CHARLES A. HARPER

# Handbook of Plastics, Elastomers, and Composites Third Edition

### Library of Congress Cataloging-in-Publication Data

Handbook of plastics, elastomers, and composites / Charles A. Harper, editor-in-chief. —3rd ed.

p. cm. Includes index. ISBN 0-07-026693-X

1. Plastics—Handbooks, manuals, etc. 2. Elastomers—Handbooks, manuals, etc. 1. Harper, Charles A.

TP1130.H36 1996

668.4—dc20

96-20787 CIP

### McGraw-Hill

A Division of The McGraw-Hill Companies

Copyright © 1996, 1992, 1975 by The McGraw-Hill Companies, Inc. All rights reserved. Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or retrieval system, without the prior written permission of the publisher.

4567890 DOC/DOC 9098765

ISBN 0-07-026693-X

The sponsoring editor for this book was Zoe G. Faundotos, the editing supervisor was Sheila Gillams, and the production supervisor was Don Schmidt. This book was set in Times Roman. It was composed by North Market Street Graphics.

Printed and bound by R. R. Donnelley & Sons Company.

This book is printed on acid-free paper.

Information contained in this work has been obtained by The McGraw-Hill Companies, Inc. ("McGraw-Hill") from sources believed to be reliable. However, neither McGraw-Hill nor its authors guarantee the accuracy or completeness of any information published herein, and neither McGraw-Hill nor its authors shall be responsible for any errors, omissions, or damages arising out of use of this information. This work is published with the understanding that McGraw-Hill and its authors are supplying information but are not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought.

## **CONTENTS**

Contributors ix Preface xi

### Chapter 1. Fundamentals of Plastics and Elastomers

1.1

- 1.1 Introduction / 1.1
- 1.2 The Nature of Plastics / 1.1
- 1.3 Polymer Structures and Polymerization Reactions / 1.2
- 1.4 Plastic-Processing Methods and Design Guidelines / 1.5
- 1.5 Plastic Properties / 1.13
- 1.6 Thermosetting Plastics / 1.22
- 1.7 Thermoplastics / 1.37
- 1.8 Glass-Fiber-Reinforced Thermoplastics / 1.69
- 1.9 Plastic Films and Tapes / 1.69
- 1.10 Plastic Surface Finishing / 1.71
- 1.11 Summary of Plastics / 1.72
- 1.12 The Nature of Elastomers / 1.75

References / 1.86

### Chapter 2. Laminates and Reinforced Plastic Materials and Processes

- 2.1 Laminates / 2.1
- 2.2 Reinforced Plastics / 2.39
- 2.3 Manufacturing Processes for Reinforced Plastics / 2.45
- 2.4 Standards / 2.55

References / 2.64

### Chapter 3. Advanced Composite Materials and Processes

3.1

- 3.1 Introduction / 3.1
- 3.2 Material Systems / 3.4
- 3.3 Composite Fabrication Techniques / 3.29
- 3.4 Overview of Mechanics of Composite Materials / 3.52
- 3.5 Design of Composites / 3.54
- 3.6 Composite Testing / 3.64
- 3.7 Safety Issues with Composite Materials / 3.69

