

EIGHTH EDITION

Welding

Principles and Applications



Larry Jeffus

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Larry Jeffus



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Contents

Preface	xvi	Chapter 2 Safety in Welding	21
Features of the Text	xix	Objectives	21
Acknowledgments	xxi	Key Terms	21
About the Author	xxiii	Introduction	21
Index of Experiments and Practices	xxv	Burn Classification	22
		First-Degree Burns	22
		Second-Degree Burns	22
		Third-Degree Burns	22
		Burns Caused by Light	23
		Personal Protection Equipment (PPE)	24
		General Work Clothing	24
		Special Protective Clothing	25
		Face and Eye Protection	27
		Goggles	27
		Full Face Shield	27
		Welding Helmets	27
		Auto Darkening Welding Helmets	28
		Shop Noise	28
		Respiratory Protection	29
		Ventilation	31
		Safety Data Sheets (SDSs)	32
		Handling and Storing Cylinders	32
		Securing Gas Cylinders	33
		Storage Areas	33
		Cylinders with Valve Protection Caps	33
		General Precautions	33
		Acetylene	34
		Fire Protection	34
		Fire Watch	34
		Fire Extinguishers	34
		Location of Fire Extinguishers	35
		Using Fire Extinguishers	35
		Equipment Maintenance	36
		Hoses	36
		Work Area Cleaning	36
		Hand Tools	37
		Hand Tool Safety	37
		Hammer Safety	38
		Electrical Safety	38
		Electrical Safety Systems	40
		Voltage Warnings	40
		Extension Cords	41
		Safety Rules for Portable Electric Tools	42
		Power Tools	42
		Grinders	42
		Drills	43
		Metal Cutting Machines	44
		Material Handling	45
		Lifting	45
SECTION 1 Introduction	01		
Chapter 1 Introduction to Welding	03		
Objectives	3		
Key Terms	3		
Introduction	3		
Welding Terminology	5		
Welding Defined	5		
Uses of Welding	5		
Welding and Cutting Processes	7		
Welding Processes	7		
Oxyacetylene Welding, Brazing, and Cutting	7		
Shielded Metal Arc Welding (SMAW)	7		
Gas Tungsten Arc Welding (GTAW)	7		
Gas Metal Arc Welding (GMAW)	9		
Flux Cored Arc Welding (FCAW)	10		
Thermal Cutting Processes	10		
Oxyfuel Gas Cutting	10		
Plasma Arc Cutting	10		
Selection of the Joining Process	11		
Occupational Opportunities in Welding	12		
Training for Welding Occupations	13		
Job-Related Skills	14		
Beginning a Welding Career	14		
Job Prospects	14		
AWS SENSE Welder Certification	14		
Level I Qualification Procedures	15		
Practical Knowledge Qualification—			
Written Test	15		
Performance Qualification—			
Workmanship Samples and Test Plates	15		
Thermal Cutting Principles and Practices	15		
Welding Inspection and Testing Principles			
and Practices	16		
Level II Advanced Welder Qualification	16		
SkillsUSA	16		
Experiments and Practices	16		
Welding Video Series	17		
Metric Units	17		
Summary	19		
Review	19		

Hoists or Cranes	45
Ladder Safety	45
Types of Ladders	45
Ladder Inspection	45
Rules for Ladder Use	46
Summary	47
Review	47

SECTION 2 Shielded Metal Arc Welding 49

Chapter 3 Shielded Metal Arc Equipment, Setup, and Operation 51

Objectives	51
Key Terms	51
Introduction	52
Welding Current	52
Electrical Measurement	52
Temperature and Heat	52
SMA Welding Arc Temperature	53
SMA Welding Arc Heat	54
Types of Welding Currents	54
Types of Welding Power	
Supplies (Machines)	55
Open Circuit Voltage	55
Operating Voltage	56
Arc Blow	56
Types of Power Sources	57
Movable Coil or Core	60
Inverter	61
Generator-Type and Alternator-Type Welders	62
Routine Maintenance	63
Converting AC to DC	63
Duty Cycle	64
Welder Accessories	64
Welding Cables	64
Electrode Holders	66
Work Clamps	66
Equipment Setup	67
Summary	68
Review	68

Chapter 4 Shielded Metal Arc Welding of Plate 69

Objectives	69
Key Terms	69
Introduction	70
Effect of Current Settings that Are Too Low or Too High	72
Too Low of a Current Setting	72
Too High of a Current Setting	72
Experiments	73
Electrode Size and Heat	73
Arc Length	74

Travel Angle, Electrode Angle and Work Angle	75
Leading Angle	75
Perpendicular Angle	76
Trailing Angle	76
Electrode Manipulation	76
Positioning of the Welder and the Plate	79
Practice Welds	80
Electrodes	80
F3 E6010 and E6011 Electrodes	80
F2 E6012 and E6013 Electrodes	80
F4 E7016 and E7018 Electrodes	80
Electrode Selection	80
Stringer Beads	81
Square Butt Joint	83
Edge Weld	87
Outside Corner Joint	91
Lap Joint	94
Tee Joint	97
Summary	100
Review	100

Chapter 5 Shielded Metal Arc Welding of Pipe 101

Objectives	101
Key Terms	101
Introduction	101
Pipe and Tubing	103
Pipe Specifications	103
Tubing Specifications	103
Pipe Applications	104
Tubing Applications	104
Advantages of Welded Pipe	104
Strength	104
Less Maintenance Required	104
Longer Lasting	106
Smoother Flow	106
Lighter Weight	106
Preparation and Fit-up	106
Practice Welds	108
Weld Standards	109
Weld Passes	109
Root Weld Pass	109
Hot Weld Pass	110
Filler Weld Pass	110
Cover Weld Pass	111
1G Horizontal Rolled Position	111
AWS SENSE Certification Test 1G	116
2G Vertical Fixed Position	116
AWS SENSE Certification Test 1G	117
5G Horizontal Fixed Position	117
AWS SENSE Certification Test 5G	119
6G 45° Inclined Position	119
AWS SENSE Certification Test 6G	120
Summary	121
Review	121

Chapter 6 Shielded Metal Arc Welding AWS**SENSE Certification 122**

Objectives	122
Key Terms	122
Introduction	122
Root Pass	123
Hot Pass	127
Filler Pass	129
Cover Pass	130
Plate Preparation	130
Restarting a Weld Bead	133
Preheating and Postheating	133
AWS Workmanship Standard for Preparation of Base Metal	134
AWS Visual Inspection Criteria	135
Preparing Specimens for Bend Testing	135
WS Specimen Preparation Criteria Preparation	135
Testing	135
AWS Acceptance Criteria for Bend Test	137
Poor Fit-Up	146
Summary	147
Review	147

SECTION 3 Cutting and Gouging 149**Chapter 7 Flame Cutting 151**

Objectives	151
Key Terms	151
Introduction	152
Metals Cut by the Oxyfuel Process	152
The Chemistry of a Cut	152
Eye Protection for Flame Cutting	152
Cutting Torches	153
Cutting Tips	154
Pressure Regulators	160
Regulator Operation	160
Regulator Gauges	161
Regulator Safety Pressure Release Device	161
Cylinder and Regulator Fittings	161
Regulator Safety Precautions	163
Regulator Care and Use	164
Backfires	165
Flashbacks	165
Reverse Flow and Flashback Valves	165
Care of the Reverse Flow Valve and Flashback Arrestor	167
Hoses and Fittings	167
Hose Care and Use	167
Leak Detection	168
Oxyfuel Cutting, Setup, and Operation	168
Torch Tip Care and Use	168
Hand Cutting	171

Layout	174
Selecting the Correct Tip and Setting the Pressure	175
The Physics of a Cut	177
Slag	178
Plate Cutting	180
Cutting Table	180
Torch Guides	180
Distortion	182
Cutting Applications	183
Pipe Cutting	184
Summary	188
Review	188

Chapter 8 Plasma Arc Cutting 190

Objectives	190
Key Terms	190
Introduction	190
Plasma	191
Arc Plasma	192
Plasma Torch	192
Torch Body	192
Torch Head	192
Power Switch	193
Torch Parts Commonly Serviced	193
Hoses and Power Cables	195
Gas Hoses	195
Power Cable	197
Coolant System	197
Coolant	197
Coolant Hoses	197
Control Wire	198
Compressed Air	198
Power Requirements	199
Voltage	199
Amperage	199
Watts	199
Heat Input	199
Distortion	199
Applications	200
Cutting Speed	200
Metals	200
Torch Standoff Distance	201
Starting Methods	202
Kerf	203
Gases	205
Stack Cutting	206
Dross	206
Machine Cutting	206
Water Tables	207
Manual Cutting	207
Setup	208
Safety	209
Straight Cuts	209
Piercing	211
Plasma Arc Gouging	213
Cutting Round Stock	215

Beveling Pipe	216	Axial Spray Metal Transfer	243
Summary	217	Pulsed-Arc Metal Transfer	245
Review	217	Pulsed-Arc Metal Transfer	
		Current Cycle	246
Chapter 9 Related Cutting Processes	219	Modulated Current	
Objectives	219	Metal Transfer	248
Key Terms	219	The Modulated Current Process	248
Introduction	219	Advantages of Modulated Current and Pulsed-Arc	
Laser Beam Cutting (LBC) and Laser Beam		Metal Transfer	248
Drilling (LBD)	220	Buried-Arc Transfer	250
Lasers	220	GMAW Filler Metal Specifications	250
Laser Types	221	Wire Melting and Deposition Rates	251
Solid State Lasers	221	Welding Power Supplies	251
Gas Laser	222	GMA Welding Machines	251
Applications	222	Speed of the Wire Electrode	252
Laser Beam Cutting	222	Power Supplies for Short-Circuiting Transfer	252
Laser Beam Drilling	223	Shielding Gas	253
Laser Beam Welding	223	Argon	254
Hybrid Laser Process	224	Argon Gas Blends	254
Laser Beam Welding with Gas Metal		Helium	255
Arc Welding	224	Carbon Dioxide	255
Laser Beam with Gas Metal Arc Welding		Nitrogen	255
Surfacing	224	Power Settings	255
Laser Beam Welding with Gas Tungsten		Weave Pattern	256
Arc Welding	224	Travel Speed	256
Laser Equipment	225	Electrode Extension	256
Air Carbon Arc Cutting (CAC-A)	225	Gun Angle	256
Manual Torch Design	226	Forehand/Perpendicular/Backhand Welding	257
Electrodes	226	Metal Core Electrodes for GMA Welding	258
Power Sources	227	Equipment	259
Air Supply	227	Power Source	260
Application	228	Electrode (Wire) Feed Unit	260
Safety	228	Electrode Conduit	262
U-Grooves	229	Welding Gun	263
Oxygen Lance Cutting	232	GMA Spot Welding	264
Applications	233	Summary	266
Safety	233	Review	266
Water Jet Cutting	233		
Applications	233	Chapter 11 Gas Metal Arc Welding	267
Arc Cutting Electrodes	233	Objectives	267
Applications	235	Key Terms	267
Summary	235	Introduction	267
Review	235	Setup	268
		Wire-Feed Speed	271
SECTION 4 Gas Shielded Welding	237	Gas Density and Flow Rates	274
		Arc-Voltage and Amperage Characteristics	275
Chapter 10 Gas Metal Arc Welding	239	Electrode Extension	277
Equipment, Setup, and Operation	239	Welding Gun Angle	278
Objectives	239	Effect of Shielding Gas on Welding	279
Key Terms	239	Practices	281
Introduction	240	Metal Preparation	282
Weld Metal Transfer Methods	242	Flat Position, 1G and 1F Positions	283
Short-Circuiting Transfer GMAW-S	242	Vertical Up 3G and 3F Positions	287
Globular Transfer	243	Vertical Down 3G and 3F Positions	288
		Horizontal 2G and 2F Positions	289
		Overhead 4G and 4F Positions	290

