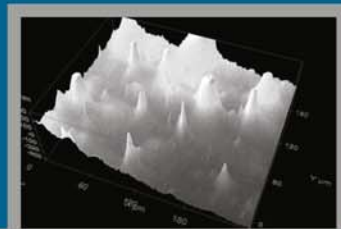


Printing on Polymers

Fundamentals and Applications



Edited by:
Joanna Izdebska
Sabu Thomas



PRINTING ON POLYMERS



PLASTICS DESIGN LIBRARY (PDL)

PDL HANDBOOK SERIES

Series Editor: Sina Ebnesajjad, PhD (sina@FluoroConsultants.com)

President, FluoroConsultants Group, LLC

Chadds Ford, PA, USA

www.FluoroConsultants.com

The **PDL Handbook Series** is aimed at a wide range of engineers and other professionals working in the plastics industry, and related sectors using plastics and adhesives.

PDL is a series of data books, reference works and practical guides covering plastics engineering, applications, processing, and manufacturing, and applied aspects of polymer science, elastomers and adhesives.

Recent titles in the series

Biopolymers: Processing and Products, Michael Niaounakis (ISBN: 9780323266987)

Biopolymers: Reuse, Recycling, and Disposal, Michael Niaounakis (ISBN: 9781455731459)

Carbon Nanotube Reinforced Composites, Marcio Loos (ISBN: 9781455731954)

Extrusion, 2e, John Wagner & Eldridge Mount (ISBN: 9781437734812)

Fluoroplastics, Volume 1, 2e, Sina Ebnesajjad (ISBN: 9781455731992)

Handbook of Biopolymers and Biodegradable Plastics, Sina Ebnesajjad (ISBN: 9781455728343)

Handbook of Molded Part Shrinkage and Warpage, Jerry Fischer (ISBN: 9781455725977)

Handbook of Polymer Applications in Medicine and Medical Devices, Kayvon Modjarrad & Sina Ebnesajjad (ISBN: 9780323228053)

Handbook of Thermoplastic Elastomers, Jiri G Drobny (ISBN: 9780323221368)

Handbook of Thermoset Plastics, 2e, Hanna Dodiuk & Sidney Goodman (ISBN: 9781455731077)

High Performance Polymers, 2e, Johannes Karl Fink (ISBN: 9780323312226)

Introduction to Fluoropolymers, Sina Ebnesajjad (ISBN: 9781455774425)

Ionizing Radiation and Polymers, Jiri G Drobny (ISBN: 9781455778812)

Manufacturing Flexible Packaging, Thomas Dunn (ISBN: 9780323264365)

Plastic Films in Food Packaging, Sina Ebnesajjad (ISBN: 9781455731121)

Plastics in Medical Devices, 2e, Vinny Sastri (ISBN: 9781455732012)

Polylactic Acid, Rahmat et al. (ISBN: 9781437744590)

Polyvinyl Fluoride, Sina Ebnesajjad (ISBN: 9781455778850)

Reactive Polymers, 2e, Johannes Karl Fink (ISBN: 9781455731497)

The Effect of Creep and Other Time Related Factors on Plastics and Elastomers, 3e, Laurence McKeen (ISBN: 9780323353137)

The Effect of Long Term Thermal Exposure on Plastics and Elastomers, Laurence McKeen (ISBN: 9780323221085)

The Effect of Sterilization on Plastics and Elastomers, 3e, Laurence McKeen (ISBN: 9781455725984)

The Effect of Temperature and Other Factors on Plastics and Elastomers, 3e, Laurence McKeen (ISBN: 9780323310161)

The Effect of UV Light and Weather on Plastics and Elastomers, 3e, Laurence McKeen (ISBN: 9781455728510)

Thermoforming of Single and Multilayer Laminates, Ali Ashter (ISBN: 9781455731725)

Thermoplastics and Thermoplastic Composites, 2e, Michel Biron (ISBN: 9781455778980)

Thermosets and Composites, 2e, Michel Biron (ISBN: 9781455731244)

