DeGarmo's MATERIALS & PROCESSES IN MANUFACTURING

TENTH EDITION

J T. BLACK | RONALD A. KOHSER

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Cover photos:

The sketchbooks of Leonardo da Vinci (1452-1519) contain two drawings that are of particular interest to the authors of this text. One is a crude sketch of an underwater device, or submarine, with the elongated sausage shape characteristic of many later day successes. The other, reproduced on the cover of this edition, is a "flying-machine," that bears an uncanny resemblance to a modern-day helicopter. Unlike many of Leonardo's creations, he apparently made no attempt to further refine the concepts, since there was never a subsequent sketch of either.

Was this man really such a genius? We have no way of knowing, but he may have realized that the construction materials of his day were totally inadequate for either task. One would not want to build a submarine or helicopter from wood, stone or leather. Today's submarines are constructed from corrosion-resistant, high-strength metals that are also selected for their ability to be fabricated by welding. Aerospace materials must offer high-strength and light-weight, along with fatigue- and fracture-resistance. The rotor arms of modern helicopters are now being made from fiber-reinforced composite materials. The components of the engine and drive assembly have some of the most demanding requirements of modern engineering.

The materials and processes presented in this book are the tools that enable ideas to be converted into reality. The myriad of manufactured items, and the range of uses and applications, demonstrates the success of those materials and processes. Like Leonardo, however, today's designers continue to push the limits–lighter, stronger, more corrosion resistant, closer to net-shape, more economical. New materials will certainly be developed, and new processes will expand our capabilities. It is the goal of this text to present the capabilities and limitations of current technology with a look toward future advances that hopefully will enable today's dreams to become tomorrow's reality.

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THE WILEY BICENTENNIAL–KNOWLEDGE FOR GENERATIONS

Each generation has its unique needs and aspirations. When Charles Wiley first opened his small printing shop in lower Manhattan in 1807, it was a generation of boundless potential searching for an identity. And we were there, helping to define a new American literary tradition. Over half a century later, in the midst of the Second Industrial Revolution, it was a generation focused on building the future. Once again, we were there, supplying the critical scientific, technical, and engineering knowledge that helped frame the world. Throughout the 20th Century, and into the new millennium, nations began to reach out beyond their own borders and a new international community was born. Wiley was there, expanding its operations around the world to enable a global exchange of ideas, opinions, and know-how.

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PREFACE

In the world of manufacturing, significant changes and trends are having a profound impact on our everyday lives. Whether we like it or not, we all live in a technological society, a world of manufactured goods. Every day we come in contact with hundreds of manufactured items, from the bedroom to the kitchen, to the workplace, we use appliances, phones, cars, trains, and planes, TVs, VCRs, DVD's, furniture, clothing, and so on. These goods are manufactured in factories all over the world using manufacturing processes. What are the trends in the manufacturing world, and how do they impact manufacturing processes?

■ TRENDS IN MANUFACTURING

First, manufacturing has become a global activity with U.S. companies sending work to other countries (China, Taiwan, Mexico) to take advantage of low-cost labor, while many foreign companies are building plants in the United States, to be nearer their marketplace, The automobile manufacturers and their suppliers use just about every process described in this book and some that we do not describe, often because they are closely held secrets.

Second, many manufacturing companies are redesigning their factories (their manufacturing systems) becoming lean producers. and learning how to make goods better (higher quality), cheaper, faster in a flexible way (i.e., they are more responsive to the customers). Almost every plant that you can visit these days is doing something to make itself leaner. Many of them have adopted some version of the Toyota Production System. More importantly, these manufacturing factories are designed with the internal customer (the workforce) in mind, so things like ergonomics and safety are key design requirements. So while this book is all about materials and processes for making the products, the design of the factory cannot be ignored when it comes to making the external customer happy with the product and the internal customer satisfied with the employer.

Third, the number and variety of products and the materials from which they are made continue to proliferate, while production quantities have become smaller. Existing processes must be modified to be more flexible, and new processes must be developed.

Fourth, consumers want better quality and reliability, so the methods, processes, and people responsible for the quality must be continually improved. The trend toward zero defects and continuous improvement requires continuous improvements of the manufacturing system.

Finally the new product development effort to reduce the *time-to-market* for new products is continuing. Many companies are taking wholistic or system wide perspectives, including concurrent engineering efforts to bring product design and manufacturing closer to the customer. There are two key aspects here. First, products are designed to be easier to manufacture and assemble (*called design for manufacture/assembly*). Second, the manufacturing system design is flexible (able to accept new products), so the company can be competitive in the global marketplace.

