metals, can be cut economically with one process. Since the plasma arc cutting process is capable of hand-held or machine torch cutting, metals ranging from thin gauge aluminum to 1 1/2-inch carbon or stainless steel can be plasma cut. It can be used in many applications, including stack and shape cutting, beveling, gouging, and piercing in all positions. The PAC process is used in industries such as metal fabrication, construction, maintenance, metal salvage (scrap and recycling), automotive repair, metal art, and sculpting.

The PAC process is compared primarily to the oxy-fuel gas cutting (OFC) process. The OFC process severs or removes metal by the chemical reaction of oxidation. It is known as “burning” or rapid oxidation. This occurs when you apply pure oxygen to hot, preheated metal and maintain the elevated temperature with a flame from a burning oxy-fuel gas mixture. It requires a high purity oxygen and fuel gas, which comprises an explosive fuel gas mixture usually supplied from high-pressure compressed gas cylinders.

A properly installed Air Plasma Arc Cutting setup can be safer than an OFC system. Safety precautions on the PAC torches can be safer than oxy-fuel gas torches where there is a chance of flashback and the danger of flammable gases in exposed hoses (*Figure 7-4*).

OFC's advantage is its capability of cutting very thick carbon steel with relatively inexpensive equipment that does not require electricity. OFC's disadvantage is its recommended limitation to cut carbon steels only.

PAC requires minimum training to operate the equipment safely and efficiently. One of PAC's major advantages is speed. PAC operates at a much higher heat energy level, so it cuts faster than OFC, especially on metal less than 2 inches thick, and cutting speed makes a significant difference in production time and operator comfort. Also, unlike the OFC process, PAC does not require preheating, another major advantage besides the faster cutting speed. Because of this, PAC results in less distortion of the metal being cut. This is due also to a very narrow heat-affected zone (area changed in characteristics near the cut). The clean, ***dross***-free cut produced with the PAC process can eliminate the secondary operations of other cutting methods such as cleaning up rough edges and dross on the bottom or backside of the cut (*Figure 7-5*).

Figure 7-4 — Oxy-fuel cutting setup.

When compared to OFC, PAC in some areas will not be as portable, due to its dependence on primary electrical power from a utility line or engine-driven generator.

Figure 7-5 — Clean cut.

Test Your Knowledge (Select the Correct Response)

1. What happens to an atom when it is exposed to very high temperatures?

    A. It adds a valence shell
    B. It becomes an ion
    C. It disintegrates
    D. It remains stable

2. What characteristic makes plasma different than a gas?

   A. It has a greater atomic weight
   B. It is incandescent
   C. It can conduct electricity
   D. It has a distinct odor

2.0.0 EQUIPMENT and CONSUMABLES

A pilot arc between the electrode and the constricting tip initiates the plasma arc process. The tip is connected to ground through a current-limiting resistor and a pilot arc relay contact in the torch assembly. One of two methods, either a high frequency generator connected to the electrode and tip or an internal contact start, initiates the pilot arc. The welding power supply then maintains a low current arc inside the torch.

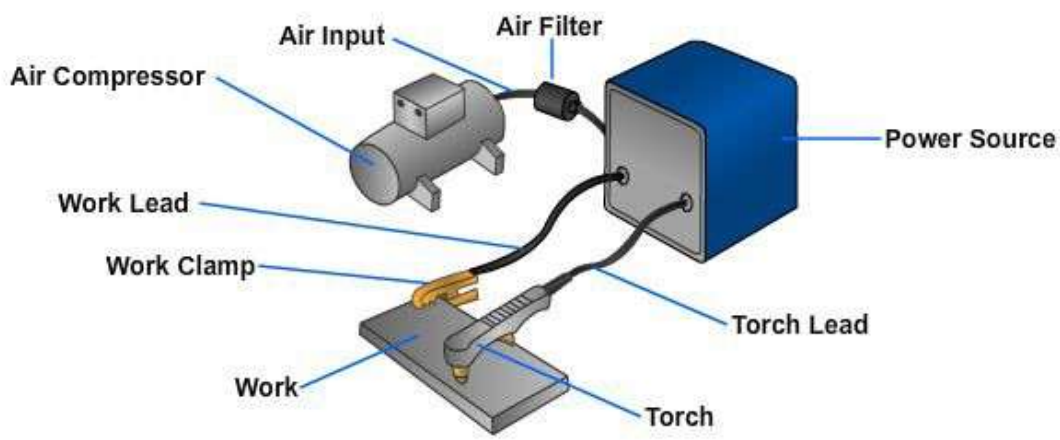

Figure 7-6 — Basic PAC setup.

Ionized orifice gas from the pilot arc is blown through the constricting tip orifice by a compressed gas. This forms a low resistance path to ignite the main arc between the electrode and the workpiece (*Figure 7-6*). When the main arc ignites, the pilot arc relay may be opened automatically to avoid unnecessary heating of the constricting tip, which helps extend the life of the tip and electrode.

2.1.1 Equipment Requirements

A typical air-cooled PAC system consists of the following components:

- Power source
- Either a hand-held or a machine-style torch
- Supply of compressed air or nitrogen

2.1.1 Power Source

Plasma arc cutting uses a direct current power source. The polarity setting for the power source is direct current electrode negative (DCEN). In most systems there is also a positive connection to the torch tip in which the current is limited by a resistor. This circuit establishes a "pilot arc," which then establishes the cutting arc.

The power source is a constant current power source with a high open circuit voltage (250-400 volts). The amperage is usually adjustable within the range of the power source, and amperage is directly proportional to the thickness and speed in which the metal can be cut.

Most manual PAC systems now use switch-mode or inverter technology. These sophisticated, electronically-controlled or microprocessor-controlled devices are better able to tolerate variations in line voltage, take more abuse in the field, and deliver better cutting performance while consuming less power with a longer duty cycle.

The term “duty cycle” identifies the number of minutes out of a 10-minute period that you can operate a plasma cutter at its rated capacity. For example, a 300-amp welder with a 60% duty could operate at 300 amps for 6 minutes and then needs to cool with its fan running for 4 minutes. Manufacturers rate their products based on ambient air temperature, so if a cutter is rated at 104º F and the ambient temperature where you are working is 84º F, the duty cycle of the machine increases. Conversely, if the ambient temperature is hotter than the manufacturer’s initial rating, the duty cycle decreases. You need to know what ambient temperature the manufacturer used to rate its PAC in order to operate the equipment at the appropriate duty cycle and prevent damage.

2.1.2 Rated Cutting Capacity

Selection of the PAC is based on the type and thickness of the metal to be cut and the speed at which the metal needs to be cut. The higher the PAC ampere and duty cycle rating, the thicker and faster it will cut *(Figure 7-7)*. While there is no standard for PAC cutting speeds in the welding/cutting industry, some manufacturing companies qualify their PAC rated cutting capacity by three (3) standards (*Figure 7-8*):

Figure 7-7 — Cutting capacity rating

Figure 7-8 — Rated cutting capacity.

- "Rated Cutting Capacity," at ten (10) inches per minute travel speed, is considered the minimum speed at which an operator achieves a smooth, steady cut using a hand-held torch at the machine's Rated Output.

- "Maximum Quality Cutting Capacity" is a good quality cut that is achieved at slower than ten (10) inches per minute travel speed.

- "Sever Cut Capacity" is the maximum metal thickness cut achieved in ideal conditions. Sever Cut does not include allowances for rating quality of cut or travel speed.

2.1.3 Cutting Speed

As indicated previously, the cutting speed will affect the thickness of the material that can be cut. The slower you move the torch, the thicker the material that can be cut, but if you move the torch too slow the plasma arc will remove all of the material directly underneath it and the arc will bend to the side of the ***kerf***, causing a jagged cut. The faster the travel speeds, the thinner the material that can be cut, but if you increase the torch speed too much, the torch will be unable to cut completely through the workpiece. Cutting speed is measured in inches per minute. Maximum cutting speed is determined by the arc current, nozzle diameter, and metal thickness.

2.2.0 Consumables

The plasma torch is designed to generate and focus the plasma cutting arc (*Figure 7-9*).

Figure 7-10 — Swirl ring.

Figure 7-9 — PAC torch assembly.

In either hand held or machine torches, the same parts are used: an electrode to carry the current from the power source, a swirl ring to spin the compressed air, a tip that constricts and focuses the cutting arc, and a shield and retaining ring to protect the torch.

2.2.1 Swirl Ring

The swirl ring, made of a high temperature plastic, is designed with angled holes to spin the cutting gas in a vortex (*Figure 7-10*). Spinning the gas centers the arc on the electrode and helps control and constrict the arc as it passes through the tip. Some plasma cutting equipment swirls the gas in a clockwise direction, others in a counter-

Figure 7-10 — Swirl ring.

clockwise direction. Check the manufacturer's manual; the direction of flow will indicate which side of the cut will be beveled.

2.2.2 Electrode

Figure 7-11 — Electrode.

The purpose of the electrode is to provide a path for the electricity from the power source and generate the cutting arc (*Figure7-11*). The electrode is typically made of copper with an insert made of ***hafnium***. The hafnium-alloyed electrodes have good wear life when you use clean, dry compressed air or nitrogen, although electrode consumption may be greater with air plasma than with nitrogen.

2.2.3 Tip

Figure 7-12 — Tip.

The purpose of the torch tip is to constrict and focus the plasma arc (*Figure 7-12*). Constricting the arc increases the energy density and velocity. The tips are made of copper, with a specifically sized hole or orifice in the center of the tip. Tips are sized according to the amperage rating of their respective torch.

2.2.4 Retaining Cup

Figure 7-13 — Retaining cup.

The retaining cup serves two functions (*Figure 7-13*). First, it holds the other consumable parts firmly in place. Second, it insulates and keeps the other consumable parts from making contact with the work piece.

2.2.5 Shields

There are two types of shields used on plasma torches: a drag shield (*Figure 7-14*) and a deflector (*Figure 7-15*). The drag shield insulates the front end of the torch from the work piece and protects the torch tip from spatter.

The deflector insulates the electrode and protects it from spatter. It is used when extended cutting consumables are needed.

Figure 7-14 — Drag shield.

Figure 7-15 — Deflector shield.

2.2.6 onsumables Used During Extended Cutting vs. Drag Cutting

The use of extended cutting consumables requires the operator to maintain a torch standoff of about 1/8". “Torch stand-off” is the distance from the outer face of the torch tip or constricting orifice nozzle to the base metal surface (*Figure 7-16*). Extended cutting is used in situations where the operator needs extra control of the cutting arc, such as when cutting in a corner or when a machine torch is used.

The drag shield is constructed so that the required standoff is maintained inside the torch. Using drag cutting consumables allows the operator to drag the torch on the work piece while cutting at full output, which increases operator comfort and makes template cutting easier.

Figure 7-16 — Extended vs. drag.

2.2.7 Consumable Tips for Different Amperages

Tip size is directly proportionate to amperage; the higher the amperage, the larger the tip you would use. As you can see in *Figure 7-17,* the 40-amp tip opening is smaller than the 80-amp tip. Exercise caution and be sure to use the correct tip for the amperage. If you use an 80-amp tip for a 40-amp machine, the plasma arc will not constrict enough and will cut an uneven wide kerf. If you use a 40-amp tip on an 80-amp machine, internal arcing will damage the tip and electrode, decreasing their service life.

Figure 7-17 — Consumables chart.

2.2.8 Replacing Consumables

Good preventive maintenance (PM) requires keeping a supply of electrodes, tips, and shield cups on hand and replacing them as wear appears. You should inspect the shield cup, tip and electrode before each use, hourly during operation, or whenever the cutting speed has reduced significantly. Do not operate the PAC torch without a tip or an electrode in place. A tip and electrode that are worn beyond the manufacturer's recommended values, or operating a torch without the tip or electrode in place can damage the torch. Refer to *Figure 7-18* for a comparison of new and worn consumables. *Figure 7-19* shows what to look for in the inspection process.

Figure 7-18 — New and worn consumables.

Figure 7-19 — Consumable inspection process.

2.2.9 Cutting Gases

Plasma arc cutting gases must have high ionization potential (energy), high thermal conductivity to deliver high heat energy to the work piece, and high atomic weight to produce the energy to blow or push out metal from the cut. Compressed air (approximately 80% nitrogen) with its high ionization potential and density is commonly used to minimize gas costs. Compressed air may require installation of filters or line dryers to remove oil vapors and moisture. Clean, dry, compressed air may be purchased in cylinders. As a plasma gas, nitrogen is considered to be the gas that creates the least slag or dross.

The gas pressure and flow rates must be properly set to the equipment manufacturer's recommendation. The gas supply piping and hoses to the cutting unit must be of sufficient size to carry the pressure and gas volume required. Use a minimum 3/8" ID (inside diameter) piping or nonconductive hoses to provide the necessary pressure and volume of gas to the PAC power source. If the piping or hose is more than 40 feet in length, use a minimum 1/2" ID (*Figure 7-20*).

Figure 7-20 — Cutting gasses.

2.3.0 Improving Consumable life

1. Maintain proper gas pressure setting.

Setting the correct amount of gas pressure is very important to consumable life. If the pressure setting is too high, electrode life will be shortened. If the pressure setting is too low, the tip life will be shortened.

2. Maintain the correct stand off.

If extended cutting consumables are being used, make sure to maintain the recommended amount of standoff. Too little standoff may damage the torch and consumables. Too much standoff will result in inconsistent arc starts.

3. Pierce within the limits of the plasma system.

Do not try to pierce metals that are too thick for the plasma cutter. The typical rating is to pierce up to half the rated cutting thickness of the plasma cutter. For example, if the plasma cutter is rated to cut 1" steel, it could pierce 1/2" steel.

4. Make sure the gas used is clean and dry.

Plasma cutting systems require clean, dry gas to operate properly. Moisture in the gas line is the cause of many system problems. It can cause shortened consumable life and premature torch failure. To check for moisture in the gas line, set the system to the gas/air set position and hold a mirror under the tip (*Figure 7-21*). If any moisture appears on the mirror, inspect the system for the source of the moisture or install an air dryer in the system.

Figure 7-21 — Checking for moisture.

5. Use edge starts.

Use edge starts whenever possible instead of pierce starts. Edge starts improve consumable life since there is less chance for molten metal to be blown back into the tip.

6. Use the tip saver setting.

Whenever possible, use the tip saver position for the pilot arc. More pilot arc time than is necessary will lead to shorter consumable life. Use the expanded metal setting only when absolutely necessary.

7. Remove buildup from shields.

Inspect the shields on the end of the torch frequently and remove any slag from the shield. Slag can cause double arcing, which shortens tip life.

8. Purge gas after changing consumables.

Purge gas lines for 2–3 minutes after changing consumables or extended periods of little or no use. This will ensure that any moisture built up in the lines is removed.

9. Keep torch and consumables clean.

Any type of contamination in the torch or consumables can affect the performance of the cutting system. When you change consumables, always try to keep the new parts on a clean rag.

Test your Knowledge (Select the Correct Response)

3. How many minutes make up a duty cycle?

    A. 5
    B. 10
    C. 15
    D. 20

4. What is hafnium used for?

    A. Shield material
    B. Grounding clamp
    C. Electrode tip
    D. Insulator

3.0.0 CUTTING and GOUGING OPERATING SEQUENCE

The first step in operating a PAC system is to perform a system check. Make sure that the torch is assembled properly. Turn the power source and air supply on. Next, check the status lights on the power source.

The status lights advise the operator if the system is ready to cut or if there is a problem that will keep the unit from operating properly. There may be two to four status lights depending on the model of the power source (*Figure 7-22*).

Typically, the top light is labeled “power.” When this light is on, it indicates the power source is on. If the power light is the only light on, that indicates that the system is ready to cut. If an additional light is on, that is the indication of a problem in the system.

Figure 7-22 — Control panel.

Three parts of the system are monitored and when not functioning properly cause the additional status light to turn on and keep the system from cutting. These parts are the torch assembly, the air pressure setting, and the internal temperature of the power supply.

Should an additional status light come on, check to make sure the torch is properly assembled, the air pressure is set to the recommended setting, and it has had a chance to cool if the power source has been cutting continuously for more than the rated duty cycle time period. Once these problems have been fixed, the status light will turn off and the system will be ready to cut.

After verifying that the status lights indicate that the system is ready to cut, purge the gas lines for a minute to get rid of any moisture that may have formed inside the lines.

When the trigger has energized the circuit, a preflow of gas will flow through the torch for a few seconds. This is done to ensure that the right amount of gas flow is available before an arc is created. The cutting arc is created by one of two different starting methods: high frequency starts or contact starts.

3.1.0 High Frequency Starts

The tried-and-true method is a high-frequency (HF) starting circuit built into the power supply. This system uses a high-voltage transformer (similar to a bug zapper), capacitors, and a spark-gap assembly to generate a high-voltage spark at the torch (*Figure 7-23)*.

The spark ionizes the plasma gas, enabling current to flow across the air gap

Figure 7-23 — HF starting circuit.

between the nozzle and electrode. The resulting arc is called the pilot arc. High-frequency starting systems are simple, relatively dependable, and require no moving parts in the torch. However, they do need periodic maintenance to prevent hard-starting problems. Another potential problem is the high frequency that radiates from the system, creating electrical noise that may interfere with sensitive electronic equipment.

3.2.0 Contact Starts

A contact start torch uses a moving electrode or nozzle to create the initial spark that enables the pilot arc (*Figure 7-24)*. When the torch is fired, the electrode and nozzle are in contact in a dead short, or short circuit. When the operator depresses the trigger, gas enters the plasma chamber; it blows the electrode back (or the nozzle forward) creating a spark. This process is similar to the spark created when an electrical plug is pulled quickly from a receptacle.

After the initial arc is created, the gas flow pushes the arc through the orifice and reestablishes it on the outside of the tip. This forms a J-shaped arc called the pilot arc. The pilot arc forms a path to the metal surface to be cut. When the torch is close enough to the metal, the arc will transfer from a pilot arc between the electrode and the tip to a cutting arc between the electrode and the workpiece.

Contact start torches produce much less electrical noise than HF systems, and they are instant-on torches, which reduces cycle time because of the lack of preflow.

3.3.0 Pilot Arc Control Methods

On some power sources the pilot arc remains on even after the cutting arc is established. An advantage to this is that if the operator is cutting over a piece of expanded metal, for example, the cutting arc is maintained as the arc moves from one piece of metal to the other. One disadvantage of leaving the pilot arc on at all times during the cutting process is that it can lead to faster consumable wear. To help address these issues, some power sources have ways of controlling the pilot arc so that it is on when needed and can be shut off when not needed.

In some cases the power source has a switch that gives the operator a choice of settings for the pilot arc. The operator can select the expanded metal position for a continuous pilot arc or the tip saver position where the pilot arc shuts off after the cutting arc is established.

Figure 7-24 — Contact start.

Other power sources are equipped with a circuit that automatically controls the pilot arc. The pilot arc will switch in and out as fast as needed when cutting expanded metal or multiple pieces of metal. When cutting on a solid piece of metal, the pilot arc will drop out after the cutting arc has been established.

3.4.0 Starting the Cut

With a hand-held torch there are two methods for starting the cut: edge starts and pierce starts. To use an edge start, place the torch directly over the edge of the work piece (*Figure 7-25*). With the tip centered on the edge of the metal, start the arc and begin moving the torch along the cut line (*Figure 7-26*).

Figure 7-25 — Starting an edge cut.

Figure 7-26 — Edge cut process.

Pierce cuts are a little more difficult. The torch will need to be angled slightly over the starting point (*Figure 7-27*).This will prevent the molten metal from the beginning of the cut from being blown back into the tip and electrode. Once the cutting arc has pierced through the metal, move the torch to a vertical position and continue along the cut line. The thicker the metal, the longer it will take the cutting arc to pierce through the metal. The process of piercing a hole in the metal will cause a blow hole that is wider than the normal kerf, so the initial pierce should be done in the scrap portion of the part not on the cut line (*Figure 7-28*).

Figure 7-27 — Pierce cut.

Figure 7-28 — Pierce cut process.

4.0.0 PLASMA ARC GOUGING

Plasma Arc Gouging is a variation or an adaptation of the PAC process. Gouging utilizes a different torch tip that produces a reduction in the arc constriction, which results in a lower arc stream velocity. Note the larger diameter orifice of the gouging tip (*Figure 7-29*). This larger diameter orifice provides the reduction in arc constriction, which results in a lower arc stream velocity. It gives a softer, wider arc and proper stream velocity. Gouging may be used for edge preparation (J or U-grooves), removal of welds, or discontinuities in welds, and it may be used in all positions.

Figure 7-29 — Gouging tips.

When comparing PAC with Air Carbon Arc Gouging (CAC-A), one major difference is that with PAC, the gouge surface is bright and clean. This is particularly true with the aluminum alloys and stainless steels. There is virtually no cleanup required because the gouges are clean and absent of carbon contamination, as is the case when using the CAC-A process. Because of this, CAC-A is not recommended as a weld preparation for stainless steel and aluminum without subsequent and sufficient cleaning.

The technique for plasma arc gouging requires the torch be angled 30° to 45° from the base metal surface. This torch angle and the speed of travel will determine the gouging depth. It is important that not too much material be removed in a single pass. It is better to remove by gouging to the required depth and width by using multiple passes (*Figure 7-30*).

Figure 7-30 — Gouging process.

5.0.0 QUALITIES of a PLASMA CUT

Good quality cuts result in less time and effort being spent on cleaning up the part before it goes to the next step in the manufacturing process. If the part is to be welded, a clean cut is important in order to produce a good weld. It takes several terms to define a quality cut (*Figures 7-31and 7-32*).

Figure 7-31 — Elements of a quality cut.

Figure 7-32 — Direction of cut.

5.1.0 Kerf

The kerf is the width of the cut, or the amount of metal removed by the cutting process. All cutting processes produce a kerf. You must account for the kerf when cutting to specific dimensions or determining the number of parts that can be cut from a piece. Factors that affect the size of the kerf include cutting speed, amperage setting, amount of standoff, and the size of the orifice in the tip.

5.2.0 Bevel Angle

As the plasma gas cuts through the metal, it has a swirling motion. As a result of this motion the arc has more energy on one side of the cut than the other. This leads to a cut that is straight on one side and has a bevel angle (typically four to six degrees) on the other side.

The direction of travel and the swirl of the gas determine which side will be straight and which side will be beveled. On a torch with a clockwise swirl (this includes all Miller torches) the straight side of the cut will be the right side of the cut in the direction of travel. Being aware of this characteristic of plasma cutting will ensure that the part being produced has straight edges while the scrap piece has the beveled edge.

5.3.0 Drag Line

Drag lines are ripples along the surface of the cut. The travel speed and amperage setting will have the most effect on the appearance of the drag lines.

5.4.0 Top Rounding

Top edge rounding is a slight rounding over of the metal at the top of the cut. It is caused by the fact that the arc is hotter at the top of the cut than at the bottom. There is usually some top edge rounding in any plasma cut part. It is most affected by material thickness and is more apparent on thicker metals.

5.5.0 Dross

Dross is re-solidified oxidized molten metal that is not fully ejected from the kerf during cutting. It is the most common cut quality problem of plasma cutting. Dross may form as a thick bubbly accumulation along the bottom edge of the plate, a small, hard bead of uncut material (high-speed dross), or a light coating along the top surface of the plate (top spatter).

Dross is affected by the material's variables, such as thickness and type, grade, chemical composition, surface condition, flatness, and even temperature changes as the material is cut. However, the three most critical variables to consider in dross formation are cutting speed, amperage, and standoff distance.

If the cutting speed is too slow, the plasma jet begins to look for more material to cut. The arc column grows in diameter, widening the kerf to a point where the high velocity portion of the plasma jet no longer ejects the molten material from the cut. As a result, this molten material begins to accumulate along the bottom edge of the plate in a thick globular form. This is called low-speed dross. At extremely low speeds the arc extinguishes because there is not enough metal to sustain a transferred arc. Increasing the amperage or decreasing the standoff (while keeping material thickness and speed constant) have a similar effect on the cut as slowing down the cut speed. Both of these changes cause more energy from the plasma jet to contact a given area of the material in a given period of time. Excessive amperage or low standoff can also cause low-speed dross. Some low speed dross in the corners of a plasma cut is normal since velocity does not remain constant through a sharp turn.

To prevent low-speed dross form forming, increase the cut speed in 5 ipm increments, increase the standoff in 1/16-inch increments or 5 volt increments, or decrease the amperage in 10 amp increments. If none of these measures improves the cut, consider a smaller nozzle size.

If the cutting speed is too fast, the arc begins to lag back in the kerf, leaving a small, hard bead of uncut material or rollover dross along the bottom of the plate. This high-speed dross is more tenacious and usually requires extensive machining to remove. At extremely high speeds, the arc becomes unstable and begins oscillating up and down in the kerf, causing a rooster tail of sparks and molten material. At these speeds, the arc may fail to penetrate the metal or may extinguish. High standoff or low amperage (for a given material thickness and cutting speed) can also cause high-speed dross since both of these changes cause a reduction in the energy of the plasma jet.

To prevent high speed dross, first check the nozzle for signs of wear (gouging, oversize or elliptical orifice), decrease the cutting speed in 5 ipm increments, decrease the standoff in 1/16-inch increments or 5 volts increments, or increase the amperage (do not exceed 95% of the nozzle orifice rating).

Top spatter is an accumulation of re-solidified metal that sprays along the top of the cut piece. It is usually very easy to remove. The usual cause is a worn nozzle, excessive cutting speed, a high standoff, or the swirling flow of the plasma jet, which at a certain angle of attack flings molten material out in front of the kerf rather than down through it.

To eliminate top spatter, check the nozzle for signs of wear, decrease the cutting speed in 5 ipm increments, or decrease the standoff in 1/16-inch increments or 5 volt increments.

Test your Knowledge (Select the Correct Response)

5. What is dross?

   A. Excess plasma formation
   B. Resolidified molten metal
   C. Angle on the top of a cut
   D. Preferred shielding material

6. What is the most likely reason the plasma torch would not cut through the work piece?

   A. Incorrect angle
   B. Wrong shielding gas
   C. Rapid torch speed
   D. Inexperienced technician

5.6.0 Six Steps to Good Cut Quality

1. Use quality consumable parts.

You will not get quality cuts without quality parts. Use the parts recommended by the manufacturer. These parts are made to the exact tolerances required to ensure quality cuts. To further ensure quality cuts, always start with a new set of consumables.

2. Assemble the torch properly.

Assemble the torch carefully, making sure the parts are properly aligned and fit together snugly. This will ensure good electrical contact and cutting performance. Keep parts in their storage containers until needed in order to prevent contamination from dirt and dust.

3. Set the amperage no higher than necessary.

The amperage should be set based on the metal thickness being cut. Using more amperage than needed will shorten consumable life.

4. Square the torch with the part to be cut.

If the torch is not aligned perpendicular with the part, the cut may form a beveled edge instead of a straight edge. Check the squareness of the torch visually before starting to cut.

5. Verify the direction of travel.

Depending on the manufacturer and the direction of the air flow, the square side of the cut may be the right-hand side in the direction of travel. Perform a test cut to verify the location of the square edge.

6. Adjust the travel speed.

During the test cut, determine the travel speed that will provide either a dross-free or minimal-dross cut. Increasing travel speed will also insure that you do not have a negative bevel angle.

6.1.1 SAFETY PROCEDURES

As it is with any cutting or welding process, safety is the prime consideration. The equipment owner's manuals will provide safety recommendations that must be followed.

The plasma arc emits intense visible and invisible radiation (ultraviolet and infrared). Operators need to be fully clothed with dark leather or woolen clothing. Ultraviolet radiation can cause rapid disintegration of cotton-based clothing.

Dark clothing reduces reflection, particularly underneath the welding helmet where reflected ultraviolet burns can occur to the face and neck.

To provide adequate protection for the eyes, use filter lenses conforming to ANSI Z49.1 (*Table 7-1*).

Table 7-1 Suggested filter glass shades for plasma.

Arc Current in Amps	Lowest Shade Number	Recommended Shade Number
Under 40	5	5
40-60	6	6
60-80	8	8
80-300	8	9
300-400	9	12
400-800	10	14

When cutting thicker materials, it may be necessary to wear ear protection.

