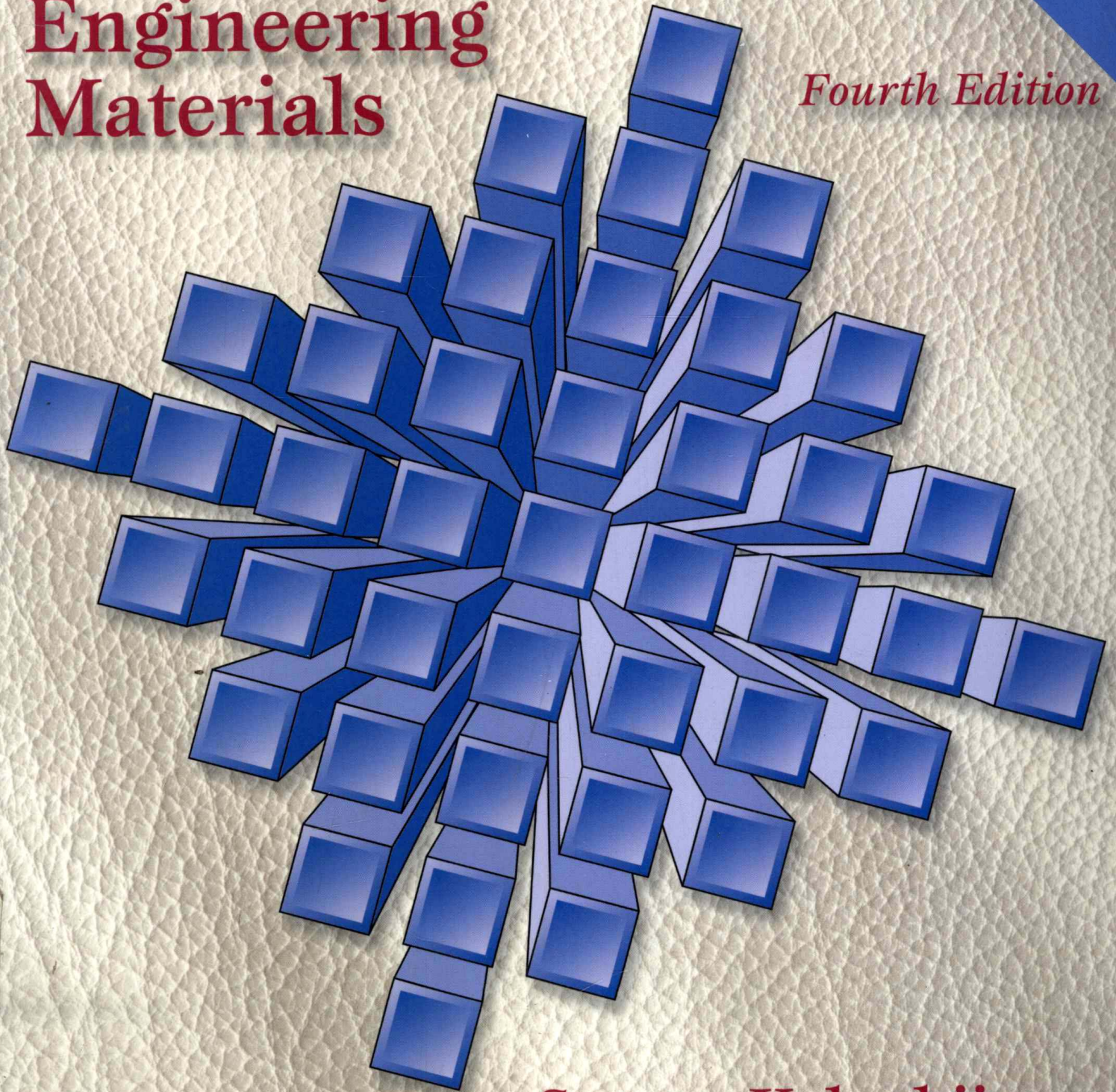


# Manufacturing Processes for Engineering Materials

International  
Edition

*Fourth Edition*



Serope Kalpakjian  
Steven R. Schmid



# Manufacturing Processes for Engineering Materials

FOURTH  
EDITION

Serope Kalpakjian

*Illinois Institute of Technology, Chicago, Illinois*

Steven R. Schmid

*University of Notre Dame, Notre Dame, Indiana*

Prentice  
Hall

Pearson Education International

Vice President and Editorial Director, ECS: *Marcia J. Horton*  
Acquisitions Editor: *Dorothy Marrero*  
Editorial Assistant: *Brian Hoehl*  
Vice President and Director of Production and Manufacturing, ESM: *David W. Riccardi*  
Executive Managing Editor: *Vince O'Brien*  
Managing Editor: *David A. George*  
Production Editor: *Tamar Savir*  
Director of Creative Services: *Paul Belfanti*  
Creative Director: *Carole Anson*  
Art Editor: *Xiaohong Zhu*  
Cover Designer: *Geoffrey Cassar*  
Manufacturing Manager: *Trudy Piscioti*  
Manufacturing Buyer: *Lisa McDowell*  
Marketing Manager: *Holly Stark*



© 2003 by Pearson Education, Inc.  
Pearson Education, Inc.  
Upper Saddle River, NJ 07458

All rights reserved. No part of this book may be reproduced in any form or by any means, without permission in writing from the publisher.

The author and publisher of this book have used their best efforts in preparing this book. These efforts include the development, research, and testing of the theories and programs to determine their effectiveness. The author and publisher make no warranty of any kind, expressed or implied, with regard to these programs or the documentation contained in this book. The author and publisher shall not be liable in any event for incidental or consequential damages in connection with, or arising out of, the furnishing, performance, or use of these programs.

This edition may be sold only in those countries to which it is consigned by Pearson Education International. It is not to be re-exported and it is not for sale in the U.S.A., Mexico, or Canada.

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

ISBN 0-13-045373-0

Pearson Education Ltd., *London*  
Pearson Education Australia Pty. Ltd., *Sydney*  
Pearson Education Singapore, Pte. Ltd.  
Pearson Education North Asia Ltd., *Hong Kong*  
Pearson Education Canada, Inc., *Toronto*  
Pearson Educación de Mexico, S.A. de C.V.  
Pearson Education—Japan, *Tokyo*  
Pearson Education Malaysia, Pte. Ltd.  
Pearson Education, Inc., *Upper Saddle River, New Jersey*

