13TH EDITION

# MODERN WELDING


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Publisher
**The Goodheart-Willcox Company, Inc.**
Tinley Park, IL
www.g-w.com

Manufactured in the United States of America.

Library of Congress Catalog Card Number 2022944169

ISBN 978-1-68584-571-1

1 2 3 4 5 6 7 8 9 – 24 – 27 26 25 24 23 22



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# Preface

*Modern Welding* is an authoritative text written for use by students and teachers in secondary schools, colleges and universities, technical, and trade schools. It is also suitable for use by individuals who wish to learn independently about contemporary processes and techniques used in welding, as well as organizations training and upskilling their workforce.

*Modern Welding* provides you with an understanding of virtually all the welding and cutting processes used in production and repair today. This book covers the theory, fundamentals of operation, equipment used, and techniques recommended for all of the welding and cutting processes in commercial use.

The many tables and charts included in *Modern Welding* provide information regarding recommended settings for the variables involved in the various welding processes. These tables include the recommended amperage and voltage settings, wire feed rates, electrode sizes, inert gas selections, welding speeds, gas pressures, tip sizes, and much more.

General shop safety, safety attitudes, and specific welding shop safety practices are covered in Chapter 1. Safety information and cautions are also printed in bold, red type throughout the text, wherever they apply. Chapters 2 and 3 cover print reading and the interpretation of the American Welding Society welding symbols found on welding prints. Chapter 4 is an overview of welding and cutting processes that are covered in detail later in the book. The remainder of the text is divided into nine sections, each covering a different welding process or group of related welding processes. Chapter 33 covers the subject of getting and holding a job in the welding industry. Technical information that may be required while working in the welding industry is included in Chapter 34. An extensive Glossary of Welding Terms is provided at the end of the book.

*Modern Welding* may be studied in order from Chapter 1 to Chapter 34, or it may be used to study welding processes in any desired order. Each section stands alone and does not rely on previously acquired knowledge.

*Modern Welding* is extensively illustrated with full-color photographs, as well as drawings that have been color-coded to help you better understand each welding process and its equipment. Be sure to read all figure captions; they may contain details that are not included in the text.

Measurements are generally shown in dual form: US Customary followed by SI (metric). Welding terms throughout the text conform to the usage in the AWS Standard A3.0:2020, *Standard Welding Terms and Definitions*. Nonstandard or "trade" terms, when given, are clearly identified. The topics covered in *Modern Welding* are presented in a logical sequence designed to make learning and teaching the technology of welding easier and more effective.

**Kevin E. Bowditch**

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# About the Authors

**Kevin E. Bowditch** is a retired welding engineer specialist for Subaru of Indiana Automotive Inc., where he worked for 22 years. His experience includes working for two automotive firms, two aerospace firms, a construction company (building nuclear plants), and a precision sheet metal firm. His initial welding training was at the Hobart Institute of Welding Technology. He went on to earn his bachelor's degree in welding engineering from The Ohio State University, and has attended specialized conferences and courses sponsored by the AWS, ASME, and ANSI. While working for one aerospace firm, he designed resistance welding and soldering equipment and special equipment for custom applications, and he developed correct welding and soldering schedules for customers. At Subaru, he helped develop and validate welding parameters to make over one billion spot and arc welds per year. He taught a fundamentals skills course to hundreds of new associates coming into the body shop. In 1984, Kevin joined his father as a coauthor of *Modern Welding* and has guided this book through many revisions. Kevin has also been a coauthor of *Welding Fundamentals* since its first edition was published in 1991.

**Mark A. Bowditch** joined the Bowditch team of welding authors in 1998, when he co-authored *Oxyfuel Gas Welding*. Mark Bowditch's initial education came from his father William (Bill) Bowditch, who was a vocational education teacher, department head, supervisor, and administrator of special needs and vocational programs, many of which were welding courses. Mark's formal welding training was at the Hobart Institute of Welding Technology. He has more than 15 years of experience as an educator and holds bachelor's, master's, and doctoral degrees. In addition to preparing revisions of *Modern Welding*, he is a coauthor for the 2005 and later revisions of *Welding Fundamentals*. He also serves as an officer in the United States Air Force Reserve, assigned to Air Force Materiel Command at Wright Patterson Air Force Base.

# Reviewers


The authors and publisher wish to thank the following industry and teaching professionals for their valuable input into the development of *Modern Welding*:

**John G. Acosta**
WELDTECH
Peru, Vermont

**Gerald Austin**
Greene Technology Center
Greenville, Tennessee

**Ed Barr**
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**Russell Wahrman**
Wake Tech Community College
Raleigh, North Carolina

**Robert White**
Everett Community College
Snohomish, Washington

**Dennis Whysong**
Bedford County Technical Center
Everett, Pennsylvania

**Brian T. Yarrison**
York County School of Technology
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# Acknowledgments

The authors and publisher would like to thank the following companies, organizations, and individuals for their contribution of resource material, images, or other support in the development of *Modern Welding.*

