

Welding

David J. Hoffman, Kevin R. Dahle, David J. Fisher



Contents

PART 1 Introductory Materials 1

Chapter 1 Welding Jobs and Employment Skills 2

Introduction 3

Chapter 2 Safety in Welding 16

Safety Overview 17

The Hazardous Materials Identification System 17

Personal Protective Equipment (PPE) 19

Electrical Considerations 24

Secondary Welding Output 26

Gases and Fumes 27

Ventilation 28

Fire Prevention 29

Explosion 31

Compressed Cylinders 31

PART 2 Commonly Used Welding Processes 37

Chapter 3 Shielded Metal Arc Welding 38

Introduction 39

SMAW Safety 40

Power Source and Peripherals 40

Controls and Characteristics 46

SMAW Setup 47

Technique 56

Electrodes 66

Chapter 4 Gas Metal Arc Welding 74

Introduction 75

Safety 40

Power Source and Peripherals 76

Controls and Characteristics 79

GMAW Setup 87

Technique 94

Modes of Metal Transfer 99

Electrodes 107

Shielding Gases 121

Codes, Standards, and Specifications	432
Qualifications	435
Welding Procedures	438
Essential and Nonessential Variables	443
Weld Testing	447
Nondestructive Testing	462
Radiographic Testing	464
Ultrasonic Testing	466
Magnetic Particle Testing	469
Dye Penetrant Testing	473

Chapter 13

Welding Design 480

Introduction	481
Welding Procedure Considerations	481
Transverse and Longitudinal Shrinkage	484
Weld Joint Design	489
Aluminum Joint Design Considerations	495
Strength of Welds	499

Chapter 14

Welding Costs 505

Introduction	506
Joint Design	506
Filler Metal Weights and Process Efficiencies	507
Welding Cost Calculations	512

Chapter 15

Power Sources 524

Introduction	525
Electron Theory	525
Electrical Current	526
Direct Current (DC)	530
Alternating Current (AC)	532
Power Sources	533
Power Source Ratings	542

PART 6 Supplementary Information 552

Appendix A	Troubleshooting 553
Appendix B	Conversion 567
Appendix C	Properties 575
Appendix D	Pipes and Beams 578
Appendix E	Load Strength 584
Appendix F	Periodic Table 593

Glossary 594

Index 619

Index

Please note: Page numbers in italics indicate figures, tables, and photographs.

- Abrasive cutting, 267
Abrasive Water Jet Cutting, 304–308
 benefits of, 307–308
 defined, 304
 drawbacks of, 308
 process, 305–307, 305–308
AC. See Alternating current
AC/DC. See Alternating current/direct current
Acetylene, 215–216, 273–274
 See also Oxygen-Fuel Cutting (OFC); Oxygen-Fuel Welding (OFW)
Acetylene cutting tip, 277
Acetylene cylinder, 217, 219, 219
Acetylene flashback arrestor, 221
Acetylene hoses (R grade), 221, 221
Acetylene regulator, 219, 220
Acetylene tanks, safety and, 32
Actuators, 241, 241
Adaptability skills, 15, 15
Agglomerated flux, 256
Air Carbon Arc Cutting (CAC-A), 284–289
 air supply, 287–288
 benefits of, 285
 carbon electrode, 287, 288
 defined, 284
 drawbacks of, 285–286
 electrode and work cable, 286–287
 electrode holder, 287, 287
 power source, 286, 286
 process, 284–285, 285
 safety precautions, 289
 technique, 288–289
Air-cooled torch, 169, 169–170
 differences and similarities with water-cooled torch, 171
Air dryer, 295, 296
Air-hardening alloys, 327, 328
Airline respirators, 29
Air Reduction Company, 75
Air supply
 Air Carbon Arc Cutting (CAC-A), 287–288
 Plasma Arc Cutting (PAC), 295, 297
AIISI. See American Iron and Steel Institute
Allowable Stress Design (ASD), 499–502
Allowable Unit Load, 499–502
Alloying elements by weight (AWS), 110, 114, 119
Alloys
 aluminum classifications and types, 328–329, 330–331, 388–394, 391–393
 carbon steel classifications and types, 323–324, 324
 cast iron classifications and types, 384–388, 387
 copper classifications and types, 329, 330
 information for calculating costs, 507, 508
 magnesium classifications and types, 394–395, 395–397
 metal alloy groups, 331
 nickel classifications and types, 396–397, 398–399
 stainless steel classification and types, 326–327, 326, 378–381, 382
 titanium classifications and types, 400–401, 401
 tool steel classification and types, 328, 328, 380, 383–384, 383
 See also Headings under specific alloys
Alloy steels, 366–378, 367–379
 AWS suffixes for filler metal classifications, 367, 368
 chromium-molybdenum steels, 376–378, 377–379
 classifications and types, 324–325, 325–326, 331
 hardness conversion table for, 577–578
 heat-treatable low-alloy (HTLA) steels, 372, 375–376, 376
 high-strength low-alloy (HSLA) steels, 368–371, 369–372
 quenched and tempered steels, 371–372, 373–374
Alloy tree, 391
All position groove 6G, 7
All position groove 6GR (T, K, and Y joints), 7
All Weld Metal Test, 460–461, 462
Alternating current (AC), 25, 48–52, 71, 525, 532–548, 532
AC/DC formulas, 575
 changing to DC (rectification), 535–536, 535–536, 570
Gas Tungsten Arc Welding (GTAW), 178–179, 185–191, 188, 191, 195–196
Oxygen-Fueled Cutting (OFC), 284
Shielded Metal Arc Welding (SMAW), 40–41
Submerged Arc Welding (SAW), 253
 See also Power sources
Alternating current/direct current (AC/DC)
 formulas for, 575
Gas Tungsten Arc Welding (GTAW), 168, 185, 190–192, 191
Plasma Arc Welding (PAW), 232
Shielded Metal Arc Welding (SMAW), 40, 41, 52
Aluminum
 AWS classification of solid aluminum electrodes, 120
 classifications of, 328–329, 329–331
 filler metals, 208
 groove joints, 496–497, 496
 lap joints, 495, 495–496
 shielding gases and, 129–130, 130
 strengthening joint welds, 497–498, 498
tapering, 498, 498
T-joints, 495–496
triangular plate, 498, 498
welding with sharpened tungsten with an inverter power source, 179, 180
Aluminum alloys, 388–394
 base metal and welding alloy tree, 390, 391
 color matching, 390
 eliminating cracks, 394
 filler metals for, 390, 392–393
 identifying base metals, 390
 shielding gases for, 389–390
 special considerations for welding, 389–391, 394
 surface oxide prevention during storage, 389
Aluminum Association classifications, 328–329, 329–330
Aluminum electrodes, 106, 106, 120, 120–121
American Iron and Steel Institute (AISI)
 abridged chart of tool steel types, 383
 minimum preheat and interpass temperatures for low-alloy steels, 376
 stainless steel classifications, 326, 326
 steel classifications, 324–325, 325
American National Standards Institute (ANSI), 17
 approved welding filters, 21
 lens shades, 22
American Petroleum Institute (API), 429, 451–452
 bend test, 455
 examination criteria after destructive testing, 461
 radiographic testing, 464
 visual examination criteria before destructive testing, 449
American Society for Mechanical Engineers (ASME), 429
 essential variables, 443, 444–445
 examination criteria after destructive testing, 461
 fillet plate and pipe test, 449, 450
 fillet weld tests, 454, 454
 radiographic testing, 463–464
 visual examination before destructive testing, 449
 welder qualifications, 437–438
Weld Testing for Plate and Pipe, 453
American Society for Testing Materials (ASTM)
 carbon steel, 324
 composition of magnesium alloys, 395
 quenched and tempered steels, 373–374
 specifications for chromium-molybdenum steel product forms, 377
 specifications for high-strength low-alloy structural steels, 369–372
American Welding Society (AWS)
 bend test, 455
 carbon equivalence formula, 363
 Certification Manual for Welding Inspectors, 430
 Certified Associate Welding Inspector (CAWI), 432, 433
 Certified Welding Inspector (CWI), 429–432, 433
 chemical composition requirements of solid stainless steel electrodes, 116
 composite stainless steel electrodes, 119
 composite steel electrodes, 114
 composition of magnesium filler metals, 395
 composition of typical heat-treatable low-alloy steels, 375
 defect and discontinuity defined, 554
 essential variables, 443, 444–445
 examination criteria after destructive testing, 461
 filler metals for Shielded Metal Arc Welding (SMAW), 67
 filler metal to weld carbon steels, 223
 fillet weld tests, 454–455, 454
 formula for carbon equivalency, 363
 low-alloy filler metal suffixes, 70
 low-alloy flux-cored electrodes, 157
 major alloying elements by weight, 110, 114, 119, 205
 mechanical properties, 117
 mild steel flux-cored electrodes, 156
 numbering system for electrode identification, 68
 radiographic testing, 464
 ranges for carbon steel electrodes, 71
 ranges for stainless steel electrodes, 72
Safety in Welding, Cutting, and Allied Processes, 17, 31
Senior Certified Welding Inspector (SCWI), 432, 433
solid aluminum electrodes, 120
solid stainless steel electrodes, 116, 206
solid steel electrodes, 110
specifications for chromium-molybdenum steels, 378–379
stainless steel flux-cored electrodes, 158
Standard Welding Terms and Definitions, 554–555, 555
steel filler metals, 205
steel fillet welds, 499
steel flux-cored electrodes, 154
steel partial penetration groove welds, 500
Structural Steel Welding Code, 464
suffixes for filler metal classifications and corresponding chemical compositions, 368

