WELDING
Fundamentals and Procedures

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WELDING

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PREFACE

This book is intended for the apprentice to the journeyman welder and nonwelding personnel who may have welding operational processes within their realm of supervision. Its aim is to provide a working knowledge of the electric and gas welding and cutting procedures that are currently used in industry.

The basic procedures described include oxy-fuel gas welding and cutting, shielded metal arc welding (S.M.A.W.), gas metal arc welding (G.M.A.W.), and gas tungsten arc welding (G.T.A.W.). In addition, blueprint reading (layout and symbols), quality control of weldments (inspection and testing), welding terminology, and an introduction into metallurgy are also discussed. These provide up-to-date practical knowledge and instruction for commonly used welding procedures.

The book places major emphasis on safety in the workplace. Although proper safety procedures in the welding and cutting of metals are described in this text, further thorough research must be done by the individuals themselves. This will ensure the safety and weld quality of particular applications.

All dimensions are in S. I. (metric) with conversions into U.S. customary units placed in parentheses. All conversions are based on personal judgments of the authors. The welder may find further conversions necessary if greater accuracy is required for the procedure.

There has never been a greater need for the skilled welder than in today's job market. The endless changes and improvements in welding processes have motivated both beginners and experienced welders. The writing has been simplified to aid students in their welding study experience. We hope that this book will provide a sound background that readers can use to establish and perfect their welding methods.

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PART ONE
OXYFUEL GAS WELDING

CHAPTER ONE

PRINCIPLES AND SAFETY PROCEDURES

Other welding processes have now replaced oxyfuel gas welding in many applications, but this method continues to be important and widely used.

This chapter will introduce the process of oxyfuel gas welding with special emphasis on common uses of the flame, common fuel gases, safety procedures, and safety equipment.

PERFORMANCE OBJECTIVES

After you complete this chapter you should be able to:

1. Describe the development of the oxyacetylene welding process.
2. Identify the two major principles on which the process is based.
3. Identify the primary uses of the oxyacetylene process.
4. Explain how the various fuel gases differ.
5. List all the safety procedures both personal and shop.
6. List the safety equipment used in the oxyfuel gas process.

BACKGROUND OF THE OXYFUEL GAS PROCESS

During the early Iron Age, metals could be formed only by casting when in a molten state or by hammering when red hot. These two methods are still used today for forming iron and steel parts. The earliest method of joining two separate pieces of steel was known as forge welding. This was the only method available and it has been in use to some extent for centuries. With this method the two parts to be jointed are heated to a cherry red temperature and then hammered or rolled together (see Figure 1-1). Obviously, in today's industrial society this method is very limited in scope and efficiency. The need for efficient methods of welding a variety of metals led to the development of the oxyfuel gas process, which has now declined in popularity over the past few decades.

Experience in handling oxygen and acetylene gases was gained slowly. Only after a period of development was compressed oxygen placed in steel cylinders for easy transportation. The compression of acetylene into steel cylinders presented more of a problem, for it was found that acetylene would explode if compressed to a pressure of more than 100 kPa (15 psi). This difficulty was overcome by the invention of a cylinder packed with a porous material to which acetone was added. Liquid acetone has the ability to absorb up to 25 times its own volume of acetylene somewhat like a sponge absorbs water.*

The ability of the oxyfuel gas flame to melt almost any metal and to fuse together two separate pieces of metal without significantly changing the metal was only one of the advantages of this process. As many craftsmen experimented in their own particular area, more varied uses for the oxyfuel gas flame were found.

FIGURE 1-1 Blacksmith forge welding.

*Note: The terms *oxyfuel gas* and *oxyacetylene* welding will both be used throughout this and following chapters to indicate the same welding process.

PRINCIPLES OF THE PROCESS

The oxyacetylene process is based on two principles.

1. Oxygen burning with proper quantities of acetylene will produce a flame so hot that it can fuse or melt almost any commercial metal.
2. A stream of pure oxygen directed against a piece of ferrous metal (steel) can cut or sever that metal if it has been previously heated to its kindling temperature.

Oxygen and acetylene combine to produce a flame the temperature of which may range from 3100 to 3500°C (5612 to 6332°F). This flame is known as the tool of the oxyacetylene process.

FIGURE 1-2 Oxyacetylene welding.

Common Uses for the Oxyacetylene-Oxyfuel Gas Flame

Joining Processes. Fusion welding, braze welding (brazing), hardfacing, silver brazing, soft soldering.

Heating Operations. Forming, annealing, flame hardening, tempering, flame priming, flame descaling, case hardening, stress relieving.

Cutting Processes. Freehand flame cutting, machine flame cutting, flame gouging.

Although the use of the oxyacetylene process has been diminishing over the last few decades, no other welding process is as portable while still providing a full program of welding, brazing, heating, and cutting operations.

