Welding

Principles and Applications

Fifth Edition

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Larry Jeffus

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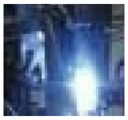

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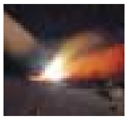

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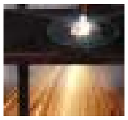

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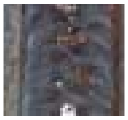

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Preface

Introduction

The welding industry today presents a continually growing and changing series of opportunities for skilled welders. Even with economic fluctuations, there is a positive job outlook in welding. 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, and large industries. The student who is preparing for a career in welding will need to

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

A thorough study of *Welding: Principles and Applications* in a classroom/shop setting will help students prepare for the opportunities in modern 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, 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 for their Certified Welder program are included within the text. Students wishing to become certified under the AWS program must contact the American Welding Society for specific details.

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 processes, and on to the related areas of welding metallurgy, weldability of metals, fabrication, certification, testing and inspection of welds, and welding joint design, costs, and welding symbols.

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.

The welding processes in the text are presented in a manner that allows the student to begin with any section. It is not necessary to learn all of the processes if only one or two are required of your job.

Each chapter begins with a list of *learning objectives* that 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, depending upon the topics selected for the program. Each major process is presented in such a way that the instructor can eliminate processes having little economic value in the market served by the program. However, the student will still learn all essential information needed for a thorough understanding of all processes studied.

In each chapter, *Key Terms* are highlighted in color and defined. In addition, the new terms are listed at the beginning of the chapter to enable students to recognize the terms when they appear. Terms and definitions used throughout the text are based on the American Welding Society's standards. Industry jargon has also been included where appropriate. The *Bilingual Glossary* includes a Spanish equivalent for each term, and many definitions feature additional drawings to assist all learners in gaining a complete understanding of the new term.

Cautions for the student are given throughout the text. *Metric equivalents* are listed in parentheses for dimensions. The metric equivalent in most cases has been rounded to the nearest whole number. Numerous full-color photographs, line drawings, and plans illustrate concepts and clarify the discussions.

Most of the chapters contain learning activities in the form of *Experiments* and *Practices*. The end of the experiments are identified by the (♦) and the end of the practices are identified by the (♦) symbol.

By completing the *Experiments,* the student learns the parameters of each welding process. Often, because it is hard both to perform the experiment and to observe the results closely, students will do most of the experiments in a small group. This will allow students both to perform the activity and to observe the reactions. In the experiments, the student changes the parameters to observe the effect on the process. In this way, the student learns 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.

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

The *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.

Computers in Welding

As in every skilled trade in today's ever changing world, computers are becoming more commonly used in welding. Some of the basic programs provide a cross-reference to welding filler metals, whereas others aid in weld symbol selection. More complex programs allow welding engineers to design structures and test them for strength without ever building them. These programs aid in proper design and make more effective use of materials, resulting in better, more cost–effective construction. The most commonly used programs are ones such as Arc Works™, published by Lincoln Electric Company, which are used to help write Welding Procedure Specifications (WPS), Procedure Qualification Records (PQR), and Welder Qualification Test Records (WQTR). These documents are extensively used throughout the welding industry.

Most of the welding programs operate on a variety of platforms, but the most popular ones use a version of Microsoft Windows. Having a good basic understanding of the Windows operating platform will give you a great start with these programs. In addition you should become familiar with one of the commonly used word processing programs, such as Microsoft Word. This will aid you in producing high-quality reports both in school and later on the job.

Revision

The fifth edition of *Welding: Principles and Applications* has been thoroughly revised and reorganized to reflect the latest welding technologies.

In this edition there are all-new, full-color photos and detailed colored line art. The unique photographs in this book were taken from the welder's viewpoint. Approximately one-third of the photos were taken from a left-handed view to aid the left-handed students. The use of quality graphics make it much easier for the student to see what is expected to produce a quality weld.

The *Success Story* vignettes of real welders have been updated to provide motivation to students considering welding as a career. *Real World Features* have been expanded and appear in every chapter.

Supplements

Accompanying the text are an *Instructor's Guide, a Study Guide/Lab Manual,* and a videotape series showing in detail many of the setups and welding practices. Throughout the text are figures with a *Video Frame* around them. These are skills that are demonstrated in the video series. Chapters that contain *Video Frame* references are noted on the section openers.