Also, water tables are sometimes used beneath cutting tables. If a water table is used, strict guidelines must be followed to avoid such problems as hydrogen gas buildup beneath the plate being cut. This is especially the case when cutting aluminum and also when argon/hydrogen mixtures are used as the cutting gas.

The PAC process produces fumes and gases that can harm your health. The composition and rate of generation of fumes and gases depend on many factors including arc current, cutting speed, material being cut, and gases used. The fume and gas by-products will usually consist of the oxides of the metal being cut, ozone, oxides of nitrogen, and phosgene gas.

Adequate ventilation is required during the plasma arc cutting process due to the brightness of the plasma arc, which causes air to break down into ozone. These fumes must be removed from the work area or eliminated at the source by an appropriate exhaust system.

Take the proper precautions to avoid being burned by hot molten material; sparks can travel in excess of 35 feet during the cutting process. Do not wear any clothing with cuffs or uncovered pockets, and always wear the proper insulated gloves.

Handle compressed gas cylinders carefully. Secure them when stored or in use; knocks, falls, or rough handling can damage cylinders and valves, causing leakage and potential accidents.

Use the following guidance when setting up and using cylinders of gas:

1. Properly secure the cylinder.
2. Before connecting a regulator, purge the valve of dust and debris.
3. When you attach a regulator to a cylinder, be sure it is in a fully closed condition. Once you have opened the cylinder valve slowly, adjust the screw on the regulator slowly until you obtain the correct pressure.
4. When the cylinder is not in use, close the valve and the regulator.

Operators and maintenance people should keep in mind that PAC equipment operates with a higher output voltage than typical welding equipment. Always follow recommended safety procedures as outlined by the equipment manufacturer. Read Material Safety Data Sheets (MSDSs) for metals, consumables, and coatings.

Further information on safety can be found in the American Welding Society publications “Safety in Welding and Cutting, ANSI ASC Z49.1.”

Summary

This chapter introduced you to the basics of plasma arc cutting, a very easy method of cutting all conductive metals, which requires very little training to use. It discussed the formation of plasma and its properties, explained the equipment used for plasma arc cutting, and gave some proper cutting techniques.

It also presented some advantages and disadvantages of plasma arc cutting over other cutting methods. The main theme of the chapter was to select the right size PAC for the job at hand based on the type and thickness of the metal to be cut, while keeping a constant eye on the torch consumables to ensure proper production efficiency is maintained. Finally, it cannot be overemphasized to follow all of the manufacturer’s recommended operating and safety procedures.

Review Questions (Select the Correct Response)

1. What is the most common form of matter in the universe?

   A. Solid
   B. Liquid
   C. Gas
   D. Plasma

2. What action is visible during an electrical arc?

   A. Ionization
   B. Fusion
   C. Fission
   D. Transpiration

3. What is responsible for the difference between the different states of the same matter?

   A. Atomic weight
   B. Chemical composition
   C. Number of protons
   D. Temperature

4. What causes atoms to break apart?

   A. Intense light
   B. Chemical reaction
   C. Weak valence shells
   D. Extremely high pressure and temperature

5. What causes the release of vast amounts of energy between electrons and ions?

   A. Their collisions
   B. Their velocity
   C. Their atomic structure
   D. The reaction of their protons

6. How is plasma produced in a plasma cutting torch?

   A. High pressure gas
   B. Extreme heat
   C. Shielding gas
   D. Chemical reaction

7. What must be created between the torch and workpiece to maintain cutting?

   A. Contact
   B. Air pressure
   C. Electrical pathway
   D. Heat transfer

8. What attribute makes plasma different from steam?

   A. Conductivity
   B. Directionality
   C. Pressure
   D. Atomic structure

9. What controls the radius of the plasma arc?

   A. Voltage
   B. Speed
   C. Tip constriction
   D. Type of electrode

10. What removes molten metal from the cut area?

   A. Shielding gas
   B. Plasma jet
   C. Gravity
   D. Skilled technician

11. What is the main reason PAC is used on aluminum?

   A. It uses less energy than oxy-fuel
   B. It causes little to no oxidation
   C. It is easier to use
   D. It results in minimal warping

12. For a plasma cutter to function on metal, what physical condition must?

   A. It must be grounded
   B. It must conduct electricity
   C. It must be fully submerged in water
   D. It must be preheated

13. What is a disadvantage of plasma cutting?

   A. Its speed
   B. Overall weight of the system
   C. Necessity of having a source of electricity
   D. Its highly flammable nature

14. Why does plasma cutting cause less workpiece distortion than oxy-fuel?

    A. No preheating is required
    B. A smaller torch is used
    C. A smaller standoff is used
    D. Plasma is not as hot as oxy-fuel

15. In the transferred arc mode where is the arc struck?

    A. Between the tip and the nozzle
    B. Between the electrode and the shield
    C. Between the electrode and the workpiece
    D. Between the tip and the workpiece

16. How do you avoid unnecessary heating of the constricting tip during cutting operations?

    A. Open the pilot arc relay
    B. Increase the output gas pressure
    C. Decrease the output current
    D. All of the above

17. What type of kerf is produced by a plasma torch?

    A. Heavy dross
    B. Double bevel
    C. Bevel and straight
    D. Double straight

18. What component does an inverter power supply use to adjust the frequency of incoming AC?

    A. Transformer
    B. Capacitor
    C. Diode
    D. Microprocessor

19. How many minutes can an 80-amp plasma arc cutter operate continuously with a duty cycle of 70%?

    A. 3
    B. 7
    C. 30
    D. 70

20. What does a rating of 104º F refer to in regard to a PAC?

    A. Ambient temperature
    B. Maximum operating temperature
    C. Preheat temperature
    D. Plasma temperature

21. How is PAC cutting speed measured?

A. Feet per second
B. Inches per second
C. Feet per minute
D. Inches per minute

22. What is the purpose of a swirl ring in a PAC torch?

A. Conduct electricity
B. Focus the plasma arc
C. Spin the compressed air
D. Control the temperature

23. What are the two most common torch systems to initiate the plasma pilot arc?

A. FM and contact
B. HF and contact
C. HF and automatic
D. CW and automatic

24. What enables current to flow across the air gap between the tip and electrode?

A. Spark
B. Gas pressure
C. Heat transfer
D. Contact with the workpiece

25. What type of torch is also known as an instant-on torch?

A. Solid state
B. Contact start
C. High frequency
D. Hafnium

26. What torch component is made of high temperature plastic?

A. Tip
B. Electrode
C. Swirl ring
D. Retaining cup

27. What type of shield is used for extended cutting applications?

A. Drag
B. Deflector
C. Directional
D. Dimensional

28. What is the recommended torch standoff of an extended tip, in inches?

A.1
B. ½
C. ¼
D. 1/8

29. The tip size of the torch is directly proportional to what PAC characteristic?

A. Voltage
B. Amperage
C. Speed rating
D. Material composition

30. What is the recommended pierce starting position of the PAC torch in relation to the workpiece?

A. Perpendicular to the workpiece
B. Parallel to the workpiece
C. Slightly angled away from you
D. Slightly angled toward you

31. What is the PAC current selection based on?

A. Ambient temperature
B. Type of electrode
C. Thickness of the workpiece
D. PAC manufacturer

32. The PAC should be inspected at the beginning of what?

A. Project
B. Workday
C. Workweek
D. Month

33. The condition of torch consumables is directly related to what torch characteristic?

A. Cutting speed
B. Production efficiency
C. Output amperage
D. Duty cycle

34. What does a kerf refer to on the workpiece?

A. Molten material left on the bottom of the workpiece
B. Amount of material removed by the cutting process
C. Direction of travel of the gas swirl
D. Bevel angle on the edge of the cut

35. What are drag lines on the surface of the cut?

A. Ripples along the surface of the cut
B. Scratches left by the torch tip
C. Gouges left by the grounding strap
D. Measurement marks

36. What causes top edge rounding on a cut edge?

A. Torch is too close to the workpiece
B. Torch is too far away from the workpiece
C. The arc is hotter at the top of the cut
D. The arc is cooler at the top of the cut

37. How often should an electrode be replaced?

A. Once a day
B. Once every ten hours of operation
C. After significant wearing appears
D. After every job

38. Which gas is considered to produce the least dross?

A. Compressed air
B. Hydrogen
C. Argon
D. Nitrogen

39. What is the effect of oxidation on a workpiece?

A. Increases melting temperature
B. Causes the metal to warp
C. Increases welding quality
D. Causes a crystalline deposit

40. How do you determine the maximum cutting speed of a PAC torch?

A. Arc current, nozzle diameter, and metal thickness
B. Arc current, electrode material, and type of metal
C. Gas pressure, nozzle diameter, and metal thickness
D. Gas pressure, electrode material, and type of metal

41. Why is very little workpiece preparation necessary after plasma cutting?

A. Preciseness of the arc
B. The lack of chemical reactions
C. The low temperature used
D. Potential harm to material

42. What causes a bevel angle on one side of a workpiece?

A. Amperage and angle of the torch
B. Direction of swirl of the plasma gas
C. Size and standoff of the torch
D. Standoff and amperage of the torch

43. How do you correct a negative bevel angle?

A. Decrease the torch speed
B. Increase the torch speed
C. Decrease the torch angle
D. Increase the torch angle

44. What occurs to the workpiece when the cutting speed is too slow?

A. Kerf gets sharper edge
B. Less dross is formed
C. Kerf gets wider
D. Oxidation increases

45. What has the greatest effect on the appearance of drag lines?

A. Amperage and angle of the torch
B. Height and speed of the torch
C. Speed and amperage of the torch
D. Standoff and amperage of the torch

46. What ANSI standards should be followed when selecting the proper filter glass shade numbers?

A. Z49.1
B. Z59.1
C. Z69.1
D. Z79.1

Trade Terms Introduced in this Chapter

Dross	The oxidized material that melts during cutting and adheres to the workpiece.
Hafnium	A grey metallic element that resembles zirconium chemically and is found in zirconium minerals; used in filaments for its ready emission of electrons.
Kerf	The groove or cut made by the cutting torch
Ionized	A gas is acted upon by the intense heat of plasma causing a net electric charge by adding or removing one or more electrons.
Oxidation	The deposit that forms on the surface of a metal as it oxidizes. This deposit increases the melting temperature of the metal causing uneven flow of welding material and therefore a bad weld.
Plenum	The state or space in which a gas, usually air, is contained at a pressure greater than atmospheric pressure.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Basic Plasma Theory, Hypertherm, New Hampshire, 2000

Colt, Jim. *The Evolution of Plasma Cutting*, Hypertherm, New Hampshire, 2004

Plasma Cutting and Gouging, Miller Electric Manufacturing Company, 2009

Plasma Cutting Guide, Miller Electric Manufacturing Company, 2009

Safety Quick-Guide for Arc Welding and Cutting the Safe Way! Miller Electric Manufacturing Company, 2007

Welding and Allied Processes, S9086-CH-STM-010/CH-074R4, Commander, Naval Sea Systems Command, Washington D.C., 1999

Welding Theory and Application, TM 9-237, Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1976

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Chapter 8

Shielded Metal Arc Welding

Topics

To hear audio, click on the box.

Overview

Shielded Metal Arc Welding (SMAW) is an arc welding process in which the fusing of metals is produced by heat from an electric arc that is maintained between the tip of a consumable covered electrode and the surface of the base metal in the joint being welded. Shielded Metal Arc welding is one of the most widely used welding processes, particularly for short welds in production, maintenance, and repair work and for field construction.

This chapter will give you an understanding of the safety precautions for SMAW and an awareness of the importance of safety in welding. You will also get a basic understanding of the SMAW process and equipment along with the key variables that affect the quality of welds such as electrode selection, polarity and amperage, arc length, travel speed, and electrode angles. We will also cover core competencies such as setting up welding equipment, preparing weld materials, fitting up weld materials, welding carbon steel plates, and repairing welds.

Always refer to the manufacturer's manuals for specific operating and maintenance instructions.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the process of shielded metal arc welding.
2. Describe the principles of operation used for shielded metal arc welding.
3. Describe the equipment associated with shielded metal arc welding.
4. Identify the classification and selection of covered electrodes used for shielded metal arc welding.
5. Identify the welding applications for shielded metal arc welding.
6. Describe the welding metallurgy of shielded metal arc welding.
7. Identify weld and joint designs used for shielded metal arc welding.
8. Describe the welding procedure variables associated with shielded metal arc welding.
9. Identify welding procedure schedules used for shielded metal arc welding.
10. Describe preweld preparations for shielded metal arc welding.
11. Identify defects and problems associated with shielded metal arc welding.
12. Describe post weld procedures for shielded metal arc welding.
13. State the welder training and qualifications associated with shielded metal arc welding.
14. Describe the welding safety associated with shielded metal arc welding.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	STEELWORKER BASIC
Introduction to Structural Steel	
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas	
Rigging	
Wire rope	
Fiber Line	
Layout and Fabrication of Sheet-Metal and Fiberglass Duct	
Welding Quality Control	
Flux Core Arc Welding-FCAW	
Gas-Metal Arc Welding-GMAW	
Gas-Tungsten Arc Welding-GTAW	
Shielded Metal Arc Welding-SMAW	
Plasma Arc Cutting Operations	
Soldering, Brazing, Braze Welding, Wearfacing	
Gas Welding	
Gas Cutting	
Introduction to Welding	
Basic Heat Treatment	
Introduction to Types and Identification of Metal	

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 INTRODUCTION to the PROCESS

Shielded Metal Arc Welding (SMAW) is an electric arc welding process in which an electric arc between a covered metal electrode and the work generates the heat for welding. The filler metal is deposited from the electrode, and the electrode covering provides the shielding. Some slang names for this process are "stick welding" or "stick electrode welding': *Figure 8-1* shows a diagram of this process.

The shielded metal arc welding process is one of the simplest and most versatile arc welding processes. It can be used to weld both ***ferrous*** and non-ferrous metals, and it can weld thicknesses above approximately 18 gauge in all positions. The arc is under the control of the welder and is visible. The welding process leaves slag on the surface of the weld bead which must be removed.

The most common use for this process is welding mild and low ***alloy*** steels. The equipment is extremely rugged and simple, and the process is flexible in that the welder needs to take only the electrode holder and work lead to the point of welding.

Figure 8-1 — Shielded metal arc welding.

Most sources give credit for the invention of the electric arc to Sir Humphrey Davy of England in 180l. For the most part, the electric arc remained a scientific novelty until 1881, when the carbon arc street lamp was invented and the first attempts to weld using the carbon arc process were made. The metal arc welding process came into being when metal rods replaced the carbon electrodes in 1889. Coverings for the bare wire electrodes were first developed in the early 1900's. The first major use occurred during World War I, especially in the shipbuilding industry. After the war, there was a period of slow growth until the early 1930's when shielded metal arc welding became a major manufacturing method and a dominant welding process. Today, the shielded metal arc welding process is widely used, even though its relative importance has been declining slowly in recent years.

1.1.0 Methods of Application

The shielded metal arc welding process is basically a manually operated process. The electrode is clamped in an electrode holder and the welder manipulates the tip of the electrode in relation to the metal being welded. The welder strikes, maintains, and stops the arc manually.

Several variations of this process are done automatically rather than manually. These are: gravity welding, firecracker welding, and massive electrode welding. These methods comprise only a very small percentage of welding done by the shielded metal arc welding process.

1.2.0 Advantages and Limitations

Shielded metal arc welding is widely used because of its versatility, portability, and comparatively simple and inexpensive equipment. In addition, it does not require auxiliary gas shielding or granular flux.

Welders can use the shielded metal arc welding process for making welds in any position they can reach with an electrode. Electrodes can be bent so they can be used to weld blind areas. Long leads can be used to weld in many locations at great distances from the power source. Shielded metal arc welding can be used in the field because the equipment is relatively light and portable. This process is also less sensitive to wind and draft than gas shielded arc welding processes.

Shielded metal arc welding can be used to weld a wide variety of metal thicknesses. This process is more useful than other welding processes for welding complex structural assemblies because it is easier to use in difficult locations and for multi-position welding.

Shielded metal arc welding is also a popular process for pipe welding because it can create weld joints with high quality and strength. However, the shielded metal arc welding process has several limitations. Operator duty cycle and overall deposition rates for covered electrodes are usually less than those of a continuous electrode process. This is because electrodes have a fixed length and welding must stop after each electrode has been consumed to discard the remaining portion of the used electrode clamped into the holder and reapply another. Another limitation is that the slag must be removed from the weld after every pass. Finally, the shielded metal arc welding process cannot be used to weld some of the non-ferrous metals.

2.0.0 PRINCIPLES of OPERATION

The shielded metal arc welding process uses the heat of the electric arc to melt the consumable electrode and the work being welded. The welding circuit includes a power source, welding cables, an electrode holder, a work clamp and a welding electrode. One of the welding cables connects the power source to the electrode holder and the other cable connects to the workpiece.

The welding begins when the welder initiates the arc by momentarily touching the electrode to the base metal, which completes the electrical circuit. The welder guides the electrode manually, controlling both the travel speed and the direction of travel. The welder maintains the arc by controlling the distance between the work material and the tip of the electrode (length of the arc). Some types of electrodes can be dragged along the surface of the work so that the coating thickness controls the arc length, which controls the voltage.

The heat of the arc melts the surface of the base metal and forms a molten weld puddle. The melted electrode metal is transferred across the arc and becomes the deposited weld metal. The deposit is covered by a slag produced by components in the electrode coating. The arc is enveloped in a gas shield provided by the disintegration of some of the ingredients of the electrode coating. Most of the electrode core wire is transferred across the arc, but small particles escape from the weld area as spatter, and a very small portion leaves the welding area as smoke.

2.1.0 Arc Systems

The constant current type of power source is best for shielded metal arc welding. The constant current welding machines provide a nearly constant welding current for the arc.

The constant current output is obtained with a drooping volt ampere characteristic, which means that the voltage reduces as the current increases. The changing arc length causes the arc voltage to increase or decrease slightly, which in turn changes the welding current. Within the welding range, the steeper the slope of the volt-ampere curve, the smaller the current change for a given change in the arc voltage.

Under certain conditions, there is a need for variations in the volt-ampere slope. A steep volt-ampere characteristic is desirable when the welder wants to achieve maximum welding speed on some welding jobs. The steeper slope gives less current variation with changing arc length, and it gives a softer arc. The types of machines that have this kind of curve are especially useful on sheet metals. Machines with this characteristic are typically used with large diameter electrodes and high amperages. On some applications, such as welding over rust, or a position pipe welding where better arc control with high penetration capability is desired, a less steep volt-ampere characteristic is more desirable. Machines with the less steep volt-ampere curve are also easier to use for depositing the root passes on joints with varying fit-up. This type of power source characteristic allows the welder to control the welding current in a specific range by changing the arc length and producing a more driving arc. Differences in the basic power source designs cause these variations in the power sources. *Figure 8-2* shows volt-ampere curves for different performance characteristics. This shows several slopes, all of which can provide the same normal voltage and current. The flatter slopes give a greater current variation for a given voltage change or arc length change. Machines that have a higher short circuit current give more positive starting.

Figure 8-2 — Typical volt-ampere curves for constant current types of power sources.

2.2.0 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.

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.

2.3.0 Metal Transfer

The intense heat of the welding arc melts the tip of the electrode and melts the surface of base metal. The temperature of the arc is about 9000°F (5000°C) which causes almost instantaneous melting of the surface of the work. Globules form on the tip of the electrode and transfer through the arc to the molten weld puddle on the surface of the work. When the detaching globules are small during the transfer, this is known as spray type metal transfer. When the globules are relatively large during transfer, it is known as globular type metal transfer. Surface tension sometimes causes a globule of metal to connect the tip of the electrode to the weld puddle. This causes an electrical short and makes the arc go out. Usually this is a momentary occurrence, but occasionally the electrode will stick to the weld puddle. When the short circuit occurs, the current builds up to a short circuit value and the increased current usually melts the connecting metal and reestablishes the arc. A welding machine with a flatter volt-ampere curve will give a higher short circuit current than one with a steeper volt-ampere curve. The electrode sticking problem will be slightly less with a machine that has a flatter volt-ampere curve. A softer arc, produced by a steeper slope, will decrease the amount of weld spatter. A more driving arc, produced by a flatter slope, causes a more violent transfer of metal into the weld puddle, which will cause a greater splashing effect. This greater splashing effect will generate more spattering from the weld puddle. When the welds are made in the flat or horizontal positions, the forces of gravity, magnetism, and surface tension induce the transfer of the metal. When the welds are made in the vertical or overhead positions, the forces of magnetism and surface tension induce the metal transfer, while the force of gravity opposes metal transfer. Lower currents are used for vertical and overhead welding to allow shorter arc lengths and promote a smaller metal droplet size less affected by gravity.

Test your Knowledge (Select the Correct Response)

1. What does the welding process leave on the surface of the weld bead which must be removed?

   A. Dross
   B. Splatter
   C. Slag
   D. Rust

2. When is a steep volt-ampere characteristic desirable?

   A. When welding thick metal
   B. When the welder wants to achieve maximum welding speed
   C. When the welder wants to gouge the work piece
   D. When welding stainless steel in the vertical position

3.0.0 EQUIPMENT for WELDING

The equipment for the shielded metal arc welding process consists of a power source, welding cable, electrode holder, and work clamp or attachment. *Figure 8*-3 shows a diagram of the equipment.

Figure 8-3 — Equipment for shielded metal arc welding.

3.1.0 Power Sources

The purpose of the power source or welding machine is to provide the electric power of the proper current and voltage to maintain a welding arc. Many different sizes and types of power sources are designed for shielded metal arc welding. Most power sources operate on 230 or 460 volt input electric power, but power sources that operate on 200 or 575 volt input power are also available.

3.1.1 Types of Current

Shielded metal arc welding can use either direct current (DC) or alternating current (AC). Electrode negative (straight polarity) or electrode positive (reverse polarity) can be used with direct current. Each type of current has distinct advantages, but selection of the type of welding current used, usually depends on the availability of equipment and the type of electrode selected. Direct current flows in one direction continuously through the welding circuit. The advantages it has over alternating current are:

Direct current is better at low currents and with small diameter electrodes.

All classes of covered electrodes can produce satisfactory results.

Arc starting is generally easier with direct current.

Maintaining a short arc is easier.

Direct current is easier to use for out-of position welding because lower currents can be used.

Direct current is easier to use for welding sheet metal.

It generally produces less weld spatter than alternating current.

Polarity or direction of current flow is important in the use of direct current. Electrode negative (straight polarity) is often used when shallower penetration is required. Electrode positive (reverse polarity) is generally used where deep penetration is needed. Normally, electrode negative provides higher deposition rates than electrode positive. The type of electrode often governs the polarity to be used .

Alternating current is a combination of both polarities that alternates in regular cycles. In each cycle the current starts at zero, builds up to a maximum value in one direction, decays back to zero, builds up to a maximum value in the other direction, and again decays to zero. The polarity of the alternating current changes 120 times during the 60 Hertz cycle used in the United States. Depths of penetration and deposition rates for alternating current are generally intermediate between those for DC electrode positive and DC electrode negative. Some advantages of alternating current are:

Arc blow is rarely a problem with alternating current.

Alternating current is well suited for welding thick sections using large diameter electrodes.

3.1.2 Power Source Duty Cycle

Duty cycle is the ratio of arc time to total time. For a welding machine, a 10 minute time period is used. Thus, for a 60% duty cycle machine, the welding load would be applied continuously for 6 minutes and would be off for 4 minutes. Most industrial type constant current machines are rated at 60% duty cycle. The formula for determining the duty cycle of a welding machine for a given load current is:

% Duty Cycle = $\frac{(\text{Rated Current})^2}{(\text{Load Current})^2} \times \text{Rated Duty Cycle}$

For example, if a welding machine is rated at a 60% duty cycle at 300 amperes, the duty cycle of the machine when operated at 350 amperes would be.

% Duty Cycle = $\frac{(300)^2}{(350)^2} \times 60 = 44\%$

Figure 8-4 represents the ratio of the square of the rated current to the square of the load current multiplied by the rated duty cycle. A line is drawn parallel to the sloping lines through the intersection of the subject machines rated current output and rated duty cycle. For example, a question might arise whether a 400 amp 60% duty cycle machine could be used for a fully automatic requirement of 300 amps for a 10-minute welding job. It shows that the machine can be used at slightly over 300 amperes at a 100% duty cycle. Conversely, there may be a need to draw more than the rated current from a welding machine, but for a short period. This illustration can be used to compare various machines. Relate all machines to the same duty cycle for a time comparison.

Figure 8-4 — Duty cycle vs. current load.

3.1.3 Types of Power Sources

The output characteristics of the power source must be of the constant-current (CC) type. The normal current range is 25 to 500 amps using conventional size electrodes. The arc voltage is 15 to 35 volts.

3.1.3.1 Generator and Alternator Welding Machines

The generator can be powered by an electric motor for shop use or by an internal combustion engine (gasoline, gas, or diesel) for field use. Engine driven welders can have either water or air cooled engines, and many of them provide auxiliary power for emergency lighting, power tools, etc. Generator welding machines can provide both AC and DC power, See *Figures 8-5 and 8-6*.

An alternator welding machine is an electric generator that produces AC power. This power source has a rotating assembly.

Figure 8-5 — Portable welder/generator.

These machines are also called rotating or revolving field machines.

On dual control machines, normally a generator, the slope of the output curve can vary. The fine adjustment control knob controls open circuit, or "no load", voltage. This control is also the fine welding current adjustment during welding. The range switch provides coarse adjustment of the welding current. In this way, a soft or harsh arc can be obtained. With the flatter curve and its low open circuit voltage, a change in arc voltage will produce a greater change in output current. This produces the digging arc preferred for pipe welding. With a steeper curve and its high open circuit voltage, the same change in arc voltage will produce less of a change in output current. This is a soft or quiet arc, useful for sheet metal welding. This type of welding machine gives the smoothest operating arc because it produces less voltage ripple.

Figure 8-6 — Diesel engine driven power source.

3.1.3.2 Transformer Welding Machines

The transformer type welding machine is the least expensive, lightest, and smallest type of welder. It produces alternating current for welding. The transformer welder takes power directly from the line, transforms it to the power required for welding, and by means of various magnetic circuits, inductors, etc., provides the volt-ampere characteristics proper for welding. The welding current output of a transformer welder may be adjusted in many different ways. The simplest method of adjusting output current is to use a tapped secondary coil on the transformer. This is a popular method many of the limited input, small welding transformers employ. The leads to the electrode holder and the work are connected to plugs, which the welder may be insert in sockets on the front of the machine in various locations to provide the required welding current. Some machines employ a tap switch instead of the plug-in arrangement. In any case, exact current adjustment is not entirely possible.

Industrial types of transformer welders usually employ a continuous output current control. This can be obtained by mechanical means, or electrical means. The mechanical method usually involves moving the core of the transformer. Any method that involves mechanical movement of the transformer parts requires considerable movement for full range adjustment. The more advanced method of adjusting current output is by means of electrical circuits. In this method the core of the transformer or reactor is saturated by an auxiliary electric circuit which controls the amount of current delivered to the output terminals. By merely adjusting a small knob, to the welder can provide continuous current adjustment from the minimum to maximum of the output.

Although the transformer type of welder has many desirable characteristics, it also has some limitations. The power required for a transformer welder must be supplied by a single phase system, and this may create an unbalance of the power supply lines, which is objectionable to most power companies. In addition, transformer welders have a rather low power factor unless they are equipped with power factor correcting capacitors. The addition of capacitors corrects the power factor under load and produces a reasonable power factor that is not objectionable to electric power companies.

Transformer welders have the lowest initial cost. They require less space and are normally quiet in operation. In addition, alternating current welding power supplied by transformers reduces arc blow, which can be troublesome on many welding applications. They do not, however, have as much flexibility for the operator as the dual controlled generator.