Joining Processes

An important application of the oxyacetylene process is fusion welding. The oxyacetylene flame melts the edges of the pieces of metal that are to be welded together. (This may be done with or without a filler metal.) The filler metal, called a welding rod, or filler rod is melted by the flame and the molten pool on the metal being welded. Since the welding rod is composed of metal similar to the metals being joined, as well as other elements that provide additional strength, the welding rod and the base metal unite to form a single homogeneous piece of metal. Welds made in this manner are known as fusion welds, because the base metal is melted or fused together with molten metal from the welding rod. See Figure 1-2.

In addition to fusion welding, the oxyacetylene process may be used to join metals in a way that *does not* require the melting and fusion of the base metals, but that nevertheless produces a joint of great strength. This operation is known as brazing.

Brazing entails a group of joining processes that use a filler metal with a lower melting point than the metal being joined. The base metal is heated to a dull red or to the melting temperature of the *brazing rod.* The brazing rod is melted and flowed onto the joint with the use of a flux. If the procedure is done correctly, a strong joint will result.

Heating Operations

The oxyfuel gas process is no longer used industrially for heating or forming operations but it is still used in many small shops for forming or heat treating operations such as annealing, flame hardening, tempering, case hardening and stress relieving.

Cutting Processes

Another important application of the oxyacetylene or oxyfuel gas process is cutting. In the cutting process, a stream of oxygen is directed against a piece of heated steel, causing the metal to oxidize or burn and thus allowing it to be cut to any desired shape.

Developments in cutting machinery and cutting techniques are also continually proving a great asset in modern industry. Research in metallurgy and the development of welding techniques have made it possible for practically all commercial metals to be welded successfully by the oxyacetylene process.

Fuel Gases

In the past two decades fuel gases other than acetylene have been developed for some welding and cutting operations. In all cases, these gases require special equipment and additional safety procedures. It should be noted that during oxyacetylene welding, the outer envelope produces carbon dioxide and water vapor that shields the molten puddle and prevents oxidization. Oxyacetylene gases are still the major gas welding combination used today.

The following gases can be used for some cutting and joining applications.

1. *Hydrogen.* Hydrogen can be used with oxygen to produce a flame that has many of the characteristics of the oxyacetylene flame. Due to its reduced heat capacity it is used mainly for welding aluminum and magnesium. Because there are no pressure restrictions as with acetylene, hydrogen and oxygen are used for underwater cutting.
2. *L.P. (liquified petroleum): Propane and butane.* Liquified petroleum products are manufactured by various companies throughout the world. These gases are usually supplied for welding in a liquid form under a positive pressure that tends to vary with temperature. L.P. gas is used mainly for soldering, brazing, and cutting. See Figure 1-3.

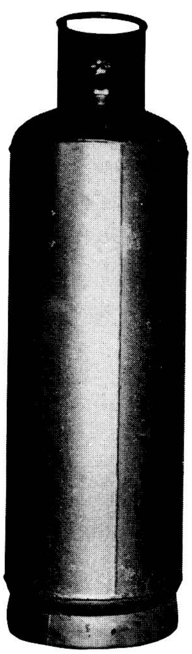

FIGURE 1-3 Propane cylinder.

3. *Natural gas.* Natural gas equipment is becoming more common in many small welding shops today. This gas can be supplied quite easily through a low-pressure piping system. Natural gas and oxygen are used for cutting, preheating, brazing, and soldering.
4. *MAPP industrial gas.* MAPP gas (methylacetylene propadiene) is a fuel gas sold under the trade name MAPP (Dow Chemical Co.). This gas handles like L.P. gas but has a heating value almost as great as that of acetylene. MAPP gas is generally stored and shipped in a liquid state and can be used for heating, brazing and most cutting operations, especially underwater cutting. See Figure 1-4.

SAFETY PROCEDURES

Most welding and cutting operations are not necessarily hazardous, but they do involve certain procedures that, if neglected, may lead to accidents or personal injury. It is necessary therefore that certain precautions be taken to protect the operator, his fellow workers, and the equipment being used.

Safety procedures are generally divided into two major groupings: personal safety and equipment safety. In this introductory chapter general safety rules are discussed.

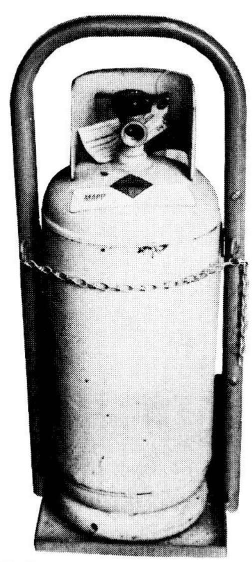

FIGURE 1-4 MAPP cylinder.

