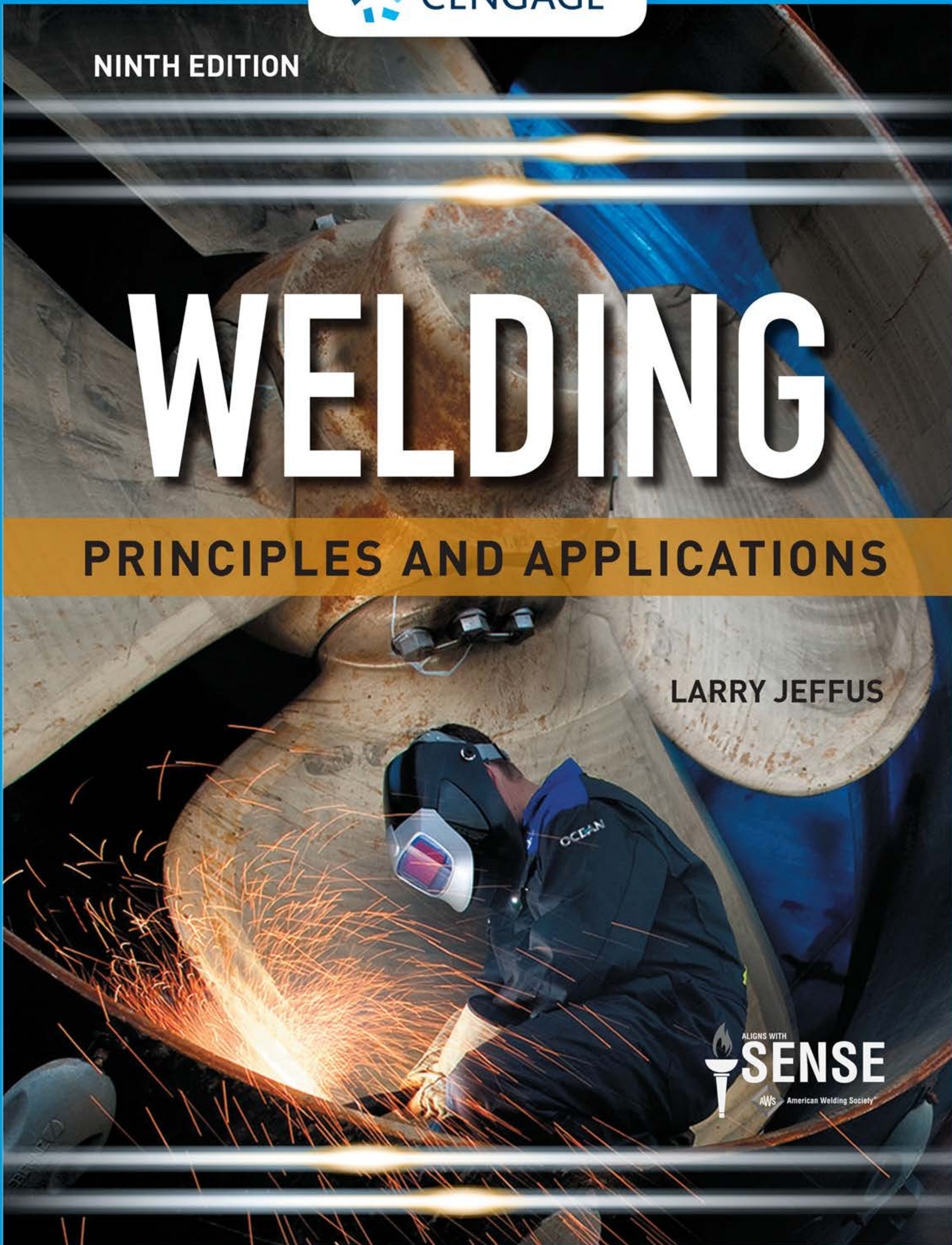
CENGAGE

NINTH EDITION

WELDING

PRINCIPLES AND APPLICATIONS

LARRY JEFFUS



WELDING

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NINTH EDITION

Larry Jeffus

CENGAGE

Australia • Brazil • Mexico • Singapore • United Kingdom • United States

***Welding: Principles and Applications*, Ninth Edition**
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This book is dedicated to two very special people—my daughters Wendy and Amy.

CONTENTS

PREFACE

INTRODUCTION (3.3.1 LI Module 1 3.1 and 3.3.1 LI Module 1 3.3)

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.

Welding has become a very sophisticated and technical science requiring not only the mental application but also hands-on abilities.* To achieve the comprehensive goal of complete welder training the AWS established guidelines for Entry Level Welders. In Welding Principles and Applications the AWS SENSE knowledge requirements are identified with the SENSE torch icon, , along with the related learning modules. The SENSE skill-learning tasks are identified with SENSE Skill and have the related task modules listed. Learning the knowledge and developing the skills established by the AWS SENSE program will help you to become an Entry Level Welder.

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

* AWS EG2.0-2017 Guide for the Training of Welding Personnel: Level I— Entry Welder.

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, performing experiments in a small group where everyone has a turn makes it easier to observe the results more closely. 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 skills using different types of filler metals on a variety of base metal types and thicknesses in all 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 access to 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 9th Edition

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

- Additional areas of safety have been included.
- The OFC chapter has been made comprehensive covering all aspects of the operation, equipment, and cylinder construction.
- The PAC chapter has been updated to reflect the advancements in the process.
- Job related personal skills have been included.
- Key information regarding materials, setup, and operation of practices have been put in an easy to read table.
- More information regarding new GTAW equipment and tungsten sharpening has been included.
- New photos, line art, and equipment for the GMAW and FCAW processes have been included.
- The GTAW cup walking technique is covered in greater detail.
- New material, photos, and line art for testing and inspection have been included.
- New material, photos, and line art for fabricating equipment, grinding materials, and power tools have been included.

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 ninth edition. The *Study Guide/Lab Manual* is designed to reinforce student's 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.

Cengage Learning Testing Powered by Cognero

- Author, edit, and manage test bank content from multiple Cengage Learning solutions.
- Create multiple test versions in an instant.
- Deliver tests from your LMS, your classroom, or wherever you want.

MINDTAP WELDING FOR WELDING: PRINCIPLES AND APPLICATIONS

- MindTap for *Welding Principles and Applications* provides a customized learning solution with relevant assignments that will help students learn and apply concepts while it allows instructors to measure skills and outcomes with ease.
- MindTap meets the needs of today's welding classroom, shop, and student. Within the MindTap, faculty and students will find editable and submittable practice sheets correlated to relevant SENSE curriculum standards. MindTap also offers students the opportunity to reinforce their understanding of theory, improve their critical thinking skills, and practice welding skills in a virtual environment with the inclusion of Cengage's unique welding simulations. A suite of S/P2® safety, pollution, and soft skills modules for welders is available in the Learning Path. Additional engaging activities include videos, animations, matching exercises, and gradable assessments.
- Instructors can customize the MindTap Learning Path by adding or hiding content to match their syllabus and grading preferences. Analytics and reports provide a snapshot of class progress, time on task, engagement, and completion rates.

AWS SENSE AND WELDING PRINCIPLES AND APPLICATIONS

Welding Principles and Applications incorporates all of the key elements found in all of the AWS SENSE *Guide for the Training of Welding Personnel: Level I-Entry Welder* Modules for Level I. The AWS SENSE entry-level welder program is voluntary, so students using this textbook to study welding principles and applications are not required to participate. One of the advantages of participating in the AWS SENSE program is that the AWS is the recognized world leader in welding standards and certifications. As a result, when you obtain your AWS SENSE certification, it will be recognized nationally and internationally.

SENSE GENERAL ELEMENTS

There are some general elements found throughout the AWS SENSE modules that are not marked in the text. Marking all of the occasions that items, such as filling out the "Student Welding Report," would result in almost every page being marked. Some of these general SENSE items are listed below.

AWS SENSE Record Keeping

Throughout the AWS SENSE guidelines, the importance to "Keep training records…" is emphasized. In *Welding Principles and Applications* that AWS SENSE record keeping requirement is incorporated at the end of every experiment and practice with the statement "Student Welding Report listed in Appendix I or provided by your instructor." Completing this report will help your instructor maintain the records that can be used for your submission to the AWS for your SENSE Certification.

Visual Inspections

Almost all of the welding practices in *Welding Principles and Applications* are visually inspected to American Welding Society standards.

Follow Verbal Instructions

Almost all of the welding instructions your welding instructor gives you are verbal. Also, most instructions given by welding shop foremen in the production shop are verbal. That is why it is so important to learn how to listen carefully, understand, remember, and follow verbal instructions.

There are drawings and written instructions included in *Welding Principles and Applications* similar to the ones you might have on the job. But there can be many additional instructions given to you by your instructor or by your boss, such as which welding machine or booth to use, where the base metal is located, which filler metal to use, or which welds you should do first. Listening skills are included throughout the AWS SENSE guidelines.

FEATURES OF THE TEXT

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*

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 **bold print** where they are first defined. These terms are also defined in the Glossary at the end of the book.