Globular Metal Transfer, 1G Position	293	V-Groove and Bevel-Groove Welds	327
Axial Spray	296	Root Pass	328
Summary	297	Filler Pass	329
Review	297	Cover Pass	329
Chapter 12 Flux Cored Arc Welding		Fillet Welds	330
Equipment, Setup, and Operation	298	Vertical Welds	333
Objectives	298	Horizontal Welds	336
Key Terms	298	Overhead-Position Welds	340
Introduction	299	Thin-Gauge Welding	341
Principles of Operation	301	Plug Welds	344
Flux Core	301	Summary	346
Gas Formers	302	Review	346
Slag	302	Chapter 14 Gas Metal Arc and Flux	
Equipment	302	Cored Arc Welding of Pipe	348
Power Supply	302	Objectives	348
FCA Welding Guns	302	Key Terms	348
Electrode Feed	303	Introduction	348
Advantages	303	Joint Preparation	349
Limitations	304	End Preparation	349
FCAW Electrodes	304	Joint Fitup	349
Electrode Cast and Helix	306	Tack Welds	349
FCA Welding Electrode Flux	306	Root Pass	349
Types of FCAW Fluxes	308	Hot Pass	350
Flux Cored Steel Electrode Identification	309	Filler Pass	350
Mild Steel	309	Cover Pass(es)	351
Stainless Steel Electrodes	309	Visual Inspection	351
Metal Cored Steel Electrode Identification	309	Practice Pipe Welds	351
Care of Flux Core Electrodes	311	Pipe to Plate Welds	351
Shielding Gas	311	Tack Welds	355
Welding Techniques	312	Root Pass	355
Gun Angle	312	Hot Pass	355
Forehand/Perpendicular/Backhand Techniques	313	Filler Pass(es)	355
Advantages of the Forehand Technique	313	Cover Pass	356
Disadvantages of the Forehand Technique	314	Summary	359
Advantages of the Perpendicular Technique	314	Review	359
Disadvantages of the Perpendicular Technique	314	Chapter 15 Gas Metal Arc and Flux Cored	
Advantages of the Backhand Technique	314	Arc Welding AWS SENSE Certification	360
Disadvantages of the Backhand Technique	314	Objectives	360
Travel Speed	314	Key Terms	360
Mode of Metal Transfer	315	Introduction	360
Spray Transfer—FCAW-G	315	Practice Welds	360
Globular Transfer—FCAW-G	315	Metal Preparation	361
Electrode Extension	316	Practice Weld Equipment and Consumables	361
Porosity	316	Summary	388
Troubleshooting FCA Welding	317	Review	388
Summary	318	Chapter 16 Gas Tungsten Arc Welding	
Review	319	Equipment, Setup, Operation,	
Chapter 13 Flux Cored Arc Welding	320	and Filler Metals	389
Objectives	320	Objectives	389
Key Terms	320	Key Terms	389
Introduction	320	Introduction	390
Practices	321		
Flat-Position Welds	324		
Square-Groove Welds	326		

Tungsten	390
High Temperature	390
Good Conductor	390
Tungsten Erosion	390
Tungsten Electrode End Shape	392
Types of Tungsten Electrodes	392
Pure Tungsten, EWP	393
Thoriated Tungsten, EWTh-1 and EWTh-2	393
Zirconium Tungsten, EWZr-1	393
Cerium Tungsten, EWCe-2	393
Lanthanum Tungsten, EWLa-1.5	394
Rare Earth Tungsten, EWG	394
Shaping the Tungsten	394
Precision Machine Tungsten Grinder	394
Hand Grinding	394
Breaking and Remelting	395
Chemical Cleaning and Pointing	396
Pointing and Remelting	397
GTA Welding Equipment	397
Torches	398
Hoses	399
Nozzles	400
Gas Lens	401
Flowmeter	401
Types of Welding Current	402
DCEN	402
DCEP	402
AC	402
Electronic Controls of AC Welding Currents	404
EP and EN Time Control	405
Sine Wave Form Control	405
Frequency Control	405
Shielding Gases	406
Argon	406
Helium	406
Hydrogen	407
Nitrogen	407
Hot Start	407
Preflow	407
Postflow	408
Shielding Gas Flow Rate	408
Remote Controls	409
Summary	412
Review	413

Chapter 17 Gas Tungsten Arc Welding of Plate 414

Objectives	414
Key Terms	414
Introduction	415
Torch Angle	415
Filler Rod Manipulation	416
Tungsten Contamination	417
Current Setting	417
Experiments	418
Gas Flow	419

Practice Welds	420
Low Carbon and Mild Steels	420
Stainless Steel	421
Aluminum	422
Metal Preparation	422
Summary	439
Review	440

Chapter 18 Gas Tungsten Arc Welding of Pipe 441

Objectives	441
Key Terms	441
Introduction	441
Practices	442
Joint Preparation	442
V-Groove	442
Joint Cleaning	442
Root	443
Incomplete Fusion	444
Concave Root Surface	445
Excessive Root Reinforcement	445
Root Contamination	445
Backing Gas	446
Purging	446
Filler Metal	447
Consumable Inserts	447
Cup Walking	449
Cup Walking Setup	449
Cup Walking Technique	450
Practice Welds	450
Hot Pass	453
Root Surface	453
Lack of Root Fusion	454
Filler Pass	457
Cover Pass	458
Summary	461
Review	461

Chapter 19 Gas Tungsten Arc Welding Plate and Pipe AWS SENSE Certification 463

Objectives	463
Key Terms	463
Introduction	463
GTA Sheet Welds	463
GTA Tubing Welds	464
AWS SENSE GTA Sheet Practice Welds	464
Weld Inspection and Testing	464
Butt Joint Welds	464
Fillet Welds, Lap and Tee Joints	464
Tubing Welds	466
Mechanical, Destructive Testing	466
Filler Metal	466
Sheet Metal Practice Welds	467
Tubing and Pipe Practice Welds	479
Summary	484
Review	485

SECTION 5 Related Technologies 487**Chapter 20 Shop Math and Weld Cost 489**

Objectives	489
Key Terms	489
Introduction	489
Shop Math	490
Types of Numbers	490
Whole Numbers	490
Decimal Fractions	490
Mixed Units	490
Fractions	490
General Math Rules	491
Letters, Numbers, and Symbols	492
Superscript and Subscripts	492
Equations and Formulas	492
Equations	492
Formulas	492
Mixed Units	493
Adding and Subtracting Mixed Units	493
Fractions	495
Finding the Fraction's Common Denominator	495
Reducing Fractions	496
Multiplying and Dividing Fractions	496
Converting Numbers	497
Converting Fractions to Decimals	497
Tolerances	497
Converting Decimals to Fractions	497
Conversion Charts	498
Angles	498
Adding and Subtracting Angles	499
Triangles	499
Right Triangle	499
Equilateral Triangle	500
Isosceles Triangle	500
Perimeter	501
Area	501
Volume	501
Measuring	502
Welding Costs	503
Cost Estimation	503
Joint Design	504
Groove Welds	505
Fillet Welds	506
Weld Metal Cost	506
Cost of Electrodes, Wires, Gases, and Flux	507
Deposition Efficiency	507
Deposition Rate	508
Deposition Data Tables	508
Coated Electrodes	509
Efficiency of Flux Cored Wires	510
Efficiency of Solid Wire for GMAW	510
Efficiency of Solid Wires for SAW	511
Operating Factor	511
Labor and Overhead	514
Cost of Power	514

Other Useful Formulas	514
Bill of Materials	515
Invoice	516
Summary	517
Review	518

Chapter 21 Reading Technical**Drawings 520**

Objectives	520
Key Terms	521
Introduction	521
Mechanical Drawings	521
Lines	523
Types of Drawings	523
Pictorial Drawings	523
Mechanical Drawings	524
Special Views	524
Dimensioning	525
Drawing Scale	527
Reading Mechanical Drawings	528
Sketching	528
Erasers and Erasing	532
Graph Paper	535
Computers and Drawings	538
Summary	541
Review	541

Chapter 22 Welding Joint Design and Welding Symbols 542

Objectives	542
Key Terms	542
Introduction	542
Weld Joint Design	543
Weld Joint Stresses	544
Welding Process	545
Edge Preparation	545
Joint Dimensions	545
Metal Thickness	545
Metal Type	547
Welding Position	547
Plate Welding Positions	548
Pipe Welding Positions	548
Code or Standards Requirements	548
Welder Skill	549
Acceptable Cost	549
Welding Symbols	549
Indicating Types of Welds	550
Weld Location	551
Location Significance of Arrow	551
Fillet Welds	552
Plug Welds	552
Spot Welds	553
Seam Welds	553
Groove Welds	553
Backing	556
Flanged Welds	557