The *Instructor's Guide* contains lesson plan outlines for each chapter. Transparency masters have also been included to assist in the classroom. Answers to the questions in the textbook and the *Study Guide/Lab Manual* are also included, along with additional questions and answers for testing. Certification information is also provided in the *Instructor's Guide,* including samples of typical certification tests from certifying agencies. Supplementary references will direct the instructor to additional sources of information for specific content areas.

The *Study Guide/Lab Manual (ISBN 1-4018-1048-9)* has been updated to reflect the changes made in this edition. The *Study Guide/Lab Manual* is designed to test student understanding of the concepts presented in the text. Each chapter starts with a review of the important topics discussed in the text. 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.

Video series on Flux Cored Arc Welding *(ISBN 0-7668-2292-3),* Gas Metal Arc Welding *(ISBN 0-7668-2299-0),* Oxyacetylene Welding *(ISBN 0-7668-2306-7),* Shielded Metal Arc Welding *(ISBN 0-7668-2313-X)* and Gas Tungsten Arc Welding *(ISBN 0-8064-1592-4)* are also available to enhance the presentation of these topics. *Video Frames* throughout the text indicate that more material is available on one of the tape series, and each set is a four-part video series that shows the fundamentals of the process. Program activity sheets based on the videos and some CD-ROM versions of the series are also available.

The *Online Companion* is a free weblink to motivate students to learn more about professional opportunities in the welding workforce. It contains material and links about careers in welding, as well as a selection of video clips, so students can see welders in action, while learning about welding processes. Visit the *Online Companion* at *www.delmarlearning.com/welding/jeffus.*

FEATURES OF THE TEXT

Chapter 27

Other Welding Processes

OBJECTIVES

After completing this chapter, the student should be able to

- ☑ explain the operating principles for the different special welding processes.
- ☑ list the reasons that a particular process should be selected to make a special weld.
- ☑ list the operational limitations of each special welding process explained in this chapter.

KEY TERMS

electrical resistance
electron beam welding (EBW)
evacuated (vacuum) chamber
flash welding (FW)
hardfacing
inertia welding
laser welding (LBW)
optical viewing system
percussion welding (PEW)
plasma-arc welding (PAW)
resistance welding (RW)
stud welding (SW)
thermal spraying (THSP)
ultrasonic welding (USW)
upset welding (UW)

INTRODUCTION

More than eighty different welding and allied processes are listed by the American Welding Society. This text covers nine of the most commonly used processes that require the welder to have a special skill. This chapter covers seventeen additional processes that call for special equipment and techniques. Some of these processes require less skill or knowledge to set up and operate, such as resistance spot welding (RSW). Others demand a great deal of technical information and training, such as electron beam welding (EBW).

The actual operating procedures vary greatly from one manufacturer's machine to another. The specific settings also change from one material to another. Because of these factors, only the general theory, procedures, and applications are discussed in this chapter. More information can be obtained from the AWS or directly from the manufacturer of the equipment being operated. The skill needed to operate this equipment can be learned quickly on the job or in classes taught by the specific equipment manufacturer.

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

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

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

Chapter 28 *Oxyfuel Welding and Cutting Equipment, Setup, and Operation* **735**

VIDEO

FIGURE 28-40 Cracking the oxygen and fuel cylinder valves to blow out any dirt lodged in the valves. Courtesy of Larry Jeffus. See OFW video series.

3. Attach the regulators to the cylinder valves, **Figure 28-42A**. The nuts can be started by hand and then tightened with a wrench, **Figure 28-42B**.
4. Attach a reverse flow valve or flashback arrestor, if the torch does not have them built in, to the hose connection on the regulator or to the hose connection on the torch body, depending on the type of reverse flow valve in the set, **Figure 28-43**. Occasionally test each reverse flow valve by blowing through it to make sure it works properly.
5. Connect the hoses. The red hose has a left-hand grooved nut and attaches to the fuel-gas regulator. The green hose has a right-hand nut without grooves and attaches to the oxygen regulator.
6. Attach the torch to the hoses, **Figure 28-44**. Connect both hose nuts fingertight before using a wrench to tighten either one.
7. Check the tip seals for nicks or O rings, if used, for damage. In most cases tips that have O rings–type seals are hand tightened, and tips that have metal-to-metal seals are wrench tightened, but it is best to check the owner's manual, or a supplier, to determine if the torch tip should be tightened, **Figure 28-45**.