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.

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.

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.

PRACTICE 7-14

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. ◆

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.

EXPERIMENT 7-6

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 7-126**. 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. ◆

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.

when you are finished welding.
plete a copy of the "Student Welding Report" listed
in Appendix I or provided by your instructor. ◆

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.

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.

REVIEW

1. Describe two methods of striking an arc with an electrode.
2. Why is it important to strike the arc only in the weld joint?
3. What problems may result by using an electrode at too low of a current setting?
4. What problems may result by using an electrode at too high of a current setting?
5. According to Table 4-1, what would the amperage range be for the following electrodes?
   a. 1/8 in. (3.2 mm), E6010 (70-130)
   b. 5/32 in. (4 mm), E7018 (125-220)
   c. 3/32 in. (2.4 mm), E7016 (75-105)
   d. 1/8 in. (3.2 mm), E6011 (85-125)
6. What makes some spatter "hard?"
7. Why should you never change the current setting during a weld?
8. What factors should be considered when selecting an electrode size?
9. What can a welder do to control overheating of the metal pieces being welded?
10. What problems can result from too long or too short of an arc length?
11. What arc problems can occur in deep or narrow weld joints?
12. Describe the difference between using a leading and a trailing electrode angle.
13. Can all electrodes be used with a leading angle? Why or why not?
14. What characteristics of the weld bead does the weaving of the electrode cause?
15. What are some of the applications for the circular pattern in the flat position?
16. Using a pencil and paper, draw two complete lines of the weave patterns you are most comfortable making.
17. Why is it important to find a good welding position?
18. Which electrodes would be grouped in the following F numbers: F3, F2, and F4?
19. Give one advantage of using electrodes with cellulose-based fluxes.
20. What are stringer beads?
21. Describe an ideal tack weld.
22. What effect does the root opening or root gap have on a butt joint?
23. What can happen if the fillet weld on a lap joint does not have a smooth transition?
24. Which plate heats up faster on a tee joint? Why?
25. Can a tee weld be strong if the welds on both sides do not have deep penetration? Why or why not?

SUCCESS STORY

My name is Brandon Pritchard. Up until I completed the welding program at Northwest Florida State College (NWF), I was working dead-end jobs, living paycheck to paycheck, never having ends meet. After seventh grade, I dropped out of school and practically lived in a different place every month, including foster homes. I made choices in my life that set me up for nothing but failure, including time in jail. I faced continuous hurdles, and at times I found myself emotionally and physically beaten down. I knew I wanted more out of life. I knew I could do it. I just needed a push and some hope from somewhere. The welding program at Northwest Florida State College did that for me.

I remember driving by the NWF State College welding trailer

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.

GLOSSARY

The terms and definitions in this glossary are extracted from the American Welding Society publication AWS A3.0-80 Welding Terms and Definitions. The terms with an asterisk are from a source other than the American Welding Society. *Note:* The English term and definition are given first, followed by the same term and definition in Spanish.

A

***abrasives.** Materials that are usually sharp and are used to clean or grind a surface. They may be used as a powder such as sand to blast the surface or they may be formed into disks or stones to be used by a grinder.

abrasivos. Materiales que son por lo general ásperos y que se utilizan para limpiar o pulir superficies. Pueden venir en polvo, como arena, para bruñir las superficies, o en forma de discos o

es C_2H_2. No tiene color, es más ligero que el aire, y tiene un olor fuerte como a ajo. El acetileno es inestable en presiones más altas de 15 psig (1.05 kg/cm^2 g). Cuando se quema en presencia del oxígeno, el acetileno produce una de las llamás con una temperatura más alta que la que se utiliza.

***acicular structure.** A fine micrograin structure found in rapidly cooled steel.

***estructura acicular.** Una estructura micro granulada fina que se encuentra en el acero que se ha enfriado con rapidez.

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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Technical College, Columbia, SC; Mohave Community College, Kingman, AZ; Mountain View College, Dallas, TX; Navarro College, Corsicana, TX; New England Institute of Technology, East Greenwich, RI; New Hampshire Technical College at Manchester, NH; New River Community College, Dublin, VA; Newberry County Career Center, Newberry, SC; Northeast Texas Community College, Mt. Pleasant, TX; Northwest Mississippi Community College, Senatobia, MS; Northwest Technical Institute, Springdale, AR; Palm Beach Community College, Lake Worth, FL; Paris Junior College, Sulphur Springs, TX; Pewitt CISD, Omaha, TX; Pueblo Community College, Pueblo, CO; Reading Area Community College, Reading, PA; Renton Technical College, Renton, WA; San Jacinto College, Central Campus, Pasadena, TX; South Garland HS, Garland, TX; Southern Union State Community College, Opelika, AL; Tarrant County College, Fort Worth, TX; Tennessee College of Applied Technology at Memphis, Memphis, TN; Texas State Technical College, Red Oak, TX; Texas State Technical College, Waco, TX; Trenholm State Community College, Montgomery, AL; Tulsa Technology Center, Tulsa, OK; Tulsa Welding School, Tulsa, OK, Houston, TX, and Jacksonville FL; Tyler Junior College, Tyler, TX; Walla Walla Community College, Walla Walla, WA; Warren Tech, Lakewood, CO; Wenatchee Valley College, Wenatchee, WA; Western High School, Las Vegas, NV; Wichita Area Technical College, Wichita, KS; Worcester Technical High School, Worcester, MA; York Technical College, Rock Hill, SC; and York Technical College, York, SC. 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.
- Kevin Gratton and Ashley Black, welding instructors at Lexington Area Technical High School, South Carolina, for sharing their knowledge gained from years of experience in welding and teaching, but most of all for their friendship.
- In memory of Brian Walker, a former student and friend who contributed to this book over the years.
- 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 was a cooperative work experience program, much like today's cooperative education programs, that coordinated 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 at Barbour Boat Works. After graduation, I started a full-time job welding and fitting at the shipyard, where I refined my welding skills and was allowed to work with the other welders in the shipyard. My first solo welding assignment was on a barge making overhead intermittent welds to attach the deck to the barge's ribs. Welding overhead all day, I quickly learned how to control the molten weld pool!

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 welded 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 attend 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 more years of welding experience, which together qualified me for my job as a vocational teacher. During my teaching career, I completed postgraduate studies at the University of Tennessee and Texas A & M Commerce.

During my career as a welder, I have welded on tanks, pressure vessels, oil well drilling equipment, farm equipment, structural steel, racecars, aircraft, piping systems, and more. I still weld on a regular basis in my fully equipped welding shop. 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 still work as an author; a consultant to the welding industry; and a resource for students, educators, and school administrators.

Larry Jeffus has more than 60 years of welding experience and more than 40 years of experience as a classroom teacher. He is the author of several Cengage Learning welding publications. Prior to retiring from teaching, Professor Jeffus taught at Eastfield College. 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 six foreign countries. In 1993 Professor Jeffus was selected as Outstanding Postsecondary Technical Educator in the State of Texas by the Texas Technical Society. During his teaching career, he completed additional postgraduate studies at the University of Tennessee and Texas A&M Commerce.

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 helped work 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 non-traditional 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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SECTION 1

Introduction

SUCCESS STORY

My name is Sophie Lewis. When I was a sophomore at Lexington High School in South Carolina, one of my friends recommended that I take a welding course at Lexington Technology Center. So the second semester of my junior year, I enrolled in Welding I and learned how to weld and cut and the basic fundamentals and theory behind many welding and cutting processes.

After completing the Welding I course, as well as getting extra time to experiment with other welding processes, I realized how much I loved welding, and I decided that I wanted to weld as a career. I had to complete two academic classes in summer school in order to fit all of the welding classes into my schedule the following year, but it was worth it.

It was exciting to see my welding skills progress in the Welding Level II classes. I always tried my best to turn out quality products and turn my assignments in early if possible. My instructors, Mr. Black and Mr. Gratton, noticed my hard work in their class and also had noticed some of the projects I had done for my advanced placement art course, another one of my passions. They approached me about the opportunity of my competing in the South Carolina SkillsUSA 2019 competition. I was very happy to accept the challenge where I would be able to combine my two passions of welding and art.

I started my welding sculpture project in November, and I soon learned how much of my focus it would require. Every school day I worked on my project the majority of the welding class time while still learning how to be proficient with the other processes so that I didn't fall behind.

I began the process by making a prototype of my sculpture. Learning to manipulate the molten weld pool was difficult but a very fun lesson on control. It took approximately 100 hours to complete my sculpture, and I finished by the end of February. In March, I took my welding sculpture of a mouse, which I named "Tungsten," to the South Carolina SkillsUSA competition. I won first place, which then qualified me to go to the national SkillsUSA Championships in Louisville, Kentucky, in June, where I competed against high school state contest winners. There I won the Bronze Medal in the Welding Sculpture competition.

