EIGHTH EDITION

Welding

Principles and Applications

Larry Jeffus

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This book is dedicated to two very special people—my daughters Wendy and Amy.

Contents

Preface

Introduction

The welding industry presents a continuously growing and changing series of opportunities for skilled welders. Even with economic fluctuations, the job outlook for skilled welders is positive. Due to a steady growth in the demand for goods fabricated by welding, new welders are needed in every area of welding, such as small shops, specialty fabrication shops, large industries, and construction. The student who is preparing for a career in welding will need to:

- be alert and work safely.
- have excellent hand–eye coordination.
- work well with tools and equipment.
- have effective written and verbal communications skills.
- be able to resolve basic mathematical problems.
- be able to follow written and verbal instructions.
- work with or without close supervision.
- work well individually and in groups.
- read and interpret welding drawings and sketches.
- know the theory and application of the various welding and cutting processes.
- be computer literate.

A thorough study of *Welding: Principles and Applications* in a classroom/shop setting will help students prepare for opportunities in welding technology. The comprehensive technical content provides the basis for the welding processes. The extensive descriptions of equipment and supplies, with in-depth explanations of their operation and function, are designed to familiarize students with the tools of the trade. The process descriptions, practices, and experiments coupled with actual performance teach the critical fabrication and welding skills required on the job. The text also discusses occupational opportunities in welding and explains the training required for certain welding occupations. The skills and personal traits recommended by the American Welding Society (AWS) for its SENSE (School Excelling through National Skill Standards Education) Welder Certification program are included within the text.

The National Center for Welding Education and Training, known as Weld-Ed, is a partnership between business and industry, community and technical colleges, universities, the American Welding Society, and government to promote welding education.

Organization

The text is organized to guide the student's learning from an introduction to welding, through critical safety information, to details of specific welding and cutting processes, and on to the related areas of shop math, welding metallurgy, weldability of metals, reading technical drawings, fabrication, testing and inspection of welds, welding joint design, welding costs, welding symbols, and AWS SENSE certification.

Each section of the text introducing a welding process or processes begins with an introduction to the equipment and materials to be used in the process(es), including setup in preparation for welding. The remaining chapters for the specific process concentrate on the actual welding techniques in various applications and positions. The content progresses from basic concepts to the more complex welding technology. Once this technology is understood, the student is able to quickly master new welding tasks or processes. All of the welding technology and practices lead the student toward the ability to take and pass an AWS SENSE certification workmanship standard.

The sections on welding processes are laid out so that they can be studied individually and in any order. This was done so students can study the process or processes that might relate to their job requirements. However, students are encouraged to study and learn all of the processes so they have the broadest possible future job opportunities.

Objectives listed at the beginning of each chapter tell the student and instructor what is to be learned while studying the chapter. A survey of the objectives will show that the student will have the opportunity to develop a full range of welding skills. Each major process is presented independently so that the instructor can include or exclude them to better meet the needs of the local area served by the program. However, the student can still learn all essential information needed for a thorough understanding of all processes studied.

Key Terms are listed at the beginning of the chapter. These key terms are **boldface** and defined throughout the chapters so students will recognize them as they appear. Terms and definitions used throughout the text are based on the American Welding Society's standards. Industry jargon has also been included when appropriate.

Cautions for the student are given throughout the text and point out potential safety concerns or give additional specific information that will make working safer.

Think Green text boxes contain information on conserving materials, energy, and other natural resources and ways to avoid potential environmental contamination.

Metric equivalents are listed in parentheses for dimensions. When the standard unit is an approximation, the metric equivalent has been rounded to the nearest whole number; however, when the standard unit is an exact value, the metric conversions are more precise.

Illustrations consist of figures, tables, and graphs. Figures include both photographs and line art. Numerous figures contain close-up full-color photos of actual welding, and others show welding products and equipment. The colorful detailed figure line art is used extensively throughout the text to help illustrate concepts and clarify the material. Tables and graphs contain valuable technical information on materials, equipment setup, and welding process parameters. They are designed to help the student in class and later serve as an on-the-job reference.

Experiments and Practices are learning activities that are presented in most of the chapters. The end of each experiment is identified by the (◆) symbol and the end of each practice is identified by the (◆) symbol.

Experiments help the student learn the parameters of each welding process. Often, because it is hard to perform the experiment and to observe the results closely, students may do most of the experiments in a small group. In the experiments, students change the parameters to observe the effect on the process. In this way, students learn to manipulate the variables to obtain the desired welding outcome for given conditions. The experiments provided in the chapters do not have right or wrong answers. They are designed to allow the student to learn the operating limitations or the effects of changes that may occur during the welding process.

Practices are included to enable the student to develop the required manipulative skills using different materials and material thicknesses in different positions for each process. A sufficient number of practices is provided so that, after the basics are learned, the student may choose an area of specialization. Materials specified in the practices may be varied in both thickness and length to accommodate those supplies that students have in their lab. Changes within a limited range of both thickness and length will not affect the learning process designed for the practice.

Mechanical drawings are included with many of the welding practices. These drawings are included to help students better understand mechanical drawings and to show them how the metal is assembled. Most of the drawings are laid out in third-angle projection format, some are in the first-angle projection format, and a few are laid out with the side view shown in an alternate position. The third-angle projection format has been the standard used in the United States for years. However, because of the increasing interaction with the world economy, and because of the fact that many other countries use the first-angle projection format, it has been included. All three drawing formats are commonly used and are included. Items not normally included on true mechanical drawings such as the weld, torch, or electrode, and filler metal have been included to aid in students' understanding of the drawings.

Summaries at the end of each chapter recap the significant material covered in the chapter. This summary will help the student more completely understand the chapter material and will serve as a handy study tool.

Review questions at the end of each chapter can be used as indicators of how well the student has learned the material in each chapter.

Glossary definitions include the key terms listed at the beginning of each chapter and also other relevant welding terms. Included in the Glossary are bilingual terms in Spanish. Many definitions feature additional drawings to assist students in gaining a complete understanding of the terms.

What's New in the 8th Edition

This eight edition of *Welding: Principles and Applications* has been thoroughly revised and reorganized to reflect the latest welding technologies. Changes include the following:

- New chapters include "SMAW SENSE Certification," "GMAW and FCAW SENSE Certification," and "GTAW SENSE Certification"
- New welding processes and technologies such as magnetic pulse welding
- Expanded material on processes such as plasma cutting, FCAW, GMAW, and others
- New feature stories at the end in many of the chapters
- New and updated illustrations and photographs in every chapter

The use of new, full-color, detailed close-up photographs and detailed colored line art makes it much easier for the student to see what is expected to produce a quality weld.

Supplements

Study Guide/Lab Manual

The *Study Guide/Lab Manual* has been updated to reflect changes made to the eighth edition. The *Study Guide/Lab Manual* is designed to reinforce student understanding of the concepts presented in the text. Each chapter starts with a review of the important topics discussed in the chapter. Students can then test their knowledge by answering additional questions. Lab exercises are included in those chapters (as appropriate) to reinforce the primary objectives of the lesson. Artwork and safety precautions are included throughout the manual.

Instructor Companion Website

The Instructor Companion Website, found on cengagebrain.com, includes the following components to help minimize instructor preparation time and engage students:

- **PowerPoint®** lecture slides, which present the highlights of each chapter.
- An **Image Gallery**, which offers a database of hundreds of images in the text. These can easily be imported into the PowerPoint® presentations.

- An **Answer Key** file, which provides the answers to all end-of-chapter questions and the quizzes found in the Study Guide/Lab Manual.

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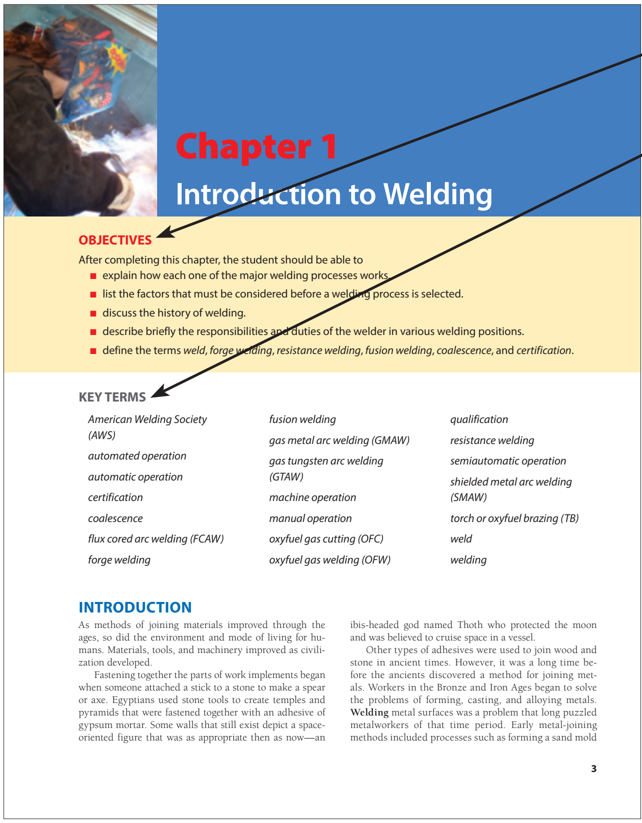
MINDTAP Welding for Welding: Principles and Applications

MindTap is a personalized teaching experience with relevant assignments that guide students to analyze, apply, and improve thinking, allowing you to measure skills and outcomes with ease.