3.1.3.3 Transformer-Rectifier Welding Machines

The previously described transformer welders provide alternating current to the arc. Some types of electrodes operate successfully only with direct current power. A method of supplying direct current power to the arc without using a rotating generator is adding a rectifier, an electrical device which changes alternating current into direct current. Transformer-rectifier welding machines operate on single phase input power. These machines are used when both AC and DC current are needed. A single phase type of AC welder is connected to the rectifier which then produces DC current for the arc. By means of a switch that can change the output terminals to the transformer or the rectifier, the operator can select either AC or DC current for the welding requirement. Transformer-rectifier welding machines are available in different sizes. These machines are more efficient electrically than the generator welding machines, and they provide quieter operation. *Figure 8-7* shows an AC/DC single phase power source.

Figure 8-7 — AC/DC single phase power source.

3.1.3.4 Three Phase Rectifier Welding Machines

Three phase rectifier welding machines provide DC welding current to the arc. These machines operate on three phase input power. The three phase input helps overcome the line unbalance that occurs with single phase transformer-rectifier welding machines. In this type of machine, the transformers feed into a rectifier bridge, which then produces direct current for the arc. The three-phase rectifier unit is more efficient electrically than a generator and provides quiet operation. This type of machine also gives the least voltage ripple and produces the smoothest arc of the static type welding machines. *Figure 8-8* shows a three phase solid state constant

Figure 8-8 — Three-phase constant voltage power source.

voltage power source. It automatically monitors output voltage and makes required changes to compensate for line voltage fluctuation.

3.1.3.5 Multiple Operator System

A multiple operator welding system uses a heavy duty, high current, and relatively high voltage power source which feeds a number of individual operator welding stations. At each welding station, a variable resistance is adjusted to drop the current to the proper welding range. Based on the duty cycle of the welding equipment, one welding machine can supply welding power simultaneously to a number of welding operators. The current supplied at the individual station has a drooping characteristic similar to the single operator welding machines described above. The power source, however, has a constant voltage Output. Constant voltage power sources are those that maintain a constant voltage for a given current setting. The volt-ampere curve for this type of power source is nearly flat. The welding machine size and the number and size of the individual welding current control stations must be carefully matched for an efficient multiple operator system. The formula for determining the number of arcs that can be operated off of one power source is:

$$\frac{\text{Available Power}}{\text{Average Arc Amperes} \times \text{Duty Cycle}} = \text{Number of Arcs}$$

3.1.3.6 Inverter Power Sources

In this type of power source, which utilizes the ***inverter***, the power from the line is first rectified to pulsing direct current (*Figure 8-9*). This current then goes to a high frequency oscillator or chopper, which changes the DC into high-voltage, high-frequency AC in the range 5 to 30 kHz. The output of the chopper circuit is controlled in accordance with welding procedure requirements. The high frequency AC is then transformed down to the operating welding voltage. The advantage of the inverter is the use of a small lightweight transformer, since transformers become smaller as frequency increases. The high frequency AC current is then rectified with silicon diodes to provide direct current output at normal welding current and voltage. The inverter power source has become economically feasible due to the availability of high current, high speed solid state electronic components at a reasonable cost. Inverter power sources are about 25% the weight of a conventional rectifier of the same power capacity and about 33% of the size. They provide higher electrical efficiency, a higher power factor, and a faster response time. Several variations of the inverter power source are available.

Figure 8-9 — Inverter power source.

3.1.4 Selecting a Power Source

Selecting a welding machine is based on:

The amount of current required for the work.

The power available to the job site.

Convenience and economic factors.

The size of the machine is based on the welding current and duty cycle required. Welding current, duty cycle, and voltage are determined by considering weld joints, weld sizes, and welding procedures. The incoming power available dictates this fact. Finally, the job situation, personal preference, and economic considerations narrow the field to the final selection. Consult the local welding equipment supplier to help make your selection. Know the following data when selecting a welding power source:

Rated load amperes (current)

Duty cycle

Voltage of power supply (incoming)

Frequency of power supply (incoming)

Number of phases of power supply (incoming)

3.2.0 Controls

The controls are usually located on the front panel of the welding machine. These usually consist of a knob or tap switch to set the rough current range and a knob to adjust the current within the set range. On DC welding machines there is usually a switch to change polarity, and on combination AC-DC machines, there is usually a switch to select the polarity or AC current. An On-Off switch is also located on the front of the machine.

Arc Force Control is a function of amperage triggered by a preset (internal module) voltage. The preset trigger voltage is 18 volts. What this means is that anytime the arc voltage drops from normal welding voltage to 18 volts or less, the drop triggers the arc force current, which gives the arc a surge of current to keep the arc from going out.

When an arc is struck, the electrode is scratched against the work. At that point, the voltage goes to -0- which triggers the arc force current and the arc is initiated quickly. On a standard machine without arc force control, arc striking is difficult and electrode sticking may occur.

After the arc is established, a steady burn-off is desired. As the electrode burns and droplets of metal are transferred from the end of the electrode to the work piece, there is a time period when the droplet is still connected to the end of the electrode but is also touching the work piece. When this occurs, the machine is, in effect, in a "dead-short" - the voltage drops, the arc force is triggered and the droplet is transferred. On machines without arc force, the burn-off is the same; however, without the arc force to help, an arc outage may occur, and the electrode will stick in the puddle.

In tight joints, such as pipe welding, the arc length is very short and with standard machines, it is difficult to maintain the arc since it wants to "short-out" against the sidewalls or bottom of the joint. The arc force control can be adjusted on this type application to prevent electrode sticking; whenever the voltage drops, the drop triggers the arc force current and the sticking doesn't happen because the current surge occurs.

In many applications, there is a need for a very forceful arc to obtain deeper penetration, or in the case of arc gouging, the forceful arc is essential in helping to force the metal out of the groove being gouged. With arc force control, this type application is made much easier than with conventional machines, with which arc length becomes critical and arc outages can occur.

When welding with a given size electrode, there is always an optimum amperage setting. When using arc force control, the optimum amperage setting is continually working to maintain the arc, which means that although we can't see it on the meters, there is usually some added amperage to assist in rod burn-off. This in turn means we really get a slightly faster burn-off than with a conventional rectifier.

When working out-of-position, a forceful arc is needed to help put metal in place. Each individual operator can adjust the arc force control to provide just the amount needed. Arc force can also be of assistance when welding rusty or scaly material, since the more forceful arc will help to break up these deposits.

3.3.0 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 (*Figure 8-10*). 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.

Figure 8-10 — Insulated pincher and collet types of electrode holders.

Electrode holders are made in different sizes, and each manufacturer has its own system of designation. Each holder is designed for use within a specified range of electrode diameters and welding current. Welding with a machine having a 300-ampere rating requires a larger holder than welding with a 100-ampere machine. If the holder is too small, it will overheat.

3.4.0 Welding Cables

The welding cables and connectors connect the power source to the electrode holder and to the work. These cables are normally made of copper or aluminum. The cable that connects the work to the power source is called the work lead. The work leads are usually connected to the work by pincher clamps or a bolt. The cable that connects the electrode holder to the power source is called the electrode lead.

The welding cables must be flexible, durable, well insulated, and large enough to carry the required current. Use only cable specifically designed for welding. Always use a highly flexible cable for the electrode holder connection. This is necessary so the operator can easily maneuver the electrode holder during the welding process. The work lead 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 must also increase. Cable sizes range from the smallest at ***AWG*** No.8 to AWG No. 4/0 with amperage ratings of 75 amperes and upward. *Table 8-1* shows recommended cable sizes for use with different welding currents and cable lengths. The best size cable is one that meets the amperage demand but is small enough to manipulate easily.

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.

Table 8-1 — Suggested copper welding cable sizes for SMAW.

Weld Type	Welding Current	Length of Cable Curcuit in Feet - Cable Size A.W.G.					
		60'	100'	150'	200'	300'	400'
Manual (Low Duty Cycle)	100	4	4	4	2	1	1/0
	150	2	2	2	1	2/0	2/0
	200	2	2	1	1/0	3/0	3/0
	250	2	2	1/0	2/0		
	300	1	1	2/0	3/0		
	350	1/0	1/0	3/0	4/0		
	400	1/0	1/0	3/0			
	450	2/0	2/0	4/0			
	500	2/0	2/0	4/0			

3.5.0 Ground Clamps

A good ground clamp is essential to produce 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, attach a spring-loaded clamp directly onto the workpiece, or bolt or tack-weld the end of the ground cable to the welding bench. The third way creates a permanent common ground.

3.6.0 Accessories

Accessory equipment used for shielded metal arc welding consists of items used for removing slag and cleaning the weld bead. Chipping hammers are often used to remove the slag. Wire brushes or grinders are the most common methods for cleaning the weld.

Manufacturers offer various options and accessories also, depending on the type of power source and the procedure recommendations.

3.7.0 Equipment Operation and Maintenance

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

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, we will only cover the highlights.

Become familiar with the welding machine you will be using. Study the manufacturer's literature and check with your senior petty officer or chief on items 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 need a minimal amount of cleaning. Only electricians should perform internal maintenance due to the possibility 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.

After checking all of the above items, you are now ready to start welding.

Listed below are some additional welding rules you must follow:

Clear the welding area of all debris and clutter.

Do not use gloves or clothing that contain oil or grease.

Check that all wiring and cables are installed properly.

Ensure that the machine is grounded and dry.

Follow all the 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 to be welded.

4.1.1 COVERED ELECTRODES

The covered electrode provides both the filler metal and the shielding for the shielded metal arc welding process. Covered electrodes have different compositions of core wire and a wide variety of types of flux coverings that perform one or all of the following functions, depending upon the type of electrode:

1. Forming a slag blanket over the molten puddle and solidified weld

2. Providing shielding gas to prevent atmospheric contamination of both the arc stream and the weld metal
3. Providing ionizing elements for smoother arc operation
4. Provides deoxidizers and scavengers to refine the grain structure of the weld metal
5. Providing alloying elements such as nickel and chromium for stainless steel
6. Providing metal such as iron powder for higher deposition rates

The first two functions listed prevent the pickup of nitrogen and oxygen into the weld puddle and the red hot solidified weld metal. The nitrogen and oxygen form nitrides and oxides which cause the weld metal to become brittle.

4.1.1 Classification

The classification system for covered electrodes used throughout industry in the United States was devised by the American Welding Society. In this system, designations for covered electrodes consist of the letter E (for electrode) and four (or five) digits for carbon steel and low-alloy steel covered electrodes. Sometimes a suffix appears on the end as well. These digits have specific meanings, which are:

1. The first two (or three) digits indicate the minimum tensile strength in 1,000 psi, of the weld metal deposited. *Table 8-2* lists the different digits used.
2. The third (or fourth) digit indicates the welding positions in which the electrode can be used. *Table 8-3* lists the use of the different digits.
3. The fourth (or fifth) digit indicates the current characteristics and the types of electrode coating. *Table 8-4* shows what the different digits indicate.
4. A suffix is sometimes added to the EXXXX designation (it does not apply to the E60XX classification). The suffix indicates the chemical composition of the deposited weld metal. *Table 8-5* shows the meaning of various suffixes.

Table 8-2 — Digit position indicating tensile and yield strength.

CLASSIFICATION	MINIMUM TENSILE STRENGTH[a] PSI (MPa)	MINIMUM YIELD STRENGTH[a] PSI (MPa)
E60XX	62,000 (425)	50,000 (345)
E70XX	70,000 (485)	57,000 (395)
E80XX	80,000 (550)	67,000 (460)
E90XX	90,000 (620)	77,000 (530)
E100XX	100,000 (690)	87,000 (600)
E110XX[b]	110,000 (760)	95,000 (655)
E120XX[b]	120,000 (825)	107,000 (740)

a- Refer to appropriate specification for exact property requirements.
b- E110XX and E120XX use low hydrogen type of coating only.

Table 8-3 — Digit indicating position electrode can be used in.

CLASSIFICATION	POSITIONS
EXX1X	Flat, Horizontal, Vertical, Overhead
EXX2X	Flat, Horizontal - Fillet
EXX4X	Flat, Horizontal, Vertical - Down, Overhead

Table 8-4 — Digits indicating electrode arc and coating characteristics.

CLASSIFICATION	TYPE OF CURRENT USED	PENETRATION	COATING
EXXX0	DCEP	Deep	Cellulose, Sodium
EXXX1	AC, DCEP	Deep	Cellulose, Potassium
EXXX2	AC, DCEN	Medium	Rutile, Sodium
EXXX3	AC, DCEP, DCEN	Light	Rutile, Potassium
EXXX4	AC, DCEP, DCEN	Light	Rutile, Iron Powder
EXXX5	DCEP	Medium	Low Hydrogen, Sodium
EXXX6	AC, DCEP	Medium	Low Hydrogen, Potassium
EXXX7	AC, DCEP, DCEN	Medium	Iron Powder, Iron Oxide
EXXX8	AC, DCEP	Medium	Low Hydrogen, Iron Powder
EXXX9	AC, DCEN, DCEP	Medium	Iron Oxide, Titania, Potassium

For example, the E8018-B1 designation indicates an electrode that deposits metal that has a minimum tensile strength of 80,000 psi (550 ***MPa***), can be used in all welding positions, has a low hydrogen iron powder classification, and has chemical composition in the weld deposit of .12 C, .90 Mn, .03 P, .04 S, .BO Si, .40-.65 Cr and .40-.65 Mo. *(Table 8-5)*.

Table 8-5 — Chemical composition.

CHEMICAL COMPOSITION, PERCENT[b]

AWS Classification[a]	C	Mn	P	S	Si	Ni	Cr	Mo	V
Carbon-Molybdenum Steel Electrodes									
E7010-A1		0.60			0.40				
E7011-A1		0.60			0.40				
E7015-A1		0.90			0.60				
E7016-A1	0.12	0.90	0.03	0.04	0.60	-	-	0.40-0.65	-
E7018-A1		0.90			0.80				
E7020-A1		0.60			0.40				
E7027-A1		1.00			0.40				
Chromium-Molybdenum Steel Electrodes									
E8016-B1	0.05 to 0.12	0.90	0.03	0.04	0.60	-	0.40-0.65	0.40-0.65	-
E8018-B1					0.80				
E8015-B2L	0.05	0.90	0.03	0.04	1.00	-	1.00-1.50	0.40-0.65	-
E8016-B2	0.05 to 0.12	0.90	0.03	0.04	0.60	-	1.00-1.50	0.40-0.65	-
E8018-B2					0.80				
E8018-B2L	0.05	0.90	0.03	0.04	0.80	-	1.00-1.50	0.40-0.65	-
E9015-B3L	0.05	0.90	0.03	0.04	1.00	-	2.00-2.50	0.90-1.20	-
E9015-B3					0.60				
E9018-B3	0.05 to 0.12	0.90	0.03	0.04	0.60	-	2.00-2.50	0.90-1.20	-
E9018-B3					0.80				
E9018-B3L	0.05	0.90	0.03	0.04	0.80	-	2.00-2.50	0.90-1.20	-
E8015-B4L	0.05	0.90	0.03	0.04	1.00	-	1.75-2.25	0.40-0.65	-
E8016-B5	0.07 to 0.15	0.04 to 0.07	0.03	0.04	0.30-0.60	-	0.40-0.60	1.00-1.25	0.05
Nickel Steel Electrodes									
E8016-C1	0.12	1.25	0.03	0.04	0.60	2.00-2.75	-	-	-
E8018-C1					0.80				
E7015-C1L									
E7016-C1L	0.05	1.25	0.03	0.04	0.50	2.00-2.75	-	-	-
E7018-C1L									
E8016-C2	0.12	1.25	0.03	0.04	0.60	3.00-3.75	-	-	-
E8018-C2					0.80				
E7015-C2L									
E7016-C2L	0.05	1.25	0.03	0.04	0.50	3.00-3.75	-	-	-
E7018-C2L									
E8016-C3[c]	0.12	0.04-1.25	0.03	0.03	0.80	0.80-1.10	0.15	0.35	0.05
E8018-C3[c]									
Nickel-Molybdenum Steel Electrodes									
E8018-NM[d]	0.10	0.80-1.25	0.02	0.03	0.60	0.80-1.10	0.05	0.40-0.65	0.02
Manganese-Molybdenum Steel Electrodes									
E9015-D1	0.12	1.25-1.75	0.03	0.04	0.60	-	-	0.25-0.45	-
E9018-D1					0.80				
E8016-D3	0.12	1.00-1.75	0.03	0.04	0.60	-	-	0.40-0.65	-
E8018-D3					0.80				
E10015-D2					0.60				
E10016-D2	0.15	1.65-2.00	0.03	0.04	0.60	-	-	0.25-0.45	-
E10018-D2					0.80				
All Other Low-Alloy Steel Electrodes[e]									
EXX10-G[e]									
EXX11-G									
EXX13-G									
EXX15-G	-	1.00 min[f]	-	-	0.80 min[f]	0.50 min[f]	0.30 min[f]	0.20 min[f]	0.10 min[f]
EXX16-G									
EXX18-G									
E7020-G									
E9018-M[c]	0.10	0.60-1.25	0.030	0.030	0.80	1.40-1.80	0.15	0.35	0.05
E10018-M[c]	0.10	0.75-1.70	0.030	0.030	0.60	1.40-2.10	0.35	0.25-0.50	0.05
E11018-M[c]	0.10	1.30-1.80	0.030	0.030	0.60	1.25-2.50	0.40	0.25-0.50	0.05
E12018-M[c]	0.10	1.30-2.25	0.030	0.030	0.60	1.75-2.50	0.30-1.50	0.30-0.55	0.05
E12018-M1[c]	0.10	0.80-1.60	0.015	0.012	0.65	3.00-3.80	0.65	0.20-0.30	0.05
E7018-W[g]	0.12	0.40-0.70	0.025	0.025	0.40-0.70	0.20-0.40	0.15-0.30	-	0.08
E8018-W[h]	0.12	0.50-1.30	0.30	0.04	0.35-0.80	0.40-0.80	0.45-0.70	-	-

Note: Single values shown are maximum percentages, except where otherwise specified.

a. The suffixes A1, B3, C2, etc. designate the chemical composition of the electrode classification.

b. For determining the chemical composition, DCEN (electrode negative) may be used where DC, both polarities, is specified.

c. These classifications are intended to conform to classifications covered by the military specifications for similar compositions.

d. Copper shall be 0.10% max and aluminum shall be 0.05% max for E8018-NM electrodes.

e. The letters "XX" used in the classification designations in this table stand for the various strength levels (70, 80, 90, 100, 110, and 120) of electrodes.

f. In order to meet the alloy requirements of the G group, the weld deposit need have the minimum, as specfied in the table, of only one of the elements listed. Additional chemical requirements may be as agreed between supplier and purchaser.

g. Copper shall be 0.30 to 0.60% for E7018-W electrodes.

h. Copper shall be 0.30 to 0.75% for E8018-W electrodes.

Other types of electrodes are classified in different ways. *Table 8-6* lists the American Welding Society (AWS) specifications covering filler metals for shielded metal arc welding.

Table 8-6 — AWS filler metal specifications for covered electrodes used in SMAW.

DESIGNATION	TITLE
A5.1	Carbon Steel Electrodes for SMAW
A5.3	Aluminum and Aluminum Alloy Electordes for SMAW
A5.4	Stainless Steel Electrodes for SMAW
A5.5	Low Alloy Steel Covered Arc Welding Electrodes
A5.6	Covered Copper and Copper Alloy Arc Welding Electrodes
A5.11	Nickel and Nickel Alloy Welding Electrodes for SMAW
A5.13	Solid Surfacing Welding Rods and Electrodes
A5.15	Welding Electrodes and Rods for Cast Iron
A5.21	Composite Surfacing Welding Rods and Electrodes

For example, stainless steel electrodes are classified according to the chemical analysis of the weld metal and the type of welding current they can use. An example of this is the E308-15 designation. The E stands for Electrode. The 308 indicates the chemical composition of the weld metal. *Table 8-7* shows the different classifications.

Table 8-7 — AWS classifications.

AWS Classification [c]	UNS Number [d]	WEIGHT PERCENT [a,b] C	Cr	Ni	Mo	Cb(Nb) plus Ta	Mn	Si	P	S	N	Cu
E209-XX [e]	W32210	0.06	20.5-24.0	9.5-12.0	1.5-3.0	-	4.0-7.0	0.90	0.04	0.03	0.10-0.30	0.75
E219-XX	W32210	0.06	19.0-21.5	5.5-7.0	0.75	-	8.0-10.0	1.00	0.04	0.03	0.10-0.30	0.75
E240-XX	W32410	0.06	17.0-19.0	4.0-6.0	0.75	-	10.5-13.5	1.00	0.04	0.03	0.10-0.30	0.75
E307-XX	W30710	0.04-0.14	18.0-21.5	9.0-10.7	0.5-1.5	-	3.30-4.75	0.90	0.04	0.03	-	0.75
E308-XX	W30810	0.08	18.0-21.0	9.0-11.0	0.75	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E308H-XX	W30810	0.04-0.08	18.0-21.0	9.0-11.0	0.75	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E308L-XX	W30813	0.04	18.0-21.0	9.0-11.0	0.75	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E308Mo-XX	W30820	0.08	18.0-21.0	9.0-12.0	2.0-3.0	-	0.5-2.5	0.90	0.04	0.03	-	0.75
308MoL-XX	W30823	0.04	18.0-21.0	9.0-12.0	2.0-3.0	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E309-XX	W30910	0.15	22.0-25.0	12.0-14.0	0.75	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E309L-XX	W30913	0.4	22.0-25.0	12.0-14.0	0.75	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E309Cb-XX	W30917	0.12	22.0-25.0	12.0-14.0	0.75	0.70-1.00	0.5-2.5	0.90	0.04	0.03	-	0.75
E309Mo-XX	W30920	0.12	22.0-25.0	12.0-14.0	2.0-3.0	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E309MoL-XX	W30923	0.04	22.0-25.0	12.0-14.0	2.0-3.0	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E310-XX	W31010	0.08-0.20	25.0-28.0	20.0-22.5	0.75	-	1.0-2.5	0.75	0.03	0.03	-	0.75
E310H-XX	W31015	0.35-0.45	25.0-28.0	20.0-22.5	0.75	-	1.0-2.5	0.75	0.03	0.03	-	0.75
E310Cb-XX	W31017	0.12	25.0-28.0	20.0-22.0	0.75	0.70-1.00	1.0-2.5	0.75	0.03	0.03	-	0.75
E310Mo-XX	W31020	0.12	25.0-28.0	20.0-22.0	2.0-3.0	-	1.0-2.5	0.75	0.03	0.03	-	0.75
E312-XX	W31310	0.15	28.0-32.0	8.0-10.5	0.75	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E316-XX	W31610	0.08	17.0-20.0	11.0-14.0	2.0-3.0	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E316H-XX	W31610	0.04-0.08	17.0-20.0	11.0-14.0	2.0-3.0	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E316L-XX	W31613	0.04	17.0-20.0	11.0-14.0	2.0-3.0	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E317-XX	W31710	0.08	18.0-21.0	12.0-14.0	3.0-4.0	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E317L-XX	W31713	0.04	18.0-21.0	12.0-14.0	3.0-4.0	-	0.5-2.5	0.90	0.04	0.03	-	0.75
E318-XX	W31910	0.08	17.0-20.0	11.0-14.0	2.0-3.0	6 X C, min to 1.00 max	0.5-2.5	0.90	0.04	0.03	-	0.75
E320-XX	W88021	0.07	19.0-21.0	32.0-36.0	2.0-3.0	8 X C, min to 1.00 max	0.5-2.5	0.60	0.04	0.03	-	3.0-4.0
E320LR-XX	W88022	0.03	19.0-21.0	32.0-36.0	2.0-3.0	8 X C, min to 0.40 max	1.50-2.50	0.30	0.020	0.015	-	3.0-4.0
E330-XX	W88331	0.18-0.25	14.0-17.0	33.0-37.0	0.75	-	1.0-2.5	0.90	0.04	0.03	-	0.75
E330H-XX	W88335	0.35-0.45	14.0-17.0	33.0-37.0	0.75	-	1.0-2.5	0.90	0.04	0.03	-	0.75
E347-XX	W34710	0.08	18.0-21.0	9.0-11.0	0.75	8 X C, min to 1.00 max	0.5-2.5	0.90	0.04	0.03	-	0.75
E349-XX [e,f,g]	W34910	0.13	18.0-21.0	8.0-10.0	0.35-0.65	0.75-1.20	0.5-2.5	0.90	0.04	0.03	-	0.75
E383-XX	W88028	0.03	26.5-29.0	30.0-33.0	3.2-4.2	-	0.5-2.5	0.90	0.04	0.02	-	0.6-1.5
E385-XX	W88904	0.03	19.5-21.5	24.0-26.0	4.2-5.2	-	1.0-2.5	0.75	0.03	0.02	-	1.2-2.0
E410-XX	W41010	0.12	11.0-13.5	0.7	0.75	-	1.0	0.90	0.04	0.03	-	0.75
E410NiMo-XX	W41016	0.06	11.0-12.5	4.0-5.0	0.40-0.70	-	1.0	0.90	0.04	0.03	-	0.75
E430-XX	W43010	0.10	15.0-18.0	0.6	0.75	-	1.0	0.90	0.04	0.03	-	0.75
E502-XX [h]	W50210	0.10	4.0-6.0	0.4	0.45-0.65	-	1.0	0.90	0.04	0.03	-	0.75
E505-XX [h]	W50410	0.10	8.0-10.5	0.4	0.85-1.20	-	1.0	0.90	0.04	0.03	-	0.75
E630-XX	W37410	0.05	16.00-16.75	4.5-5.0	0.75	0.15-0.30	0.25-0.75	0.75	0.04	0.03	-	3.25-4.0
E16-8-2-XX	W36810	0.10	14.5-16.5	7.5-9.5	1.0-2.0	-	0.5-2.5	0.60	0.03	0.03	-	0.75
E7Cr-XX [h]	W50310	0.10	6.0-8.0	0.4	0.45-0.65	-	1.0	0.90	0.04	0.03	-	0.75
E2209-XX	W39209	0.04	21.5-23.5	8.5-10.5	2.5-3.5	-	0.5-2.0	0.90	0.04	0.03	-	0.75
E2553-XX	W39553	0.06	24.0-27.0	6.5-8.5	2.9-3.9	-	0.5-1.5	1.0	0.04	0.03	-	1.5-2.5

Notes:

a. Analysis shall be made for the elements for which specific values are shown in the table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements, except iron, is not present in excess of 0.50 percent.

b. Single values are maximum percentages.

c. Classification suffix -XX may be -15,-16,-17,-25, or -26. See Section A8 of the Appendix for an explanation.

d. SAE/ASTM Unified Number System for Metals and Alloys.

e. Vanadium shall be 0.10 to 0.30 percent.

f. Titanium shall be 0.15 percent max.

g. Tungsten shall be from 1.25 to 1.75 percent.

h. This grade also will appear in the next revision of AWS A5.5, Specifications for Low Alloy Steel Electrodes for Shielded Metal Arc Welding. It will be deleted from A5.4 at the first revision of A5.4 following publication of the revised A5.5.

The suffix indicates the positions and the type of welding current to be used. A suffix of 15 means to use direct current electrode positive and a 16 means that you may use alternating current or direct current electrode positive. All stainless steel electrode classifications that are now used have a one in the suffix that indicates that they are all position electrodes.

4.2.0 Sizing

The size of the electrode is designated by the diameter of the core wire and the length of the electrode. Standard electrode diameters are 1/16 in. (1.6 mm) to 5/16 in. (7.9 mm). Lengths of the electrodes are from 9 in. (229 mm) to 18 in. (457 mm), although electrodes for special applications can be up to 36 in. (914 mm) long. The most common electrode length is 14 in. (346 mm). The bare uncoated end of the electrode, which is needed to make electrical contact with the electrode holder, is standardized at lengths ranging from 3/4 in. (19 mm) to 11/2 in. (38 mm).

4.3.0 Selection of Electrode Class

The deposited weld metal should equal or exceed the mechanical properties of the base metal and have approximately the same composition and physical properties. Identification of the base metal is absolutely required to properly select the correct electrode. If you do not know the identification, you must make tests based on appearance, magnetic check, chisel test, flame test, fracture test, spark test, or chemistry test. The selection of welding electrodes for specific job applications is quite involved, but can be based on the following eight factors:

4.3.1 Base Metal Strength Properties

Identification of the base metal is required. In the cases of mild and low alloy steels, choose the electrodes to match (at least) the tensile strength of the base metal.