# PREFACE

The fourth edition of this text, like the previous editions, continues to make an attempt at presenting a comprehensive, balanced, and up-to-date coverage of the relevant fundamentals and real-world applications of engineering materials and manufacturing processes and systems and the analytical approaches involved. The topics covered throughout the 16 chapters reflect the rapid and significant advances that have taken place in various areas in manufacturing, and they are organized and described in such a manner to draw the interest of students. The case studies, mostly from industry, make the subject of manufacturing science and engineering less abstract by showing students the practical aspects of process applications.

Integration of product design and manufacturing has justly resulted in greater recognition and prestige for these disciplines, and this edition therefore puts greater emphasis and better focus on this increasingly important subject. While studying this text, students should be able to assess the capabilities, limitations, and potential of production processes, including, particularly, the processes' economic and competitive aspects. The discussions throughout the chapters are aimed at motivating and challenging students to explore technically and economically viable solutions to a wide variety of important questions and problems in product design and manufacturing.

This book has been written mainly for undergraduate students in mechanical, industrial, and metallurgical and materials engineering programs; it is also useful for graduate courses in manufacturing science and engineering. The text, as well as the numerous examples and case studies in each chapter, clearly shows that manufacturing engineering is an interdisciplinary and complex subject and that it is as important, exciting, and challenging as any other engineering discipline.

## **What's new in this edition**

- A new chapter has been added that covers the fabrication of microelectronic and micromechanical devices.
- The discussion of design considerations in each chapter have been expanded.
- Several new examples and case studies have been added throughout all chapters.
- A total of 1230 questions and problems has been added—30% more than in the third edition.
- Questions and problems now include a total of 140 design problems.
- Figures have been improved for better graphical impact.
- More cross-references to sections and chapters have been added throughout the text.
- All chapter bibliographies have been thoroughly updated.