- *Personalize Teaching*: Becomes YOURS with a Learning Path that is built with key student objectives. Control what your students see and when they see it—match your syllabus exactly by hiding, rearranging, or adding your own content.
- *Guide Students*: Goes beyond the traditional "lift and shift" model by creating a unique learning path of relevant readings, multimedia, and activities that move students up the learning taxonomy from basic knowledge and comprehension to analysis and application.
- *Measure Skills and Outcomes*: Analytics and reports provide a snapshot of class progress, time on task, engagement, and completion rates.

FEATURES OF THE TEXT



Chapter 1
Introduction to Welding

OBJECTIVES

After completing this chapter, the student should be able to

- explain how each one of the major welding processes works.
- list the factors that must be considered before a welding process is selected.
- discuss the history of welding.
- describe briefly the responsibilities and duties of the welder in various welding positions.
- define the terms *weld, forge welding, resistance welding, fusion welding, coalescence*, and *certification*.

KEY TERMS

American Welding Society (AWS)	*fusion welding*	*qualification*
automated operation	*gas metal arc welding (GMAW)*	*resistance welding*
automatic operation	*gas tungsten arc welding (GTAW)*	*semiautomatic operation*
certification	*machine operation*	*shielded metal arc welding (SMAW)*
coalescence	*manual operation*	*torch or oxyfuel brazing (TB)*
flux cored arc welding (FCAW)	*oxyfuel gas cutting (OFC)*	*weld*
forge welding	*oxyfuel gas welding (OFW)*	*welding*

INTRODUCTION

As methods of joining materials improved through the ages, so did the environment and mode of living for humans. Materials, tools, and machinery improved as civilization developed.

Fastening together the parts of work implements began when someone attached a stick to a stone to make a spear or axe. Egyptians used stone tools to create temples and pyramids that were fastened together with an adhesive of gypsum mortar. Some walls that still exist depict a space-oriented figure that was as appropriate then as now—an ibis-headed god named Thoth who protected the moon and was believed to cruise space in a vessel.

Other types of adhesives were used to join wood and stone in ancient times. However, it was a long time before the ancients discovered a method for joining metals. Workers in the Bronze and Iron Ages began to solve the problems of forming, casting, and alloying metals. **Welding** metal surfaces was a problem that long puzzled metalworkers of that time period. Early metal-joining methods included processes such as forming a sand mold

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Objectives, found at the beginning of each chapter, are a brief list of the most important topics to study in the chapter.

Key Terms are the most important technical words you will learn in the chapter. These are listed at the beginning of each chapter following the Objectives and appear in **color print** where they are first defined. These terms are also defined in the Glossary at the end of the book.

Cautions summarize critical safety rules. They alert you to operations that could hurt you or someone else. They are not only covered in the safety chapter but also found throughout the text when they apply to the discussion, practice, or experiment.

Think Green boxes contain information on conserving materials, energy, and other natural resources and ways to avoid potential environmental contamination.

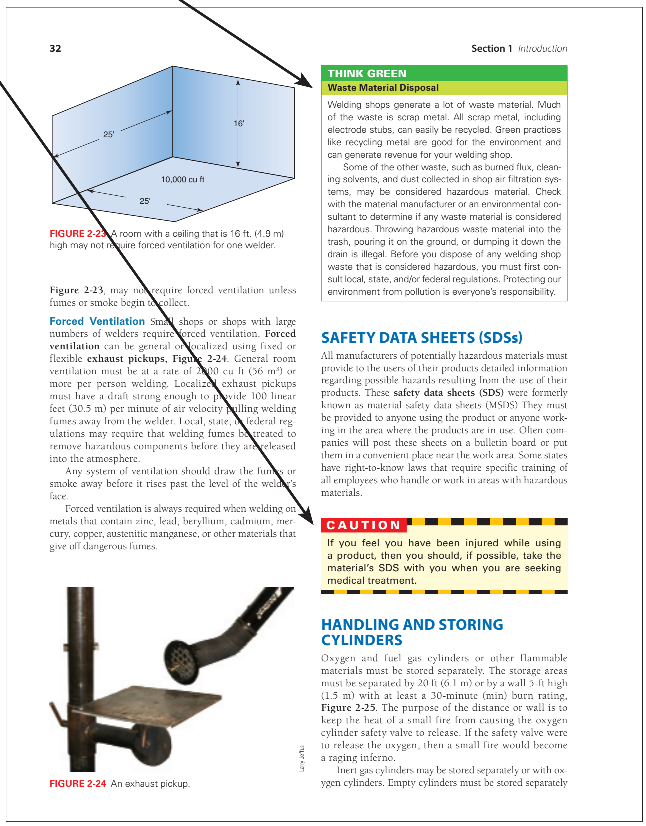

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FIGURE 2-23 A room with a ceiling that is 16 ft. (4.9 m) high may not require forced ventilation for one welder.

Figure 2-23, may not require forced ventilation unless fumes or smoke begin to collect.

Forced Ventilation Small shops or shops with large numbers of welders require forced ventilation. **Forced ventilation** can be general or localized using fixed or flexible **exhaust pickups**, **Figure 2-24**. General room ventilation must be at a rate of 2000 cu ft (56 m³) or more per person welding. Localized exhaust pickups must have a draft strong enough to provide 100 linear feet (30.5 m) per minute of air velocity pulling welding fumes away from the welder. Local, state, or federal regulations may require that welding fumes be treated to remove hazardous components before they are released into the atmosphere.

Any system of ventilation should draw the fumes or smoke away before it rises past the level of the welder's face.

Forced ventilation is always required when welding on metals that contain zinc, lead, beryllium, cadmium, mercury, copper, austenitic manganese, or other materials that give off dangerous fumes.

FIGURE 2-24 An exhaust pickup.

THINK GREEN
Waste Material Disposal

Welding shops generate a lot of waste material. Much of the waste is scrap metal. All scrap metal, including electrode stubs, can easily be recycled. Green practices like recycling metal are good for the environment and can generate revenue for your welding shop.

Some of the other waste, such as burned flux, cleaning solvents, and dust collected in shop air filtration systems, may be considered hazardous material. Check with the material manufacturer or an environmental consultant to determine if any waste material is considered hazardous. Throwing hazardous waste material into the trash, pouring it on the ground, or dumping it down the drain is illegal. Before you dispose of any welding shop waste that is considered hazardous, you must first consult local, state, and/or federal regulations. Protecting our environment from pollution is everyone's responsibility.

SAFETY DATA SHEETS (SDSs)

All manufacturers of potentially hazardous materials must provide to the users of their products detailed information regarding possible hazards resulting from the use of their products. These **safety data sheets (SDS)** were formerly known as material safety data sheets (MSDS) They must be provided to anyone using the product or anyone working in the area where the products are in use. Often companies will post these sheets on a bulletin board or put them in a convenient place near the work area. Some states have right-to-know laws that require specific training of all employees who handle or work in areas with hazardous materials.

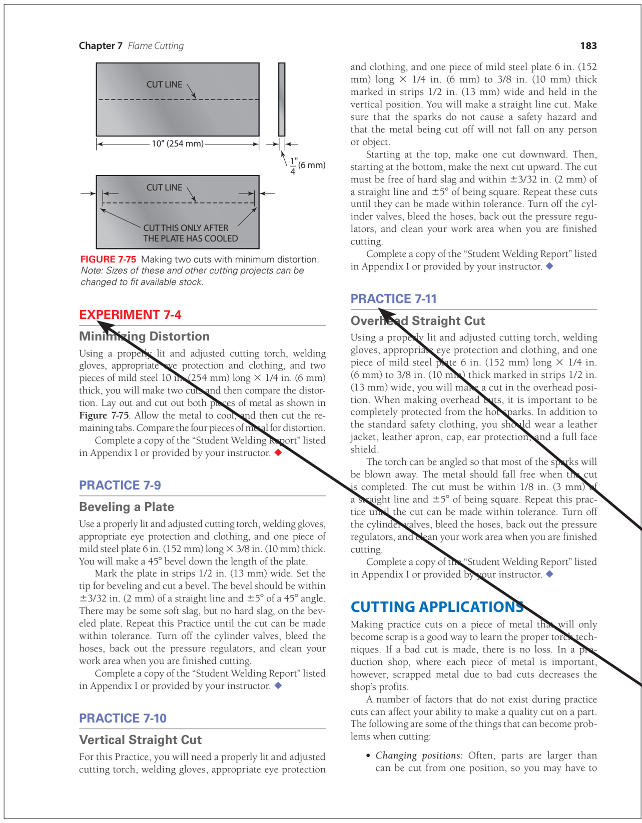
CAUTION

If you feel you have been injured while using a product, then you should, if possible, take the material's SDS with you when you are seeking medical treatment.