Nondestructive Testing Symbols	557	Incomplete Fusion	606
Summary	560	Arc Strikes	607
Review	560	Overlap	607
Chapter 23 Fabricating Techniques and Practices	561	Undercut	608
Objectives	561	Crater Cracks	608
Key Terms	561	Underfill	609
Introduction	561	Plate-Generated Problems	609
Fabrication	562	Lamination	609
Safety	562	Delamination	609
Parts and Pieces	563	Lamellar Tears	610
Preformed	563	Destructive Testing (DT)	610
Custom Fabrication	563	Tensile Testing	610
Layout	564	Fatigue Testing	612
Nesting	569	Shearing Strength Test	612
Kerf Space	570	Welded Butt Joints	612
Material Shapes	573	Nick-Break Test	612
Bill of Materials Form	574	Guided-Bend Test	612
Overall Tolerance	575	Free-Bend Test	616
Assembly	576	Alternate Bend	616
Overall Dimensions and Thick Materials	578	Fillet Weld Break Test	616
Part Identification	578	Testing by Etching	617
Assembly Tools	578	Impact Testing	618
Fitting	581	Nondestructive Testing (NDT)	619
Tack Welds	582	Visual Inspection (VT)	619
Welding	584	Penetrant Inspection (PT)	619
Arc Strikes	584	Magnetic Particle Inspection (MT)	619
Finishing	585	Radiographic Inspection	621
Summary	585	Ultrasonic Inspection	621
Review	586	Leak Checking	625
Chapter 24 Welding Codes and Standards	587	Eddy Current Inspection (ET)	625
Objectives	587	Hardness Testing	626
Key Terms	587	Summary	627
Introduction	587	Review	627
Codes, Standards, Procedures, and Specifications	588	Chapter 26 Welding Metallurgy	629
Welding Procedure Qualification	588	Objectives	629
Welding Procedure		Key Terms	629
Specification (WPS)	588	Introduction	629
Qualifying the Welding Procedure Specification	588	Heat, Temperature, and Energy	630
Qualifying and Certifying	589	Heat	630
General Information	589	Temperature	631
Summary	600	Production of Metals	632
Review	601	Steel Making	632
Chapter 25 Testing and Inspection	602	Iron Ore	632
Objectives	602	Ingot Casting	633
Key Terms	602	Continuous Casting	633
Introduction	602	Metal Forming	633
Quality Control (QC)	603	Grain Structure	634
Discontinuities and Defects	603	Mechanical Properties	634
Porosity	603	Hardness	634
Inclusions	605	Brittleness	635
Inadequate Joint Penetration	606	Ductility	635
		Toughness	635
		Strength	635
		Other Mechanical Properties	636
		Structure of Solid Matter	636
		Crystalline Structures of Metal	637

Phase Diagrams	638	Martensitic Stainless Steel	667
Lead-Tin Phase Diagram	638	Chromium-Molybdenum Steel	668
Iron-Carbon Phase Diagram	639	Cast Iron	668
Strengthening Mechanisms	642	Preweld and Postweld Heating of Cast Iron	669
Solid-Solution Hardening	642	Practice Welding Cast Iron	670
Precipitation Hardening	643	Welding without Preheating or Postheating	671
Mechanical Mixtures of Phases	643	Nonferrous Metals	673
Quench, Temper, and Anneal	644	Copper and Copper Alloys	673
Quenching	644	Aluminum Weldability	673
Martensitic Reactions	645	Titanium	674
Cold Work	648	Magnesium	674
Grain Size Control	648	Repair Welding	674
Heat Treatments Associated with Welding	648	Summary	677
Preheat	648	Review	678
Stress Relief, Process Annealing	649		
Annealing	650	Chapter 28 Filler Metal Selection	679
Normalizing	650	Objectives	679
Time-Temperature-Transformation (TTT) Diagrams	650	Key Terms	679
Martensite	650	Introduction	679
Bainite	651	Manufacturers' Electrode Information	680
Pearlite	651	Understanding the Electrode Data	680
TTT Diagrams	651	Data Resulting from Mechanical Tests	680
Thermal Effects Caused		Data Resulting from Chemical Analysis	680
by Arc Welding	652	Carbon Equivalent (CE)	681
Heat-Affected Zone (HAZ)	652	SMAW Operating Information	681
Gases in Welding	654	Core Wire	682
Nitrogen	655	Functions of the Flux Covering	682
Oxygen	655	Filler Metal Selection	683
Carbon Dioxide	655	Shielded Metal Arc Welding Electrode Selection	683
Hydrogen	655	AWS Filler Metal Classifications	686
Metallurgical Defects	656	Carbon Steel	686
Cold Cracking	656	Carbon and Low-Alloy Steel-Covered Electrodes	686
Hot Cracking	656	Wire-Type Steel Filler Metals	690
Carbide Precipitation	657	Solid Wire	690
Summary	658	Tubular Wire	690
Review	658	Metal Cored Arc Welding	
		Electrodes	692
Chapter 27 Weldability of Metals	660	Stainless Steel Electrodes	692
Objectives	660	Nonferrous Electrodes	692
Key Terms	660	Aluminum and Aluminum Alloys	695
Introduction	660	Aluminum-Covered Arc Welding Electrodes	695
Weldability	660	Aluminum Bare Welding Rods and Electrodes	696
Thermal Cycling	661	Special-Purpose Filler Metals	696
Steel Classification and Identification	663	Surface and Buildup Electrode Classification	696
SAE Classification Systems	663	Magnesium Alloys	696
AISI Classification Systems	663	Hydrogen Embrittlement	696
Unified Numbering System (UNS)	663	Summary	697
Carbon and Alloy Steels	663	Review	697
Low-Carbon, Also Called Mild, Steel	663		
Medium-Carbon Steel	665	Chapter 29 Welding Automation	699
High-Carbon Steel	665	and Robotics	
Tool Steel	666	Objectives	699
High-Manganese Steel	666	Key Terms	699
Low-Alloy, High-Tensile Strength Steels	666	Introduction	699
Stainless Steels	666	Manual Joining Process	700
Austenitic Stainless Steel	667	Semiautomatic Joining Processes	701
Ferritic Stainless Steel	667		

Machine Joining Processes	702
Automatic Joining Processes	702
Automated Joining	702
Industrial Robots	703
Robot Programming	704
System Planning	706
Present and Future Needs	706
Parts Design	706
Equipment Selection	707
Safety	710
Future Automation	712
Summary	712
Review	712

Chapter 30 Other Welding Processes 714

Objectives	714
Key Terms	714
Introduction	715
Constant Current Welding Processes	715
Submerged Arc Welding (SAW)	715
Flux	717
Advantages of SAW	717
Disadvantages of SAW	718
Handheld SAW	718
Electroslag Welding (ESW)	718
Advantages	719
Disadvantages	720
Electrogas Welding (EGW)	720
Resistance Welding	720
Resistance Spot Welding (RSW)	721
Spot Welding Machines	722
Multiple-Spot Welders	722
Seam Welding (RSEW)	722
Types of Resistance Seam Welds	723
Electron Beam Welding (EBW)	726
Electron Beam Welding Gun	726
Electron Beam Seam Tracking	726
Ultrasonic Welding	727
Ultrasonic Welding (USW) Applications	728
Inertia Welding Process (FRW-I)	728
Inertia Weld Bond Characteristics	729
Advantages of the Process	731
Laser Beam Welding (LBW)	731
Laser Welding Advantages and Disadvantages	731
Laser Beam	731
Laser Beam Heat Treating	732
Plasma Arc Welding (PAW)	732
Stud Welding (SW)	733
Thermal Spraying (THSP)	733
Thermal Spraying Equipment	733
Thermospray (Powder) Process	734
Thermospray Gun	734
Torch Spraying	734
Applying Sprayed Metal	736
Plasma Spraying Process	736
Cold Welding (CW)	736

Thermite Welding	736
Hardfacing	738
Selection of Hardfacing Metals	739
Hardfacing Welding Processes	739
Quality of Surfacing Deposit	740
Hardfacing Electrodes	740
Shielded Metal Arc Method	741
Hardfacing with Gas Shielded Arc	741
Friction Stir Welding (FSW)	741
Magnetic Pulse Welding (MPW)	742
Hybrid Welding Processes	742
Summary	743
Review	743

SECTION 6 OXYFUEL PROCESSES 745

**Chapter 31 Oxyfuel Welding and Cutting
Equipment, Setup, and Operation 747**

Objectives	747
Key Terms	747
Introduction	748
Pressure Regulators	748
Regulator Operation	748
Regulator Gauges	750
Regulator Safety Pressure Release Device	751
Cylinder and Regulator Fittings	752
Cryogenic Cylinders	752
Fittings	753
Regulator Safety Precautions	753
Regulator Care and Use	754
Welding and Cutting Torches: Design and Service	755
Combination Torches	755
Dedicated Cutting Torches	755
Mixing the Gases	756
Mixing Chamber	756
Injector Mixing	756
Torch Care and Use	757
Welding and Heating Torch Tips	757
Torch Tip Care and Use	758
Backfires and Flashbacks	759
Backfires	759
Flashbacks	759
Reverse Flow and Flashback Valves	759
Care of the Reverse Flow Valve and Flashback Arrestor	759
Hoses and Fittings	761
Hose Care and Use	761
Leak Detection Hoses	761
Leak Detection Fittings	762
Manifold Systems	762
Manifold Operation	763
Oxyfuel Flame	764
Characteristics of the Fuel-Gas Flame	764
Fuel Gases	764
Flame Rate of Burning	766
Acetylene (C ₂ H ₂)	767

Acetone	768	Introduction	815
Heat and Temperature of Acetylene	769	Brazing, Braze Welding, and Soldering	816
Liquefied Fuel Gases	769	Brazing	816
Pressure	769	Braze Welding	816
Methylacetylene-Propadiene (MPS)	769	Soldering	816
MAPP®	771	Advantages of Brazing and Soldering	816
Oxy-MAPP® Flames	771	Physical Properties of the Brazed	
Propane and Natural Gas	772	or Soldered Joint	818
Hydrogen	773	Tensile Strength	818
Filler Metals	776	Shear Strength	818
Ferrous Metals	776	Ductility	818
Mild Steel	776	Fatigue Resistance	818
Cast Iron	777	Corrosion Resistance	819
Summary	783	Fluxes Used in Brazing, Braze Welding,	
Review	783	and Soldering	819
		Flux	819
		Forms of Fluxes	820
		Fluxing Action	821
Chapter 32 Oxyacetylene Welding	785	Brazing and Soldering Methods	821
Objectives	785	Torch Brazing and Soldering	821
Key Terms	785	Furnace Brazing and Soldering	822
Introduction	785	Induction Brazing and Soldering	823
Mild Steel Welds	786	Dip Brazing and Soldering	824
Factors Affecting the Weld	786	Resistance Brazing and Soldering	824
Characteristics of the Weld	787	Special Methods	825
Flat Position Welding	794	Filler Metals	825
Outside Corner Joint	794	Types of Filler Metals	825
Butt Joint	794	Soldering Alloys	826
Lap Joint	797	Tin-Lead	826
Tee Joint	798	Tin-Antimony	826
Out-of-Position Welding	800	Cadmium-Silver	826
Vertical Welds	800	Cadmium-Zinc	826
Butt Joint	803	Brazing Alloys	827
Lap Joint	804	Copper-Zinc	827
Tee Joint	804	Copper-Zinc and Copper-Phosphorus A5.8	828
Horizontal Welds	805	Copper-Phosphorus	828
Horizontal Stringer Bead	805	Copper-Phosphorus-Silver	829
Butt Joint	806	Silver-Copper	829
Lap Joint	806	Nickel	829
Tee Joint	806	Nickel and Nickel Alloys A5.14	829
Overhead Welds	806	Aluminum-Silicon (BAISi)	829
Stringer Bead	807	Copper and Copper Alloys A5.7	829
Butt Joint	807	Silver and Gold	829
Lap Joint	807	Joint Design	829
Tee Joint	807	Joint Spacing	829
Mild Steel Pipe and Tubing	807	Brazing Practices	832
Horizontal Rolled Position 1G	808	Surface Buildup and Hole Fill Practices	838
Horizontal Fixed Position 5G	810	Silver Brazing Practices	839
Vertical Fixed Position 2G	811	Soldering Practices	842
45° Fixed Position 6G	812	Summary	846
Thin-Wall Tubing	813	Review	846
Summary	813		
Review	814		
		Appendix	848
Chapter 33 Brazing, Braze Welding, and Soldering	815	I. Student Welding Report	849
Objectives	815	II. SENSE	850
Key Terms	815	III. SENSE	851

Contents

IV. Conversion of Decimal-Inches to Millimeters and Fractional Inches to Decimal-Inches and Millimeters	852	VIII. Pressure Conversion	856
V. Conversion Factors: U.S. Customary (Standard) Units and Metric Units (SI)	853	IX. Welding Codes and Specifications	857
VI. Abbreviations and Symbols	855	X. Welding Associations and Organizations	858
VII. Metric Conversion Approximations	856	Glossary	859
		Index	910



Preface

Introduction

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

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

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

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

xvi

Organization

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

What's New in the 8th Edition

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

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

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

Supplements

Study Guide/Lab Manual

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

Instructor Companion Website

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

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

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

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 is a personalized teaching experience with relevant assignments that guide students to analyze, apply,

and improve thinking, allowing you to measure skills and outcomes with ease.

