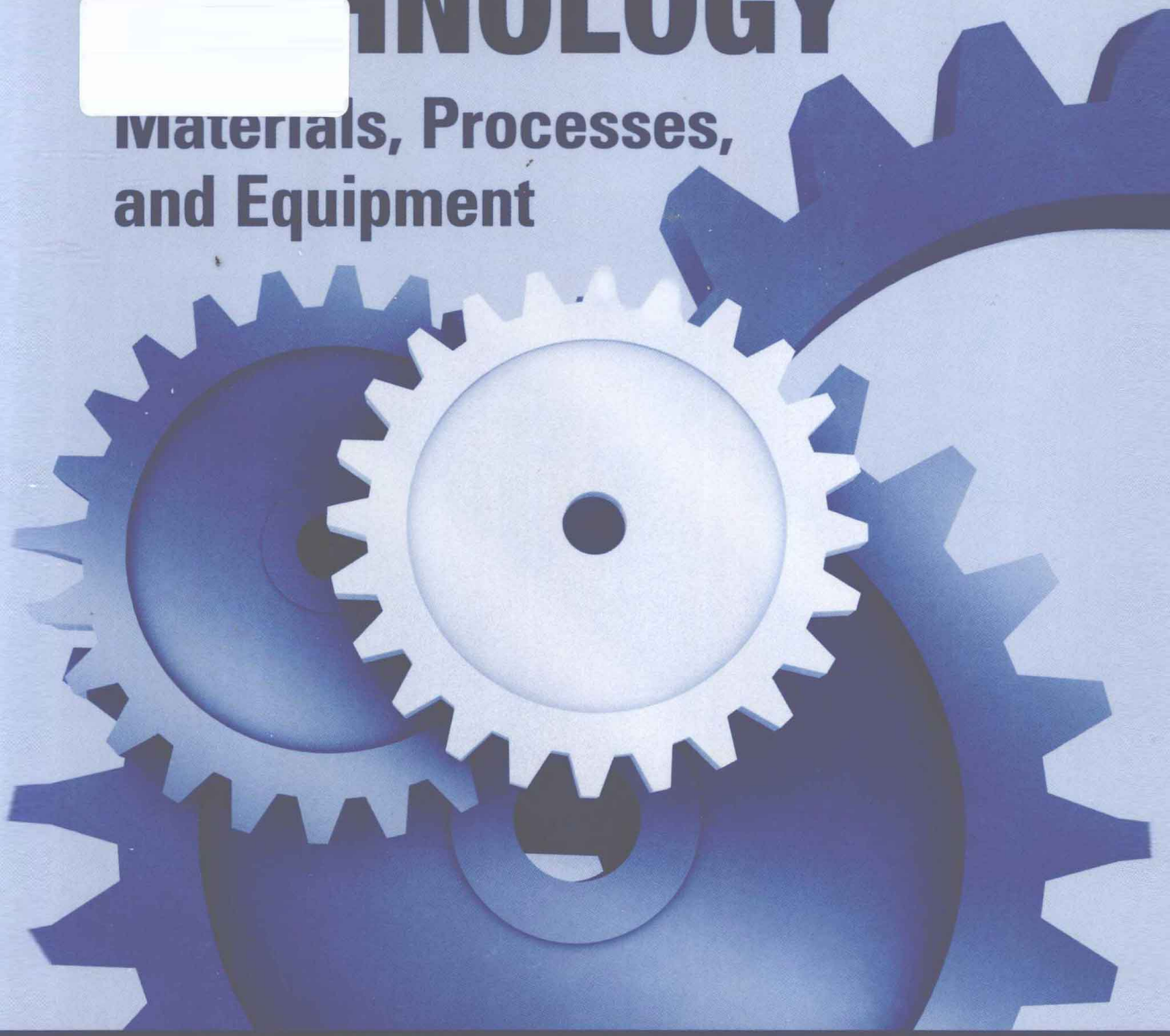
MANUFACTURING TECHNOLOGY

Materials, Processes, and Equipment



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CRC Press
Taylor & Francis Group

Manufacturing Technology

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CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number: 978-1-4398-1085-9 (Hardback)

Library of Congress Cataloging-in-Publication Data

Youssef, Helmi A.
Manufacturing technology : materials, processes, and equipment / authors: Helmi A. Youssef, Hassan A. El-Hofy, and Mahmoud H. Ahmed.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-4398-1085-9 (hardback)
1. Manufacturing processes. I. El-Hofy, Hassan. II. Ahmed, Mahmoud H. III. Title.