HANDLING AND STORING CYLINDERS

Oxygen and fuel gas cylinders or other flammable materials must be stored separately. The storage areas must be separated by 20 ft (6.1 m) or by a wall 5-ft high (1.5 m) with at least a 30-minute (min) burn rating, **Figure 2-25**. The purpose of the distance or wall is to keep the heat of a small fire from causing the oxygen cylinder safety valve to release. If the safety valve were to release the oxygen, then a small fire would become a raging inferno.

Inert gas cylinders may be stored separately or with oxygen cylinders. Empty cylinders must be stored separately



Chapter 7 *Flame Cutting* 183

FIGURE 7-75 Making two cuts with minimum distortion.
Note: Sizes of these and other cutting projects can be changed to fit available stock.

EXPERIMENT 7-4

Minimizing Distortion

Using a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and two pieces of mild steel 10 in. (254 mm) long × 1/4 in. (6 mm) thick, you will make two cuts and then compare the distortion. Lay out and cut out both pieces of metal as shown in **Figure 7-75**. Allow the metal to cool, and then cut the remaining tabs. Compare the four pieces of metal for distortion.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 7-9

Beveling a Plate

Use a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece of mild steel plate 6 in. (152 mm) long × 3/8 in. (10 mm) thick. You will make a 45° bevel down the length of the plate.

Mark the plate in strips 1/2 in. (13 mm) wide. Set the tip for beveling and cut a bevel. The bevel should be within ±3/32 in. (2 mm) of a straight line and ±5° of a 45° angle. There may be some soft slag, but no hard slag, on the beveled plate. Repeat this Practice until the cut can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 7-10

Vertical Straight Cut

For this Practice, you will need a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece of mild steel plate 6 in. (152 mm) long × 1/4 in. (6 mm) to 3/8 in. (10 mm) thick marked in strips 1/2 in. (13 mm) wide and held in the vertical position. You will make a straight line cut. Make sure that the sparks do not cause a safety hazard and that the metal being cut off will not fall on any person or object.

Starting at the top, make one cut downward. Then, starting at the bottom, make the next cut upward. The cut must be free of hard slag and within ±3/32 in. (2 mm) of a straight line and ±5° of being square. Repeat these cuts until they can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 7-11

Overhead Straight Cut

Using a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece of mild steel plate 6 in. (152 mm) long × 1/4 in. (6 mm) to 3/8 in. (10 mm) thick marked in strips 1/2 in. (13 mm) wide, you will make a cut in the overhead position. When making overhead cuts, it is important to be completely protected from the hot sparks. In addition to the standard safety clothing, you should wear a leather jacket, leather apron, cap, ear protection, and a full face shield.

The torch can be angled so that most of the sparks will be blown away. The metal should fall free when the cut is completed. The cut must be within 1/8 in. (3 mm) of a straight line and ±5° of being square. Repeat this practice until the cut can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

CUTTING APPLICATIONS

Making practice cuts on a piece of metal that will only become scrap is a good way to learn the proper torch techniques. If a bad cut is made, there is no loss. In a production shop, where each piece of metal is important, however, scrapped metal due to bad cuts decreases the shop's profits.

A number of factors that do not exist during practice cuts can affect your ability to make a quality cut on a part. The following are some of the things that can become problems when cutting:

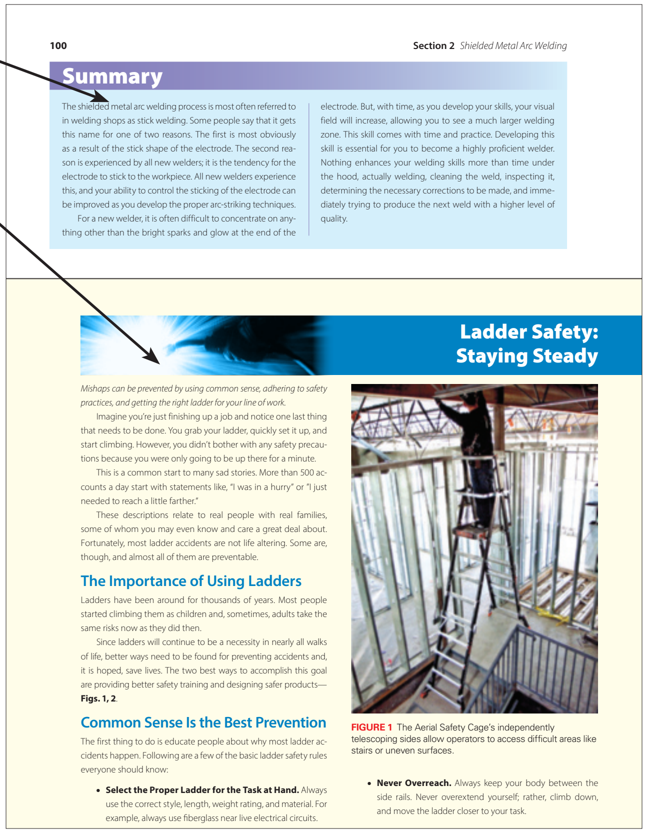
- *Changing positions:* Often, parts are larger than can be cut from one position, so you may have to

Practices are hands-on exercises designed to build your welding skills. Each practice describes in detail what skill you will learn and what equipment, supplies, and tools you will need to complete the exercise.

Experiments are designed to allow you to see what effect changes in the process settings, operation, or techniques have on the type of weld produced. Many are group activities and will help you learn as a team.

Summaries review the important points in the chapter and serve as a useful study tool.

Real-World Features at the end of all chapters present a story that describes a real-world application of the theory learned in the chapter. You will see how particular knowledge and skills are important to the world.



100 Section 2 *Shielded Metal Arc Welding*

Summary

The shielded metal arc welding process is most often referred to in welding shops as stick welding. Some people say that it gets this name for one of two reasons. The first is most obviously as a result of the stick shape of the electrode. The second reason is experienced by all new welders; it is the tendency for the electrode to stick to the workpiece. All new welders experience this, and your ability to control the sticking of the electrode can be improved as you develop the proper arc-striking techniques.

For a new welder, it is often difficult to concentrate on anything other than the bright sparks and glow at the end of the electrode. But, with time, as you develop your skills, your visual field will increase, allowing you to see a much larger welding zone. This skill comes with time and practice. Developing this skill is essential for you to become a highly proficient welder. Nothing enhances your welding skills more than time under the hood, actually welding, cleaning the weld, inspecting it, determining the necessary corrections to be made, and immediately trying to produce the next weld with a higher level of quality.

Ladder Safety: Staying Steady

Mishaps can be prevented by using common sense, adhering to safety practices, and getting the right ladder for your line of work.

Imagine you're just finishing up a job and notice one last thing that needs to be done. You grab your ladder, quickly set it up, and start climbing. However, you didn't bother with any safety precautions because you were only going to be up there for a minute.

This is a common start to many sad stories. More than 500 accounts a day start with statements like, "I was in a hurry" or "I just needed to reach a little farther."

These descriptions relate to real people with real families, some of whom you may even know and care a great deal about. Fortunately, most ladder accidents are not life altering. Some are, though, and almost all of them are preventable.

The Importance of Using Ladders

Ladders have been around for thousands of years. More people started climbing them as children and, sometimes, adults take the same risks now as they did then.