3M Company – Personal Safety Division
ABB Robotics – U.S.
ACRO Automation Systems, Inc.
ALM Positioners, Inc.
The Aluminum Association
AMADA MIYACHI AMERICA, Inc.
American Iron and Steel Institute
American Torch Tip Company
American Welding Society
Aquasol Corporation
Arcsmith
Aubrey Bowditch
Bay-Tech Industries, Inc.
Belchfire Corp.
®Bernd Siegmund GmbH
Bessey Tools North America
Bethlehem Steel Corporation
Brendon Kirby
Brian Derby, EPIC Divers and Marine
Broco, Inc.
Bug-O Systems
BWE Ltd.
CenterLine (Windsor) Limited
Central Georgia Technical College
Cincinnati Incorporated
CK Worldwide, Inc.
CMW, Inc.
COB Industries Inc.
CONCOA
Cronatron Welding Systems, Inc.
Dennis Nance; CWI Consultants Co.
De-Sta-Co
Diamond Ground Products Inc.
Dow Chemical Co.
E.H. Wachs Company
Electrode Dressers, Inc.
Electron Beam Technologies, Inc.
Electron Microscopy Sciences
Electrovert
Emhart Teknologies
ESAB Welding and Cutting Products
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Greg Cain of Oxylance, Inc.
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Oceaneering International, Inc.
Olympus Scientific Solutions
The Ohio Nut and Bolt Co.
Parker Research Corp.
PEMAMEK Ltd.
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Pressed Steel Tank Co.
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Profiler, Inc.
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Raytheon Company
Reelcraft Industries, Inc.
Reiner Eggendorfer for Oxylance, Inc.
Resistance Welding Manufacturing Alliance
Rexarc International, Inc.
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Sensor Development, Inc.
Shore Instrument Company
SMC CORPORATION OF AMERICA
Sommer Metalcraft
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Suhner Industrial Products Corp.
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SuperFlash Compressed Gas Equipment/IBEDA
TAFA, Inc.
Taylor Winfield Technologies, Inc.
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Thermco Instrument Corp.
Tim Bowditch
Tinius Olsen Testing Machine Co., Inc.
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Vista Industrial Products, Inc.
Wachs Subsea LLC
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Wilton Tool Company
Worthington Cylinders
Yaskawa Motoman Robotics

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In addition to being correlated to the AWS SENSE I and II standards, *Modern Welding* is correlated to the Welding industry-based credential offered by NOCTI and to the Welding Technician, Entry; Welding Technician, Intermediate; and Welding Technician, Expert Standards offered by Precision Exams by YouScience.

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To see how *Modern Welding* correlates to credentialing and certification standards, visit the Correlations tab at www.g-w.com/modern-welding-2024.

# New to This Edition

This edition of *Modern Welding* includes updated content and coverage of welding topics in accordance with the latest technology and industry advancements. Many figures and tables have been evaluated and revised to present relevant information for the welding student, and those working in the industry, in a clear and straightforward way. In addition, new and vibrant figures showing a broad spectrum of welding equipment and applications have been added.

The learning objectives have been modified to reflect changes in AWS publications and carefully aligned with the content in the chapters. As safety during welding processes is paramount, Chapter 1 includes new details and assessment on safety precautions that are specific to the various welding processes. These safety precautions are also addressed in more detail within the chapters that cover these specific welding processes.

In addition, new details within the chapters provide an invaluable look at complex welding principles and processes from the welder's perspective. Chapter 6 provides step-by-step instruction on how to best prepare for and pass a structural welding qualification test. Chapters 6, 8, and 10 discuss how to adjust setting on a power supply from a welder's point of view. Chapter 11 provides exacting details on using plasma arc cutting for joint preparation prior to welding.

New and updated content in Chapter 20 discusses high-energy beam welding. There is also a wealth of new material in Chapter 21 on welding the various types of stainless steel, including information on carbide precipitation (sensitization) and how to prevent it. Chapter 26 introduces collaborative robots, or cobots, a robotic system designed to work with people to accomplish industry tasks. Finally, Chapter 34 features new material on practical measurements and conversions.



# Color Code

## How to Use the Key

Many of the drawings in *Modern Welding* are color coded for easy identification and to help students determine the function of the component. Travel angles are shown in red and work angles are shown in black to help differentiate between these important angles. In addition, colors are used to help show the flow of different gases and to indicate various materials or equipment features. The following key shows what each color represents.

**Gases**

- Oxygen — high-pressure; low-pressure
- Fuel gas — high-pressure; low-pressure
- Shielding gas (1) — high-pressure; low-pressure
- Shielding gas (2) — high-pressure; low-pressure
- Air — high-pressure; vacuum

**Weld**

- Base metal or plastic
- Molten metal or plastic
- Welding rod
- Weld bead or surfacing material
- Flame, arc, or plasma
- Electrode
- Flux
- Slag
- Fumes
- Direction or motion
- Welding machines/equipment
- Wires, leads, graph curves
- Water

**Other Materials**

- Special features, materials, or components not otherwise color-coded

# Features of the Textbook

The instructional design of Modern Welding includes student-focused learning tools to help you succeed. This visual guide highlights these features.