CAUTION

Tightening a tip the incorrect way may be dangerous and might damage the equipment.

Check all connections to be sure they are tight. The oxyfuel equipment is now assembled and ready for use.

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

(A)

(B)

(C)

FIGURE 28-41 Nonadjustable wrenches for acetylene cylinders. (A) Small Combination Wrench, (B) Large Combination Wrench, (C) T-Wrench. Courtesy of ESAB Welding & Cutting Products.

PRACTICE 28-2

Turning On and Testing a Torch

Using the oxyfuel equipment that was properly assembled in Practice 28-1, a nonadjustable tank wrench, and a leak-detecting solution, you will pressurize the system and test for leaks.

1. Back out the regulator pressure adjusting screws until they are loose, **Figure 28-46**.

754 **Section 7** *Oxyfuel*

Application	Acetylene	MAPP® Gas	Propylene
Cutting			
Under 3/8 in. thick	100	95	90
5/8 in to 5 in. thick	95	100	95
Over 5 in. thick	80	100	95
Cutting dirty or scaled surfaces	100	95	80
Repetitive cutting	100	100	80
Stack cutting	90	100	95
Cutting low alloy specialty steels	100	90	80
Beveling	100	100	85
Cutting rounds	95	100	85
Piercing	100	100	85
Blind-hole piercing	100	90	80
Rivet washing	100	95	80
Gouging	100	100	85
Wire metallizing	80	100	90
Powder metallizing	100	0	0
Heating, stress relief, bending	70	100	90
Deep flame hardening	90	100	90
Shallow flame hardening	95	100	80
Cobalt-base hardsurfacing	100	0	0
Other alloy hardsurfacing	100	85	70
Welding	100	70	0
Braze welding	100	90	70
Brazing	100	100	90

TABLE 29-6 Average Performance Ratings of Some Oxyfuel Flames. Courtesy of BOC Gases.

is that both gases consume a large amount of oxygen. Propane requires 85% of the flame's oxygen from the cylinder, and natural gas requires 95% of its oxygen from the cylinder, compared with an oxygen consumption of as little as 50% for the oxyacetylene flame.

Hydrogen

Oxyhydrogen produces only a primary combustion flame, unlike hydrocarbon gases, which have both primary and secondary combustion. The hydrogen flame is almost colorless and can be seen only when dirt, dust, and other contaminants from the air glow while burning in the flame. Hydrogen is not widely used in welding because of its expense, its limited availability, and some myths about its safety.

Hydrogen has the fastest burning velocity of any of the fuel gases at 36 ft/s (10.9 m/s). Acetylene has a burn rate of less than one-half that of hydrogen. Hydrogen has a very slight tendency to backfire, yet it does not flashback. Unlike acetylene, which can explosively decompose without oxygen, hydrogen cannot be made to react without the presence of sufficient oxygen.

Hydrogen is much lighter than air. Therefore, when it is released, it diffuses quickly, reducing the possibility of accidental combustion. If a large quantity of hydrogen is allowed to burn uncontrolled, the gas rises into the flame. This means it burns in an upward direction, away from people in an area. Most other gases burn in a downward direction, which can trap people in an area. The chance of large quantities of hydrogen exploding is limited. For example, when the hydrogen-filled airship, the *Hindenburg*, caught fire and burned in 1931, no explosion occurred, and most of the people on board the airship survived.

The low-flame temperature restricts the use of the oxy-hydrogen flame to cutting, usually underwater, and to gas welding and brazing on low-temperature metals such as aluminum. The flame can be made reducing (needing oxygen) to help protect the aluminum from oxidation, without having excessive carbon to contaminate the weld. The finished flame product is water, H_2O. Only one-quarter of the flame oxygen comes from the cylinder.

Two major safety problems exist when hydrogen is used as a fuel gas. First, hydrogen has no smell, which makes it difficult to detect leaks. Second, the molecule is extremely small so that it leaks easily. When using hydrogen, an active leak-checking schedule must be followed to find small problems before they develop into disasters. It is possible for a leak to be on fire and not be noticed, because the hydrogen flame is almost invisible.

EXPERIMENT 29-2

Oxyfuel Flames

Using an identical torch set with each available fuel gas, you are going to observe the flame as each fuel gas is safely lit, adjusted, and extinguished.