TS183.Y68 2011
670.42'7--dc22 2011007861

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Little Drops of Water,
Little Grains of Sand,
Make the Mighty Ocean,
and the Pleasant Land

Julia Carney, 1845

Dedicated to our little angels
H. Youssef: To Youssef, Nour, Anorine, Fayrouz, and Yousra
H. El-Hofy: To Omar, Youssef, and Zaina
M. Ahmed: To Nada

Preface

This textbook provides comprehensive knowledge and insight into various aspects of manufacturing technology, processes, materials, tooling, and equipment. Its main objective is to introduce the grand spectrum of manufacturing technology to individuals who will be involved in the design and manufacturing of finished products, to provide them with the basic information on manufacturing technologies. The text material is presented mainly in descriptive manner, where the emphasis is on the fundamentals of the process, its capabilities, typical applications, advantages, and limitations. Mathematical modeling and equations are used only when they enhance the basic understanding of with which the material deals.

The book has been written specifically for undergraduates in mechanical, industrial, manufacturing, and materials engineering disciplines of the second to fourth levels to cover complete courses of manufacturing technology taught in engineering colleges and institutions all over the world. It also covers the needs of production and manufacturing engineers and technologists participating in related industries where it is expected to be part of their professional library. Additionally, the book can be used by students in other disciplines concerned with design and manufacturing, such as automotive and aerospace engineering.

The book is a fundamental textbook that covers all of the manufacturing processes, materials, and equipment used to convert raw materials to a final product. It presents the materials used in manufacturing processes. The book also presents heat treatment processes, smelting of metals, and other technological processes such as casting, forming, powder metallurgy, joining, and surface technology. Manufacturing processes for polymers, ceramics, and composites are also covered.

The book also covers traditional, nontraditional, and advanced manufacturing technologies and applications. It sheds light on modern manufacturing technologies. In this regard, numerical control, industrial robots, and hexapods are covered. Product quality control, automation in manufacturing, and health, safety, and environmental aspects in manufacturing are also discussed.

The book is written in 26 chapters and 3 appendices having the following titles:

1. Introduction to Manufacturing Technology
2. Properties of Engineering Materials
3. Structure of Metals and Alloys
4. Engineering Materials and Their Applications
5. Heat Treatment of Metals and Alloys
6. Smelting of Metallic Materials
7. Casting of Metallic Materials
8. Fundamentals of Metal Forming
9. Bulk Forming of Metallic Materials
10. Sheet Metal Forming Processes
11. High-Velocity Forming and High-Energy-Rate Forming
12. Powder Metallurgy and Processing of Ceramic Materials
13. Polymeric Materials and Their Processing
14. Composite Materials and Their Fabrication Processes
15. Fundamentals of Traditional Machining Processes
16. Machine Tools for Traditional Machining
17. Fundamentals of Nontraditional Machining Processes
18. Numerical Control of Machine Tools
19. Industrial Robots and Hexapods

20. Surface Technology
21. Joining Processes
22. Advanced Manufacturing Techniques
23. Materials, Processes, and Design for Manufacturing
24. Quality Control
25. Automation in Manufacturing Technology
26. Health and Safety Aspects in Manufacturing

Appendix A: List of Symbols
Appendix B: Greek Letters
Appendix C: List of Acronyms

OUTLINE OF THE BOOK

The following topics are covered by individual chapters of the book:

Chapter 1 presents a general classification showing the importance of manufacturing technology, its attainable accuracy, and economical considerations.

Chapter 2 presents the physical, mechanical, and fabricating properties of engineering materials.

Chapter 3 presents the structures of metals and alloys. The lattice structures and imperfections (point, line, surface, and volume defects) are presented. The solidification of pure metals and alloys along with the related phase diagrams and lever rule are described. The iron–carbon phase diagram is also considered.

Engineering materials are classified and discussed in Chapter 4, which deals mainly with ferrous and nonferrous metals and alloys. Steels and alloy steels are classified according to AISI and DIN standards. They are categorized according to their applications. The production of common types of cast iron is presented. Nonferrous metals and alloys, in addition to superalloys, refractory and noble metals, are surveyed. Newly developed materials, such as nanomaterials, metal foams, amorphous alloys, and shape memory alloys (SMAs) are also presented. Non-metallic materials such as polymers, ceramics, and composites are discussed in subsequent chapters.