## Chapter Opening Materials

Each chapter opener contains an introduction and a list of learning objectives.

**Learning Objectives** clearly identify the knowledge and skills to be gained when the chapter is completed.

The **Introduction** provides an overview and preview of the chapter content.


CHAPTER 1

Safety in the Welding Shop

Learning Objectives

After studying this chapter, you will be able to:

- Identify common causes of accidents.
- Recognize health and safety hazards in the welding shop or other work environments and take appropriate measures to prevent accidents and injuries.
- Select and properly use safety equipment appropriate to working conditions, including the clothing items that should be worn during welding or cutting.
- Explain where to find information about welding on hazardous containers and disposing of hazardous waste legally and safely.
- Explain the purpose of a safety data sheet (SDS).
- Identify safety considerations unique to various welding processes including oxyfuel gas welding and cutting, arc welding and cutting, resistance welding, robotic welding, and other special welding processes.

Welding poses a wide range of safety and health risks to welders. Welding health hazards include exposure to toxic fumes and ultraviolet rays. Potential safety hazards, such as burns, eye damage, and electrical shock can arise from the use of powerful welding equipment. Careful training in proper work practices and the use of quality personal protective equipment (PPE) helps to reduce these dangers.

While many important safety procedures are outlined in this chapter, always read and comply with owner's manuals, safety labels on products, and all applicable safety standards. Before operating, installing, or servicing any tool or unit, consult and follow the directions in the owner's manual. Also, carefully read the safety data sheets for all metals and materials used.

Pro Tip

To ensure safety in a welding environment, every welder needs to read and understand *Safety in Welding, Cutting, and Allied Processes* (ANSI Z49.1) and keep a copy on hand.

1.1 Accidents

The *American Heritage Dictionary* defines ***accident*** as "an unexpected undesirable event." Many of the experts who study accidents and safe practices believe that some personal or physical factor is responsible in every accident. The following are some personal factors that may cause or contribute to accidents:

- **Stress.** People who are under stress may be distracted from their work by worry, anger, sorrow, love, or hate.
- **Illness.** When a person is ill, they may not be able to give all the attention necessary to a task.
- **Fatigue.** If a person does not get sufficient sleep, for whatever reason, they may be less alert to the requirements of the job.
- **Lack of job knowledge.** When a person is not sufficiently trained for the job or task and its safety hazards, accidents can more readily occur.
- **Age.** There are more accidental deaths at age 18 than at any other age. Wisdom and a concern for the results of personal actions normally increase with age. However, the age at which these changes take place varies considerably.

Part opener image: Hobart Brothers Co.

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## Additional Features

Additional features are used throughout the body of each chapter to further learning and knowledge.

**Pro Tips** provide advice and guidance that is especially applicable for on-the-job situations.

**Cautions** alert you to practices that could potentially damage equipment or instruments.

**Technical Terms** appear in ***bold/italic*** when introduced in the text.


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Caution

Store and handle SMAW electrodes carefully to protect the coating from damage or cracking.

Electrodes are sold in cardboard boxes, tubes, or metal cans, depending on the quantity purchased. Often there is a resealable plastic bag inside the container. The packaging identifies the electrode type and diameter and keeps the electrodes safe. The packaging should be resealed after each time electrodes are removed. Small quantities of electrodes are sold in resealable plastic bags. For most electrodes, keeping them in their original packaging is recommended.

Low-hydrogen electrodes are often stored in an oven, **Figure 5-26**. Electrode manufacturers may recommend a storage temperature, often 250°F to 300°F (120°C to 150°C), to keep the electrodes from absorbing moisture (hydrogen).

If low-hydrogen electrodes are exposed to the atmosphere for too long, they pick up hydrogen. Remove only the quantity of electrodes that can be used before the end of the exposure time limit from the oven. Different electrode types have different time limits for exposure. E7018 electrodes with the R designation can be removed from an oven for twice as long as low-hydrogen electrodes without the R designation.

Most low-hydrogen SMAW electrodes can be reconditioned if their exposure time limit is exceeded. ***Reconditioning*** involves placing the electrodes in an oven for a period of time at a temperature that is higher than that used for storage. For example, electrodes can be reconditioned by heating them at 575°F (300°C) for one hour. Always check with the manufacturer or the original packaging for reconditioning recommendations. Some electrodes have a limit of how many times they can be reconditioned.

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Figure 5-26. An electrode drying oven is used to remove moisture from the electrode covering before use.

Electrodes that are not properly stored and handled can produce poor-quality or defective welds. Poor quality and defects in welds include surface and internal porosity, underbead cracking, a rough surface, and slag that is hard to remove. These can lead to rework or scrap, which costs time and money.

5.10 Power Source Remote Controls

Welders work on a variety of joints and materials with varying metal thicknesses. They use different electrodes and weld in various positions. All these variables require changes in welding current. Often the welding machine is at a distance from where the welding is being done. The welder may be welding on a structure or pipeline and the machine is on a truck or support equipment.