## **New or expanded topics for this edition include the following:**

- Automated guided vehicles
- Biodegradable plastics
- Cryogenic machining and grinding
- Cryogenic treatment of cutting tools
- Design considerations for casting
- Design considerations for powder metallurgy

- Design considerations for sheet-metal forming
- Electrically conducting adhesives
- Enterprise resource planning
- Flexible fixturing
- ISO 9000 and 14000 standards
- Life-cycle assessment
- LIGA process
- Metal foams
- Microelectromechanical systems fabrication
- Microelectronics device fabrication
- Micromachining
- Modeling of casting
- Nanomaterials
- Plasma and wet etching
- Polymer processing
- Printed circuit boards
- Rapid prototyping and rapid tooling
- Rotary ultrasonic machining
- Silicon microstructure
- Six-sigma quality
- Solid free-form fabrication
- Stick-slip in extrusion
- Superconductor processing
- Surface-mount technology
- Value assessment
- Vibration and chatter in rolling
- Water-jet peening

## Acknowledgments

We gratefully acknowledge the following colleagues and associates for their contributions to the various sections of this book:

K. Anderson (Baxter Healthcare Corp.), P. J. Courtney (Loctite Corp.), D. Furrer (Ladish Corp.), K. L. Graham (Guidant Corp.), M. Hawkins (Zimmer, Inc.), K. M. Kalpakjian (Micron Technology, Inc., Mr. Kalpakjian is principal author of the sections on fabrication of microelectronic devices in Chapter 13), R. Kassing (University of Kassel), K. M. Kulkarni (Advanced Manufacturing Practices, Inc.), M. Madou (Nanogen, Inc.), A. Marsan (Ford Motor Co.), S. Paolucci (University of Notre Dame), C. Petronis (ST Microelectronics, Inc.), S. Petronis (Zimmer Holdings, Inc.), M. Pradheeradhi (Concurrent Technologies Corp.), Y. Rong (Worcester Polytechnic Institute), P. Saha (Boeing Co.), S. Shepel (University of Notre Dame), M. T. Siniawski (Northwestern University), P. Stewart (Ford Motor Co.), S. Vaze (Concurrent Technologies Corp.), J. E. Wang (Texas A&M University), K. J. Weinmann (Michigan Technological University), and K. R. Williams (Agilent, Inc.).

Many thanks to our colleagues at various institutions for their help, their detailed reviews, comments contributions, and many constructive suggestions for this edition:

D. D. Arola (University of Maryland), S. Mantell (University of Minnesota), M. H. Miller (Michigan Technological University), J. Moller (Miami University), D. J. Morrison (Clarkson University), U. Pal (Boston University), B. S. Thakkar (Lucent Technologies), and A. Tseng (Arizona State University), Dr. Rajiv Shivpuri (Ohio State University), Dr. Shaochen Chen (Iowa State University), Dr. Nicholas Zabararas (Cornell University), Dr. Mark Tuttle (University of Washington), Dr. Donald W. Radford (Colorado State University), Dr. Mica Grujicic (Clemson University).

We would also like to acknowledge the dedication and continued help of our editor, Laura Fischer, and the editorial staff at Prentice Hall, including Tamar Savir, David George, and Xiaohong Zhu. We appreciate the help of the many organizations that supplied us with various case studies and numerous illustrations. And, finally, many thanks to Jean Kalpakjian for her help in the final preparation of this book.

SEROPE KALPAKJIAN  
*Chicago, Illinois*

STEVEN R. SCHMID  
*Notre Dame, Indiana*

# ABOUT THE AUTHORS

**Serope Kalpakjian** taught and conducted research at the Illinois Institute of Technology for 38 years prior to his retirement in 2001 as professor emeritus of mechanical and materials engineering. After graduating from Robert College (high honors), Harvard University, and the Massachusetts Institute of Technology, he joined Cincinnati Milacron, where he was a research supervisor in advanced metal-forming processes. He is the author of numerous technical papers and several articles in handbooks and encyclopedias and has edited various conference proceedings. In addition, Professor Kalpakjian has served on the editorial boards of several journals and the *Encyclopedia Americana* and is the coauthor of *Lubricants and Lubrication in Metalworking Operations*. Both first editions of his textbooks, *Manufacturing Processes for Engineering Materials* and *Manufacturing Engineering and Technology*, have received the M. Eugene Merchant Manufacturing Textbook Award. He is a Life Fellow of the ASME, Fellow of the SME, Fellow and Life Member of ASM International, emeritus member of CIRP (International Institution for Production Engineering Research), and a founding member and past president of NAMRI/SME.

Among the awards Professor Kalpakjian has received are the Forging Industry Educational and Research Foundation Best Paper Award (1966), an Excellence in Teaching Award from IIT (1970), the Centennial Medallion from the ASME (1980), the International Education Award from the SME (1989), a Person of the Millennium Award from IIT (1999), and the Albert Easton White Distinguished Teacher Award from ASM International (2000). SME named the Outstanding Young Manufacturing Engineer Award after Professor Kalpakjian for the year 2002.