Chapter 5 covers the basics of heat treatment operations of metals and alloys. The heat treatment of steels and alloy steels, such as annealing, normalizing, tempering, austempering, martempering, hardening, and surface hardening techniques are described. Also, the heat treatment operations of cast iron and the precipitation hardening of nonferrous alloys are considered.

Chapter 6 deals with smelting, extraction, and refining technologies of metals. Smelting and refining of ferrous metals using blast furnaces and steel refining furnaces are described. The technology of continuous casting is presented. Smelting and extraction processes of some important nonferrous metals are also covered.

Chapter 7 presents casting of metallic materials. It covers a wide variety of processes adopted by industry, including sand casting using different molding techniques, investment casting, permanent mold casting, and centrifugal casting. The furnaces used in foundries are also introduced. The basic relations controlling the process variables are presented as an introduction for process modeling.

Chapter 8 presents both the mechanical and metallurgical fundamentals of the plastic deformation of metals as a prelude to the next two chapters dealing with bulk forming and sheet forming of metallic materials. Mechanical fundamentals cover the analysis of the limiting forces, stresses, strains, and strain rates involved in the metal flow during the process as well as the associated work hardening. Metallurgical aspects include the effect of temperature and plastic deformation on the crystal structure of the material, and accordingly, on the resulting mechanical properties. The effects of friction and lubrication on the forming process are also included.

Chapter 9 introduces plastic forming processes for bulk metallic materials, including forging, rolling, extrusion, and drawing. The different techniques adopted in these processes are discussed, emphasizing the applications, advantages and limitations of each, as well as the utilized equipment

and tooling. Modeling of these processes is also included by using simple mathematical relations based on the element equilibrium approach to train students on estimating the limiting stresses, strains, strain rates, forces, and consumed power. These calculations are applied in designing the required dies and selecting the right capacity for equipment. Solved examples are given to support appreciation of how to apply the driven and commonly used mathematical relations.

Chapter 10 presents sheet metal forming processes, including shearing, bending, deep drawing, spinning, and superplastic forming of sheet blanks. Similar to Chapter 9, a variety of techniques involved in these processes are discussed, stressing the applications, tooling, and equipment as well as the advantages and limitations of each. The limiting characteristics of sheet metals such as the spring back, anisotropy, limiting-drawing ratio, and residual stresses are discussed to a reasonable depth to convey the limits of sheet processing. The chapter ends with an introduction of the technological characteristic of sheet formability, the standard tests for its measurement, and the forming limit diagrams for determining the limiting conditions for sheet forming applications.

Chapter 11 introduces the nonconventional family of forming processes based on developing high-velocity forming hammers (high-velocity forming, HVF) or adopting other physical techniques for sudden release of energy (high–energy rate forming, HERF). The presented processes include high velocity forming, explosive forming, electromagnetic forming, and electrohydraulic forming. The principles, equipment and tooling, applications, advantages and limitations are discussed for each process. The basic mathematical relations serving the objectives of process understanding are presented without details that are beyond the scope of the book.

Chapter 12 presents powder metallurgy as an alternative manufacturing technique that was first developed to form high precision (net shape) metallic products. The procedure involves producing metals first in the form of powder using different methods, and then consolidating powders into a solid form by the application of pressure (compaction), and heat (sintering) at a temperature below the melting point of the main constituent. Powder metallurgy was later adopted as a major process for manufacturing advanced ceramic products using the same steps. Therefore, it is crucial in this chapter to introduce ceramic materials and discuss the methods used in their manufacture, including powder metallurgy procedures.

Chapter 13 presents polymeric materials and their processing techniques. The definition and polymerization reactions are first introduced. Due to the different nature and thermomechanical behavior of polymers compared to metals, their structure and properties are discussed for the three classes of polymeric materials, namely, thermoplastics, thermosettings and elastomers. The presented manufacturing processes include extrusion, calendaring, spinning, injection molding, compression molding, transfer molding, thermoforming, casting, foaming, and joining of plastics.

Chapter 14 introduces composite materials, their classes and the main characteristics of their constituents, emphasizing their applications. Then their major manufacturing processes are presented. These processes include the different types of molding, prepeg fabrication, filament winding, and pultrusion.

The fundamentals of traditional machining are presented in Chapter 15. The mechanics and kinematics of chipping processes are investigated. Tool geometry, tool material, tool life, machining economy, and machinability are discussed. This chapter also considers the thermal aspects of chipping operations. The basics of abrasion processes, such as grinding, honing, superfinishing, and lapping along with mechanics and kinematics of the grinding operation are considered.

