

影印版

PLASTICS TECHNOLOGY HANDBOOK

塑料技术手册

VOLUME 1
THERMOFORMING

热成型

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

影印版

PLASTICS TECHNOLOGY HANDBOOK

塑料技术手册

VOLUME 1

THERMOFORMING

热成型

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

黑版贸审字08-2014-092号

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

Plastics Technology Handbook Volume 1

9781606500798

Copyright © 2010 by Momentum Press, LLC

All rights reserved.

Originally published by Momentum Press, LLC

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

This edition is authorized for sale in the People's Republic of China only, excluding Hong Kong, Macao SAR and Taiwan.

本书封面贴有McGraw-Hill Education公司防伪标签, 无标签者不得销售。
版权所有, 侵权必究。

图书在版编目(CIP)数据

塑料技术手册. 第1卷. 热成型 = Plastics technology handbook volume 1 thermoforming: 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 978-7-5603-5045-5

I. ①塑… II. ①罗… III. ①塑料-技术手册-英文 ②塑料成型-热成型-技术手册-英文
IV. ①TQ320.6-62

中国版本图书馆CIP数据核字(2014)第280082号



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 7.5

版 次 2015年6月第1版 2015年6月第1次印刷

书 号 ISBN 978-7-5603-5045-5

定 价 38.00元

(如因印刷质量问题影响阅读, 我社负责调换)

影印版说明

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。

原版 2 卷影印时分为 11 册, 第 1 卷分为 :

塑料基础知识·塑料性能

塑料制品生产

注射成型

挤压成型

吹塑成型

热成型

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

唐纳德 V·罗萨多, 波士顿大学化学学士学位, 美国东北大学 MBA 学位, 马萨诸塞大学洛厄尔分校工程塑料和加州大学工商管理博士学位(伯克利)。著有诸多论文及著作, 包括《塑料简明百科全书》、《注塑手册(第三版)》以及塑料产品材料和工艺选择手册等。活跃于塑料界几十年, 现任著名的 Plasti Source Inc. 公司总裁, 并是美国塑料工业协会(SPI)、美国塑料学会(PIA)和 SAMPE(The Society for the Advancement of Material and Process Engineering)的重要成员。

材料科学与工程图书工作室

联系电话 0451-86412421

0451-86414559

邮 箱 yh_bj@aliyun.com

xuyaying81823@gmail.com

zhxh6414559@aliyun.com

PLASTICS TECHNOLOGY HANDBOOK

VOLUME 1

EDITED BY

Donald V. Rosato, PhD, MBA, MS, BS, PE

Plastisource Inc.

Society of Plastics Engineers

Plastics Pioneers Association

University of Massachusetts—Lowell Plastics Advisory Board

Marlene G. Rosato, BAsC (ChE) P Eng

Gander International Inc.

Canadian Society of Chemical Engineers

Association of Professional Engineers of Ontario

Product Development and Management Association

Nick R. Schott, PhD, MS, BS (ChE), PE

University of Massachusetts—Lowell Professor of Plastics Engineering & Plastics Department Head (Retired)

Plastics Institute of America

Secretary & Director for Educational and Research Programs



MOMENTUM PRESS

Momentum Press, LLC, New York

PREFACE

This book, as a four-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 for example to gain understanding of the advantages of different materials and product shapes. 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 tool maker (mold, die, 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 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 four 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 four 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/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 and/or fabricated can directly or indirectly be related to products reviewed in this book. Important are behaviors associated with and interrelated with the many different plastics materials (thermoplastics, thermosets, 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 that total about 35000 different types. Unfortunately, as with other materials, a single plastic material does not exist that will meet all performance requirements. However, more so than with any other materials, there is a plastic that can be used to meet practically any product requirement(s). 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 small to large and simple to complex shaped products. 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 that can exist, 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/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 that profitably and successfully meet high quality, consistency, and long-life standards. All that is needed is to understand the behavior of plastics and properly apply these behaviors.

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 freely. While the information presented represents useful information that can be studied or

analyzed and is believed to be true and accurate, neither the authors, contributors, reviewers, nor the publisher can accept any legal responsibility for any errors, omissions, inaccuracies, or other factors. Information is provided without warranty of any kind. No representation as to accuracy, usability, or results should be inferred.

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, 2010

ABOUT THE EDITORS

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 plus 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, MBA at Northeastern University, MS in plastics engineering from University of Massachusetts Lowell, and PhD in business administration at University of California, Berkeley.