Basically, manufacturing is a *value-adding* activity, where the conversion of materials into products adds value to the original material. Thus, the objective of a company engaged in manufacturing is to add value and do so in the most efficient manner, using the least amount of time, material, money, space, and labor. To minimize waste and maximize efficiency, the processes and operations need to be properly selected and arranged to permit smooth and controlled flow of material through the factory and provide for product variety. Meeting these goals requires a well-designed and efficient manufacturing system.

Purpose of the Book

The purpose of this book is to give design and manufacturing engineers and technicians basic information on materials, manufacturing processes and systems. The materials section focuses on properties and behavior. Thus, aspects of smelting and refining (or other material production processes) are presented only as they affect manufacturing and manufactured products. In terms of the processes used to manufacture items (converting materials into products), this text seeks to provide a descriptive introduction to a wide variety of options, emphasizing how each process works and its relative advantages and limitations. Our goal is to present this material in a way that can be understood by individuals seeing it for the very first time. This is not a graduate text where the objective is to thoroughly understand and optimize manufacturing processes. Mathematical models and analytical equations are used only when they enhance the basic understanding of the material. So, while the text is an introductory text, we do attempt to incorporate new and emerging technologies like a welding process that is being adapted to alter and improve material properties and performance without creating a joint.

The book also serves to introduce the *language of manufacturing*. Just as there is a big difference between a gun hand and a hand gun, there is a big difference between an engine lathe and a lathe engine. Everyday English words (words like *climb, bloom, allowance, chuck, coin, head,* and *ironing*) have entirely different meanings on the factory floor, a place where misunderstandings can be very costly. Pity the engineer who has to go on the plant floor not knowing an engine lathe from a milling machine or what a press brake can do. This engineer quickly loses all credibility with the people who make the products (and pay the engineers' salaries). However, the modern manufacturing engineer must be able to deal with real workplace problem-solving techniques like Taguchi methods and six sigma and developing manufacturing cells to make product families. This requires redesign of all the elements of the manufacturing systems—the machine tools and manufacturing processes, the workholding devices, the material handling equipment, and the retraining of the people who work in the system.

History of the Text

In 1957, E. Paul DeGarmo was a mechanical engineering professor at the University of California, Berkley when he wrote the first edition of Materials and Processes in Manufacturing. The book quickly became the emulated standard for introductory texts in manufacturing. Second, third, and fourth editions followed in 1962, 1969, and 1974. DeGarmo had begun teaching at Berkeley in 1937, after earning his M.S. in mechanical engineering from California Institute of Technology. He worked as a factory control engineer at Firestone Tire and Rubber Company while attending Caltech. DeGarmo was a founder of the Department of Industrial Engineering (now Industrial Engineering and Operations Research) and served as its chair from 1956–1960. He was also assistant dean of the College of Engineering for three years while continuing his teaching responsibilities.

He retired from active teaching in 1971 and he continued his research, writing, and consulting for many years. In 1977, after the publication of the fourth edition of *Materials and Processes in Manufacturing*, he received a letter from Ron Kohser, then an assistant professor at Missouri-Rolla who had many suggestions regarding the materials chapters. DeGarmo asked Kohser to rewrite those chapters for the fifth edition, which Ron did. After the fifth edition DeGarmo decided he was really going to retire and after a national search, recruited J T. Black, then a Professor at Ohio State, to co-author the book. For the sixth edition, seventh edition, eighth and ninth editions (published in 1984, 1988, and 1997, respectively, by Macmillan, Prentice Hall and 1999 and 2003 by John Wiley & Sons), Ron Kohser and J T. Black have shared the responsibility for the text. The chapters on engineering materials, casting, forming, powder metallurgy, joining and non-destructive testing have been written or revised by Ron Kohser. J T. Black has assumed the responsibility for the introduction and chapters on material removal, metrology, surface finishing, quality control and manufacturing systems design.

DeGarmo died in 2000, three weeks short of his 93rd birthday. His wife Mary died in 1995; he is survived by his sons, David and Richard, and many grandchildren. For this 10th edition, we honor our mentor E. Paul DeGarmo with a change in the title to include his name. We are forever indebted to Paul for selecting us to carry on the tradition of his book on its' fiftieth anniversary!

50th Anniversary Edition!

