Contents

Fundamentals of Joining

Fundamentals of Welding

Chairperson: Thomas W. Eager, Massachusetts Institute of Technology

Energy Sources Used for Fusion Welding ........................................ 3
Heat Flow in Fusion Welding .......................................................... 7
Fundamental Flow Phenomena During Welding .................................. 19
Transfer of Heat and Mass to the Base Metal in Gas-Metal Arc Welding ........... 25
Arc Physics of Gas-Tungsten Arc Welding ....................................... 30
Power Sources .................................................................................. 36
Fundamentals of Weld Solidification .................................................. 45
Nature and Behavior of Fluxes Used for Welding ................................. 55
Shielding Gases ............................................................................. 64
Solid-State Transformations in Weldments .......................................... 70
Cracking Phenomena Associated With Welding .................................. 88
Characterization of Welds ................................................................. 97

Fundamentals of Brazing and Soldering

Chairperson: Mel M. Schwartz, Sikorsky Aircraft

Introduction to Brazing and Soldering .............................................. 109
Fundamentals of Brazing ................................................................. 114
Fundamentals of Soldering ............................................................... 126

Fundamentals of Solid-State Welding

Chairperson: Ray Dixon, Los Alamos National Laboratory

Introduction to Solid-State Welding ................................................. 141
Fundamentals of Metal and Metal-to-Ceramic Adhesion .......................... 143
Fundamentals of Friction Welding .................................................... 150
Fundamentals of Diffusion Bonding .................................................. 156
Fundamentals of Solid-State Welding .................................................. 160
Mechanical Properties of Soft-Interlayer Solid-State Welds ................. 165

Joining Processes

Fusion Welding Processes

Chairperson: Howard Cary, Hobart Brothers Company

Shielded Metal Arc Welding ............................................................... 175
Gas-Metal Arc Welding ................................................................. 180
Flux-Cored Arc Welding ............................................................... 186
Gas-Tungsten Arc Welding ............................................................ 190
Plasma Arc Welding ............................................................... 195
Carbon Arc Welding ............................................................... 200
Submerged Arc Welding ............................................................... 202
Stud Arc Welding ............................................................... 210
Capacitor Discharge Stud Welding ................................................. 221
Plasma-MIG Welding ............................................................... 223
Resistance Spot Welding ............................................................... 226
Projection Welding ............................................................... 230
Resistance Seam Welding ............................................................... 238
Flash Welding ............................................................... 247
Upset Welding ............................................................... 249
High-Frequency Welding .............................................................. 252
Electron-Beam Welding ............................................................... 254
Laser-Beam Welding ............................................................... 262
Electroslag and Electrogas Welding .................................................. 270
Oxyfuel Gas Welding ............................................................... 281
Thermite Welding ............................................................... 291

Solid-State Welding, Brazing, and Soldering Processes

Chairperson: Randy Roper, EG&G Rocky Flats

Solid-State Welding Processes

High-Temperature Solid-State Welding ............................................. 297
Low-Temperature Solid-State Welding ............................................. 300
Explosion Welding ............................................................... 303
Forge Welding ............................................................... 306
Cold-Welding ................................................................. 307
Coaxial Welding ................................................................. 311
Roll Welding ............................................................... 312
Friction Welding ............................................................... 315
Radial Friction Welding ............................................................ 318
Friction Surfacing ............................................................... 321
Ultrasonic Welding ............................................................... 324

Brazing Processes

Torch Brazing ............................................................... 328
Furnace Brazing ............................................................... 330
Induction Brazing ............................................................... 333
Dip Brazing ............................................................... 336
Resistance Brazing ............................................................... 339
Diffusion Brazing ............................................................... 343
Exothermic Brazing ............................................................... 345
Brazing With Clad Brazing Materials ............................................. 347

Soldering Processes

Iron Soldering ............................................................... 349
Torch Soldering ............................................................... 351
Furnace Soldering ............................................................... 353
Infrared Soldering ............................................................... 356
Resistance Soldering ............................................................... 357
Laser Soldering ............................................................... 359
Hot Gas Soldering ............................................................... 361
Induction Soldering ............................................................... 363
Wave Soldering ............................................................... 366
Vapor-Phase Soldering ............................................................... 369

Materials Selection for Joined Assemblies

Material Requirements for Service Conditions

Chairperson: R. David Thomas, Jr.

Material Requirements for Service Conditions ................................ 373

Selection of Carbon and Low-Alloy Steels

Chairperson: Bruce R. Somers, Lehigh University

Introduction to the Selection of Carbon and Low-Alloy Steels ........ 405
Selection of Stainless Steels
Chairperson: John C. Lippold, Edison Welding Institute

Introduction to the Selection of Stainless Steels
- 431
Selection of Wrought Martensitic Stainless Steels
- 432
Selection of Wrought Ferritic Stainless Steels
- 443
Selection of Wrought Austenitic Stainless Steels
- 456
Selection of Wrought Duplex Stainless Steels
- 471
Selection of Wrought Precipitation-Hardening Stainless Steels
- 482
Selection of Cast Stainless Steels
- 495
Dissimilar Welds With Stainless Steels
- 500

Selection of Nonferrous Low-Temperature Materials
Chairperson: William A. Baeslack III, The Ohio State University

Selection and Weldability of Conventional Titanium Alloys
- 507
Selection and Weldability of Advanced Titanium-Base Alloys
- 524
Selection and Weldability of Heat-Treatable Aluminum Alloys
- 528
Selection and Weldability of Non-Heat-Treatable Aluminum Alloys
- 537
Selection and Weldability of Dispersion-Strengthened Aluminum Alloys
- 541
Selection and Weldability of Aluminum-Lithium Alloys
- 549
Selection and Weldability of Aluminum Metal-Matrix Composites
- 554

Selection of Nonferrous High-Temperature Materials
Chairperson: Raymond G. Thompson, University of Alabama

General Welding Characteristics of High-Temperature Materials
- 563
Welding Metallurgy of Nonferrous High-Temperature Materials
- 566
Postweld Heat Treatment of Nonferrous High-Temperature Materials
- 572
Special Metallurgical Welding Considerations for Nickel and Cobalt Alloys and Superalloys
- 575
Special Metallurgical Welding Considerations for Refractory Metals
- 580

Selection of Nonferrous Corrosion-Resistant Materials
Chairperson: S.J. Matthews, Haynes International Inc.

