

影印版

# PLASTICS TECHNOLOGY HANDBOOK

# 塑料技术手册

VOLUME 2  
MOLD AND DIE TOOLING

模 具

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



哈尔滨工业大学出版社  
HARBIN INSTITUTE OF TECHNOLOGY PRESS

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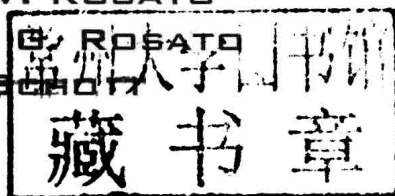
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Donald V. Rosato, Marlene G. Rosato, Nick R. Schott

Plastics Technology Handbook Volume 2

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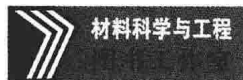
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MOMENTUM PRESS 出版的 *Plastics Technology Handbook* (2 卷) 是介绍塑料知识与技术的大型综合性手册, 内容涵盖了从高分子基本原理, 到塑料的合成、种类、性能、配料、加工、制品, 以及模具、二次加工等各个方面。通过阅读、学习本手册, 无论是专业人员还是非专业人员, 都会很快熟悉和掌握塑料制品的设计和制造方法。可以说一册在手, 别无他求。

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塑料制品生产

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挤压成型

吹塑成型

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发泡成型·压延成型

第 2 卷分为 :

涂层·浇注成型·反应注射成型·旋转成型

压缩成型·增强塑料·其他工艺

模具

辅机与二次加工设备

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# PLASTICS TECHNOLOGY HANDBOOK

## VOLUME 2

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# ABBREVIATIONS

|                                                                 |                                                                                    |
|-----------------------------------------------------------------|------------------------------------------------------------------------------------|
| <b>AA</b> acrylic acid                                          | <b>AIMCAL</b> Association of Industrial Metallizers, Coaters, and Laminators       |
| <b>AAE</b> American Association of Engineers                    | <b>AISI</b> American Iron and Steel Institute                                      |
| <b>AAES</b> American Association of Engineering Societies       | <b>AMBA</b> American Mold Builders Association                                     |
| <b>ABR</b> polyacrylate                                         | <b>AMC</b> alkyd molding compound                                                  |
| <b>ABS</b> acrylonitrile-butadiene-styrene                      | <b>AN</b> acrylonitrile                                                            |
| <b>AC</b> alternating current                                   | <b>ANSI</b> American National Standards Institute                                  |
| <b>ACS</b> American Chemical Society                            | <b>ANTEC</b> Annual Technical Conference (of the Society of the Plastic Engineers) |
| <b>ACTC</b> Advanced Composite Technology Consortium            | <b>APC</b> American Plastics Council                                               |
| <b>ad</b> adhesive                                              | <b>APET</b> amorphous polyethylene terephthalate                                   |
| <b>ADC</b> allyl diglycol carbonate (also CR-39)                | <b>APF</b> Association of Plastics Fabricators                                     |
| <b>AFCMA</b> Aluminum Foil Container Manufacturers' Association | <b>API</b> American Paper Institute                                                |
| <b>AFMA</b> American Furniture Manufacturers' Association       | <b>APME</b> Association of Plastics Manufacturers in Europe                        |
| <b>AFML</b> Air Force Material Laboratory                       | <b>APPR</b> Association of Post-Consumer Plastics Recyclers                        |
| <b>AFPA</b> American Forest and Paper Association               | <b>AQL</b> acceptable quality level                                                |
| <b>AFPR</b> Association of Foam Packaging Recyclers             | <b>AR</b> aramid fiber; aspect ratio                                               |
| <b>AGMA</b> American Gear Manufacturers' Association            | <b>ARP</b> advanced reinforced plastic                                             |
| <b>AIAA</b> American Institute of Aeronautics and Astronauts    | <b>ASA</b> acrylonitrile-styrene-acrylate                                          |
| <b>AIChE</b> American Institute of Chemical Engineers           | <b>ASCII</b> american standard code for information exchange                       |
|                                                                 | <b>ASM</b> 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<sub>3</sub>** 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** chlorotrifluoroethylene  
**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 Experiments  
**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<sub>c</sub>** modulus, creep (apparent)
- EC** ethyl cellulose
- ECTFE** polyethylene-chlorotrifluoroethylene
- EDM** electrical discharge machining
- E/E** electronic/electrical
- EEC** European Economic Community
- EI** modulus  $\times$  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<sub>r</sub>** modulus, relaxation
- E<sub>s</sub>** modulus, secant
- ESC** environmental stress cracking
- ESCR** environmental stress cracking resistance
- ESD** electrostatic safe discharge
- ET** ethylene polysulfide
- ETFE** ethylene tetrafluoroethylene
- ETO** ethylene oxide
- EU** entropy unit; European Union
- EUPC** European Association of Plastics Converters
- EUPE** European Union of Packaging and Environment
- EUROMAP** European 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  $\times$  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



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

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

- PB** polybutylene  
**PBA** physical blowing agent  
**PBNA** phenyl- $\beta$ -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

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

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

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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.

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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