影印版

PLASTICS TECHNOLOGY HANDBOOK

塑料技术手册

VOLUME 2

COMPRESSION MOLDING·REINFORCED PLASTIC·OTHER PROCESSES

压缩成型·增强塑料·其他工艺

EDITED BY
DONALD V. ROSATO
MARLENE G. ROSATO
NICK R. SCHOTT

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黑版贸审字08-2014-093号

Donald V.Rosato,Marlene G.Rosato,Nick R.Schott
Plastics Technology Handbook Volume 2
9781606500828

Originally published by Momentum Press, LLC
English reprint rights arranged with Momentum Press, LLC through McGraw-Hill Education (Asia)

图书在版编目（CIP）数据

塑料技术手册. 第2卷. 压缩成型·增强塑料·其他工艺 =Plastics technology handbook volume 2 compression molding·reinforced plastic·other processes : 英文 /（美）罗萨多（Rosato, D. V.）等主编. —影印本. — 哈尔滨 : 哈尔滨工业大学出版社, 2015.6
ISBN 978-7-5603-5048-6

Ⅰ. ①塑… Ⅱ. ①罗… Ⅲ. ①塑料 - 技术手册 - 英文 ②塑料成型 - 技术手册 - 英文 ③增强塑料 - 技术手册 - 英文 ④塑料 - 生产工艺 - 技术手册 - 英文 Ⅳ. ①TQ320.6-62

中国版本图书馆CIP数据核字（2014）第280096号

材料科学与工程
图书工作室

责任编辑 张秀华 杨 桦 许雅莹
出版发行 哈尔滨工业大学出版社
社 址 哈尔滨市南岗区复华四道街10号 邮编 150006
传 真 0451-86414749
网 址 http://hitpress.hit.edu.cn
印 刷 哈尔滨市石桥印务有限公司
开 本 787mm × 960mm 1/16 印张14
版 次 2015 年 6 月 第 1 版 2015 年 6 月第 1 次印刷
书 号 ISBN 978-7-5603-5048-6
定 价 70.00元

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VOLUME 2

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MOMENTUM PRESS
Momentum Press, LLC, New York

Abbreviations

AA acrylic acid
AAE American Association of Engineers
AAES American Association of Engineering Societies
ABR polyacrylate
ABS acrylontrile-butadiene-styrene
AC alternating current
ACS American Chemical Society
ACTC Advanced Composite Technology Consortium
ad adhesive
ADC allyl diglycol carbonate (also CR-39)
AFCMA Aluminum Foil Container Manufacturers' Association
AFMA American Furniture Manufacturers' Association
AFML Air Force Material Laboratory
AFPA American Forest and Paper Association
AFPR Association of Foam Packaging Recyclers
AGMA American Gear Manufacturers' Association
AIAA American Institute of Aeronautics and Astronauts
AIChE American Institute of Chemical Engineers
AIMCAL Association of Industrial Metallizers, Coaters, and Laminators
AISI American Iron and Steel Institute
AMBA American Mold Builders Association
AMC alkyd molding compound
AN acrylonitrile
ANSI American National Standards Institute
ANTEC Annual Technical Conference (of the Society of the Plastic Engineers)
APC American Plastics Council
APET amorphous polyethylene terephthalate
APF Association of Plastics Fabricators
API American Paper Institute
APME Association of Plastics Manufacturers in Europe
APPR Association of Post-Consumer Plastics Recyclers
AQL acceptable quality level
AR aramid fiber; aspect ratio
ARP advanced reinforced plastic
ASA acrylonitrile-styrene-acrylate
ASCII american standard code for information exchange
ASM American Society for Metals