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

writing background authoring or editing numerous papers and major books, including the *Concise Encyclopedia of Plastics*, *Injection Molding Handbook 3rd ed.*, and the *Plastics Institute of America Plastics Engineering, Manufacturing and Data Handbook*. A senior member of the Canadian Society of Chemical Engineering and the Association of Professional Engineers of Canada, Ms. Rosato is a licensed professional engineer of Ontario, Canada. She received a Bachelor of Applied Science in chemical engineering from the University of British Columbia with continuing education at McGill University in Quebec, Queens University and the University of Western Ontario both in Ontario, Canada, and also has extensive executive management training.

Professor Nick Schott, a long-time member of the world-renowned University of Massachusetts Lowell Plastics Engineering Department faculty, served as its department head for a quarter of a century. Additionally, he founded the Institute for Plastics Innovation, a research consortium affiliated with the university that conducts research related to plastics manufacturing, with a current emphasis on bioplastics, and served as its director from 1989 to 1994. Dr. Schott has received numerous plastics industry accolades from the SPE, SPI, PPA, PIA, as well as other global industry associations and is renowned for the depth of his plastics technology experience, particularly in processing-related areas. Moreover, he is a quite prolific and requested industry presenter, author, patent holder, and product/process developer, in addition to his quite extensive and continuing academic responsibilities at the undergraduate to postdoctoral level. Among America's internationally recognized plastics professors, Dr. Nick R. Schott most certainly heads everyone's list not only within the 2500 plus global UMASS Lowell Plastics Engineering alumni family, which he has helped grow, but also in broad global plastics and industrial circles. Professor Schott holds a BS in ChE from UC Berkeley, and an MS and PhD from the University of Arizona.

CONTENTS

LIST OF FIGURES	10
LIST OF TABLES	13
PREFACE	15
ABOUT THE EDITORS	18
7.THERMOFORMING	1141
INTRODUCTION	1141
Process	1144
Growth	1146
Product	1146
OPERATING BASICS	1147
Forming Pressure	1151
Controlling Pressure	1152
Mold Construction	1154
Sheet Prestretch	1156
PLASTIC	1159
Overview	1159
Property/Performance	1163
Plastics Thermal Expansion	1164
Thermoforming Polypropylene	1166
Thermoforming Reinforced Plastic	1167
HEATING	1167
Heating Method	1173
Heat Control	1176
Heater Type	1177
Annealing	1177

COOLING	1180
Heat-Transfer Requirement	1181
EQUIPMENT	1182
Function	1189
MOLD	1190
Overview	1190
Detail	1191
Design	1192
Material of Construction	1194
PROCESSING	1195
Processing Phase	1199
Process Control	1200
Vacuum Forming	1200
Pressure Forming	1201
Vacuum/Air Pressure Forming	1203
Blow Forming	1203
Drape Forming	1204
Drape Vacuum Forming	1205
Drape Vacuum-Assisted Frame Forming	1205
Drape with Bubble Stretching Forming	1206
Snap-Back	1206
Plug-Assisted Forming	1206
Plug-Assisted and Ring Forming	1210
Ridge Forming	1210
Billow Forming	1211
Billow Plug-Assisted Forming	1211
Billow-Up Vacuum Snap-Back	1213
Billow Snap-Back Forming	1213
Air-Slip Forming	1214
Air-Slip Plug-Assisted Forming	1214
Blister Package Forming	1214
Draw Forming	1214
Dip Forming	1215
Form, Fill, and Seal	1217
Form, Fill, and Seal vs. Preform	1217
Form, Fill, and Seal with Zipper In-Line	1217
Multiple-Step Forming	1218
Matched Mold Forming	1218
Mechanical Forming	1219
Forging Forming	1219

Twin-Sheet Forming	1219
Cold Forming	1221
Comoform Cold Forming	1222
Shrink-Wrap Forming	1222
Scrapless Forming	1222
Forming and Spraying	1222
Postforming	1222
Bend Forming	1223
TRIMMING/SECONDARY EQUIPMENT	1224
DESIGN	1229
Overview	1229
Tolerance	1230
Plastics Memory	1231
TROUBLESHOOTING	1232
SUMMARY	1232

FIGURES

Figure 7.1	Examples of thermoforming methods	1142–1143
Figure 7.2	Thermoformed TPO front bumper fascia for a Colombian-built Renault car (551)	1147
Figure 7.3	Thermoformed TPO truck fender (551)	1147
Figure 7.4	Thermoformed Bayer's Triax nylon/ABS auto panel heat sag test results (552)	1148
Figure 7.5	Thermoformed automotive gasoline tank	1148
Figure 7.6	Thermoformed electronic printer housings	1149
Figure 7.7	Thermoformed polystyrene foam food container	1149
Figure 7.8	SPE Thermoformed Div. 2001 product award winners (553)	1150
Figure 7.9	Influence of plug profile on sheet thinning	1157
Figure 7.10	Effect of plug prestretch timing on the crush resistance of cups thermoformed from Fina-pro PPH 4042 S polypropylene homopolymer (221)	1158
Figure 7.11	(1) In-line high-speed sheet extruder feeding a rotary thermoformer and (2) view of the thermoforming drum (courtesy of Welex/Irwin)	1161
Figure 7.12	In-line high-speed sheet extruder feeding a stamping/trimming thermoformer (courtesy of Brown Machinery)	1162
Figure 7.13	Example of applying uniform heat to a sheet that will be vacuum formed	1168
Figure 7.14	Example of shielding from heat a section on the sheet that will remain flat after thermoforming	1168
Figure 7.15	Relatively uniform curved lines indicate a uniform thermoformed wall thickness	1170