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

FEATURES OF THE TEXT



Chapter 1 Introduction to Welding

OBJECTIVES

After completing this chapter, the student should be able to

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

KEY TERMS

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

INTRODUCTION

As methods of joining materials improved through the ages, so did the environment 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

ithis-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

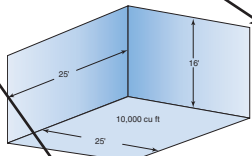
Objectives, found at the beginning of each chapter, are a brief list of the most important topics to study in the chapter.

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

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

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

32
Section 1 Introduction



THINK GREEN
Waste Material Disposal

Welding shops generate a lot of waste material. Much of this 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.

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

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

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

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

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

SAFETY DATA SHEETS (SDSs)

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

CAUTION

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




FIGURE 2-24 An exhaust pickup.

HANDLING AND STORING CYLINDERS

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

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

Chapter 7 Flame Cutting 183

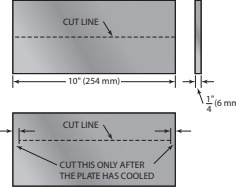


FIGURE 7-76 Making two cuts with minimum distortion. Note: Sizes of these and other cutting projects can be changed to fit available stock.

EXPERIMENT 7-4
Minimizing Distortion

Using a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece 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 7-76**. Allow the metal to cool, and then cut the remaining tabs. Compare the four pieces of metal for distortion.

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

PRACTICE 7-9
Beveling a Plate

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

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

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

PRACTICE 7-10
Vertical Straight Cut

For this Practice, you will need a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection

and clothing, and one piece of mild steel plate 6 in. (152 mm) long × 1/4 in. (6 mm) thick marked in strips 1/2 in. (13 mm) wide and held in the vertical position. You will make a straight line cut. Make sure that the sparks do not cause a safety hazard and that the metal being cut off will not fall on any person or object.

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

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

PRACTICE 7-11
Overhead Straight Cut

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

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

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

CUTTING APPLICATIONS

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

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

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

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

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

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

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

518 Section 5 Related Technologies

Review

- What are two ways math is most commonly used in the welding shop?
- What is the two-letter abbreviation for the metric system?
- List factors that affect the cost of producing weldments.
- List three examples of whole numbers.
- List three examples of decimal fractions.
- List three examples of a mixed unit.
- List three examples of fractions.
- Add the following angles:
 - $30^\circ 50' + 20^\circ 5'$
 - $25^\circ 20' + 62^\circ 45'$
- Subtract the following angles:
 - $45^\circ 48' - 10^\circ 20'$
 - $90^\circ 5' - 31^\circ 15'$
- Using the Pythagorean theorem, find "c" if "a" = 6 and "b" = 8.
- Sketch a right triangle, equilateral triangle, and isosceles triangle.
- Find the area of the following:
 - Square that is 55" wide
 - Circle with a 22" diameter
 - Equilateral triangle with a 5" base and 3" height
 - Oval that is 20" wide and 11" high
 - Parallelogram with a 3" base and 7" height
- Find the volume of the following:
 - 5" cube
 - 10" of 8" pipe
- What would the labor cost be if 20 hours were worked at an hourly rate of \$25?
- What is the first step in the sequence of mathematical operations?
- If you need two pieces of pipe—one must be 15 ft and the other 10 ft—what is the total amount of pipe needed?
- How many total feet of metal stock would you need if one piece is 12 ft 5 in. long and the other is 7 ft 3 in. long?
- How many total feet of metal stock would you need if one piece is 11 ft 9 in. long and the other is 6 ft 5 in. long?
- How many feet of scrap pipe will you have left from a 9 ft 6 in. pipe when 4 ft 2 in. is cut off?
- How much scrap pipe will you have once you cut out 5.5 ft from a 20-ft length of pipe?
- When the denominators of two fractions to be added or subtracted are different, what must be done before they can be added?
- How thick will the finished part be if two pieces of metal are welded together if one is 3/4 in. thick and the other is 5/16 in. thick?
- How much metal is left if 1/8 in. is ground off a 5/16-in.-thick plate?
- What is a dimensioning tolerance?
- What is the minimum and maximum length a part can be if it is shown as needing to be 5.78 in. \pm 1/8?
- Give examples of welding applications where angles would be used.
- Write the Pythagorean Theorem formula for a right triangle.
- What is the name of a triangle where all three sides are the same length?
- Why is it important to know the perimeter measurement of a weldment before cutting?
- In what welding applications might you need to know the area of a part's surface?
- List examples of fixed and variable costs that must be considered when estimating a job.
- List examples of overhead costs that a welding shop might have.
- When estimating weld cost, what weld joint design factors should be considered?
- When a weld is oversized, what joint failure problem can result?
- How does the bevel angle in a groove weld affect the filler metal volume?
- What is the cross-sectional area of a V-groove weld that is 6 mm wide and 8 mm deep on a 10-mm-thick plate with a 2-mm root opening? What would the area be in square inches?
- What is the cross-sectional area of a fillet weld that has an equal leg of 1/2 in.? What is the Si area?
- What two amounts must be multiplied to determine the weight of weld metal required to fill a groove or make a fillet weld?
- How many pounds of steel electrode are required to make a weld that has a volume of 18 in.³?

100 Section 2 Shielded Metal Arc Welding

Summary

The shielded metal arc welding process is most often referred to in welding shops as stick-welding. Some people say that it gets this name for one of two reasons. The first is most obviously as a result of the stick shape of the electrode. The second reason is experienced by all new welders; it is the tendency for the electrode to stick to the workpiece. All new welders experience this, and your ability to control the sticking of the electrode can be improved as you develop the proper arc-striking techniques. For a new welder, it is often difficult to concentrate on anything other than the bright sparks and glow at the end of the electrode. But, with time, as you develop your skills, your visual field will increase, allowing you to see a much larger welding zone. This skill comes with time and practice. Developing this skill is essential for you to become a highly proficient welder. Nothing enhances your welding skills more than time under the hood, actually welding, cleaning the weld, inspecting it, determining the necessary corrections to be made, and immediately trying to produce the next weld with a higher level of quality.

Ladder Safety: Staying Steady



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

Mishaps can be prevented by using common sense, adhering to safety practices, and getting the right ladder for your line of work. Imagine you're just finishing up a job and notice one last thing that needs to be done. You grab your ladder, quickly set it up, and start climbing. However, you didn't bother with any safety precautions because you were only going to be up there for a minute. This is a common start to many sad stories. More than 500 accidents a day start with statements like, "I was in a hurry" or "I just needed to reach a little farther." These descriptions relate to real people with real families, some of whom you may even know and care a great deal about. Fortunately, most ladder accidents are not life altering. Some are, though, and almost all of them are preventable.

The Importance of Using Ladders

Ladders have been around for thousands of years. Most people started climbing them as children and, sometimes, adults take the same risks now as they did then. Since ladders will continue to be a necessity in nearly all walks of life, better ways need to be found for preventing accidents and, it is hoped, save lives. The two best ways to accomplish this goal are providing better safety training and designing safer products—

FIGS. 1, 2

Common Sense Is the Best Prevention

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

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

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

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

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

Success Story



My name is Shakirah Harrell. I was born in Newark, New Jersey and raised in the little town of Powellsville, North Carolina. I graduated from Hertford County High School in Ahoskie, North Carolina. As a single young parent, I needed to find a career field that would support my family, so I moved to Hampton, Virginia. I started my welding career at the age of 23. At that time, the only thing I knew about welding was that it was a good paying job. I applied at Northrop Grumman, a shipyard in Newport News, Virginia, and began my training as a welder. To help support my family, I worked as a grocery store manager in the morning and welder at night. After one year in the field as a 3rd class welder, I got accepted into the apprenticeship program. I spent the next five years learning the welding trade while still being able to support my family. I graduated from the apprenticeship program in 2008. Then I decided to pursue another angle in the welding trade. I got hired at a local welding school where I began instructing basic welding during the day while working on my Bachelor's Degree in business management at night and online. After only a few months, I was asked to take a position at the school as the welding coordinator for the entire program. After four years, I missed welding and the money I would make, so I decided to go back into the field as a contractor at another local shipyard in Norfolk, Virginia. Over the next few years, I followed welding opportunities across other parts of the United States. I was a structural welder at an ethanol plant project in Liberal, Kansas. Following that, I moved to Freeport, Texas, took a refresher pipe welding course offered by Fluor, and started working on a chemical plant project for Dow Chemical Company. After being away from Virginia for so many years, I was homesick and decided to go back to Virginia; but as a result of the downturn in the economy, I was not able to find a good high-paying job, so I moved back to Texas. I am currently a welding instructor at Tulsa Welding School and Technology Center at the Houston campus. Welding has been a great career for me and a skill that has provided for my family. My oldest son has joined the United States Navy, one of the others is a high school senior, and the youngest is a high school junior. I'm proud to be a welder, I'm proud of my kids, and proud of the life that welding has provided for us.

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About the Author

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

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

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

In my senior year I was given an opportunity to join Mr. Z. T. Koonce's first class in a new program called Industrial Cooperative Training (ICT). ICT is a cooperative

work experience program that coordinates school experiences with real jobs. This allowed me to attend high school in the morning, where I completed my required English, math, and other academic courses for graduation. In my ICT class we were taught skills that would help us get a job—such as how to fill out a job application, how to interview, and so on. In the afternoons I worked as a welder. After graduation, I started a full-time job as a welder at Barbour Boat Works, where I refined my welding skills and was allowed to work with the other welders in the shipyard. My first welding assignment was on a barge making intermittent welds to attach the deck to the barge's ribs.