PERSONAL SAFETY

Clothing

1. Always wear proper safety clothing when welding or cutting. These articles should be fire resistant and made from heavy cotton or leather. Do not wear polyester or double-knit materials.
2. Wear gauntlet-type gloves of a heat-resistant material.
3. Always wear proper welding goggles when welding or cutting and safety glasses whenever you are in the shop area.
4. Be sure to keep sleeves rolled down, pocket flaps closed, and trouser cuffs turned down to avoid catching sparks and slag. High-top boots with safety toes should be worn. Do not carry matches in your shirt pocket.

Shop Procedures

1. Never allow grease or oil to come in contact with oxygen under pressure. Never use oil around oxygen cylinders, regulators, hoses, or torches. Keep hands and gloves free of oil and grease at all times. (Oil and grease burn quite rapidly when they come in contact with oxygen under pressure.)
2. Never use oxygen as a substitute for compressed air to blow out dirt, parts or clothing.
3. Avoid welding or cutting on parts suspected of being coated with zinc, aluminum, or cadmium. All of these coatings give off toxic fumes.
4. Never use equipment that you suspect of being defective; always report it immediately.
5. Do not carry or use disposable butane lighters in the welding shop or near any open flames or sparks.
6. Do not carry any flammable objects in your pockets while operating equipment that produces heat, sparks, or open flames.
7. Be sure your work area is properly ventilated.

Fire Prevention

1. Check for and remove all flammable materials from the work place before welding or cutting.
2. Always know the location of the nearest fire extinguisher, fire alarm, fire blanket, and fire exit before starting to work.
3. Never crack (open) an acetylene cylinder near an open flame or sparks.
4. Be sure all equipment has been turned off after work has been completed and that all lines have been drained.
5. Never weld or cut on a container suspected of having held or that is holding a flammable liquid or mixture without consulting the proper safety procedures.

In most of the following chapters, safety procedures that relate directly to certain processes and equipment will be covered in detail. It is very important that the beginning student be aware of all safety principles and procedures and keep them in mind at all times.

SAFETY EQUIPMENT

Gloves

Good quality gloves should be worn when welding or cutting or working with rough or hot materials. Gauntlet-type gloves or mittens of tanned leather or any other fire-resistant material should be worn by the operator. Gloves should always be kept free of oil and grease. Remember, a violent explosion can occur if oil or grease comes in contact with oxygen under pressure. See Figure 1-5.

Goggles

Welding goggles, similar to those shown in Figures 1-6 and 1-7, are vitally important to the welder. They are used to protect his eyes from the intense glare of the inner cone of the oxyfuel gas flame and from the sparks and bits of metal that may spatter about while

FIGURE 1-5 Leather gloves.

FIGURE 1-6 Standard welding goggles.

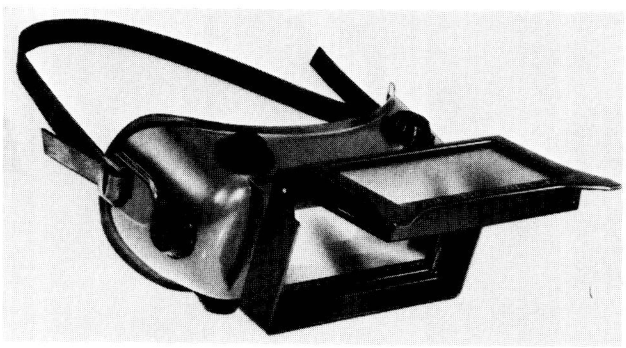

FIGURE 1-7 Welding goggles with flip-up cover lens.

welding or cutting is in progress. Most goggles used for oxyfuel gas welding use a number five green shade lens. For various welding or cutting operations on different metals (welding of mild steel or aluminum), different shades may be used. Goggles should be adjusted so that they fit snugly and comfortably. Remember, welding goggles should be of a style that permits the operator to wear safety glasses under them at all times.

Aprons

Welding aprons are generally made from leather with extra chrome content to increase heat resistance. Other pieces of protective clothing may include jackets, sleevelets, cape sleeves, and split-leg aprons. See Figure 1-8.

Safety Glasses

Safety glasses must be worn at all times in the welding shop. The welding goggles must fit over safety glasses. It is more important to have your safety glasses on when grinding, chipping, or working with any process or material that could cause eye damage. Sparks or flying objects can cause permanent eye injury and may originate from any part of the shop area. Face shields should be worn over safety glasses when grinding. Do not wear plastic goggles in the welding shop. See Figure 1-9.