Several manufacturers provide remote control devices, **Figure 5-27**, that may be kept near the operator for convenient control of the machine.

A Miller Electric Mfg. LLC

B Miller Electric Mfg. LLC

Figure 5-27. These devices allow a welder to adjust the welding amperage set on the power supply remotely. A—Wired remote amperage adjuster. B—Wireless remote amperage adjuster.

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**Notes** provide additional information about a particular topic covered in the chapter.

**Procedures** are highlighted throughout the textbook to provide clear instructions for hands-on service activities.

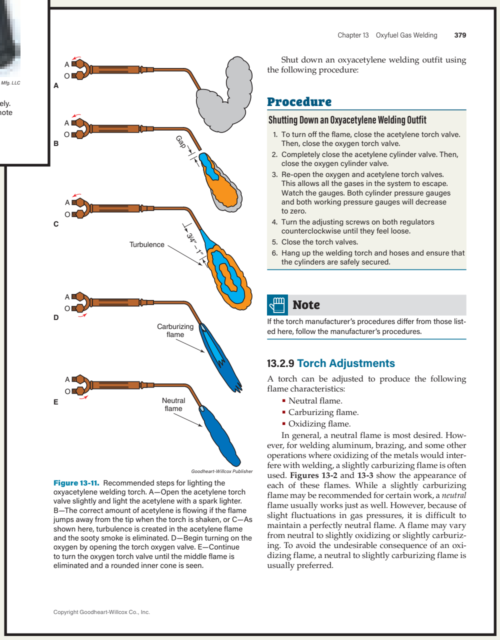
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Figure 13-11. Recommended steps for lighting the oxyacetylene welding torch. A—Open the acetylene torch valve slightly and light the acetylene with a spark lighter. B—The correct amount of acetylene is flowing if the flame jumps away from the tip when the torch is shaken, or C—As shown here, turbulence is created in the acetylene flame and the sooty smoke is eliminated. D—Begin turning on the oxygen by opening the torch oxygen valve. E—Continue to turn the oxygen torch valve until the middle flame is eliminated and a rounded inner cone is seen.

Shut down an oxyacetylene welding outfit using the following procedure:

Procedure

Shutting Down an Oxyacetylene Welding Outfit

1. To turn off the flame, close the acetylene torch valve. Then, close the oxygen torch valve.
2. Completely close the acetylene cylinder valve. Then, close the oxygen cylinder valve.
3. Re-open the oxygen and acetylene torch valves. This allows all the gases in the system to escape. Watch the gauges. Both cylinder pressure gauges and both working pressure gauges will decrease to zero.
4. Turn the adjusting screws on both regulators counterclockwise until they feel loose.
5. Close the torch valves.
6. Hang up the welding torch and hoses and ensure that the cylinders are safely secured.

Note

If the torch manufacturer's procedures differ from those listed here, follow the manufacturer's procedures.

13.2.9 Torch Adjustments

A torch can be adjusted to produce the following flame characteristics:

- Neutral flame.
- Carburizing flame.
- Oxidizing flame.

In general, a neutral flame is most desired. However, for welding aluminum, brazing, and some other operations where oxidizing of the metals would interfere with welding, a slightly carburizing flame is often used. **Figures 13-2** and **13-3** show the appearance of each of these flames. While a slightly carburizing flame may be recommended for certain work, a *neutral* flame usually works just as well. However, because of slight fluctuations in gas pressures, it is difficult to maintain a perfectly neutral flame. A flame may vary from neutral to slightly oxidizing or slightly carburizing. To avoid the undesirable consequence of an oxidizing flame, a neutral to slightly carburizing flame is usually preferred.

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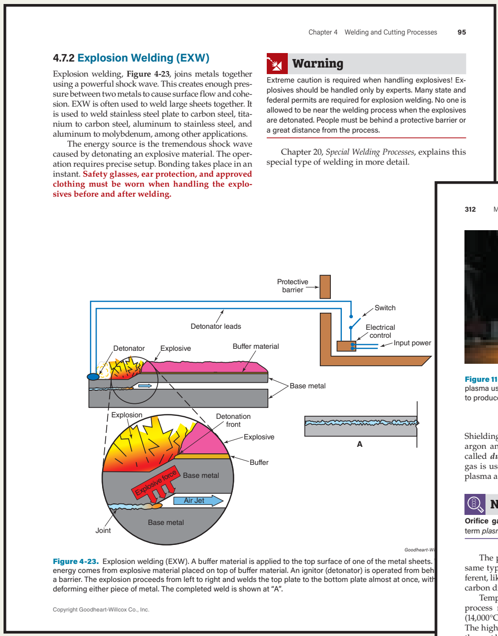