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

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

During my career as a welder, I have welded on tanks, pressure vessels, oil well drilling equipment, farm equipment, buildings, racecars, aircraft, piping systems,

and more. As a vocational teacher, I have taught in high schools, schools for special education, schools for the deaf, three colleges, and numerous industrial shops. I have also been a consultant to the welding industry and a resource for students, educators, and school administrators.

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

ing Postsecondary Technical Educator in the State of Texas by the Texas Technical Society. He holds a bachelor of science degree and has completed postgraduate studies.

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

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

Index of Experiments and Practices

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

Chapter 3

Experiment 3-1	Estimating Amperages	59
Experiment 3-2	Calculating the Amperage Setting	59
Practice 3-1	Estimating Amperages	60
Practice 3-2	Calculating Amperages	60
Practice 3-3	Reading the Duty Cycle Chart	64
Practice 3-4	Determining Welding Lead Sizes	65
Practice 3-5	Repairing Electrode Holders	66

Chapter 4

Practice 4-1	Shielded Metal Arc Welding Safety	70
Practice 4-2	Striking the Arc	70
Practice 4-3	Striking the Arc Accurately	71
Experiment 4-1	Effect of Amperage Changes on a Weld Bead	73
Experiment 4-2	Excessive Heat	74
Experiment 4-3	Effect of Changing the Arc Length on a Weld	75
Experiment 4-4	Effect of Changing the Electrode Angle on a Weld	76
Practice 4-4	Straight Stringer Beads in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	81
Practice 4-5	Stringer Beads in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	82
Practice 4-6	Horizontal Stringer Beads Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	82
Practice 4-7	Welded Square Butt Joint in the Flat Position (1G) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	83
Practice 4-8	Vertical (3G) Up-Welded Square Butt Weld Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	84
Practice 4-9	Welded Horizontal (2G) Square Butt Weld Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	87
Practice 4-10	Edge Weld in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	87
Practice 4-11	Edge Joint in the Vertical Down Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	88
Practice 4-12	Edge Joint in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	89
Practice 4-13	Edge Joint in the Horizontal Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	89
Practice 4-14	Edge Joint in the Overhead Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	90
Practice 4-15	Outside Corner Joint in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	91
Practice 4-16	Outside Corner Joint in the Vertical Down Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	91
Practice 4-17	Outside Corner Joint in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	92
Practice 4-18	Outside Corner Joint in the Horizontal Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	92

Practice 4-19	Outside Corner Joint in the Overhead Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	93
Practice 4-20	Welded Lap Joint in the Flat Position (1F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	94
Practice 4-21	Welded Lap Joint in the Horizontal Position (2F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	96
Practice 4-22	Lap Joint in the Vertical Position (3F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes	96
Practice 4-23	Lap Joint in the Overhead Position (4F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	96
Practice 4-24	Tee Joint in the Flat Position (1F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	98
Practice 4-25	Tee Joint in the Horizontal Position (2F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	99
Practice 4-26	Tee Joint in the Vertical Position (3F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	99
Practice 4-27	Tee Joint in the Overhead Position (4F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes.	99

Chapter 5

Practice 5-1	Beading, 1G Position, Using E6010 or E6011 Electrodes and E7018 Electrodes	111
Practice 5-2	Butt Joint, 1G Position, Using E6010 or E6011 Electrodes.	113
Practice 5-3	Butt Joint, 1G Position, Using E6010 or E6011 Electrodes for the Root Pass with E7018 Electrodes for the Filler and Cover Passes	115
Practice 5-4	Stringer Bead, 2G Position, Using E6010 or E6011 Electrodes and E7018 Electrodes	116
Practice 5-5	Butt Joint, 2G Position, Using E6010 or E6011 Electrodes.	116
Practice 5-6	Butt Joint, 2G Position, Using E6010 or E6011 Electrodes for the Root Pass and E7018 Electrodes for the Filler and Cover Passes	117
Practice 5-7	Stringer Bead, 5G Position, Using E6010 or E6011 Electrodes and E7018 Electrodes	118
Practice 5-8	Butt Joint, 5G Position, Using E6010 or E6011 Electrodes for the Root Pass and E7018 Electrodes for the Filler and Cover Passes	119
Practice 5-9	Butt Joint, 5G Position, Using E6010 or E6011 Electrodes.	119
Practice 5-10	Stringer Bead, 6G Position, Using E6010 or E6011 Electrodes and E7018 Electrodes	119
Practice 5-11	Butt Joint, 6G Position, Using E6010 or E6011 Electrodes	120
Practice 5-12	Butt Joint, 6G Position, Using E6010 or E6011 Electrodes for the Root Pass and E7018 Electrodes for the Filler and Cover Passes	120

Chapter 6

Practice 6-1	Root Pass on Plate with a Backing Strip in All Positions	124
Practice 6-2	Root Pass on Plate with an Open Root in All Positions	125
Practice 6-3	Open Root Weld on Plate Using the Step Technique in All Positions	126
Experiment 6-1	Hot Pass to Repair a Poor Weld Bead	128
Practice 6-4	AWS SENSE Welding Procedure Specification (WPS).	137
Practice 6-5	Welding Procedure Specification (WPS).	139
Practice 6-6	Welding Procedure Specification (WPS).	141
Practice 6-7	AWS SENSE Welding Procedure Specification (WPS).	144
Practice 6-8	Single V-Groove Open Root Butt Joint with an Increasing Root Opening.	146
Practice 6-9	Single V-Groove Open Root Butt Joint with a Decreasing Root Opening	147

Chapter 7

Practice 7-1	Setting Up a Cutting Torch	169
Practice 7-2	Cleaning a Cutting Tip	169
Practice 7-3	Lighting the Torch.	170
Practice 7-4	Setting the Gas Pressures	175
Experiment 7-1	Observing Heat Produced During a Cut	176
Experiment 7-2	Effect of Flame, Speed, and Pressure on a Machine Cut	178
Experiment 7-3	Effect of Flame, Speed, and Pressure on a Hand Cut.	178

Practice 7-5	Flat, Straight Cut in Thin Plate	180
Practice 7-6	Flat, Straight Cut in Thick Plate	181
Practice 7-7	Flat, Straight Cut in Sheet Metal	181
Practice 7-8	Flame Cutting Holes	181
Experiment 7-4	Minimizing Distortion	183
Practice 7-9	Beveling a Plate	183
Practice 7-10	Vertical Straight Cut	183
Practice 7-11	Overhead Straight Cut.	183
Practice 7-12	Cutting Out Internal and External Shapes	184
Practice 7-13	Square Cut on Pipe, 1G (Horizontal Rolled) Position	186
Practice 7-14	Square Cut on Pipe, 1G (Horizontal Rolled) Position	187
Practice 7-15	Square Cut on Pipe, 5G (Horizontal Fixed) Position	187
Practice 7-16	Square Cut on Pipe, 2G (Vertical) Position	187

Chapter 8

Practice 8-1	Flat, Straight Cuts in Thin Plate	209
Practice 8-2	Flat, Straight Cuts in Thick Plate.	210
Practice 8-3	Flat Cutting Holes	211
Practice 8-4	Beveling of a Plate	213
Practice 8-5	U-Grooving of a Plate	214
Practice 8-6	Cutting Round Stock.	215
Practice 8-7	Beveling Pipe.	216

Chapter 9

Practice 9-1	Air Carbon Arc Straight U-Groove in the Flat Position	229
Practice 9-2	Air Carbon Arc Edge J-Groove in the Flat Position	230
Practice 9-3	Air Carbon Arc Back Gouging in the Flat Position	231
Practice 9-4	Air Carbon Arc Weld Removal in the Flat Position	231

Chapter 11

Practice 11-1	GMAW Equipment Setup	268
Practice 11-2	Threading GMAW Wire	271
Experiment 11-1	Setting Wire-Feed Speed	271
Experiment 11-2	Setting Gas Flow Rate	274
Experiment 11-3	Setting the Current	276
Experiment 11-4	Electrode Extension	277
Experiment 11-5	Welding Gun Angle.	278
Experiment 11-6	Effect of Shielding Gas Changes	280
Practice 11-3	Stringer Beads Using the Short-Circuiting Metal Transfer Method in the Flat Position	283
Practice 11-4	Flat Position Butt Joint, Lap Joint, and Tee Joint	283
Practice 11-5	Flat Position Butt Joint with 100% Penetration	284
Practice 11-6	Stringer Bead at a 45° Vertical Up Angle	287
Practice 11-7	Stringer Bead in the Vertical Up Position	288
Practice 11-8	Butt Joint, Lap Joint, and Tee Joint in the Vertical Up Position at a 45° Angle	288
Practice 11-9	Butt Joint in the Vertical Up Position with 100% Penetration	288
Practice 11-10	Stringer Bead at a 45° Vertical Down Angle.	288
Practice 11-11	Stringer Bead in the Vertical Down Position	289
Practice 11-12	Butt Joint, Lap Joint, and Tee Joint in the Vertical Down Position.	289
Practice 11-13	Butt Joint in the Vertical Down Position with 100% Penetration.	289
Practice 11-14	Horizontal Stringer Bead at a 45° Angle	289
Practice 11-15	Stringer Bead in the Horizontal Position	290
Practice 11-16	Butt Joint, Lap Joint, and Tee Joint in the Horizontal Position.	290
Practice 11-17	Butt Joint in the Horizontal Position with 100% Penetration	290
Practice 11-18	Stringer Bead Overhead Position.	291
Practice 11-19	Butt Joint, Lap Joint, and Tee Joint in the Overhead Position	292
Practice 11-20	Butt Joint in the Overhead Position with 100% Penetration	292
Practice 11-21	Stringer Bead.	293

Practice 11-22	Butt Joint	293
Practice 11-23	Butt Joint with 100% Penetration	293
Practice 11-24	Tee Joint and Lap Joint in the 1F Position	295
Practice 11-25	Tee Joint and Lap Joint in the 2F Position	295
Practice 11-26	Stringer Bead, 1G Position	296
Practice 11-27	Butt Joint, Lap Joint, and Tee Joint Using the Axial Spray Method	296
Practice 11-28	Butt Joint and Tee Joint	296

Chapter 13

Practice 13-1	FCAW Equipment Setup	322
Practice 13-2	Threading FCAW Wire	323
Practice 13-3	Stringer Beads Flat Position	324
Practice 13-4	Square Butt Joint 1G	327
Practice 13-5	V-Groove Butt Joint 1G	329
Practice 13-6	Lap Joint and Tee Joint 1F	333
Practice 13-7	Butt Joint at a 45° Vertical Up Angle	333
Practice 13-8	Square Groove Butt Joint 3G	333
Practice 13-9	V-Groove Butt Joint 3G	333
Practice 13-10	Fillet Weld Joint at a 45° Vertical Up Angle	335
Practice 13-11	Lap Joint and Tee Joint 3F	336
Practice 13-12	Lap Joint and Tee Joint 2F	336
Practice 13-13	Lap and Tee Joint 2F	338
Practice 13-14	Stringer Bead at a 45° Horizontal Angle	338
Practice 13-15	Bevel Butt Joint 2G	338
Practice 13-16	V-Groove Butt Joint 2G	338
Practice 13-17	Square Butt Joint 4G	340
Practice 13-18	V-Groove Butt Joint 4G	340
Practice 13-19	Lap Joint and Tee Joint 4F	340
Practice 13-20	Butt Joint 1G	341
Practice 13-21	Lap Joint and Tee Joint 1F	341
Practice 13-22	Butt Joint 3G	343
Practice 13-23	Lap Joint and Tee Joint 3F	343
Practice 13-24	Lap Joint and Tee Joint 2F	344
Practice 13-25	Butt Joint 2G	344
Practice 13-26	Butt Joint 4G	344
Practice 13-27	Lap Joint and Tee Joint 4F	344
Practice 13-28	Plug Weld	344