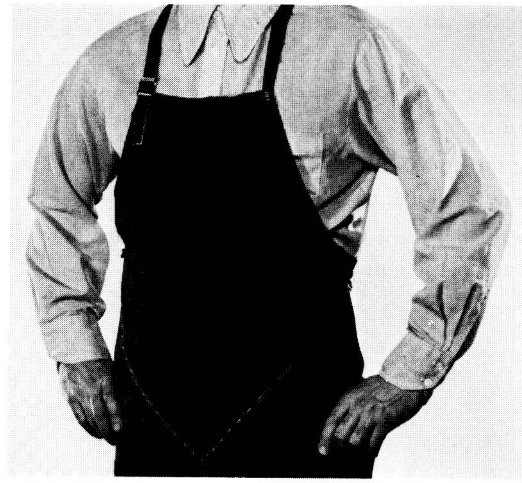

FIGURE 1-8 Apron.

ASSIGNMENT

1. Explain how metal was joined together by heating before the welding processes were developed.
2. Explain why it was important to find a safe method for storing and transporting acetylene gas.
3. List the common uses for the oxyacetylene or oxyfuel gas flame.
4. Describe the two principles of the oxyfuel gas process.

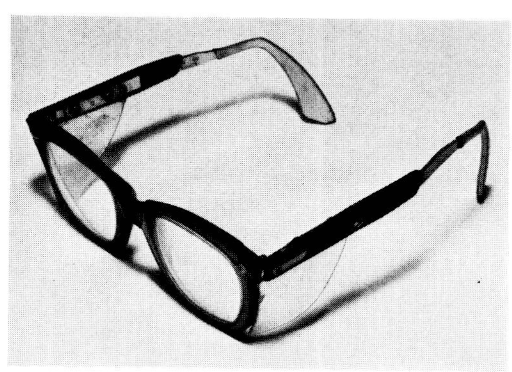

FIGURE 1-9 Safety glasses.

5. Explain the difference between fusion welding and brazing.
6. List four other fuel gases and explain the primary uses of each one.
7. List the four major safety rules under the heading Personal Safety (clothing).
8. Why is it important never to oil or grease any part of the oxyacetylene equipment?
9. List the four major safety rules under the heading Fire Prevention.
10. List four pieces of safety equipment that should be used in the welding shop and explain the importance of each.
11. When should safety glasses be worn in the welding shop?

CHAPTER TWO
PRODUCTION AND DISTRIBUTION OF GASES

The development of manufacturing and control devices for oxygen, acetylene, and other fuel gases was the major step in making the oxyfuel gas process as useful as it is today.

This chapter will cover the manufacture of oxygen and acetylene gases, the construction of cylinders and valves, the manifold system, and safety procedures that relate to all these topics.

PERFORMANCE OBJECTIVES

After you complete this chapter you should be able to:

1. Describe how oxygen is produced by the liquid air process.
2. Explain the manufacture of oxygen cylinders and the operation of oxygen cylinder valves.
3. List all safety procedures for oxygen and oxygen cylinders.
4. Describe the production of acetylene gas.
5. Explain how acetylene cylinders are manufactured and how the acetylene cylinder valve operates.
6. List all safety procedures for acetylene and acetylene cylinders.
7. Explain the purpose and operation of a manifold system.

MAJOR GAS GROUPS

Gases that are used for various welding processes may be divided into three distinct groups.

1. *Oxidants.* Oxygen and air
2. *Fuel gases.* Acetylene, propane, hydrogen, butane, and MAPP gas
3. *Shielding gases.* Nitrogen, argon, helium, and carbon dioxide. These gases may be mixed or used in their free state and are mainly used for the special electric welding processes to be discussed in a later chapter.

Our major interest in this chapter is the production, distribution, and safe use of oxygen and acetylene for the oxyacetylene welding and cutting processes. See Figure 2-1.

Oxygen

The air we breathe is a mixture (not a compound) of the following gases: oxygen (approximately 20 percent), nitrogen (79 percent), argon, neon, helium, carbon dioxide, and water vapor (1 percent). The discovery of oxygen as a separate element is attributed to the English chemist Priestley, in the year 1774. See Table 2-1.

Although the air of the atmosphere is a mechanical mixture and not chemically united, it is nevertheless difficult to separate the oxygen from the other gases. The process by which this is done and by which oxygen is chiefly produced is the liquid air process.

THE LIQUID AIR PROCESS

Oxygen is produced for industrial use by a low-temperature separation method. Filtered, clean air is pumped into a series of compressors that reduce its temperature to 20°C (68°F). By this process carbon dioxide and all particles of moisture are removed. The low-temperature air is then forced through an expansion engine where a heat exchanger cooled by nitrogen gas changes the gas into a liquid. This remaining air mixture is drastically reduced in temperature to −170°C (−274°F). At this point in the separation process, liquid air is forced through large condensers where a portion of the liquid nitrogen is withdrawn. The increased pressure raises the condensing temperature of the nitrogen so that heat available can be used to evaporate the liquid oxygen.

Because of their different boiling points, the various gases are easily separated by the distillation process. (The boiling point of liquid oxygen, for example is