ASME American Society of Mechanical Engineers
ASNDT American Society for Non-Destructive Testing
ASQC American Society for Quality Control
ASTM American Society for Testing Materials
atm atmosphere
bbl barrel
BFRL Building and Fire Research Laboratory
Bhn Brinell hardness number
BM blow molding
BMC bulk molding compound
BO biaxially oriented
BOPP biaxially oriented polypropylene
BR polybutadiene
Btu British thermal unit
buna polybutadiene
butyl butyl rubber
CA cellulose acetate
CAB cellulose acetate butyrate
$CaCO_3$ calcium carbonate (lime)
CAD computer-aided design
CAE computer-aided engineering
CAM computer-aided manufacturing
CAMPUS computer-aided material preselection by uniform standards
CAN cellulose acetate nitrate
CAP cellulose acetate propionate
CAS Chemical Abstract Service (a division of the American Chemical Society)
CAT computer-aided testing
CBA chemical blowing agent
CCA cellular cellulose acetate
CCV Chrysler composites vehicle
CEM Consorzio Export Mouldex (Italian)
CFA Composites Fabricators Association
CFC chlorofluorocarbon
CFE polychlorotrifluoroethylene
CIM ceramic injection molding; computer integrated manufacturing
CLTE coefficient of linear thermal expansion
CM compression molding
CMA Chemical Manufacturers' Association
CMRA Chemical Marketing Research Association
CN cellulose nitrate (celluloid)
CNC computer numerically controlled
CP Canadian Plastics
CPE chlorinated polyethylene
CPET crystallized polyethylene terephthalate
CPI Canadian Plastics Institute
cpm cycles/minute
CPVC chlorinated polyvinyl chloride
CR chloroprene rubber; compression ratio
CR-39 allyl diglycol carbonate
CRP carbon reinforced plastics
CRT cathode ray tube
CSM chlorosulfonyl polyethylene
CTFE chlorotrifluorethylene
DAP diallyl phthalate
dB decibel
DC direct current
DEHP diethylhexyl phthalate
den denier
DGA differential gravimetric analysis
DINP diisononyl phthalate
DMA dynamic mechanical analysis
DMC dough molding compound
DN *Design News* publication
DOE Design of Experments
DSC differential scanning calorimeter
DSD Duales System Deutschland (German Recycling System)
DSQ German Society for Quality
DTA differential thermal analysis
DTGA differential thermogravimetric analysis
DTMA dynamic thermomechanical analysis
DTUL deflection temperature under load
DV devolatilization
DVR design value resource; dimensional velocity research; Druckverformungsrest (German

compression set); dynamic value research; dynamic velocity ratio

E modulus of elasticity; Young's modulus

EBM extrusion blow molding

E_c modulus, creep (apparent)

EC ethyl cellulose

ECTFE polyethylene-chlorotrifluoroethylene

EDM electrical discharge machining

E/E electronic/electrical

EEC European Economic Community

EI modulus × moment of inertia (equals stiffness)

EMI electromagnetic interference

EO ethylene oxide (also EtO)

EOT ethylene ether polysulfide

EP ethylene-propylene

EPA Environmental Protection Agency

EPDM ethylene-propylene diene monomer

EPM ethylene-propylene fluorinated

EPP expandable polypropylene

EPR ethylene-propylene rubber

EPS expandable polystyrene

E_r modulus, relaxation

E_s modulus, secant

ESC environmental stress cracking

ESCR environmental stress cracking resistance

ESD electrostatic safe discharge

ET ethylene polysulfide

ETFE ethylene terafluoroethylene

ETO ethylene oxide

EU entropy unit; European Union

EUPC European Association of Plastics Converters

EUPE European Union of Packaging and Environment

EUROMAP Eu^ropean Committee of Machine Manufacturers for the Rubber and Plastics Industries (Zurich, Switzerland)

EVA ethylene-vinyl acetate

E/VAC ethylene/vinyl acetate copolymer

EVAL ethylene-vinyl alcohol copolymer (trade-name for EVOH)

EVE ethylene-vinyl ether

EVOH ethylene-vinyl alcohol copolymer (or EVAL)