- T-joint fillet weld test, 450
 tungsten electrodes, 209, 209–210
 ultrasonic testing, 464
 visual examination criteria before destructive testing, 449
 weldability, defined, 362
 weld and supplementary symbols, 409
 welder qualifications, 437–438
 welding and brazing processes, 408
 welding positions (standardized), 6, 7–9
 weld symbols, 405, 408
 Weld Testing for Plate and Pipe, 452
- Ampere**, 46, 52
 insufficient, 564
- Amperage control**
 Flux Cored Arc Welding (FCAW), 138, 139, 144
 Gas Metal Arc Welding (GMAW), 88–89, 99
 Gas Tungsten Arc Welding (GTAW), 183, 184, 191–192, 195–196, 195
- Shielded Metal Arc Welding (SMAW)**, 46, 46
- Angle iron**, 323
- Angular shrinkage of groove joints**, 484, 487–488, 487
- Annealing**, 353–356, 354–356
- ANSI**. See American National Standards Institute
- API**. See American Petroleum Institute
- Arc**
 erratic arc, 564
 no arc, 564
 starting (scratch technique), 61, 61
- Arc blow**, controlling, 50, 50–51
- Arc burns**, 19
- Arc control**, 47, 47, 52–53, 82
 See also Arc force; Inductance
- Arc cutting**. See Air Carbon Arc Cutting (CAC-A); Plasma Arc Cutting (PAC)
- Arc flashes**, 21
- Arc force**, 82
 See also Arc control; Inductance
- Arc gap**, 189, 189, 525–526
- Arc gouging**, 484
- Arc length**, 50, 50–51, 89, 89, 138, 138, 201
 determining, 56, 56
 tungsten and, 201
- Arc rays**, 23–24
- Arc strikes**, 555, 555
- Arc voltage**, 57, 89, 144
 See also Voltage
- Arc welding**, 26, 408, 524–551
 See also Flux Cored Arc Welding; Gas Metal Arc Welding; Gas Tungsten Arc Welding; Plasma Arc Welding; Power sources and peripherals; Shielded Metal Arc Welding; Submerged Arc Welding
- Area equivalents**, 572
- Argon/carbon dioxide/hydrogen tri-mix shielding gas**, 128
- Argon/carbon dioxide/oxygen tri-mix shielding gas**, 126
- Argon/carbon dioxide shielding gas blend**, 124, 153, 161–163, 162–163
- Argon/helium/carbon dioxide tri-mix shielding gas**, 127–128
- Argon/helium shielding gas blend**, 130, 161–163, 162–163
- Argon/nitrogen/carbon dioxide tri-mix shielding gas**, 128
- Argon/oxygen shielding gas blend**, 124–125, 127
- Argon shielding gas**, 28, 129–130, 130
 for Gas Tungsten Arc Welding (GTAW), 181–182, 181, 208–209
 for Plasma Arc Welding (PAW), 235
 for titanium alloys, 400–401
- Arrow of a welding symbol**, 406, 406
- Arrow side of a welding symbol**, 406, 407
- Artisans**, 10
- ASD**. See Allowable Stress Design
- ASME**. See American Society for Mechanical Engineers
- Asperities**, 259
- Asphyxiant**, 182
- ASTM**. See American Society for Testing Materials
- Atoms**, 337–338, 526–527, 527
- Austempering**, 353, 354
- Austenite (gamma iron)**, 340, 341, 345–347, 362
- Austenitic stainless steel**, 326–327, 381
- Auto-darkening welding helmets**, 21–22, 22
- Autogenous (fusion) weld**, 203
- Automatic welding**, 75
- AWS**. See American Welding Society
- Axial-spray transfer**, 99, 104–105, 105, 107, 124, 125
- Baby boomer generation**, 3
- Back cap**, 173–174, 174
- Background current**, 193, 193
- Backhand technique (drag)**, 58, 58, 96, 97, 98, 149–150, 150
- Backing play symbol**, 420, 420
- Backing weld**, 422
- Backstep sequence**, 365
- Back weld**, 421
- Bainite**, 350
- Balance control**, 186–188, 188
- Balance for AC**, 196
- Base metal and welding alloy tree**, 391
- Base metals**
 cracking and, 366
 electrode positioning and, 57–66, 58–66
 filler metal classifications for, 367, 368, 370–372
 hydrogen in, 362–364
 testing compatibility with filler metals (coupons), 429
 thickness, 152–153
- Battelle Memorial Institute**, 75
- Bead shape**, 59, 89, 89
- Beams**, 583, 583–584
- Belt grinder**, 177, 177–178
- Bend tests**, 455–456, 455–457, 461
- Bevel angle (taper)**, 268, 268
- Bevel cut**, 271, 271
- Bevel-groove welds**, 490–491, 491
- Bevel-groove weld symbols**, 420–421, 420
- Bird's nest**, 88, 89
- Black pipe**, 580, 580–581
- Blacksmithing**, 3, 10
- Block sequence**, 365, 365
- Blueprint reading**, 13, 15
- Body-centered tetragonal space lattice**, 345
- Bolting**, 3
- Bonded flux**, 256
- Box weave pattern**, 65
- Brasses**, 329
- Brazing**, 387–388, 408
- Breaker requirements**, 545
- Breakers**, 525, 548–549
- Bridge Cam Gauge**, 463
- Bright annealing**, 355
- Brinell testing for hardness**, 320, 576–578
- Brittleness**, 318
- Bronze Age**, 3
- Bronzes**, 329
- Bureau of Labor and Statistics (U.S. Department of Labor)**
- job category 51–4121, Welders, Cutters, Solderers, and Brazers**, 3–4, 4
- job category 51–4122, Welding, Soldering, and Brazing Machine Setters, Operators, and Tenders**, 4, 6
- Burns**, 24
 electrical, 24–25
- Burst disc**, 32
- Business use, power sources and**, 77–78, 86, 136–137
- Butt joint**, 149
- CAC-A**. See Air Carbon Arc Cutting
- Carbide precipitation**, 117, 380–381
- Carbon dioxide**, 123, 153, 161–163, 162–163, 301
- Carbon equivalence**, 363, 363
- Carbon monoxide**, 28
- Carbon steel**, 323–324, 324
 carbon equivalence, 363, 363
 classifications and weldability, 68, 68, 324–325, 325–326, 362–363, 362–363
 cracking, 362–364
 distortion, 364–365, 365
 filler metal for Gas Tungsten Arc Welding, 205–206
 filler metal for Oxygen-Fueled Welding, 223
 hardness conversion table for, 577–578
 heat treatments for, 355–356, 356
- high-carbon steels**, 323
- joint design and**, 494
- low-carbon steels**, 323
- medium-carbon steels**, 323
- Oxygen-Fuel Cutting (OFC)** and, 273, 275
- preheat, interpass, and postheats**, 365–366, 366
- problems with carbon steel welds**, 363–364
- ranges for common carbon steel electrodes**, 71
- shielding gases for**, 123–126, 125–126
- ultra-high carbon steels**, 323
- Carburizing flame**, 223, 224
- Career opportunities**, 10
 See also Employment
- Cascade sequence**, 365, 365
- Cast and helix**, 567, 567
- Cast irons**
 classifications of, 327–328
 filler metals for, 387, 387
 joining with an oxy-fuel torch, 387–388
 process of welding, 385–387
 weldability of, 384–385
- Cast iron spark testing**, 335, 335
- Cathodic etching**, 186, 187
- CAWI**. See Certified Associate Welding Inspector (American Welding Society), 432
- CC**. See Constant current
- CC/CV**. See Constant current/constant voltage (CC/CV) power source
- Cellulose-coated electrodes**, 65–66, 66
- Celsius/Fahrenheit conversion**, 574
- Cementite (iron carbide)**, 341, 341
- Certification**, for welding inspectors, 430–432, 432–433
 See also Qualifications
- Certification Manual for Welding Inspectors** (Educational Department of AWS), 430
- Certified Associate Welding Inspector (CAWI)** (American Welding Society), 432, 433
- Certified Welding Inspector (CWI)** (American Welding Society), 429–432, 432, 433
- Chain intermittent weld**, 412, 412
- Channel iron**, 323, 584, 584
- Charpy and Izon impact testing**, 318–319, 318
- Check valves**, 220, 220
- Chemical etching**, 186
- Chemical laboratory wet testing techniques**, 336
- Chemical reaction welding**, 525
 See also Oxygen-Fuel Welding (OFW)
- Chromium alloys**, 327
- Chromium carbides**, 494
- Chromium-molybdenum steels**, 376–378, 377–379
- Chromium-nickel alloys**, 380
- Chromium-nickel-manganese alloys**, 381
- Circuit requirements**, 545
- Circular welding technique**, 66, 66
- Cloisonné**, 11, 12
- Closed circuit**, 529–530, 530
- Clothing, for safety**, 19–20, 20
- Coalescence**, 525
- Coated electrodes**, 39
- Codes**, 434
- Codes, standards, and specifications**, 432–435
 differences among, 433–434, 434
 how codes are used in industry, 434–435, 435
- Procedure Qualification Record (PQR)**, 433
- reason for**, 432–433
- Welder Qualification Test Record (WQTR)**, 434
- Welding Procedure Specifications (WPS)**, 433
- Cold Drawn Seamless**, 581
- Cold-rolled steels (CRS)**, 323, 356–357, 357, 579
- Cold starts**, 498, 500
- Cold welding (CW)**, 261
- Collet**, 171, 172
- Collet body**, 171, 172–173, 173
- Combination weld symbols**, 421–422, 421
- Compacted graphite cast iron**, 327
- Compensation (wages)**, 4, 6
- Complete cut**, 269
- Complete joint penetration groove welds**, 499
- Composite electrodes**, 113–115, 114–115, 118–120, 119–120
- Compressed cylinders**, 31–34, 33
- Compression loads**, 482
- Compressive strength testing**, 319
- Concave fillet welds**, 5
- Concave groove welds**, 447, 448
- Concave root surface (suck back)**, 556, 556

Conductors, 24, 526–530, 528–529

recommended primary conductor size, 545

Constant current (CC), 545–546

Stud Welding (SW), 247

Submerged Arc Welding (SAW), 252–253

Constant current/constant voltage (CC/CV) power source, 545–546, 546

Constant voltage (CV), 545–546

Consumable insert, 423

Contact tips, 77, 77, 142, 142

Controllers

Abrasive Water Jet Cutting, 307, 307

Plasma Arc Welding (PAW), 232

Stud Welding (SW), 248

Controls

Flux Cored Arc Welding (FCAW), 137–140, 138–140

Gas Metal Arc Welding (GMAW), 79–85, 80–86

Gas Tungsten Arc Welding (GTAW), 174–175, 175–176, 183–196, 184–196

Shielded Metal Arc Welding (SMAW), 46–47, 46–47

See also Output control

Conversions

AC/DC formulas, 575

area equivalents, 572

common formulas, 574

decimal/fractional chart, 568–570

electrode length per unit of weight, 574

Fahrenheit/Celsius, 574

fluid capacity equivalents, 573

kinetic energy, 575

length equivalents, 572

millimeters to decimal conversion, 571

Ohm's law, 575

sheet metal gauge, decimal equivalent, and weight equivalent, 570–571

voltage drop formulas, 575

volume and capacity equivalents, 573

weight equivalents, 572

welding-related conversion formulas, 573–574

Convex fillet welds, 5, 463

Convex groove welds, 447, 448

Convex weld bead, 364

Coolant, in a water circulator, 181

Coolant line, 172, 172

Cooling curves for steels. See Time Temperature Transformation (TTT) diagrams

Cooling rates

effects on metal grains, 338–339 on the iron-carbon diagram, 343–345, 344

Time Temperature Transformation (TTT) diagrams for determining, 346–355, 347–356

See also Time Temperature Transformation (TTT)

Copper, 529–530

Copper alloys, 11, 329, 330

Copper atom, 527–529, 527

Corner joint, 48

Costs, 505–523

calculations

efficiency, 509, 513–515

flux use, 518–519

labor costs, 519–520

overhead costs, 520–521

power costs, 521–522

price variables, 515–517

spot welding, 518

typical welding operations, 518

weight, 508, 510–511, 512

efficiency variables for, 508–509, 509

electrode information for, 508, 509

key acronyms, 505

metals/alloys information needed for calculating, 507, 508

size, cross-sectional area (CSA), and steel weld deposit information for, 509, 510–511

weld joint design, 506–507, 507

Coupons. See Weld coupons

Cracking, 362–366, 386, 394, 401,

457, 457, 483–484, 483, 556–557,

556

types of, 556

Craftsmen, 10

Creep strength testing, 319

Crescent weave pattern, 64, 65

Critical core skills cluster, 14–15, 15

Cross-sectional area and steel weld deposit, 509, 510–511

CRS. See Cold-rolled steels

Crystalline structure of metals, 336–340

make-up of metals, 336–338, 337

metal grains, 336–340, 337,

339–340

effects of cooling on metal grains, 338–339

effects on metal grains from forming operations, 339–340,

339–340

grain direction, 339–340, 340

unit cells, 336–338, 337

Cup nozzle, 171, 172

Current (welding amperage), 528–529, 529

Current controls, remote, 174–175, 175–176

Current density, 108

Cutting bed, 307, 307

Cutting processes, 266–310

Abrasive Water Jet Cutting,

304–308, 305–308

Air Carbon Arc Cutting (CAC-A), 284–289, 285–288

Laser Beam Cutting (LBC), 300–304,

301, 303

operations

bevel cut, 271, 271

complete cut, 269

edge cut, 269–270, 270

etching, 271–272, 272

gouging, 271, 271

piercing cut, 270–271, 270

Oxygen-Fuel Cutting (OFC), 268,

271–283, 272–284

Plasma Arc Cutting (PAC), 269–271,

289–300, 290–299

terminology

drag lines, 268–269, 269

dross, 268, 269

heat-affected zone (HAZ), 268,

268

kerf, 267, 268

taper (bevel angle), 268, 268

ways to cut and shape metal, 267

See also Abrasive Water Jet

Cutting; Air Carbon Arc Cutting

(CAC-A); Laser Beam Cutting

(LBC); Oxygen-Fuel Cutting (OFC);