Chapter 16 presents the general purpose machine tools used for cutting cylindrical surfaces such as lathe, boring, and drilling machines. Additionally machine tools used for cutting flat surfaces such as shapers, planers, and slotters, and milling and broaching machines are given. It presents surface and cylindrical grinding machines as well as honing, superfinishing, and lapping machines normally used for microfinishing operations. Machines used for thread and gear cutting and finishing are also described.

Chapter 17 describes the fundamentals of nontraditional machining processes. Mechanical nontraditional machining is represented by jet machining and ultrasonic machining (USM). Chemical

milling, spray etching, electrochemical machining (ECM), and electrochemical grinding (ECG) are also described, along with the thermal nontraditional processes represented by electrodischarge machining (EDM), electrodischarge wire cutting (EDWC), ED-milling, laser beam machining (LBM), electron beam machining (EBM), and plasma beam machining (PBM). Related machines and equipment, their elements, and accuracies are given.

Chapter 18 provides the CNC concepts, movements in CNC systems, control of CNC machine tools, types of CNC machines, and features of CNC systems. It provides the fundamentals of part programming using manual, computer-assisted, and CAD/CAM methods.

Chapter 19 introduces robotics and hexapods and their role in manufacturing technology. The basic elements of industrial robots and hexapods are examined. The economical features and characteristics of robots and hexapods are presented.

Chapter 20 presents the different surface technologies, which include smoothing, cleaning, protection, deburring, and roll burnishing and ballizing. The surface protection methods are sacrificial and direct protection. The latter comprises conversion coating, electroplating, organic coatings, vaporized metal coating (PVD and CVD), metalizing and cladding, all of which are presented in this chapter.

Chapter 21 covers fusion welding operations such as gas welding, thermit welding, and methods of electric arc welding. Methods of resistance spot, projection, seam, and flash welding are introduced. High energy beam welding by electron and laser beams are given. The chapter covers the metallurgy of welded joints, welding defects, and welding quality control. Solid state and solid-liquid state welding techniques, in addition to welding of plastics and mechanical joining, are also explained.

Chapter 22 describes the concept of near net shape manufacturing, microfabrication technology, and nanotechnology. Semiconductor device fabrication, testing, assembly, and packaging are explained. It also introduces the concept of sustainable and green manufacturing.

Function, material, process, and shape interaction are given in Chapter 23. Manufacturing process capabilities and their selection through process information maps and elimination and ranking strategy are given. Design for manufacturing is presented by setting design rules and recommendations for many manufacturing technologies such as casting, sheet metal forming, die forging, machining and welding, as well as assembly operations and design for environment.

Chapter 24 introduces the principles of statistical quality control, control charts, control limits and specifications, process capability as well as acceptance sampling. Concepts of total quality control and the ISO 9000 Standard are also covered. Dimensional control, interchangeability, tolerance and fit are discussed. Measuring tools and equipment commonly used for measuring quality characteristics such as limit gauges and those used for dimensional, angular, and geometric measurements are described. Surface measurements, nondestructive testing and inspection, and destructive testing are introduced.

In Chapter 25, automation in manufacturing technology is presented. The difference between automation and mechanization is clearly defined. The necessity of adopting automation in manufacturing is discussed. Automation is realized in the form of MSs, FMSs, CAD, CAM, CAPP, CIM, lean production, AC, AI, CNC, robotics, and hexapods.

Chapter 26 covers the issues of health and safety at work, different sources of manufacturing hazards, and necessary personal protective equipment. It focuses on the different hazards associated with several manufacturing processes such as melting of metals, sand casting, welding, metal forming operations, and machining by traditional and nontraditional techniques.

Many solved examples are introduced in the text to make students aware of the importance of the relevant topics. At the end of each chapter, review questions and problems are provided. Individuals desiring additional information on specific items of the book are directed to the various references listed at the end of each chapter.