Set all fuel and oxygen regulators at approximately 5 psig (35 kPag). Each torch should have the same-size tip. The tip should have an orifice equal to a number 53 to 60 drill. Place the torches on a table with the tips pointed up, **Figure 29-20**.

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

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

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

Summary

In many applications, such as home and farm work, the oxyacetylene welding process is by far the most desirable because of its flexibility, portability, and cost. These factors will keep this process in the forefront of welding for the foreseeable future.

The wide variety of fuel gases available for oxyfuel welding, cutting, and brazing has offered the welder some unique challenges in determining the most appropriate fuel gas for their processes. Although acetylene and oxygen are the most common, acetylene is not always the most appropriate gas for a number of reasons, primarily cost. When treated properly the waste product from acetylene production has little or no environmental impact, but such treatments can be expensive. This significantly increases the cost of acetylene and has made other fuel gases more desirable. Other fuel gases do not have all of the characteristics of acetylene. Each gas has unique advantages and disadvantages. You must look at the advantages and disadvantages of all the gases before selecting the fuel gas that will be most appropriate for your applications.

Filler metal selection for the oxyfuel welding processes used in a home hobby application is not often given much thought. In industrial applications the proper selection of an oxyfuel filler metal is critical to the success of your product.

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

Welding with the Right Shielding Gas

Quality and consistency are key to any quality assurance program. You must be confident your processes are consistent and repeatable and that the products being used in production meet specific requirements and specifications.

To maintain a stable, consistent welding process and ensure repeatable results, you should implement a welding specification (WPS). A WPS gives the welder or welding operator the recipe for producing acceptable welds on a given application, time after time. In developing a WPS for gas metal arc or gas tungsten arc welding, many variables must be taken into account, such as voltage, amperage, electrode extension, and shielding gas. These and other variables are called "essential variables" as defined in AWS D1.1, Structural Welding Code—Steel.

The Classification System

With respect to shielding gases, AWS D1.1 states that a procedure qualification record (PQR) requires requalification when there is "a change in shielding gas from a single gas to any other single gas or mixture of gases, or in the specified nominal percentage composition of a gas mixture, or to no gas." Therefore, it is essential that your shielding gas composition be accurate and consistent to ensure WPSs are being followed and the desired weld quality is maintained.

It is the responsibility of your gas supplier to ensure you receive an accurate, consistent shielding gas supply that conforms to AWS A5.32, Specification for Welding Shielding Gases. AWS A5.32 sets the standards for the classification of shielding gases, similar to the way AWS 5.18, Specification for Carbon Steel Electrodes and Rods for Gas Metal Arc Welding, prescribes a classification system for identifying carbon steel electrodes and rods.

The label on your gas cylinders should state whether your supplier is complying with the AWS specification on shielding gases.

In electronic and electrical applications, metals, ceramics, semiconductors, and metal matrix composites (MMCs) need to be joined. Research on active solders showed a capability to join this range of electronic materials, using essentially the same active soldering process used in other metal joining.

Active solders have been able to wet, join, and even metallurgically interact with various structural and conductor metals, including aluminum, copper, titanium, stainless steel, nickel alloys, magnesium alloys, and refractory metals.

Applications

The advantages and capabilities of active solder technology enable it to be considered for a wide range of applications. Active solder alloys can join many materials, including all metals, most ceramics, metal matrix composites, glasses, carbon (graphite/diamond), and ceramic.

Active solders provide metallic, thermally and electrically conductive joints that are tough but have sufficient ductility to effectively join many dissimilar material combinations. Its low-temperature joining, compared to brazing (for example, in joining aluminum alloys, metal-to-glass, or ceramic joints), offers advantages when joining mismatched materials.

Electronic Packaging

Electronic packages contain electronic devices and require material combinations that manage thermal and electrical conductivity while having low thermal expansion. Applications include satellite electronics, power devices, radiation shields, avionics, computers, microwave/radar, and power interconnections.

Typically, such packages use metallic materials for good thermal conductivity but then need to have electrically insulating materials joined to them.