Plasma Arc Cutting (PAC)

Cutting tips, 276–277, 277

CV. See Constant voltage

CW. See Cold welding

CWI. See Certified Welding Inspector (American Welding Society)

Cylinders

acetylene, 217, 219, 219

compressed, 31–34, 33

oxygen, 217, 218

DC. See Direct current (DC)

DCCV. See Direct current constant voltage

DCEN. See Direct current electrode negative

DCEP. See Direct current electrode positive

Decimal/fractional chart, 568–570

Decimal to millimeter conversion, 571

Defects

defined by AWS, 554

identifying, 554–555, 555

See also Testing; Troubleshooting defects and discontinuities

Deoxidizers, 123, 153

Deposition efficiency, 514

Deposition rate (DR), 515–517

Dermis, 24

Design. See Weld joint design

Destuctive testing, 429, 447–462

examination criteria after (AWS, ASME, and API), 461

See also Testing

Diameter conductors, 532

Diffusion, 259–260

See also Solid state welding processes

Diffusion welding, 262

DINSE adapter, 45, 46

Diode, 535, 535

Direct current (DC), 525, 530–531, 531

AC/DC formulas, 575

changing of AC to DC (rectification), 535–536, 535–536, 540

Gas Tungsten Arc Welding (GTAW) and, 168, 196

Plasma Arc Welding (PAW) and, 232

Shielded Metal Arc Welding (SMAW) and, 40, 41

Stud Welding (SW), 247

Submerged Arc Welding (SAW), 252–253

Direct current constant voltage (DCCV) welder, 77

Direct current electrode negative (DCEM), 48–52, 49, 176, 178–179,

185–189, 186, 188, 191–192,

195–196

See also Polarities

Direct current electrode positive (DCEP), 48–52, 49, 71, 179,

185–188, 187–188, 191–192, 195,

284, 531, 531

See also Polarities

Discontinuities, 362–363, 447

defined by AWS, 554

identifying, 554–555, 555

measuring the greatest dimension of, 457, 457

undesirable weld discontinuities, 449

visual types, 447–448, 448–449

See also Testing; Troubleshooting defects and discontinuities

Distortion, 321, 327, 364–365, 365

Doubler, 498

DR. See Deposition rate

Drag/backhand technique. See Backhand technique (drag)

Drag lines, 268–269, 269

Drag shield, 296–297, 297

Drawn Over Mandrel, 581–582

Drive rolls, 83, 83–84, 87, 141

See also Knurled drive rolls

Drop-through, 557–558, 557

Dross, 268, 269

Dual blends/binary blends (shielding gases), 124–125, 127, 130

Dual-shielded shielding gas, 134

Ductile cast iron, 327

Ductile metals, 261, 364, 483

Ductility, 316–318, 316–317

Duplex stainless steel, 327

Duty cycles, 41, 84, 137, 525, 543–544, 543–544

Dye penetrant testing, 464, 473–477, 474–477

Dynamic loads, 482

Earplugs, 21

Edge cut, 269–270, 270

Edge joint, 48

Edge weld symbol, 424, 424

Effective throat, 420, 491, 491

Efficiency, calculating costs and, 508–509, 509, 513–515

EGW. See Electrogas Welding

Elasticity, 315–316, 316

Electrical arc welding, 525

See also Power sources

Electrical current, 24–27, 26–27,

525–530, 527–530

Electrical grid system, 525

Electrical hazards, 24–27, 26–27

Electrode coatings, 67

Electrode extension (stick out), 94, 94, 148, 148

Electrode holder, 27, 43–45, 44–45, 287, 287

Electrode lead, 27, 42

Electrode manipulation, 364–365

Electrode oscillation, 203–204, 204

Electrodes, 39, 367, 531, 531

Air Carbon Arc Cutting (CAC-A), 286–289, 287–288

cellulose-coated, 65–66, 66

composite, 113–115, 114–115,

118–120, 119–120

mild steel, 152, 154–157, 154–156

stainless steel, 158–159, 158

weld parameters, 159, 159–161

Gas Metal Arc Welding (GMAW), 87

aluminum electrode wire, 120, 120–121

categories/classifications,

154–159, 154–158

choosing, 152–154

low-alloy, 157, 157–158

mild steel, 152, 154–157, 154–156

stainless steel, 158–159, 158

weld parameters, 159, 159–161

Gas Tungsten Arc Welding (GTAW), 176–179, 176–180, 209, 209–210

information for calculating costs, 508, 509

length per unit of weight, 574

manipulating, 62–63, 62–63

melting of mild steel and electrodes, 529–530

- Plasma Arc Cutting (PAC), 294–295, 295
 Resistance Spot Welding (RSW), 240, 241
 selecting, 47–48, 48
 Shielded Metal Arc Welding (SMAW), 47–48, 48, 57–71, 58–70
 classifications, 66–70, 67–70
 settings for, 70–71, 71–72
 Submerged Arc Welding (SAW), 255, 255
 Electrode tension, 88
 Electrode tips, 240, 241
 Electrogas Welding (EGW), 258
 Electromotive force (voltage), 528–529, 529
 Electron flow, 49
 Electrons, 24, 526–529, 527–529
Electroslag Consumable Guide Welding (ESW-CG), 258
 Electroslag welding, 257–258, 257
 Elements, periodic table of, 594
 Elongation, 316–318, 316
 Employment
 compensation, 4, 6
 demands for, 3
 job types, 3–4, 4, 6, 6
 joint nomenclature, 4, 5–6
 skill sets for, 13–15, 14–15
 welder, cutter, solderer, and brazer applications, 10–12, 10–13
 welding inspectors, 430–432, 432–433
 welding positions, 6, 7–9
 See also Bureau of Labor and Statistics
 Endurance limit, 319
 Epidermis, 24
 Essential variables, 439, 443, 444–445
ESW-CG. See *Electroslag Consumable Guide Welding*
 Etching, 271–272, 272
 Examinations, for welding inspectors, 430–431
 Excessive melt-through, 560, 560
 Explosions, 31
 Explosion welding (EXW), 262–263
 Extra-low-carbon alloys, 380
 EXW. See *Explosion welding*
 Eye protection, 21–23, 22, 23
 Fahrenheit/Celsius conversion, 574
 Fatigue strength testing, 319
FCAW. See *Flux Cored Arc Welding*
 Feet, safety and, 21
 Ferrite (alpha iron), 340, 341
 Ferritic stainless steel, 327
 Ferrous metals
 background information, 322–323
 carbon steels, 323–324, 324
 cast irons, 327–328
 metal alloy group, 331
 stainless steel, 326–327, 326
 steels, 324–325, 325–326
 tool steels, 328, 328
 See also Headings under specific ferrous metals
 Ferrules, 250
 Filigree welding, 11, 12
 Filler addition, 202–203, 203
Filler metals, 3
 aluminum welding, 208, 390, 392–393
 for cast irons, 387, 387
 for chromium-molybdenum alloys, 376–377, 378
 classifications for matching base metals, 367, 368, 370–372, 378
 costs, 507–509, 508–511
 Gas Metal Arc Welding (GMAW), 111–112, 116–118, 118–120, 120–121, 121
 Gas Tungsten Arc Welding (GTAW), 182, 182, 202–208, 203, 205–206
 low-alloy suffixes, 70, 368
 magnesium alloys, 394–395, 395–397
 melting temperatures and, 322
 for Oxy-Fuel Welding, 222–223, 223
 Shielded Metal Arc Welding (SMAW), 66, 67
 for stainless steels, 206–207, 206, 382
 for steels, 205
 testing compatibility with base metals (coupons), 429
 titanium alloys, 401, 401
 for tool steels, 384
 weights and process efficiencies, 507–509, 508–511
 to weld carbon steels, 223
 for welding nickel alloys, 399–400
Fillet multiple position 6F, 8
Fillet plate and pipe test (ASME), 449, 450
Fillet welds, 5, 7–9, 58, 59, 149
 continuous, 488
 gauges for measuring, 462–463, 462–464
 overwelded, 506–507, 507
 performance weld tests, 450
 poor fit-up, 507, 507
 tests on, 454, 454–455, 461, 462–463, 463
 transverse shrinkage in, 488
 weld joint design, 490–491, 490–491, 496
 See also Welding positions; Welding symbols
Fillet weld shear test, 319, 499–502, 499–502
Fillet weld symbol, 405, 410–414, 411–413
Fire prevention, 29–31
Fire watchers, 30
Flame types, in Oxy-Fuel Welding, 223–224, 224
Flare bevel-groove weld symbols, 423–424, 423
Flare V-groove weld symbols, 423, 423
Flashback, 220
Flashback arrestors, 220–221, 221
Flashlight, 530, 531
Flash Welding (FW), 242
Flat fillet position 1F, 9
Flat fillet position 1F (rotated), 7
Flat groove position 1G, 8
Flat groove position 1G (rotated), 7
Flow meters, 85, 86, 140
Flow rate, 122
Fluid capacity equivalents, 573
Fluorescent bulbs, 302
Flux, 39
 agglomerated, 256
 bonded, 256
 cost equation for, 518–519
 fused, 256
 lines of between primary and secondary coils, 534, 534
 Submerged Arc Welding (SAW), 254–256, 254
 See also Flux Cored Arc Welding (FCAW)
Flux coatings, 66–67
Flux Cored Arc Welding (FCAW), 133–164
 compared to Gas Metal Arc Welding (GMAW), 134–137, 139–140, 140, 142, 142
 compared to Gas Tungsten Arc Welding (GTAW), 182
 compared to Shielded Metal Arc Welding (SMAW), 134
 controls and characteristics, 137–140
 voltage control: potential, 137–138, 138
 welding torches (guns), 139–140, 140
 wire feed speed, 138–139, 139
electrodes, 141–144, 142, 148–151, 148–150
 categories, 154
 choosing, 152–154
 classifications, 154–159, 154–159
 low-alloy, 157, 157–158
 stainless steel, 158–159, 158, 381
 steel, 152, 154–157, 154–156
 weld parameters, 159, 159–161
 generators and, 548
 gloves and, 21
 historical background, 134
 power source and peripherals, 135–137, 136, 140–144, 141–143, 545
 basic equipment, 135
 safety, 134, 135
 setup and step-by-step directions, 140–144, 141–148
 shielding gases, 141, 141, 153–154, 161–163, 162–163
 technique, 148–151, 148–151
 troubleshooting, 566–567
Flux-cored electrodes
 low-alloy classifications (AWS), 157–158
 mild steel classifications (AWS), 156
 stainless steel classifications (AWS), 158
 steel classifications (AWS), 154
 weld parameters, 159, 159–161
 See also Flux Cored Arc Welding (FCAW)
Flux delivery system, Submerged Arc Welding (SAW), 254, 255
F-numbers grouping of electrode and welding rods, 446
Foot control, remote, 175, 175, 234
Forehand technique (push), 96, 97, 98, 99, 150, 150, 201
Forge-welded 33 layers, 10–11, 11
Forge-welded Mezzaluna cutter, 11
Forge welding, 3, 10, 261–262
Forming operations, 339–340, 339–340
Formulas
 AC/DC, 575
 common formulas, 574
 Fahrenheit/Celsius conversion, 574
 to get electrode length per unit of weight, 574
 kinetic energy, 575
 Ohm's law, 575
 voltage drop formulas, 575
 welding-related conversions, 573–574
 See also Conversions
Fractional/decimal chart, 568–570
Frequency (Hz), 532
Friction lighter, 222, 223, 277, 277
Friction welding (FRW), 263, 525
FRW. See *Friction welding*
Fuel gases
 cutting tips and, 276, 277
 safety and, 32
 types of, 278
Full annealing, 353–356, 354
Full-face shield, 22, 22
Full Range Potentiometer, 80–82, 81, 83
Fumes, safety and, 27–28
Fused flux, 256
Fuse requirements, 545
Fusion incomplete, 558–559, 558
Fusion welding, 387–388
FW. See *Flash Welding*
Garnet hopper, 305–306, 306
Gases
 safety and, 27–28
 toxic, 28
Gas hose, 172, 172
Gas leaks, testing for, 33–34
Gas lens collet body, 173, 173
Gas mark (worm tracking), 560–561, 561
Gas Metal Arc Welding (GMAW), 74–132
 compared to Flux Cored Arc Welding (FCAW), 134–137, 139–140, 140, 142, 142
 compared to Submerged Arc Welding (SAW), 250–251
 controls and characteristics, 79–85, 80–86
 drive rolls, 83, 83–84
 gas regulator or flow meter selection, 85, 86
 inductance or pinch effect control on a power source, 82, 82
 slope control on a power source, 81–82, 82
 voltage (potential), 79–81, 80–81
 welding torches (guns), 83–85, 85
 wire feed speed, 81, 82
electrical current flow of, 26, 27
electrodes
 aluminum electrode wire, 120–121, 120–121
 categories of, 108–110, 109–110
 composite electrodes, 113–115, 114–115, 118–120, 118–120
 filler metal characteristics of steel electrodes, 111–112, 112–113
 stainless steel specifications/classifications, 115–120, 116–120
 steel electrodes, 107–108, 111–112, 112–113
 historical background, 75
 home and business use, 77–78, 79
 metal transfer modes, 99–106, 100–107
 axial-spray transfer, 104–105, 105, 107, 124, 125
 globular transfer and, 104, 104–105
 inductance and, 103–104, 103
 pulse-spray transfer, 105–106, 106, 107
 short-circuit, 99–104, 100–103, 105, 107, 124, 125
 slope and, 101–102, 101–102
 parts of, 76–77, 77
 power source and peripherals, 76–78, 77–79, 545–546
 power source guide chart, 86
 safety, 75–76, 76