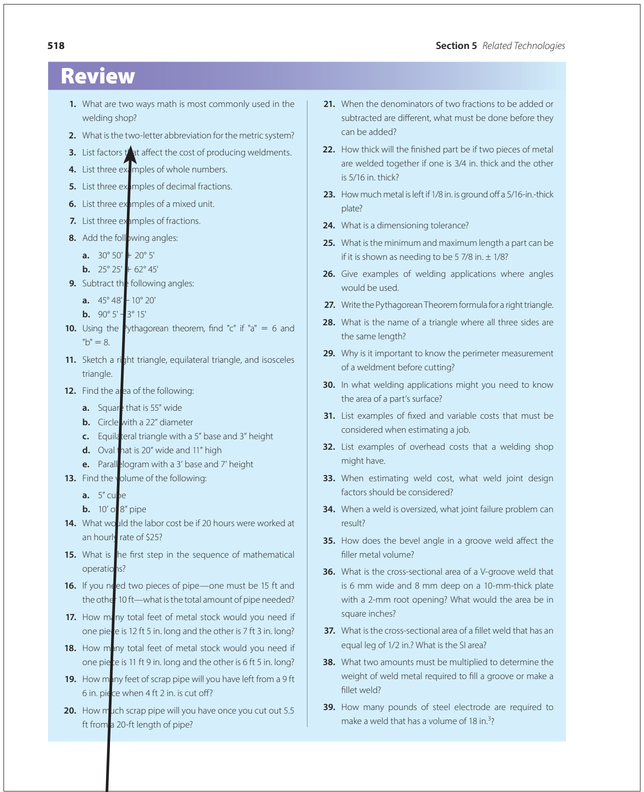
Since ladders will continue to be a necessity in nearly all walks of life, better ways need to be found for preventing accidents and, it is hoped, save lives. The two best ways to accomplish this goal are providing better safety training and designing safer products—**Figs. 1, 2**.

Common Sense Is the Best Prevention

The first thing to do is educate people about why most ladder accidents happen. Following are a few of the basic ladder safety rules everyone should know:

- **Select the Proper Ladder for the Task at Hand.** Always use the correct style, length, weight rating, and material. For example, always use fiberglass near live electrical circuits.
- **Never Overreach.** Always keep your body between the side rails. Never overextend yourself; rather, climb down, and move the ladder closer to your task.

FIGURE 1 The Aerial Safety Cage's independently telescoping sides allow operators to access difficult areas like stairs or uneven surfaces.



518 Section 5 *Related Technologies*

Review

1. What are two ways math is most commonly used in the welding shop?
2. What is the two-letter abbreviation for the metric system?
3. List factors that affect the cost of producing weldments.
4. List three examples of whole numbers.
5. List three examples of decimal fractions.
6. List three examples of a mixed unit.
7. List three examples of fractions.
8. Add the following angles:
   a. 30° 50′ + 20° 5′
   b. 25° 25′ + 62° 45′
9. Subtract the following angles:
   a. 45° 48′ − 10° 20′
   b. 90° 5′ − 3° 15′
10. Using the Pythagorean theorem, find "c" if "a" = 6 and "b" = 8.
11. Sketch a right triangle, equilateral triangle, and isosceles triangle.
12. Find the area of the following:
    a. Square that is 55″ wide
    b. Circle with a 22″ diameter
    c. Equilateral triangle with a 5″ base and 3″ height
    d. Oval that is 20″ wide and 11″ high
    e. Parallelogram with a 3′ base and 7′ height
13. Find the volume of the following:
    a. 5″ cube
    b. 10′ of 8″ pipe
14. What would the labor cost be if 20 hours were worked at an hourly rate of $25?
15. What is the first step in the sequence of mathematical operations?
16. If you need two pieces of pipe—one must be 15 ft and the other 10 ft—what is the total amount of pipe needed?
17. How many total feet of metal stock would you need if one piece is 12 ft 5 in. long and the other is 7 ft 3 in. long?
18. How many total feet of metal stock would you need if one piece is 11 ft 9 in. long and the other is 6 ft 5 in. long?
19. How many feet of scrap pipe will you have left from a 9 ft 6 in. piece when 4 ft 2 in. is cut off?
20. How much scrap pipe will you have once you cut out 5.5 ft from a 20-ft length of pipe?
21. When the denominators of two fractions to be added or subtracted are different, what must be done before they can be added?
22. How thick will the finished part be if two pieces of metal are welded together if one is 3/4 in. thick and the other is 5/16 in. thick?
23. How much metal is left if 1/8 in. is ground off a 5/16-in.-thick plate?
24. What is a dimensioning tolerance?
25. What is the minimum and maximum length a part can be if it is shown as needing to be 5 7/8 in. ± 1/8?
26. Give examples of welding applications where angles would be used.
27. Write the Pythagorean Theorem formula for a right triangle.
28. What is the name of a triangle where all three sides are the same length?
29. Why is it important to know the perimeter measurement of a weldment before cutting?
30. In what welding applications might you need to know the area of a part's surface?
31. List examples of fixed and variable costs that must be considered when estimating a job.
32. List examples of overhead costs that a welding shop might have.
33. When estimating weld cost, what weld joint design factors should be considered?
34. When a weld is oversized, what joint failure problem can result?
35. How does the bevel angle in a groove weld affect the filler metal volume?
36. What is the cross-sectional area of a V-groove weld that is 6 mm wide and 8 mm deep on a 10-mm-thick plate with a 2-mm root opening? What would the area be in square inches?
37. What is the cross-sectional area of a fillet weld that has an equal leg of 1/2 in.? What is the SI area?
38. What two amounts must be multiplied to determine the weight of weld metal required to fill a groove or make a fillet weld?
39. How many pounds of steel electrode are required to make a weld that has a volume of 18 in.^{3}?

Review questions help measure the skills and knowledge you learned in the chapter. Each question is designed to help you apply and understand the information in the chapter.

Success Stories are found at the beginning of each of the seven sections in the text. These stories are about real people who have become successful by using their welding skills. Each story is different, but one message is repeated by all story contributors: welding can be a rich and rewarding career.

Bilingual Glossary definitions provide a Spanish equivalent for each new term. Additional line art in the Glossary will also help you gain a greater understanding of challenging terms.

Success Story

My name is Shakirah Harrell. I was born in Newark, New Jersey and raised in the little town of Powellsville, North Carolina. I graduated from Hertford County High School in Ahoskie, North Carolina. As a single young parent, I needed to find a career field that would support my family, so I moved to Hampton, Virginia. I started my welding career at the age of 23.

At that time, the only thing I knew about welding was that it was a good paying job. I applied at Northrop Grumman, a shipyard in Newport News, Virginia, and began my training as a welder. To help support my family, I worked as a grocery store manager in the morning and welder at night. After one year in the field as a 3rd class welder, I got accepted into the apprenticeship program. I spent the next five years learning the welding trade while still being able to support my family. I graduated from the apprenticeship program in 2008.

Then I decided to pursue another angle in the welding trade. I got hired at a local welding school where I began instructing basic welding during the day while working on my Bachelor's Degree in business management at night and online. After only a few months, I was asked to take a position at the school as the welding coordinator for the entire program.

After four years, I missed welding and the money I would make, so I decided to go back into the field as a contractor at another local shipyard in Norfolk, Virginia. Over the next few years, I followed welding opportunities across other parts of the United States. I was a structural welder at an ethanol plant project in Liberal, Kansas. Following that, I moved to Freeport, Texas, took a refresher pipe welding course offered by Fluor, and started working on a chemical plant project for Dow Chemical Company.

After being away from Virginia for so many years, I was homesick and decided to go back to Virginia; but as a result of the downturn in the economy, I was not able to find a good high-paying job, so I moved back to Texas. I am currently a welding instructor at Tulsa Welding School and Technology Center at the Houston campus.

Welding has been a great career for me and a skill that has provided for my family. My oldest son has joined the United States Navy, one of the others is a high school senior, and the youngest is a high school junior. I'm proud to be a welder, I'm proud of my kids, and proud of the life that welding has provided for us.

Acknowledgments

To bring a book of this size to publication requires the assistance of many individuals, and the author and publisher thank the following for their unique contributions to this and/or prior editions:

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- The following individuals who are featured in the Success Stories in the text. They are valuable contributors to the textbook and an inspiration for those entering the welding industry: Erin Boren, Matthew Lee, Shakirah Harrell, Matthew Boomer, Ken Leonard, John Karney

The author also expresses his deepest appreciation to:

- The welding instructors at Worcester Technical High School, Massachusetts; Craven Community College, North Carolina; Great Plains Technology Center, Oklahoma; Atlantic Technical Center, Florida; El Camino Community College, California; Wichita Area Technical College, Kansas; Antelope Valley College, California; Blackhawk Technical College, Wisconsin; Wenatchee Valley College, Washington; Tyler Junior College, Texas; Midlands Technical College, South Carolina; John A. Logan College, Illinois; Northwest Mississippi Community College, Mississippi; Tarrant County College, Texas; Greater Lowell Technical High School, Massachusetts; Long Beach City College, California; Reading Area Community College, Pennsylvania; College of the Ozarks, Missouri; Bessemer State Technical College, Alabama; York Technical College, South Carolina; Lakeview High School, Texas; Newberry County Career Center, South Carolina; Palm Beach Community College, Florida; Texas State Technical College, Texas; Grand Rapids Community College, Michigan; Kilgore College, Texas; Tulsa Technology Center, Oklahoma; Calcasieu Parish School, Louisiana; Florence-Darlington Technical College, South Carolina; Jefferson High School, Texas; Coastal Carolina Community College, North Carolina; Los Angeles Unified School District, California; Vatterott College, Missouri; New River Community College, Virginia; New Hampshire Technical College at Manchester, New Hampshire; Augusta Technical College, Georgia; and Austin Community College, Texas. The welders at all of these institutions have shared with me their welding experiences, teaching experiences, and students' experiences, which have helped form the basis for many of the updates in this edition.
- David DuBois, for the use of his welding shop for many of the photo shootings, and both David and Amy DuBois, for their editorial assistance in preparing the text.
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from years of experience in welding and teaching, but most of all for their friendship.