Chapter 14

Practice 14-1	Fillet Weld, 1F Position, Using GMAW, FCAW-S, and FCAW-G	351
Practice 14-2	Fillet Weld, 2F Position, Using GMAW, FCAW-S, and FCAW-G	353
Practice 14-3	Fillet Weld, 5F Position, Using GMAW, FCAW-S, and FCAW-G	354
Practice 14-4	Butt Joint, 1G Position, Using GMAW, FCAW-S, and FCAW-G	355
Practice 14-5	Butt Joint, 2G Position, Using GMAW, FCAW-S, and FCAW-G	356
Practice 14-6	Butt Joint, 5G Position, Using GMAW, FCAW-S, and FCAW-G	356
Practice 14-7	Butt Joint, 6G Position, Using GMAW, FCAW-S, and FCAW-G	357

Chapter 15

Practice 15-1	All Positions Butt Joint, Tee Joint, and Lap Joint	361
Practice 15-2	AWS SENSE Gas Metal Arc Welding—Short-Circuit Metal Transfer (GMAW-S) Workmanship Sample	362
Practice 15-3	V-Groove Butt Joint 1G	365
Practice 15-4	Fillet Weld Tee Joint 1F	366
Practice 15-5	AWS SENSE Gas Metal Arc Welding (GMAW) Spray Transfer Workmanship Sample	367
Practice 15-6	AWS SENSE Gas Metal Arc Welding (GMAW) Spray Transfer Workmanship Sample	370
Practice 15-7	V-Groove Butt Joint 1G and 3G Positions	372
Practice 15-8	Bevel Groove Butt Joint 2G	375

Practice 15-9	Bevel Groove Butt Joint 4G	374
Practice 15-10	All Positions Fillet Welds on Lap Joint and Tee Joint.	375
Practice 15-11	AWS SENSE AWS SENSE Entry-Level Welder Workmanship Sample for Flux Cored Arc Welding, Gas-Shielded (FCAW-G)	375
Practice 15-12	AWS SENSE AWS SENSE Entry-Level Welder Workmanship Sample for Flux Cored Arc Welding Self-Shielded (FCAW-S)	378
Practice 15-13	AWS SENSE Gas Metal Arc Welding—Short-Circuit Metal Transfer (GMAW-S) Workmanship Sample	379
Practice 15-14	AWS SENSE AWS SENSE Entry-Level Welder Workmanship Sample for Flux Cored Arc Welding, Gas-Shielded (FCAW-G)	383
Practice 15-15	AWS SENSE AWS SENSE Entry-Level Welder Workmanship Sample for Flux Cored Arc Welding Self-Shielded (FCAW-S)	386

Chapter 16

Experiment 16-1	Hand Grinding the Tungsten to the Desired Shape.	394
Experiment 16-2	Removing a Contaminated Tungsten End by Breaking	396
Experiment 16-3	Melting the Tungsten End Shape.	397
Experiment 16-4	Setting Up a GTA Welder	409
Experiment 16-5	Striking an Arc	411

Chapter 17

Experiment 17-1	Setting the Welding Current	418
Experiment 17-2	Setting Gas Flow	419
Practice 17-1	Stringer Beads, Flat Position, on Mild Steel	422
Practice 17-2	Stringer Beads, Flat Position, on Stainless Steel.	424
Practice 17-3	Stringer Beads, Flat Position, on Aluminum	424
Practice 17-4	Flat Position, Using Mild Steel, Stainless Steel, and Aluminum.	424
Practice 17-5	Outside Corner Joint, 1G Position, Using Mild Steel, Stainless Steel, and Aluminum	426
Practice 17-6	Butt Joint, 1G Position, Using Mild Steel, Stainless Steel, and Aluminum	426
Practice 17-7	Butt Joint, 1G Position, with Minimum Distortion, Using Mild Steel, Stainless Steel, and Aluminum	427
Practice 17-8	Lap Joint, 1F Position, Using Mild Steel, Stainless Steel, and Aluminum	429
Practice 17-9	Tee Joint, 1F Position, Using Mild Steel, Stainless Steel, and Aluminum.	430
Practice 17-10	Stringer Bead at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, and Aluminum	431
Practice 17-11	Stringer Bead, 3G Position, Using Mild Steel, Stainless Steel, and Aluminum.	431
Practice 17-12	Butt Joint at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, and Aluminum	432
Practice 17-13	Butt Joint, 3G Position, Using Mild Steel, Stainless Steel, and Aluminum	432
Practice 16-14	Lap Joint at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, and Aluminum	432
Practice 17-15	Lap Joint, 3F Position, Using Mild Steel, Stainless Steel, and Aluminum	434
Practice 17-16	Tee Joint at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, and Aluminum.	434
Practice 17-17	Tee Joint, 3F Position, Using Mild Steel, Stainless Steel, and Aluminum.	434
Practice 17-18	Stringer Bead at a 45° Reclining Angle, Using Mild Steel, Stainless Steel, and Aluminum	434
Practice 17-19	Stringer Bead, 2G Position, Using Mild Steel, Stainless Steel, and Aluminum.	435
Practice 17-20	Butt Joint, 2G Position, Using Mild Steel, Stainless Steel, and Aluminum	436
Practice 17-21	Lap Joint, 2F Position, Using Mild Steel, Stainless Steel, and Aluminum	436
Practice 17-22	Tee Joint, 2F Position, Using Mild Steel, Stainless Steel, and Aluminum.	437
Practice 17-23	Stringer Bead, 4G Position, Using Mild Steel, Stainless Steel, and Aluminum.	437
Practice 17-24	Butt Joint, 4G Position, Using Mild Steel, Stainless Steel, and Aluminum	438
Practice 17-25	Lap Joint, 4F Position, Using Mild Steel, Stainless Steel, and Aluminum	439
Practice 17-26	Tee Joint, 4F Position, Using Mild Steel, Stainless Steel, and Aluminum.	439

Chapter 18

Practice 18-1	Tack Welding Pipe	447
Practice 18-2	Root Pass, Horizontal Rolled Position (1G)	450
Experiment 18-1	Repairing a Root Pass Using a Hot Pass.	454
Practice 18-3	Stringer Bead, Horizontal Rolled Position (1G)	454
Practice 18-4	Weave and Lace Beads, Horizontal Rolled Position (1G)	456

Practice 18-5	Filler Pass (1G Position)	457
Practice 18-6	Cover Pass (1G Position)	458
Practice 18-7	Stringer Bead, Horizontal Fixed Position (5G)	458
Practice 18-8	Stringer Bead, Vertical Fixed Position (2G)	459
Practice 18-9	Stringer Bead on a Fixed Pipe at a 45° Inclined Angle (6G Position)	460

Chapter 19

Practice 19-1	Butt Joint, All Positions Using Mild Steel with 100% Joint Penetration to be Tested	467
Practice 19-2	Lap and Tee Joints, All Positions Using Mild Steel with 100% Root Penetration to be Tested	467
Practice 19-3	Butt Joint, All Positions Using Austenitic Stainless Steel with 100% Joint Penetration to be Tested	469
Practice 19-4	Lap and Tee Joints, All Positions Using Stainless Steel with 100% Root Penetration to be Tested	469
Practice 19-5	Butt Joint, All Positions Using Aluminum with 100% Joint Penetration to be Tested	469
Practice 19-6	Lap and Tee Joints, All Positions Using Aluminum with 100% Root Penetration to be Tested	469
Practice 19-7	AWS SENSE Gas Tungsten Arc Welding (GTAW) on Plain Carbon Steel Workmanship Sample	470
Practice 19-8	AWS SENSE Gas Tungsten Arc Welding (GTAW) on Stainless Steel Workmanship Sample	473
Practice 19-9	AWS SENSE Gas Tungsten Arc Welding (GTAW) on Aluminum Workmanship Sample	476
Practice 19-10	AWS SENSE 2G and 5G Pipe Welds on Mild Steel Tubing with and without a Backing	479
Practice 19-11	AWS SENSE 2G and 5G Pipe Welds on Stainless Steel Tubing with and without a Backing	479
Practice 19-12	AWS SENSE 2G and 5G Pipe Welds on Aluminum Tubing with and without a Backing	480
Practice 19-13	Single V-Groove Pipe Weld, 1G Position, to be Tested.	480
Practice 19-14	Single-V Butt Joint (5G Position) 100% Root Penetration to be Tested.	482
Practice 19-15	Single-V Butt Joint (2G Position) 100% Root Penetration to be Tested.	483
Practice 19-16	Single-V Butt Joint (6G Position) 100% Root Penetration to be Tested.	484

Chapter 20

Practice 20-1	Calculate the Area Using a Calculator	501
Practice 20-2	Calculate the Volume Using a Calculator	502
Practice 20-3	Finding Weld Groove Volume	506
Practice 20-4	Finding Weld Weight of Filler Metal	507
Practice 20-5	Create a Bill of Materials	516

Chapter 21

Practice 21-1	Reading Mechanical Drawings	528
Practice 21-2	Sketching Straight Lines	530
Practice 21-3	Sketching Circles and Arcs	531
Practice 21-4	Sketching a Block	532
Practice 21-5	Sketch a Candlestick Holder	532
Practice 21-6	Sketching the Parts of a Workmanship Qualification Test.	535
Practice 21-7	Sketching Curves and Irregular Shapes.	536

Chapter 22

Practice 22-1	Reading Welding Symbols.	559
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Chapter 23

Practice 23-1	Laying Out Square, Rectangular, and Triangular Parts	566
Practice 23-2	Laying Out Circles, Arcs, and Curves	569
Practice 23-3	Nesting Layout	569
Practice 23-4	Bill of Materials	570
Practice 23-5	Allowing Space for the Kerf.	570

Chapter 24

Practice 24-1	Writing a Welding Procedure Specification (WPS)	596
Practice 24-2	Procedure Qualification Record (PQR)	598

Chapter 26

Experiment 26-1	Latent and Sensible Heat	630
Experiment 26-2	Temper Colors.	631
Experiment 26-3	Crystal Formation	643
Experiment 26-4	Effect of Quenching and Tempering on Metal Properties	644