Amidst all the excitement of competition, I knew that I had to buckle down and work hard to get all of my welding tests completed back at school; and with the encouragement from my instructors, I was able to complete them all successfully. In the beginning of April, I was offered a full tuition scholarship to Tulsa Welding School in Jacksonville, Florida. I am very excited to be able to continue my education to become a professional welder. I never knew that I could accomplish so much, but I couldn't have done it without my welding instructors, Mr. Black and Mr. Gratton.

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

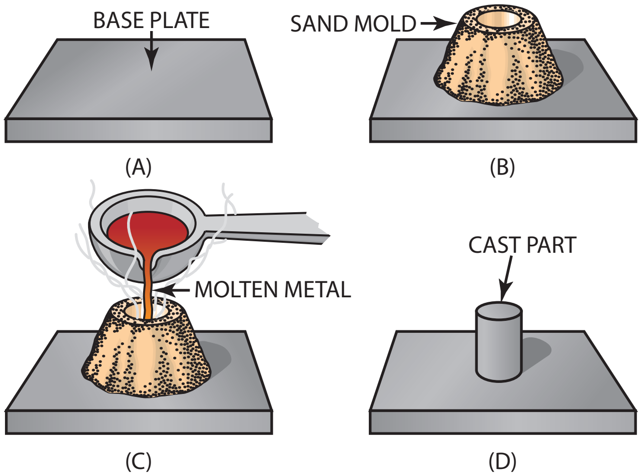

FIGURE 1-1 Direct casting: (A) base plate to have part cast on it, (B) sand molded into shape desired, (C) pouring hot metal into mold, and (D) part cast is now part of the base plate.

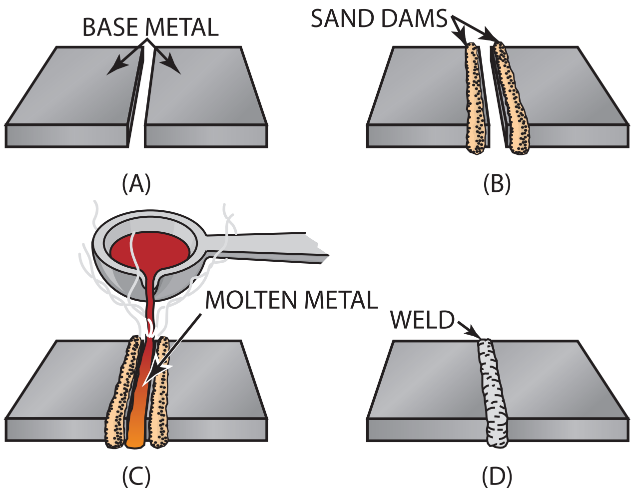

FIGURE 1-2 Flow welding: (A) two pieces of metal plate, (B) sand dams to hold molten metal in place, (C) molten metal poured between metal plates, and (D) finished welded plate.

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.

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.

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.

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, **Figures 1-4** and **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. As 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

NASA

(A)

NASA

(B)

FIGURE 1-4 (A) Test flight for Orion Spacecraft as NASA prepares to send a crew to Mars. (B) Artist rendering of Orion deep spacecraft.

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.

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 and 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


Larry Jeffus

Open pit gold mine near Fairbanks, Alaska

Larry Jeffus

National Park Service all welded pilot boat


Larry Jeffus

Welded sculpture, Manchester College, NH


Larry Jeffus

Steel framework for a 22-story building


Larry Jeffus

1900 coal fired forge and tools for forge welding

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

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

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

(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 1-6**.

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

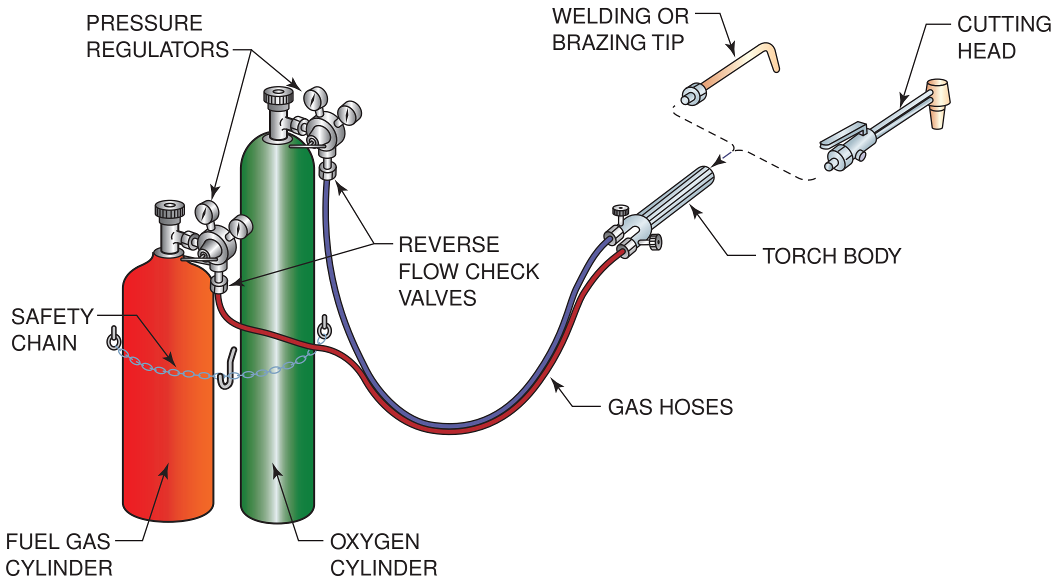

FIGURE 1-6 Oxyfuel welding and cutting equipment.

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 1-7**. 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 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

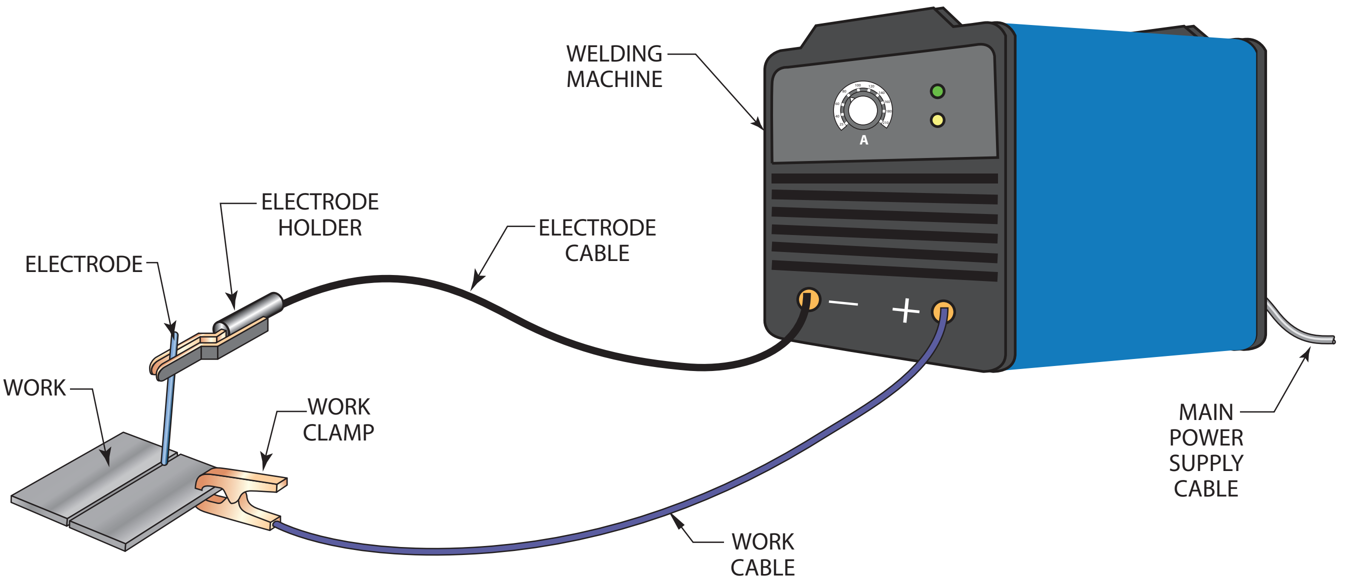

FIGURE 1-7 Shielded metal arc welding equipment.