**Warnings** alert you to situations and actions that have the potential to cause bodily harm or death.

**Safety Notes** alert you to potentially dangerous materials and practices.

**Nonstandard Terminology** features provide alternate words for technical terms in the chapter.

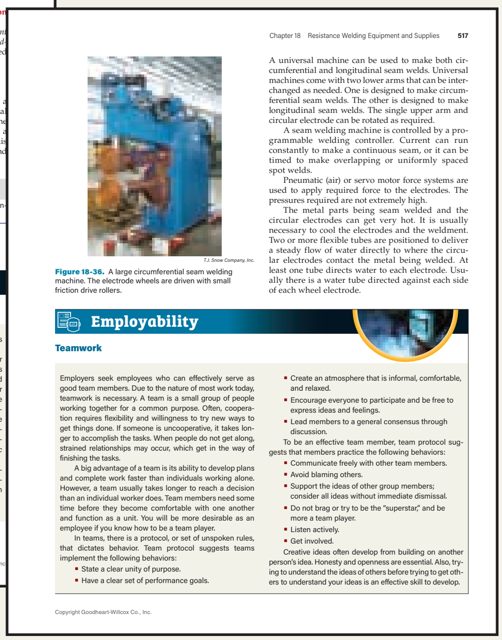
# Illustrations

**Illustrations** have been designed to clearly and simply communicate the specific topic. Illustrations have been completely replaced and updated for this edition.

**Photographic images** have been updated to show the latest equipment.

# Career Features

**Employability** features help you understand what you can anticipate and expect in the workplace. These features also present useful information for finding the job you want and developing the skills that you need to get there.



# End-of-Chapter Content

End-of-chapter material provides an opportunity for review and application of concepts.

A concise **Summary** provides an additional review tool and reinforces key learning objectives. This helps you focus on important concepts presented in the text.

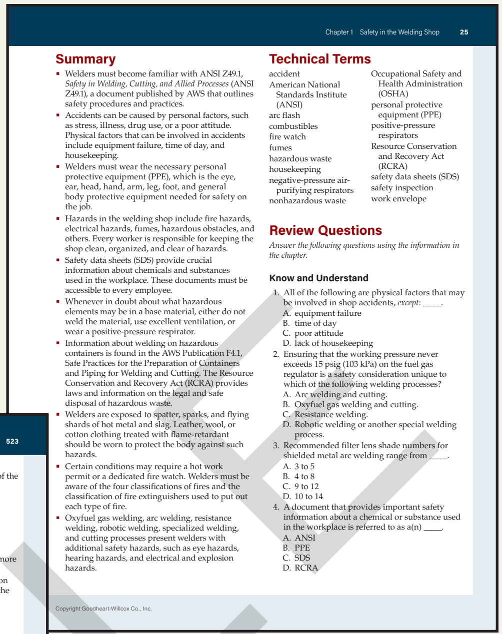
**Technical Terms** list the key words that were covered in the chapter.

**Know and Understand** questions enable you to demonstrate knowledge, identification, and comprehension of chapter material.

**Apply and Analyze** questions extend learning and develop your abilities to use learned material in new situations and to break down material into its component parts.

**Critical Thinking** questions develop higher-order thinking and problem solving, personal, and workplace skills.

**Experiment** questions extend your learning and help you apply knowledge.



Chapter 1 Safety in the Welding Shop 25

Summary

- Welders must become familiar with ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (ANSI Z49.1), a document published by AWS that outlines safety procedures and practices.
- Accidents can be caused by personal factors, such as stress, illness, drug use, or a poor attitude. Physical factors that can be involved in accidents include equipment failure, time of day, and housekeeping.
- Welders must wear the necessary personal protective equipment (PPE), which is the eye, ear, head, hand, arm, leg, foot, and general body protective equipment needed for safety on the job.
- Hazards in the welding shop include fire hazards, electrical hazards, fumes, hazardous obstacles, and others. Every worker is responsible for keeping the shop clean, organized, and clear of hazards.
- Safety data sheets (SDS) provide crucial information about chemicals and substances used in the workplace. These documents must be accessible to every employee.
- Whenever in doubt about what hazardous elements may be in a base material, either do not weld the material, use excellent ventilation, or wear a positive-pressure respirator.
- Information about welding on hazardous containers is found in the AWS Publication F4.1, Safe Practices for the Preparation of Containers and Piping for Welding and Cutting. The Resource Conservation and Recovery Act (RCRA) provides laws and information on the legal and safe disposal of hazardous waste.
- Welders are exposed to spatter, sparks, and flying shards of hot metal and slag. Leather, wool, or cotton clothing treated with flame-retardant should be worn to protect the body against such hazards.
- Certain conditions may require a hot work permit or a dedicated fire watch. Welders must be aware of the four classifications of fires and the classification of fire extinguishers used to put out each type of fire.
- Oxyfuel gas welding, arc welding, resistance welding, robotic welding, specialized welding, and cutting processes present welders with additional safety hazards, such as eye hazards, hearing hazards, and electrical and explosion hazards.