**Steven R. Schmid** is an associate professor with the Department of Aerospace and Mechanical Engineering, University of Notre Dame, where he teaches and performs research in the general areas of manufacturing, machine design, and tribology. As the director of the Manufacturing Tribology Laboratory at the university, he oversees industry- and government-funded research on a variety of manufacturing topics, including tribological issues in rolling, forging and sheet-metal forming, polymer processing, medical-device design and manufacture, and nanomechanics.

He received the B.S. degree in mechanical engineering from the Illinois Institute of Technology (with honors) and M.S. and Ph.D. degrees, both in mechanical engineering, from Northwestern University. He has received numerous awards, including the John T. Parsons Award from the SME (2000), the Newkirk Award from the ASME (2000), and the Kaneb Center Teaching Award (2000). He is the recipient of a National Science Foundation CAREERS Award (1996) and an ALCOA Foundation Award (1994). Dr. Schmid is the author of over 50 technical papers; has edited three conference proceedings; has coauthored two books, *Fundamentals of Machine Elements* and *Manufacturing Engineering and Technology*; and has contributed two chapters to the *CRC Handbook of Modern Tribology*. He serves on the Tribology Division Executive Committee of the ASME, is an associate editor of the *Journal of Manufacturing Science and Engineering*, and is a registered professional engineer and certified manufacturing engineer.

# CONTENTS

## Preface xiii

## 1 Introduction 1

- 1.1 What Is Manufacturing? 1
- 1.2 Product Design and Concurrent Engineering 6
- 1.3 Design for Manufacture, Assembly, Disassembly,  
and Service 8
- 1.4 Environmentally Conscious Design and Manufacturing 10
- 1.5 Selecting Materials 11
- 1.6 Selecting Manufacturing Processes 14
- 1.7 Computer-Integrated Manufacturing 17
- 1.8 Quality Assurance and Total Quality Management 20
- 1.9 Product Liability 21
- 1.10 Manufacturing Costs, Lean Production, and Agile  
Manufacturing 22
- 1.11 General Trends in Manufacturing 23
- 1.12 Responsibilities of Manufacturing Engineers 24
- Summary 24

## 2 Fundamentals of the Mechanical Behavior of Materials 26

- 2.1 Introduction 26
- 2.2 Tension 27
- 2.3 Compression 43
- 2.4 Torsion 46
- 2.5 Bending 48
- 2.6 Hardness 49
- 2.7 Fatigue 54
- 2.8 Creep 55
- 2.9 Impact 56
- 2.10 Residual Stresses 57
- 2.11 Triaxial Stresses and Yield Criteria 60
- 2.12 Work of Deformation 68
- Summary 72
- Summary of Equations 74
- Bibliography 75
- Questions 75
- Problems 77



### **3 Structure and Manufacturing Properties of Metals 81**

- 3.1 Introduction 81
- 3.2 The Crystal Structure of Metals 82
- 3.3 Deformation and Strength of Single Crystals 83
- 3.4 Grains and Grain Boundaries 89
- 3.5 Plastic Deformation of Polycrystalline Metals 92
- 3.6 Recovery, Recrystallization, and Grain Growth 93
- 3.7 Cold, Warm, and Hot Working 95
- 3.8 Failure and Fracture 96
- 3.9 Physical Properties 103
- 3.10 Properties and Applications of Ferrous Alloys 108
- 3.11 Properties and Applications of Nonferrous Metals and Alloys 112
- Summary 124
- Summary of Equations 125
- Bibliography 125
- Questions 126
- Problems 127

### **4 Surfaces, Tribology, Dimensional Characteristics, Inspection, and Product Quality Assurance 128**

- 4.1 Introduction 128
- 4.2 Surface Structure and Properties 129
- 4.3 Surface Texture 130
- 4.4 Tribology: Friction, Wear, and Lubrication 134
- 4.5 Surface Treatments, Coatings, and Cleaning 151
- 4.6 Engineering Metrology and Instrumentation 160
- 4.7 Dimensional Tolerances 165
- 4.8 Testing and Inspection 167
- 4.9 Quality Assurance 170
- Summary 180
- Summary of Equations 181
- Bibliography 182
- Questions 183
- Problems 184
- Design 185