Any long-term user of this book will note a significant change in its title—from *Materials and Processes in Manufacturing* by DeGarmo, Black, and Kohser to *DeGarmo's Materials and Processes in Manufacturing* by Black and Kohser. Paul DeGarmo initiated this text in 1957 and nurtured it through a number of editions. Even after his retirement, through his death in 2000, Paul maintained an active interest and involvement. In recognition, the 9th edition, published in 2003, carried his name as a posthumous coauthor. For 50 years, this text has been known by many as simply "DeGarmo," and it is this identity that we wish to continue by moving his name to become a preface to the former title.

In 1957 Dr. DeGarmo observed that engineering education had begun to place more emphasis on the underlying sciences at the expense of hands on experience. Most of his students were coming to college with little familiarity with materials, machine tools, and manufacturing methods that their predecessors had acquired through the old "shop" classes. If these engineers and technicians were to successfully convert their ideas into reality, they needed a foundation in materials and processes, with emphasis on their opportunities and their limitations. He sought to provide a text that could be used in either a one- or two-semester course designed to meet these objectives. The materials sections were written with an emphasis on use and application. Processes and machine tools were described in terms of what they could do, how they do it, and their relative advantages and limitations, including economic considerations. Recognizing that many students would be encountering the material for the first time, clear description was accompanied by numerous visual illustrations.

Paul's efforts were well received, and the book quickly became the standard text in many schools and curricula. As materials and processes evolved, advances were incorporated into subsequent editions. Computer usage, quality control, and automation were added to the text, along with other topics, so that it continued to provide state-of-the-art instruction in both materials and processes. As competing books entered the market, one was forced to note that their subject material and organization tended to mimic the DeGarrno text.

Professors Black and Kohser are proud to continue Paul's legacy. It is fitting that this 10th edition will be published in 2007, 50 years following the initial efforts of Professor DeGarmo. It is further fitting that his name continue to appear on this 50th anniversary edition and any subsequent editions.

The 10th Edition

E. Paul DeGarmo wanted a book that explained to engineers how the things they designed are made. *DeGarmo's Materials and Processes in Manufacturing* is still written providing a broad, basic introduction to the fundamentals of manufacturing. The book begins with a survey of engineering materials, the "stuff" that manufacturing begins with, and seeks to provide the basic information that can be used to match the properties of a material to the service requirements of a component. A variety of engineering materials are presented, along with their properties and means of modifying them. The materials section can be used in curricula that lack preparatory courses in metallurgy, materials science, or strength of materials, or where the student has not yet been exposed to those topics. In addition, various chapters in this section can be used as supplements to a basic materials course, providing additional information on topics such as heat treatment, plastics, composites, and material selection.

Following the materials chapters, measurement and nondestructive testing are introduced with a manufacturing perspective. Then chapters on casting, forming, powder metallurgy, material removal, and joining are all developed as families of manufacturing processes.

Each section begins with a presentation of the fundamentals on which those processes are based. This is followed by a discussion of the various process alternatives, which can be selected to operate individually or be combined into an integrated system.

In the last two chapters there is some in depth material on surface engineering and quality control. Engineers need to know how to determine process capability and if they get involved in six sigma projects, to know what sigma really measures. There is also introductory material on surface integrity, since so many processes produce the finished surface and residual stresses in the components.

■ What's New in 10e:

- New chapter on measurement, inspection and testing
- New chapter on *electronic processes*
- New examples of basic calculations in machining chapters
- NC chapter reorganized with more examples
- Reclassification of metal deformation processes into bulk and sheet
- Expanded coverage of new and emerging technology, such as friction-stir welding
- Expanded coverage of polymers; ceramic materials and composites, and the processes that are unique to those materials.

Throughout the book, case studies have been designed to make students aware of the great importance of properly coordinating design, material selection, and manufacturing to produce a satisfactory and reliable product.

The text is intended for use by engineering (mechanical, manufacturing, and industrial) and engineering technology students, in both two- and four-year undergraduate degree programs. In addition, the book is also used by engineers and technologists in other disciplines concerned with design and manufacturing (such as aerospace and electronics). Factory personnel will find this book to be a valuable reference that concisely presents the various production alternatives and the advantages and limitations of each. Additional or more in-depth information on specific materials or processes can be found in the various references posted on the internet along with chapters on rapid prototyping, automation and enterprise systems.

■ Supplements

For instructors adopting the text for use in their course, an *instructor solutions manual* is available through the book website: www.wiley.com/college/degarmo. Also available on the website is a set of *powerpoint lecture slides* created by Philip Appel at Gonzaga University.