Introduction to the Selection of Nonferrous Corrosion-Resistant Materials
- 585
Selection of Nickel, Nickel-Copper, Nickel-Chromium, and Nickel-Chromium-Iron Alloys
- 586
Selection of Nickel-Base Corrosion-Resistant Alloys Containing Molybdenum
- 593
Selection of Cobalt-, Titanium-, Zirconium-, and Tantalum-Based Corrosion-Resistant Alloys
- 598

Weldability Testing
Chairpersons: Richard D. Campbell, Joining Services Inc.
Daniel W. Walsh, California Polytechnic State University

Weldability Testing
- 603

 Brazeeability and Solderability of Engineering Materials
Chairperson: Stephen Liu, Colorado School of Mines

Brazeability and Solderability of Engineering Materials
- 617

Consumable Selection, Procedure Development, and Practice Considerations

Practice Considerations for Arc Welding
Chairperson: Damian Kotecki, Lincoln Electric Company

Welding of Carbon Steels
- 641
Welding of Low-Alloy Steels
- 662
Welding of Stainless Steels
- 677
Welding of Cast Irons
- 708
Welding of Aluminum Alloys
- 722
Welding of Nickel Alloys
- 740
Welding of Copper Alloys
- 752
Welding of Magnesium Alloys
- 772
Welding of Titanium Alloys
- 783
Welding of Zirconium Alloys
- 787
Hardfacing, Weld Cladding, and Dissimilar Metal Joining
- 789

Practice Considerations for Resistance Welding & High-Energy-Beam Welding

Procedure Development and Practice Considerations for Resistance Welding
- 833
Procedure Development and Practice Considerations for Electron-Beam Welding
- 851
Procedure Development and Practice Considerations for Laser-Beam Welding
- 874

Procedure Development and Practice Considerations for Solid-State Welding
Chairperson: Dan Hauer, Edison Welding Institute

Procedure Development and Practice Considerations for Diffusion Welding
- 883
Procedure Development and Practice Considerations for Inertia and Direct-Drive Friction Welding
- 888
Procedure Development and Practice Considerations for Ultrasonic Welding
- 893
Procedure Development and Practice Considerations for Explosion Welding
- 896

Practice Considerations for Brazing and Soldering
Chairperson: Anatol Rabinkin, Metglas Products

Selection Criteria for Brazing and Soldering Consumables
- 903
Brazing of Cast Irons and Carbon Steels
- 906
Brazing of Stainless Steels
- 911
Brazing of Heat-Resistant Alloys, Low-Alloy Steels, and Tool Steels
- 924
Brazing of Copper, Copper Alloys, and Precious Metals
- 931
Brazing of Aluminum Alloys
- 937
Brazing of Refractory and Reactive Metals
- 941
Brazing of Ceramic and Ceramic-Metal Joints
- 948
Application of Clad Brazing Materials
- 961
General Soldering
- 964
Soldering in Electronic Applications
- 985

Special Welding and Joining Considerations

Special Welding and Joining Topics
Chairperson: Hendrikus H. Vanderveelt, American Welding Institute

Introduction to Special Welding and Joining Topics
- 1003
Thermal Spray Coatings
- 1004
Underwater Welding
- 1010
Welding for Cryogenic Service
- 1016
Welding in Space and Low-Gravity Environments
- 1020
Joining of Organic-Matrix Composites
- 1026
Joining of Oxide-Dispersion-Strengthened Materials
- 1037
Composite-to-Metal Joining
- 1041
Welding of Plastics
- 1048
Intelligent Automation for Joining Technology
- 1057
Corrosion of Weldments
- 1065

Joint Evaluation and Quality Control
Chairperson: Robin Gordon, Edison Welding Institute

Overview of Weld Discontinuities
- 1073
Inspection of Welded Joints ............................................. 1081
Weld Procedure Qualification ...................................... ..., 1089
Residual Stresses and Distortion .................................... :...1094
Repair Welding .................................................. .......... 1103
Fitness-for-Service Assessment of Welded Structures .......... 1108
Evaluation and Quality Control of Brazed Joints .............. 1117
Evaluation and Quality Control of Soldered Joints .......... 1124

Modeling of Joining Processes
Chairperson: Kim Mahin, Sandia National Laboratories

Numerical Aspects of Modeling Welds .............................. 1131
Characterization and Modeling of the Heat Source ............... 1141
Validation Strategies for Heat-Affected Zone and Fluid-Flow Calculations .................................................. 1147

Cutting Processes
Chairperson: Lance R. Soisson, Welding Consultants Inc.

Oxyfuel Gas Cutting ..................................................... 1155
Plasma Arc Cutting ..................................................... 1166
Air-Carbon Arc Cutting ................................................... 1172
Mechanical Cutting for Weld Preparation ......................... 1178

Safe Practices ............................................................. 1189
Glossary of Terms .......................................................... 1206
Metric Conversion Guide .................................................. 1216
Temperature Conversion Table ......................................... 1218
Abbreviations, Symbols, and Tradenames ......................... 1221
Index ........................................................................ 1225