### **5 Metal-Casting Processes and Equipment; Heat Treatment 186**

- 5.1 Introduction 186
- 5.2 Solidification of Metals 187
- 5.3 Cast Structures 195
- 5.4 Fluid Flow and Heat Transfer 199

5.5	Melting Practice and Furnaces	207
5.6	Casting Alloys	209
5.7	Ingot Casting and Continuous Casting	215
5.8	Casting Processes: Expendable Mold, Permanent Pattern	218
5.9	Casting Processes: Expendable Mold, Expendable Pattern	224
5.10	Casting Processes: Permanent Mold	227
5.11	Heat Treatment	235
5.12	Design Considerations	245
5.13	Economics of Casting	249
	CASE STUDY: Permanent-Mold Casting of Aluminum	
	Automotive Pistons	250
	Summary	252
	Summary of Equations	253
	Bibliography	254
	Questions	254
	Problems	256
	Design	258

## 6 Bulk Deformation Processes 260

6.1	Introduction	260
6.2	Forging	260
6.3	Rolling	282
6.4	Extrusion	300
6.5	Rod, Wire, and Tube Drawing	312
6.6	Swaging	321
6.7	Die Manufacturing Methods	322
6.8	Die Failures	324
	CASE STUDY: Manufacturing Solid Rocket-Motor Case Segments	
	for the Space Shuttle	325
	Summary	327
	Summary of Equations	328
	Bibliography	329
	Questions	330
	Problems	332
	Design	335

## 7 Sheet-Metal Forming Processes 336

7.1	Introduction	336
7.2	Sheet-Metal Characteristics	336
7.3	Shearing	341
7.4	Bending of Flat Sheet and Plate	349
7.5	Stretch Forming	360
7.6	Bulging	362
7.7	Rubber Forming and Hydroforming	363
7.8	Spinning	364
7.9	High-Energy-Rate Forming	368
7.10	Superplastic Forming	371
7.11	Various Forming Methods	372

- 7.12 Deep Drawing 374
- 7.13 Formability of Sheet Metals 385
- 7.14 Equipment for Sheet-Metal Forming 391
- 7.15 Design Considerations 392
- 7.16 Economics of Sheet-Metal Forming 394
  - CASE STUDY: Can Manufacturing 394
  - Summary 397
  - Summary of Equations 399
  - Bibliography 399
  - Questions 400
  - Problems 401
  - Design 403

## **8 Material-Removal Processes: Cutting 404**

- 8.1 Introduction 404
- 8.2 Mechanics of Chip Formation 405
- 8.3 Tool Wear and Failure 426
- 8.4 Surface Finish and Integrity 434
- 8.5 Machinability 437
- 8.6 Cutting-Tool Materials 440
- 8.7 Cutting Fluids 451
- 8.8 Cutting Processes and Machine Tools for Producing Round Shapes 454
- 8.9 Cutting Processes and Machine Tools for Producing Various Shapes 468
- 8.10 Machining and Turning Centers 482
- 8.11 Vibration and Chatter 486
- 8.12 Machine-Tool Structures 488
- 8.13 Design Considerations 489
- 8.14 Economics of Machining 490
  - CASE STUDY: High-Speed Dry Machining of Cast-Iron Engine Blocks 493
  - Summary 494
  - Summary of Equations 496
  - Bibliography 497
  - Questions 498
  - Problems 501
  - Design 502

## **9 Material Removal Processes: Abrasive, Chemical, Electrical, and High-Energy Beams 504**

- 9.1 Introduction 504
- 9.2 Abrasives 505
- 9.3 Bonded Abrasives 506
- 9.4 Mechanics of Grinding 510

- 9.5 Grinding-Wheel Wear 517
- 9.6 Grinding Operations and Machines 521
- 9.7 Ultrasonic Machining 527
- 9.8 Finishing Operations 528
- 9.9 Deburring 532
- 9.10 Chemical Machining 533
- 9.11 Electrochemical Machining 537
- 9.12 Electrochemical Grinding 539
- 9.13 Electrical-Discharge Machining 540
- 9.14 High-Energy-Beam Machining 544
- 9.15 Water-Jet, Abrasive Water-Jet, and Abrasive-Jet Machining 547
- 9.16 Design Considerations 549
- 9.17 Process Economics 549
- CASE STUDY: Manufacture of Stents 551
- Summary 553
- Summary of Equations 554
- Bibliography 554
- Questions 555
- Problems 557
- Design 558

