

CONTENTS

1 INTRODUCTION AND OVERVIEW OF MANUFACTURING 1

- 1.1 What Is Manufacturing? 2
- 1.2 Materials in Manufacturing 6
- 1.3 Manufacturing Processes 9
- 1.4 Production Systems 14
- 1.5 Manufacturing Economics 17

Part I Material Properties and Product Attributes 26

2 THE NATURE OF MATERIALS 26

- 2.1 Atomic Structure and the Elements 26
- 2.2 Bonding between Atoms and Molecules 29
- 2.3 Crystalline Structures 31
- 2.4 Noncrystalline (Amorphous) Structures 36
- 2.5 Engineering Materials 37

3 MECHANICAL PROPERTIES OF MATERIALS 40

- 3.1 Stress–Strain Relationships 40
- 3.2 Hardness 53
- 3.3 Effect of Temperature on Properties 57
- 3.4 Fluid Properties 59
- 3.5 Viscoelastic Behavior of Polymers 61

4 PHYSICAL PROPERTIES OF MATERIALS 66

- 4.1 Volumetric and Melting Properties 66
- 4.2 Thermal Properties 69
- 4.3 Mass Diffusion 70
- 4.4 Electrical Properties 72
- 4.5 Electrochemical Processes 74

5 DIMENSIONS, SURFACES, AND THEIR MEASUREMENT 77

- 5.1 Dimensions, Tolerances, and Related Attributes 77

- 5.2 Conventional Measuring Instruments and Gages 78
- 5.3 Surfaces 85
- 5.4 Measurement of Surfaces 89
- 5.5 Effect of Manufacturing Processes 91

Part II Engineering Materials 94

6 METALS 94

- 6.1 Alloys and Phase Diagrams 95
- 6.2 Ferrous Metals 99
- 6.3 Nonferrous Metals 115
- 6.4 Superalloys 123

7 CERAMICS 126

- 7.1 Structure and Properties of Ceramics 127
- 7.2 Traditional Ceramics 129
- 7.3 New Ceramics 131
- 7.4 Glass 133
- 7.5 Some Important Elements Related to Ceramics 136

8 POLYMERS 140

- 8.1 Fundamentals of Polymer Science and Technology 141
- 8.2 Thermoplastic Polymers 150
- 8.3 Thermosetting Polymers 155
- 8.4 Elastomers 158
- 8.5 Polymer Recycling and Biodegradability 162

9 COMPOSITE MATERIALS 166

- 9.1 Technology and Classification of Composite Materials 167
- 9.2 Metal Matrix Composites 174
- 9.3 Ceramic Matrix Composites 176
- 9.4 Polymer Matrix Composites 177

Part III Solidification Processes 181**10 FUNDAMENTALS OF METAL CASTING 181**

- 10.1 Overview of Casting Technology 182
- 10.2 Heating and Pouring 184
- 10.3 Solidification and Cooling 188

11 METAL CASTING PROCESSES 198

- 11.1 Sand Casting 198
- 11.2 Other Expendable-Mold Casting Processes 202
- 11.3 Permanent-Mold Casting Processes 207
- 11.4 Foundry Practice 215
- 11.5 Casting Quality 219
- 11.6 Castability and Casting Economics 221
- 11.7 Product Design Considerations 225

12 GLASSWORKING 230

- 12.1 Raw Materials Preparation and Melting 230
- 12.2 Shaping Processes in Glassworking 231
- 12.3 Heat Treatment and Finishing 236
- 12.4 Product Design Considerations 237

13 SHAPING PROCESSES FOR PLASTICS 239

- 13.1 Properties of Polymer Melts 240
- 13.2 Extrusion 242
- 13.3 Production of Sheet and Film 251
- 13.4 Fiber and Filament Production (Spinning) 254
- 13.5 Coating Processes 255
- 13.6 Injection Molding 256
- 13.7 Compression and Transfer Molding 266
- 13.8 Blow Molding and Rotational Molding 268
- 13.9 Thermoforming 273
- 13.10 Casting 277
- 13.11 Polymer Foam Processing and Forming 278
- 13.12 Product Design Considerations 279

14 PROCESSING OF POLYMER MATRIX COMPOSITES AND RUBBER 285

- 14.1 Overview of PMC Processing 285
- 14.2 Open-Mold Processes 289

- 14.3 Closed-Mold Processes 293
- 14.4 Other PMC Shaping Processes 295
- 14.5 Rubber Processing and Shaping 299
- 14.6 Manufacture of Tires and Other Rubber Products 304