ADVANTAGES OF THE BOOK

- Introduces new trends in surface hardening technology
- Introduces the newly developed materials such as nanomaterials, memory shape materials, amorphous alloys, metal foams, advanced ceramics, and composite materials. It also introduces smart materials and strategic engineering materials
- Provides selection guidelines for engineering materials and manufacturing processes
- Presents the principles of design for manufacturing
- Presents the principles of CNC, robotics, and hexapods as well as their application in manufacturing technology
- Covers the fundamentals of traditional and nontraditional machining processes
- Presents nontraditional forming processes such as high velocity and high energy rate forming
- Presents the technologies of surface treatment
- Presents the ultrasonic technology and its applications in manufacturing industries.
- Introduces the safe technologies for manufacturing toxic materials such as beryllium and asbestos
- Provides the new trends in centrifugal casting
- Presents nano- and micromachining technologies
- Explains the concept and environmental aspects of manufacturing and clean factories
- Explains the principles of near-net shape and net-shape processing and rapid prototyping
- Presents the surface characteristics due to manufacturing processes
- Introduces the recently developed advanced ceramics and their latest processing techniques
- Presents novel composite materials and their fabrication
- Introduces the superplastic phenomenon in some metallic alloys and the related superplastic forming processes
- Cover the manufacturing topic in a simple and descriptive way.
- Covers new topics that are not mentioned in earlier books.
- Presents engineering materials, processes, tools, and equipment used in manufacturing.
- Covers the basic as well as the most recent advanced manufacturing technologies.

Acknowledgments

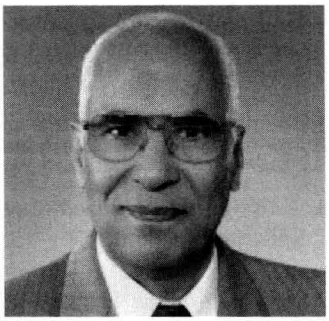
Many individuals have contributed to the development of this textbook. It is a pleasure to express our deep gratitude to Professor E. M. Abdel-Rasoul, Mansoura University, Egypt, for supplying valuable materials during the preparation of this book. The assistance of Nagham Elberishi, Production Engineering Department, Alexandria University, and Saeid Teileb of the Lord Alexandria Razor Company for their valuable AutoCAD drawings is greatly appreciated. Thanks and apologies to others whose contributions have been overlooked.

We appreciate very much permission from many publishers to reproduce illustrations and tabulated data from a number of authors as well as the courtesy of many industrial companies that provided photographs and drawings of their products to be included in the book. Their generous cooperation is a mark of sincere interest in enhancing the level of engineering education. The credits for all such great help are provided in the captions under the corresponding illustrations.

We would like to acknowledge with thanks the dedication and continued help of the editorial board and production staff of CRC Press for their effort in ensuring that the book is as well designed as possible.

Last, but not least, we sincerely appreciate the support, great patience, encouragement, and enthusiasm of our families during the preparation of the manuscript.

Authors



Helmi A. Youssef earned his BSc with honors in production engineering from Alexandria University in 1960. He then completed his scientific degree in Carolo-Wilhelmina during the period 1961–1967. In June of 1964, he acquired his Dipl-Ing, then in December of 1967, he completed his Dr-Ing in the domain of nontraditional machining. In 1968, he returned to Alexandria University's Production Engineering Department as an assistant professor. In 1973, he was promoted to associate, and in 1978, to full professor. In the period of 1995–1998, Professor Youssef was the chairman of the Production Engineering Department at Alexandria University. Since 1989, he has been a member of the scientific committee for promotion of professors in Egyptian universities.

His experience extends to include topics related to machining technology such as theories of metal cutting, machine tools, automatics, gear cutting, tool design, jigs and fixtures, NC and CNC machines, automation in production technology, and theories and technologies of nontraditional machining.

Based on several research and educational laboratories that he has built, Professor Youssef founded his own scientific school for both traditional and non-traditional machining technologies. In the early 1970s, he established the first NTM research laboratory in Alexandria University, and perhaps in the whole region. Since then, he has carried out intensive research in his fields of specialization and supervised many PhD and MSc theses.

Between 1975 and 1995, Professor Youssef was a visiting professor in Arabic universities, such as El-Fateh University in Tripoli, the Technical University in Baghdad, King Saud University (KSU) in Riyadh, and Beirut Arab University (BAU) in Beirut. In addition to his teaching activities in these universities, he established laboratories and supervised many MSc theses. Moreover, he was a visiting professor in different academic institutions in Egypt and abroad.

Professor Youssef has organized and participated in a number international conferences. He has published many scientific papers in specialized journals, and has authored books in his fields of specialization, two of which are single-authored. One book, which he coauthored on machining technology, was published in 2008 by CRC Press. Currently, he is an emeritus professor in PED, Alexandria University.