## 10 Properties and Processing of Polymers and Reinforced Plastics; Rapid Prototyping and Rapid Tooling 559

- 10.1 Introduction 559
- 10.2 The Structure of Polymers 560
- 10.3 Thermoplastics: Behavior and Properties 568
- 10.4 Thermosets: Behavior and Properties 575
- 10.5 Thermoplastics: General Characteristics and Applications 576
- 10.6 Thermosets: General Characteristics and Applications 578
- 10.7 High-Temperature Polymers, Electrically Conducting Polymers, and Biodegradable Plastics 579
- 10.8 Elastomers (Rubbers): General Characteristics and Applications 581
- 10.9 Reinforced Plastics 582
- 10.10 Processing of Plastics 590
- 10.11 Processing of Polymer-Matrix-Reinforced Plastics 605
- 10.12 Rapid Prototyping and Rapid Tooling 610
- 10.13 Design Considerations 619
- 10.14 Economics of Processing Plastics 621
- CASE STUDY: The EPOCH Hip 622
- Summary 623
- Summary of Equations 624
- Bibliography 625
- Questions 626
- Problems 628
- Design 629

# **11 Properties and Processing of Metal Powders, Ceramics, Glasses, Composites, and Superconductors 630**

- 11.1 Introduction 630
- 11.2 Production of Metal Powders 631
- 11.3 Compaction of Metal Powders 636
- 11.4 Sintering 644
- 11.5 Secondary and Finishing Operations 649
- 11.6 Design Considerations for Powder Metallurgy 651
- 11.7 Economics of Powder Metallurgy 653
- 11.8 Ceramics: Structure, Properties, and Applications 655
- 11.9 Shaping Ceramics 663
- 11.10 Glasses: Structure, Properties, and Applications 668
- 11.11 Forming and Shaping Glass 671
- 11.12 Design Considerations for Ceramics and Glasses 675
- 11.13 Graphite and Diamond 675
- 11.14 Processing Metal-Matrix and Ceramic-Matrix Composites 676
- 11.15 Processing Superconductors 679
  - CASE STUDY: Production of High-Temperature Superconducting Tapes 679
  - Summary 682
  - Summary of Equations 683
  - Bibliography 683
  - Questions 685
  - Problems 686
  - Design 687

# **12 Joining and Fastening Processes 688**

- 12.1 Introduction 688
- 12.2 Arc-Welding Processes: Consumable Electrode 690
- 12.3 Arc-Welding Processes: Nonconsumable Electrode 697
- 12.4 High-Energy-Beam Welding 699
- 12.5 The Fusion-Welded Joint 701
- 12.6 Cold Welding 712
- 12.7 Ultrasonic Welding 713
- 12.8 Friction Welding 714
- 12.9 Resistance Welding 716
- 12.10 Explosion Welding 721
- 12.11 Diffusion Bonding 722
- 12.12 Brazing and Soldering 723
- 12.13 Adhesive Bonding 730
- 12.14 Mechanical Fastening 734
- 12.15 Joining Plastics, Ceramics, and Glasses 737
- 12.16 Design Considerations in Joining 740
- 12.17 Economic Considerations 743
  - CASE STUDY: Light-Curing Acrylic Adhesives for Medical Products 744



Summary	746
Bibliography	747
Questions	749
Problems	751
Design	752

## 13 Fabrication of Microelectronic and Micromechanical Devices 753

13.1	Introduction	753
13.2	Semiconductors and Silicon	756
13.3	Crystal Growing and Wafer Preparation	757
13.4	Films and Film Deposition	759
13.5	Oxidation	761
13.6	Lithography	762
13.7	Diffusion and Ion Implantation	765
13.8	Etching	766
13.9	Metallization and Testing	776
13.10	Wire Bonding and Packaging	778
13.11	Yield and Reliability of Chips	781
13.12	Printed Circuit Boards	782
13.13	Micromachining of MEMS Devices	785
13.14	The LIGA Microfabrication Process	794
13.15	Solid Free-Form Fabrication of Devices	799
	CASE STUDY: Accelerometer for Automotive Air Bags	800
	Summary	803
	Bibliography	804
	Questions	805
	Problems	806
	Design	806