Technical Terms

accident
American National Standards Institute (ANSI)
arc flash
combustibles
fire watch
fumes
hazardous waste
housekeeping
negative-pressure air-purifying respirators
nonhazardous waste
Occupational Safety and Health Administration (OSHA)
personal protective equipment (PPE)
positive-pressure respirators
Resource Conservation and Recovery Act (RCRA)
safety data sheets (SDS)
safety inspection
work envelope

Review Questions

*Answer the following questions using the information in the chapter.*

Know and Understand

1. All of the following are physical factors that may be involved in shop accidents, *except:* _____.
   A. equipment failure
   B. time of day
   C. poor attitude
   D. lack of housekeeping
2. Ensuring that the working pressure never exceeds 15 psig (103 kPa) on the fuel gas regulator is a safety consideration unique to which of the following welding processes?
   A. Arc welding and cutting.
   B. Oxyfuel gas welding and cutting.
   C. Resistance welding.
   D. Robotic welding or another special welding process.
3. Recommended filter lens shade numbers for shielded metal arc welding range from _____.
   A. 3 to 5
   B. 4 to 8
   C. 9 to 12
   D. 10 to 14
4. A document that provides important safety information about a chemical or substance used in the workplace is referred to as a(n) _____.
   A. ANSI
   B. PPE
   C. SDS
   D. RCRA

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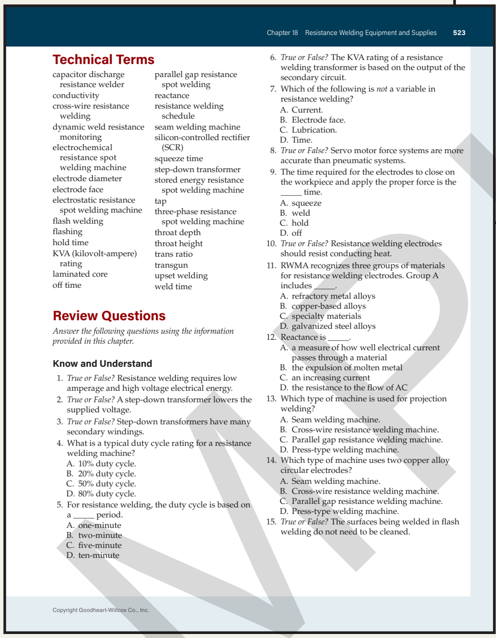

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Technical Terms

capacitor discharge resistance welder
conductivity
cross-wire resistance welding
dynamic weld resistance monitoring
electrochemical resistance spot welding machine
electrode diameter
electrode face
electrostatic resistance spot welding machine
flash welding
flashing
hold time
KVA (kilovolt-ampere) rating
laminated core
off time
parallel gap resistance spot welding
reactance
resistance welding schedule
seam welding machine
silicon-controlled rectifier (SCR)
squeeze time
step-down transformer
stored energy resistance spot welding machine
tap
three-phase resistance spot welding machine
throat depth
throat height
trans ratio
transgun
upset welding
weld time

Review Questions

*Answer the following questions using the information provided in this chapter.*

Know and Understand

1. *True or False?* Resistance welding requires low amperage and high voltage electrical energy.
2. *True or False?* A step-down transformer lowers the supplied voltage.
3. *True or False?* Step-down transformers have many secondary windings.
4. What is a typical duty cycle rating for a resistance welding machine?
   A. 10% duty cycle.
   B. 20% duty cycle.
   C. 50% duty cycle.
   D. 80% duty cycle.
5. For resistance welding, the duty cycle is based on a _____ period.
   A. one-minute
   B. two-minute
   C. five-minute
   D. ten-minute
6. *True or False?* The KVA rating of a resistance welding transformer is based on the output of the secondary circuit.
7. Which of the following is *not* a variable in resistance welding?
   A. Current.
   B. Electrode face.
   C. Lubrication.
   D. Time.
8. *True or False?* Servo motor force systems are more accurate than pneumatic systems.
9. The time required for the electrodes to close on the workpiece and apply the proper force is the _____ time.
   A. squeeze
   B. weld
   C. hold
   D. off
10. *True or False?* Resistance welding electrodes should resist conducting heat.
11. RWMA recognizes three groups of materials for resistance welding electrodes. Group A includes _____.
    A. refractory metal alloys
    B. copper-based alloys
    C. specialty materials
    D. galvanized steel alloys
12. Reactance is _____.
    A. a measure of how well electrical current passes through a material
    B. the expulsion of molten metal
    C. an increasing current
    D. the resistance to the flow of AC
13. Which type of machine is used for projection welding?
    A. Seam welding machine.
    B. Cross-wire resistance welding machine.
    C. Parallel gap resistance welding machine.
    D. Press-type welding machine.
14. Which type of machine uses two copper alloy circular electrodes?
    A. Seam welding machine.
    B. Cross-wire resistance welding machine.
    C. Parallel gap resistance welding machine.
    D. Press-type welding machine.
15. *True or False?* The surfaces being welded in flash welding do not need to be cleaned.