Chapter 27

Practice 27-1	Arc Welding a Cast Iron Break with Preheating and Postheating	670
Practice 27-2	Arc Welding a Cast Iron Crack without Preheating or Postheating	671
Practice 27-3	Gas Welding a Cast Iron Break with Preheating or Postheating	672
Practice 27-4	Braze Welding a Cast Iron Crack with Preheating or Postheating	673
Experiment 27-1	Identifying Metal Using a Spark Test.	675

Chapter 31

Experiment 31-1	Line Resistance	751
Experiment 31-2	Burn Rate	766
Experiment 31-3	Oxyfuel Flames.	774
Practice 31-1	Setting Up an Oxyfuel Torch Set.	777
Practice 31-2	Turning On and Testing a Torch	780
Practice 31-3	Lighting and Adjusting an Oxyacetylene Flame	781
Practice 31-4	Shutting Off and Disassembling Oxyfuel Welding Equipment	782

Chapter 32

Experiment 32-1	Flame Effect on Metal	788
Practice 32-1	Pushing a Molten Weld Pool	789
Experiment 32-2	Effect of Torch Angle and Torch Height Changes	790
Practice 32-2	Beading	792
Experiment 32-3	Effect of Rod Size on the Molten Weld Pool.	793
Practice 32-3	Stringer Bead, Flat Position	793
Practice 32-4	Outside Corner Joint, Flat Position	794
Practice 32-5	Butt Joint, Flat Position	795
Practice 32-6	Butt Joint with 100% Penetration	795
Practice 32-7	Butt Joint with Minimum Distortion	796
Practice 32-8	Lap Joint, Flat Position	798
Practice 32-9	Tee Joint, Flat Position.	800
Practice 32-10	Stringer Bead at a 45° Angle	802
Practice 32-11	Stringer Bead, Vertical Position	802
Practice 32-12	Butt Joint at a 45° Angle	803
Practice 32-13	Butt Joint, Vertical Position	803
Practice 32-14	Butt Joint, Vertical Position, with 100% Penetration	803
Practice 32-15	Lap Joint at a 45° Angle.	804
Practice 32-16	Lap Joint, Vertical Position	804
Practice 32-17	Tee Joint at a 45° Angle	805
Practice 32-18	Tee Joint, Vertical Position.	805
Practice 32-19	Horizontal Stringer Bead at a 45° Angle	805
Practice 32-20	Stringer Bead, Horizontal Position	805
Practice 32-21	Butt Joint, Horizontal Position.	806
Practice 32-22	Lap Joint, Horizontal Position	806
Practice 32-23	Tee Joint, Horizontal Position	806
Practice 32-24	Stringer Bead, Overhead Position	807
Practice 32-25	Butt Joint, Overhead Position	807
Practice 32-26	Lap Joint, Overhead Position.	807
Practice 32-27	Tee Joint, Overhead Position	807
Experiment 32-4	Effect of Changing Angle on Molten Weld Pool.	808
Experiment 32-5	Stringer Bead, 1G Position.	808
Experiment 32-6	Stops and Starts.	809
Practice 32-28	Stringer Bead, 1G Position.	809

Practice 32-29	Butt Joint, 1G Position	810
Experiment 32-7	5G Position	810
Practice 32-30	Stringer Bead, 5G Position	811
Practice 32-31	Butt Joint, 5G Position	811
Practice 32-32	Stringer Bead, 2G Position	811
Practice 32-33	Butt Joint, 2G Position	812
Practice 32-34	Stringer Bead, 6G Position	812
Practice 32-35	Butt Joint, 6G Position	813

Chapter 33

Experiment 33-1	Paste Range	825
Experiment 33-2	Fluxing Action	830
Experiment 33-3	Uniform Heating	831
Experiment 33-4	Tinning or Phase Temperature	831
Practice 33-1	Brazed Stringer Bead	832
Practice 33-2	Brazed Butt Joint	833
Practice 33-3	Brazed Butt Joint with 100% Penetration	833
Practice 33-4	Brazed Tee Joint	834
Practice 33-5	Brazed Lap Joint	834
Practice 33-6	Brazed Lap Joint with 100% Penetration	835
Practice 33-7	Brazed Tee Joint, Thin to Thick Metal	835
Practice 33-8	Brazed Lap Joint, Thin to Thick Metal	836
Practice 33-9	Braze Welded Butt Joint, Thick Metal	836
Practice 33-10	Braze Welded Tee Joint, Thick Metal	837
Practice 33-11	Braze Welding to Fill a Hole	838
Practice 33-12	Flat Surface Buildup	838
Practice 33-13	Round Surface Buildup	838
Practice 33-14	Silver Brazing Copper Pipe, 2G Vertical Down Position	840
Practice 33-15	Silver Brazing Copper Pipe, 5G Horizontal Fixed Position	841
Practice 33-16	Silver Brazing Copper Pipe, 2G Vertical Up Position	842
Practice 33-17	Soldered Tee Joint	842
Practice 33-18	Soldered Lap Joint	843
Practice 33-19	Soldering Copper Pipe, 2G Vertical Down Position	843
Practice 33-20	Soldering Copper Pipe, 1G Position	844
Practice 33-21	Soldering Copper Pipe, 4G Vertical Up Position	845
Practice 33-22	Soldering Aluminum to Copper	845

Section 1

Introduction

Chapter 1

Introduction to Welding

Chapter 2

Safety in Welding



Success Story

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



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

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

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

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

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

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

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



Chapter 1

Introduction to Welding

OBJECTIVES

After completing this chapter, the student should be able to

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

KEY TERMS

American Welding Society (AWS)

automated operation

automatic operation

certification

coalescence

flux cored arc welding (FCAW)

forge welding

fusion welding

gas metal arc welding (GMAW)

gas tungsten arc welding (GTAW)

machine operation

manual operation

oxyfuel gas cutting (OFC)

oxyfuel gas welding (OFW)

qualification

resistance welding

semiautomatic operation

shielded metal arc welding (SMAW)

torch or oxyfuel brazing (TB)

weld

welding

INTRODUCTION

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

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

ibis-headed god named Thoth who protected the moon and was believed to cruise space in a vessel.

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

on top of a piece of metal and casting the desired shape directly on the base metal so that both parts fused together, forming a single piece of metal, **Figure 1-1**. Another metal-joining method used in early years was to place two pieces of metal close together and pour molten metal between them. When the edges of the base metal melted, the flow of metal was then dammed up and allowed to harden, **Figure 1-2**.

This bronze goat statue at the Qingyang Taoist Temple in Chengdu, China was cast more than 1500 years ago and

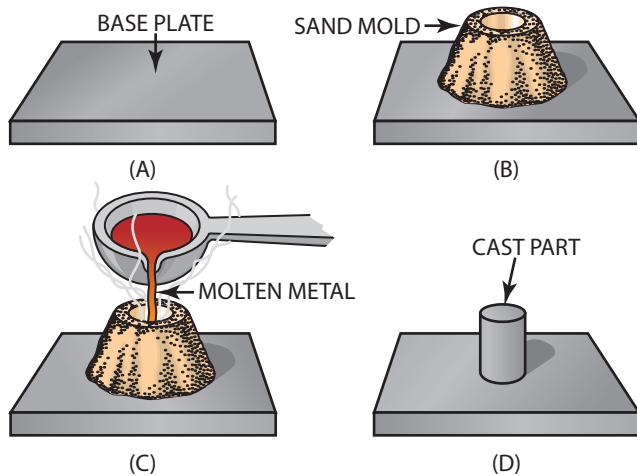


FIGURE 1-1 Direct casting: (A) base plate to have part cast on it, (B) sand molded into shape desired, (C) pouring hot metal into mold, and (D) part cast is now part of the base plate.

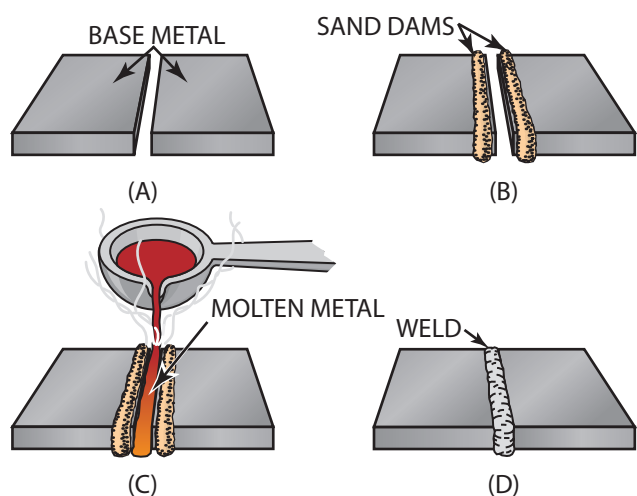


FIGURE 1-2 Flow welding: (A) two pieces of metal plate, (B) sand dams to hold molten metal in place, (C) molten metal poured between metal plates, and (D) finished welded plate.

repaired with braze welding approximately 1000 years ago, **Figure 1-3**.

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

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

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

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



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

Welding Terminology

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

WELDING DEFINED

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

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

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

USES OF WELDING

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



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

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

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

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

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

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



Larry Jeffus

Welded sculpture, Seattle, Washington.



Larry Jeffus

Roller coaster at Silver Dollar City, Branson, Missouri.



Larry Jeffus

Roller coaster at Silver Dollar City, Branson, Missouri.



Larry Jeffus

Spiral staircase in Missouri City, Texas.



Larry Jeffus

Voyager of the Sea, Haiti.



Larry Jeffus

Voyager of the Sea dining room.

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

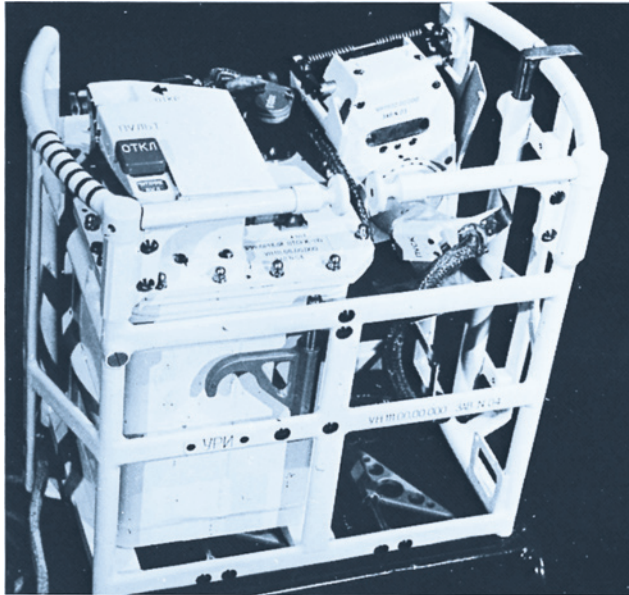


FIGURE 1-6 Machine designed to be used to weld in space.