## 14 Automation of Manufacturing Processes and Systems 808

14.1	Introduction	808
14.2	Automation	809
14.3	Numerical Control	815
14.4	Programming for Numerical Control	821
14.5	Adaptive Control	822
14.6	Material Handling and Movement	825
14.7	Industrial Robots	827
14.8	Sensor Technology	833
14.9	Flexible Fixturing	837
14.10	Assembly, Disassembly, and Service	839
14.11	Design Considerations	842
14.12	Economic Considerations	845
	CASE STUDY: Development of a Modular Fixture	845
	Summary	847
	Bibliography	848
	Questions	849
	Design	850

## **15 Computer-Integrated Manufacturing Systems 852**

- 15.1 Introduction 852
- 15.2 Manufacturing Systems 853
- 15.3 Computer-Integrated Manufacturing 854
- 15.4 Computer-Aided Design and Engineering 856
- 15.5 Computer-Aided Manufacturing 861
- 15.6 Computer-Aided Process Planning 861
- 15.7 Computer Simulation of Manufacturing Processes and Systems 864
- 15.8 Group Technology 866
- 15.9 Cellular Manufacturing 872
- 15.10 Flexible Manufacturing Systems 874
- 15.11 Just-in-Time Production 876
- 15.12 Communications Networks in Manufacturing 878
- 15.13 Artificial Intelligence 880
- 15.14 The Factory of the Future 883
- 15.15 Economic Considerations 885
- CASE STUDY: CAD Model Development for Automotive Components 886
- Summary 889
- Bibliography 890
- Questions 891
- Design 892

## **16 Product Design and Competitive Aspects of Manufacturing 893**

- 16.1 Introduction 893
- 16.2 Product Design and Robust Design 894
- 16.3 Product Quality and Life Expectancy 898
- 16.4 Life-Cycle Assessment, Life-Cycle Engineering, and Sustainable Manufacturing 899
- 16.5 Selection of Materials for Products 901
- 16.6 Substitution of Materials in Products 905
- 16.7 Capabilities of Manufacturing Processes 907
- 16.8 Selection of Manufacturing Processes 911
- 16.9 Manufacturing Costs and Cost Reduction 915
- 16.10 Value Analysis 919
- CASE STUDY: Concurrent Engineering for Intravenous Solution Containers 920
- Summary 922
- Bibliography 923
- Questions 924
- Design 925