Gas Metal Arc Welding (*continued*)
 setup and step-by-step procedures, 87–89, 88–93
 shielding gases, 121–130
 comparison chart for carbon steels, 126
 properties and characteristics of, 122–123, 122–123
 for welding aluminum, 129–130, 130
 for welding carbon steel, 123–126, 124–126
 for welding stainless steel, 126–128, 128–129
 stainless steel and, 381
 technique, 94–99, 94–99
 drag/backhand technique, 96–98, 97
 electrode extension, 94, 94
 oscillation and travel speed, 97–98, 98
 push/forehand technique, 96–98, 97
 travel angle, 94–96, 95–97
 work angle, 94–95, 95
 troubleshooting, 566–567
 variations in the GMAW process, 107
 Gas regulators, 85, 86, 140
 Gas-shielded electrodes, 134, 151, 153
 Gas Tungsten Arc Welding (GTAW), 165–211, 183–196
 AC frequency control, 190, 191
 background, 166
 compared to Plasma Arc Welding (PAW), 230–231
 controls and characteristics
 AC frequency control, 190, 191
 AC wave form, 191, 191
 amperage, 183, 184, 195–196, 195
 balance control, 186–188, 188, 196
 high frequency, 188–189, 189, 191
 independent amperage control, 191–192
 lift arc, 189–190, 190
 polarity, 185–188, 185–188, 190–191, 190–192
 postflow of shielding gas, 184, 184, 196
 preflow of shielding gas, 184, 196
 pulser control, 192–194, 192–193
 remote current control, 174–175, 175
 sequencer, 194
 spot timer, 194
 electrodes, 176–179, 176–180, 209, 209–210
 filler metals, 182, 182, 202–208, 203, 205–206
 aluminum, 208
 carbon steel, 205–206
 categories and classifications of, 204–205, 205
 stainless steel, 206–207, 206
 gloves and, 20
 power source and peripherals, 167–183, 187–188, 187, 545–546
 air-cooled torch, 169, 169–170
 argon (shielding gas), 181–182, 181
 basic equipment, 167, 167
 components, 171–174, 171–174
 fillers and differences from other welding processes, 182–183, 182

remote current control, 174–175, 175–176
 tungsten electrodes, 176–179, 176–180
 typical GTAW setup, 168
 water circulator, 180–181, 180
 water-cooled torch, 169–172, 170–172
 welding regulator gauges (two), 174, 174
 power source settings (prior to welding), 198–200, 199–200
 safety, 167
 setup and step-by-step procedures, 168, 197–200
 shielding gases
 argon, 181–182, 181, 208–209
 helium, 208–209
 hydrogen, 208–209
 similarities and differences with other welding processes, 166–167, 182–183
 stainless steel and, 381
 technique, 201–204, 201–204
 torch parts, 171–174, 171–174
 troubleshooting, 566
 typical GTAW torch and welding arc, 166
 Gauges for measuring fillet welds, 462–463, 462–463
 Gauntlet-style welding glove, 20
 General Electric Company, 75
 Generators, 525, 532, 547–550, 548
 auxiliary output voltage ranges, 548
 continuous wattage output, 549–550, 550
 output circuit breaker size, 548–549
 peak wattage output, 549
 Globular transfer, 99, 104, 104–105
 Gloves, 20–21
 GMAW. See Gas Metal Arc Welding
 Gouging, 271, 271, 296, 484
 Grain direction, 339–340, 340, 363
 Grains. See Metal grains; Crystalline structure of metals
 Granular flux, 255
 Gray cast iron, 327
 Grinding/machining, 186
 Grinding marks, 456, 456
 Groove (butt) joint, 48
 Groove face, 399
 Groove positions. See Welding positions
 Groove weld joints, 6, 7–9, 149, 365
 aluminum weld design, 496–497, 496
 angular shrinkage, 484, 487–488, 487
 with concavity, 447, 448
 with convexity, 447, 448
 with incomplete root penetration, 447, 448
 longitudinal shrinkage in, 484, 486, 486
 radiographic image of, 466
 transverse shrinkage in, 484–485, 484–485
 undercut, 447, 448
 undersized, 448, 448
 See also Welding symbols
 Groove weld symbols, 409, 419–424, 420–423
 Ground conductor, 25, 26
 Grounded connections, 25, 26
 Grouping codes, 443, 445, 445–446, 447
 Groups of Graphic Symbols, 434

GTAW. See Gas Tungsten Arc Welding
 Guided bend test machine, 456, 457
 Guides, 434
 Hammering, 260, 261
 Hand control, remote, 175, 176
 Hand-held X-ray fluorescence testing, 336
 Hands, safety and, 20–21
 Hardenability, 346–347, 493–494, 494
 Hardening processes, 345–347
 austempering, 353, 354
 isothermal quench and tempering, 353, 353
 martempering, 352–353, 352
 standard quench and tempering, 351, 352
 See also Heat-treating processes
 Hardness testing, 333
 Brinell testing of, 320, 320
 hardness conversion table for carbon and alloy steels, 577–578
 Rockwell testing of, 320, 320
 Hard steels, Rockwell “C” (Rc) testing or, 320, 320
 HAZ. See Heat-affected zone
 Hazard Communication Standard (OSHA), 17
 Hazardous Materials Identification System, 17–18, 18–19
 H-beams, 583, 584
 HCS. See Hazard Communication Standard
 Head protection, 21
 Heat-affected zone (HAZ), 217, 231, 268, 275, 313, 381
 Heat input control, 365
 Heat-treatable alloys, 327–328
 Heat-treatable low-alloy (HTLA) steels, 372, 375–376, 376
 Heat-treating processes, 313, 345, 345–357
 affect on a weld, 356–357, 357
 defined, 345
 hardening, 345–347
 on nonferrous metals, 356
 Time Temperature Transformation (TTT) diagrams (for determining cooling rates), 347–356, 347–356
 See also Time Temperature Transformation (TTT) diagrams
 Heights, 13, 14
 Helium, 208–209
 Helium/argon/carbon dioxide shielding gas blend, 127
 Helmets. See Welding helmets
 High-carbon steels, 323
 High-carbon steel spark testing, 335, 335
 High-frequency current, 188–189, 189
 High-pressure water jet, 304–305
 See also Abrasive Water Jet Cutting
 High-strength low-alloy (HSLA) steels, 368, 369–372, 370–371
 High-temperature welding process (GMAW, FCAW, SMAW, GTAW), 259
 alternative to (solid state welding processes), 259–263
 Home use, power sources and, 78, 79, 85, 86, 135–137, 136, 143
 Horizontal fillet position 2F, 7, 9
 Horizontal fillet position 2FR (rotated), 8
 Horizontal groove position 2G, 7, 8
 Hoses, 221, 221
 Hot-rolled pickled and oiled steels, 323, 359

Hot-rolled steels (HRS), 323, 356–357, 357
 Hot work permit, 30–31
 Hot work safety checklist, 30–31
 HRS. See Hot-rolled steels
 HSLA steels. See High-strength low-alloy steels
 HTLA steels. See Heat-treatable low-alloy steels
 Hydrocarbons, 278
 Hydrogen, 208–209
 in base metals, 362–365
 See also Low-hydrogen-type welding procedures
 Hydrogen cracking, 364
 Hydrogen porosity, 561
 Hz. See Frequency
 IGBT. See Insulated gate bipolar transistor
 Image Quality Indicators, 466
 Inclusion, 558, 558
 Incomplete fusion, 558–559, 558
 Incomplete joint penetration, 559–560, 559
 Incomplete root penetration, 447, 448
 Indoor operations, 153
 Inductance, 82, 83, 103–104, 103
 See also Arc control; Arc force
 Inert gas, 31, 181–182, 229–230
 See also Argon
 Infrared rays, 21
 Insulated gate bipolar transistor (IGBT), 540–542
 Inspection tool kit, 462
 Insulators, 526–527
 Inter-granular corrosion, 380
 Intermittent weld, 411, 412
 Interpass temperature, 357, 366, 376, 377, 384, 385
 Interstitial alloying, 338, 340
 Inverter power sources, 192, 540–542, 540
 Ionization potential, 129
 Ionized gas, 290
 See also Plasma Arc Cutting (PAC)
 Iron Age, 3
 Iron-carbon phase diagrams, 340–345, 341
 austenite, 340, 341
 cementite (iron carbide), 341, 341
 ferrite (alpha iron), 340, 341
 heating steels, 345
 parts of, 342–343, 342
 pearlite, 341, 341–342
 use of, 343–345, 344
 Isothermal quench and tempering, 353, 353
 Jaeger J-1 near vision acuity test, 431
 J-groove weld symbols, 422–423, 422
 John Hancock Center (Chicago), 134
 Joining methods, 3
 Joint design. See Weld joint design
 Joint nomenclature, 4, 5–6
 Joint penetration, incomplete, 559–560, 559
 Kerf, 267, 268, 275
 Kindling temperature, 273–274
 Kinetic energy, 575
 Knurled drive rolls, 83, 83, 136, 136, 141
 Labeling system, for personal protection, 18–19
 Labor costs, 519–520
 Lamellar tearing, 483–484