Three additional chapters, as identified in the table of contents, are available on the book website. The registration card attached on the inside front cover provides information on how to access and download this material. If the registration card is missing, access can be purchased directly on the website www.wiley.com/college/degarmo, by clicking on "student companion site" and then an the links to the chapter titles.

■ Acknowledgments

The authors wish to acknowledge the multitude of assistance, information, and illustrations that have been provided by a variety of industries, professional organizations, and trade associations. The text has become known for the large number of clear and helpful photos and illustrations that have been graciously provided by a variety of sources. In some cases, equipment is photographed or depicted without safety guards, so as to show important details, and personnel are not wearing certain items of safety apparel that would be worn during normal operation.

Over the many editions, there have been hundreds of reviewers, faculty, and students who have made suggestions and corrections to the text. We continue to be grateful for the time and interest that they have put into this book. In this edition we benefited from the comments of the following reviewers: J. Don Book, Pittsburg State University;

Jan Brink, Midwestern State University; Rene A.Chapelle, University of Houston; Joe Chow, Florida International University; Kurt Colvin, California Polytechnic State University, Pomona; Subi Dinda, Oakland University; Roman Dubrovsky, New Jersey Institute of Technology; Richard B. Griffin, Texas A&M University–Main; Rodney G. Handy, Purdue University; T. Kesavadas, State University of New York, Buffalo; John Lee, San Jose State University; H. Joel Lenoir, Western Kentucky University; Steven Y.Liang, Georgia Institute of Technology; Victor Okhuysen, California Polytechnic State University, Pomona; Lewis N. Payton, Auburn University; Zhijian Pei, Kansas State University; William Schoech, Valparaiso University; Mala M.Sharma, Bucknell University; Bharat S.Thakkar, Illinois Institute of Technology; and Alan Zoyhofski, Rochester Institute of Technology.

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As always, our wives have played a major role in preparing the manuscript. Carol Black and Barb Kohser have endured being "textbook widows" during the time when the last four editions were written. Not only did they provide loving support, but Carol also provided hours of expert proofreading, typing, and editing as the manuscript was prepared.

Finally special thanks to our acquisitions editor, Joseph P. Hayton, for putting up with two procrastinating professors, who tried both his patience and his abilities as he coordinated all the various activities required to produce this text as scheduled. We also thank Suzanne Ingrao and Sandra Dumas for all their help in bringing the 10th edition to reality.

■ About the Authors

J T. Black received his Ph.D. from Mechanical and Industrial Engineering, University of Illinois, Urbana in 1969, an M.S. in Industrial Engineering from West Virginia University in 1963 and his B.S. in Industrial Engineering, Lehigh University in 1960. J T. is Professor Emeritus from Industrial and Systems Engineering in the Samuel Ginn College of Engineering at Auburn University. He was the Chairman and a Professor of Industrial and Systems Engineering at The University of Alabama-Huntsville He also taught at The Ohio State University, the University of Rhode Island, the University of Vermont, the University of Illinois and West Virginia University. J T. is a Fellow in the American Society of Mechanical Engineers, the Institute of Industrial Engineering and the Society of Manufacturing Engineers. J loves to write music (mostly down home country) and poetry. Co-authoring with Ron Kohser makes this book a success, just as picking his doubles partner in tennis has given him the #1 doubles ranking for 65 year olds in the State of Alabama.

Ron Kohser received his Ph.D. from the Lehigh University Institute for Metal Forming in 1975. Ron is currently in his 32nd year on the faculty of the University of Missouri-Rolla, where he is a Professor of Metallurgical Engineering and Dean's Teaching Scholar. While maintaining a full commitment to classroom instruction, he has served as department chair and Associate Dean for Undergraduate Instruction. He currently teaches courses in Metallurgy for Engineers, Introduction to Manufacturing Processes, and Material Selection, Fabrication and Failure Analysis. In addition to the academic responsibilities, Ron and his wife Barb operate *A Miner Indulgence*, a bed-and-breakfast in Rolla, Missouri.