EX extrusion

F coefficient of friction; Farad; force

FALLO follow all opportunities

FDA Food and Drug Administration

FEA finite element analysis

FEP fluorinated ethylene-propylene

FFS form, fill, and seal

FLC fuzzy logic control

FMCT fusible metal core technology

FPC flexible printed circuit

fpm feet per minute

FRCA Fire Retardant Chemicals Association

FRP fiber reinforced plastic

FRTP fiber reinforced thermoplastic

FRTS fiber reinforced thermoset

FS fluorosilicone

FTIR Fourier transformation infrared

FV frictional force × velocity

G gravity; shear modulus (modulus of rigidity); torsional modulus

GAIM gas-assisted injection molding

gal gallon

GB gigabyte (billion bytes)

GD&T geometric dimensioning and tolerancing

GDP gross domestic product

GFRP glass fiber reinforced plastic

GMP good manufacturing practice

GNP gross national product

GP general purpose

GPa giga-Pascal

GPC gel permeation chromatography

gpd grams per denier

gpm gallons per minute

GPPS general purpose polystyrene

GRP glass reinforced plastic

GR-S polybutadiene-styrene

GSC gas solid chromatography

H hysteresis; hydrogen
HA hydroxyapatite
HAF high-abrasion furnace
HB Brinell hardness number
HCFC hydrochlorofluorocarbon
HCl hydrogen chloride
HDPE high-density polyethylene (also PE-HD)
HDT heat deflection temperature
HIPS high-impact polystyrene
HMC high-strength molding compound
HMW-HDPE high molecular weight–high density polyethylene
H-P Hagen-Poiseuille
HPLC high-pressure liquid chromatography
HPM hot pressure molding
HTS high-temperature superconductor
Hz Hertz (cycles)
I integral; moment of inertia
IB isobutylene
IBC internal bubble cooling
IBM injection blow molding; International Business Machines
IC *Industrial Computing* publication
ICM injection-compression molding
ID internal diameter
IEC International Electrochemical Commission
IEEE Institute of Electrical and Electronics Engineers
IGA isothermal gravimetric analysis
IGC inverse gas chromatography
IIE Institute of Industrial Engineers
IM injection molding
IMM injection molding machine
IMPS impact polystyrene
I/O input/output
ipm inch per minute
ips inch per second
IR synthetic polyisoprene (synthetic natural rubber)
ISA Instrumentation, Systems, and Automation
ISO International Standardization Organization or International Organization for Standardization
IT information technology
IUPAC International Union of Pure and Applied Chemistry
IV intrinsic viscosity
IVD in vitro diagnostic
J joule
JIS Japanese Industrial Standard
JIT just-in-time
JIT just-in-tolerance
J_p polar moment of inertia
JSR Japanese SBR
JSW Japan Steel Works
JUSE Japanese Union of Science and Engineering
JWTE Japan Weathering Test Center
K bulk modulus of elasticity; coefficient of thermal conductivity; Kelvin; Kunststoffe (plastic in German)
kb kilobyte (1000 bytes)
kc kilocycle
kg kilogram
KISS keep it short and simple
Km kilometer
kPa kilo-Pascal
ksi thousand pounds per square inch (psi $\times 10^3$)
lbf pound-force
LC liquid chromatography
LCP liquid crystal polymer
L/D length-to-diameter (ratio)
LDPE low-density polyethylene (PE-LD)
LIM liquid impingement molding; liquid injection molding
LLDPE linear low-density polyethylene (also PE-LLD)
LMDPE linear medium density polyethylene
LOX liquid oxygen
LPM low-pressure molding
m matrix; metallocene (catalyst); meter