- Special thanks to Lincoln Electric for providing their women's welding gear for the cover photo.
- In memory of Leo Taylor, an outstanding welder educator and welder who trained many young people in the art and skill of welding.
- Sam Burris, for his expertise in computer graphics that helped make the illustrations and photographs dynamic.
- To my wife, Carol, for all of her moral support, and to my daughters, Wendy and Amy, for all of the general office help they provided.

About the Author

In 1965, during my senior year at New Bern High School in North Carolina, while taking shop classes, I am proud to say I joined the Vocational Industrial Clubs of America (VICA), now SkillsUSA-VICA. SkillsUSA brings together educators, administrators, corporate America, labor organizations, trade associations, and government in a coordinated effort to address America's need for a globally competitive, skilled workforce. The mission of SkillsUSA is to help our students become world-class workers and responsible American citizens. Through my involvement in SkillsUSA, I learned a great deal about industry and business. In SkillsUSA I learned the value of integrity, responsibility, citizenship, service, and respect. In addition, I developed leadership skills, established goals, and learned the value of performing quality work. These are all things that I still use in my life today.

During my junior year of high school, I learned to weld in metal shop. I was taught basic welding principles and applications, and I was able to build a number of projects in shop using oxyacetylene welding, shielded metal arc welding, twin carbon arc welding, and torch brazing.

The practice welds helped me develop welding skills, and building the projects allowed me to start developing some fabrication skills. By the end of my junior year, I had become a fairly skilled welder.

In my senior year I was given an opportunity to join Mr. Z. T. Koonce's first class in a new program called Industrial Cooperative Training (ICT). ICT is a cooperative work experience program that coordinates school experiences with real jobs. This allowed me to attend high school in the morning, where I completed my required English, math, and other academic courses for graduation. In my ICT class we were taught skills that would help us get a job—such as how to fill out a job application, how to interview, and so on. In the afternoons I worked as a welder. After graduation, I started a full-time job as a welder at Barbour Boat Works, where I refined my welding skills and was allowed to work with the other welders in the shipyard. My first welding assignment was on a barge making intermittent welds to attach the deck to the barge's ribs.

As my welding skills improved, my supervisor allowed me to apply my new welding skills to more difficult jobs. I welded on barges, military landing crafts, tugboats, PT boats, small tankers, and other marine vessels. This is how I earned money toward my college education.

With my welding skills, I was able to get a job in a small welding shop in Madisonville, Tennessee and attended Hiwassee College. After graduating from Hiwassee, I found other welding jobs that allowed me to continue my education at the University of Tennessee, where I earned a bachelor's degree. After four years, I had both a college degree and four years of welding experience, which together qualified me for my job as a vocational teacher.

During my career as a welder, I have welded on tanks, pressure vessels, oil well drilling equipment, farm equipment, buildings, racecars, aircraft, piping systems, and more. As a vocational teacher, I have taught in high schools, schools for special education, schools for the deaf, three colleges, and numerous industrial shops. I have also been a consultant to the welding industry and a resource for students, educators, and school administrators.

Larry Jeffus has more than 50 years of welding experience and more than 40 years of experience as a classroom teacher. He is the author of several Delmar Cengage Learning welding publications. Prior to retiring from teaching, Professor Jeffus taught at Eastfield College, part of the Dallas County Community College District. Since retiring from full-time teaching, he remains very active in the welding community, especially in the field of education. He serves on several welding program technical advisory committees and has visited high schools, colleges, universities, and technical campuses in more than 40 states and four foreign countries. Professor Jeffus was selected as Outstanding Postsecondary Technical Educator in the State of Texas by the Texas Technical Society. He holds a bachelor of science degree and has completed postgraduate studies.

Professor Jeffus has served for 12 years as a board member on the Texas Workforce Investment Council in the Texas Governor's office, where he works to develop a skilled workforce and bring economic development to the state. He served as a member of the Apprenticeship Project Leadership Team, where he helped establish apprenticeship training programs for the State of Texas, and he has made numerous trips to Washington, DC, to lobby for vocational and technical education.

He has been actively involved in the American Welding Society for more than 40 years, and has served on the General Education Committee and as the chairman of the North Texas Section of the American Welding Society. He is a Life Member of the American Welding Society.

Index of Experiments and Practices

The following Experiments and Practices are listed in the order in which they appear in the chapter. It should be noted that not all chapters have Experiments and Practices.

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Chapter 13

Chapter 14

Chapter 15

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Chapter 18

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Chapter 27

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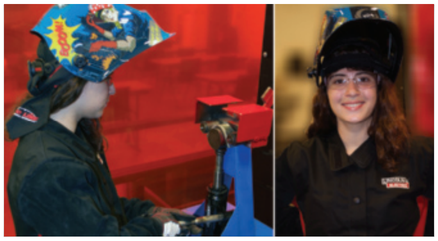
Chapter 33

Section 1

Introduction

Success Story



My name is Erin Boren and I'm 21. I first learned to weld while in high school at Lakeview Centennial High School in Garland, Texas. My welding instructor was Mr. Jim Barnett. He taught me the basics of all of the welding processes. My favorite welding process was and still is GMAW. While in high school I passed the 1/2 in. thick open root V-groove guided bend test with the GMAW process.

In addition to making practice welds on a variety of different types of metals and metal thicknesses with all of the different welding processes, Mr. Barnett had us fabricate welding projects. I made a vase, picture frame, and some other projects. My favorite project was when Mr. Barnett let me program the plasma cutter to cut out my name and a silhouette of my favorite animal. He then let me gas weld all of it together to make a nameplate. I loved being able to make these welded projects. It was really fun cutting out the parts and fitting them together so I could weld them up.

Of all my high school courses I loved my welding classes most. Welding classes gave me a chance to learn a skill that I have truly enjoyed.

I have always loved the water. My life goal is to become an underwater welder, so I took classes to become certified as a scuba diver. In addition I worked at Surf and Swim during the summers. Not all of my time was spent as fun in the sun; I used the flux core process to build a long section of security fence. The fence owner said she "loved it" which made me feel proud of my work.

I'm currently enrolled in welding classes at Eastfield College in Mesquite, Texas. My first welding class was a welding 6-week survey course that covered all of the welding processes. Currently my welding instructor is Mr. Jeff Mitchell. He helped me develop my welding skills, and I passed the 4G (overhead) open root V-groove bend test in 3/8 in. plate with the shielded metal arc welding process.

My next class will be the AWS SENSE Level I certification. Mr. Mitchell feels I'm ready to pass both the workmanship qualification test and the V-groove certification. I'm looking forward to the challenge.

One of the highlights of my welding career was being asked by Mr. Mitchell to help Larry Jeffus take the cover photo for this textbook. I'm sure with all of my welding equipment and PPE on you might not recognize me, but I know it's me and that's good enough.

Erin's high school teacher, Mr. Barnett said, "There's no greater thrill than having a student like Erin become a successful welder." Her college professor Mr. Mitchell said, "Erin's great work ethic, positive can-do attitude, and friendly personality have equipped her very well. With her outstanding welding skills, I expect her to be very successful in the future."

Chapter 1
Introduction to Welding

OBJECTIVES

After completing this chapter, the student should be able to

- explain how each one of the major welding processes works.
- list the factors that must be considered before a welding process is selected.
- discuss the history of welding.
- describe briefly the responsibilities and duties of the welder in various welding positions.
- define the terms *weld*, *forge welding*, *resistance welding*, *fusion welding*, *coalescence*, and *certification*.

KEY TERMS

American Welding Society (AWS)
automated operation
automatic operation
certification
coalescence
flux cored arc welding (FCAW)
forge welding
fusion welding
gas metal arc welding (GMAW)
gas tungsten arc welding (GTAW)
machine operation
manual operation
oxyfuel gas cutting (OFC)
oxyfuel gas welding (OFW)
qualification
resistance welding
semiautomatic operation
shielded metal arc welding (SMAW)
torch or oxyfuel brazing (TB)
weld
welding

INTRODUCTION

As methods of joining materials improved through the ages, so did the environment and mode of living for humans. Materials, tools, and machinery improved as civilization developed.