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



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

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

WELDING AND CUTTING PROCESSES

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

The most popular welding processes are as follows: oxyacetylene welding (OAW); shielded metal arc welding (SMAW), often called stick welding; **gas tungsten arc**

welding (GTAW); gas metal arc welding (GMAW); flux cored arc welding (FCAW); and torch or oxyfuel brazing (TB). The two most popular thermal cutting processes are oxy-acetylene cutting (OAC) and plasma arc cutting (PAC).

WELDING PROCESSES

Oxyacetylene Welding, Brazing, and Cutting

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

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

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

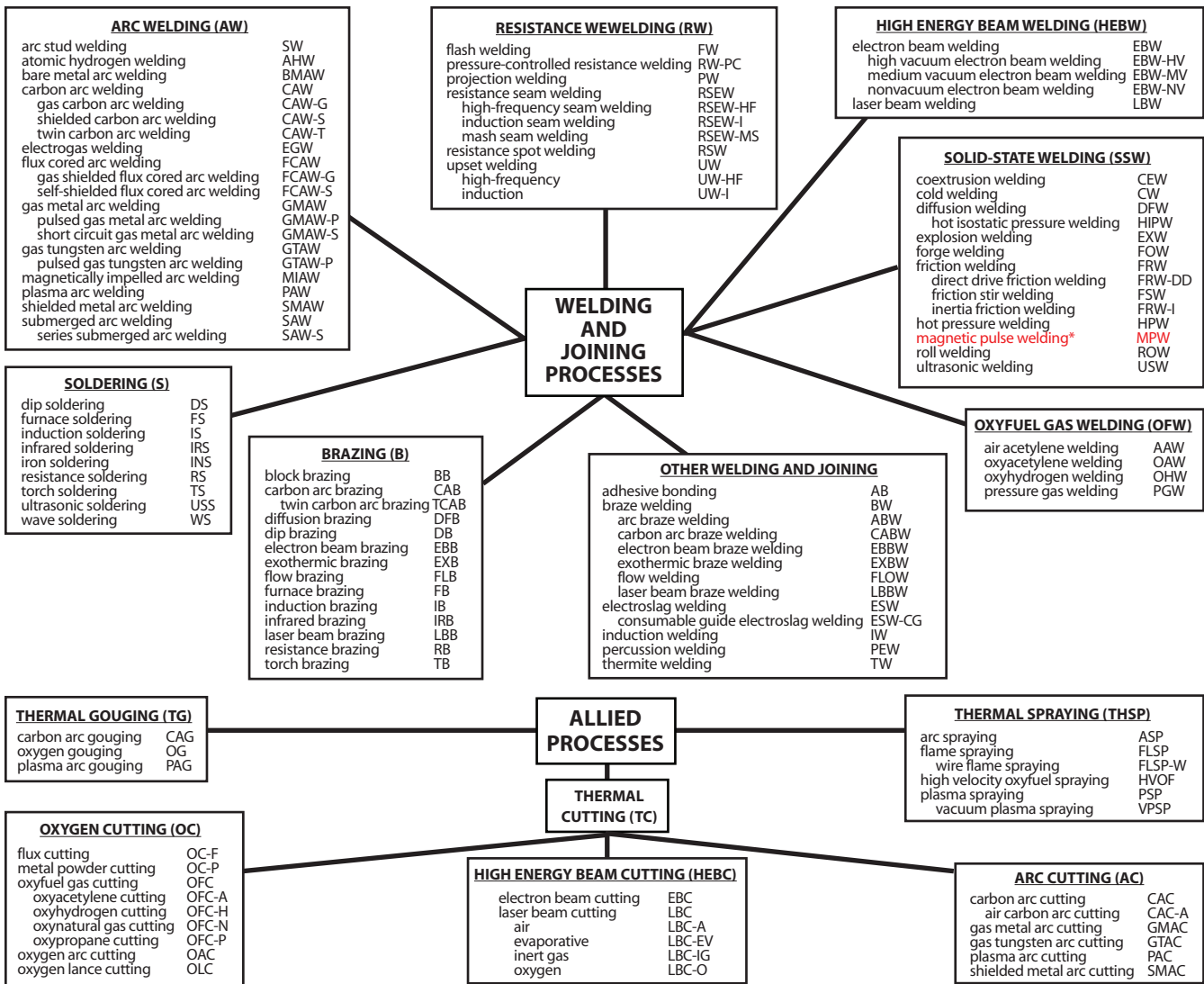
Shielded Metal Arc Welding (SMAW)

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

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

Gas Tungsten Arc Welding (GTAW)

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



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*New welding process

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

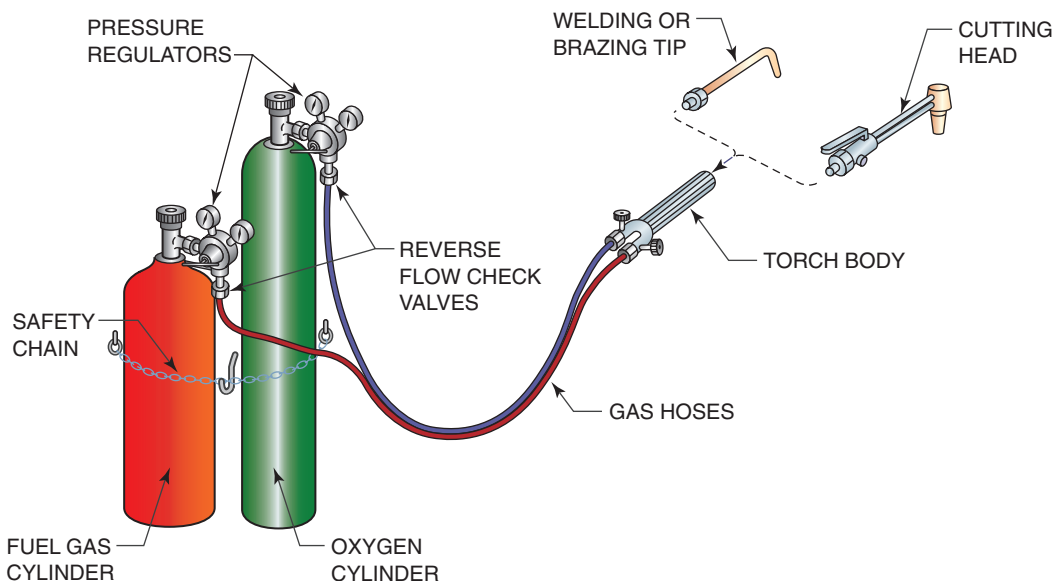


FIGURE 1-8 Oxyfuel welding and cutting equipment.

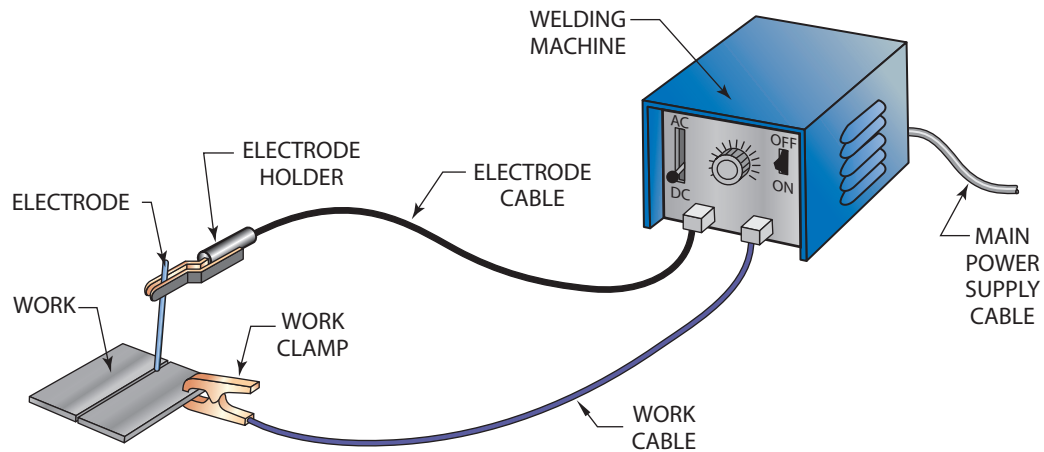


FIGURE 1-9 Shielded metal arc welding equipment.

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

GTA welding is the cleanest of all the manual welding processes. But because there is no flux used to clean the weld in GTA welding, all surface contamination, such as oxides, oil, dirt, and others, must be cleaned from the part being welded and the filler metal so they do not contaminate the weld. Even though GTA welding is slower and requires a higher skill level as compared to other manual welding processes, it is still in demand because it can be

used to make extremely high-quality welds in applications where weld integrity is critical. And there are metal alloys that can be joined only with the GTA welding process.

Gas Metal Arc Welding (GMAW)

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

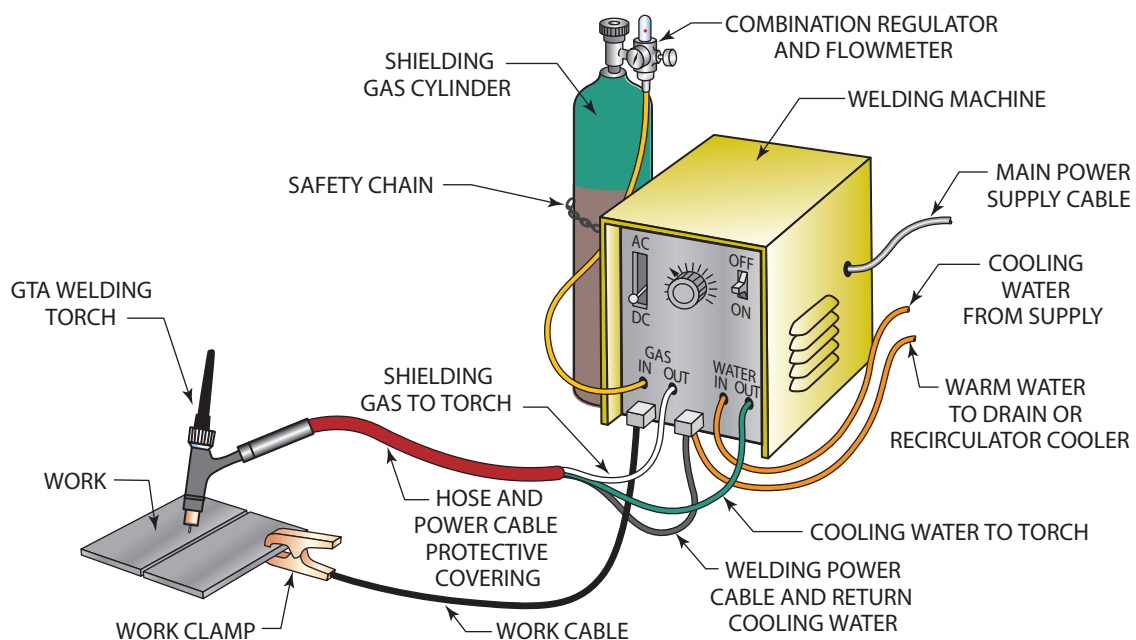


FIGURE 1-10 Gas tungsten arc welding equipment.