mμ micromillimeter; millicron; 0.000001 mm
μm micrometer
MA maleic anhydride
MAD mean absolute deviation; molding area diagram
Mb bending moment
MBTS benzothiazyl disulfide
MD machine direction; mean deviation
MD&DI Medical Device and Diagnostic Industry
MDI methane diisocyanate
MDPE medium density polyethylene
Me metallocene catalyst
MF melamine formaldehyde
MFI melt flow index
mHDPE metallocene high-density polyethylene
MI melt index
MIM metal powder injection molding
MIPS medium impact polystyrene
MIT Massachusetts Institute of Technology
mLLDPE metallocene catalyst linear low-density polyethylene
MMP multimaterial molding or multimaterial multiprocess
MPa mega-Pascal
MRPMA Malaysian Rubber Products Manufacturers' Association
Msi million pounds per square inch (psi $\times 10^6$)
MSW municipal solid waste
MVD molding volume diagram
MVT moisture vapor transmission
MW molecular weight
MWD molecular weight distribution
MWR molding with rotation
N Newton (force)
NACE National Association of Corrosion Engineers
NACO National Association of CAD/CAM Operation
NAGS North America Geosynthetics Society
NASA National Aeronautics Space Administration
NBR butadiene acrylontrile
NBS National Bureau of Standards (since 1980 renamed the National Institute Standards and Technology or NIST)
NC numerical control
NCP National Certification in Plastics
NDE nondestructive evaluation
NDI nondestructive inspection
NDT nondestructive testing
NEAT nothing else added to it
NEMA National Electrical Manufacturers' Association
NEN Dutch standard
NFPA National Fire Protection Association
NISO National Information Standards Organization
NIST National Institute of Standards and Technology
nm nanometer
NOS not otherwise specified
NPCM National Plastics Center and Museum
NPE National Plastics Exhibition
NPFC National Publications and Forms Center (US government)
NR natural rubber (polyisoprene)
NSC National Safety Council
NTMA National Tool and Machining Association
NWPCA National Wooden Pallet and Container Association
OD outside diameter
OEM original equipment manufacturer
OPET oriented polyethylene terephthalate
OPS oriented polystyrene
OSHA Occupational Safety and Health Administration
P load; poise; pressure
Pa Pascal
PA polyamide (nylon)
PAI polyamide-imide
PAN polyacrylonitrile

PB polybutylene
PBA physical blowing agent
PBNA phenyl-β-naphthylamine
PBT polybutylene terephthalate
PC permeability coefficient; personal computer; plastic composite; plastic compounding; plastic-concrete; polycarbonate; printed circuit; process control; programmable circuit; programmable controller
PCB printed circuit board
pcf pounds per cubic foot
PCFC polychlorofluorocarbon
PDFM Plastics Distributors and Fabricators Magazine
PE plastic engineer; polyethylene (UK polythene); professional engineer
PEEK polyetheretherketone
PEI polyetherimide
PEK polyetherketone
PEN polyethylene naphthalate
PES polyether sulfone
PET polyethylene terephthalate
PETG polyethylene terephthalate glycol
PEX polyethylene crosslinked pipe
PF phenol formaldehyde
PFA perfluoroalkoxy (copolymer of tetrafluoroethylene and perfluorovinylethers)
PFBA polyperfluorobutyl acrylate
phr parts per hundred of rubber
PI polyimide
PIA Plastics Institute of America
PID proportional-integral-differential
PIM powder injection molding
PLASTEC Plastics Technical Evaluation Center (US Army)
PLC programmable logic controller
PMMA Plastics Molders and Manufacturers' Association (of SME); polymethyl methacrylate (acrylic)
PMMI Packaging Machinery Manufacturers' Institute
PO polyolefin
POE polyolefin elastomer
POM polyoxymethylene or polyacetal (acetal)
PP polypropylene
PPA polyphthalamide
ppb parts per billion
PPC polypropylene chlorinated
PPE polyphenylene ether
pph parts per hundred
ppm parts per million
PPO polyphenylene oxide
PPS polyphenylene sulfide
PPSF polyphenylsulfone
PPSU polyphenylene sulphone
PS polystyrene
PSB polystyrene butadiene rubber (GR-S, SBR)
PS-F polystyrene-foam
psf pounds per square foot
PSF polysulphone
psi pounds per square inch
psia pounds per square inch, absolute
psid pounds per square inch, differential
psig pounds per square inch, gauge (above atmospheric pressure)
PSU polysulfone
PTFE polytetrafluoroethylene (or TFE)
PUR polyurethane (also PU, UP)
P-V pressure-volume (also PV)
PVA polyvinyl alcohol
PVAC polyvinyl acetate
PVB polyvinyl butyral
PVC polyvinyl chloride
PVD physical vapor deposition
PVDA polyvinylidene acetate
PVdC polyvinylidene chloride
PVDF polyvinylidene fluoride
PVF polyvinyl fluoride
PVP polyvinyl pyrrolidone