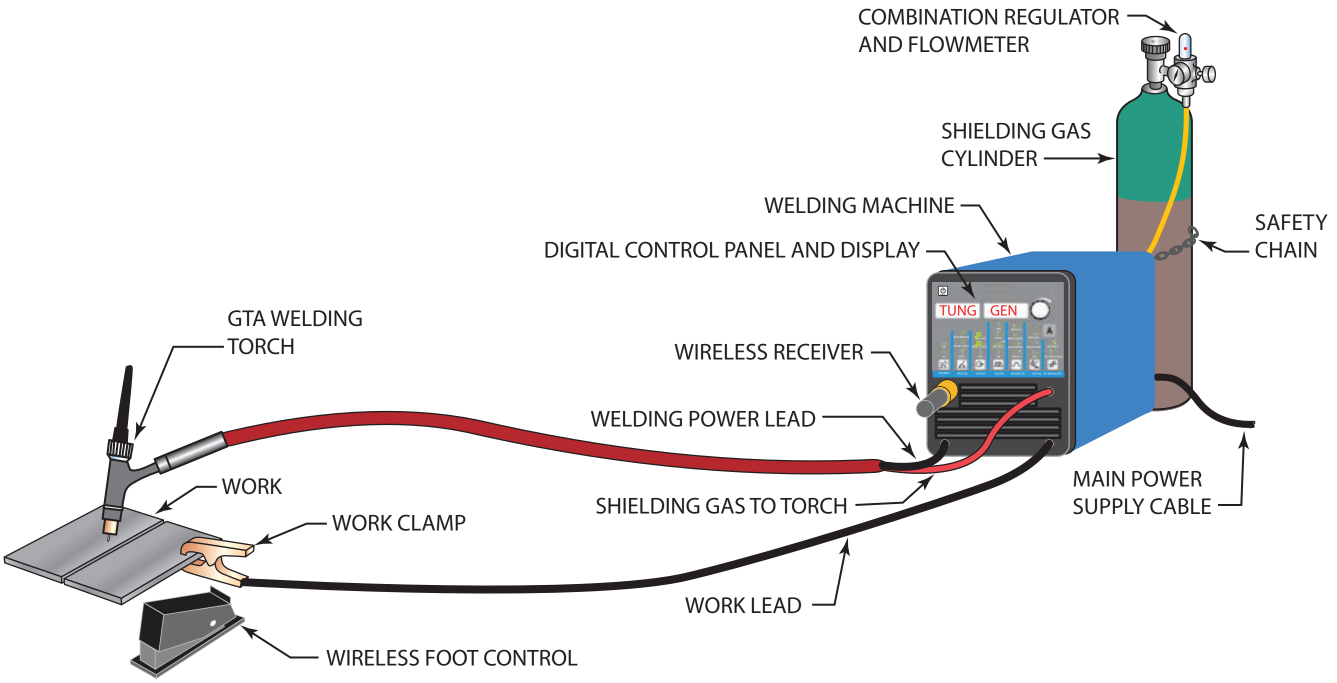

FIGURE 1-8 Gas tungsten arc welding equipment.

allow the welder better control, **Figure 1-8**. 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 the welding gun nozzle to protect the molten weld from atmospheric contamination.

GMA welding is extremely fast and economical because it can produce long welds rapidly that require very little postweld cleanup. This process can be used to weld metal ranging in thickness from thin-gauge sheet metal to heavy plate by making only a few changes in the welding setup.

Flux Cored Arc Welding (FCAW)

Flux cored arc welding (FCAW) uses a flux core electrode wire that is continuously fed from a spool, through the welding cable assembly, and out through the gun. The welding power also flows through the cable assembly. Some welding electrode wire types must be used with a shielding gas, as in GMA welding, but others have enough shielding produced as the flux core vaporizes. The welding current melts both the filler wire and the base metal. When some of the flux vaporizes, it forms a gaseous cloud that protects the surface of the weld. Some of the flux that melts travels across the arc with the molten filler metal where it enters the molten weld pool. Inside the molten weld metal, the flux gathers the impurities and floats them to the surface, where it forms a slag covering on the weld as it cools.

Although slag must be cleaned from the FCA welds after completion, the advantages of the process are its high quality, versatility, and welding speed, which offset this requirement.

Gas metal arc welding and flux cored arc welding are very different welding processes, but they use very similar welding equipment, **Figure 1-9**. Both GMA and FCA weldings are classified as semiautomatic processes because the filler metal is automatically fed into the welding arc, and the welder manually moves the welding gun along the joint being welded. GMA and FCA welding are the first choice for many welding fabricators because these processes are

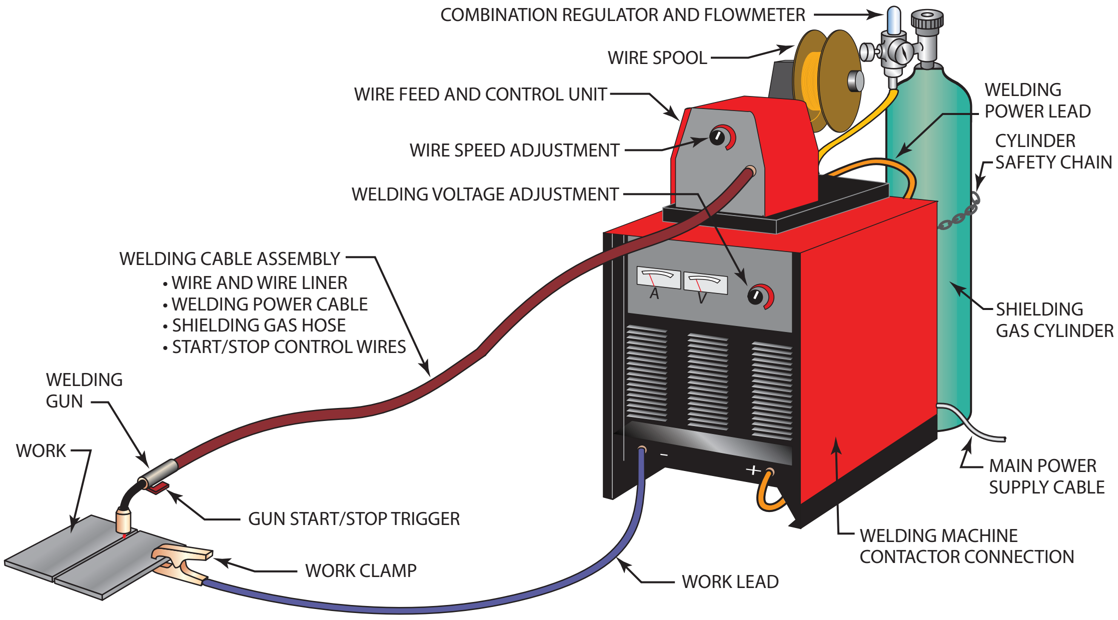

FIGURE 1-9 Gas metal arc welding equipment.

cost-effective, produce high-quality welds, and are flexible and versatile. In addition to welding supply stores, many others stores such as hardware stores, building supply stores, automotive supply stores, and others carry GMA/FCA welding equipment and filler metals.

THERMAL CUTTING PROCESSES

There are a number of thermal cutting processes such as oxyfuel cutting (OFC) and plasma arc cutting (PAC). They are the most commonly used in most welding shops. Air carbon arc (AAC) cutting is also frequently used, and many larger fabrication shops have started using laser beam cutting (LBC).

Oxyfuel Gas Cutting

Oxyfuel gas cutting uses the high-temperature flame to heat the surface of a piece of steel to a point where a forceful stream of oxygen flowing out a center hole in the tip causes the hot steel to burn away, leaving a gap or cut. Because OF cutting relies on the rapid oxidation of the base metal at elevated temperatures to make a cut, the types of metals and alloys it can be used on are limited. OF cutting can be used on steel from a fraction of an inch thick to several feet depending on the capacity of the torch and tip being used.

Plasma Arc Cutting

Plasma arc cutting (PAC) uses a stiff, highly ionized, extremely hot column of gas to almost instantly vaporize the metal being cut. Most ionized plasma is formed as high-pressure air is forced through a very small opening between a tungsten electrode and the torch tip, **Figure 1-10**. As the air is ionized, it heats up, expands, and exits the torch tip at supersonic speeds. PAC does not rely on rapid oxidation of the metal being cut, like OFC, so almost any metal or alloy can be cut.

PA cutting equipment consists of a transformer power supply, plasma torch and cable, work clamp and cable, and an air supply. Some PA cutting equipment has self-contained air compressors. Because the PA cutting process can be performed at some very high travel speeds, it is often used on automated cutting machines. The high travel speeds and very low heat input help to reduce or eliminate part distortion, a common problem with some OF cutting.

SELECTION OF THE JOINING PROCESS

The selection of the joining process for a particular job depends on many factors. No one specific rule controls the welding process to be selected for a certain job. The following are a few of the factors that must be considered when choosing a joining process.

- Availability of equipment—The types, capacity, and condition of equipment that can be used to make the welds.
- Repetitiveness of the operation—How many of the welds will be required to complete the job, and are they all the same?
- Quality requirements—Is this weld going to be used on a piece of furniture, to repair a piece of equipment, or to join a pipeline?
- Location of work—Will the weld be in a shop or on a remote job site?
- Materials to be joined—Are the parts made out of a standard metal or some exotic alloy?
- Appearance of the finished product—Will this be a weldment that is needed only to test an idea, or will it be a permanent structure?