Part IV Particulate Processing of Metals and Ceramics 309**15 POWDER METALLURGY 309**

- 15.1 Characterization of Engineering Powders 310
- 15.2 Production of Metallic Powders 314
- 15.3 Conventional Pressing and Sintering 316
- 15.4 Alternative Pressing and Sintering Techniques 322
- 15.5 Materials and Products for Powder Metallurgy 325
- 15.6 Design Considerations in Powder Metallurgy 326

16 PROCESSING OF CERAMICS AND CERMETS 331

- 16.1 Processing of Traditional Ceramics 331
- 16.2 Processing of New Ceramics 339
- 16.3 Processing of Cermets 341
- 16.4 Product Design Considerations 343

Part V Metal Forming and Sheet Metalworking 345**17 FUNDAMENTALS OF METAL FORMING 345**

- 17.1 Overview of Metal Forming 345
- 17.2 Material Behavior in Metal Forming 348
- 17.3 Temperature in Metal Forming 349
- 17.4 Strain Rate Sensitivity 351
- 17.5 Friction and Lubrication in Metal Forming 353

18 BULK DEFORMATION PROCESSES IN METAL WORKING 356

- 18.1 Rolling 356
- 18.2 Forging 365
- 18.3 Extrusion 380
- 18.4 Wire and Bar Drawing 390

19 SHEET METALWORKING 401

- 19.1 Cutting Operations 401
- 19.2 Bending Operations 408
- 19.3 Drawing 412
- 19.4 Dies and Presses for Sheet Metal Processes 419
- 19.5 Other Sheet-Metal-Forming Operations 425
- 19.6 Sheet Metal Operations Not Performed on Presses 428
- 19.7 Bending of Tube Stock 433

Part VI Material Removal Processes 439**20 THEORY OF METAL MACHINING 439**

- 20.1 Overview of Machining Technology 441
- 20.2 Theory of Chip Formation in Metal Machining 444
- 20.3 Force Relationships and the Merchant Equation 448
- 20.4 Power and Energy Relationships in Machining 453
- 20.5 Cutting Temperature 455

21 MACHINING OPERATIONS AND MACHINE TOOLS 459

- 21.1 Machining and Part Geometry 459
- 21.2 Turning and Related Operations 462
- 21.3 Drilling and Related Operations 470
- 21.4 Milling 475
- 21.5 Machining Centers and Turning Centers 482
- 21.6 Other Machining Operations 484
- 21.7 Machining Operations for Special Geometries 489
- 21.8 High-Speed Machining 495

22 CUTTING-TOOL TECHNOLOGY 500

- 22.1 Tool Life 500
- 22.2 Tool Materials 506
- 22.3 Tool Geometry 513
- 22.4 Cutting Fluids 523

23 ECONOMIC AND PRODUCT DESIGN CONSIDERATIONS IN MACHINING 529

- 23.1 Machinability 529
- 23.2 Tolerances and Surface Finish 530
- 23.3 Machining Economics 535
- 23.4 Product Design Considerations in Machining 541

24 GRINDING AND OTHER ABRASIVE PROCESSES 546

- 24.1 Grinding 546
- 24.2 Related Abrasive Processes 562

25 NONTRADITIONAL MACHINING AND THERMAL CUTTING PROCESSES 568

- 25.1 Mechanical Energy Processes 569
- 25.2 Electrochemical Machining Processes 572
- 25.3 Thermal Energy Processes 576
- 25.4 Chemical Machining 585
- 25.5 Application Considerations 590

Part VII Property Enhancing and Surface Processing Operations 595**26 HEAT TREATMENT OF METALS 595**

- 26.1 Annealing 595
- 26.2 Martensite Formation in Steel 596
- 26.3 Precipitation Hardening 600
- 26.4 Surface Hardening 601
- 26.5 Heat Treatment Methods and Facilities 602

27 SURFACE PROCESSING OPERATIONS 606

- 27.1 Industrial Cleaning Processes 606
- 27.2 Diffusion and Ion Implantation 610
- 27.3 Plating and Related Processes 611
- 27.4 Conversion Coating 615
- 27.5 Vapor Deposition Processes 616
- 27.6 Organic Coatings 622
- 27.7 Porcelain Enameling and Other Ceramic Coatings 624
- 27.8 Thermal and Mechanical Coating Processes 625