Fastening together the parts of work implements began when someone attached a stick to a stone to make a spear or axe. Egyptians used stone tools to create temples and pyramids that were fastened together with an adhesive of gypsum mortar. Some walls that still exist depict a space-oriented figure that was as appropriate then as now—an ibis-headed god named Thoth who protected the moon and was believed to cruise space in a vessel.

Other types of adhesives were used to join wood and stone in ancient times. However, it was a long time before the ancients discovered a method for joining metals. Workers in the Bronze and Iron Ages began to solve the problems of forming, casting, and alloying metals. **Welding** metal surfaces was a problem that long puzzled metalworkers of that time period. Early metal-joining methods included processes such as forming a sand mold on top of a piece of metal and casting the desired shape directly on the base metal so that both parts fused together, forming a single piece of metal, **Figure 1-1**. Another metal-joining method used in early years was to place two pieces of metal close together and pour molten metal between them. When the edges of the base metal melted, the flow of metal was then dammed up and allowed to harden, **Figure 1-2**.

This bronze goat statue at the Qingyang Taoist Temple in Chengdu, China was cast more than 1500 years ago and repaired with braze welding approximately 1000 years ago, **Figure 1-3**.

The Industrial Revolution, from 1750 to 1850, introduced a method of joining pieces of iron together known as **forge welding** or hammer welding. This process involved the use of a forge to heat the metal to a soft, plastic temperature. The ends of the iron were then placed together and hammered until fusion took place.

Forge welding remained as the primary welding method until Elihu Thomson, in the year 1886, developed the **resistance welding** technique. This technique provided a more reliable and faster way of joining metal than did previous methods.

As techniques were further developed, riveting was replaced in the United States and Europe by **fusion welding**. At that time the welding process was considered to be vital to military security. Welding repairs to the ships damaged during World War I were done in great secrecy. Even today some aspects of welding are closely guarded secrets.

Since the end of World War I, many welding methods have been developed for joining metals. These various welding methods play an important role in the expansion and production of the welding industry. Welding has become a dependable, efficient, and economical method for joining metal.

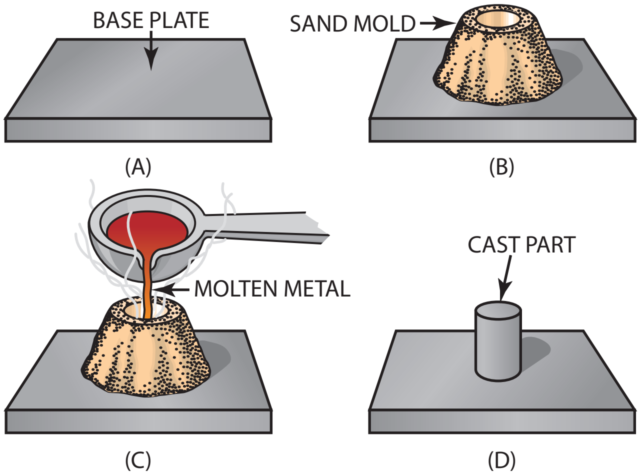


FIGURE 1-1 Direct casting: (A) base plate to have part cast on it, (B) sand molded into shape desired, (C) pouring hot metal into mold, and (D) part cast is now part of the base plate.

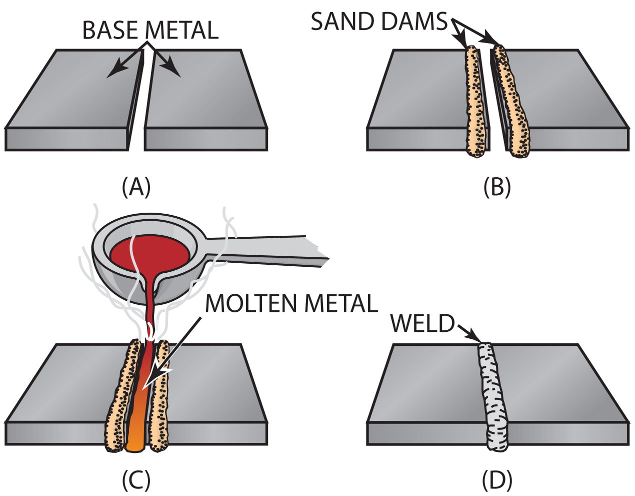


FIGURE 1-2 Flow welding: (A) two pieces of metal plate, (B) sand dams to hold molten metal in place, (C) molten metal poured between metal plates, and (D) finished welded plate.

FIGURE 1-3 Bronze goat statue in Chengdu, China cast more than 1,500 years ago and repaired with braze welding about 1,000 years ago.

Welding Terminology

The use of regional terms by skilled workers is a common practice in all trade areas, including welding. As an example, oxyacetylene welding is one part of the larger group of processes known as **oxyfuel gas welding (OFW)**. Some of the names used to refer to oxyacetylene welding (OAW) include *gas welding* and *torch welding*. **Shielded metal arc welding (SMAW)** is often called *stick welding*, *rod welding*, or just *welding*. As you begin your work career you will learn the various names used in your area, but you should always keep in mind and use the more formal terms whenever possible.

FIGURE 1-4 Space shuttle being made ready for its launch into space. Notice the large welded support structure used to prepare the shuttle for launch.

WELDING DEFINED

A **weld** is defined by the American Welding Society (AWS) as "a localized **coalescence** (the fusion or growing together of the grain structure of the materials being welded) of metals or nonmetals produced either by heating the materials to the required welding temperatures, with or without the application of pressure, or by the application of pressure alone, and with or without the use of filler materials." **Welding** is defined as "a joining process that produces coalescence of materials by heating them to the welding temperature, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal." In less technical language, a weld is made when separate pieces of material to be joined combine and form one piece when

- enough heat is applied to raise the temperature high enough to cause softening or melting and the pieces flow together,
- enough pressure is used to force the pieces together so that the surfaces coalesce, or
- enough heat and pressure are used together to force the separate pieces of material to combine and form one piece.

A filler material may or may not be added to the joint to form a completed weld joint. It is also important to note that the word *material* is used because today welds can be made from a growing list of materials such as plastic, glass, and ceramics.

USES OF WELDING

Modern welding techniques are used in the construction of numerous products, **Figure 1-4** and **Figure 1-5**. Ships, buildings, bridges, and recreational rides are fabricated by welding processes. Welding is often used to produce the machines that are used to manufacture new products.

Welding has made it possible for airplane manufacturers to meet the design demands of strength-to-weight ratios for both commercial and military aircraft.

The exploration of space would not be possible without modern welding techniques. From the very beginning of early rockets to today's aerospace industry, welding has played an important role. The space shuttle's construction required the improvement of welding processes. Many of these improvements have helped improve our daily lives.

Welding, brazing, and cutting experiments were conducted aboard the Skylab from May 1973 to February 1974. Today welding, brazing, and cutting experiments are often conducted aboard the International Space Station. We built the International Space Station by taking large parts into space and assembling them. Someday welders will be required to build even larger structures in the vacuum of space. **Figure 1-6** is a welding machine designed to be used in space. **Figure 1-7** shows cosmonaut Svetlana Savitskaya, the first woman to space walk and the first person to use a welding and cutting machine in open space. The specialized welder was developed at the E.O. Paton Electric Welding Institute. As the welding techniques are developed for this major project, we will see them being used here on Earth to improve our world.

Welding is used extensively in the manufacture of automobiles, farm equipment, home appliances, computer components, mining equipment, and construction equipment. Railway equipment, furnaces, boilers, air-conditioning units, and hundreds of other products we use in our daily lives are also joined together by some type of welding process.

Items ranging from dental braces to telecommunication satellites are assembled by welding. Very little in our modern world is not produced using some type of welding process.

Larry Jeffus

Welded sculpture, Seattle, Washington.

Larry Jeffus

Roller coaster at Silver Dollar City, Branson, Missouri.

Larry Jeffus

Roller coaster at Silver Dollar City, Branson, Missouri.

Larry Jeffus

Spiral staircase in Missouri City, Texas.