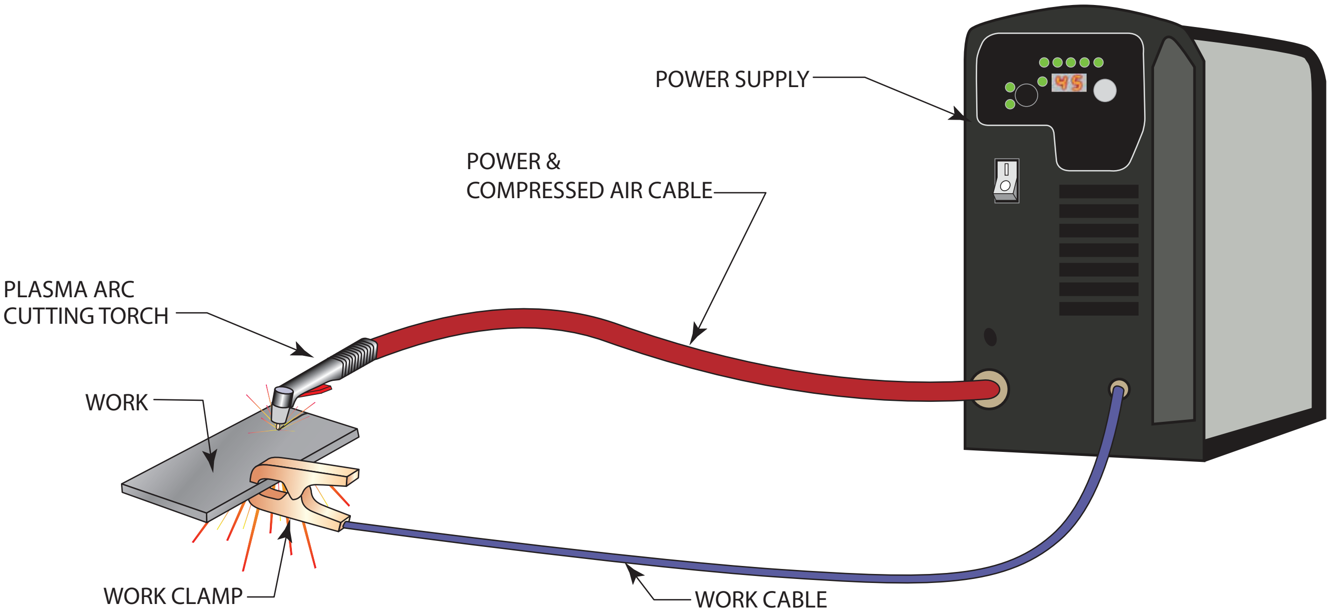

FIGURE 1-10 Plasma arc cutting equipment.

- Size of the parts to be joined—Are the parts small, large, or different sizes, and can they be moved or must they be welded in place?
- Time available for work—Is this a rush job needing a fast repair, or is there time to allow for preweld and postweld cleanup?
- Skill or experience of workers—Do the welders have the ability to do the job?
- Cost of materials—Will the weldment be worth the expense of special equipment materials or finishing time?
- Code or specification requirements—Often the selection of the process is dictated by the governing agency, codes, or standards.

The welding engineer and/or the welder not only must decide on the welding process but also must select the method of applying it. The following methods—**manual operation**, **semiautomatic operation**, **machine operation**, **automatic operation**, and **automated operation**—are used to perform welding, cutting, or brazing operations.

- **Manual**—The welder is required to manipulate the entire process.
- **Semiautomatic**—Filler metal is added automatically, and all other manipulation is done manually by the welder.
- **Machine**—Operations are done mechanically under the observation and correction of a welding operator.
- **Automatic**—Operations are performed repeatedly by a machine that has been programmed to do an entire operation without interaction of the operator.
- **Automated**—Operations are performed repeatedly by a robot or other machine that is programmed flexibly to do a variety of processes.

OCCUPATIONAL OPPORTUNITIES IN WELDING

The American welding industry has contributed to the widespread growth of the welding and allied processes. Without welding, much of what we use on a daily basis could not be manufactured. The list of these products grows every day, thus increasing the number of jobs for people with welding skills. The need to fill these well-paying jobs is not concentrated in major metropolitan areas, but rather is found throughout the country and the world. Because of the diverse nature of the welding industry, the exact job duties of each skill area will vary. The following are general descriptions of the job classifications used in our profession; specific tasks may vary from one location to another.

Welders perform the actual welding. They are the skilled craftspeople who, through their own labor, produce the welds on a variety of complex products, **Figure 1-11**. In many industries, the welder, welding operator, and tack welder must be able to pass a performance test to a specific code or standard.

Tack Welders, also skilled workers, often help the welder by making small welds to hold parts in place. The tack weld must be correctly applied so that it is strong enough to hold the assembly and still not interfere with the finished welding.

Welding Operators, often skilled welders, operate machines or automatic equipment used to make welds.

Welders' Helpers are employed in some welding shops to clean slag and grind welds and help the welder.

Welder Assemblers, or welder fitters, position all the parts in their proper places and make them ready for the

Larry Jeffus

(A)

Larry Jeffus

(B)

Larry Jeffus

(C)

FIGURE 1-11 Amusement parks like Silver Dollar City in Branson, Missouri require a lot of talented welders to produce attractions such as these. (A) Fabricating an antique train engine to be used in a parade. (B) Air-powered guns for launching toy balls. (C) The Branson Belle paddleboat.

tack welders. These skilled workers must be able to interpret blueprints and welding procedures. They must also have knowledge of the effects of contraction and expansion of the various types of metals.

Welding Inspectors are often required to hold a special **certification** such as the one supervised by the American Welding Society known as Certified Welding Inspector (CWI). To become a CWI, candidates must pass a test covering the welding process, blueprint reading, weld symbols, metallurgy, codes and standards, and inspection techniques. Vision screening is also required on a regular basis, once the technical skills have been demonstrated.

Welding Shop Supervisors may or may not weld on a regular basis, depending on the size of the shop. In addition to their welding skills, they must demonstrate good management skills by effectively planning jobs and assigning workers.

Welding Salespersons may be employed by supply houses or equipment manufacturers. These jobs require a broad understanding of the welding process as well as good marketing skills. Good salespersons are able to provide technical information about their products to convince customers to make a purchase.

Welding Shop Owners are often welders who have a high degree of skill and knowledge of small business management and prefer to operate their own businesses. These individuals may specialize in one field, such as hardfacing, repair and maintenance, or specialty fabrications, or they may operate as subcontractors of manufactured items. A welding business can be as small as one individual, one truck, and one portable welder, or as large as a multimillion-dollar operation employing hundreds of workers.

Welding Engineers design, specify, and oversee the construction of complex weldments. The welding engineer may work with other engineers in areas such as mechanics, electronics, chemicals, or civil engineering in the process of bringing a new building, ship, aircraft, or product into existence. The welding engineer is required to know all of the welding process and metallurgy, as well as to have good math, reading, communication, and design skills. This person usually has an advanced college degree and possesses a professional certification.

Related Welding Jobs The highest-paid welders are those who have the education and skills to read blueprints and do the required work to produce a weldment to strict specifications.

Large industrial firms employ workers who serve as support for the welders. These engineers and technicians must have knowledge of chemistry, physics, metallurgy, electricity, and mathematics. Engineers are responsible for research, design, development, and fabrication of a project. Technicians work as part of the engineering staff. These individuals may oversee the actual work for the engineer by providing the engineer with progress reports as well as chemical, physical, and mechanical test results. Technicians may also require engineers to build prototypes for testing and evaluation.

Another group of workers employed by industry does layouts or makes templates. These individuals have had drafting experience and have knowledge of operations such as punching, cutting, shearing, twisting, and forming,

Courtesy of ESAB Welding & Cutting Products

FIGURE 1-12 Numerical control oxygen cutting machine.

among others. The layout is generally done directly on the material. A template is used for repetitive layouts and is made from sheet metal or other suitable materials.

Some operators use handheld torches, and others are skilled operators of oxyfuel cutting machines. These machines range from simple mechanical devices to highly sophisticated, computer-controlled, multiple-head machines that are operated by specialists, **Figure 1-12**.

TRAINING FOR WELDING OCCUPATIONS

Generally, several months of training are required to learn to weld. To become a skilled welder, both welding school and on-the-job experience are required. Because of the diverse nature of the welding industry, no single list of skills can be used to meet every job's requirements. However, there are specific skills that are required of most entry-level welders. This text covers those skill requirements.

Some welding shops require that welders have proficiency in reading, writing, math, communication, and science, as well as good work habits and an acceptance of close supervision. Some welding jobs may also require a theoretical knowledge of welding, blueprint reading, welding symbols, metal properties, and electricity. A few of the jobs that require less skill can be learned after a few months of on-the-job training. The fabrication of certain alloys requires knowledge of metallurgical properties as well as the development of a greater skill in cutting and welding them.

JOB-RELATED SKILLS

In addition to welding skills, an entry-level welder must possess workplace skills such as teamwork, leadership, integrity, honesty, organizational skills, time management, understand the importance of workplace diversity, and the Equal Employment Opportunity law.

Robotics and computer-aided manufacturing (CAM) both require more than a basic understanding of the welding process; they require that the student be computer literate.

A young person planning a career as a welder needs good eyesight, manual dexterity, hand-and-eye coordination, and understanding of welding technology. For entry into manual welding jobs, employers prefer to hire young people who have high school or vocational training in welding processes. Courses in drafting, blueprint reading, mathematics, and physics are also valuable.