References / 3.72

vii

CONTENTS

Chapter 4. Liquid and Low-Pressure Resin Systems	4.1	7.4 Surface Preparation for Adhesive Bonding / 7.28 7.5 Types of Adhesives / 7.50	
4.1 Introduction / 4.1 4.2 Epoxies / 4.9 4.3 Polyesters / 4.23 4.4 Polyurethanes / 4.30 4.5 Silicones / 4.37 4.6 Cast Phenolics / 4.42 4.7 Allylic Resins / 4.46 4.8 Polybutadienes / 4.52		7.6 Selecting an Adhesive / 7.64, 7.7 Methods of Welding Polymeric Substrates / 7.69 7.8 Methods of Mechanical Joining / 7.78 7.9 Recommended Processes for Common Polymeric Substrates / 7.84 7.10 Effect of Environment / 7.87 7.11 Processing and Quality Control / 7.94 References / 7.101	
<ul><li>4.9 Depolymerized Rubber / 4.56</li><li>4.10 Polysulfide Rubber / 4.57</li></ul>		Chapter 8. Plastics in Packaging	8.1
4.11 Ethylene-Propylene Liquid Polymers / 4.58 4.12 Cast Nylon / 4.58 4.13 Acrylics / 4.60 4.14 Vinyl Plastisols / 4.62 4.15 Cyclic Thermoplastics / 4.63 4.16 Expanding Monomer / 4.64 4.17 Vinyl Esters / 4.64		<ul> <li>8.1 Packaging Plastics / 8.3</li> <li>8.2 Properties of Packaging Plastics / 8.17</li> <li>8.3 Mass Transfer in Polymeric Packaging Systems / 8.30</li> <li>References / 8.61</li> </ul>	
4.18 Cyanate Esters / 4.64 4.19 Photopolymers / 4.67 References / 4.67		Chapter 9. Elastomers and Engineering Thermoplastics for Automotive Applications	9.1
		<ul><li>9.1 Introduction / 9.1</li><li>9.2 Elastomers and Plastics / 9.2</li></ul>	
5.1 Introduction / 5.1 5.2 TPEs in the Rubber and Plastics Industries / 5.2 5.3 Comparison of TPEs and Thermoset Rubbers / 5.5 5.4 Chemistry, Morphology, and Properties of TPEs / 5.8 5.5 Generic Classes of TPEs / 5.11 5.6 Processing of TPEs / 5.27 5.7 Applications and Markets for TPEs / 5.37 5.8 The Recovery and Recycle of TPEs / 5.39 5.9 Acknowledgments / 5.40 References / 5.40	5.1	9.3 Why Use Elastomers? / 9.3 9.4 Why Use Plastics? / 9.3 9.5 The Importance of Material Selection / 9.4 9.6 Engineering the Automobile / 9.5 9.7 Automotive Elastomers / 9.12 9.8 Automotive Engineering Thermoplastics / 9.25 9.9 Selection Protocol for Automotive Elastomers and Plastics / 9.31 9.10 Specification and Testing of Elastomers / 9.35 9.11 Conclusion—A Look to the Future / 9.39 References / 9.39	
		Chapter 10. Design and Processing of Plastic Parts	10.1
6.1 Introduction / 6.1 6.2 Ecology / 6.3 6.3 Surface Preparation / 6.4 6.4 Coating Selection / 6.6 6.5 Coating Materials / 6.8 6.6 Application Methods / 6.27 6.7 Curing / 6.41 6.8 Summary / 6.43 References / 6.45	6.1	10.1 Introduction / 10.1 10.2 Design Procedure / 10.1 10.3 Prototyping / 10.2 10.4 Processes for Producing Plastic Parts / 10.3 10.5 Assembly and Machining Guidelines / 10.19 10.6 Postmolding Operations / 10.23 10.7 Process-Related Design Considerations / 10.26 10.8 Mold Construction and Fabrication / 10.31 10.9 Summary / 10.33	
		Chapter 11. Recycling of Plastic Materials	11.1
Chapter 7. Joining of Plastics, Elastomers, and Composites  7.1 Introduction / 7.1 7.2 Design of Joints / 7.11 7.3 Test Methods / 7.19	7.1	<ul> <li>11.1 Introduction / 11.1</li> <li>11.2 Polyethylene Terephthalate (PET) Recycling / 11.14</li> <li>11.3 High-Density Polyethylene (HDPE) Recycling / 11.21</li> <li>11.4 Low-Density Polyethylene (LDPE) Recycling / 11.24</li> <li>11.5 Polystyrene (PS) Recycling / 11.26</li> </ul>	

			•
**	1		
v	ц	1	

### CONTENTS

11.6 Polypropylene (PP) Recycling / 11.28 11.7 Polyvinyl Chloride (PVC) Recycling / 11.30	
11.8 Recycling of Commingled Plastics / 11.32 11.9 Recycling of Thermosets / 11.34	
11.10 Recycling of Automotive Plastics / 11.36	
11.11 Recycling of Other Thermoplastics / 11.38	
11.12 Sorting, Separation, and Compatibilization of Plastics / 11.39	
11.13 Thermal Recycling / 11.44	
11 14 Design Issues / 11.45	
11.15 The Future of Plastics Recycling / 11.48	
References / 11.50	
Further Reading / 11.54	
Appendix A. Glossary of Terms and Definitions	A.1
Appendix B. Some Common Abbreviations Used in the Plastics Industry	B.1
	B.1 C.1
Industry	

### Index I.1

# **CONTRIBUTORS**

Leonard S. Buchoff Elastomeric Technologies, Inc., Hatboro, Pennsylvania. (CHAP. 4)

Ruben Hernandez The School of Packaging, East Lansing, Michigan (CHAP. 8)

John L. Hull Hull Corporation, Hatboro, Pennsylvania. (CHAP. 10)

Carl P. Izzo Industry Consultant, Export, Pennsylvania. (CHAP. 6)

Joseph F. Meier Industry Consultant, Export, Pennsylvania. (CHAP. 1)

Stanley T. Peters Process Research, Mountain View, California (CHAP. 3)

**Edward M. Petrie** ABB Transmission Technology Institute, Raleigh, North Carolina. (CHAP. 7)

 $\textbf{Charles P. Rader} \quad \textit{Advanced Elastomer Systems, L.P., Akron, Ohio} \ (\textbf{CHAP. 5})$ 

Ronald N. Sampson Technology Seminars, Pittsburgh, Pennsylvania. (CHAP. 2)

Susan E. Selke The School of Packaging, East Lansing, Michigan (CHAP. 11)

Ronald Toth Chrysler Corporation, Dearborn, Michigan (CHAP. 9)