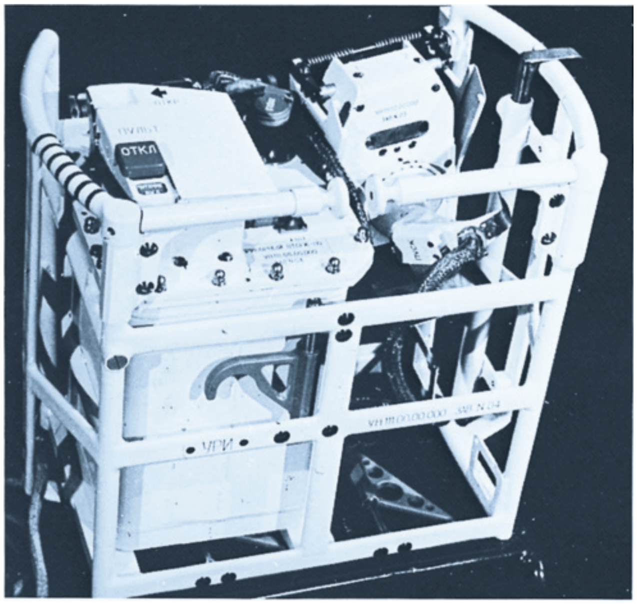
Larry Jeffus

Voyager of the Sea, Haiti.

Larry Jeffus

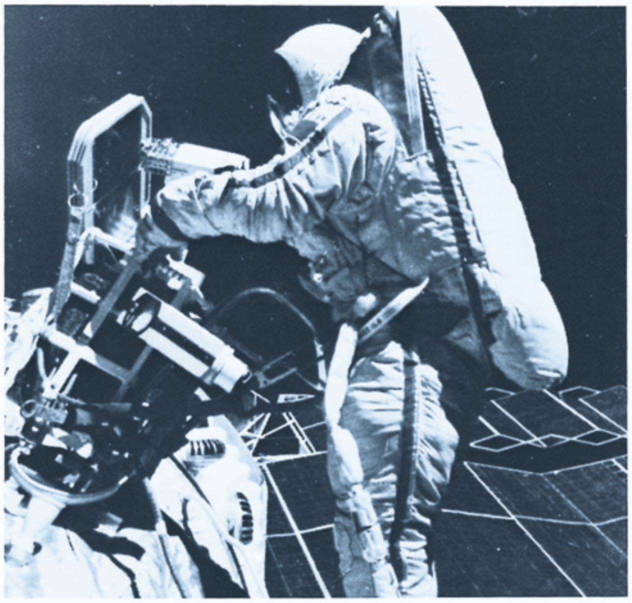
Voyager of the Sea dining room.

FIGURE 1-5 Welded joints are a critical component of structures.



Courtesy of E.O. Paton Electric Welding Institute, Commonwealth of Independent States, the former Soviet Union.

FIGURE 1-6 Machine designed to be used to weld in space.



Courtesy of E.O. Paton Electric Welding Institute, Commonwealth of Independent States, the former Soviet Union.

FIGURE 1-7 A cosmonaut makes a weld outside a space ship.

WELDING AND CUTTING PROCESSES

Welding processes differ greatly in the manner in which heat, pressure, or both heat and pressure are applied and in the type of equipment used. **Table 1-1** lists various welding and allied processes. One hundred twenty-one welding processes are listed, all of which require hammering, pressing, or rolling to affect the coalescence in the weld joint. Other methods bring the metal to a fluid state, and the edges flow together.

The most popular welding processes are as follows: oxyacetylene welding (OAW); shielded metal arc welding (SMAW), often called stick welding; **gas tungsten arc welding (GTAW)**; **gas metal arc welding (GMAW)**; **flux cored arc welding (FCAW)**; and **torch or oxyfuel brazing (TB)**. The two most popular thermal cutting processes are oxy-acetylene cutting (OAC) and plasma arc cutting (PAC).

WELDING PROCESSES

Oxyacetylene Welding, Brazing, and Cutting

Oxyacetylene welding (OAW) and torch brazing (TB) can be done with the same equipment, and **oxyfuel gas cutting (OFC)** uses very similar equipment, **Figure 1-8**.

In OF welding and TB a high-temperature flame is produced at the torch tip by burning oxygen and a fuel gas. The most common fuel gas is acetylene; however, other combinations of oxygen and fuel gases (OF) can be used for welding, such as hydrogen, MAPP, or propane. In OF welding, the base metal is melted and a filler metal may be added to reinforce the weld. No flux is required to make an OF weld of steel.

In TB, the metal is heated to a sufficient temperature but below its melting point so that a brazing alloy can be melted and bond to the hot base metal. A flux may be used to help the brazing alloy bond to the base metal. Both OF welding and TB are used primarily on smaller, thinner-gauge metals.

Shielded Metal Arc Welding (SMAW)

Shielded metal arc welding (SMAW) uses a consumable stick electrode that conducts the welding current from the electrode holder to the work, and as the arc melts the end of the electrode away, it becomes part of the weld metal. Stick electrodes are available in lengths of 12 in., 14-in., and 18 in. (300 mm, 350 mm, and 450 mm). The welding arc vaporizes the solid flux that covers the electrode so that it forms an expanding gaseous cloud to protect the molten weld metal. In addition to fluxes protecting molten weld metal, they also perform a number of beneficial functions for the weld, depending on the type of electrode being used.

SMA welding equipment can be very basic as compared to other welding processes. It can consist of a welding transformer and two welding cables with a work clamp and electrode holder, **Figure 1-9**. There are more types and sizes of SMA welding electrodes than there are filler metal types and sizes for any other welding process. This wide selection of filler metal allows welders to select the best electrode type and size to fit their specific welding job requirements. Therefore, a wide variety of metal types and metal thicknesses can be joined with one machine.

Gas Tungsten Arc Welding (GTAW)

Gas tungsten arc welding (GTAW) uses a nonconsumable electrode made of tungsten. In GTA welding the arc between the electrode and the base metal melts

WELDING AND JOINING PROCESSES

ARC WELDING (AW)

arc stud welding	SW
atomic hydrogen welding	AHW
bare metal arc welding	BMAW
carbon arc welding	CAW
gas carbon arc welding	CAW-G
shielded carbon arc welding	CAW-S
twin carbon arc welding	CAW-T
electrogas welding	EGW
flux cored arc welding	FCAW
gas shielded flux cored arc welding	FCAW-G
self-shielded flux cored arc welding	FCAW-S
gas metal arc welding	GMAW
pulsed gas metal arc welding	GMAW-P
short circuit gas metal arc welding	GMAW-S
gas tungsten arc welding	GTAW
pulsed gas tungsten arc welding	GTAW-P
magnetically impelled arc welding	MIAW
plasma arc welding	PAW
shielded metal arc welding	SMAW
submerged arc welding	SAW
series submerged arc welding	SAW-S

RESISTANCE WEWELDING (RW)

flash welding	FW
pressure-controlled resistance welding	RW-PC
projection welding	PW
resistance seam welding	RSEW
high-frequency seam welding	RSEW-HF
induction seam welding	RSEW-I
mash seam welding	RSEW-MS
resistance spot welding	RSW
upset welding	UW
high-frequency	UW-HF
induction	UW-I

HIGH ENERGY BEAM WELDING (HEBW)

electron beam welding	EBW
high vacuum electron beam welding	EBW-HV
medium vacuum electron beam welding	EBW-MV
nonvacuum electron beam welding	EBW-NV
laser beam welding	LBW

SOLID-STATE WELDING (SSW)

coextrusion welding	CEW
cold welding	CW
diffusion welding	DFW
hot isostatic pressure welding	HIPW
explosion welding	EXW
forge welding	FOW
friction welding	FRW
direct drive friction welding	FRW-DD
friction stir welding	FSW
inertia friction welding	FRW-I
hot pressure welding	HPW
magnetic pulse welding*	MPW
roll welding	ROW
ultrasonic welding	USW

SOLDERING (S)

dip soldering	DS
furnace soldering	FS
induction soldering	IS
infrared soldering	IRS
iron soldering	INS
resistance soldering	RS
torch soldering	TS
ultrasonic soldering	USS
wave soldering	WS

BRAZING (B)

block brazing	BB
carbon arc brazing	CAB
twin carbon arc brazing	TCAB
diffusion brazing	DFB
dip brazing	DB
electron beam brazing	EBB
exothermic brazing	EXB
flow brazing	FLB
furnace brazing	FB
induction brazing	IB
infrared brazing	IRB
laser beam brazing	LBB
resistance brazing	RB
torch brazing	TB

OTHER WELDING AND JOINING

adhesive bonding	AB
braze welding	BW
arc braze welding	ABW
carbon arc braze welding	CABW
electron beam braze welding	EBBW
exothermic braze welding	EXBW
flow welding	FLOW
laser beam braze welding	LBBW
electroslag welding	ESW
consumable guide electroslag welding	ESW-CG
induction welding	IW
percussion welding	PEW
thermite welding	TW

OXYFUEL GAS WELDING (OFW)

air acetylene welding	AAW
oxyacetylene welding	OAW
oxyhydrogen welding	OHW
pressure gas welding	PGW