4.3.2 Base Metal Composition

The chemical composition of the base metal must be known, but matching the chemical composition is not as important for mild steels as it is for stainless steels, low alloy steels, and nonferrous metals. For these metals, matching the chemical composition of the filler metal to the base metal is required.

4.3.3 Welding Position

Electrodes are designed to be used in specific positions. Choose the electrodes to match the positions of the welding you will encounter.

4.3.4 Welding Current

Covered electrodes are designed to operate on specific currents and polarity. The type of electrode you use might depend on the type of welding current available. Operate electrodes on their recommended current type.

4.3.5 Joint Design and Fit-Up

Choose the electrodes according to their penetration characteristic. For joints with no beveling or tight fit-up, an electrode with a digging arc would be the best. For welding on thin material, a light penetrating electrode would be the best.

4.3.6 Thickness and Shape of Base Metal

Weldments may include thick sections or complex shapes which require maximum ductility to avoid weld cracking. Use electrodes that give the best ductility.

4.3.7 Service Conditions and/or Specifications

For weldments subject to severe service conditions such as low temperature, high temperature, or shock loading, use the electrode that matches the base metal composition, ductility, and impact resistance properties. This usually indicates selecting low hydrogen types of electrodes.

4.3.8 Production Efficiency and Job Condition

Some electrodes are designed for high deposition rates but may be used under specific position requirements. If they can be used, the high deposition electrodes would be the best.

According to Section IX of the ASME Boiler and Pressure Vessel Code and the AWS Structural Welding Code, the covered electrodes for welding mild and low-alloy steel can be placed into four categories. The electrodes within each of these categories generally operate and run the same way.

F-1 High Deposition Group (EXX20, EXX24, EXX27, EXX28)

F-2 Mild Penetration Group (EXX12, EXX13, EXX14)

F-3 Deep Penetration Group (EXX10, EXX11)

F-4 Low-Hydrogen Group (EXX15, EXX16, EXX18)

The high deposition types of electrodes have additions of iron powder in their coatings. These additions of iron powder usually range from 40-55% of the weight of the coating. During welding, the large amounts of iron powder in the electrode coating go into the weld puddle which increases the deposition rates. These electrodes are usually selected when high deposition welding is desired.

The mild penetration types of electrodes are generally used for welding sheet metal, partial penetration welds when strength is not the governing factor, and other less critical applications. These electrodes have ***rutile*** as a main component in their coatings. The EXX14 electrodes have an addition of 25-40% iron powder in the coatings to give them a higher deposition rate than the EXX12 and EXX13 types.

The deep penetration types of electrodes are the EXX10 and the EXX11 electrodes. The electrodes are used on applications where the deep penetrating characteristics of the weld are needed and for full penetration welding. These electrodes have cellulose as the major component in their coatings. The cellulose is the material that gives these electrodes their deep penetrating characteristic.

The low hydrogen electrodes are those which have very low moisture content in their coatings. These electrodes are used for welding steels when hydrogen cracking can be a problem, such as in many of the low alloy steels. Much of the hydrogen in the weld metal comes from the electrode coating. The cellulose types of electrodes require higher moisture contents in their coatings to operate properly.

Table 8-8 shows the general characteristics of different types of electrodes on penetration, surface contour, and deposition rates.

Table 8-8 — Relative Comparison of different characteristics for several mild steel electrodes.

AWS Classification	Penetration	% Cellulose in Coating	Deposition Rate	% iron Powder In Coating	Typical bead Surface of Fillet Weld
E6010	Deep	25-40	Lower	0-10	Slightly concave to flat
E6011	Deep	25-40	Lower	0-10	Slightly convex
E6012	Moderate	2-12	Lower	0-10	Convex
E6013	Light to Moderate	2-12	Lower	0-10	Convex
E6027	Moderate	0-15	Higher	40-55	Flat to slightly concave
E7014	Light to Moderate	2-6	Moderate	25-40	Slightly concave to flat
E7016	Moderate	—	Lower	—	Flat to slightly convex
E7018	Moderate	—	Moderate	25-40	Slightly convex
E7024	Light to Moderate	1-5	Higher	40-55	Flat to slightly concave
E7028	Moderate	25-40	Higher	40-55	Flat to slightly concave

4.4.0 Selection of Electrode Size

The correct choice of electrode size involves consideration of a variety of factors such as:

1. Type, position, and preparation of the joint
2. Ability of the electrode to carry high current values without weakening the weld metal or losing deposition efficiency
3. Mass of the work metal and its ability to maintain its original properties after welding
4. Characteristics of the assembly with reference to the effect of stresses set up by heat application

5. Practicability of heat treatment before and/or after welding
6. Specific requirements as to welding quality
7. Cost of achieving the desired results

Most classes of electrodes are designed for multiple pass welding. Each diameter electrode has its own specific limits on the current carrying capacity. The large diameter electrodes are also used to give the highest welding speed possible. When welding in the vertical and overhead positions, smaller diameter electrodes are preferred because gravity will affect a smaller weld puddle less than a larger one. The weld puddle small diameter electrodes create is easier for the welder to control. The type of weld joint also has a limiting effect on the size of the electrodes. Small diameter electrodes may have to be used to reach the root of the joint where larger electrodes would not fit. For example, in V groove joints, smaller diameter electrodes may have to be used to put in the root pass and possibly several more of the initial passes. The experience of the welder will also influence the size of the electrode used depending on the welder's manipulative skill with the electrode. Use the largest possible electrode size to obtain the fastest welding speeds, providing that this does not cause overwelding. Overwelding can be harmful and wasteful. The proper electrode diameter to use is the one that, when used with the proper welding conditions, will result in a weld of the required quality and size at the greatest productivity.

4.5.0 Conformances and Approvals

Covered electrodes must conform to the specifications of or be approved by code making organizations for many applications of shielded metal arc welding. Some of the organizations that issue specifications or approvals are the American Welding Society (AWS), American Society of Mechanical Engineers (ASME), American Bureau of Shipping (ABS), Federal Bureau of Roads, U.S. Coast Guard, Canadian Welding Bureau, and the Military. The American Welding Society (AWS) provides specifications for covered electrodes. The electrodes manufactured must meet specific requirements in order to conform to a specific electrode classification. Most code making organizations such as the American Society of Mechanical Engineers (ASME) and the American Petroleum Institute (API) recognize and use the AWS Specifications. Some of the code making organizations such as the American Bureau of Shipping (ABS) and the Military must directly approve the electrodes before they can be used for welding on a project covered by that code. These organizations send inspectors to witness welding and testing and approve the classification of covered electrodes.

To conform to the AWS specifications for mild steel electrodes, the covered electrode must be able to produce a weld deposit that meets specified mechanical properties. The requirements vary depending on the class of electrode. *Table 8-9* gives a list of mechanical properties different mild steel covered electrodes require.

Table 8-9 — Minimum mechanical properties required for the different mild steel covered electrodes (AWS A5.1).

AWS Classification	Tensile Strength		Yield Strength at 0.2% Offset		Elongation in 2 inches (50.8 mm) percent
	ksi	MPa	ksi	MPa	
E6010	60	414	48	331	22
E6011	60	414	48	331	22
E6012	60	414	48	331	17
E6013	60	414	48	331	17
E6019	60	414	48	331	22
E6020	60	414	48	331	22
E6022[a]	60	414	NOT SPECIFIED		NOT SPECIFIED
E6027	60	414	48	339	22
E7014	70	482	58	339	17
E7015	70	482	58	339	22
E7016	70	482	58	339	22
E7018	70	482	58	339	22
E7024	70	482	58	339	17[b]
E7027	70	482	58	339	22
E7028	70	482	58	339	22
E7048	70	482	58	339	22
E7018M	note d	482	53-72[c]	365-496[c]	24

Notes:
a. A transverse tension test and a longitudinal guided bend test, as specified in AWS A5.1, are required.
b. Weld metal from electrodes identified as E7024-I shall have elongation of 22% minimum.
c. For 3/32 inches (2.4mm) electrodes, the maximum for the yield strength shall be 77 ksi (531 MPa).
d. Tensile strength of this weld metal is a nominal 70 ksi (482 MPa).

Test your Knowledge (Select the Correct Response)

3. What is the normal current range of a power supply when using conventional size electrodes?

   A. 25 to 500 amps
   B. 500 to 750 amps
   C. 750 to 900 amps
   D. 900 to 1250 amps

4. **(True or False)** Electrodes are designed to be used in specific positions.

   A. True
   B. False

5.0.0 WELDING APPLICATIONS

Shielded metal arc welding is widely used because of its versatility. Welding can be performed at a distance from the power source which makes it popular for welding in the field. The equipment for this process is relatively simple to operate, portable, and inexpensive. Shielded metal arc welding is a major process used for maintenance and repair work. It is popular in small production shops where limited capital is available and where the amount of welding done is minor compared to other manufacturing operations. Shielded metal arc welding is often used for tacking parts together which are then welded by another process.

5.1.0 Industries

Shielded metal arc welding is the welding process of choice in a number of civilian industries because it is versatile and user friendly. It has been replaced in recent years by flux cored arc welding but remains competitive because of the low equipment costs and wide applicability.

5.1.1 Field Welded Storage Tanks

Field welded storage tanks differ from pressure vessels because they are used to store petroleum, water or other liquids at atmospheric pressure. Shielded metal arc welding is widely used in the fabrication and erection of field welded storage tanks. These tanks are generally constructed of low-carbon and structural steels. Nickel steels are employed when the tanks require higher toughness. This process is used to weld longitudinal and circumferential seams on the tanks as well as the structural support members. *Figure 8-11* shows field welding of a large circumference pipe. An engine driven generator power source is being used because there is no electricity available.

Figure 8-11 — Pipe welding.

5.1.2 Pressure Vessels

Pressure vessels and boilers are also welded using this process. Shielded metal arc welding is primarily used for welding attachments to the vessel. This kind of welding commonly uses all sizes of electrodes. For applications where the vessels will be operating at low temperatures, smaller electrodes are used on multiple pass welds. This will produce smaller weld beads that build up the weld in relatively thin layers. The smaller weld beads give a stronger, tougher weld.

5.1.3 Industrial Piping

Shielded metal arc welding is widely used in the industrial piping industry which includes many types of pressure piping. The types of electrodes most often used are the E6010 and E7018 electrodes for welding low-carbon steel pipe. A common practice is the use of E6010 electrodes to weld in the root passes and the E7018 electrodes to weld in the fill and cover passes. Industrial piping is generally welded from the bottom to the top, except on small diameter pipe where it is done both ways. The reason that welding from bottom to top is most common is because slag is often trapped when welding in the opposite direction. For welding low-carbon steel pipe with a 70,000 psi (485 MPa) tensile strength, use E7010 and E7018 electrodes. *Figure 8-12* shows shielded metal arc welding with E7018 electrodes to weld structural supports.

Another example of this process is shown in *Figure 8-13*, where pulsed shielded metal arc welding is being used to cylindrical support beams. Shielded metal arc welding is often used for welding on other types of industrial piping. EXX15, EXX16, and EXX18 electrodes are used for welding chromium-molybdenum alloy pipe. When welding stainless steel pipe, gas tungsten arc welding (TIG) is often used to put in the root pass, and shielded metal arc welding is used to weld in the fill and cover passes. Medium and high-carbon steel pipe are also welded by this process. For these, smaller diameter electrodes are used than on low-carbon steels, in order to reduce the heat effect on the pipe.

Figure 8-12 — E7018 electrode being used to weld structural supports.

Figure 8-13 —SMAW cylindrical support beams.

5.1.4 Transmission Pipelines

The shielded metal arc welding process is by far the major process for welding on transmission or cross-country pipelines. Welding is done in the field, usually from the outside of the pipe, but whenever possible, welding should be done from both sides of the pipe. E6010 and E7018 electrodes are the types used for welding transmission pipelines. Several common procedures are in use for welding transmission pipelines. One of these is to put in the root pass with E6010 electrodes and put in the fill and cover passes with E7018 electrodes. Another is to use E7018's to weld in all passes, and a third is to weld in the root pass with the gas metal arc welding process and put in the rest of the passes with E7018 electrodes.

5.1.5 Nuclear Power Plants

The nuclear power industry employs this process for many applications. It is often used in the shop fabrication of low-carbon and low alloy steel heavy-walled pressure vessels and for welding longitudinal and circumferential weld seams. Shielded metal arc welding is the best method for welding nozzles and attachments to the vessels. A major application of this process is welding pressure piping for use in the nuclear power facilities. Nuclear power system pressure piping requires stronger quality control than normal pressure piping.

Figure 8-14 — Structural welding with the SMAW process.

5.1.6 Structures

The construction industry is a major application for shielded metal arc welding. Most of the welding on buildings and bridges is done in the field at long distances from the power sources, which makes this process popular for these applications. Most types of covered electrodes are used in structural work because of the wide variety in the tensile strengths of the steels used. *Figure 8-14* shows structural welding with the shielded

Figure 8-15 — Hinge support welding.

Figure 8-16 — I beam welding.

metal arc welding process. *Figure 8-15* shows a section of hinge being welded. In *Figure 8-16*, a Seabee is welding an I-beam. Another example of the use of shielded metal arc welding in the construction industry is shown in *Figure 8-17*, where this process is being used to weld armor plating.

Figure 8-17 — Welding armor plating.

5.1.7 Ships

Shielded metal arc welding is still the major process used in shipbuilding. It is used for many different applications including welding in areas where the other processes cannot reach. Most types of low-carbon steel covered electrodes are used except the EXX12, EXX13, and EXX14 types. These three types of electrodes are not approved for use on the main structural members in the ship because of the relatively low ductility obtained from the weld deposits of these electrodes. The electrodes with large amounts of iron powder in their coatings are popular for many shipbuilding applications because of the high deposition rates obtained. These types of electrodes are especially used on the many fillet welds that are made in a ship structure. Backing tape is often used for backing the weld metal when one side welding is done.

5.1.8 Transportation

Another industry that widely uses this welding process is the railroad industry. It uses E60XX and E70XX electrodes to weld many parts of the underframe, cab, and engine of the locomotive. The underframe fabrication consists of mostly fillet welds. The frames and brackets for the diesel engines are also welded with these electrodes.

Railroad cars are commonly welded together by the shielded metal arc process. Underframes are often welded with E6020, E7016, and E7018 electrodes. The sills for the underframes are welded using E7024 electrodes because high deposition rates are desired for this application.

Figure 8-18 — Welding bars on a door.

The automotive industry uses this process to a lesser extent. There, it is mainly used for welding low production components or on items where there are frequent model changes. This is because the fixtures and equipment for this process are less expensive.

5.1.9 Industrial Machinery

The frames of many types of heavy industrial machinery are welded together using this process. It is the major process used for welding piping associated with this machinery. Shielded metal arc welding is used for welding areas the other processes cannot reach. *Figure 8-18* shows a welder welding bars on a door.

5.1.10 Heavy Equipment

Another major application of this process is in the heavy equipment industry such as mining, agricultural, and earthmoving equipment. In these industries, shielded metal arc welding is used for welding structural steels, which are used for the frames, beams, and many other items in the assembly. Most types of covered electrodes are used depending on the type of steel being welded. Stainless steel and nonferrous metals are also used for some parts. *Figure 8-19* shows a Seabee welding a plate for a backhoe bucket.

Figure 8-19 — Welding a structural plate.

5.1.11 Maintenance and Repair

One industry where shielded metal arc welding is and will probably always remain the major welding process is the maintenance and repair industry. This is especially true in small shops and general plant maintenance, where relatively inexpensive equipment, portability, and versatility are important considerations. This process is the major one for repair welding on railroad engines and cars as well as cast iron engine blocks and heads on automobiles. This kind of welding commonly employs nickel electrodes for repairing cast iron parts. Resurfacing worn parts and putting a hard surface on parts (wearfacing) are two other applications. Special surfacing and build-up electrodes are used for these purposes.

5.2.0 Variations of the Process

Gravity welding, which is seldom used today, was an automatic variation of the shielded metal arc welding process. Gravity welding was popular because one operator could operate several gravity feeders at the same time, increasing the production rate. The welder installed the electrode in the feeder and the electrode fed as it burned off, which gave a high quality horizontal fillet weld. The welders usually used 28 in. (710 mm) long electrodes of the drag type (E6027, E7024, E7028). These were used in diameters of 7/32 in. (5.6 mm) and in 1/4 in. (6.4 mm). This was possible in some shipbuilding work since the welds were often close together, which allowed the welding operator to quickly move from one holder to another to reload them, start them, and allow them to operate unattended.

Firecracker welding is a method of automatically making welds using a long electrode with an electrically nonconductive heavy coating. This method has been used very little in North America because of the popularity of semi-automatic processes. This method can be used for square groove butt welds and full fillet lap welds. To make a firecracker fillet weld, position the work flat. Place the welding electrode in the joint and place a retaining bar over it. Start the arc by shorting the end of the electrode to the work. The arc length depends on the thickness of the coating. As the arc travels along the electrode, the electrode melts and makes a deposit on the metal immediately underneath it. Once the arc is started, the process automatically proceeds to completion.

Another variation of shielded metal arc welding is the use of massive electrodes which have extremely large diameters and long lengths. These electrodes are so heavy that they require a manipulator to hold and feed them. Massive electrode welding is primarily used for repairing very large castings.

5.3.0 Wearfacing

The Seabee welder can greatly extend the life of construction equipment by using 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 a 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.

5.3.1 Workpiece Preparation

Before you wearface a workpiece, remove all dirt, oil, rust, grease, and other foreign matter. 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.

5.3.2 Preheating

Depending on the type of metal, sometimes it is necessary to preheat the base metal to lessen distortion, prevent spalling or cracking, and 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. However, improper heating can adversely affect a metal by reducing its resistance to wear, making it hard and brittle or more prone to oxidation and scaling.

To preheat properly, you must know the composition of the base metal. You can use a magnet 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 non-worked 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 a chisel strikes them.

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

5.3.3 Techniques

Where possible, position the workpiece for downhand welding. This allows you to finish the job more quickly and at less cost.

Building up and wearfacing 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 or hammering the 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 the base metal and the wearfacing overlay and strong enough to meet the structural requirements. Also, they must have the properties that enable them to resist cold flowing, mushing under high-compressive loads, and plastic deformation under heavy impact. Without these properties, the buildup materials cannot support the wearfacing overlay. When the overlay is not properly supported, it will spall.

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. (*Figure 8-20*) Limit the thickness of a single pass bead to 3/16-inch. Use the same technique for each layer and avoid severe quenching.

Figure 8-20 — Wearfacing techniques.

Deposits made with high-alloy electrodes should check on the surface. Checking reduces residual (locked-in) stresses. Without checking, the combination of residual stresses and service stresses may exceed tensile strength and cause deep cracks or

Figure 8-21 — Comparison between cross-checking and cracking.

spalling (*Figure 8-21*). 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 the deposit with a hammer while it is cooling. When you require a check-free deposit, use a softer alloy and adjust preheating and post-heating requirements.

5.3.3.1 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 (*Figure 8-22*).

Figure 8-22 — Wearfacing.

5.3.3.2 Shovel teeth

Shovel teeth should be wear-faced 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 (*Figure 8-23*). This allows the rock to ride on the hard metal beads. Wear-face teeth that are primarily used to work in dirt, clay, or sand with beads running across the width of each tooth, perpendicular to the direction of the material that flows past the teeth. This allows the material to fill the spaces between the beads and provides more protection to the base metal. Another effective pattern is the waffle or crosshatch (*Figure 8-24*). Lay the wearfacing on the top and sides of each tooth, 2 inches from its point. Stringer beads behind a solid deposit reduce wash (*Figure 8-25*).

Figure 8-23 — Wearfacing shovel teeth.

Figure 8-24 — Waffle or crosshatching

Figure 8-25 – Comparison of wearfacing patterns for shovel teeth.

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

5.4.0 Carbon-Arc Cutting

Metals can be cut cleanly with a carbon electrode arc because it does not introduce foreign metals at the arc. The cutting current should be 25 to 50 amps above the welding current for the same thickness of metal. See *Table 8-10* for more information.

Table 8-10 — Recommended Electrode Sizes, Current Settings, and Cutting Speeds for Carbon-Arc Cutting Different Thickness of Steel Plate

Current Setting and Carbon Diameter				
Thickness of Plate Inches	300 amps. ½ in. Diameter	500 amps. 5/8 in. Diameter	700 amps. ¾ in. Diameter	1000 amps. 1 in. Diameter
Speed of Cutting in Minutes Per Foot				
½	3.5	2.0	1.5	1.0
¾	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

Grind the carbon electrode point 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 removing the molten metal. As in oxygen cutting, a crescent motion is preferred. *Figure 8-26* shows the relative positions of the electrode and the work in the cutting of 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 8-10* 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, do not let it extend more than 6 inches beyond the holder when cutting. If the carbon burns away too fast, shorten the length 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.

Figure 8-26 — Carbon-arc cutting on cast iron.

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

Because of the high temperature and the intensity of the arc, choose a shade of helmet lens 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.

5.4.1 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 metal. *Figure 8-27* shows the process. The equipment consists of a special holder, shown in *Figure 8-28*, 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 between 60 and 100 psig.

Figure 8-27 — Air carbon-arc cutting.

Figure 8-28 — Air carbon-arc electrode holder with carbon electrode installed.

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 prolongs 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. Adjust the electrode relative to the holder.

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

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.

5.4.2 Air Carbon-Arc Gouging

Air carbon-arc gouging is useful in many 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 electrode angle and travel speed control the depth and contour of the groove. The diameter of the electrode governs the width of the groove.

When cutting or gouging a shallow groove on the surface of a piece of metal, 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 you can cut the groove. *Figure 8-29* shows an example of a V-groove cut made in a 2-inch-thick mild steel plate by a machine guided carbon-arc air-jet.

Figure 8-29 — V-groove gouged in 2-inch thick carbon steel.

5.4.3 Metal Electrode Arc Cutting

You can remove metal with the standard electric arc, but for good gouging or cutting results, use special metal electrodes 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 (*Figure 8-30*). The main disadvantage of these electrodes is that the additional metal they produce must be removed.

Figure 8-30 — Steel electrode being used to cut plate.

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

A typical gouge-cutting operation is shown in *Figure 8-31*. Notice that the angle between the electrode and plate is small (5 degrees or less). This makes it easy to remove the extra metal the electrode produces.

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 from 125 to 300 amperes; for 5/32-inch electrodes, the setting ranges from 250 to 375 amperes; and for 3/16-inch electrodes, the setting ranges from 300 to 450 amperes. Use a very short arc, and when cutting takes place underwater, the coating must be waterproof.

Figure 8-31 — Gouge-cutting operation using a solid core arc-cutting electrode.

Test your Knowledge (Select the Correct Response)

5. Which of the following electrodes is typically used to weld in the root passes in industrial piping?

   A. E6010
   B. E7010
   C. E6024
   D. E7024

6. What characteristic makes the carbon-arc method of cutting successful on cast iron?

   A. Directionality
   B. Versatility
   C. High temperature
   D. Low voltage

6.0.0 WELDING METALLURGY

Welding metallurgy concerns the chemical, physical, and atomic properties and structures of metals and the principles by which metals are combined to form alloys.

6.1.0 Properties of the Weld

The properties of the weld are items such as chemical composition, mechanical strength and ductility, and microstructure. These items will determine the quality of the weld. The types of materials used affect the chemical properties. The heat input of welding and the chemical composition of the materials determine the mechanical properties and microstructure of the weld.

6.1.1 Chemical Properties

The chemical composition of the base metal is a major factor in determining the choice of the electrodes to use for welding. The chemical composition of the base metal influences the need for preheating and postheating, because preheating and postheating are used to prevent the weld area from becoming brittle and weak.

When welding steels, the carbon and other alloy content influences the hardness and hardenability of the weld metal, which in turn influences the amount of preheat and postheat needed. The two terms, hardness and hardenability, are not the same. The maximum hardness of the steel is primarily a function of the amount of carbon in the steel. Hardenability is a measure of how easily a ***martensite*** structure is formed when the steel is quenched. Martensite is the phase or metallurgical structure in steel where the maximum hardness of the steel can be obtained. Steels with low hardenability must have very high cooling rates to form martensite; whereas, steels with high hardenability will form martensite even when slow cooled in air. The hardenability will determine the extent to which a steel will harden during welding. The carbon equivalent formula is one of the best methods of determining the weldability of steels. The amounts of some of the alloying elements used determine this. There are several different formulas used, one of these is as follows:

$$\text{Carbon Equivalent} = \%\text{C} + \frac{\%\text{Cr}}{10} + \frac{\%\text{Mn}}{6} + \frac{\%\text{Mo}}{10} + \frac{\%\text{Ni}}{20} + \frac{\%\text{Cu}}{40}$$

Steels with lower carbon equivalents generally are more readily weldable and require fewer precautions such as the use of preheat and postheat.

Steels with higher carbon equivalents are generally more difficult to weld. Matching the chemical properties of the filler metal is not as important as matching the mechanical properties when welding many of the steels. Often, filler metal with a lower carbon content than the base metal is used because the weld metal absorbs carbon from the base metal during solidification.

The amount of preheat needed depends on the type of metal being welded, the metal thickness, and the amount of joint restraint. Preheating helps reduce the cooling rate of the part being welded. This is important on many steels because a slower cooling rate will not allow as much of the hard and brittle martensite structure to form in the metal. Since martensite formation is the carbon equivalent, steels with high-carbon equivalents will generally require higher preheat temperatures than those with low-carbon equivalent values. *Table 8-11* shows typical preheat values for different steels and cast iron.

Table 8-11 — Typical Recommended Preheats for Various Steels and Cast Iron Welded by the SMAW Process

Type of Steel	Preheat
Low-Carbon Steel	Room Temperature or up to 200°F (93°C)
Medium-Carbon Steel	400-500°F (205-260°C)
High-Carbon Steel	500-600°F (260-315°C)
Low Alloy Nickel Steel -Less than ¼' (6.4 mm) thick -More than ¼' (6.4 mm) thick	Room Temperature 500°F (260°C)
Low Alloy Nickel-Chrome Steel -Carbon content below .20% -Carbon content .20% to .35% -Carbon content above .35%	200-300°F (93-150°C) 600-800°F (315-425°C) 900-1100°F (480-595°C)
Low Alloy Manganese Steel	400-600°F (205-315°C)
Low Alloy Chrome Steel	Up to 750°F (400°C)
Low Alloy Molybdenum Steel Carbon content below .150% Carbon content above .15%	Room Temperature 400-650°F (205-345°C)
Low Alloy High Tensile Steel	150-300°F (66-150°C)
Austenitic Stainless Steel	Room Temperature
Ferritic Stainless Steel	300-500°F (150-260°C)
Martensitic Stainless Steel	400-600°F (205-315°C)
Cast Irons	700-900°F (370-480°C)

NOTE

The actual preheat needed may depend on several other factors such as the thickness of the base metal, the amount of joint restraint, and whether or not low-hydrogen types of electrodes are used. This chart is intended as general information; check the specifications of the job for the specific preheat temperature to use.

Another major factor that determines the amount of preheat needed is the base metal thickness. Thicker base metals usually need higher preheat temperatures than thinner base metals because of the larger heat sinks that the thicker metals provide. Thick metals draw the heat away from the welding zone more quickly because there is a larger mass of metal. This increases the cooling rate of the weld if the same preheat temperature is used as with thinner base metals. The third major factor determining preheat is the amount of joint restraint. Joint restraint is the resistance of a joint configuration to moving during the heating and cooling of the weld zone. When there is high resistance to moving or high joint restraint, large amounts of internal stress builds up. Higher preheat temperatures are needed as the amount of joint restraint increases. Slower cooling rates reduce the amount of internal stresses that build up as the weld cools.

For welding nickel-base metals, copper base metals, and stainless steels, the chemical properties of the weld metal are often the most important properties of the weld. The chemical composition of the weld metal must closely match the chemical composition of the base metal to give the weldment good corrosion resistance and creep resistance. Creep resistance of a metal is the resistance to softening at high temperatures which can cause deformation if there is a load on the metal.