Figure 7.16	Process phases for thermoforming polypropylene	1172
Figure 7.17	Effect of sheet-forming temperature on the crush resistance of cups thermoformed from Fina-pro polypropylenes	1173
Figure 7.18	Schematic of roll-fed thermoforming line	1182
Figure 7.19	Schematic of simplified in-line thermoforming line	1183
Figure 7.20	Schematic of in-line thermoforming line including auxiliary equipment	1183
Figure 7.21	Schematic of rotating clockwise three-stage machine	1183
Figure 7.22	View of a rotating clockwise three-stage machine midway in being manufactured	1184
Figure 7.23	View of a rotating clockwise three-stage machine	1185
Figure 7.24	View of a rotating clockwise five-stage machine (courtesy of Wilmington Machinery)	1186
Figure 7.25	Rotary thermoformer (courtesy of Welex Inc.)	1187
Figure 7.26	Compact in-line sheet extrusion thermoforming machine provides more heat retention for the thermoformer (courtesy of Welex Inc.)	1187
Figure 7.27	Thermoforming machine starts with a plastic extruded tube, flattens it with rolls, then forms the molds on a rotary wheel (courtesy of Brown Machinery)	1188
Figure 7.28	Example of the cost of equipment compared to the forming line output	1189
Figure 7.29	Comparison of vacuum and pressure-forming processes	1198
Figure 7.30	Views of vacuum thermoforming	1202
Figure 7.31	Basic pressure-forming process	1203
Figure 7.32	Example of pressure-vacuum thermoforming	1204
Figure 7.33	Examples of drape forming	1205
Figure 7.34	Examples of snap-back processing	1207
Figure 7.35	Examples of plug-assisted processes	1208–1209
Figure 7.36	Examples of billow process	1212
Figure 7.37	Example of air-slip process	1215
Figure 7.38	Example of blister packages being thermoformed on a shuttle-type mold operation	1216
Figure 7.39	Examples of card pack blister packages	1216
Figure 7.40	Example of matched mold process	1219
Figure 7.41	Examples of twin-sheet process	1220
Figure 7.42	Example of compression action for the cold forming process	1221

Figure 7.43	Forming occurs after a shot of melted plastic is injection molded into the forming cavity (chapter 4)	1223
Figure 7.44	Dow's COFO process heats and forms plastic blanks	1224
Figure 7.45	Example of Dow's SFP process going from an extruder to the formed products	1225
Figure 7.46	Thermoformed plastic backed up with sprayed reinforced plastics	1226
Figure 7.47	Examples of thermoforming and trimming in the same mold	1227
Figure 7.48	Example of coextruded sheet with scrap used on the sides	1229

TABLES

Table 7.1	Options available in thermoforming processes	1143
Table 7.2	Introduction to some of the thermoforming processes	1144
Table 7.3	Thin-gauge and thick-gauge thermoforming materials	1145
Table 7.4	Comparison of pressure scales for thermoforming	1153
Table 7.5	Pressure measurements comparing gauge, absolute, and inches of mercury	1154
Table 7.6	Formula to determine the vacuum surge tank size in cubic feet	1155
Table 7.7	Forming temperature profiles for various plastics	1159
Table 7.8	Examples of coefficients of thermal expansion for different materials	1165
Table 7.9	Typical solid-phase forming conditions for selected types of polypropylene	1167
Table 7.10	Thermoformed mold and plastic temperature processing guide	1169
Table 7.11	Thermal conductivity and other thermal properties of a few plastics	1171
Table 7.12	Examples of the range of temperatures and specific heats required for thermoforming	1174
Table 7.13	Examples of types of radiant heating elements	1175
Table 7.14	Examples of different types of heaters	1178
Table 7.15	Comparison of thermoformer heaters	1179
Table 7.16	Examples of different thermoforming processes	1196
Table 7.17	Guide to determine size of cut sheet and draw ratio	1197
Table 7.18	Comparison of product behavior in solid-phase and melt-phase thermoforming	1200