ALLIED PROCESSES

THERMAL GOUGING (TG)

carbon arc gouging	CAG
oxygen gouging	OG
plasma arc gouging	PAG

THERMAL SPRAYING (THSP)

arc spraying	ASP
flame spraying	FLSP
wire flame spraying	FLSP-W
high velocity oxyfuel spraying	HVOF
plasma spraying	PSP
vacuum plasma spraying	VPSP

THERMAL CUTTING (TC)

OXYGEN CUTTING (OC)

flux cutting	OC-F
metal powder cutting	OC-P
oxyfuel gas cutting	OFC
oxyacetylene cutting	OFC-A
oxyhydrogen cutting	OFC-H
oxynatural gas cutting	OFC-N
oxypropane cutting	OFC-P
oxygen arc cutting	OAC
oxygen lance cutting	OLC

HIGH ENERGY BEAM CUTTING (HEBC)

electron beam cutting	EBC
laser beam cutting	LBC
air	LBC-A
evaporative	LBC-EV
inert gas	LBC-IG
oxygen	LBC-O

ARC CUTTING (AC)

carbon arc cutting	CAC
air carbon arc cutting	CAC-A
gas metal arc cutting	GMAC
gas tungsten arc cutting	GTAC
plasma arc cutting	PAC
shielded metal arc cutting	SMAC

*New welding process

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TABLE 1-1 Master Chart of Welding, Joining, and Allied Processes

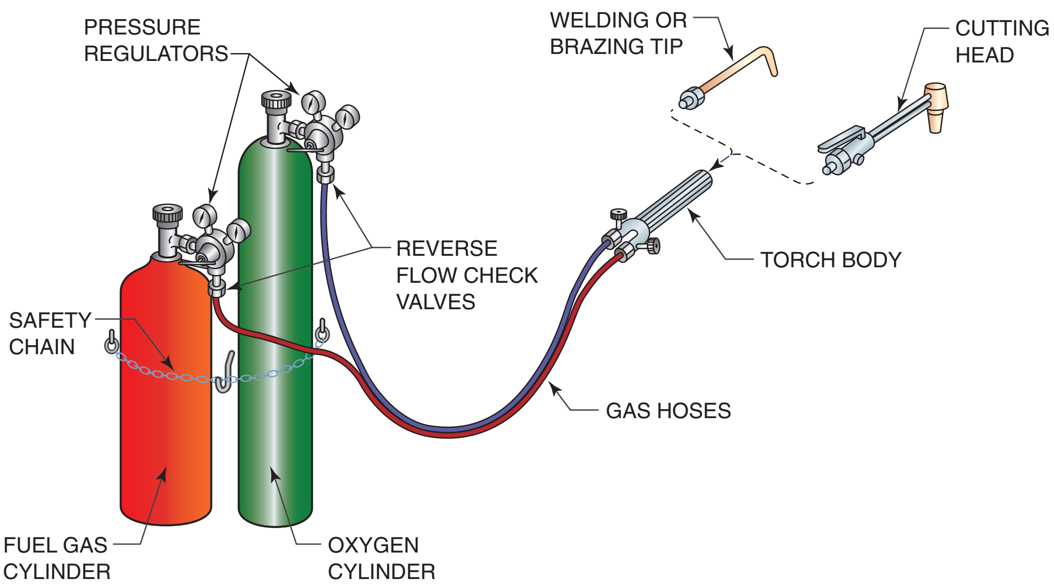

FIGURE 1-8 Oxyfuel welding and cutting equipment.

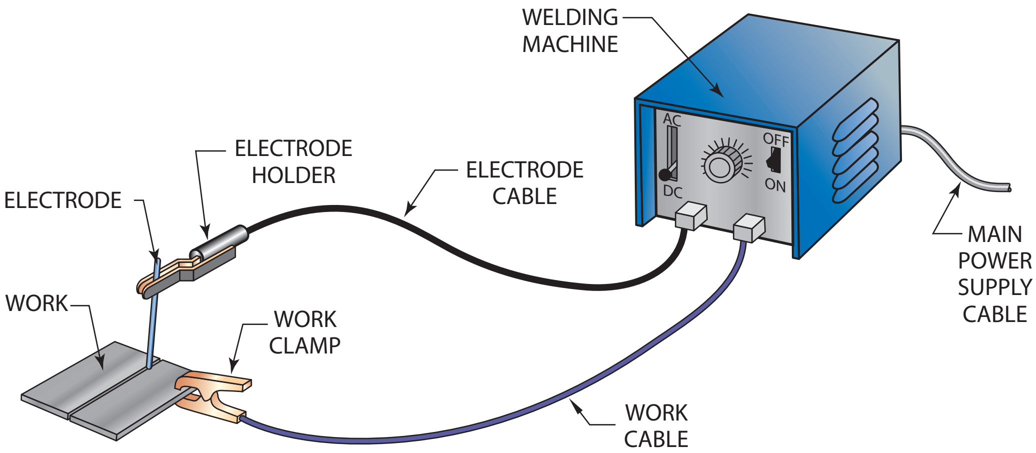

FIGURE 1-9 Shielded metal arc welding equipment.

the base metal and the end of the filler metal as it is manually dipped into the molten weld pool. A shielding gas flowing from the gun nozzle protects the molten weld metal from atmospheric contamination. A foot or thumb remote control switch may be added to the basic GTA welding setup to allow the welder better control, **Figure 1-10**. This remote control switch is often used to start and stop the welding current as well as make adjustments in the power level.

GTA welding is the cleanest of all the manual welding processes. But because there is no flux used to clean the weld in GTA welding, all surface contamination, such as oxides, oil, dirt, and others, must be cleaned from the part being welded and the filler metal so they do not contaminate the weld. Even though GTA welding is slower and requires a higher skill level as compared to other manual welding processes, it is still in demand because it can be used to make extremely high-quality welds in applications where weld integrity is critical. And there are metal alloys that can be joined only with the GTA welding process.

Gas Metal Arc Welding (GMAW)

Gas metal arc welding (GMAW) uses a solid electrode wire that is continuously fed from a spool, through the welding cable assembly, and out through the gun. A shielding gas flows through a separate tube in the cable assembly, out of the welding gun nozzle, and around the electrode wire. The welding power flows through a cable in the cable assembly and is transferred to the electrode wire at the welding gun. The GMA weld is produced as the arc melts the end of the continuously fed filler electrode wire and the surface of the base metal. The molten electrode metal transfers across the arc and becomes part of the weld. The gas shield flows out of

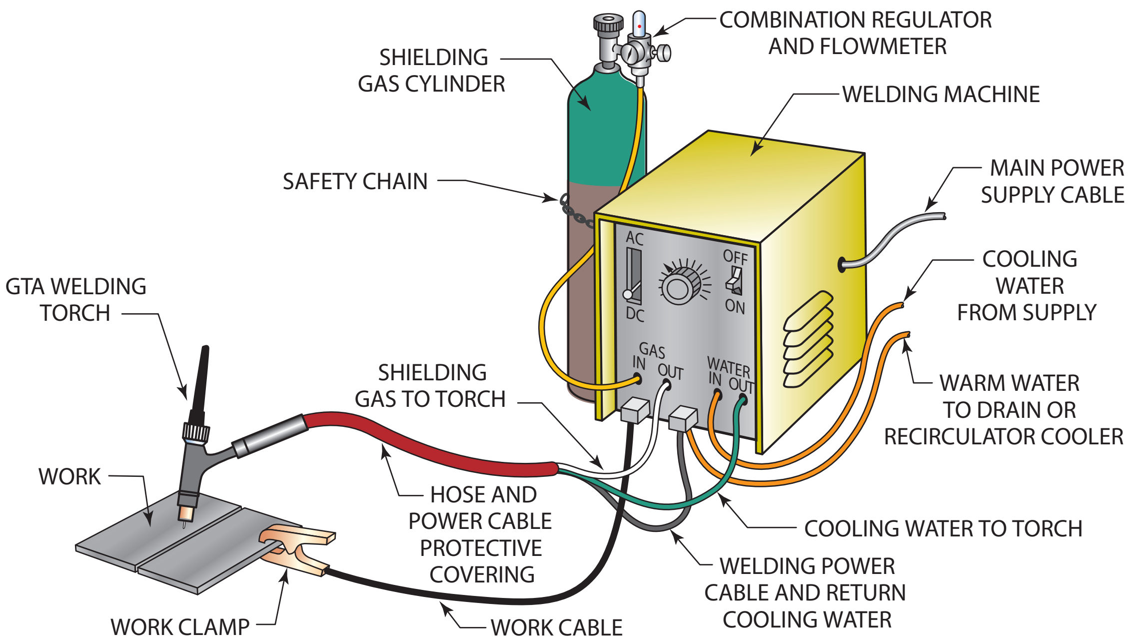

FIGURE 1-10 Gas tungsten arc welding equipment.