6.1.2 Mechanical Properties

The mechanical properties that are most important in the weld are the tensile strength, yield strength, elongation, reduction of area, and impact strength. The first two are measures of the strength of the material, the next two are a measure of ductility, and the last is a measure of impact toughness. These properties are important in shielded metal arc welding.

Yield strength, ultimate tensile strength, elongation, and reduction of area are all measured from a .505 in. (12.B mm) diameter machined testing bar. The metal is tested by pulling it in a tensile testing machine. *Figure 8-32* shows a tensile bar before and after testing. The yield strength of the metal is the stress at which the material is pulled beyond the point where it will return to its original length. The tensile strength is the maximum load the metal can carry. This is also measured in psi (MPa). Elongation is a measure of ductility that is also measured on the tensile bar. Two points are marked on the bar 2 in. (51 mm) apart before testing. After testing, the distance between the two points is measured again and the percent of change in the distance between them, or percent elongation, is measured.

Figure 8-32 — Tensile strength testing bars.

Reduction of area is another method of measuring ductility. The original area of the cross section of the testing bar is .505 sq. in (104 sq. mm). During the testing, the diameter of the bar reduces as it elongates. When the bar finally breaks, the diameter of the bar at the breaking point is measured, which is then used to determine the area. The percent reduction of this cross sectional area is called the reduction of area.

Impact tests are used to measure the toughness of a metal. The toughness of a metal is its ability to absorb mechanical energy by deforming before breaking. The Charpy Vee-notch test is the most commonly used method of testing impact toughness. *Figure 8-33* shows some typical Charpy Vee-notch test bars. Bars with Vee-notches are put in a machine where they are struck by a hammer attached to the end of a

Figure 8-33 — Charpy V-notch bars

pendulum. The energy required to break these bars is known as the impact strength and is measured in foot-pounds (Newton-meters).

6.1.3 Microstructure

Figure 8-34 shows a cross section of a weld bead showing the weld metal zone, the heat affected zone, and the base metal zone. The weld metal zone is where the metal was molten during welding. The heat affected zone is the area where the heat from welding has had an effect on the microstructure of the base metal. The base metal zone is the area that was not affected by the welding. The extent of change of the microstructure depends on four factors:

1. Maximum temperature to which the weld metal was subjected
2. The time that the weld spent at that temperature
3. The chemical composition of the base metal
4. The cooling rate of the weld

Figure 8-34 — Cross section of weld bead showing in the three areas.

The weld metal zone, the area heated above about 2800°F (1540°C) and melted, generally has the coarsest grain structure of the three areas. For the most part, welding with the shielded metal arc process produces a fairly fine grain size in steels, so a large grain size in the weld zone is not much of a problem when this process is used. Large grain size is undesirable because it gives the weld poor toughness and cracking resistance. The solidification of the weld metal starts at the edge of the weld puddle next to the base metal. The grains that form at the edge are called dendrites and they grow toward the center of the weld into the area that is still molten. This gives the weld metal its characteristic columnar grain structure. The grains that form in the weld zone are similar to the grains that form in castings. The grain size in the weld zone can be affected by the electrode covering as well as the factors mentioned before. One of the functions of the electrode coverings is to provide deoxidizers and scavengers to reduce the grain size of the metal. The greater the heat input to the weld and the longer it is held at high temperatures, the larger the grain size will be. A fast cooling rate will produce a smaller grain size than a slower cooling rate. Preheating will give larger grain sizes, but it is often necessary to prevent the formation of the hard and brittle martensite structure.

The heat affected zone is the area around the metal zone which has been affected by the heat of welding but did not become molten. For example, in mild steels, the area that reaches a temperature of 2200-2800°F (1220-1550°C) goes through a grain coarsening. The area of the heat affected zone that reaches 1700-2200°F (950-1220°C) will go through grain refinement. The area that is heated from 1400-1700°F (780-950°C) is annealed and made considerably softer.

The base metal zone is the area that is heated to 1300°F (720°C) or less and is basically unchanged.

6.2.0 Metals Weldable

Shielded metal arc welding may be used to weld a wide variety of base metals. The metals that are the most easily welded with the shielded metal arc welding process are the mild steels, low alloy steels, stainless steels and chromium-molybdenum steels. Cast irons, medium- and high-carbon steels, and hardenable types of steel may also be welded using this process, but special precautions must be taken. The selection and care of the electrodes is more critical when welding hardenable steels. Copper alloys and nickel are often welded by this process, but gas metal arc welding (MIG) and gas tungsten arc welding (TIG) are more widely used for welding these metals. Zinc, lead, and tin cannot be welded by shielded metal arc welding because of their low melting points. Aluminum can be welded by this process, but it is not very popular. Magnesium is not welded with the shielded metal arc welding process.

6.2.1 Steels

In general, steels are classified according to carbon content, such as low-carbon, medium-carbon, or high-carbon steels. Steels are also classified according to the types of alloy used such as chrome-moly, nickel-manganese, etc. For the purpose of discussion in this chapter, steels will be classified according to their welding characteristics.

6.2.1.1 Mild Steels

Mild steels are generally those that have low carbon content and are most readily weldable. These steels are the most widely used type of metal for industrial fabrication. Included in this group are the low-carbon steels and the high strength structural steels.

Low-carbon steels have carbon content up to .30%. Mild steel electrodes of the E60XX series classification may be used for welding these steels, but E70XX series electrodes are used when higher strengths are required. The E70XX series electrodes are used, especially when the carbon content of the steels approach .30%. Preheating is often used, especially on thicker sections, highly restrained joints, or where codes require preheating. Other precautions such as controlled interpass temperature and postheating are often required. These heat controls help reduce the cooling rate of the weld metal and prevent large amounts of martensite from forming. On thicker sections, cracking may occur in the weld deposit or the heat affected zone. If preheating, interpass temperature control and postheating are not used. Use of these heat controls will help prevent the reduction of weld toughness, strength, and ductility.

The high strength structural steels are steels with yield strength between 45,000 psi (310 MPa) and 70,000 psi (485 MPa) and carbon content generally below .25%. These steels have relatively small amounts of alloying elements. Some common examples of these steels are ASTM designations A242, A441, A572, A588, A553 and A537. Preheating is generally not required when low hydrogen electrodes are used, except on thick sections or highly restrained joints where preheating is required. Preheating is required when the higher hydrogen types of electrode are used.

6.2.1.2 Low Alloy Steels

The low alloy steels discussed here will be those that are low-carbon and have alloy additions less than 5%. This includes the quenched and tempered steels, heat treated low alloy steels, and low nickel alloy steels. Elements such as nickel, chromium, manganese, and molybdenum are the main alloying elements these steels contain. These steels have a higher hardenability than mild steels and this factor is the principal complication in welding. This higher hardenability permits martensite to form at lower cooling rates. As the alloy content and the carbon content increase, the hardenability also increases. In general, the weldability of the steel decreases as the hardenability increases. One of the best methods for determining the weldability of a low alloy steel is the carbon equivalent formula. Steels that have carbon equivalents below about .40% usually do not require preheating and postheating in the welding procedure and generally have the best weldability. Steels with carbon equivalents higher than .40% require more precautions for welding. Generally, the higher the carbon equivalent, the more difficult the steel is to weld. Low alloy steels are fairly weldable but not as easily weldable as the mild steels. Except in the case of the low nickel alloys, the selection of electrodes for welding these steels is based on the strength and mechanical properties desired of the weld rather than matching chemical compositions.

The quenched and tempered heat treated steels have yield strengths ranging from 50,000 psi (345 MPa) to very high yield strengths and have carbon content up to .25%. Some common examples of these types of steel are ASTM designations A533 Grade B, A537 Grade B, A514, A517, A543, and A553. The .25% carbon limit provides fairly good weldability. These steels provide high tensile and yield strength along with good ductility, notch toughness, corrosion resistance, fatigue strength and weldability. The presence of hydrogen is always bad in steel but it is even more critical in these types of steels compared to mild steels. Low hydrogen electrodes should be used when welding these steels. Preheat is generally not used on thinner sections, but it is used on thicker or highly restrained sections. Postweld heat treatment is generally not used because the shielded metal arc welds made in these have good toughness. The steels are generally used in the welded or stress relieved conditions.

The nickel alloy steels in these low alloy steel groups are those with less than 5% nickel content. The 2 1/4% and 3 1/2% nickel steels are usually welded with covered electrodes that have the same general chemical composition as the base metal. Preheating is required with highly restrained joints.

6.2.1.3 Heat Treatable Steels

The heat treatable steels are the medium- and high-carbon steels and medium-carbon steels that have been alloyed. This group includes steels quenched and tempered after welding, normalized or annealed steels, and medium- and high-carbon steels. These steels are more difficult to weld than the other types this chapter mentions. The most important factor for selecting the type of covered electrode to use is matching the chemical compositions of the base metal and the filler metal.

Medium-carbon steels have carbon content ranging from .30% to .60% and high-carbon steels have carbon content ranging from .6% to about 1.0%. When welding medium- and high-carbon steels, include precautions in the welding procedure because of the hardness that can occur in the weld joint. As the carbon content increases up to .60%, the hardness of the fully hardened structure (or martensite) increases to a maximum value. When the carbon content is above .60%, the hardness of the fully hardened structure does not increase, so these steels can be welded using about the same welding procedures as the medium-carbon steels. Martensite, which is the phase in which steel is at its fullest hardness, is harder and more brittle in high-carbon steel than in low-carbon steel. A high-carbon martensitic structure can have a tendency to crack in the weld metal and the heat affected zone during cooling. Welding procedures that lower the hardness of the heat affected zone and the weld metal reduce the cracking tendency. This can be done by using a procedure that reduces the carbon content in the filler metal and by slowing the cooling rate. The procedure includes the use of low hydrogen electrodes, preheat, interpass temperature control, and a postheat. The procedures for welding medium-carbon steels can be simpler than the one just mentioned, but that depends on the specific application. Medium-carbon steels can be welded with the low hydrogen electrodes of the E70XX, E80XX, or E90XX classifications. Weld high-carbon steels with the low hydrogen electrodes of the E80XX to the E120XX classes using the electrode of the proper tensile strength to match the tensile strength of the base metal. Generally, high-carbon steels are not used in welded production work. These steels are usually only welded in repair work. Mild steel electrodes may also be used, but the deposited weld metal absorbs carbon from the base metal and thus loses a considerable amount of ductility. Stainless steel electrodes of the austenitic type are sometimes used, but the fusion zone may still be hard and brittle. A preheat and/or postheat wiIl help eliminate the brittle structure.

The steels quenched and tempered after welding have carbon content from about .25% to .45%, which distinguishes them from the steels that are quenched and tempered before welding. These steels also have small additions of alloying elements. Some common examples of these steels are the AISI designations 4130, 4140 and 4340. Because of the higher carbon contents, the steels in this group can be heat treated to extremely high levels of strength and hardness. Some of these steels have enough alloy content to give them high hardenability. Because of this combination of carbon and alloy content, the steels must be preheated before welding. The weldability of these steels is also influenced by the purity of the steels. High amounts of sulfur and phosphorous in the steel increase sensitivity to cracking and reduce ductility. The shielded metal arc welding process is often used for welding steels that are quenched and tempered after welding. The selection of the proper electrode to use is based on the chemical composition, strength required, and thickness of the base metal. The composition of the weld metal is usually similar to that of the base metal. Low hydrogen electrodes are the most commonly used for welding of steels.

6.2.1.4 Chromium-Molybdenum Steels

The chromium-molybdenum steels in this section are those with alloy contents of 6% or less. These steels are in the low-carbon range, generally up to .15%, and are readily weldable. The chromium and molybdenum alloying elements provide these steels with good oxidation resistance and high temperature strength. The chromium is mainly responsible for the oxidation resistance, the molybdenum mainly responsible for the high temperature strength. All of the electrodes manufactured for welding stainless steels, recognized by the AWS, are of the low hydrogen type. Stainless steel electrodes of the EXXX-15 type have a lime based coating and the EXXX-16 types have a Titania based coating. The type EXXX-15 electrodes give greater penetration where the EXXX-16 type gives a smoother surface finish.

The shielded metal arc welding process is one of the most common methods of welding the chromium-molybdenum steels. The stainless steel low hydrogen electrodes (EXXX-15, EXXX-16.and EXXX-18) are used for welding except on the 1/2% Cr % Mo steels where the mild steel EXX10, EXX11, and EXX13 may be used. The cellulose coated electrodes for welding the other chromium-molybdenum steels are not used because they can cause underbead cracking. The use of the low hydrogen electrodes greatly reduces the amount of hydrogen present during welding.

6.2.1.5 Stainless & Higher Chromium-Molybdenum Steels

The steels included in this group are the higher chrome-moly steels, martensitic stainless steels, ***ferritic*** stainless steels and austenitic stainless steels. The major element that sets these steels apart from other steels is the high chromium content. Stainless steels have more than 11% chromium. The addition of chromium gives the steels a very high resistance to oxidation and increases the hardenability up to a point. If steel has too much chromium in it, it cannot be hardened at all. Stainless steels containing chromium above about 16% are generally non-hardenable. Chromium levels above about 25% give the stainless steel very good oxidation resistance at high temperatures. Normally, when you weld stainless steel, you should match the chemical composition of the filler metal and the base metal.

The higher chrome-moly steels contain about 6-10% chromium and .5-1% molybdenum. These steels are limited to a maximum carbon content of about .10% to limit the hardness because these steels are very sensitive to air hardening. For welding these steels, preheating, interpass temperature control, slow cooling, and postweld heat treatment are required to make a weld with good mechanical properties.

The martensitic hardenable stainless steels generally have chromium contents between 11 and 13%. Some typical examples of these kinds of steels are the American Iron and Steel Institute (AISI) designations 403, 405, 410, 420, and 440. The most easily weldable are the steels with the lowest carbon contents. For applications requiring high hardness, such as cutlery, higher carbon contents, such as those types 420 and 440 contain, are desired. Types such as 420 and 440 are rarely welded. Electrodes with the same chemical compositions as the base metal are usually required for welding martensitic stainless steels. Sometimes, austenitic stainless steel or ***Inconel*** types of covered electrodes are used to weld martensitic stainless steel to avoid the use of preheat, but they give weld metal with lower strength than the base metal. When using martensitic stainless steel covered electrodes, preheating and postheating are required so that the weld metal will not be weaker than the base metal. The ferritic nonhardenable stainless steels have chromium contents greater than 13%. As mentioned before, the higher chromium content makes these steels nonhardenable. Some typical examples of these types of stainless steels are the AISI designations 430, 436, 442 and 446. These stainless steels require preheating and postheating. Type 446 steel, which has 25% chromium, is very susceptible to rapid grain growth in the weld heat affected zone. Large grain sizes reduce the toughness and make the weld area more susceptible to cracking. Preheating and postheating minimize this grain growth. Austenitic stainless steel electrodes are often used, but this does not help reduce the grain size of the heat affected zone.

The austenitic nonhardenable stainless steels have at least 11 or 12% chromium and up to about 26% chromium with additions of nickel ranging from about 3.5 to 22%. Nickel is a strong austenite former, and it helps keep these kinds of steels in the austenitic phase at all temperatures, which also makes these steels nonhardenable. Austenitic stainless steels have very good oxidation resistance and high temperature strength. The austenitic stainless steels are designated by the AISI as the 200 and 300 series. In the 200 series of steels, manganese is used to replace some of the nickel. Some common examples of these steels are the Types 302, 304, 308, 310, 316, 321, 347, 201, and 202. Austenitic stainless steels have good toughness and ductility and are the most readily weldable of the stainless steels. When shielded metal arc welding is used to weld austenitic stainless steel, the filler metal composition is generally chosen to match the base metal.

The weld metal deposited by austenitic stainless steel electrodes generally has higher chromium and nickel contents than the base metal. Distortion is often a problem when welding these steels because they have a coefficient of expansion that is about 50%

higher than for carbon steels, which creates residual stresses. Preheating and postheating are usually not required, but preheating may be used to remove the chill.

6.2.1.6 Free Machining Steels

Free machining steels are steels that have additions of sulfur, phosphorous, or lead in them to make these steels easier to machine. Except for the lead, phosphorous, and sulfur contents, these steels often have chemical compositions of mild, low alloy, and stainless steels. This addition of these elements makes these steels unweldable. The reason for this is because the elements lead, phosphorous and sulfur have melting points that are much lower than the melting point of steel. As the weld solidifies, these elements remain liquid much longer than the steel so that they coat the grain boundary which causes hot cracking in the weld. Hot cracking is cracking that occurs before the weld has had a chance to cool. Because of this hot cracking problem, free machining steels cannot be welded successfully.

6.2.2 Cast Irons

Many types of cast irons may be welded using shielded metal arc welding. Cast irons have a carbon content higher than that of steel. Carbon is present in cast irons in two forms, as free carbon (graphite) and as combined carbon (as in steels). There are several types of cast irons: white, gray, ***malleable***, modular, and austenitic. All of these are weldable except white cast iron, which is considered unweldable.

6.2.2.1 Gray Cast Iron

In gray cast irons, the graphite has a flake appearance. These flakes produce sharp notches and discontinuities which make gray cast iron brittle. The tensile strength of gray cast iron is usually between 30,000 psi (210 MPa) and 40,000 psi (280 MPa).

The success of shielded metal arc welding usually depends on the specific tensile strength, the form and distribution of graphite, the amount of sulfur and phosphorous, and the amount of joint restraint. Nickel base welding electrodes are widely used for welding gray cast iron, and preheating and interpass temperature controls are required except on minor repair jobs.

6.2.2.2 Nodular and Malleable Cast Irons

In malleable cast irons, the graphite has a nearly spheroidal appearance and in ***nodular*** iron, the graphite has a spheroidal appearance. The malleable and nodular cast irons do not have the brittleness that the gray cast irons have because of the shape of the graphite.

Nickel-base covered electrodes are also used for welding malleable and nodular cast irons. After these cast irons have been welded, they should be annealed to obtain optimum ductility.

6.2.3 opper and Copper Alloys

When it is used to weld copper and copper alloys, shielded metal arc welding is mainly used for minor repair jobs, difficult to reach fillets, or dissimilar metals. Shielded metal arc welding does not do as good a job as the gas metal arc welding (MIG) or the gas tungsten arc welding (TIG) process. The filler metal used for welding copper and copper alloys contains deoxidizers. Shielded metal arc welding of these metals is generally restricted to the flat position. Out of position welding can only be performed satisfactorily on phosphor bronzes and copper nickels. Shielded metal arc welding is usually not recommended for welding many of the copper alloys because it produces poor mechanical properties and many unsound welds. The coppers and brasses are generally not welded using this process.

6.2.4 Nickel and Nickel Alloys

The shielded metal arc welding process can be used to weld nickel and nickel alloys in thicknesses ranging down to about .050" (1.3 mm). The covered electrodes used have chemical compositions similar to the base metals being welded. Elements such as manganese, columbium and titanium are contained by the electrodes and act as deoxidizers and prevent weld metal cracking. Direct current electrode positive welding current is used when welding nickel and nickel alloys. Flat position welding is used whenever possible because it produces a better quality weld. Molten nickel alloy weld metal does not flow as well as molten steel weld metal so the nickel alloy weld metal must be deposited where it is needed. Oscillating or weaving techniques are usually needed because of this. The heat of the welding arc usually does not have a negative effect on the nickel base metals. Preheat is usually not required for welding these metals, but the base metal should be warmed to at least 70°F (21°C) to avoid condensation of moisture, which could produce porosity in the weld metal.

Test your Knowledge (Select the Correct Response)

7. What primary property determines the maximum hardness of steel?

   A. The amount of heat used to make the steel
   B. The amount of carbon in the steel
   C. The amount of alloy in the steel
   D. The thickness of the steel

8. Which cast iron is considered unweldable?

   A. White
   B. Gray
   C. Modular
   D. Austenitic

7.0.0 WELD AND JOINT DESIGN

The weld joint design used for shielded metal arc welding is determined by the design of the workpiece, metallurgical considerations, and codes or specifications. Joints are designed for accessibility and economy during construction. Good accessibility during construction also helps reduce the cost and generally raises the quality of the weld joint. A weld joint consists of a type of weld made in a type of joint. There are five basic types of joints, but these can be used in various combinations. A joint is the junction of members that are to be joined or have been joined. *Figure 8-35* shows the five basic joint classifications.

Figure 8-35 — Types of joints.

Each type of joint can be joined by many different types of welds. *Figure 8-36* shows the most common types of welds made. The type of weld made is governed by the joint configuration. *Figure 8-37* shows the weld nomenclature for groove and fillet welds.

Figure 8-36 — Types of welds.

Figure 8-37 — Weld nomenclature.

7.1.0 Strength

The strength required of the weld joint is a major consideration for determining the design of a welded joint. Weld joints are either full penetration or partial penetration, depending on the strength required for the weld joint. Full penetration weld joints have weld metal through the full cross section of the joint. Partial penetration weld joints have an unfused area in the joint. Welded joints subject to dynamic, cyclic, or impact loads usually require full penetration when full strength is required. These factors are even more important when the weld joints are used for low temperature service. Partial penetration welds may be adequate for joints that are statically loaded. These types of joints are easier to prepare and require less filler metal than full penetration joints.

7.2.0 Position

The shielded metal arc welding process can be used in all welding positions. The position in which the welding is to be done affects the design of the joint. The figures at the end of the section show some examples of this. A diagram of the welding position capabilities of shielded metal arc welding is shown in *Figure 8-38*. Welding in the horizontal, vertical, and overhead positions depends on the skill of the welder and the type of electrode the welder uses. The high deposition class of electrodes can normally only be used in the flat and horizontal positions because of the large weld puddles they produce.

Welding positions are classified by a set of numbers and letters. The four basic welding positions are designated by the numbers 1 for flat, 2 for horizontal, 3 for vertical, and 4 for overhead. F designations are used for fillet welds and G designations for groove welds. The 5G and 6G positions are test positions used in pipe welding. *Figure 8-38* also shows the number and letter designations for both plate and pipe.

Figure 8-38 — Welding test positions.

7.3.0 Thickness

The thickness of the metal that can be welded by the shielded metal arc welding process depends on welder skill, joint position, type of joint, fit-up, type of electrode, welding speed, arc length, welding current, and arc characteristics. The minimum thickness of metal that can be welded is dependent on the skill of the welder; a skilled welder can weld steel as thin as 1/16 in. (1.6 mm). Steel as thick as 1/4 in. (6.4 mm) can be welded without groove preparation if the width of the root opening is adequate to achieve full penetration welds. Partial penetration welds can be made in 1/2 in. (12.7 mm) thick metal without beveling. Thicker materials than those mentioned require joint preparation and multiple passes. Common beveled joint configurations for groove welds are the U, V, J, bevel, and combination grooves. The J, bevel, and combination groove configurations are also used for fillet welds. These configurations make it possible to get full penetration welds on thicker material. The thicker the material, the more passes it takes to fill the joint for a given joint design. Single bevel and V groove are the most often used types of edge preparation.

U grooves are the most common because they are the easiest to prepare. The bevels on the sides of the groove can be prepared by flame cutting; the joint faces of the J and U grooves are prepared by machining. Flame cutting is quicker than machining, so flame cutting reduces the preparation time.

U grooves generally require less filler metal than V grooves. Welding U grooves allows use of larger electrodes for the first pass than does welding V grooves because of the U grooves' rounded bottom. However, spacer strips may be used in V grooves to provide easier access to the root.

Single bevel and J grooves are often used for corner and Tee-joints. Single V, single U, and single bevel grooves are the most common types of edge preparation for butt joints 3/16 in. (4.8 mm) or 1/4 in. (6.5 mm) thick to about 3/4 in. (19.1 mm) thick.

When the base metal is 3/4 in. (19.1 mm) or more, double V, double U, double bevel, and double J grooves are usually recommended if welding from both sides is possible. Joints welded with these grooves produce less distortion and require less filler metal than grooves that must be welded from one side. Groove angles of 45° to 60° are used for thinner base metals needing grooves, but are too large for use in thicker base metals. Smaller groove angles are used for the larger metal thicknesses because they require less welding time to fill than a 45° or 60° groove angle.

Figure 8-39 — Variation of single V-groove joint design for unlimited thickness base metal.

There are many variations of the basic joint designs. One design often used for the welding of thick walled pipe and thick plate over 3/4 in. (19.1 mm) is the variation of the single V groove joint shown in *Figure 8-39*. This is used when the joint is accessible from one side. It uses a steeper slope toward the top of the joint where the bevel angle has been reduced. The advantage of this type of joint design over a normal V groove design is that it is less expensive to weld because it requires less filler metal to fill the joint. The wider V groove toward the bottom gives good accessibility to the root of the joint. A disadvantage of this joint design is that it is more difficult to prepare the two different bevel angles.

7.4.0 Accessibility

Accessibility is another important factor in determining the joint design for shielded metal arc welding. Welds can be made either from one side or from both sides of the base metal. On thicker metals, when both sides of the joint are accessible, double bevels are usually made. The advantage of this is that the double bevels have less area to fill than single bevels and require less filler material. The roots of the welds are usually near the center of the base metal when double bevels are used. When the joints are only accessible from one side, U and J groove preparations are often used so that the root is more easily accessible, and on thick sections, less filler metal is required to fill the joint than with a standard V groove preparation. However, U and J grooves are harder and more expensive to prepare.

Table 8-12 — Effective throat thickness for partial joint penetration grove welds.

Base Metal Thickness of Thicker Part Joined			Minimum Effective Throat	
	In	(mm)	In	(mm)
To	1/4	(6.4) inclusive	1/8	(3)
Over	1/4 to 1/2	(6.4 to 12.7) inclusive	3/16	(5)
Over	1/2 to 3/4	(12.7 to 19.0) inclusive	1/4	(6)
Over	3/4 to 1 1/2	(19.0 to 38.1) inclusive	5/16	(8)
Over	1 1/2 to 2 1/4	(38.0 to 57.1) inclusive	3/8	(10)
Over	2 1/4 to 6	(57.1 to 152) inclusive	1/2	(13)
Over	6	(152)	5/8	(16)

The weld joint designs in the rest of the chapter are those commonly used for shielded metal arc welding. *Table 8-12* shows the minimum effective throat thicknesses for partial penetration welds, according to the AWS Structural Welding Code (AWS D1.1). The effective throat thickness is the minimum distance between the root of the weld and the surface less the reinforcement. *Figures 8-40* and *8-41* show the American Welding Society's "Standard Welding Symbols," some of which have been used in the weld joint designs.

Figures 8-42 through 8-52 show different welding position symbols.

Figure 8-40 — Welding symbols.

Figure 8-41 — Welding symbols (cont.).

Figure 8-42 — Basic joints.

Figure 8-43 — Applications of arrow and other side conventions.

Figure 8-44 — Applications of break in arrow of welding symbol.

Figure 8-45 — Combinations of weld symbols.

Figure 8-46 — Combinations of weld symbols (cont.).

Figure 8-47 — Specification of location and extent of fillet welds.

Figure 8-48 — Specification of location and extent of fillet welds (cont.).

Figure 8-49 — Specification of extent of welding.

Figure 8-50 — Specification of extent of welding (cont.).

Figure 8-51 — Applications of “typical” welding symbols.

Figure 8-52 — Applications of melt-through symbol.

7.5.1 Weld Joint Designs

The details of a joint, which include 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, other factors must be considered. A few of these factors are as follows:

1. Whether the load will be in tension or compression and whether bending, fatigue, or impact stresses will be applied
2. How a load will be applied; that is, whether the load will be steady, sudden, or variable
3. The direction of the load as applied to the joint
4. The cost of preparing the joint

Another consideration 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 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 course, we discussed the five basic types of welded joints—butt, corner, tee, lap, and edge.

Keep in mind that there are many different variations of the basic joint welds. If you want more information, refer to Chapter 3, “Introduction to Welding.”

7.6.0 Arc Welding Positions

The types of welds, joints, and welding positions used in shielded metal arc welding are very similar to those used in oxygas welding. Naturally, the techniques are somewhat different because the equipment involved is different.

7.6.1 Flat-Position Welding

Welding can be done in any position, but it is much simpler 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 you can achieve better penetration. 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.

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 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. *Figure 8-53* shows several forms of butt joints.