PVT pressure-volume-temperature (also P-V-T or pvT)
PW *Plastics World* magazine
QA quality assurance
QC quality control
QMC quick mold change
QPL qualified products list
QSR quality system regulation
R Reynolds number; Rockwell (hardness)
rad Quantity of ionizing radiation that results in the absorption of 100 ergs of energy per gram of irradiated material.
radome radar dome
RAPRA Rubber and Plastics Research Association
RC Rockwell C (R_c)
RFI radio frequency interference
RH relative humidity
RIM reaction injection molding
RM rotational molding
RMA Rubber Manufacturers' Association
RMS root mean square
ROI return on investment
RP rapid prototyping; reinforced plastic
RPA Rapid Prototyping Association (of SME)
rpm revolutions per minute
RRIM reinforced reaction injection molding
RT rapid tooling; room temperature
RTM resin transfer molding
RTP reinforced thermoplastic
RTS reinforced thermoset
RTV room temperature vulcanization
RV recreational vehicle
Rx radiation curing
SAE Society of Automotive Engineers
SAMPE Society for the Advancement of Material and Process Engineering
SAN styrene acrylonitrile
SBR styrene-butadiene rubber
SCT soluble core technology
SDM standard deviation measurement
SES Standards Engineering Society
SF safety factor; short fiber; structural foam
s.g. specific gravity
SI International System of Units
SIC Standard Industrial Classification
SMC sheet molding compound
SMCAA Sheet Molding Compound Automotive Alliance
SME Society of Manufacturing Engineers
S-N stress-number of cycles
SN synthetic natural rubber
SNMP simple network management protocol
SPC statistical process control
SPE Society of the Plastics Engineers
SPI Society of the Plastics Industry
sPS syndiotactic polystyrene
sp. vol. specific volume
SRI Standards Research Institute (ASTM)
S-S stress-strain
STP Special Technical Publication (ASTM); standard temperature and pressure
t thickness
T temperature; time; torque (or T_t)
TAC triallylcyanurate
T/C thermocouple
TCM technical cost modeling
TD transverse direction
TDI toluene diisocyanate
TF thermoforming
TFS thermoform-fill-seal
T_g glass transition temperature
TGA thermogravimetric analysis
TGI thermogravimetric index
TIR tooling indicator runout
T-LCP thermotropic liquid crystal polymer
TMA thermomechanical analysis; Tooling and Manufacturing Association (formerly TDI); Toy Manufacturers of America
torr mm mercury (mmHg); unit of pressure equal to 1/760th of an atmosphere

TP thermoplastic
TPE thermoplastic elastomer
TPO thermoplastic olefin
TPU thermoplastic polyurethane
TPV thermoplastic vulcanizate
T_s tensile strength; thermoset
TS twin screw
TSC thermal stress cracking
TSE thermoset elastomer
TX thixotropic
TXM thixotropic metal slurry molding
UA urea, unsaturated
UD unidirectional
UF urea formaldehyde
UHMWPE ultra-high molecular weight polyethylene (also PE-UHMW)
UL Underwriters Laboratories
UP unsaturated polyester (also TS polyester)
UPVC unplasticized polyvinyl chloride
UR urethane (also PUR, PU)
URP unreinforced plastic
UV ultraviolet
UVCA ultra-violet-light-curable-cyanoacrylate
V vacuum; velocity; volt
VA value analysis
VCM vinyl chloride monomer
VLDPE very low-density polyethylene
VOC volatile organic compound
vol% percentage by volume
w width
W watt
W/D weight-to-displacement volume (boat hull)
WIT water-assist injection molding technology
WMMA Wood Machinery Manufacturers of America
WP&RT World Plastics and Rubber Technology magazine
WPC wood-plastic composite
wt% percentage by weight
WVT water vapor transmission
XL cross-linked
XLPE cross-linked polyethylene
XPS expandable polystyrene
YPE yield point elongation
Z-twist twisting fiber direction