Acronyms

AC	Adaptive Control
AFM	Abrasive Flow Machining
AGVS	Automated Guided Vehicle System
AI	Artificial Intelligence
APT	Automatic Programming of Tools
AQL	Acceptable Quality Limit (or Level)
ASCII	American Standard Code
AS/RS	Automatic Storage/Retrieval System
ATE	Automatic Test Equipment
AWJM	Abrasive Water Jet Machining
BASIC	Beginner's All-Purpose Symbolic Instruction Code
BTRI	Behind the Tape Reader Interface
CAD	Computer-Aided Design
CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
CAD/D	Computer-Aided Drafting and Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CAPP	Computer-Aided Process Planning
CATI	Computer-Aided Testing and Inspection
CDC	Cutter Diameter Compensation
CHM	Chemical Machining
CIM	Computer-Integrated Manufacturing
CL	Center Line
CMM	Coordinate Measuring Machine
CMS	Cellular Manufacturing System
CNC	Computer Numerical Control
COBOL	Common Business Oriented Language
CPR	Capacity Resources Planning
CPU	Central Processing Unit *(Computer)*
CRT	Cathode Ray Tube
CVD	Chemical Vapor Deposition
DBM	Data-Base Management
DDAS	Direct Data Acquisition System
DDC	Direct Digital Control
DNC	Digital (or Direct or Distributed) Numerical Control
DOS	Disk Operating System
DP	Diametrical Pitch
DPRO	Digital Position Readout
DRO	Digital Readout
EAROM	Electrically-Alterable Read-Only Memory
EBCDIC	Extended Binary Coded Decimal Interchange Code
EBM	Electron Beam Machining *(EBW = Welding) (EBC = Cutting)*
ECM	Electrochemical Machining
EDM	Electrodischarge Machining *(EDG = Grinding)*
EMI	Electromagnetic Interface
EOB	End of Block
EOP	End of Program (workpiece)
EOT	End of Tape
EROM	Eraseable Read-Only Memory
ESW	Electroslag Welding
FCAW	Flux Cored Arc Welding
FEM	Finite-Element Method
FMC	Flexible Manufacturing Cell
FMS	Flexible Manufacturing System
FORTRAN	Formula Translation
FRN	Feed Rate Number
GMAW	Gas Metal Arc Welding
GT	Group Technology
GTAW	Gas Tungsten Arc Welding
HAZ	Heat Affected Zone
HERF	High Energy Rate Forming

HGVS	Human-Guided Vehicle System *(fork-lift with driver)*
HIP	Hot Isostatic Pressing
IGES	Initial Graphics Exchange System
IMPSs	Integrated Manufacturing Production Systems
I/O	Input/Output
IOCS	Input/Output Control System
JIT	Just-In-Time
LAN	Local Area Network
LASER	Light Amplification by Stimulated Emission of Radiation
LBM	Laser Beam Machining *(LBW = Welding) (LBC = Cutting)*
L-CMS	Linked-Cell Manufacturing System
LED	Light Emitting Diode
LP	Lean Production
LSI	Large Scale Integration
MAP	Manufacturing Automation Protocol
MCU	Machine Control Unit
MDI	Manual Data Input
MIG	Metal–Inert Gas
MPS	Manufacturing Production System
mrp	Material Requirements Planning
MRPII	Manufacturing Resources Planning
MSD	Manufacturing System Design
NC	Numerically Control
NDT	NonDestructive Testing *(NDE = Evaluation) (NDI = Inspection)*
OCR	Optical Character Recognition
OM	Orthogonal Machining
OPM	Orthogonal Plate Machining
OS	Operating System
OTT	Orthogonal Tube Turning
PAW	Plasma Arc Welding *(PAC = Cutting) (PAM = Machining)*
PCB	Printed Circuit Board
PD	Pitch Diameter
PDES	Product Design Exchange Specification
PLC	Programmable Logic Controller
POK	Production Ordering Kanban
PROM	Programmable Read-Only Memory
PS	Production System
P/M	Powder Metallurgy
PVD	Physical Vapor Deposition
QC	Quality Control
QMS	Quality Management System
RAM	Random Access Memory
RIM	Reaction Injection Molding
ROM	Read-Only Memory
SAW	Submerged Arc Welding
SCA	Single Cycle Automatic
SMAW	Shielded Metal Arc Welding
SPC	Statistical Process Control
SPF	Single Piece Flow
SQC	Statistical Quality Control
TCM	Thermochemical Machining
TIR	Total Indicator Readout
TPS	Toyota Production System
TQC	Total Quality Control
USM	Ultrasonic Machining *(USW = Welding)*
VA	Value Analysis
WAN	Wide Area Network
WIP	Work-In-Progress (or Process)
WJM	Water Jet Machining
WLK	Withdrawl Kanban
YAG	Yttrium-Aluminum Garnet

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