Beginning a Welding Career

Beginners in welding who have no training often start in manual welding production jobs that require minimum skill. Occasionally, they first work as helpers and are later moved into welding jobs. General helpers, if they show promise, may be given a chance to become welders by serving as helpers to experienced welders.

A formal apprenticeship is usually not required for general welders. A number of large companies have welding apprenticeship programs. The military has programs in welding at several of its installations.

Skill and technical knowledge requirements are higher in some industries. In the fields of atomic energy, aerospace, and pressure vessel construction, high standards for welders must be met to ensure that weldments will withstand the critical forces that they will be subjected to in use.

Job Prospects

After two years of training at a vocational school or technical institute, the skilled welder may qualify as a technician. Technicians are generally involved in the interpretation of engineers' plans and instructions. Employment of welders is increasing rapidly for a number of reasons.

Many more skilled welders will be needed for maintenance and repair work in the expanding metalworking industries. The number of welders in production work is expected to increase in plants manufacturing sheet metal products, pressure vessels, boilers, railroads, storage tanks, air-conditioning equipment, ship yards, pipe lines, petrochemical plants, and all other areas of energy exploration and production. The construction industry will need an ever-increasing number of good welders as the use of welded steel buildings grows.

Before being assigned a job where service requirements of the weld are critical, welders usually must pass a certification test given by an employer. In addition, some localities require welders to obtain a license for certain types of outside construction.

THINK GREEN All welding and cutting processes consume large quantities of energy and materials, and some produce environmental pollution. It is important that you always look at ways to minimize the impact these processes have on our environment. For example, if a spill occurs, notify your supervisor and clean it up promptly and properly. Always look for ways to be better stewards of our environment.

After welders, welding operators, or tack welders have received a certification or **qualification** by passing a standardized test, they are only allowed to make welds covered by that specific test. The welding certification is very restrictive; it allows a welder to perform only code welds covered by that test. Certifications are usually good for a maximum of six months unless a welder is doing code-quality welds routinely. As a student, you should check into the acceptance of a welding qualification test before investing time and possibly money in the test.

JOB-RELATED PERSONAL SKILLS

(3.3.1 LI Module 1 Occupational Orientation)

Job-related personal skills are important because people are hired based on their welding skills, but too often they may be later fired for not having good job-related personal skills. The material that follows is designed to give you some sense of the various important job related personal skills that you need to be practicing daily. Some of these skills include teamwork, communication, problem solving, and technical reading.

Teamwork (3.3.1 LI Module 1: Key Indicator 2)

It is often necessary to collaborate and work as a team on large fabrications. Each individual working on a project has to work efficiently and effectively with the other team members.

Do not wait to be given instructions or be told what to do; a self-starting mindset and keeping busy by asking for more work when your task is completed, shows initiative and increases efficiency and productivity. If you need additional information, ask for help, but do not be a pest.

Welding can be a dirty occupation, and keeping your tools clean is important for safety and efficiency. You may want to have a clean change of clothes available if needed. From time to time, you may need to borrow tools from the tool room or from a coworker. Be sure that any borrowed tools are returned and are cleaner than when you received them and that they are in good working condition.

To effectively work as a team, distractions must be kept to a minimum. Clothing should not be offensive; tee shirts, hats, or clothes should be appropriate. Stay off your cell phone during work hours, and refrain from using profanity and discussing politics or religion. Horseplay is not considered appropriate in a work environment and can cause safety issues and decreased productivity.

A work environment should be courteous and respectful; be mindful of others.

It's important to have a good reputation on the job, so be careful not to use harsh words in haste by saying something you will regret later. And remember that you do not learn by talking but by listening.

PRACTICE 1-1

Working as a Team Member

Form a small group and have each member of the team fold a paper airplane using a standard 8.5-by-11 sheet of paper. As a group, decide which paper airplane will represent the group in a competition between your group and the other groups. The team must decide on how to select the one paper airplane that will be used in the competition.

All the teams must decide on how the competition is to be judged—i.e., is it the plane that flies the furthest, the one that is in the air the longest, the one that flies in the biggest loop, or the one that has the safest landing? Whatever the competition rules are, you must work as a member of your team and negotiate for the best rules that will benefit your team's entry.

As a team, write a short report describing how the competition worked, and include a sketch of the team's paper airplane. Turn your report in to your teacher. ◆

Communication

Communication can be formal or informal and can take several forms. For example, written communication can be given as detailed as in a Welding Procedure Specification or as informally as a handwritten note or email. Drawings can be detailed blueprints or quick sketches on the part with soapstone or on a pad of paper with a pencil. You may even see drawings made on the floor with soapstone when parts are being laid out. Verbal communication can be part of a company meeting where new company policies and procedures are presented. Communication can also be as simple as two or more coworkers discussing what has to be done next.

All communication is crucial to the success of any project. While many welding tasks are individually completed, many tasks are part of a larger project. The specifications, requirements, measurements, and other factors need to be communicated to all members working on a project so that the project runs smoothly and is completed accurately and on time. Communication should be as brief and specific as necessary to convey understanding in any situation.

Verbal communication may happen quickly in a shop or work environment and is likely to be the most common means of communication between workers. Sometimes it may be difficult to hear verbal instructions because of the noise level in the shop environment. If you are not sure what you were told, repeat it back to verify what you think you heard. Verbal instructions may also include receiving directions for work assignments, asking for assistance from coworkers, and describing welding progress to managers.

Written communication is used to record information or relay it in an easily understood method. Welders may be required to update reports and record data for invoices and time spent on projects. Written communication also may involve specific parameters for a project; updates to a plan; and completing required forms for safety, materials, or project reports.

You may be asked to take a leadership role. Leadership requires you to be an effective communicator with coworkers, management, and possibly the welding engineer. Leaders need to communicate in a positive, constructive, clear, and concise manner to ensure good morale.

PRACTICE 1-2

Communication to a Group

Form a small group, and take turns leading a discussion of a topic that your instructor has recently covered in class. Use the whiteboard or paper to make sketches or diagrams as needed to help illustrate your topic. Make sure everyone in your group has had his or her turn.

Following the discussions, each group member writes a paragraph to communicate to the instructor what was discussed. Turn in your written communication paper to your instructor. ◆

Problem Solving

As a welder, there will be many types of problems to solve. In these situations, the ability to use an adaptive thinking process is important as well as an important skill that will set you apart to your employers. Each welding project may have unique challenges that must be overcome in order to complete the task or work, requiring welders to have the ability to adapt their thinking to solve different and unique problems.

Critical thinking is the process of being able to objectively analyze and evaluate a problem or issue. Being able to be objective and logical enables facts to guide the thinking process. An effective welder must be able to solve problems without constant direction and guidance from managers and supervisors.

Problem solving is the brainstorming process used to create different solutions to one problem. Once several solutions are identified, evaluation is used to narrow the solution by which is the most reasonable and practical method. For welders, this could mean identifying multiple—or developing the best—welding procedures for a given weld requirement.

Planning and organization is developing logical systems and procedures to get a task completed. This skill is important as it helps to break down and plan processes needed to complete a job efficiently. A foreman or supervisor may divide a large welding project into smaller jobs or by putting more skilled welders on difficult welds and less skilled welders on easier tasks.

Researching means being able to seek information that is needed to understand a problem better. Finding relevant information could include using the Internet, product manuals, MSDS sheets, textbooks, or other references. As a welder, knowing how to find useful information for a project or job will produce a better weld and product.

Be Sure Not to Fall into the Red Car Trap If I tell you whatever you do, don't think of a red car, the first thing that everyone does is picture a red car. Sometimes when trying to solve a complex problem you can be swayed by the "red car syndrome." That is where someone makes a suggestion that subconsciously can become a barrier to your contemplating other solutions. The best way to avoid that trap is to realize that you have been "had" by the red car and move on beyond that in your thought processes.

Reading and Understanding Text (3.3.1 LI Module 1: Key Indicator 4)

Welders are required to read and understand a variety of written material such as safety precautions, text assignments, and codes and standards. In some cases, you will be giving the material a quick scan to locate specific information. Scanning is a reading technique where you quickly look over printed material to gain an overview while looking for a specific piece of information. For example, you might be looking through a manufacturer's equipment manual to locate the recommended machine setting for a specific welding task. In this case, you might flip through the entire manual in less than a minute. However, if you are reading the entire text for comprehension and understanding, you might spend the better part of an hour going through the same manual.

In this section, you will be asked to perform reading tasks such as scanning text for information, reading text for learning, and evaluating text for comprehension.