Consumer Applications

Applications in the consumer market that involve the joining of aluminum, stainless steel, copper, and titanium range from cooking utensils to sports equipment. There is also an increased use of materials such as carbides and diamond. Pots and pans are fabricated from aluminum or copper due to the high thermal conductivity of these metals. Aluminum and/or copper joining to stainless steel has been done by brazing, but it is difficult because of the differing oxide films, which must be removed by chemical fluxes. Zinc-based active solders have the potential to meet such needs in housewares. Golf and tennis equipment increasingly use titanium that could benefit from soldering fabrication. Additionally, joints of dissimilar or composite materials are often required for new golf club designs, which incorporate carbides and even diamonds for club faces. High-density refractory metals such as tungsten have also been added to modify swing stability. Active solders have the potential, and are being considered for, such joining needs.

Art, photo, and article courtesy of the American Welding Society.

Review

1. Explain the difference between brazing and soldering.
2. How does capillary action separate brazing?
3. Why can brazing be both a permanent and a temporary joining method?
4. Why is it less likely that a semiskilled worker would damage a part with brazing than with welding?
5. What is the effect of joint spacing on joint tensile strength?
6. Why are braze joints subject to fatigue failure?
7. Do all braze joints resist corrosion? Give an example.
8. What are the three primary functions that a flux must perform?
9. In what forms are fluxes available?
10. How can liquid fluxes be delivered to the joint through the torch?
11. How do fluxes react with the base metal?
12. How are soldering and brazing methods grouped?
13. What are the advantages of torch soldering?
14. What are the advantages of furnace brazing?
15. How does the induction brazing method heat the part being brazed?
16. What soldering process can be used to join parts and provide a protective coating to the part at the same time?
17. What soldering or brazing process uses a machine similar to a spot welder to produce the heat required to make a joint?

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

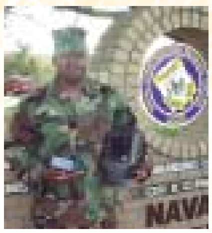
Success STORY

When award-winning Navy welder SW1 Moses E. Sampson, Jr., was deployed to Po-Hang, South Korea, to assist in building headquarters facilities, he faced plenty of challenges—a language barrier, unfamiliar equipment, and lots of welding outdoors in near-zero temperatures. "But our team worked together to overcome those challenges," says Sampson. Now his toughest welding assignment has turned into his biggest accomplishment—two troop-processing facilities in South Korea, ready for the United States to defend South Korea—or itself—against North Korea. "We hope the buildings never come into play, but if they do, we can feel proud that we contributed," says Sampson.

Thirteen years in the Navy as a steelworker has taught Sampson a lot about the importance of his welding jobs. From welding assignments all over Europe, Asia, the Middle East, and Central America, Sampson has seen first-hand how much quality, consistency, and teamwork matter, especially during Operations Desert Storm and Desert Shield. "Welding is not a dead-end job," explains Sampson. "It's important to somebody else's life."

As a high-school senior in Summerville, South Carolina, Sampson did not have that kind of focus. "The area I grew up in didn't have anything to offer as far as jobs, and I wanted to do some traveling and learn a trade," says Sampson. He joined the Navy when he graduated, at age seventeen.

But Sampson knew right off the bat that he did not like ships, so he researched all the skills the Navy taught and discovered that CB Units, the construction units that house the welders, fly to their assignments, stay for six months, and move on. "Plus welders make pretty good money after leaving the military," says Sampson. Learning to weld was tough but rewarding, and last year Sampson knew he had finally made his mark when he was selected to teach recruits. Some have outside welding experience; others are completely new to the trade, just as Sampson was.



"I think welding is exciting, and it's a privilege to teach," says Sampson. "When you're done, you have something you can see, something you've created with your own hands." And Sampson knows how hard it is to be a welding student trying to learn to be consistent. "Welding is nothing but patience and motivation," Sampson explains. "If you've got that drive, you can be a perfect welder—because practice makes perfect."

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.

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

About the Author

During my junior year of high school, I learned to weld in metal shop. There 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, and 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 sophomore year 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. I learned in SkillsUSA 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.

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

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

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

During my career as a welder, I have welded on tanks, pressure vessels, oil well drilling equipment, farm equipment, buildings, race cars, and more. As a vocational teacher, I have taught in high schools, schools for special education, schools for the deaf, and three colleges. I have also been a consultant to the welding industry.

Larry Jeffus is a recognized welding instructor with many years of experience teaching welding technology at the community college level. He has been actively involved in the American Welding Society, having served on the General Education Committee and as the chairman of the North Texas Section 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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