Lap joints, 48, 490, 495, 495–496
 LASER acronym (Light Amplification by Stimulated Emission of Radiation), 300–303
See also Laser Beam Cutting (LBC)
 Laser Beam Cutting (LBC), 300–304
 benefits of, 303
 defined, 300
 drawbacks of, 303–304
 LASER acronym (Light Amplification by Stimulated Emission of Radiation), 300–303
 laser beam cutting head, 301
 process, 300–303
 safety precautions, 304
 Lasing material, 301–302
 Lattice structure, 345, 364
 LBC. *See* Laser Beam Cutting
 Lead cable sizes, 43, 43–44
 Leak detecting solution, 34
 Length equivalents, 572
 Lens shades, 21–22, 23, 40, 167
 Letter designations of welding symbols, 407, 409
 Lift arc, 189–190, 190
 Light beams, 302–303
 Lincoln Arc Welding company, 39
 Lincoln Electric, 134
 Linear porosity, 561, 561
 Liners, 85
 Liquid gases, safety and, 32
 Load strength, 585–593, 585–593
 Local exhaust ventilation, 29, 29
 Longitudinal shear test, 500
 Longitudinal shrinkage of groove joints, 484, 486, 486
 Low-alloy filler metals, 70, 70
 Low-alloy flux-cored electrodes, 157–158, 157–158
 Low-alloy steels, 366–378, 367–378
 Low-carbon steels, 323
 Low-carbon steel spark testing, 334, 334
 Low-hydrogen-type welding procedures, 69, 69, 364, 366–367, 370, 377, 483
Machinery's Handbook, 347, 585, 591
 Magnesium alloys, 394
 filler metals for, 394–395, 395–397
 Magnetic output control, 536–538, 537–538
 Magnetic particle testing, 464, 469–472, 470–472
 Magnets, 528, 528
 Malleability, 319
 Malleable cast iron, 327
 Mandrel piercing a billet, 581, 582
 Manganese, 381
 MAPP cutting tip, 277
 Maps, 12, 13
 Martempering, 352–353, 352
 Martensite formation, 345–346, 362–364, 363, 365
 Martensitic stainless steel, 327, 381
 Material Safety Data Sheets (MSDS), 17
 Mechanical cutting, 267
 Mechanical properties of metals. *See* Metal properties
 Medium-carbon steels, 323
 Medium-carbon steel spark testing, 335, 335
 Mega pascal (Mpa), 314, 316
 Melting, 267
 Melting temperatures, 322, 322
 Melt-through, excessive, 560, 560
 Mercury vapor, 301

Metal alloy group, 331
 Metal/alloys, information for calculating costs, 507, 508
 Metal-cored electrodes. *See* Composite electrodes
 Metal fasteners, 249, 249
 Metal grains, 336–340, 337, 339–340, 357
See also Crystalline structure of metals
 Metal identification methods
 hardness testing, 333
 magnetic properties, 333
 scratch/file testing, 333
 spark testing, 333–336, 334–336
 surface conditions, 332–333
 visual examination, 331–332, 332
 weight/density, 332, 333
 Metallurgy, defined, 313
 Metal properties, 313–322
 average properties of standard steels, 576
 mechanical properties
 brittleness, 318
 Charpy and Izod impact strength test, 318–319, 318
 compressive strength test, 319
 creep strength test, 319
 defined, 314
 ductility, 316–318, 316–317
 elasticity, 315–316, 316
 elongation, 316–318, 316
 fatigue strength test, 319
 hardness measurements
 (Rockwell and Brinell tests), 320, 320
 malleability, 319
 plasticity, 316
 reduction in area, 317–318, 317
 shear strength test, 319, 319
 strength types, 314
 tensile strength test, 314–318, 314–318
 torsion strength test, 319–320
 types of, 314
 physical properties
 defined, 314
 melting temperatures, 322, 322
 thermal conductivity, 321, 322
 thermal expansion, 321, 321
 Metals formed from unit cells, 337
 Metal transfer modes, 99–106, 100–107, 151, 151
 Middle Ages, 3
 Mild steel cutting, 289, 290, 303, 306, 307
 Mild steel welding, 156, 216, 236–237, 529–530
 Mill Certification Test Reports, 324, 324
 Millimeters to decimal conversion, 571
 Mill scale, 324, 333–334, 579
 Ming Dynasty, 11
 Molten weld pool, 166
 Molten weld puddle, 217
 Movable shunt power source, 537, 537
 MSDS. *See* Material Safety Data Sheets
 Multiple-pass welding, 153
 National Electrical Manufacturers Association (NEMA), 27
 National Institute for Occupational Safety and Health (NIOSH), 17
 ventilation, 29
 National Paint & Coatings Association, Hazardous Materials Identification System (HMIS), 17–18, 18–19
 Nd: YAG laser, 301
 NEMA. *See* National Electrical Manufacturers Association
 Neodymium (Nd), 301
 Nervous system, electrical current and, 24
 Neutral flame, 223, 224
 NHZ. *See* Nominal hazard zone
 Nick-break tests, 460–461, 460–462
 Nickel alloys, 381, 396–397
 composition of, 398
 filler metals for, 399–400
 groove face, 399
 joint design for, 399
 NIOSH. *See* National Institute for Occupational Safety and Health
 Nitrogen dioxide, 28
 Nixon, Richard M., 17
 Nobel, P.O., 75
 Nominal hazard zone (NHZ), 304
 Nondestructive testing, 429, 462–477
See also Testing
 Nondestructive weld symbols (testing), 425, 425
 Nonessential variables, 439, 443
 Nonferrous metals, 328–331
 aluminum, 328–329, 329–330
 brasses, 329
 bronzes, 329
 copper alloys, 329, 330
 heat treatments and, 356
 metal alloy group, 331
 Nonheat-treatable stainless steel (austenitic), 326–327
 Normalizing, 355, 355
 Nozzles, 87, 88, 142, 297, 305
 Nucleation, 337
 Nucleus (of an atom), 527
 Nuggets, 237, 237
 Occupational Safety and Health Act, 17
 Occupational Safety and Health Association (OSHA), 17
 fire prevention, 30
 Hazard Communication Standard (HCS), 17
 ventilation, 28
 Occupational Safety and Health Standards, Subpart Q, Welding, Cutting, and Brazing, 17
 OCV. *See* Open-circuit voltage
 OFC. *See* Oxygen-Fuel Cutting
 OFW. *See* Oxygen-Fuel Welding
 Ohm's law, 575
 Oil-hardening alloys, 328
 Open-circuit voltage (OCV), 56–57, 57, 239
 Opened circuit, 529–530, 530
 Operator appeal, 506
 Operator factor cost equation, 519–520
 Optical thermometer, 367, 367
 Orifice jewels, 305–306, 305–306
See also Abrasive Water Jet Cutting
 Oscillation, 97–98, 98, 151, 203–204, 204
 OSHA. *See* Occupational Safety and Health Association
 Other side of a welding symbol, 406, 407
 Outdoor operations, 153
 Output control, 541–542
 inverter, 540–542, 570
 magnetic control, 536–538, 537–538
 solid state, 538–539, 538–539
 tap select, 536, 536
 Oval weld pool, 364
 Over-alloying, 153
 Overhead costs, 520–521
 Overhead fillet position 4F, 8, 9
 Overhead groove position 4G, 9
 Oxidation, 267, 272
See also Oxygen-Fuel Cutting (OFC); Oxygen-Fuel Welding (OFD)
 Oxidizing flame, 224, 224
 Oxy-acetylene welding. *See* Oxygen-fuel welding
 Oxygen atom, 527, 527
 Oxygen cylinder, 217, 218
 Oxygen flashback arrestor, 221
 Oxygen-Fuel Cutting (OFC), 268, 271, 272–284, 272, 275–276
 acetylene and alternative fuel gases, 278, 278
 benefits of, 274–275
 cutting tip, 276–277, 277
 defined, 272–273, 273
 drawbacks to, 275
 friction lighter, 277, 277
 neutral flame type, 278, 278
 process, 273–274, 274
 safety procedures, 283–284
 step-by-step lighting torch setup, 279–281
 step-by-step torch shutdown setup, 282, 282–283
 torch, 276, 276
 troubleshooting, 565
 Oxygen-fuel welding (OFW), 215–227, 408
 acetylene cylinder, 217, 219, 219
 acetylene regulator, 219, 220
 benefits of, 216–217
 cast irons, 387–388
 check valves and flashback arrestors, 220–221, 220–221
 defined, 215
 drawbacks of, 217
 filler metal, 222–223, 223
 flame types
 carburizing flame, 223, 224
 neutral flame, 223, 224
 oxidizing flame, 224, 224
 friction lighter, 222, 223
 hoses, 221, 221
 lens shade selection, 23
 oxygen cylinder, 217, 218
 oxygen regulator, 217, 218
 process, 215–217, 216
 safety precautions, 229
 step-by-step lighting torch setup, 225–227
 step-by-step torch shutdown setup, 224, 228–229
 torch handle, 222, 222
 troubleshooting, 565
 a typical OFW rig, 218
 welding mild steel, 216
 welding tip, 222, 222
 Oxygen hoses, 221, 221
 Oxygen regulator, 217, 218
 Ozone, 28
 PAC. *See* Plasma Arc Cutting
 Partial penetration groove welds, 499, 499–500
 Passive-style welding helmets, 21–22, 22
 PAW. *See* Plasma Arc Welding
 Peak current, 193, 193
 Peak time (pulse time), 193
 Pearlite, 341, 341–342