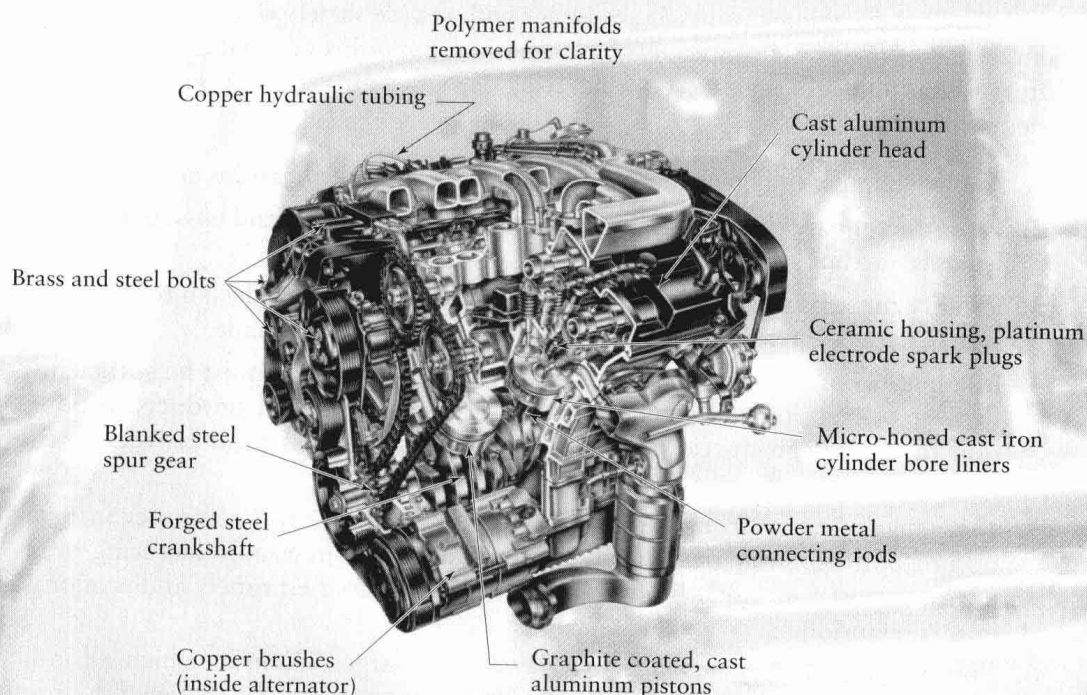
## **Index 928**

# Introduction

## 1.1 | What Is Manufacturing?

As you read this Introduction, take a few moments to inspect the different objects around you: your watch, chair, stapler, pencil, calculator, telephone, and light fixtures. You will soon realize that all these objects have been transformed from various raw materials into individual parts and assembled into specific products. Some objects, such as nails, bolts, and paper clips, are made of one material; however, most objects, such as light bulbs, toasters, bicycles, computers, all types of instruments and machinery, and automotive engines (Fig. 1.1), and countless other products, are made of numerous parts from a wide variety of materials. A ballpoint pen, for example, consists of about a dozen parts, a lawnmower about 300 parts, a grand piano

- 1.1 What Is Manufacturing?
- 1.2 Product Design and Concurrent Engineering
- 1.3 Design for Manufacture, Assembly, Disassembly, and Service
- 1.4 Environmentally Conscious Design and Manufacturing
- 1.5 Selecting Materials
- 1.6 Selecting Manufacturing Processes
- 1.7 Computer-Integrated Manufacturing
- 1.8 Quality Assurance and Total Quality Management
- 1.9 Product Liability
- 1.10 Manufacturing Costs, Lean Production, and Agile Manufacturing
- 1.11 General Trends in Manufacturing
- 1.12 Responsibilities of Manufacturing Engineers



**FIGURE 1.1** Section of an automotive engine—the Duravec V-6—showing various components and the materials used in making them. *Source:* Courtesy of Ford Motor Company. Illustration by David Kimball.

12,000 parts, a typical automobile 15,000 parts, a C-5A transport plane more than 4 million parts, and a Boeing 747-400 about 6 million parts; all are produced by a combination of various processes called *manufacturing*.

**Manufacturing**, in its broadest sense, is the process of converting raw materials into products; it encompasses the design and fabrication of goods by means of various production methods and techniques. Manufacturing began around 5000 to 4000 BC with the production of various articles of wood, ceramic, stone, and metal (Table 1.1). The word *manufacturing* is derived from the Latin *manu factus*, meaning made by hand; the word *manufacture* first appeared in AD 1567 and the word *manufacturing* in 1683. The word **production** is also used interchangeably with the word *manufacturing*. Manufacturing represents approximately 20% to 30% of the value of all goods and services produced in industrialized countries. Generally, the higher the level of manufacturing in a country, the higher the standard of living of its people. Manufactured products are also used to make other products; examples include large presses to form sheet metal for car bodies, metalworking machinery used to make parts for other products, and sewing machines for making clothing.

Manufacturing may produce *discrete products*, meaning individual parts or pieces of parts, or it may produce continuous products. Nails, gears, steel balls, beverage cans, and engine blocks are examples of discrete products. Wire, metal or plastic sheet, hose, and pipe are *continuous products* that may be cut into individual pieces and thereby become discrete products.

Because a manufactured item has undergone a number of changes during which raw material has become a useful product, it has **added value**, defined as monetary worth in terms of price. For example, clay has a certain value when mined. When the clay is used to make a ceramic dinner plate, cutting tool, or electrical insulator, value is added to the clay; similarly, a wire coat hanger or a nail has added value over and above the cost of a piece of wire.

Manufacturing is generally a complex activity involving people who have a broad range of disciplines and skills, together with a wide variety of machinery, equipment, and tools with various levels of automation, including computers, robots, and material-handling equipment. Manufacturing activities must be responsive to several demands and trends:

1. A product must fully meet **design requirements and specifications and standards**.
2. A product must be manufactured by the most **economical and environmentally friendly** methods.
3. **Quality** must be built into the product at each stage, from design to assembly, rather than relying on quality testing after the product is made.
4. In a highly competitive environment, production methods must be sufficiently **flexible** to respond to changing market demands, types of products, production rates, and production quantities and to provide on-time delivery to the customer.
5. New developments in **materials, production methods, and computer integration** of both technological and managerial activities in a manufacturing organization must constantly be evaluated with respect to their timely and economic implementation.
6. Manufacturing activities must be viewed as a large **system** in which all individual components are interrelated. Such systems can now be modeled in order to study the effects of various factors, such as changes in market demands, product design, materials, costs, and production methods, on product quality and cost.