Plates up to 1/8-inch thick can be welded in one pass with no special edge preparation.

Figure 8-53 — Butt joints in the flat position.

Plates from 1/8- to 3/16 -inch thick also can be welded with no special edge preparation by welding on both sides of the joint. Use tack welds to keep the plates aligned for welding. The electrode motion is the same as that used in making a bead weld.

Figure 8-54 — Butt welds with multipass beads.

In welding 1/4-inch plate or heavier, prepare the edges of the plates by beveling or by J-, U-, or V-grooving, whichever is the most applicable. Use single or double bevels or grooves when the specifications and/or the plate thickness require it. Deposit the first bead to seal the space between the two plates and to weld the root of the joint. Thoroughly clean this bead or layer of weld metal to remove all slag and dirt before depositing the second layer of metal.

In making multi pass welds, as shown in *Figure 8-54,* make the second, third, and fourth layers of weld metal with a weaving motion of the electrode. Clean each layer of metal before laying additional beads. Use one of the weaving motions shown in *Figure 8-55*, 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. Improper weaving motion could result in undercutting at the joint, as shown in *Figure 8-56*. Excessive welding speed also can cause undercutting and poor fusion at the edges of the weld bead.

Figure 8-55 — Weave motions used in SMAW.

Butt joints with backing strips — Welding 3/16-inch or thicker plate 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. 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 8-57*. 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 cut away with a cutting torch. When specified, place a seal bead along the root of the joint.

Figure 8-56 — Undercutting in butt joint welds.

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

Figure 8-57 — Use of back strips in welding butt joints.

7.6.2 Horizontal-Position Welding

You will discover that it is impossible to weld all pieces in the flat position. Often you must do the work 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 (*Figure 8-58)*. In a fillet weld, the welding is performed on the upper side of a relatively horizontal surface and against an approximately vertical plane (*Figure 8-59*).

Inexperienced welders usually find the horizontal position of arc welding difficult, until they develop 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.

Figure 8-58 — Horizontal groove weld.

7.6.2.1 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 (*Figure 8-60*). 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. Use the shortest arc length possible, and when the force of the arc undercuts the plate at the top of the bead, lower the electrode holder a little to increase the upward angle.

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

Figure 8-59 — Horizontal fillet weld.

Figure 8-60 — Horizontal welding angles.

7.6.2.2 Joint Type

Horizontal-position welding can be used on most types of joints, but it is most commonly used on 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 8-61*.

Use a fillet weld in making the tee joint, and use a short arc to provide good fusion at

Figure 8-61 — Tack-weld to hold the tee joint elements in place.

Figure 8-62 — Position of electrode on a fillet weld.

the root and along the legs of the weld (*Figure 8-62*, *view A*). Hold the electrode at an angle of 45 degrees to the two plate surfaces (*Figure 8-62*, *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 8-63.* To ensure good fusion and the prevention of undercutting, 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 8-64.*

Figure 8-63 — Weave motion for multipass fillet weld.

Figure 8-64 — Order of string beads for tee joint on heavy

Chain-intermittent or staggered-intermittent fillet welds, as shown in *Figure 8-65*, are used on long tee joints. Fillet welds of these types are for joints that do not require high weld strength; however, the short welds are arranged so the finished joint is equal in strength to 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.

Figure 8-65 — Intermittent fillet welds.

Figure 8-66 — Tack welding a lap joint.

Lap joints — To make a lap joint, tack-weld two overlapping plates in place (*Figure 8-66*), and deposit a fillet weld along the joint.

The procedure for making this fillet weld is similar to that used for making fillet welds in tee joints. 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 8-67*. 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 8-67*.

In making lap joints on plates of different thickness, hold the electrode so that it forms an angle of between 20 and 30 degrees from the vertical (*Figure 8-68*). 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 (*Figure 8-69*). Often, both edges are beveled to form a 60-degree included angle. Using this type of joint requires more skill because there is no retaining shelf to hold the molten puddle.

Figure 8-67 — Position of electrode on a lap joint.

Figure 8-68 — Lap joints on plates of different thickness.

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 (*Figure 8-70*), place the first bead deep in the root of the joint. Incline the electrode holder 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.

Figure 8-69 — Horizontal butt joint.

Figure 8-70 — Multiple passes.

7.6.3 Vertical-Position Welding

A “vertical weld” is a weld applied to a vertical surface or inclined 45 degrees or less (*Figure 8-71*). Erecting structures, such as buildings, pontoons, tanks, and pipelines, requires 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, 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.

Figure 8-71 — Vertical weld plate positions.

7.6.3.1 Current Settings and Electrode Movement

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

To produce good welds, maintain the proper angle between the electrode and the base metal. In welding upward, hold the electrode at 90 degrees to the vertical, as shown in *Figure 8-72,* view A. When weaving is necessary, oscillate the electrode, as shown in Figure *8-72*, 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 8-72*, view C). When vertical down welding requires a weave bead, oscillate the electrode, as shown in *Figure 8-72*, view D.

Figure 8-72 — Bead welding in vertical position.

7.6.3.2 Joint Type

Vertical welding is used on most types of joints, but the types 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. Move the electrode in a triangular weaving motion, as shown in *Figure 8-73, 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, quickly shift the electrode away from the crater without breaking the arc, as shown in *Figure 8-73, 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, use either of the weaving motions shown in *Figure 8-73, 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, move the electrode in a triangular weaving motion, as shown in *Figure 8-73* , *View E*. Use the same procedure

Figure 8-73 — Fillet welds in the vertical position.

outlined above for the tee joint except direct the electrode more toward the vertical plate marked “G.” Hold the arc short and pause slightly at the surface of plate G. Try not to undercut either of the plates or allow the molten metal to overlap at the edges of the weave.

A lap joint 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 8-73, View F*. The precautions to ensure good fusion and uniform weld deposits, 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, hold a short arc and carefully control the motion of the arc.

You can weld butt joints on beveled plates 1/4-inch thick in one pass by using a triangular weave motion, as shown in *Figure 8-74*, *View A*.

Figure 8-74 — Butt joint welding in the vertical position.

Make welds on 1/2-inch plate or heavier should in several passes, as shown in *Figure 8-74*, *View B*. Deposit the last pass with a semicircular weaving motion and a slight "whip-up" and pause of the electrode at the edge of the bead. This produces a good cover pass with no undercutting. Make welds on plates with a backup strip in the same manner.

7.6.3.3 E-7018 Electrode Welding Technique

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

When vertical down welding, 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 better than 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.

7.6.4 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.

7.6.4.1 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 you hold too long an arc, 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 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.

7.6.4.2 Type of Welds

The following paragraphs discuss techniques used in making bead welds, butt joints, and fillet welds in the overhead position.

Bead welds — For bead welds, the work angle of the electrode is 90 degrees to the base metal (*Figure 8-75*, *View A*). The travel angle is 10 to 15 degrees in the direction of welding (*Figure 8-75*, *View B*).

Make weave beads using the motion shown in *Figure 8-75*, *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.

Figure 8-75 — Position of electrode and weave motion in the overhead position.

Butt Joint — Prepare the plates for overhead butt welding in the same manner as required for the flat position. The best results are obtained using backing strips; 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 you take extreme care.

For overhead butt welding, bead welds are better than 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 8-76*, views B and C. Make the first pass with the electrode held at 90 degrees to the plate, as shown in *Figure 8-76*, view A. When you use an electrode that is too large, you cannot hold a short arc in the root area. This results in insufficient root penetration and inferior joints.

Figure 8-76 — Multipass butt joint in the overhead position.

Fillet welds — In making fillet welds in either tee or lap joints in the overhead position, maintain a short arc and refrain from weaving the electrode. Hold the electrode at approximately 30 degrees to the vertical plate and move it uniformly in the direction of welding, as shown in *Figure 8-77*, *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 8-77*, *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 8-77*, *View C*, and with a slight circular motion make the second, third, and fourth pass. 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.

Figure 8-77 – Fillet welding in the overhead position.

7.6.5 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 less flow restriction 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 (TIG & MIG) have made big inroads as a result of 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 unique 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.

The following paragraphs, discuss pipe welding positions, pipe welding procedures, definitions, and related information.

Figure 8-78 — Butt joints and socket fitting joints.

7.6.5.1 Pipe welding positions

You may recall that there are four positions used in pipe welding (*Figure 8-38*). 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.

7.6.5.2 Pipe welding procedures

Welds that you cannot make in a single pass, make 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, clean each layer thoroughly before depositing the next one.

Butt joints are commonly used between pipes and between pipes and welded fittings. They are also used for butt welding flanges and welding stubs. In making a butt joint, place two pieces of pipe end to end, align

Figure 8-79 — Flange connections.

them, and then weld them. (See *Figure 8-78*).

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

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 (*Figure 8-79*). Single fillet welds are also used in welding screw or socket couplings to pipe (*Figure 8-78)*. Sometimes flanges require alignment. *Figure 8-80* 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 do not add strength to the joint.

7.6.5.3 Joint preparation and fit-up

Prepare pipe joints for welding carefully 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 to cut bevels accurately. You can make bevels by machining, grinding, or using a gas cutting torch. In fieldwork, you 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.

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, use clamps or jigs as holding devices. A piece of angle iron makes a good jig for a small-diameter pipe (*Figure 8-81*), while a section of channel or I-beam is more suitable for larger diameter pipe.

Figure 8-80 — Flange alignment.

Figure 8-81 — Angle iron jig.

7.6.6 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 pipe. The size of a tack weld is determined by the wall thickness of the pipe. Be sure the 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.

7.6.7 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; for example, they provide a means of maintaining the specified root opening, provide a convenient location for tack welds, and aid in pipe alignment. In addition, spacers can prevent weld spatter and the formation of slag or icicles inside the pipe.

7.6.8 Electrode selection

Select the electrode best suited for the position and type of welding you are doing. For the root pass of a multilayer weld, you need an electrode large enough, without exceeding 3/16-inch, to ensure 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.

7.6.9 Weather conditions

Do not assign a welder to a job under any of the 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, within 3 inches of the joint, heat the weld area with a torch to a temperature warm to the hand before beginning to weld.

Test your Knowledge (Select the Correct Response)

9. How many basic types of weld joints are there?

   A. 4
   B. 5
   C. 6
   D. 8

10. Which type of weld is used for welding slip-on and threaded flanges to pipe?

A. Fillet
B. Bead
C. Butt
D. Tee

8.0.0 WELDING PROCEDURE VARIABLES

The welding procedure variables are those that control the welding process and the quality of the welds produced. There are three major types of welding variables. These are the fixed or preselected, primary adjustable, and the secondary adjustable variables.

The fixed or preselected welding variables are set before the actual welding takes place. These are items such as electrode type, electrode size, and type of current. These variables cannot be changed after welding starts.

The primary adjustable variables are the major variables used to control the welding process once the fixed variables have been selected. The primary variables control the formation of the weld bead by affecting the bead width, bead height, penetration, arc stability, and weld soundness. The primary welding variables are welding current, arc voltage, and travel speed. These can be easily adjusted and measured so they can be used effectively to control the welding process.

The secondary adjustable variables are the minor adjustable variables used to control the welding process. These variables are usually more difficult to measure. Secondary adjustable variables are the work angle and the travel angle of the electrode.

The penetration of the weld is the greatest depth below the surface of the base metal that the weld metal reaches. The bead height or reinforcement is the height of the weld metal above the surface of the base metal. The deposition rate is the weight of the metal that is deposited per unit of time. *Figure 8-82* shows the definitions of bead height, bead width, and penetration.

Figure 8-82 — Bead height, bead width and penetration.

The welding variables are discussed with particular attention to the three major characteristics of penetration, deposition rate, and bead shape. *Table 8-13* is a chart showing the effects of welding variables on the three major characteristics.

Table 8-13 — Effects of welding variables on the penetration, the bead size and shape, and the deposition rate.

Characteristic		Arc Length	Current	Travel Speed	Travel Angle	Electrode Diameter
Deeper Penetration		—	Increase	—	Drag	Smaller
Shallower Penetration		—	Decrease	—	Push	Larger
Bead	Larger Bead	—	Increase	Decrease	—	—
Height	Smaller Bead	—	Decrease	Increase	—	—
and	Higher Narrower Bead	Decrease	—	Increase	Drag	—
Width	Flatter Wider Bead	Increase	—	Decrease	Push	—
Faster Deposition Rate		—	Increase	—	—	Smaller
Slower Deposition Rate		—	Decrease	—	—	Larger

Note: These are the effects of changing only one variable at a time.

8.1.0 Fixed Variables

Fixed variables include electrode size and type, welding current type, and polarity.

8.1.1 Electrode Type

The type of electrode used has an effect on the penetration, deposition rate, and shape of the weld bead and usually depends upon the specific application. Some types of electrodes have a digging arc and produce welds with deep penetration. The deep penetrating effect of these electrodes results from the high amount of cellulose in their coatings. Some types of electrodes produce moderate penetration while others produce light penetration. The type of electrode used also greatly influences the deposition rate of the electrode. Iron powder is the main influence on deposition rate. Electrodes with high amounts of iron powder in their coatings can operate at higher welding currents than other types of electrodes. The iron powder goes into the weld metal and helps give the electrodes with iron powder in their coatings the highest deposition rates of any of the mild steel electrodes. The electrodes with the thinnest electrode coatings generally have the lowest deposition rates. The type of electrode used also influences the bead size and shape. The iron powder electrodes generally produce wider and flatter beads. The characteristics of the different electrodes were discussed in topic 4.

8.1.2 Electrode Size

Larger diameter electrodes use higher welding currents, so the deposition rates and penetration depths increase as the electrode wire diameter increases. Lower deposition rates and penetration depths are obtained with smaller electrode wire diameters because they use lower welding currents. Table 8-14 shows typical deposition rates for different sizes of E6010, E7018, and E7024 electrodes.

Table 8-14 — Typical deposition rates of different sizes of E6010, E7018, and E7024 electrodes.

Core Wire Diameter		E6010			E7018			E7024		
In	(mm)	Lbs./hr	(kg/hr)	Amps	Lbs./hr	(kg/hr)	Amps	Lbs./hr	(kg/hr)	Amps
3/32	(2.4)	1.3	(.6)	60	1.7	(.6)	90	—	—	—
1/8	(3.2)	2.1	(.9)	100	3.1	(.9)	150	5.3	(2.4)	150
5/32	(4.0)	3.1	(1.4)	130	4.7	(1.4)	230	6.9	(3.1)	225
3/16	(4.8)	4.0	(1.8)	180	6.5	(1.8)	300	9.5	(4.3)	280
7/32	(5.4)	—	—	—	9.5	(4.3)	350	9.8	(4.5)	320
1/4	(6.4)	—	—	—	9.6	(4.4)	400	12.2	(5.5)	360

8.1.3 Current Type

The melting rate in the arc zone is directly related to the electrical energy in the welding arc. Part of the energy is used to melt the electrode and coating, some is lost to the atmosphere, and the rest goes to melt the base metal. The electrical polarity determines the energy balance, and the constituents of the electrode covering the different types of current affect the deposition rate and depth of penetration.

Direct current electrode positive gives the *most penetration* at a given welding current setting, followed by alternating current, with direct current electrode negative giving the least penetration. However, direct current electrode negative gives the *highest deposition* rates at a given welding current setting, followed by alternating current, with direct current electrode positive giving the lowest deposition rates.

8.2.0 Primary Variables

Primary variables include welding current, travel speed, and welding voltage.

8.2.1 Welding Current

The welding current is the most important factor in determining the characteristics of the weld. The welding current is controlled by a knob or handle on the welding machine. 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 8-83*.

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. This piling up of molten metal is called overlap. The molten metal from the electrode lays on the work without penetrating the base metal. Poor welds result from both undercutting and overlapping.

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.

8.2.2 Travel Speed

Travel speed is another important factor in controlling the weld characteristics. The travel speed is determined by the welder, who manually controls the rate that the arc travels along the work. Increasing travel speed while the other variables remain constant reduces the width of the weld bead and increases the weld penetration. There is an optimum travel speed at which the penetration is at its maximum. Increasing the travel speed beyond this point will decrease the penetration. Excessive travel speed will produce a weld bead that is too small with an irregular contour. This can produce welds that have too small a cross section. A very slow travel speed can result in excessive piling up of weld metal and lack of fusion at the edges of the weld. The effects of travel speed are also shown in Figure 8-83.

Figure 8-83 — Effects of the welding variables on the weld bead.

8.2.3 Welding Voltage (Arc Length)

The welding voltage is another important variable in shielded metal arc welding. The arc voltage is determined by the arc length between the end of the electrode and the base metal. The welder controls the arc voltage manually by moving the tip of the electrode close to or away from the surface of the base metal. Increasing the arc length increases the arc voltage; decreasing the arc length decreases the arc voltage. The welding voltage primarily affects the shape of weld bead cross-section and the general appearance of the weld. Increasing the welding voltage produces a wider and flatter weld bead and increases the susceptibility to arc blow. When the arc length is too long, which makes the welding voltage too high, the weld bead can look irregular with poor penetration and spatter. Also, the weld metal may be not be properly shielded by the gas from the decomposition of the electrode coating and much of the heat may be lost to the atmosphere. Decreasing the arc length will produce a stiffer and more easily controlled arc, but a very short arc length can cause the electrode to stick to the base metal. The effects of too long an arc length are also shown in *Figure 8-83*.

8.2.4 Starting the Arc

There are two basic methods for starting the arc: the striking or brushing method (*Figure 8-84*) and the tapping method (*Figure 8-85*). 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, bring the electrode down to the work with a lateral motion similar to striking a match. As soon as the electrode touches the work surface, raise it to establish the arc (*Figure 8-84*). The arc length or gap between the end of the electrode and the work should be equal to the diameter of the electrode. When you have obtained the proper arc length, it produces a sharp, crackling sound.

Figure 8-84 — Striking or brushing method of starting the arc.

Figure 8-85 — Tapping method of starting the arc.

In the tapping method, hold the electrode in a vertical position to the surface of the work. Start the arc by tapping or bouncing it on the work surface and then raising it to a distance equal to the diameter of the electrode (*Figure 8-85*). When you have established the proper length of arc, you will hear a sharp, crackling sound.

In either of the starting methods described above, withdrawing the electrode too slowly will cause it to 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, and use a light blow with a chipping hammer or 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 emit a humming 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 controlling the motion of the electrode along the surface of the base metal.

8.2.4.1 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.

8.2.4.2 Reestablishing the Arc

To reestablish the arc (as in a long weld that requires the use of more than one electrode), clean the crater 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.

8.2.4.3 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 check the weld specification before peening.

8.3.0 Secondary Variables

Secondary variables include work and travel angles of the electrode,

8.3.1 Angles of the Electrode

The angular position of the electrode in relation to the work may have an effect on the quality of the weld deposit. The position of the electrode determines the ease with which the filler metal is deposited, freedom from undercutting and slag inclusions, and the uniformity of the bead.

Figure 8-86 — Travel angle and work angle.

The electrode angles are called the travel angle and the work angle. The travel angle of the electrode is the angle between the joint and the electrode in the longitudinal plane. The work angle is the angle between the electrode and the perpendicular plane to the direction of travel. These are shown in *Figure 8-86*. Increasing the travel angle in the direction of welding generally builds up the bead height. A work angle that is too large may result in undercutting. Especially with the low-hydrogen types of electrodes, the electrode angles are important in maintaining weld quality.

9.0.0 WELDING PROCEDURE SCHEDULES

The welding procedure schedules in this chapter give typical welding specifications that can be used to obtain high quality welds under normal welding conditions. These welding procedure schedules provide only a few examples of the many different welding procedures you can use. These tables are not the only conditions that can be used, because factors such as weld appearance, operator skill, and the specific application often require variation from the schedules. As the particular requirements of the application become better known, the settings may be adjusted to obtain the optimum welding conditions. Make qualifying tests or trials prior to actual production. The following schedules are based on welding low-carbon mild steels with recommended types of mild steel, covered electrodes under normal welding conditions.

When adjusting or changing the variables for welding, you must consider the effect of one variable on the others. You cannot usually change one variable very much without adjusting or changing the other variables in order to maintain a stable arc and good overall welding conditions.

Figures 8-87 through *8-90* show the type of weld, base metal thickness, welding position, number of passes, welding current, travel speed, electrode size, and type of covered electrode used. The arc voltage is not included because it depends on the arc length held by the welder; it is not constant and will vary from welder to welder.

Figure 8-87 — Square groove welds in plate 1/8- to ¼-in. thick.

Base Metal Thickness		Positions	Root Opening RO		Electrode Type	Electrode Diameter	Welding Current	Travel Speed	
In	(mm)		In	(mm)				In/min	(mm/min)
1/8	(3.2)	Flat Horizontal	0		E6010	3/32	60-80	8-10	(3.4-4.2)
3/16	(4.8)	Flat Horizontal	0-1/16	(0-1.6)	E6010	1/8	100-120	8-10	(3.4-4.2)
1/4	(6.4)	Flat Horizontal	1/16-3/32	(1.6-2.4)	E6010	5/32	120-140	8-10	(3.4-4.2)
1/8	(3.2)	Vertical Overhead	0		E6010	3/32	60-80	7-8	(3.0-3.4)
3/16	(4.8)	Vertical Overhead	0-1/16	(0-1.6)	E6010	1/8	110-120	7-8	(3.0-3.4)
1/4	(6.4)	Vertical Overhead	1/16-3/32	(1.6-2.4)	E6010	5/32	130-140	7-9	(3.0-3.8)

Figure 8-88 — Vee groove welds in plate 3/8- to 5/8-in. thick

Base Metal Thickness In	Base Metal Thickness (mm)	Positions	Number of Passes	Electrode Type	Electrode Diameter In	Electrode Diameter (mm)	Welding Current	Travel Speed In/min	Travel Speed (mm/min)
3/8	(9.5)	Flat	3	E6010	3/16	(4.8)	160-175	9-11	(3.8-4.7)
		Horizontal	4	E6010	3/32	(4.8)	160-175	9-11	(3.8-4.7)
				E7018	5/32	(4.0)	170-190	9-11	(3.8-4.7)
		Vertical Up	3	E6010	3/16	(4.8)	150-165	6-7	(2.5-3.0)
		Overhead	4	E7018	5/32	(4.0)	130-150	7-9	(3.0-3.8)
1/2	(12.7)	Flat	4	E6010	3/16	(4.8)	160-175	9-11	(3.8-4.7)
		Horizontal	6	E6010	3/16	(4.8)	160-175	9-11	(3.8-4.7)
				E7018	5/32	(4.0)	170-190	9-11	(3.8-4.7)
		Vertical Up	3	E6010	3/16	(4.8)	150-165	6-7	(2.5-3.0)
		Overhead	7	E7018	5/32	(4.0)	130-150	7-9	(3.0-3.8)
5/8	(15.9)	Flat	5	E6010	3/16	(4.8)	160-175	9-11	(3.8-4.7)
		Horizontal	7	E6010	3/16	(4.8)	160-175	9-11	(3.8-4.7)
				E7018	5/32	(4.0)	170-190	9-11	(3.8-4.7)
		Vertical Up	4	E6010	3/16	(4.8)	150-165	6-7	(2.5-3.0)
		Overhead	10	E7018	5/32	(4.0)	130-150	7-9	(3.0-3.8)

Figure 8-89 — U-groove welds in plate greater than 1 inch (2.54 mm) thick. First pass put back side and its root gouged or chipped out.

Base Metal Thickness		Positions	Number of Passes	Electrode Type	Electrode		Welding Current	Travel Speed	
In.	(mm)				In.	(mm)		In./min	(mm/min)
1	(25.4)	Flat	9	E7018	1/4	(6.4)	320-350	8-9	(3.4-3.8)
		Horizontal	13	E7018	5/32	(4.0)	160-180	10-12	(4.2-5.1)
		Vertical	11	E6010	3/16	(4.8)	150-165	6-7	(2.5-3.0)
				E7018	5/32	(4.0)	130-150	6-9	(2.5-3.8)
		Overhead	13	E7018	5/32	(4.0)	130-150	6-9	(2.5-3.8)
2 and Over	(51)	Flat	25 +	E7018	1/4	(6.4)	320-350	8-9	(3.4-3.8)
		Horizontal	35 +	E7018	5/32	(4.0)	160-180	10-12	(4.2-5.1)
		Vertical	30 +	E6010	3/16	(4.8)	150-165	6-7	(2.5-3.0)
				E7018	5/32	(4.0)	130-150	6-9	(2.5-3.0)
		Overhead	35 +	E7018	5/32	(4.0)	130-150	6-9	(2.5-3.8)

Figure 8-90 — Filet Welds

Fillet Size In.	Fillet Size (mm)	Positions	Number of Passes	Electrode Type	Electrode Diameter In.	Electrode Diameter (mm)	Welding Current	Travel Speed In./min	Travel Speed (mm/min)
1/4	(6.4)	Flat	1	E7024	5/32	(4.0)	320-350	8-9	(3.4-3.8)
		Horizontal	1	E7024	5/32	(4.0)	160-180	10-12	(4.2-5.1)
		Vertical	1	E7018	5/32	(4.0)	150-165	6-7	(2.5-3.0)
		Overhead	3	E6010	3/16	(4.8)	130-150	6-9	(2.5-3.8)
				E7018	5/32	(4.0)	130-150	6-9	(2.5-3.8)
1/2	(12.7)	Flat	2	E7024	1/4	(6.4)	320-350	8-9	(3.4-3.8)
		Horizontal	3	E7024	1/4	(6.4)	160-180	10-12	(4.2-5.1)
		Vertical	2	E7018	5/32	(4.0)	150-165	6-7	(2.5-3.0)
		Overhead	4	E6010	3/16	(4.8)	130-150	6-9	(2.5-3.0)
				E7018	5/32	(4.0)	130-150	6-9	(2.5-3.8)
3/4	(19.1)	Flat	4	E7024	1/4	(6.4)	370-400	10-12	(4.2-5.1)
		Horizontal	6	E7024	1/4	(6.4)	370-400	10-12	(4.2-5.1)
		Vertical	5	E7018	5/32	(4.0)	160-180	4-6	(1.7-2.5)
		Overhead	7	E6010	3/16	(4.8)	150-165	6-7	(2.5-3.0)
				E7018	5/32	(4.0)	130-150	4-6	(1.7-2.5)

10.0.0 PREWELD PREPARATIONS

Several operations may be required before making a weld. These include: preparing the weld joint, setting up or fixturing the weldment, setting the variables, and in some cases preheating. The amount of preweld preparation depends upon the size of the weld, the material to be welded, the ease of fit-up, the quality requirements, the governing code or specification, and the welder.

10.1.0 Preparing the Weld Joint

There are different ways of preparing the edge of the joint for welding. Joints for fillet or square groove welds are prepared simply by squaring off the edges of the members to be welded. Common types of machined bevels are V, U, J, bevel, and combination grooves. The more complex the type of bevel, the longer the edge preparation takes and the more expensive it becomes. The methods that are the most often used for edge preparation are oxygen-fuel gas cutting, shearing, machining, air carbon arc gouging, grinding, chipping, and plasma arc cutting. Plasma arc cutting is widely used for the cutting and beveling of stainless steels and nonferrous metals.

V groove and single bevel grooves are the types of grooves most often used because they can easily be prepared by oxygen-fuel cutting. If correctly done, this process leaves a smooth surface with a scale that can be easily removed. The edges of U grooves can be done by using special types and techniques, or by machining which will produce a more uniform groove.

To produce good quality welds, the surfaces of the weld joint should be clean of rust, scale, dirt, oil and grease. Grinding is useful for removing rust and scale including the scale left by oxyacetylene cutting and other related processes. Grease and oil must be removed from the joint surfaces by wiping or using degreasers. Scale, rust, dirt, oil, and grease can contaminate the weld metal and cause defects in the weld.

10.2.1 Fixturing and Positioning

Fixtures and jigs are devices used to hold the parts to be welded in proper relation to each other. This alignment is called fit-up. Good fit-up is required for obtaining high quality welds. Poor fit-up increases welding time and causes many poor quality welds. The size of the root opening has an effect on the speed at which the welding of the root pass can be accomplished. Root openings are used so that full penetration welds can be made. Root passes in joints with a proper root opening can be welded much faster than joints that have excessive root opening.