- Peening, 497
 Penetrators, 320, 320
 Perchloroethylene, 24
 Performance Qualification, 450–452
 Periodic table, 594
 Peripherals. *See* Power sources
 Personal protective equipment (PPE), 18–24, 18
 clothing, 19–20, 20
 eye protection, 21–22, 22–23
 hands and feet, 20–21
 head protection, 21
 ultraviolet (UV) considerations, 19, 21–24, 22–23
 Phase control, 539
 Phosgene gas, 23
 Physical properties of metals. *See*
 Metal properties
 Pickled cold-rolled steel, 579
 Piercing cut, 270–271, 270, 296
 Pinch effect control, 82
 See also Arc control; Inductance
 Pipe fillets, 7–8
 Pipe grooves, 7
 Pipeline welding (Egypt), 10
 Pipes, 323
 Piping porosity, 561
 Pitch, 411, 412
 Plasma, defined, 290
 Plasma Arc Cutting (PAC), 269–271, 289–300, 291
 air supply, 297
 benefits of, 290–291
 defined, 289
 drawbacks of, 291
 power source, 292–293, 292
 process, 289–290, 290
 safety precautions, 300
 setup/step-by-step procedure, 298–299
 torch, 293–297, 293–297
 Plasma Arc Welding (PAW), 229–235
 benefits of, 231
 compared to Gas Tungsten Arc
 Welding (GTAW), 230–231
 controller, 232
 defined, 229–230
 drawbacks of, 231–232
 power source, 232, 233
 process, 230–231, 230
 remote control, 234, 234
 shielding gas, 235
 torch, 233, 233
 water circulator, 233–234, 234
 work lead/clamp, 234, 235
 Plasticity, 316
 Plate fillets, 9
 Plate grooves, 8–9
 Plug weld symbol, 417–418, 418
 Plumes, 27
 Polarities, 528–529, 529, 546
 selecting, 48–50, 49, 87–88,
 142–143, 185–188, 185–188
See also Alternating current;
 Alternating current/direct current;
 Direct current; Direct current electrode negative; Direct current electrode positive
 Poor fit-up, 507, 507
 Porosity, 560
 hydrogen porosity, 561
 linear porosity, 561, 561
 piping porosity, 561
 scattered porosity, 561–562, 561
 Postflow of shielding gas, 184, 184, 196
 Postheat treatment, 357, 366, 377, 381, 384, 386–387, 483, 493–494
 Potential (voltage control), 79–81, 80–81
 See also Voltage
 Pounds per square inch (psi), 314
 Power cable, air-cooled and water-cooled torches, 171–172, 172
 Power cords, 25, 42, 42
 Power costs, 521–522
 Power sources, 524–551
 Air Carbon Arc Cutting (CAC-A), 286, 286
 alternating current (AC), 532–548, 532
 direct current (DC), 530–531, 531
 electrical current, 526–530
 atom, 526–527, 527
 conductor, 526–527
 current defined, 528
 electron movement, 528–529, 528–529
 insulator, 524–527
 melting of mild steel and
 electrode, 529–530
 semiconductor, 527
 valence shell, 526–527
 voltage, 528–529, 529
 electron theory, 525–526
 Flux Cored Arc Welding (FCAW), 135–137, 136, 140–144, 141–143, 545
 Gas Metal Arc Welding (GMAW), 76–78, 77–79, 86, 545–546
 Gas Tungsten Arc Welding (GTAW), 167–183, 167–182, 187–188, 188
 guide chart, 86
 movable shunt, 537, 537
 output control, 533, 536–542, 536–540
 inverter, 540–542, 540
 magnetic control, 536–538, 537–538
 solid state, 538–539, 538–539
 tap select, 536, 536
 Plasma Arc Cutting (PAC), 292–293, 292
 Plasma Arc Welding (PAW), 232, 233
 ratings, 542–550
 AC, DC, or AC/DC power source, 546
 CC (constant current), CV
 (constant voltage), or CC/CV
 power source, 545–546, 546
 duty cycle, 543–544, 543–544
 generators, 547–550, 548, 550
 primary current draw, 545
 primary voltage requirements, 544
 recommended primary conductor size, 545
 recommended primary current protection, 545
 single- or three-phase power, 545
 warranties, 546–547
 welding output range, 543, 543
 rectification, 533, 535–536, 535–536, 540–542
 Resistance Spot Welding (RSW), 238, 239
 setting the polarity on the power source, 51–52, 51–52
 Shielded Metal Arc Welding (SMAW), 40–46, 40, 42–46
 silicon controlled rectifier (SCR), 538–539, 538–539
 step-down transformers, 533–535, 533–534, 541
 Stud Welding (SW), 247, 247
 Submerged Arc Welding (SAW), 252–253, 252
 PPE. *See* Personal protective equipment; Safety
 Precipitation-hardening (PH) alloys, 327
 Preflow of shielding gas, 184, 196
 Preheat treatment, 357, 365–366, 366, 376, 377, 379, 381, 384, 385, 483, 493–494
 Prequalified Procedures (AWS), 464
 Pressure application, 3
 Price variables, 515–517
 Primary current draw, 545
 Primary input power, 25
 Problem solving, 14, 15
 See also Troubleshooting defects and discontinuities
 Procedure Qualification Record (PQR), 433, 439, 441, 443, 444, 447, 450–452, 463–464
 Procedures, 434
 Procedures, written. *See* Written welding procedures
 Process annealing, 355, 356
 Productivity skills, 14, 15
 Projection Welding (PW), 241–242
 Projection weld symbol, 416, 416
 Propane, 32
 Propane cutting tip, 277
 Proportional limit (elastic limit), 315
 Propylene cutting tip, 277
 Puddle width, affects of pulser on, 193
 Pulser, 192–194, 192–193
 Pulses per second (pulsing frequency), 193
 Pulse-spray transfer, 99, 105–106, 106, 107
 Purging, 31
 Push/forehand technique. *See*
 Forehand technique (push)
 PW. *See* Projection Welding
 Qualifications
 performance qualification
 limitations, 437–438, 437–438
 steps to become a qualified welder, 436–437
 Quenched and tempered steels, 351–353, 352–353, 371–372, 373–374
 Quenching, 346–347
 See also Quenched and tempered steels
 Radiographic testing, 463–466, 465–466
 Range/tap control, 79–80, 80
 Recommended Practices, 434
 Rectification (changing of AC to DC), 533, 535–536, 535–536, 540–542
 silicon controlled rectifier (SCR), 538–539, 538–539
 Reduction in area, 316–318, 316–317
 Reference line of a welding symbol, 406, 406
 Reflectivity, 302–303
 Regulators, 140
 acetylene, 219, 220
 choosing, 85, 86
 gas, 85, 86
 gauges on, 174, 174
 oxygen, 217, 218
 for shielding gas, 33, 33
 Remote current controls, 174–175, 175–176
 Remote foot control, 175, 175, 234
 Remote hand control, 175, 176
 Replacement parts, 84, 85
 Residual stresses, 363–365, 483–484
 Resistance, 529–530
 Resistance heaters, 366
 Resistance Seam Welding (RSEW), 242
 Resistance Spot Welding (RSW), 194, 235–241
 actuator, 241, 241
 benefits of, 237–238
 drawbacks of, 238
 electrode tips, 240, 241
 of mild steel, 236–237
 power source, 238, 239
 process, 235–237, 236–237
 safety precautions, 244–245
 setup/step-by-step procedures, 242–244
 timer(s), 239, 239
 tongs, 240, 240
 transformer, 238–239
 Resistance Welding processes, 408, 525
 See also Flash Welding (FW);
 Projection Welding (PW);
 Resistance Seam Welding (RSEW); Resistance Spot Welding (RSW)
 Restrained welded members, 483, 488, 489
 Retaining cup, 296–297, 297
 Riveting, 3
 Robotic welding, 13, 14, 75
 Rockwell “B” (Rb) scale for testing soft metals, 320, 320, 576–578
 Rockwell “C” (Rc) scale for testing hard steels, 320, 320, 576–578
 Round pipe, 580
 Round tubing, 581–582, 582
 RSEW. *See* Resistance Seam Welding
 Rust, 579
 SAE. *See* Society of Automotive Engineers
 Safety, 16–35
 Air Carbon Arc Cutting (CAC-A), 289
 compressed cylinders, 31–34, 33
 electrical considerations, 24–26, 26
 explosion, 31
 fire prevention, 29–31
 Flux Cored Arc Welding (FCAW), 134, 135
 gases and fumes, 27–28
 Gas Metal Arc Welding (GMAW), 75–76, 76
 Gas Tungsten Arc Welding (GTAW), 167
 Hazardous Materials Identification System, 17–19, 18–19
 hot work safety checklist, 30–31
 Laser Beam Cutting (LBC), 304
 organizations and overview of, 17
 Oxygen-Fueled Cutting (OFC), 283–284
 Oxygen-Fuel Welding (OFW), 229
 personal protective equipment (PPE)
 clothing, 19–20, 20
 eye protection, 21–22, 22, 23
 hands and feet, 20–21
 head protection, 21
 ultraviolet (UV) considerations, 19, 21–24, 22–23
 Plasma Arc Cutting (PAC), 300
 Resistance Spot Welding (RSW), 244–245
 secondary welding output, 26–27, 27
 Shielded Metal Arc Welding (SMAW), 40
 Stud Welding (SW), 250
 ventilation, 28–29, 28–29