Part VIII Joining and Assembly Processes 628

28 FUNDAMENTALS OF WELDING 628

- 28.1 Overview of Welding Technology 629
- 28.2 The Weld Joint 631
- 28.3 Physics of Welding 634
- 28.4 Features of a Fusion-Welded Joint 637

29 WELDING PROCESSES 641

- 29.1 Arc Welding 641
- 29.2 Resistance Welding 650
- 29.3 Oxyfuel Gas Welding 657
- 29.4 Other Fusion-Welding Processes 661
- 29.5 Solid-State Welding 663
- 29.6 Weld Quality 669
- 29.7 Weldability and Welding Economics 673
- 29.8 Design Considerations in Welding 676

30 BRAZING, SOLDERING, AND ADHESIVE BONDING 681

- 30.1 Brazing 681
- 30.2 Soldering 686
- 30.3 Adhesive Bonding 690

31 MECHANICAL ASSEMBLY 697

- 31.1 Threaded Fasteners 697
- 31.2 Rivets and Eyelets 704
- 31.3 Assembly Methods Based on Interference Fits 705
- 31.4 Other Mechanical Fastening Methods 708
- 31.5 Molding Inserts and Integral Fasteners 709
- 31.6 Design for Assembly 710

Part IX Special Processing and Assembly Technologies 716

32 RAPID PROTOTYPING AND ADDITIVE MANUFACTURING 716

- 32.1 Fundamentals of Rapid Prototyping and Additive Manufacturing 717
- 32.2 Additive Manufacturing Processes 719

- 32.3 Cycle Time and Cost Analysis 726
- 32.4 Additive Manufacturing Applications 730

33 PROCESSING OF INTEGRATED CIRCUITS 734

- 33.1 Overview of IC Processing 735
- 33.2 Silicon Processing 738
- 33.3 Lithography 743
- 33.4 Layer Processes Used in IC Fabrication 747
- 33.5 Integrating the Fabrication Steps 753
- 33.6 IC Packaging 755
- 33.7 Yields in IC Processing 759

34 ELECTRONICS ASSEMBLY AND PACKAGING 764

- 34.1 Electronics Packaging 764
- 34.2 Printed Circuit Boards 766
- 34.3 Printed Circuit Board Assembly 773
- 34.4 Electrical Connector Technology 780

35 MICROFABRICATION TECHNOLOGIES 785

- 35.1 Microsystem Products 785
- 35.2 Microfabrication Processes 788

36 NANOFABRICATION TECHNOLOGIES 797

- 36.1 Nanotechnology Products and Applications 797
- 36.2 Introduction to Nanoscience 801
- 36.3 Nanofabrication Processes 805

Part X Manufacturing Systems 812

37 AUTOMATION TECHNOLOGIES FOR MANUFACTURING SYSTEMS 812

- 37.1 Automation Fundamentals 812
- 37.2 Hardware for Automation 815
- 37.3 Computer Numerical Control 819
- 37.4 Industrial Robotics 830

38 INTEGRATED MANUFACTURING SYSTEMS 838

- 38.1 Material Handling 838
- 38.2 Fundamentals of Production Lines 839

- 38.3 Manual Assembly Lines 841
- 38.4 Automated Production Lines 845
- 38.5 Cellular Manufacturing 849
- 38.6 Flexible Manufacturing Systems 853
- 38.7 Computer-Integrated Manufacturing 857

Part XI Manufacturing Support Systems 861

39 PROCESS PLANNING AND PRODUCTION CONTROL 861

- 39.1 Process Planning 862
- 39.2 Other Manufacturing Engineering Functions 869
- 39.3 Production Planning and Control 872

- 39.4 Just-In-Time Delivery Systems 879
- 39.5 Lean Production 882

40 QUALITY CONTROL AND INSPECTION 887

- 40.1 Product Quality 887
- 40.2 Process Capability and Tolerances 888
- 40.3 Statistical Process Control 890
- 40.4 Quality Programs in Manufacturing 894
- 40.5 Inspection Principles 898
- 40.6 Modern Inspection Technologies 900

APPENDIX: Answers to Selected Problems 909

INDEX 913