PRACTICE 1-3

In this practice, you will scan Chapter 1 and identify two occupational opportunities in welding. Write the page number where you found this information. ◆

PRACTICE 1-4

In this practice, you will scan Chapter 2 and identify three face and eye PPEs. Write the page number where you found this information. ◆

PRACTICE 1-5

In this practice, you will scan Chapter 2 and locate the correct term for a GFI device. Write the page number where you found this information. ◆

PRACTICE 1-6

In this practice, you will scan Chapter 28 to locate the heading for Tubular Wire and then read that section to learn about the AWS abbreviation for tubular wires. Write the page number where you found this information. ◆

PRACTICE 1-7

In this practice, you will use the index to locate the submerged arc welding material. Scan the material to locate the advantages of SAW, and then read that section to learn its advantages. Write the page number where you found this information. ◆

PRACTICE 1-8

In this practice, you will use the glossary to locate the terms *reducing atmosphere* and *reducing flame* to understand the differences between these two similar terms. Write the page number where you found this information. ◆

PRACTICE 1-9

In this practice, you will use the index to locate the submerged arc welding material. Locate in Chapter 1 the section on Thermal Cutting Processes. Compare and contrast the processes. Write the page number where you found this information. ◆

Punctuality

Punctuality is a work-related trait that is easy for your boss to notice. You need to demonstrate to your boss that you enjoy your job and are interested in working for the company by being on time, being ready to work, having all your tools, etc. Texting, talking, or web surfing on your phone doesn't count as being ready and willing to work. In fact, it can be a major distraction, and distractions can lead to accidents.

It is important that you be punctual for work. That includes arriving in the morning at least 15 or 20 minutes before work begins so that you can be ready to start work promptly. It is not fair to your coworkers for you to dally around after the workday has begun as you are looking for your tools or getting ready to work. Use the time before work to take care of any personal needs such as finishing the last few sips of coffee or bites of your breakfast sandwich and getting ready to start work immediately on time.

Being punctual also includes getting back to work immediately following scheduled breaks and lunch. Don't wait until it is time to be back at your workstation before leaving the break or lunch area; start back early to be on time even if other workers are still hanging around.

Another key aspect of punctuality is not rushing the time clock; don't stop work and start cleaning up well before the end of your shift. Your work should stop at quitting time and not earlier.

Missing Work

It is important that you show up at work every day ready and willing to work. The company is counting on you being there to get your job done so that it can deliver the parts that you have been working on to the customer. When you are absent from work, your job may not get done, which can delay delivery to the customer. The company's reputation can be seriously damaged if it is not able to deliver the goods on time. In many cases, production contracts have penalty clauses that can cost the company significant financial losses if the schedule is not met. Absences can cause lost productivity and potential lost contracts for the company and lost earnings.

You need to be aware of the company policy regarding missing work. Most policies require that you notify your supervisor or the personnel office if you are going to be out of work or late to work. Failing to notify the company or accruing excessive absences can result in your termination. Everyone has unexpected things happen, and sometimes they can interfere with your ability to get to work or be on time. If this happens to you or you are sick, be prompt in talking with your employer so they might be able to find a replacement or at least know they are going to be shorthanded for the day. Letting them know early can let them make schedule changes to work around your not being there.

Being at work is important, but if you are truly sick, you should stay home to minimize the risk of infecting coworkers. Welding can be a hazardous profession, and being sick or taking cold medication can make you less attentive, which can result in your being injured in an accident.

From time to time, everyone has to miss work for illness, family, doctor's appointments, car trouble, etc. The most important thing is to have a plan so that you can minimize the impact on yourself, your coworkers, and your company.

PRACTICE 1-10

Missing Class

Write a detailed plan as if you were an employee of a company to let your instructor know if you are going to miss class. Include in your plan various scenarios such as car trouble, childcare, illness, appointments, etc., and what actions you might take to make it to class or notify your instructor of your impending absence. Be sure your plan complies with your school's rules and regulations regarding absenteeism.

Turn in your plan to your instructor. ◆

Continued Education

After you graduate or complete your welding program, you need to continue to learn. In order to stay up with the latest technologies and advancements in welding and manufacturing, it requires dedication on your part. You can continue your education by taking classes or attending seminars put on by companies or professional organizations. A good source of current welding technologies is the American Welding Society's *Welding Journal*.

Being willing and able to learn how to apply new technology is a valuable skill in today's workplace that employers look for and need in employees. Continuing your education can be a major consideration for advancement within your company. It shows that you have a true passion for welding and take pride in your work.

AWS SENSE WELDER CERTIFICATION

The **American Welding Society (AWS)** has developed two levels of certification for welders. The first level, Entry-Level Welder, is for the beginning welder, and Level II is for the more skilled welders. The AWS Schools Exceling through National Skills Standards Education (SENSE) certifications have gained widespread acceptance by the industry. SENSE certifications allow welders to demonstrate their skills on a standard welding test.

The AWS SENSE guidelines have been established as the minimum skill standards according to AWS QC10 Specifications for Qualification and Certification for Entry-Level I Welders and according to AWS QC11 Specifications for Qualification and Certification for Level II—Advanced Welders.

Schools that become Participating Organizations of the AWS SENSE program can forward the records of students who have passed the required knowledge test and one or more workmanship standard to the AWS. The AWS will then post the students' information on the National Registry of SENSE Program Welders. The National Registry is a web-based program available to employers looking for skilled welders.

LEVEL I QUALIFICATION PROCEDURES

The Entry Level Welder SENSE program is divided into nine modules. The first three modules relate to practical knowledge that is common to all areas of welding and that welders must have to succeed in the welding field. Modules 4 through 7 relate to welding performance (skills) in each of the major welding processes.

Documentation must be kept for all the knowledge tests and workmanship tests. Examples of forms that can be used for student record keeping can be found in Appendixes I, II, and III.

Practical Knowledge Qualification—Written Test

The three areas covered in the knowledge modules are: Module 1, Occupational Orientation; Module 2, Safety and Health of Welders; and Module 3, Drawing and Welding Symbol Interpretation. The chapters in this textbook that relate to these performance qualifications areas are listed in **Table 1-2**.

As part of the qualification process students must pass a closed book test regarding Module 2 (Safety and Health of Welders) with minimum grade of 90%. Closed book test regarding material covered in Modules 1 and 3 must be passed with a minimum grade of 70%.

Performance Qualification—Workmanship Samples and Test Plates

Each of the four major welding processes are covered in Modules 4 through 7: Module 4, Shielded Metal Arc Welding (SMAW) Principles and Practices; Module 5, Gas Metal Arc Welding (GMAW, GMAW-S) Principles and Practices; Module 6, Flux Cored Arc Welding (FCAW, FCAW-G/GM) Principles and Practices; and Module 7, Gas Tungsten Arc Welding (GTAW) Principles and Practices. The chapters in this textbook that relate to these performance qualifications areas are listed in **Table 1-3**.

Each of the welding performance qualification workmanship tests has a list of acceptable limits for discontinuities that must be met for the student to pass. Students can pass one or more of the workmanship qualification standard welding tests.

Learning Module or Unit	Competency	Written	Visual	Destructive	Competency Achieved by
Module 1	Occupational Orientation	N/A	N/A	N/A	Instructor/Advisor observation
Module 2	Safety and Health of Welders	Yes	N/A	N/A	Written Test Score 100% minimum
Module 3	Drawing and Welding Symbol Interpretation	Yes	N/A	N/A	Written Test Score 75% minimum
Module 4	Shielded Metal Arc Welding (SMAW)	Yes	Yes	Yes	Written Test Score 75% minimum Visual Inspection Passed Destructive Test Passed
Module 5	Gas Metal Arc Welding (GMAW, GMAW-S)	Yes	Yes	N/A	Written Test Score 75% minimum Visual Inspection Passed
Module 6	Flux Cored Arc Welding (FCAW-G/GM, FCAW-S)	Yes	Yes	N/A	Written Test Score 75% minimum Visual Inspection Passed
Module 7	Gas Tungsten Arc Welding (GTAW)	Yes	Yes	N/A	Written Test Score 75% minimum Visual Inspection Passed
Module 8	Thermal Cutting Processes	Yes	Yes	N/A	Written Test Score 75% minimum Visual (see below)
Unit 1	Manual Oxyfuel Gas Cutting (OFC)	Yes	Yes	N/A	Included in Module 8 Test
Unit 2	Mechanized Oxyfuel Gas Cutting (OFC)	Yes	Optional	N/A	Included in Module 8 Test
Unit 3	Manual Plasma Arc Cutting (PAC)	Yes	Yes	N/A	Included in Module 8 Test Visual Inspection Passed
Unit 4	Manual Air Carbon Arc Cutting (CAC-A)	Yes	Optional	N/A	Included in Module 8 Test
Module 9	Welding Inspection and Testing	Yes	N/A	N/A	Written Test Score 75% minimum

TABLE 1-2 AWS SENSE Knowledge Subjects for Level I Entry-Level Welder Qualification

Level 1 Module	Welding Process	Chapter Number(s)
4	SMAW	3, 4, 5, and 6
5	GMAW & GMAW-S	10, 11, 14, and 15
6	FCAW-S & FCAW-G	12, 13, 14, and 15
7	GTAW	16, 17, 18, and 19
8 Unit 1	OFC Manual	7
8 Unit 2	OFC Machine	7
8 Unit 3	PAC	8
8 Unit 4	CAC-A	9
9	Inspection and Testing	6, 15, 19, and 24

TABLE 1-3 AWS SENSE Performance Skills for Level I Entry-Level Welder Qualification

The welding practices in this textbook that are based on these SENSE standards are identified as "AWS SENSE Level I." The practices are set up in the same way as a Welding Procedure Specification (WPS) for SMA welding of plate and pipe. The welding and testing procedures are in accordance with the AWS QC10 standards.