- Safety glasses, 21
Safety in Welding, Cutting, and Allied Processes (American Welding Society), 17, 31
SAW. See Submerged Arc Welding
S-beams, 583
Scaring, 271, 272
Scattered porosity, 561–562, 561
SCR. See Silicon controlled rectifier
Scratch/file testing, 333
Scratch technique, 61, 67
SCWI. See Senior Certified Welding Inspector (American Welding Society)
Seam weld symbol, 414–415, 414–415
Sears Tower, 134
Secondary welding output, 26–27, 27
Self-shielded electrode classification, 134, 151, 153
Semi-austenitic stainless steel, 327
Semi-automatic welding, 75
Semiconductors, 527
Senior Certified Welding Inspector (SCWI) (American Welding Society), 432
Sequencers, 194
Setup/step-by-step procedures
 Flux Cored Arc Welding (FCAW), 140–144, 141–148
 Gas Metal Arc Welding (GMAW), 87–89, 88–93
 Gas Tungsten Arc Welding (GTAW), 168, 197–200
 Oxygen-Fueled Cutting (OFC) lighting torch setup, 279–281
 Oxygen-Fueled Cutting (OFC) torch shutdown, 282, 282–283
 Oxygen-Fuel Welding (OFW) torch setup, 225–227
 Oxygen-Fuel Welding (OFW) torch shutdown, 224, 228–229
 Plasma Arc Cutting (PAC), 298–299
 Resistance Spot Welding (RSW), 242–244
 Shielded Metal Arc Welding (SMAW), 47–53, 48–55
 Shear Plane in Weld, 499
 Shear strength testing, 319, 319, 499–502, 499–502
 Sheet metal and plate, 579, 579–580
 Sheet metal gauge, decimal equivalent, and weight equivalent, 570–571
 Sheet metal thickness, 579, 579–580
 Shielded Metal Arc Welding (SMAW), 38–73, 529
 breakdown of, 39
 controls and characteristics
 amperage control, 46, 46
 arc control, 47, 47
 electrodes, 62–71, 62–72
 AWS filler metal specifications, 66, 67
 electrode classifications, 67–70, 68–70
 selecting, 47–48, 48
 settings for, 70–71, 71–72
 generators and, 548
 historical background, 39
 lens shades for welding at varying amperage ranges, 40
 power source and peripherals
 basic equipment, 40, 40, 545, 546
 power cord, 42, 42
 power source, 40, 41
 welding electrode holder, 43–45, 44–46
 welding leads, 42–43, 43–44
 work clamp, 45–46, 46
safety, 40
scratch technique to strike the arc, 61, 61
setup
 amperage, 52
 arc blow and control of, 50, 50–51
 arc control setting, 52–53
 electrode selection, 47–48, 48
 polarity choices, 48–50, 49
 setting polarity on the power source, 51–52, 51–52
 step-by-step setup, 53–55
simplicity of, 39
stainless steel and, 381
tapping technique to start the arc, 60–61, 60
technique
 arc length, 56, 56
 positioning electrode in relation to the base metal, 57–66, 58–66
 voltage, 56–57, 57
troubleshooting, 565, 565
welding circuit, 526
Shielding gases
 aluminum welding, 129–130, 130, 389–390
 Flux Cored Arc Welding (FCAW), 141, 141, 153–154, 161–163, 162–163
 Gas Metal Arc Welding (GMAW), 87, 121–130, 122–123, 125–126, 128–130
 Gas Tungsten Arc Welding (GTAW), 181–182, 181, 208–209
 Plasma Arc Welding (PAW), 235
 See also Argon entries
Shields, 296–297, 297
Short-circuit metal transfer mode, 99–104, 100–103, 105, 107, 124, 125
Shot peening, 497
Shrinkage. See Weld joint design
Shrinkage stresses, 483, 483
Shrinkage void, 562, 562
Silicon controlled rectifier (SCR), 538–539, 538–539
Sinewave form, 188, 188, 532, 532
Single-pass welding, 153
Single-phase current, 41, 42, 545
Single-phase primary electrical circuit, 25, 26
Single-phase transformer, 533, 534
Single-stage flow gauge, 85, 86
Single-stage flow meter, 85, 86
Skill sets, 13–15, 14–15
 See also Soft skills
Slab, 579
Slope, 81–82, 82, 101–102, 101–102
 See also Volt/amp curves
Slot weld symbol, 418, 419
SMAW. See Shielded Metal Arc Welding
Smoke, 27–28
Society of Automotive Engineers (SAE), 324–326, 325–326, 334–335, 334–335, 383
Softening processes, 345
 full annealing, 353–356, 354
 normalizing, 355, 355
 stress relief treatments, 355–356, 356
Soft metals, 3
 Rockwell "B" (Rb) testing for, 320, 320
Soft skills, 14–15, 15
Soldering, 408
Solid-state power sources, 538–539, 538–539
Solid state welding processes, 259–263, 408
 cold welding (CW), 261
 diffusion process, 259–260
 diffusion welding, 262
 explosion welding (EXW), 262–263
 forge welding, 261–262
 friction welding (FRW), 263
 ultrasonic welding (USW), 263
Spacer, 420
Spark testing, 333–336, 334–336
Spatter, 562, 562
Specialists, 10
Specifications. See Codes, standards, and specifications
Specifications, 434
Spectral analysis, 336
Spheroidizing, 356, 356
Spool drag, 88
Spot timer, 194
Spot weld cost equation, 518
Spot weld nugget, 237
Spot weld symbol, 415–416, 415–416
Square groove weld symbol, 419, 420
Staggered intermittent weld, 412, 413, 414
Stainless steel, 378–382, 379–382
 composite stainless steel electrodes (AWS), 119
 filler metals for, 206, 382
 Flux Cored Arc Welding (FCAW), 158–159, 158
 Gas Metal Arc Welding (GMAW) and, 115–120, 116–120, 126–128, 128–129
 Gas Tungsten Arc Welding (GTAW) and, 206–207, 206
 Laser Beam Cutting (LBC), 303
 ranges for stainless steel electrodes (AWS), 72
 solid stainless steel electrodes (AWS), 116
 stainless steel flux-cored electrodes (AWS), 158
 types and classifications of, 326–327, 326
 types of stainless steel alloys, 379–381, 380
 weld joint design, 494, 494
Stainless steel spark testing, 335, 335
Standard quench and tempering, 351, 352
Standards. See Codes, standards, and specifications
Standard shield, 296–297, 297
Standard Welding Terms and Definitions (AWS), 554–555, 555
Static loads, 482, 482
Steel
 average properties of standard steels, 576
 classifications of, 324–325, 324–326
 composite steel electrodes (AWS), 114
 cooling curves for. See Time Temperature Transformation (TTT) diagrams
 defined, 323
 filler metals (AWS), 205
 fillet welds (AWS), 499
 hardening, 345–347
 heating, 345
 mild steel cutting, 303, 306, 307
 mild steel flux-cored electrodes (AWS), 156
 mild steel welding, 216, 236–237, 529–530
 partial penetration groove welds, 500
 quenched and tempered, 351–353, 352–353
 solid steel electrodes (AWS), 110
 steel flux-cored electrodes (AWS), 154
 tool steels, 328, 328
Steel bridges, 12, 14
Steel electrodes, 107–108, 111–112, 112–113
 mild steel flux-cored electrodes, 154–157, 154–156
Step-by-step setup. See Setup/step-by-step procedures
Step-down transformers, 532–535, 533–534, 541
Step-up transformers, 532
Stick out. See Electrode extension
Stonecutters Bridge (container port in Hong Kong), 12, 14
Street scape, 12, 13
Strength calculations, 499–502, 499–502
Strengthening aluminum welds, 497–498, 498
Strength testing
 Charpy and Izod impact testing, 318, 318
 compressive strength, 319
 creep strength, 319
 fatigue strength, 319
 longitudinal shear test, 500
 shear strength, 319, 319, 499–502, 500–502
 strength defined, 314
 tables for, 576–578
 tensile strength testing, 314–318, 314–318, 576–578
 torsion strength, 319–320
 transverse shear test, 500–502, 500–502
 yield strength, 316, 576
 See also Metal properties; Strength calculations; Testing
Stress relief treatments, 345, 356, 377–378, 379
 bright annealing, 355
 process annealing, 355, 356
 spheroidizing, 356, 356
 stress relief annealing, 355, 356
Stringer bead welds, 63–64, 63, 65
Structural beams, 583, 583–584
Structural Steel Welding code (AWS), 464
Stud Welding (SW), 245–250
 benefits of, 246
 controller, 248
 drawbacks of, 246–247
 ferrules, 250
 metal fasteners, 249, 249
 power source, 247, 247
 process, 245–246, 245
 safety precautions, 250
 stud welding gun, 248, 248
 work lead/clamp, 248–249, 248
Stud weld symbol, 417, 417
Submerged Arc Welding (SAW), 250–256
 benefits of, 251–252
 compared to Gas Metal Arc Welding (GMAW), 250–251
 defined, 250
 drawbacks of, 252
 electrodes, 255
 flux, 255–256, 255
 flux delivery system, 254, 255

- Submerged Arc Welding (continued)**
 power source, 252–253, 252
 process, 250–251, 251
 travel system, 253–254, 254
 welding torch, 253, 253
 wire feeder, 253
 work lead/clamp, 254–255
Substitutional alloying, 338
Suck back. See Concave root surface
Surface tension, 123
Surface weld symbol, 425, 425
Swirl rings, 294, 294
Switching, 541–542
Symbols. See *Welding symbols*
Tail of a welding symbol, 406, 406, 408
Taper (bevel angle), 268, 268
Tapering, 498, 498
Tapping technique, 60–61, 60
Tap select output control, 536, 536
Team skills, 14–15, 15
Tee joint. See *T-joints*
Temperature crayon, 367, 367
Tempering, 346
 See also *Quenched and tempered steels*
Tensile strength testing, 260, 314–318, 314–318, 458–459, 458–461, 576–578
Testing, 447–477
 destructive testing, 447–462
 acceptance criteria for bend weld test specimens, 456–457, 457
All Weld Metal Test, 460–461, 462
 examination criteria after (AWS, ASME, and API), 461
 nick-break tests, 460, 460–461
 tensile specimens, 458–459, 458–461
 visual examination criteria before, 447–448, 448–449
 weld coupon preparation, testing, and evaluation, 447–457, 448–457
 for gas leaks, 33–34
 nondestructive testing, 462–477
 dye penetrant testing, 464, 473–477, 474–477
 gauges for fillet welds, 462–463, 463
 inspection tool kit, 462
 magnetic particle testing, 464, 469–472, 470–472
 radiographic testing, 463–466, 465–466
 ultrasonic testing, 464, 466–469, 467–469
 See also *Strength testing*
Thermal conductivity, 302, 321, 322
Thermal expansion, 320–321, 321, 381
Thermal stress, 483
Thickness, of sheet metal or plates, 579, 579–580
Third-degree burns, 24
Three-phase current, 41, 42
Three-phase power, 545
TIG. See *Tungsten Inert Gas*
Timers, Resistance Spot Welding (RSW), 239, 239
Time-temperature effects, 313
Time Temperature Transformation (TTT) diagrams, 347–356, 347–356
 effect of cooling curves on steel structures, 350–351, 351
 determining cooling rates, 347–348, 347
 hardening processes
 austempering, 353, 354
 isothermal quench and tempering, 353, 353
 martempering, 352–353, 352
 standard quench and tempering, 351, 352
 softening processes
 full annealing, 353–355, 354
 normalizing, 355, 355
 stress relief treatments, 355–356, 356
 transformation products from the controlled cooling of steels, 349–350, 350
 transformation region, 348–349, 348–349
Titanium alloys, 400–401
 filler metals for, 401, 401
 processes for, 400
 special considerations, 400–401
Titanium spark testing, 336, 336
T-joints, 48, 450, 490–491, 491, 495–496
Tongs, Resistance Spot Welding (RSW), 240, 240
Tool steels, 383–384
 classifications of, 328, 328, 380, 383
Torch angle, 201, 201–202
Torch body, 171, 172
Torches. See *Welding torches*
Torch handle, 222, 222
Torch setup, Oxy-Fuel Welding, 225–227
Torch shutdown, Oxy-Fuel Welding, 224, 228–229
Torsion strength testing, 319–320
Toxic gases, 28
Transfer modes, 99–106, 100–107, 151, 151
Transformation. See *Time Temperature Transformation (TTT)*
Transformers, 533–535, 533–534
 Resistance Spot Welding (RSW), 238–239
Transition current, 105, 105
Transverse shear test, 500–502, 500–502
Transverse shrinkage in fillet welds, 488
Transverse shrinkage in groove joints, 484–485, 484–485
Travel angle
 Air Carbon Arc Cutting (CAC-A), 289
 Flux Cored Arc Welding (FCAW), 149–151, 149–150
 Gas Metal Arc Welding (GMAW), 94–96, 95–97
 Gas Tungsten Arc Welding (GTAW), 201
 Shielded Metal Arc Welding (SMAW), 57, 58
Travel direction
 Flux Cored Arc Welding (FCAW), 149–150, 150
 Gas Metal Arc Welding (GMAW), 75, 96, 97
 Shielded Metal Arc Welding (SMAW), 57–58, 58
Travel manipulation, 151
Travel speed
 Abrasive Water Jet Cutting, 306–307
 aluminum welding and, 394
 Flux Cored Arc Welding (FCAW), 150–151
 Gas Metal Arc Welding (GMAW), 75, 97–98, 98
 Gas Tungsten Arc Welding (GTAW), 201–202
Plasma Arc Cutting (PAW), 292
Shielded Metal Arc Welding (SMAW), 59–60, 59
Travel system, Submerged Arc Welding (SAW), 253–254, 254
Triangle welding technique, 66, 66
Triangular plate, 498, 498
Trichloroethylene, 24
Tri-mixed shielding gases, 126–129
Troubleshooting, defects and discontinuities, 554–567
 arc strikes, 555, 555
 cast and helix, 567, 567
 concave root surface (suck-back), 556, 556
 cracks, 556–557, 556
 defects defined by AWS, 554
 discontinuities defined by AWS, 554
 drop-through, 557–558, 557
 erratic arc, 564
 excessive melt-through, 560, 560
 for Flux Cored Arc Welding (FCAW), 566–567
 gas mark (worm tracking), 560–561, 560
 for Gas Tungsten Arc Welding (GTAW), 566–567
 general, 564
 hydrogen porosity, 561
 inclusion, 558, 558
 incomplete fusion, 558–559, 558
 incomplete joint penetration, 559–560, 559
 insufficient amperage, 564
 linear porosity, 561, 561
 no arc, 564
 for Oxy-Fuel Welding, 565
 piping porosity, 561
 porosity, 560
 scattered porosity, 561–562, 561
 for Shielded Metal Arc Welding (SMAW), 565, 565
 shrinkage void, 562, 562
 spatter, 562, 562
 terms and definitions, 554–555, 555
 undercut, 563, 563
 underfill, 564, 564
 for wire-feed welding processes (GMAW/FCAW), 566–567
Trusses, 482, 482
TTT diagrams. See *Time Temperature Transformation (TTT) diagrams*
Tungsten electrode, 176–179, 176–180, 532, 532
 rounded tip, 178–179, 179–180
 sharpened tip, 176–178, 176–178, 179, 180
 types of, 196, 196
 See also *Gas Tungsten Arc Welding (GTAW)*
Tungsten Inert Gas (TIG), 166
 See also *Gas Tungsten Arc Welding (GTAW)*
Tungsten-to-work distance, 201
Tungsten types, 196
 U-groove drive rolls, 83, 83–84
 U-groove welds, 386, 491
 U-groove weld symbols, 422, 422
 Ultimate tensile strength, 458–459
 Ultra-high-carbon steels, 323
Ultrasonic testing, 464, 466–469, 467–469
Ultrasonic welding (USW), 263
Ultraviolet (UV) rays, 19, 21–23
Ultraviolet photons, 301–302
Undercut, 563, 563
Undercut groove weld, 447, 448
Undercutting weld toes, 162, 162
Underfill, 564, 564
Undersized weld, 448, 448
Unified Numbering System (UNS), 329, 331, 339
Unit cells, 336–338, 337
Unrestrained welded members, 483, 488, 489
UNS. See *Unified Numbering System*
USW. See *Ultrasonic welding*
UV rays. See *Ultraviolet (UV) rays*
Valence shell, 526–528, 527
Valve opening, 33, 33
Vapors, 23–24
Ventilation, 28–29, 28–29
Vertical fillet position 3F, 9
Vertical fillet position 5F (fixed position), 8
Vertical groove position 3G, 9
Vertical groove position 5G, 7
Vertical welding, 150, 150
V-groove (double) joint, angular shrinkage and, 487–488, 487
V-groove drive rolls, 83, 83–84
V-groove welds, 386, 491–494, 492–494, 496, 496
V-groove weld symbols, 419–420, 420
Visual acuity, 430
Visual inspection
 before destructive testing, 447–448, 448–449
 nondestructive testing, 462–463, 462–464
Voltage, 25, 525, 528–529, 529
 aluminum welding and, 394
Flux Cored Arc Welding (FCAW), 137–138, 138
Gas Metal Arc Welding (GMAW), 79–81, 80–81, 89, 89
 generators and, 548
 primary requirements, 544
Shielded Metal Arc Welding (SMAW), 56–57, 57
 See also *Arc voltage*
Voltage drop formulas, 575
Volt/amp curves, 101–102, 101–102
 See also *Slope*
Volt/amp relationships, 104, 105
Volume and capacity equivalents, 573
Walking the cup, 204, 204
Warranties, 546–547
Water circulators
 Gas Tungsten Arc Welding (GTAW), 180–181, 180
 Plasma Arc Welding (PAW), 233–234, 234
Water-cooled torch, 169–172, 170–172
 differences and similarities with air-cooled torch, 171
Water-hardening alloys, 328
Wattage, 549
Wattage output, generators, 549–550, 550
Waveform, 532, 532
Wave forms, 191, 191
Weave beads, 64, 64–65
Weave patterns, 64–66, 64–66
Weaving, 151
Weight cost calculations, 508, 510–511, 512
Weight equivalents, 572
Weldability, defined by AWS, 362