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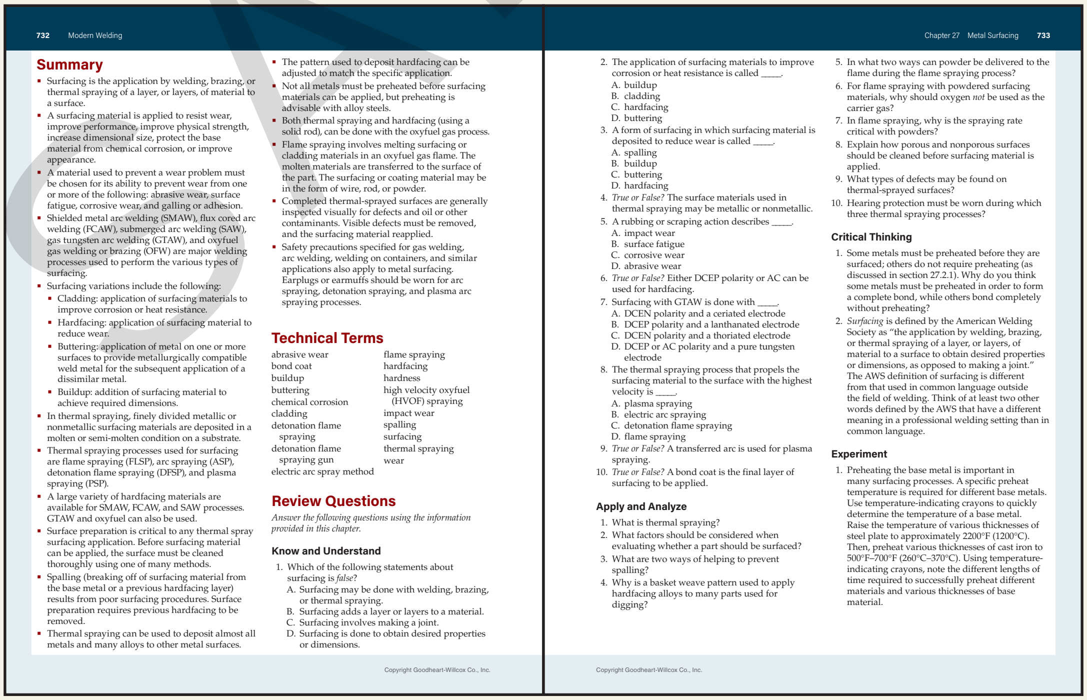

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Summary

- Surfacing is the application by welding, brazing, or thermal spraying of a layer, or layers, of material to a surface.
- A surfacing material is applied to resist wear, improve performance, improve physical strength, increase dimensional size, protect the base material from chemical corrosion, or improve appearance.
- A material used to prevent a wear problem must be chosen for its ability to prevent wear from one or more of the following: abrasive wear, surface fatigue, corrosive wear, and galling or adhesion.
- Shielded metal arc welding (SMAW), flux cored arc welding (FCAW), submerged arc welding (SAW), gas tungsten arc welding (GTAW), and oxyfuel gas welding or brazing (OFW) are major welding processes used to perform the various types of surfacing.
- Surfacing variations include the following:
  - Cladding: application of surfacing materials to improve corrosion or heat resistance.
  - Hardfacing: application of surfacing material to reduce wear.
  - Buttering: application of metal on one or more surfaces to provide metallurgically compatible weld metal for the subsequent application of a dissimilar metal.
  - Buildup: addition of surfacing material to achieve required dimensions.
- In thermal spraying, finely divided metallic or nonmetallic surfacing materials are deposited in a molten or semi-molten condition on a substrate.
- Thermal spraying processes used for surfacing are flame spraying (FLSP), arc spraying (ASP), detonation flame spraying (DFSP), and plasma spraying (PSP).
- A large variety of hardfacing materials are available for SMAW, FCAW, and SAW processes. GTAW and oxyfuel can also be used.
- Surface preparation is critical to any thermal spray surfacing application. Before surfacing material can be applied, the surface must be cleaned thoroughly using one of many methods.
- Spalling (breaking off of surfacing material from the base metal or a previous hardfacing layer) results from poor surfacing procedures. Surface preparation requires previous hardfacing to be removed.
- Thermal spraying can be used to deposit almost all metals and many alloys to other metal surfaces.
- The pattern used to deposit hardfacing can be adjusted to match the specific application.
- Not all metals must be preheated before surfacing materials can be applied, but preheating is advisable with alloy steels.
- Both thermal spraying and hardfacing (using a solid rod), can be done with the oxyfuel gas process.
- Flame spraying involves melting surfacing or cladding materials in an oxyfuel gas flame. The molten materials are transferred to the surface of the part. The surfacing or coating material may be in the form of wire, rod, or powder.
- Completed thermal-sprayed surfaces are generally inspected visually for defects and oil or other contaminants. Visible defects must be removed, and the surfacing material reapplied.
- Safety precautions specified for gas welding, arc welding, welding on containers, and similar applications also apply to metal surfacing. Earplugs or earmuffs should be worn for arc spraying, detonation spraying, and plasma arc spraying processes.