Fixtures and jigs are used for three major purposes:

1. To minimize distortion caused by welding heat
2. To minimize fit-up problems
3. To increase the welding efficiency of the welder.

When a welder employs a welding fixture or jig, the components of a weldment can be assembled and securely held in place while the weldment is positioned and welded. The use of those devices is dependent on the specific application. These devices are more often used when a large number of similar parts are produced. Using fixtures and jigs, when possible can greatly reduce the production time for the weldments.

Positioners are used to move the workpiece into a position so that welding can be done more conveniently. Positioning is sometimes needed simply to make the weld joint accessible. The main objective of positioning is to put the joint in the flat or other position that increases the efficiency of the welder because the welder can use higher welding speeds. Flat position welding usually increases the quality of the weld because it makes the welding easier.

10.3.0 Preheating

Preaheat is sometimes necessary, depending on the type of metal being welded, the base metal thickness, and the amount of joint restraint. The specific amount of preheat needed for a given application is often obtained from the welding procedure.

The preheat temperature of the base metal is often carefully controlled. Several good methods of doing this are furnace heating, electric induction coils, and electric resistance heating blankets. On thin metals, hot air blasts or radiant lamps may be used. With these methods, temperature indicators are connected to parts being preheated. Another method of preheating is using torches; these give more localized heating than the previously mentioned methods. However, when using torches for preheating, it is important to avoid localized overheating and prevent deposits of incomplete combustion products from collecting on the surface of the parts to be welded. Colored chalks and pellets that melt at a specific predetermined temperature are often used to measure the preheat temperature. Another method of measuring the temperature is by using a hand held temperature indicator. These can give meter readings, digital readings or recorder readings depending on the type of temperature indicator.

Test your Knowledge (Select the Correct Response)

11. Which of the following is NOT a major type of welding variable?

    A. Fixed
    B. Primary adjustable
    C. Secondary adjustable
    D. Secondary fixed

12. Fixtures and jigs are devices used to hold the parts to be welded in proper relation to each other. What is this alignment called?

    A. Fixed-up
    B. Jigged-up
    C. Fit-up
    D. Butted-up

11.0.0 WELDING DEFECTS and PROBLEMS

Shielded metal arc welding, like other welding processes, may develop welding procedure problems that can cause defects in the weld. Some defects are caused by problems with the materials. Others may not be foreseeable and may require immediate corrective action.

11.1.0 Discontinuities Caused by Welding Technique

A poor welding technique and improper choice of welding parameters can cause weld defects. Defects that can occur when using the shielded metal arc welding process are slag inclusions, wagon tracks, porosity, wormhole porosity, undercutting, lack of fusion, overlapping, burn through, arc strikes, craters, and excessive weld spatter. Many of these welding technique problems weaken the weld and can cause cracking. Other problems that can reduce the quality of the weld are arc blow, fingernailing, and improper electrode coating moisture contents.

11.1.1 Slag Inclusions

Slag inclusions (*Figure 8-91*) occur when slag particles are trapped inside the weld metal, which produces a weaker weld. These can be caused by:

1. Erratic travel speed
2. Too wide a weaving motion
3. Slag left on the previous weld pass
4. Use of too large an electrode
5. Letting slag run ahead of the arc

Figure 8-91 — Slag inclusions.

This defect can be prevented by:

1. A uniform travel speed
2. A tighter weaving motion
3. Complete slag removal before welding
4. Using a smaller electrode
5. Keeping the slag behind the arc by shortening the arc, increasing the travel speed, or changing the electrode angle

Figure 8-92 — Wagon tracks.

11.1.2 Wagon Tracks

Wagon tracks (*Figure 8-92*) are linear slag inclusions that run the longitudinal axis of the weld. They result from allowing the slag to run ahead of the weld puddle and by slag left on the previous weld pass. These occur at the toe lines of the previous weld bead.

11.1.3 Porosity

Porosity (*Figure 8-93*) is gas pockets in the weld metal. They may be scattered in small clusters or along the entire length of the weld. Porosity weakens the weld in approximately the same way that slag inclusions do. Porosity may be caused by:

1. Excessive welding current
2. Rust, grease, oil, or dirt on the surface of the base metal
3. Excessive moisture in the electrode coatings
4. Impurities, such as sulfur or phosphorous in the base metal
5. Too short an arc length, except when using low-hydrogen or stainless steel electrodes
6. Travel speed too high, which causes freezing of the weld puddle before gases can escape

Figure 8-93 — Porosity.

Porosity can be prevented by:

1. Lowering the welding current
2. Cleaning the surface of the base metal
3. Redrying electrodes
4. Changing to a different base metal with a different composition
5. Using a slightly longer arc length
6. Lowering the travel speed to let the gases escape
7. Preheating the base metal, using a different type of electrode, or both

11.1.4 Wormhole Porosity (Piping Porosity)

Wormhole porosity (*Figure 8-94*) is the name given to elongated gas pockets and is usually caused by sulfur or moisture trapped in the weld joint. The best method of preventing this is to lower the travel speed to permit gases to escape before the weld metal freezes.

Figure 8-94 — Wormhole.

11.1.5 Undercutting

Undercutting (*Figure 8-95*) is a groove melted in the base metal next to the toe or root of a weld that is not filled by the weld metal. Undercutting causes a weaker joint and can cause cracking. This defect is caused by:

1. Excessive welding current
2. Too long an arc length
3. Excessive weaving speed
4. Excessive travel speed

On vertical and horizontal welds, it can also be caused by too large an electrode size and incorrect electrode angles. This defect can be prevented by:

1. Choosing the proper welding current for the type and size of electrode and the welding position
2. Holding the arc as short as possible
3. Pausing at each side of the weld bead when using a weaving technique
4. Using a travel speed slow enough so that the weld metal can completely fill all of the melted-out areas of the base metal

Figure 8-95 — Undercutting.

11.1.6 Lack of Fusion

Lack of fusion (*Figure 8-96*) is when the weld metal is not fused to the base metal. This can occur between the weld metal and the base metal or between passes in a multiple pass weld. Causes of this defect can be:

Figure 8-96 — Lack of fusion.

1. Excessive travel speed
2. Electrode size too large
3. Welding current too low
4. Poor joint preparation
5. Letting the weld metal get ahead of the arc

Lack of fusion can usually be prevented by:

1. Reducing the travel speed
2. Using a smaller diameter electrode
3. Increasing the welding current
4. Better joint preparation
5. Using a proper electrode angle

11.1.7 Overlapping

Overlapping (*Figure 8-97*) is the protrusion of the weld metal over the edge or toe of the weld bead. This defect can cause an area of lack of fusion and create a notch which can lead to crack initiation. Overlapping is often produced by:

1. Too slow a travel speed which permits the weld puddle to get ahead of the electrode
2. An incorrect electrode angle that allows the force of the arc to push the molten weld metal over unfused sections of the base metal
3. Welding away from the ground connection with large electrodes like the E6020, E6027, E7024, and E7028, which have very fluid weld puddles

Figure 8-97 — Overlapping.

Overlapping can be prevented by or corrected by:

1. A higher travel speed
2. The electrode angle should be such that the force of the arc does not push the molten metal out of the weld puddle and over the cold base metal
3. Grinding off excess weld metal

11.1.8 urn Through

Burn-through (*Figure 8-98*) is when the arc burns through the bottom of the weld. This can be caused by:

1. Excessive welding current
2. Too slow a travel speed
3. Too wide a root gap

Figure 8-98 — Burn through.

This can be prevented by:

1. Reducing the welding current
2. Increasing the travel speed
3. Reducing the size of the root gap

11.1.9 Arc Strikes

Many codes prohibit striking the arc on the surface of the workpiece. Striking the arc on the base metal outside of the weld joint can produce a hard spot on the base metal surface. Failures can then occur due to the notch effect. The arc strikes might create a small notch on the surface of the metal which can act as an initiating point for cracks.

11.1.10 Craters

A weld crater (*Figure 8-99*) is a depression on the weld surface at the point where the arc was broken. These are caused by the solidification of the metal after the arc has been broken. The weld crater often cracks and can serve as an origin for linear cracking back into the weld metal or into the base metal. These craters can usually be removed by chipping or grinding and the depression can be filled in with a small deposit of filler metal. The best way of preventing weld craters is to reverse the travel of the electrode a little way back into the weld bead from the end of the weld bead before breaking the arc.

Figure 8-99 — Weld crater.

11.1.11 Excessive Weld Spatter

Excessive weld spatter gives the weld a poor appearance, wastes electrodes, spreads difficult-to-remove slag, and can lead to lack of fusion in the case of multiple pass welds. If the spatter is coarse, it is usually produced by an arc length that is too long. If the spatter is fine, it is usually caused by too high a welding current. Spatter can be removed by grinding or prevented by using a shorter arc length and lower welding currents.

11.2.1 Cracking

Cracking may be caused by an improper welding procedure, welder technique, or materials. All types of cracking can be classified as either hot cracking or cold cracking, and these cracks can be oriented transversely or longitudinally to the weld. Transverse cracks are perpendicular to the axis of the weld; longitudinal cracks are parallel to the axis of the weld. Transverse cracks are often the result of longitudinal shrinkage strains acting on excessively hard and brittle weld metal. Longitudinal cracks are often caused by high joint restraint and high cooling rates. Hot cracking is a defect that occurs at higher temperatures and generally happens just after the weld metal starts to solidify. This type of cracking is often caused by excessive sulfur, phosphorous, and lead content in the base metal. It can also occur because of an improper method of breaking the arc or in a root pass when the cross sectional area of the weld bead is small compared to the mass of the base metal. Hot cracking often occurs in deep penetrating welds and it can continue through successive layers if it is not repaired. Hot cracking may be prevented or minimized by:

1. Preheating
2. Using low-hydrogen electrodes
3. Increasing the cross sectional area of the weld bead
4. Changing the contour of the weld bead
5. Using base metal with very low sulfur, phosphorous, and lead content

Crater cracks are shallow hot cracks caused by improperly breaking the arc. Several types of these are shown in *Figure 8-100*.

Figure 8-100 — Crater cracks.

Crater cracks may be prevented the same way that craters are, by reversing the travel of the electrode a little way back into the weld from the end of the weld before breaking the arc.

Cold cracking occurs after the weld metal solidification is complete. Cold cracking may occur several days after welding and is generally caused by hydrogen embrittlement, excessive joint restraint, and rapid cooling. Preheating and using low hydrogen electrodes helps reduce this problem. Centerline cracks are cold cracks that often occur in single pass concave fillet welds. A centerline crack is a longitudinal crack that runs down the center of the weld, as shown in *Figure 8-101*.

This problem may be caused by:

1. Too small a weld bead for the thickness of the base metal
2. Poor fit-up
3. High joint restraint
4. Extension of a crater crack

Figure 8-101 — Centerline crack.

The major methods of preventing centerline cracks are:

1. Increasing the bead size
2. Decreasing the gap width
3. Positioning the joint slightly uphill
4. Preventing weld craters

Base metal and underbead cracks are cold cracks that form in the heat affected zone of the base metal. Underbead cracks occur underneath the weld bead as shown in *Figure 8-102*.

Figure 8-102 — Centerline crack.

Base metal cracks originate in the heat affected zone of the weld. These types of cracking are caused by excessive joint restraint, hydrogen, and a brittle microstructure. A brittle microstructure is caused by rapid cooling or excessive heat input. Underbead and base metal cracking can be reduced or eliminated by using preheat and low-hydrogen electrodes.

11.3.0 Other Problems

A number of other welding problems may occur, such as those caused by magnetic fields, improper moisture, or indirect electrode arc.

11.3.1 Arc Blow

The electric current that flows through the electrode, workpiece, and ground cable sets up magnetic fields in a circular path perpendicular to the direction of the current. When the magnetic fields around the arc are unbalanced, it tends to bend away from the greatest concentration of the field. This deflection of the arc is called arc blow. Deflection is usually in the direction of travel or opposite it, but it sometimes occurs to the side. Arc blow can result in excessive weld spatter and lack of fusion.

Direct current is highly susceptible to arc blow, especially in welding corners and near the end of joints. Arc blow also occurs in welding complex structures and on massive structures with high currents and poor fit-up. Arc blow occurs with direct current because the induced magnetic field is in one direction. Alternating current is rarely subject to arc blow because the magnetic field is building and collapsing all the time due to the reversing current. Forward arc blow is encountered when welding away from the ground connection or at the beginning of the weld joint. Backward arc blow occurs toward the ground connection, into a corner, or toward the end of a weld joint. There are several methods to correct the arc blow problem:

1. Changing to alternating current
2. Welding towards an existing weld or a heavy tack weld
3. Placing the work connection as far as possible from the weld at the end of the weld, or at the start of the weld and welding toward a heavy tack weld
4. Reducing the welding current and making the arc length as short as possible
5. Wrapping the work lead around the workpiece so that the magnetic field caused by the current in the ground cable will neutralize the magnetic field causing the arc blow

11.3.2 Improper Moisture Content

The coatings of all covered electrodes contain a certain amount of moisture. Incorrect moisture content in an electrode coating can cause operating problems with the electrode. Some typical coating moisture contents of various mild steel electrode coatings are shown in *Table 8-15*.

Table 8-15 — Moisture Contents of Various Mild Steel Electrode Coverings

Electrode Type	Moisture Content
E6010	3-6%
E6011	3-5%
E6012	.8-1.2%
E6013	.8-1.2%
E6027	.4-.6%
E7014	.4-.6%
E7016	.3-.5%
E7018	.3-.5%
E7024	.4-.6%
E7028	.4-.6%

The E6010 and E6011 electrodes have relatively high moisture content in their coverings. These electrodes can operate fairly well when the moisture content is above the maximum limit, but an excessive amount of moisture in these electrode coatings can cause blistering of the coatings and poor arc operation. Low moisture content will cause the electrodes to give excessive amounts of spatter and possibly porosity. Too much moisture in the coatings of the other types of electrodes can cause blistering of the coating, poor arc operation, and underbead cracking.

Low hydrogen electrodes are called low hydrogen because of their very low moisture content. Covered electrodes should always be stored in dry places. High moisture content in low hydrogen electrode coatings will damage the quality of the weld deposit. Redrying is often done after a long storage period except on the cellulose electrodes for which it is generally not recommended.

11.3.3 Fingernailing

Fingernailing is a problem that occurs when the arc does not come straight off the tip of the electrode, but moves over and comes more off the side of the electrode. This is usually because the electrode core wire is not concentric in the electrode coating. Fingernailing is shown in *Figure 8-103*. When the core wire is off center, a hard to control arc is produced because the electrode burns off more quickly on the side with the thinner coating. A cracked or damaged coating can also cause this problem.

Figure 8-103 — Fingernailing.

12.0.0 POSTWELD PROCEDURE

Several operations may be done after the weld. The first postweld procedure is to clean the slag off the weld bead. Other postweld procedures might call for cleaning, inspecting the weld for defects, straightening, and postheating.

12.1.0 Cleaning

After depositing the weld bead and breaking the arc broken, begin the clean up process. Remove the slag covering either by chipping or some other form of slag removal. This is particularly important when making multiple-pass welds. Complete removal of the slag for multiple pass welds prevents slag inclusions, porosity, and lack of fusion in the weld. After removal of the slag, a grinder is often used to grind the surface of the weld to give a more uniform surface. A wire brush is also often used to clean up the surface of the weld.

12.2.0 Inspection and Testing

The weld is inspected and tested after cleaning to determine the quality of the weld joint. There are many different methods of inspection and testing which will not be covered in detail in this course. The use of these methods wiIl often depend on the code or specification that covered the welding. Testing of a weldment may be done nondestructively or destructively.

Nondestructive testing is used to locate defects in the weld and base metal. There are many different nondestructive testing methods. Some of the most widely used methods are visual, magnetic particle, liquid penetrant, ultrasonic, and radiographic. Visual, magnetic particle, and liquid penetrant inspection are used to locate surface defects; ultrasonic and radiographic inspections are used to locate internal defects.

Destructive testing is used to determine the mechanical properties of the weld such as the strength, ductility, and toughness. Destructive testing is also done by several methods, depending on the mechanical properties being tested for. Some of the most common types of destructive testing are tensile bar tests, impact tests, and bend tests.

12.2.1 Welding Quality Control

In the fabrication or repair of equipment, there are tests to determine the quality and soundness of 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. This section will briefly discuss nondestructive and destructive testing.

12.3.0 Repairing of Welds

Repair of the weld metal is sometimes necessary when testing reveals defects. The defects may be discovered by visual inspection and by other nondestructive testing methods. Where a defect is found, it is usually ground out or gouged out. Using a grinder is usually better for surface defects and for defects fairly near the surface of the weld metal. For deeper defects, an air carbon-arc gouging torch or some similar gouging method is often used for removal. Once the defects have been removed, the low areas created by the grinding and gouging can be filled in using the shielded metal arc process. The parts are then reinspected to make sure that the defects have been properly repaired.

12.4.0 Postheating

Postheating is a heat treatment applied to the metal after welding. Postheating is often required after the weld has been completed, but this depends upon the type of metal being welded, the specific application, and the governing codes or specifications. Various types of postheating are used to obtain specific properties. Types of postheating are annealing, stress relieving, normalizing, as well as quenching and tempering. Postheating is done with many of the same methods used for preheating, such as furnace heating, induction coils, and electric resistance heating blankets. One method used for stress relieving that does not involve heating is called vibratory stress relief. This method does not use heating because the part being stress relieved is vibrated mechanically to relieve the residual stresses.

Annealing is a process involving heating and cooling that is usually applied to induce softening. There are different kinds of annealing, but when it is applied to ferrous alloys, it is called full annealing. Full annealing is a softening process in which a ferrous alloy is heated, usually in a furnace, to a temperature above the transformation range and slowly cooled to a temperature below the transformation range.

Stress relieving is the uniform heating of a structure to a high enough temperature, but below the critical range, to relieve most of the residual stresses due to welding. This is followed by uniform cooling. The terms normalizing and annealing are often misnomers for this application.

Normalizing is a process in which a ferrous alloy is heated to a temperature above the transformation range and then cooled in still air to a temperature below the transformation range.

Quenching and tempering is another postweld heat treatment commonly used. The metal is heated and then quenched to provide a very hard and brittle metallurgical structure. The part is then tempered by reheating to a particular temperature dependent upon the degree of ductility, tensile strength, yield strength, and hardness required.

After welding with the shielded metal arc process, postheating is often required. For many applications, heat treating low-carbon steels after welding is unnecessary. The medium-carbon steels usually use postheating from 1100 to 1200°F (590 to 650°C) to remove the brittle microstructure that may have been caused by too rapid cooling. High-carbon steels are often stress relieved at 1200°F (650°C). The various low alloy steels often require stress relieving from 1100-1250°F (590-680°C). Stainless steels are often post-weld heat treated to reduce the grain size and preserve good corrosion resistance. Annealing is used to reduce the grain size, which gives better ductility. The temperatures used depend on the specific stainless steel.

Test your Knowledge (Select the Correct Response)

13. What causes slag inclusions?

    A. Steady travel speed
    B. Too narrow a weaving motion
    C. Slag left on the previous weld pass
    D. Too small an electrode being used

14. Which of the following is a nondestructive test?

    A. Etching
    B. Liquid penetrant
    C. Tensile strength
    D. Free-bend

13.0.0 WELDER TRAINING and QUALIFICATION

To become a fully certified welder, you must know the requirements for training and qualifications. While these may differ somewhat from organization to organization, and you may need to demonstrate your skills to qualify for a particular project and specific welding task, the basic guidelines are the same for achieving the training and qualifications.

13.1.0 Welder Training

Shielded metal arc welding generally requires a high degree of welder skill to produce good quality welds. As a result, many training programs emphasize this process in their training schedule. A welder skilled in this process generally has much less trouble learning to weld with the other arc welding processes.

The exact content of a training program will vary depending on the specific application of the process. The training program should be flexible enough to be adapted to changing needs and applications. Emphasis may be placed on certain areas of the training schedule because of this. The complexity of the parts to be welded and the governing codes or specifications involved also dictate the length of such a training program.

The United States Department of Labor published a book entitled "Dictionary of Occupational Titles" that describes the duties of the different job titles for welders. The training programs used to develop the entry level skills for these job titles may vary depending on the amount of skill required. For instance, a pipe welder needs more skill than a tack welder, so the length of a training program for a pipe welder is greater than the length of a training program for a tack welder.

The job title of arc welder (DOT 810.384-014) describes a person who has the duty of welding together components of many products made of metal. This job includes setting up the machine and part to be welded, striking the arc and guiding it along the joint, and performing duties such as chipping, grinding, and slag removal. The welder should be able to weld in all positions, be able to pass employer performance tests, and meet certification standards of governmental agencies or professional and technical associations.

A tack welder (DOT 810.684-010) makes short beads at specified points to hold the parts in place for final welding. The tack welder also performs the duties of fitter helper.

A production line welder (DOT 819.684-01 0) welds previously set up parts on a production line. The production line welder may also perform tack welding.

A combination welder (DOT 819.384-010) welds metal parts together to fabricate or repair the assembly. The combination welder uses both gas welding and any combination of arc welding processes. Other duties include seting up parts, cutting, grinding, and other related tasks. A combination welder may be required to pass employer performance tests to meet certification standards of governmental agencies or professional and technical associations.

The welder portion of the pipefitter course(DOT 862.381-018) is a person who welds the pipe together after it has been located and tacked in place.

13.1.1 Basic Shielded Metal Arc Welding

The basic shielded metal arc welding training program is used to teach the student the basic entry level skills required for the job titles of arc welder, tack welder, production line welder, and the arc welder portion of combination welder. This course provides training on how to strike an arc, run weld beads, make good quality fillet welds, and an introduction to making groove welds. The training the student receives should impart enough skill to get a job as a tack welder, production line welder and enough skill for many of the simple arc welding jobs. This course should also provide the background skill required to take an advanced shielded metal arc welding course. The following is an outline for an approximately 140 hour course:

Topic

1. Lecture/Discussion, "Arc Welding Introduction"
2. Lecture/Discussion, "Safety and Health of Welders"
3. Strike Arc and Run Bead, Surface Weld, Flat Position
4. Pad of Beads, Surface Weld, Flat Position
5. Fillet Weld, Lap Joint, Horizontal Position
6. Lecture/Discussion, "Visual Inspection and Practical Weld Tests"
7. Fillet Weld, Tee Joint, Horizontal Position
8. Fillet Weld, Tee Joint, Flat Position
9. Pad of Beads, Surface Weld, Horizontal Position
10. Square Groove Weld, Butt Joint, Horizontal Position
11. Lecture/Discussion, "Electrode Selection"
12. Fillet Weld, Lap Joint, Vertical-Up Position
13. Fillet Weld, Tee Joint, Vertical-Up Position
14. Square Groove, Butt, Joint, Vertical-Up Position
15. Lecture/Discussion "Power Sources for Welding"
16. Fillet Weld, Lap Joint, Overhead Position
17. Fillet Weld, Tee Joint, Overhead Position
18. Square Groove Weld, Butt Joint, Overhead Position
19. Lecture/Discussion, "Welding Distortion Control"
20. Fillet Weld, Lap and Tee Joints, Flat and Vertical Down Positions
21. String Beads, Flat, Horizontal and Vertical Positions
22. Fillet and Square Groove Weld Lap-Butt and Corner Joints, Flat-Horizontal and Vertical Positions
23. Fillet Weld, Lap Joint, Vertical-Down Position
24. Square Groove Weld, Butt Joint, Flat Position
25. Fillet Weld, Lap Joint, Horizontal Position
26. Lecture/Discussion, "The Low Hydrogen Electrode and Its Use"
27. Fillet Weld, Tee Joint, Vertical-Up Position
28. Fillet Weld, Tee Joint, Overhead Position

13.1.2 Advanced Shielded Metal Arc Welding

The prerequisites for the advanced shielded metal arc welding course should be successful completion of the basic shielded metal arc welding course or equivalent welding training or experience. The purpose of this course is to develop the entry level skills for arc welder, production line welder, tack welder and the arc welding portion of combination welder. This course provides the skill training required for the student to make good quality fillet and multiple pass groove welds. This includes learning to use the proper weld bead sequence and welding grooved joints in all positions. A student who successfully completes this course should be able to do more complicated arc welding jobs on plate material. The following is approximately a 140 hour course outline for advanced shielded metal arc welding:

Topic

1. Lecture/Discussion, "Introduction"
2. Lecture/Discussion, "Safety and Health of Welders"
3. Fillet Weld, Lap Joint, Horizontal Position
4. Lecture/Discussion, "Air Arc Cutting and Gouging"
5. Fillet Weld, Lap Joint, Overhead Position
6. Lecture/Discussion, "Procedure and Welder Qualification"

7. Fillet Weld, Lap Joint, Vertical Position, Up Hill Travel
8. Lecture/Discussion, "Destructive Testing"
9. Fillet Weld, Lap Joint, Cross Section Etch test
10. Lecture/Discussion, "Non-Destructive Testing"
11. Single Vee Groove Weld, Butt Joint, Horizontal Position
12. Single Vee Groove Weld, Butt Joint, Overhead Position
13. Single Vee Groove Weld, Butt Joint, Overhead Position, Guided Bend Test
14. Lecture/Discussion," Metals Identification for Welding"
15. Single Vee Groove Weld, Butt Joint, Vertical Position
16. Single Vee Groove Weld, Butt Joint, Vertical Position, Guided Bend Test
17. Lecture/Discussion, "Welding of Cast Iron and Surfacing of Steel"
18. Single Vee Groove Weld, Butt Joint, Flat Position
19. Fillet Weld, Lap Joint, All Positions

13.1.3 Shielded Metal Arc Pipe Welding

The prerequisites for the shielded metal arc pipe welding should be to have successfully completed the basic and advanced shielded metal arc welding courses or have equivalent welding training or experience. The pipe welding is divided into two categories, uphill and downhill pipe welding. The purpose of these courses is to develop the entry level skills required for the welder portion of pipefitter.

Since pipe welding is more difficult than plate welding, the student should be proficient in welding groove joints in plate in all positions before starting pipe welding.

Shielded metal arc pipe welding, uphill method is used on power plant, refinery, and chemical installation construction. This course covers pipe welding in the 2G, 5G, and 6 G positions on mild steel pipe. An outline for approximately a 210 hour course is as follows:

1. Lecture/Discussion, "Introduction to Up Hill Pipe Welding"
2. Lecture/Discussion, "Safety and Health of Welders"
3. Prerequisite Skill Test, Single Groove Weld, Butt Joint, Vertical and Overhead Positions
4. Lecture/Discussion, "How to Read and Apply Pipe Welding Procedures"
5. Preparation and Assembly of a Pipe Joint
6. Lecture/Discussion, "Weld Quality: Reading the Puddle"
7. Single Groove Weld, Butt Joint, Horizontal Fixed Position (5G)
8. Single V-Groove Weld, Butt Joint, Horizontal Fixed Position (5G), Visual Inspection
9. Single V-Groove Weld, Butt Joint, Vertical Fixed Position (2G)
10. Single V-Groove Weld, Butt Joint, Vertical Fixed Position (2G), Visual Inspection
11. Lecture/Discussion, "Preheat and Interpass"
12. Single V-Groove Weld, Butt Joint, 45° Fixed Position (6G)
13. Single V-Groove Weld, Butt Joint, 45° Fixed Position (6G), Guided-Bend Test

In addition to the basic course outline, topics covering the welding of stainless steel pipe and the use of backing rings may be covered. Both of these are specialty items that are commonly welded by the uphill pipe welding method and are covered for use on special applications. Each of these items consists of approximately 70 hours additional training time.