Thermal Cutting Principles and Practices

Module 8, Thermal Cutting Principles and Practices, is divided into four units, with each covering different types of thermal cutting: Unit 1, Manual Oxyfuel Gas Cutting (OFC); Unit 2, Mechanized Oxyfuel Gas Cutting (OFC); Unit 3, Plasma Arc Cutting (PAC); and Unit 4, Air Carbon Arc Cutting (CAC-A). The chapters in this textbook that relate to these performance qualifications areas are listed in Table 1-3.

Welding Inspection and Testing Principles and Practices

Module 9 covers two main areas of inspection and testing. The first covers the examination of cut surfaces and edges of prepared base metal parts. The second covers the examination of tack welds, intermediate welding layers, and completed welds, Table 1-3.

LEVEL II ADVANCED WELDER QUALIFICATION

Level II Advanced Welding Qualifications are divided into two sections: Knowledge Subjects, which require students to be tested, and Performance Testing, which requires students to pass a welding skill test, **Table 1-4**. For Level II, the students must pass the safety test with a grade of at least 90% and the other knowledge areas with a grade of at least 75%.

The welding practices in this textbook that are based on these SENSE standards are identified as "AWS SENSE Level II." The practices are set up in the same way as a Welding Procedure Specification (WPS) for SMA welding of plate and pipe. The welding and testing procedures are in accordance with the AWS QC11 standards.

AWS SENSE Level II—Advanced Welder Compulsory Modules					
Module	**Prerequisite**	**Practical Knowledge Exam**	**NDE**	**Destructive**	**Competency Achieved by**
1. Trade Math	None	Yes	NA	NA	Practical knowledge exam score 75%
2. Welding Metallurgy	None	Yes	NA	NA	Practical knowledge exam score 75%
3. Welding Inspection & Testing Methods	Level I Welding Inspection & Testing	Yes	Yes (Visual, Liquid Penetrant)	Yes (Fillet Break, Macroetch[a])	Practical knowledge exam score 75% Fillet break, liquid penetrant tests, and visual examination completed
4. Documents Governing Welding & Welding Inspection	None	Yes	NA	NA	Practical knowledge exam score 75%
5. Thermal Cutting Processes	Level I Thermal Cutting Processes	Yes	Yes (Visual)	NA	Practical knowledge exam score 75% Visual examination passed
AWS SENSE Level II—Advanced Welder Optional Plate Modules					
6. SMAW Plate	SMAW Level I	Yes	Yes (Visual)	Yes[a]	Practical knowledge exam score 75% Visual inspection passed Destructive test passed[a] (QC7 Cert optional)
8. GMAW Plate	GMAW Level I	Yes	Yes (Visual)	Yes[a]	Practical knowledge exam score 75% Visual inspection passed Destructive test passed[a] (QC7 Cert optional)
10. FCAW Plate	FCAW Level I	Yes	Yes (Visual)	Yes[a]	Practical knowledge exam score 75% Visual inspection passed Destructive test passed[a] (QC7 Cert optional)
12. GTAW Plate	GTAW Level I	Yes	Yes (Visual)	Yes[a]	Practical knowledge exam score 75% Visual inspection passed Destructive test passed[a] (QC7 Cert optional)

(continued)

TABLE 1-4 AWS SENSE Knowledge Subjects for Level 2 Advanced Welders

Module	Prerequisite	Practical Knowledge Exam	NDE	Destructive	Competency Achieved by
AWS SENSE Level II—Advanced Welder Optional Pipe Modules					
7. SMAW Pipe	SMAW Level I SMAW Level II Plate	Yes[a]	Yes (Visual)	Yes[b]	Practical knowledge exam score 75% Visual inspection passed Destructive test passed[a] (QC7 Cert optional)
9. GMAW Pipe	GMAW Level I GMAW Level II Plate	Yes[a]	Yes (Visual)	Yes[b]	Practical knowledge exam score 75% Visual inspection passed Destructive test passed[a] (QC7 Cert optional)
11. FCAW Pipe	FCAW Level I FCAW Level II Plate	Yes[a]	Yes (Visual)	Yes[b]	Practical knowledge exam score 75% Visual inspection passed Destructive test passed[a] (QC7 Cert optional)
13. GTAW Pipe	GTAW Level I GTAW Level II Plate	Yes[a]	Yes (Visual)	Yes[b]	Practical knowledge exam score 75% Visual inspection passed Destructive test passed[a] (QC7 Cert optional)

[a]The pipe practical knowledge exam is generic to all pipe welding processes.
[b]Radiographic Examination (RT) accepted in lieu of destructive testing.

TABLE 1-4 (Continued)

SKILLSUSA

Each year SkillsUSA sponsors a series of welding skill competitions for its student members. Students can begin by joining their local SkillsUSA chapter. They can then compete in local, regional, and state competitions. Each time, the students with the best welding skills and knowledge can advance to the next level of competition. Contestants are challenged with a written test and must show their proficiency in welding and fabrication. There is a national SkillsUSA Olympics competition held each year in Kansas City, Missouri. The winners at the national competition can then go on to the International Skill Olympics. The international competition is held in a different country each year. Like most professional organizations, SkillsUSA emphasizes community service and citizenship as key components to the philosophy of the organization.

EXPERIMENTS AND PRACTICES

A number of the chapters in this book contain both experiments and practices. These are intended to help you develop your welding knowledge and skills.

The 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. The knowledge gained from the experiments will help you troubleshoot welding problems. When you try an experiment, you should observe and possibly take notes on how the change affected the weld. Often as you make a weld, it will be necessary for you to make changes in your equipment settings or your technique to ensure you are making an acceptable weld. By watching what happens when you make the changes in the welding shop, you will be better prepared to decide on changes required to make good welds on the job.

It is recommended that you work in a small group as you try the experiments. When trying the experiments in a small group, one person can be welding, one can be adjusting the equipment, and the others can be recording the machine settings and weld effects. This also allows you to watch the weld change more closely if someone is welding as you look on. Then, as a group member, changing places will reinforce your learning.

The practices are designed to build your welding skills. Each practice tells you in detail what equipment, supplies, and tools you will need as you develop the specific skill. In most chapters, the practices are easy in the beginning and become progressively harder. Welding is a skill that requires you to develop in stages from the basic to the more complex.

Each practice gives the evaluation or acceptable limits for the weld. All welds have some discontinuities, but if they are within the acceptable limits, then they are not defects. Instead, they are called flaws. As you practice your welding, keep in mind the acceptable limits so that you can progress to the next level when you have mastered the process and weld you are working on.

WELDING VIDEO SERIES

Cengage Learning, in cooperation with the author, has produced a series of videotapes. Each of the four tape sets covers specific equipment setup and operation for welding, cutting, soldering, or brazing. When there are specific skills shown both in this textbook and on a videotape, you will see a framed shot from the video, as shown in **Figure 1-13**. Reading the material, watching the video, and practicing should help you to develop your welding skills more rapidly.

Larry Jeffus

FIGURE 1-13 This GMA welding can be seen in the Gas Metal Arc Welding video series on tape 2.

1/4 inch	= 6 mm
1/2 inch	= 13 mm
3/4 inch	= 18 mm
1 inch	= 25 mm
2 inches	= 50 mm
1/2 gal	= 2 L
1 gal	= 4 L
1 lb	= 1/2 K
2 lb	= 1 K
1 psig	= 7 kPa
1°F	= 2°C

TABLE 1-5 Conversion Approximations

METRIC UNITS

Both standard and metric (SI) units are given in this text. The SI units are in parentheses ( ) following the standard unit. When nonspecific values are used—for example, "set the gauge at 2 psig" where 2 is an approximate value—the SI units have been rounded to the nearest whole number. Rounding occurs in these cases to agree with the standard value and because whole numbers are easier to work with. The only time that SI units are not rounded is when the standard unit is an exact measurement.

Often students have difficulty understanding metric units because exact conversions are used even when the standard measurement was an approximation. Rounding the metric units makes understanding the metric system much easier, **Table 1-5**. Estimating the approximate conversion from one unit type to another makes it possible to quickly have an idea of how large or heavy an object is. When estimating a conversion, it is not necessary to be concise.

By using this approximation method, you can make most standard-to-metric conversions in your head without needing to use a calculator.

Once you have learned to use approximations for metric, you will find it easier to make exact conversions whenever necessary. Conversions must be exact in the shop when a part is dimensioned with one system's units and the other system must be used to fabricate the part. For that reason you must be able to make those conversions. **Tables 1-6** and **1-7** are set up to be used with or without the aid of a calculator. Many calculators today have built-in standard–metric conversions. Of course, it is a good idea to know how to make these conversions with and without these aids. Practice making such conversions whenever the opportunity arises.