- Weld coupons, 429
 acceptance criteria for, 456–461, 457–462
 destructive testing of, 448–453, 449–453
 first step after sample has been taken, 447
 preparation, testing, and evaluating, 453–456, 454–457
 See also Testing
Welder Qualification Test Record (WQTR), 434, 439, 442
Welders, Cutters, Solderers, and Brazers (Bureau of Labor and Statistics job category 51–4121), 3, 4
Welding, defined, 3
Welding amperage (current), 52, 144
Welding booths, 28, 28
Welding Code Interpretation exam, 430–431
Welding costs. See Costs
Welding electrode holder, 43–45, 44–46
Welding employment. See Employment
Welding frequency, for AC, 196
Welding heat, affect on a weld, 356–357, 357
Welding heights, 13, 14
Welding helmets, 21–22, 22, 23
Welding inspectors, 430–432
 industries that employ, 430
 job duties, 430
 knowledge and, 431–432
 levels of certification, 432, 432–433
 three-part exam, 430–431
 visual acuity and, 431
Welding leads, 42–43, 43–44
Welding output range, 543, 543
Welding positions, 6
 pipe fillets, 7–8
 pipe grooves, 7
 plate fillets, 9
 plate grooves, 8–9
Welding Procedure Specification (WPS), 433, 439, 440, 447, 539
Welding range, 84
Welding-related conversion formulas, 573–574
Welding, Soldering, and Brazing Machine Setters, Operators, and Tenders (Bureau of Labor and Statistics job category 51–4122), 4, 6
Welding symbols, 13, 15, 404–427
 arrow, 406, 406
 arrow side, 406, 407
 AWS welding symbol, 406
 chain intermittent weld, 412, 412
 correct geometry of a fillet weld symbol, 405
 defined, 405
 edge weld symbol, 424, 424
 fillet weld symbol, 405, 410–414, 411–413
 finishing methods and contours, 409–410
 groove weld symbols, 409
 combination weld symbols, 421–422, 421
 common symbol, 420
 double bevel-groove, 421, 421
 double-flare bevel groove, 423, 424
 double-flare V-groove, 423, 423
 double J-groove, 422, 423
 double U-groove, 422, 422
 double V-groove, 420, 420
 single bevel-groove, 420–421, 421
 single-flare bevel-groove, 423, 423
 single-flare V-groove, 423, 423
 single J-groove, 422–423, 422
 single U-groove, 422, 422
 single V-groove, 419–420, 420
 square groove, 419, 420
 incorrect geometry of a fillet weld symbol, 405
 intermittent weld, 411
 letter designations, 407, 409
 nondestructive weld symbols (testing), 425, 425
 other side, 406, 407
 pitch, 411, 412
 plug weld symbol, 417–418, 418
 projection weld symbol, 416, 416
 reading, 406–407, 407
 reference line, 406, 406
 seam weld symbol, 414–415, 414–415
 slot weld symbol, 418, 419
 spot weld symbol, 415–416, 415–416
 staggered intermittent weld, 412, 413, 414
 stud weld symbol, 417, 417
 surface weld symbol, 425, 425
 tail, 406, 406
 welding processes on, 408
 typical applications of, 409
 weld and weld symbol location, 407
 welding and brazing processes, 408
 weld profiles, 470
 weld symbols, 407, 409–410, 409–410
Welding tip, 222, 222
Welding torches (guns)
 Gas Metal Arc Welding (GMAW), 83–85, 85
 options for, 83–85, 85, 139–140, 140, 168–171, 169–171
 Oxygen-Fuel Cutting (OFC), 276, 276
 parts of (Gas Tungsten Arc Welding), 171–174, 171–174
Plasma Arc Cutting (PAC), 293–297, 293–297
Plasma Arc Welding (PAW), 233, 233
Submerged Arc Welding (SAW), 253, 253
Weld joint design, 480–504
 aluminum
 groove joints, 496–497, 496
 lap joints, 495, 495–496
 strengthening aluminum welds, 497–498, 498
 tapering, 498, 498
 T-joints, 495–496
 triangular plate, 498, 498
 angular shrinkage, 484, 487–488, 487
 considerations, 489–490, 490
 continuous fillet welds, 488–489, 489
 costs and, 506–507, 507
 dynamic loads, 482
 fillet welds, 490–491, 490–491
 an impossible-to-reach design, 490
 lamellar tearing, 483
 longitudinal shrinkage in groove joints, 486, 486
 residual stress, 483–484
 shear strength, 490, 499–502, 499–502
 shrinkage stresses, 483, 483
 stainless steel compared to plain carbon steels, 494, 494
 static loads, 482, 482
 strength calculations (allowable stress design), 499–502, 499–502
 thermal stress, 483
 transverse shrinkage in fillet welds, 488
 transverse shrinkage in groove joints, 484–485, 484–485
 V-groove welds, 491–494, 492–494
 welding procedures and, 481–482
Weld joints, 47
 corner joint, 48
 edge joint, 48
 groove (butt) joint, 48
 lap joint, 48
 T-joint, 48
Weldment, 429
Weldment temperatures, 367
Weld metal failures, 362–364
 See also Troubleshooting
Weld parameters, for flux-cored electrodes, 159, 159–161
Weld passes, 365
Weld pool, 59, 151, 151, 166, 394
Weld position, 153
Weld puddles, 191
Weld testing. See Testing
WFS. See Wire feed speed
Whipping technique, 65–66, 65
White cast iron, 327
Wide flange beams, 323
Wide-flange beams, 583, 583–584
Wire feeder, Submerged Arc Welding (SAW), 253
Wire feed speed (WFS), 77, 80, 81, 82, 88–89, 137–139, 139
Work angle
 Flux Cored Arc Welding (FCAW), 149–150, 149–150
 Gas Metal Arc Welding (GMAW), 94–95, 95
 Gas Tungsten Arc Welding (GTAW), 201
 Shielded Metal Arc Welding (SMAW), 58, 63, 63
Work cable, Air Carbon Arc Cutting (CAC-A), 286–287
Work clamp, 45–46, 46
 Air Carbon Arc Cutting (CAC-A), 287
Work distance. See Arc length
Work lead, 42
Work lead/clamp
 Plasma Arc Welding (PAW), 234–235, 235
 Stud Welding (SW), 248–249, 248
 Submerged Arc Welding (SAW), 254–255
Wrap-around guided bend test machine, 456, 457
Written welding procedures
 costs and quality and, 506
 essential and nonessential variables, 439, 443, 444–445
 essential components of, 506
Procedure Qualification Record (PQR), 439, 441
Welder Qualification Test Record (WQTR), 439, 442
Welding Procedure Specification (WPS), 439, 440
Wrought iron spark testing, 334, 334
Wrought iron/spring steel 5 layers, 10
X-ray testing. See Radiographic testing
X-Y axis control system, 300, 304
 See also Abrasive Water Jet Cutting; Laser Beam Cutting (LBC)
X-Y gantry system, 307, 308
Yield, 513
Yield point, 315–316, 316
Yield strength, 316, 576
Zinc oxide, 23
Z weave pattern, 64, 65