Technical Terms

abrasive wear
bond coat
buildup
buttering
chemical corrosion
cladding
detonation flame spraying
detonation flame spraying gun
electric arc spray method
flame spraying
hardfacing
hardness
high velocity oxyfuel (HVOF) spraying
impact wear
spalling
surfacing
thermal spraying
wear

Review Questions

*Answer the following questions using the information provided in this chapter.*

Know and Understand

1. Which of the following statements about surfacing is *false?*
   A. Surfacing may be done with welding, brazing, or thermal spraying.
   B. Surfacing adds a layer or layers to a material.
   C. Surfacing involves making a joint.
   D. Surfacing is done to obtain desired properties or dimensions.

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2. The application of surfacing materials to improve corrosion or heat resistance is called _____.
   A. buildup
   B. cladding
   C. hardfacing
   D. buttering
3. A form of surfacing in which surfacing material is deposited to reduce wear is called _____.
   A. spalling
   B. buildup
   C. buttering
   D. hardfacing
4. *True or False?* The surface materials used in thermal spraying may be metallic or nonmetallic.
5. A rubbing or scraping action describes _____.
   A. impact wear
   B. surface fatigue
   C. corrosive wear
   D. abrasive wear
6. *True or False?* Either DCEP polarity or AC can be used for hardfacing.
7. Surfacing with GTAW is done with _____.
   A. DCEN polarity and a ceriated electrode
   B. DCEP polarity and a lanthanated electrode
   C. DCEN polarity and a thoriated electrode
   D. DCEP or AC polarity and a pure tungsten electrode
8. The thermal spraying process that propels the surfacing material to the surface with the highest velocity is _____.
   A. plasma spraying
   B. electric arc spraying
   C. detonation flame spraying
   D. flame spraying
9. *True or False?* A transferred arc is used for plasma spraying.
10. *True or False?* A bond coat is the final layer of surfacing to be applied.

Apply and Analyze

1. What is thermal spraying?
2. What factors should be considered when evaluating whether a part should be surfaced?
3. What are two ways of helping to prevent spalling?
4. Why is a basket weave pattern used to apply hardfacing alloys to many parts used for digging?
5. In what two ways can powder be delivered to the flame during the flame spraying process?
6. For flame spraying with powdered surfacing materials, why should oxygen *not* be used as the carrier gas?
7. In flame spraying, why is the spraying rate critical with powders?
8. Explain how porous and nonporous surfaces should be cleaned before surfacing material is applied.
9. What types of defects may be found on thermal-sprayed surfaces?
10. Hearing protection must be worn during which three thermal spraying processes?

Critical Thinking

1. Some metals must be preheated before they are surfaced; others do not require preheating (as discussed in section 27.2.1). Why do you think some metals must be preheated in order to form a complete bond, while others bond completely without preheating?
2. *Surfacing* is defined by the American Welding Society as "the application by welding, brazing, or thermal spraying of a layer, or layers, of material to a surface to obtain desired properties or dimensions, as opposed to making a joint." The AWS definition of surfacing is different from that used in common language outside the field of welding. Think of at least two other words defined by the AWS that have a different meaning in a professional welding setting than in common language.

Experiment

1. Preheating the base metal is important in many surfacing processes. A specific preheat temperature is required for different base metals. Use temperature-indicating crayons to quickly determine the temperature of a base metal. Raise the temperature of various thicknesses of steel plate to approximately 2200°F (1200°C). Then, preheat various thicknesses of cast iron to 500°F–700°F (260°C–370°C). Using temperature-indicating crayons, note the different lengths of time required to successfully preheat different materials and various thicknesses of base material.

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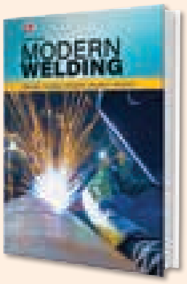


*Modern Welding* is a comprehensive text that provides curriculum support for academic and professional welding programs. The textbook is an exciting, full-color, and highly illustrated learning resource. It is available in print and online versions.

### Lab Workbook

- Activities and review questions that relate to the content of the textbook chapters. Questions designed to reinforce the textbook content help students review their understanding of the terms, concepts, theories, and procedures presented in each chapter.
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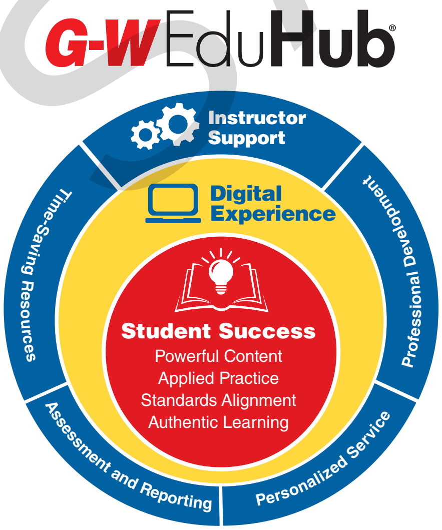


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