Hassan A. El-Hofy received a BSc in production engineering from Alexandria University (Egypt) in 1976 and then served as a teaching assistant in the same department. He received an MSc in production engineering from Alexandria University in 1979 under the supervision of Professor H. Youssef. Professor El-Hofy has had a successful university career in education, training, and research. Following his MSc, he worked as an assistant lecturer until October of 1980, when he went to Aberdeen University in Scotland and began his PhD work with Professor J. McGeough in hybrid machining processes. He won the Overseas Research Student (ORS) Award during pursuit of his doctoral degree, which was completed in 1985. He then went back to Alexandria University and resumed his work as an assistant professor. In 1990, he was promoted to an associate professor. He was on leave as a visiting professor for Al-Fateh University in Tripoli between 1989 and 1994.

In July of 1994, Professor El-Hofy returned to Alexandria University, and in November of 1997, he was promoted to a full professor. In September of 2000, he was selected to work as a professor in the University of Qatar. He chaired the accreditation committee for the Mechanical Engineering program toward ABET Substantial Equivalency Recognition that was granted to the College of Engineering programs in 2005. Due to his role, he received the Qatar University Award and a certificate of appreciation. Professor El-Hofy wrote his first book, *Advanced Machining Processes: Nontraditional and Hybrid Processes*, which was published by McGraw-Hill Company on March 1, 2005. His second book, *Fundamentals of Machining Processes*, was published in September of 2007 by CRC, Taylor & Francis. He coauthored his third book *Machining Technology–Machine Tools and Operations* with Professor Youssef, published by CRC in 2008. He has published over 50 scientific and technical papers and supervised many graduate students in the area of machining by nontraditional methods. He is a consulting editor to many international journals and a regular participant in international conferences.

Between August 2007 and August 2010, he was a professor and chairman of the Production Engineering Department of Alexandria University, College of Engineering, where he taught several machining and related courses.

Mahmoud H. Ahmed received a BSc in production engineering from Alexandria University in 1970, with First Degree of Honors. He was assigned as an instructor in the same department, where he obtained an MSc in 1973. Accordingly, he was promoted to the position of assistant lecturer. In 1974, he was granted a scholarship from the University of Birmingham, United Kingdom, to study for the PhD degree in the Department of Mechanical Engineering. He pursued his research in the field of shearing of metals until he obtained his PhD in 1978. During that period, he contributed to the teaching effort in the department as a teaching assistant.

In 1978, he returned to his homeland and resumed work at Alexandria University as an assistant professor. He left for the United Arab Emirates, on secondment, to work for the UAE University over the period of five years, from 1982 to 1987. He was promoted to the position of associate professor at Alexandria University in 1986 while working at the UAE University and returned back home one year later. He was assigned, for another secondment, to King Abdul Aziz University in Saudi Arabia starting in 1997. He returned home again to Alexandria University in 2002, where he has been working since. In addition to the long-term secondments, Professor Ahmed worked as a part-time visiting professor for the Arab University of Beirut, Lebanon (for 3 months in 1980/1981 and for 2 months in 1981/1982), Qatar University (for one semester, in 1995), and many Egyptian universities, including The Arab Academy for Science and Technology-Alexandria (1995–1997, 2002–2007), El-Mansoura University (1978–1981), Kima High Institute of Technology-Aswan (1979–1982), High Institute of Public Health-Alexandria (1980–1982), El-Minia University (1978–1982), and El-Menoufia University (1981–1982).

During his career, Professor Ahmed has constructed and taught numerous graduate and undergraduate courses in the general fields of materials and manufacturing: failure analysis, material selection, finite element analysis, fracture mechanics, non-destructive testing, advanced manufacturing processes, theory of plasticity, solid mechanics, die design, metal forming, metal cutting, nonconventional machining, welding technology, engineering materials, and manufacturing technology, to name a few. Professor Ahmed took part in establishing and developing laboratories in the same fields, including the Material Technology Laboratory (Alexandria University), Material Testing, Forming Machines, CNC Machining, Metrology, and Electroplating Laboratories (UAE University), as well as Nonconventional Machining and CNC Machining Laboratories (King Abdul Aziz University, KSA). Over the years, Professor Ahmed has supervised numerous MSc and PhD

degrees, covering the areas of electrodischarge machining, failure of welded joints, extrusion of fluted sections, plasma cutting, ultrasonic machining, pulsed current MIG welding, compression of tubular sections, forward tube spinning, characterization of engineering materials using nodal analysis, selection of nontraditional machining processes, and thermomechanical rolling. Professor Ahmed has a record of publishing in national and international conferences and reputable journals. He has also contributed to the development and improvement of industrial activities within Alexandria through consultations related to solving design and manufacturing problems, material and product inspection, failure analysis, plant layouts, feasibility and opportunity studies, as well as running crash and training courses in the relevant fields of interest.

Contents