The downhill pipe welding method is primarily used on cross country transmission pipelines. This course covers welding downhill in the 5G and 6G positions on mild steel pipe. The following is an outline for approximately a 140 hour course:

1. Lecture/Discussion, "Introduction to Downhill Pipe Welding"
2. Lecture/Discussion, "The Safety and Health of Welders"
3. Prerequisite Skill Test, Single Vee Groove Weld, Butt Joint, Vertical and Overhead Positions
4. Lecture/Discussion, "How to Read and Apply Pipe Welding Procedures"
5. Preparation and Assembly of a Pipe Joint
6. Lecture/Discussion, "Weld Quality-Reading the Puddle"
7. Single Vee Groove Weld, Butt Joint, Horizontal Fixed Position (5G), Downhill
8. Single Vee Groove Weld, Butt Joint, Horizontal Fixed Position (5G), Visual Inspection
9. Lecture/Discussion, "Pipe Welding Fixtures and Line-up Clamps"
10. Single Vee Groove Weld, Butt Joint, 45° Fixed Position (6G), Downhill
11. Single Vee Groove Weld, Butt Joint, 45° Fixed Position, Guided-Bend Test

13.2.0 Welder Qualification

Before a welder can begin work on any job covered by a welding code or specification, he must become certified under the code that applies. Many different codes are in use today, and it is exceedingly important that the specific code is referred to when taking qualification tests. In general, the following type of work is covered by codes: pressure vessels and pressure piping, highway and railway bridges, public buildings, tanks and containers that hold flammable or explosive materials, cross country pipeline, aircraft, ordnance material, ships and boats, and nuclear power plants.

Certification is obtained differently under the various codes. Certification under one code will not necessarily qualify a welder to weld under a different code. In most cases certification for one employer will not allow the welder to work for another employer. Also, if the welder uses a different process or if the welding procedure is altered drastically, recertification is required. In most codes, if the welder is continually employed, welding recertification is not required providing the work performed meets the quality requirement. An exception is the military aircraft code which requires requalification every six months.

Responsible manufacturers or contractors may give qualification tests. On pressure vessel work, the welding procedure must also be qualified, and this must be done before the welders can be qualified; under other codes, this is not necessary. To become qualified, the welder must make specified welds using the required procedure, base metal, thickness, electrode type, position, and joint design. Test specimens must be made according to standardized sizes and under the observation of a qualified person. In most government specifications, a government inspector must witness the making of welding specimens. Specimens must be properly identified and prepared for testing. The most common test is the guided-bend test. However, in some cases, X-ray examinations, fracture tests, or other tests are employed. Satisfactory completion of test specimens, providing they meet acceptability standards, will qualify the welder for specific types of welding. Again, the welding that will be allowed depends on the particular code. In general, however, the code indicates the range of thicknesses which may be welded, the positions which may be employed and the alloys which may be welded.

Qualification of welders is a highly technical subject and cannot be covered fully here. You should obtain the actual code, study it, and practice it prior to taking any qualification test.

Some often used codes are:

"Structural Welding Code", AWS D1.1

"ASME Boiler and Pressure Vessel Code", Section IX, Welding Qualifications

"Standard For Welding Pipelines and Related Facilities", API 1104

14.1.1 WELDING SAFETY

Safety is an important consideration when welding. Every welding shop should have a safety program and take adequate safety precautions to help protect welders. The welders should also be made aware of safety precautions and procedures. Employees who fail to follow adequate safety precautions can cause physical injury to themselves and others and damage property. Any of these conditions can result in physical discomfort and loss of property, time, and money. Welding is a safe occupation when safety rules and common sense are followed. A set of safety rules is presented in the American National Standard Z49.1, "Safety in Welding and Cutting", published by the American Welding Society. Welders must follow these rules.

There are several types of hazards associated with shielded metal arc welding. These do not necessarily result in serious injuries; they can also be of a minor nature. Even these minor injuries, however, can cause discomforts that irritate and reduce the efficiency of the welders. These hazards are:

1. Electrical shock
2. Arc radiation
3. Air contamination
4. Fire and explosion
5. Weld cleaning and other hazards

14.1.0 Electrical Shock

Several precautions should be taken to prevent an electrical shock hazard. The first is to make sure before welding that the arc welding equipment is installed properly, grounded, and in good working condition. The electrical equipment should be maintained and installed in accordance with the National Electrical Code and any state and local codes that apply. Power supplies should be connected to an adequate electrical ground such as an approved building ground, cold water pipe, or ground rod. Power supplies are connected to ground through the cable that connects the power supply to the electrical system ground. Cables with frayed or cracked insulation and faulty or badly worn connections can cause electrical short circuits and shocks. If it is necessary to splice lengths of welding cable together, make sure the electrical connections are tight and insulated. Use the proper size welding cables also because constantly overloading a welding cable that is too small can destroy the insulation and create bare spots in the insulation. This occurs because excessive heat builds up in the cable and destroys the insulation. An improperly insulated welding cable is both an electrical shock hazard and a fire hazard. Be sure the welding area is dry and free of any standing water which could cause electrical shock. When it is necessary to weld in a damp or wet area, wear rubber boots and stand on a dry insulated platform.

14.2.0 Arc Radiation

The welding arc of shielded metal arc welding emits large amounts of invisible ultraviolet and infrared rays. Skin that is exposed to the arc even for a short time can suffer serious ultraviolet and infrared burns, which are essentially the same as sunburn, but the burn caused by welding can take place in a much shorter time and be very painful. Because of this, always wear protective clothing suitable for welding. These clothes should be fairly heavy and not easily burned. Leather is often used to make jackets, capes and bibs, or other similar arrangements to shield the arms, shoulders, chest, and stomach from the arc radiation and arc spatter. Leather is also used to make gloves and gauntlets for the welder.

The eyes should also be protected from the radiation emitted by the welding arc. Arc-burn can result if the eyes are not protected. Arc-burn of the eye is similar to sunburn of the skin and it is extremely painful for about 24 to 48 hours. Usually arc-burn does not permanently injure the eyes, but it can cause intense pain as though several grains of sand were in your eyes. There are several commercial solutions available to soothe the skin and eyes during the period of suffering.

Infrared arc rays can cause fatigue of the retina. The effects of infrared rays are not nearly as noticeable or immediate as the effects of ultraviolet rays. Infrared rays are probably more dangerous in that their effects can be longer lasting and result in impaired vision. The best protection for the eyes and face is a headshield that has a window set in it with a filter lens in the window. Headshields are generally made of fiberglass or a pressed fiber material to be lightweight. The filter lens is made of a dark glass capable of absorbing infrared rays, ultraviolet rays and most visible light coming from the arc. The type of lens used varies for different welders but it should be dark enough so the arc can be viewed without discomfort yet not so dark the welder cannot see what he or she is doing. *Table 8-4* shows the different lenses commonly recommended for use in shielded metal arc welding. The higher the lens numbers the darker the lens. A clear, replaceable glass should be put on the outside of the welding lens to protect it from spatter and breakage.

Table 8-4 -Recommended Filter Lens Shades Used in Shielded Metal Arc Welding (ANSI/AWS Z49.1)

Electrode Diameter-In. (mm)	Lens Shade Number
1/16 (1.6), 3/32 (2.4), 1/8 (3.2), 5/32 (4.0)	10
3/16 (4.8), 7/32 (5.6), 1/4 (6.4)	12
5/16 (7.9), 3/8 (9.5)	14

14.3.0 Air Contamination

The arc and the decomposition of the electrode coating during welding generate welding smoke and fumes. Because of this, the following warning is printed on the containers packaging the covered electrodes: "Welding may produce fumes and gases hazardous to health. Avoid breathing these fumes and gases. Use adequate ventilation. See American National Standard Z49.1, Safety in Welding and Cutting, published by the American Welding Society."

The welding area should be adequately ventilated because welding produces fumes and gases such as ozone, which is a hazardous gas for the welder to breathe. Welding in confined areas requires an external air supply. This is furnished by a gas mask on a special helmet. A second person should stand just outside the confined area to lend assistance to the welder if necessary. Use a mechanical exhaust when welding metals with toxic coatings such as lead, copper, cadmium, and zinc.

14.4.0 Fires and Explosions

Fires and explosions are hazards that can exist in a welding area if the proper precautions are not taken. The shielded metal arc welding process produces sparks and spatters which can start a fire or explosion in the welding area if it is not free of flammable, volatile, or explosive materials. Never weld near degreasing and other, similar operations. Wear leather clothing for protection from burns, because leather is fireproof. Electrical shorts or overheated worn cables can also start fires. In case of a fire started by a flammable liquid or an electrical fire, a CO2 or dry chemical type of fire extinguisher is used. Fire extinguishers should be kept at handy spots around the shop and welders should make a mental note of where they are located.

Other precautions that have to do with explosions are also important. Do not weld on containers that have held combustibles unless it is absolutely certain there are no fumes or residue left. Do not weld on sealed containers without providing vents and taking special precautions. Never strike the welding arc on a compressed gas cylinder. When the electrode holder is set down or not in use never allow it to touch a compressed gas cylinder.

14.5.0 Weld Cleaning and Other Hazards

Welders can also encounter hazards during the weld cleaning process. Always take precautions to protect the skin and eyes from hot slag particles. The welding helmet, gloves, and heavy clothing protect the skin from slag chipping and grinding of the weld metal. Wear safety glasses underneath the welding helmet to protect the eyes from particles that could get inside the welding helmet.

The discarded stubs of the electrodes can also be a safety hazard. If these are dropped on the floor during electrode changes they can become a hazard because they roll or slide easily. If a welder steps on one, he or she could fall and possibly sustain injury, so it is necessary to keep the floor of the welding area clear of electrode stubs.

14.6.1 Summary of Safety Precautions

1. Make sure your arc welding equipment is properly installed, grounded, and in good working condition.
2. Always wear protective clothing suitable for welding.
3. Always wear proper eye protection when welding, grinding or cutting.
4. Keep your work area clean and free of hazards. Make sure no flammable, volatile, or explosive materials are in or near the work area.
5. Do not weld in a confined space without special precautions.
6. Do not weld on containers that have held combustibles without taking special precaution.
7. Do not weld on sealed containers or compartments without providing vents and taking special precautions.
8. Use mechanical exhaust at the point of welding when welding lead, cadmium, chromium, manganese, brass, bronze, zinc, or galvanized steel.
9. When it is necessary to weld in a damp or wet area, wear rubber boots and stand on a dry, insulated platform.

10. If it is necessary to splice lengths of welding cable together, make sure all electrical connections are tight and insulated. Do not use cables with frayed, cracked, or bare spots in the insulation.
11. When the electrode holder is not in use, hang it on brackets provided. Never let it touch a compressed gas cylinder.
12. Dispose of electrode stubs in a proper container since stubs on the floor are a safety hazard.
13. Shield others from the light rays produced by your welding arc.
14. Do not weld near degreasing operations.
15. Ensure that the scaffold, ladder, or work surface has a solid base when working above ground.
16. When welding in high places without railings, use a safety belt or lifeline.

Summary

This chapter has introduced you to the SMAW process from the types of power sources, controls, and electrodes to the types of training and qualifications needed. It also described the industries that use the SMAW process and its applications. Welding metallurgy, weld and joint design as well as welding procedure variables were also discussed. The chapter finished up with a description of possible weld defects, and how to identify for them using multiple methods of destructive and nondestructive tests and inspections. As always, use the manufacturer's operator manuals for the specific setup and safety procedures of the welder you will be using.

Review Questions (Select the Correct Response)

1. What type of current is used in shielded metal arc welding?

   A. Constant
   B. Indirect
   C. Unmodulated low frequency
   D. Modulated high frequency

2. A constant flow of electrical current that travels in one direction only has what type of polarity?

   A. Alternating
   B. Reverse
   C. Direct
   D. Straight

3. What factors determine the size of a welding cable needed for a job?

   A. The size of the electrode and number of lock connections
   B. The amperage rating of the machine and distance from the work to the machine
   C. The size of the ground cable and capacity of the electrode holder
   D. The distance from the ground clamp and type of electrode

4. The distance between an operator and any joint in the welding cable should be a minimum of how many feet?

   A. 35
   B. 25
   C. 15
   D. 10

5. When selecting an electrode holder for a specific task, you should base your selection on what criteria?

   A. Current capacity and cable size
   B. Type of machine and polarity
   C. Electrode diameter and welding current
   D. Type of holder insulation and polarity

6. The use of a good ground clamp that provides proper grounding is essential to the production of quality welds. Which of the following conditions could develop without this proper grounding?

   A. Circuit voltage that fails to produce enough heat
   B. A damaged welding machine
   C. Damaged cables
   D. All of the above

7. Which of the following safety devices should you use to protect other personnel in a welding work area from eye flash burns?

   A. Welding helmets
   B. Flash goggles
   C. Face masks
   D. Welding screens

8. The coating on an arc-welding electrode provides which of the following advantages?

   A. Improved weld penetration
   B. Prevention of oxidation
   C. Control and increased stability of the arc
   D. All of the above

9. Electrodes manufactured in the U.S. must conform to what standards?

   A. AISC/CRSI
   B. AWS /ASTM
   C. NAVOP 1061 (welding)
   D. Engineering Standards, U.S. (1996 Ed.)

10. An electrode that has a minimum tensile strength of 80,000 psi for use in all positions for low alloy has what designation?

   A. E11810
   B. E8024
   C. E8018-C3
   D. E7018

11. A welding electrode that has an AWS classification of E-7024 should be used for a metal-arc welding job in what position(s)?

   A. Horizontal position only
   B. Flat position only
   C. Horizontal and flat positions
   D. Vertical and overhead

12. When welding stainless steel, you must use what type of electrode?

   A. Sulfur/titanium
   B. Hydrogen/manganese
   C. Cellulose/sodium
   D. Chromium/nickel

13. Which of the following properties is the basic criterion for selecting an electrode for a job?

    A. Great tensile strength
    B. Composition similar to the base metal
    C. The melting temperature
    D. The least expensive

14. When the electrode is positive and the workpiece is negative, the electrons flow from the workpiece to the electrode. What polarity is being used?

    A. Straight
    B. Negative
    C. Positive
    D. Reverse

15. Which of the following factors is a reason why reverse polarity is used in out-of-position welding?

    A. Greater heat is generated at the workpiece.
    B. Less heat is generated in the workpiece.
    C. Greater heat is required in the base metal.
    D. A higher deposition of filler metal is required.

16. What kind of sound does improper polarity emit?

    A. Cracking
    B. Humming
    C. Whistling
    D. Hissing

17. Which one of the following steps do you take to correct arc blow?

    A. Change the position of the work piece.
    B. Weld away from the ground clamp.
    C. Change to alternating current.
    D. All of the above

18. What is the first thing you should do to start an arc by the striking method?

    A. Hold the electrode at right angles to the work and strike it sharply against the base metal.
    B. Bring the electrode into contact with the work using a lateral motion.
    C. Slowly lower the electrode on to the work until the arc strikes.
    D. Place the electrode on the work until the base metal melts.

19. **(True or False)** Upon striking an arc; you immediately start the weld to ensure good fusion and penetration.

A. True
B. False

20. What ampere setting should you initially use when welding with a 5/32-inch diameter electrode?

A. 125
B. 250
C. 380
D. 450

21. What condition occurs when the welding current is too high?

A. Overlap
B. Poor fusion
C. Undercutting
D. Porosity

22. What condition(s) can develop when the welding current is too low?

A. Overlap only
B. Poor fusion only
C. Undercutting and poor fusion
D. Overlap and poor fusion

23. What kind of sound does a good arc produce when the electrode, current, and polarity are correct?

A. Sharp cracking
B. Humming
C. Whistling
D. Hissing

24. When shield metal arc welding, the distance between the electrode and the base metal, except in vertical and overhead welding, should be approximately equal to which of the following characteristic?

A. Length of the electrode
B. Length of the electrode holder
C. Thickness of the base metal
D. Diameter of the electrode

25. Of the following practices, which one is correct for breaking an arc with an electrode?

    A. Withdrawn it slowly from the crater after the arc has lengthened.
    B. Hold it stationary until the crater is filled, then withdraw it slowly.
    C. Hold it stationary until the equipment is secured.
    D. Lower it into the crater until contact is made, then quickly withdraw it.

26. What is the maximum thickness a plate can be welded, in one pass, without edge preparation?

    A. 1/16-inch
    B. 1/8-inch
    C. 3/16-inch
    D. 1/4-inch

27. For what purpose do you use a backing strip when making a butt weld on 3/16-inch plate or heavier in the flat position?

    A. To reinforce the weld
    B. To hold plates in position while tack welding in place
    C. To obtain complete fusion at the root pass of the weld
    D. To reflect the heat from the electrode

28. What (a) width and (b) thickness of backing strip should be used on plate over 1/2-inch thick?

    A. (a.) 1 1/2 inches (b.) 1/4-inch
    B. (a.) 1 1/4 inches (b.) 3/8-inch
    C. (a.) 1 1/4 inches (b.) 1/8-inch
    D. (a.) 1 1/2 inches (b.) 1/4-inch

29. What angle should be maintained between the electrode and the vertical plate of a tee joint when 1/4-inch plate is used in the flat position?

    A. 35°
    B. 40°
    C. 45°
    D. 50°

30. What angle from the vertical should you hold the electrode when welding a lap joint on plates of varying thicknesses?

    A. 15° to 20°
    B. 20° to 30°
    C. 30° to 40°
    D. 40° to 50°

31. When vertical welding upwards, how many degrees do you hold the electrode to the vertical?

    A. 30°
    B. 45°
    C. 60°
    D. 90°

32. For which of the following reasons do you use relatively small electrodes for overhead butt welding?

    A. A long arc is needed to penetrate to the root of the joint.
    B. A short arc is needed to develop penetration at the root of the joint.
    C. Reduced current flow through the small electrode is needed to create a fluid puddle.
    D. Accelerated current flow is needed to control the fluid puddle.

33. What string bead do you deposit without the weaving motion of the electrodes when making a fillet weld of a lap or Tee-joint-in the overhead position?

    A. First
    B. Second
    C. Third
    D. Fourth

34. Which of the following mistakes can cause undercutting in welds?

    A. Current too high
    B. Current too low
    C. Faulty preheating
    D. Joints too rigid

35. Which of the following mistakes can cause excessive spatter in welds?

    A. Arc too short
    B. Arc too long
    C. Current too low
    D. Rigid joints

36. Which of the following mistakes can cause cracked welds?

    A. Faulty preparation
    B. Using the wrong electrode
    C. Using a rigid joint
    D. All of the above

37. Which of the following mistakes can cause poor penetration?

A. Current too low
B. Current too high
C. Welding Voltage too high
D. Welding voltage too low

38. Which of the following mistakes can cause brittle welds?

A. Current too low
B. Current too high
C. Rigid joints
D. Faulty preheating

39. When pipe has _ wall thickness, only the single U-type of butt joint should be used.

A. 1/4-inch or less
B. 1/2-inch or less
C. 1/2-inch or more
D. 3/4-inch or more

40. You do NOT need to do which of the following procedures when preparing a joint for welding?

A. Clean the edges of surfaces to be welded.
B. Adjust the joint surfaces so they are smooth and uniform.
C. Remove slag from flame-cut edges.
D. Remove temper color.

41. What is the maximum size a tack weld should be when applied to a pipe with a wall thickness of 1/2-inch?

A. 1-inch long and two thirds of the thickness of the pipe in depth
B. 3/4-inch long and two thirds of the thickness of the pipe in depth
C. 1/2-inch long and 2/3-inch deep
D. 1 1/4-inches long and 1/8-inch deep

42. What maximum nominal diameter of electrode should you NOT exceed when making the root pass of a multilayer weld on pipe?

A. 3/32-inch
B. 1/8-inch
C. 3/16-inch
D. 1/4-inch

43. The root of a fillet weld is where the ______.

A. edge of the weld intersects the base metal
B. back of the weld intersects the base metal surfaces
C. face of the weld and the base metal meet
D. face and the toe meet

44. The face of a fillet weld is the ______.

A. exposed surface of the weld
B. edge of the weld that intersects the base metal
C. groove face adjacent to the root joint
D. separation between the members to be joined

45. The toe of a fillet weld is the ______.

A. junction between the face of the weld and the base metal
B. rippled surface of the weld
C. root of the weld to the face
D. edge of the weld that intersects the base metal

46. The leg of the weld is the ______.

A. length of the weld
B. distance from the root of the joint to the toe
C. groove face adjacent to the root joint
D. exposed surface of the weld

47. The throat of a fillet is the shortest distance from the ______.

A. face to the toe
B. root of the weld to the face
C. root to the toe
D. toe to the leg

48. Electrode holders should be ______.

A. uninsulated
B. insulated
C. powder coated
D. laminated

49. Welding machine installations should be ______.

A. installed according to electrical codes
B. plugged into the nearest receptacle
C. connected to mobile generators only
D. simple with no grounding

50. Welding machine frames should be ________.

A. grounded electrically
B. not grounded electrically
C. rigid and heavy
D. insulated from ground

51. The welding arc gives off ultra-violet rays which can cause eye injury. Injury can be prevented by ________.

A. wearing the proper lens shade in the helmet
B. using eye drops
C. closing your eyes
D. turning your head away from the arc

52. Ultra-violet rays from the arc ________.

A. do not damage skin
B. can cause skin damage similar to sunburn
C. are a good source of vitamin C
D. are harmful if inhaled

53. You only need ventilation when ________.

A. an inspector is near
B. working in a closed area
C. working with nickel alloys
D. a fan is not available

54. Vaporized metals, such as zinc, cadmium, lead, and beryllium ________.

A. are hazardous
B. can be ignored
C. are used as shielding gases
D. are inert gases

55. Carbon dioxide produced by shielded metal arc welding is not considered harmful ________.

A. if properly ventilated
B. in confined areas
C. when using a dust mask
D. in tank welding operations

56. Before welding in a new area, ________.

A. get to know the people you will be working with
B. find out where the emergency room is located
C. thoroughly search the area for flammable material and remove or cover it with the fireproof material
D. assume that the area is safe for welding

57. Safety glasses with side shields ______.

A. are not needed in welding areas
B. should be worn during welding and cleaning operations
C. are not authorized at any time during welding operations
D. provide adequate protection for welding operations

58. When working in confined areas ______.

A. have a look-out stand by for quick rescue if needed
B. take a fire extinguisher with you
C. ensure another person is in the space with you
D. bring an oscillating fan

59. When you stop welding, you should ______.

A. leave the electrode in the holder and lay the holder on the weld table
B. remove the electrode and hang the holder on an ungrounded bracket
C. remove all power and grounds from output power
D. return all knobs and switches to the off or zero position

60. When striking an arc, hold the arc length for a moment to ______.

A. preheat the base metal
B. light up the area so you can see
C. clear the slag from the workpiece
D. clean the dirt from the workpiece

61. When welding over a previously deposited bead ______.

A. hold a long arc to melt the slag on the previous bead
B. use a weaving motion for deep penetration
C. tap the weld bead and electrode several times
D. clean the previous bead thoroughly before depositing the next weld

62. At the completion of the weld, the crater should ______.

A. overlap the workpiece
B. be filled to the height of the bead
C. remain unfilled
D. be twice the size it originally was

63. When welding in the overhead position the electrode should be______.

A. 120° to the weld face
B. 90° to the weld face
C. 45° to the weld face
D. 15° to the weld face

64. How is the melting rate related to the arc zone?

A. The output current of the power supply
B. The electrical energy in the welding arc
C. The power supplies current rating
D. The travel speed of the electrode

65. When restriking an arc to continue a bead (such as when changing electrodes), the arc should be restruck ______.

A. in the crater
B. as far away from the crater as possible
C. about 1/2-inch ahead of the crater
D. at least two electrode widths ahead of the crater

66. The axis of a weld is ______.

A. an imaginary line drawn through the weld along its length
B. an imaginary line drawn through the weld across its width
C. the rippled surface of the weld
D. parallel to the leg of the weld

67. Flat position welding is done from the ______.

A. upper side of the joint
B. lower side of the joint
C. perpendicular to the weld
D. opposite side of the face of the joint

68. In the flat position welding, the face of the weld is approximately ______.

A. parallel
B. at a right angle
C. horizontal
D. vertical

69. Horizontal position fillet welding is performed ______.

A. with the electrode in the horizontal position
B. with the electrode in the vertical position
C. on the upper side of an approximately horizontal surface and against an approximately vertical surface
D. on the lower side of an approximately vertical surface against an approximately horizontal surface

70. In a horizontal position groove weld, the axis of the weld lies in an approximately _____.

A. horizontal plane and the face of the weld lies in an approximately vertical position
B. horizontal plane and the face of the weld lies in an approximately horizontal position
C. vertical plane and the face of the weld lies in an approximately horizontal position
D. vertical plane and the face of the weld lies in an approximately vertical position

71. In vertical position welding, the axis of the weld is _____.

A. in an approximately vertical position
B. in an approximately horizontal position
C. welded with an electrode held in the vertical position
D. welded with an electrode held in the horizontal position

72. When making a horizontal fillet weld in a lap joint, the electrode should be positioned with a _____.

A. 90° angle not more than 15° off the horizontal
B. 60° angle not more than 15° off the horizontal
C. 90° angle not more than 45° off the horizontal
D. 60° angle not more than 45° off the horizontal

73. When lap welding base metal of different thickness the electrode should form an angle between _____.

A. 5 and 10°
B. 20 and 30°
C. 30 and 45°
D. 45 and 90°

74. Tack welds should be _____.

A. cleaned before the full weld is made
B. half the length of the weld joint
C. welded over without cleaning
D. only on opposite corners

75. Compared to an E6012 electrode, an E6010 electrode _____.

A. Deeper penetration
B. Shallower penetration
C. Higher deposition
D. Lower deposition

76. When ending a butt joint on a multipass weld you should whip up and pause the electrode ______.

A. 1 diameter back from the edge of the bead
B. 2 diameters back from the edge of the bead
C. 1/4 diameter back from the edge of the bead
D. At the edge of the bead

77. **(True or False)** Before a welder can begin work on any job covered by a welding code or specification, he must become certified under the code that applies.

A. True
B. False

78. **(True or False)** A combination welder welds metal parts together to fabricate or repair the assembly

A. True
B. False

79. **(True or False)** The downhill pipe welding method is primarily used on cross country transmission pipelines

A. True
B. False

80. **(True or False)** Using a filler metal not matching the base material may produce a faulty weldment.

A. True
B. False

81. **(True or False)** A sound weld can be made over dirt, paint, and grease if the correct electrode is used.

A. True
B. False

82. Some of the most common types of destructive testing are ______.

A. tensile bar
B. big break
C. liquid penetrant
D. ultrasonic

83. Lay the wearfacing on the top and sides of each tooth ______.

A. 4 inches from the point
B. 2 inches from the point
C. 4 inches from the base
D. 2 inches from the base

84. The minimum tensile strength of an E11018 electrode is ______.

A. 11,018 pounds per square inch
B. 110,000 pounds per square inch
C. 100,000 pounds per square inch
D. 18,000 pounds per square inch

Trade Terms Introduced in this Chapter

Alloy	An alloy is a compound of one or more metals or other elements. For example, Brass is the alloy of copper and zinc.
American Wire Gauge (AWG)	Standard numbering system for the diameters of round, solid, nonferrous, electrically conducting wire.
Austenitic	Consisting mainly of austenite, which is a nonmagnetic solid solution of ferric carbide, or carbon in iron used in making corrosion-resistant steel.
Ferritic	Consisting of the pure iron constituent of ferrous metals, as distinguished from the iron carbides.
Ferrous	An adjective used to indicate the presence of iron. The word is derived from the Latin word *ferrum* ("iron"). Ferrous metals include steel and pig iron (with a carbon content of a few percent) and alloys of iron with other metals (such as stainless steel).
Inconel	A registered trademark that refers to a family of austenitic nickel-chromium-based super alloys. Inconel alloys are typically used in high temperature applications, and often referred to in English as "Inco" (or occasionally "Iconel")
Inverter	An electrical converter that converts direct current into alternating current.
Malleable	Capable of great deformation without breaking, when subject to compressive stress.
Martensite	A solid solution of iron and up to one percent of carbon, the chief constituent of hardened carbon tool steels.
MPa	Mega Pascal. The Pascal (unit) (Pa), is the International Standard (SI) unit of pressure (equivalent to one Newton per square meter).
Nodular	Occurring in the form of small rounded or irregular shapes.
Nonferrous	The term used to indicate metals other than iron and alloys that do not contain an appreciable amount of iron.
Rutile	A natural mineral composed primarily of titanium dioxide, TiO_2, and widely used as a welding electrode covering.
Spalling	Chipping or flaking