Acknowledgments

Undertaking the development through to the completion of the *Plastics Technology Handbook* required the assistance of key individuals and groups. The indispensable guidance and professionalism of our publisher, Joel Stein, and his team at Momentum Press was critical throughout this enormous project. The coeditors, Nick R. Schott, Professor Emeritus of the University of Massachusetts Lowell Plastics Engineering Department, and Marlene G. Rosato, President of Gander International Inc., were instrumental to the data, information, and analysis coordination of the eighteen chapters of the handbook. A special thank you is graciously extended to Napoleao Neto of Alphagraphics for the organization and layout of the numerous figure and table graphics central to the core handbook theme. Finally, a great debt is owed to the extensive technology resources of the Plastics Institute of America at the University of Massachusetts Lowell and its Executive Director, Professor Aldo M. Crugnola.

Dr. Donald V. Rosato, Coeditor and President, PlastiSource, Inc.

Preface

This book, as a two-volume set, offers a simplified, practical, and innovative approach to understanding the design and manufacture of products in the world of plastics. Its unique review will expand and enhance your knowledge of plastic technology by defining and focusing on past, current, and future technical trends. Plastics behavior is presented to enhance one's capability when fabricating products to meet performance requirements, reduce costs, and generally be profitable. Important aspects are also presented to help the reader gain understanding of the advantages of different materials and product shapes. The information provided is concise and comprehensive.

Prepared with the plastics technologist in mind, this book will be useful to many others. The practical and scientific information contained in this book is of value to both the novice, including trainees and students, and the most experienced fabricators, designers, and engineering personnel wishing to extend their knowledge and capability in plastics manufacturing including related parameters that influence the behavior and characteristics of plastics. The toolmaker (who makes molds, dies, etc.), fabricator, designer, plant manager, material supplier, equipment supplier, testing and quality control personnel, cost estimator, accountant, sales and marketing personnel, new venture type, buyer, vendor, educator/trainer, workshop leader, librarian, industry information provider, lawyer, and consultant can all benefit from this book. The intent is to provide a review of the many aspects of plastics that range from the elementary to the practical to the advanced and more theoretical approaches. People with different interests can focus on and interrelate across subjects in order to expand their knowledge within the world of plastics.

Over 20000 subjects covering useful pertinent information are reviewed in different chapters contained in the two volumes of this book, as summarized in the expanded table of contents and index. Subjects include reviews on materials, processes, product designs, and so on. From a pragmatic standpoint, any theoretical aspect that is presented has been prepared so that the practical person will understand it and put it to use. The theorist in turn will gain an insight into the practical

limitations that exist in plastics as they exist in other materials such as steel, wood, and so on. There is no material that is "perfect." The two volumes of this book together contain 1800-plus figures and 1400-plus tables providing extensive details to supplement the different subjects.

In working with any material (plastics, metal, wood, etc.), it is important to know its behavior in order to maximize product performance relative to cost and efficiency. Examples of different plastic materials and associated products are reviewed with their behavior patterns. Applications span toys, medical devices, cars, boats, underwater devices, containers, springs, pipes, buildings, aircraft, and spacecraft. The reader's product to be designed or fabricated, or both, can be related directly or indirectly to products reviewed in this book. Important are behaviors associated with and interrelated with the many different plastics materials (thermoplastics [TPs], thermosets [TSs], elastomers, reinforced plastics) and the many fabricating processes (extrusion, injection molding, blow molding, forming, foaming, reaction injection molding, and rotational molding). They are presented so that the technical or nontechnical reader can readily understand the interrelationships of materials to processes.

This book has been prepared with the awareness that its usefulness will depend on its simplicity and its ability to provide essential information. An endless amount of data exists worldwide for the many plastic materials, which total about 35000 different types. Unfortunately, as with other materials, a single plastic material that will meet all performance requirements does not exist. However, more so than with any other materials, there is a plastic that can be used to meet practically any product requirement. Examples are provided of different plastic products relative to critical factors ranging from meeting performance requirements in different environments to reducing costs and targeting for zero defects. These reviews span products that are small to large and of shapes that are simple to complex. The data included provide examples that span what is commercially available. For instance, static physical properties (tensile, flexural, etc.), dynamic physical properties (creep, fatigue, impact, etc.), chemical properties, and so on, can range from near zero to extremely high values, with some having the highest of any material. These plastics can be applied in different environments ranging from below and on the earth's surface to outer space.

Pitfalls to be avoided are reviewed in this book. When qualified people recognize the potential problems, these problems can be designed around or eliminated so that they do not affect the product's performance. In this way, costly pitfalls that result in poor product performance or failure can be reduced or eliminated. Potential problems or failures are reviewed, with solutions also presented. This failure-and-solution review will enhance the intuitive skills of people new to plastics as well as those who are already working in plastics. Plastic materials have been produced worldwide over many years for use in the design and fabrication of all kinds of plastic products. To profitably and successfully meet high-quality, consistency, and long-life standards, all that is needed is to understand the behavior of plastics and to apply these behaviors properly.

Patents or trademarks may cover certain of the materials, products, or processes presented. They are discussed for information purposes only and no authorization to use these patents or trademarks is given or implied. Likewise, the use of general descriptive names, proprietary names, trade names, commercial designations, and so on does not in any way imply that they may be used

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Preparation for this book drew on information from participating industry personnel, global industry and trade associations, and the authors' worldwide personal, industrial, and teaching experiences.

DON & MARLENE ROSATO AND NICK SCHOTT, 2011

About the Authors

Dr. Donald V. Rosato, president of PlastiSource Inc., a prototype manufacturing, technology development, and marketing advisory firm in Massachusetts, United States, is internationally recognized as a leader in plastics technology, business, and marketing. He has extensive technical, marketing, and plastics industry business experience ranging from laboratory testing to production to marketing, having worked for Northrop Grumman, Owens-Illinois, DuPont/Conoco, Hoechst Celanese/Ticona, and Borg Warner/G.E. Plastics. He has developed numerous polymer-related patents and is a participating member of many trade and industry groups. Relying on his unrivaled knowledge of the industry and high-level international contacts, Dr. Rosato is also uniquely positioned to provide an expert, inside view of a range of advanced plastics materials, processes, and applications through a series of seminars and webinars. Among his many accolades, Dr. Rosato has been named Engineer of the Year by the Society of Plastics Engineers. Dr. Rosato has written extensively, authoring or editing numerous papers, including articles published in the *Encyclopedia of Polymer Science and Engineering*, and major books, including the *Concise Encyclopedia of Plastics*, *Injection Molding Handbook 3rd ed.*, *Plastic Product Material and Process Selection Handbook*, *Designing with Plastics and Advanced Composites*, and *Plastics Institute of America Plastics Engineering, Manufacturing, and Data Handbook*. Dr. Rosato holds a BS in chemistry from Boston College, an MBA from Northeastern University, an MS in plastics engineering from the University of Massachusetts Lowell, and a PhD in business administration from the University of California, Berkeley.

Marlene G. Rosato, with stints in France, China, and South Korea, has comprehensive international plastics and elastomer business experience in technical support, plant start-up and troubleshooting, manufacturing and engineering management, and business development and strategic planning with Bayer/Polysar and DuPont. She also does extensive international technical, manufacturing, and management consulting as president of Gander International Inc. She also has