To submit a new book proposal for the series, or place an order, please contact David Jackson, Acquisitions Editor
david.jackson@elsevier.com

PRINTING ON POLYMERS

Fundamentals and Applications

Joanna Izdebska

Sabu Thomas



ELSEVIER

Amsterdam • Boston • Heidelberg • London • New York • Oxford
Paris • San Diego • San Francisco • Singapore • Sydney • Tokyo

William Andrew is an imprint of Elsevier



William Andrew is an imprint of Elsevier
The Boulevard, Langford Lane, Kidlington, Oxford, OX5 1GB, UK
225 Wyman Street, Waltham, MA 02451, USA

Copyright © 2016 Elsevier Inc. All rights reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. Details on how to seek permission, further information about the Publisher's permissions policies and our arrangements with organizations such as the Copyright Clearance Center and the Copyright Licensing Agency, can be found at our website: www.elsevier.com/permissions.

This book and the individual contributions contained in it are protected under copyright by the Publisher (other than as may be noted herein).

Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

ISBN: 978-0-323-37468-2

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data

A catalog record for this book is available from the Library of Congress

For information on all William Andrew publications
visit our website at <http://store.elsevier.com/>



Publisher: Matthew Deans

Acquisition Editor: David Jackson

Editorial Project Manager: Peter Gane

Production Project Manager: Susan Li

Designer: Mark Rogers

Typeset by TNQ Books and Journals

www.tnq.co.in

Printed and bound in the United States of America

Contents

Contributors	xvii
Preface	xix
1 Printing on Polymers: Theory and Practice	1
<i>Joanna Izdebska</i>	
1.1 Introduction—The Impact of Printing.....	1
1.2 Printing Techniques	2
1.2.1 Flat Printing	3
1.2.2 Relief Printing.....	4
1.2.3 Gravure Printing.....	5
1.2.4 Stencil Printing	5
1.2.5 Digital Printing	6
1.2.6 Three-Dimensional Printing	7
1.2.7 Hybrid Printing	7
1.2.8 Various Printing Techniques for Polymer Decoration	7
1.3 Printing Bases	7
1.3.1 Films.....	9
1.3.2 Multilayer Films	10
1.3.3 Semirigid and Rigid Plastic Sheets	10
1.3.4 Injection Molded Products.....	11
1.3.5 Synthetic Papers and Polymer-Coated Boards.....	11
1.4 Printability.....	11
1.5 Surface Wettability	12
1.5.1 Surface Tension of Inks	12
1.5.2 Surface Free Energy of Printing Substrates	13
1.5.2.1 Devices for Measurement of the Contact Angle.....	13
1.5.2.2 Measurement Liquid, Pens, etc.	14
1.6 Print Quality.....	15
1.6.1 Factors of Printing Processes Influencing the Print Quality	15
1.6.2 Impact of Ink and Substrate Properties on the Print Quality	15
1.6.3 Parameters Used in Quality Assessment	16
1.7 Plastic Printing Industry	17
References.....	18
2 Polymeric Materials—Structure, Properties, and Applications.....	21
<i>C.V. Pious and Sabu Thomas</i>	
2.1 Introduction.....	21
2.2 Structure of a Polymer.....	25
Configuration.....	25
Conformation.....	26

2.2.1	Classification of Polymers	26
2.2.1.1	Crystalline and Amorphous Polymers.....	26
2.2.1.2	Thermoplastics and Thermosetting Plastics	26
2.2.1.3	Homopolymers and Copolymers	27
2.2.2	Designing the Structure of Polymers	27
2.3	Properties of Polymers.....	28
2.3.1	Thermal Properties.....	28
2.3.1.1	Thermal Transitions of Polymers	28
2.3.1.2	Thermal Stability of Polymers	29
2.3.1.3	Coefficient of Thermal Expansion and Thermal Conductivity.....	29
2.3.2	Mechanical Properties.....	31
2.3.3	Electrical Properties of Polymers	32
2.3.4	Polymer Blends.....	32
2.3.5	Polymer Composites	33
2.3.6	Polymer Nanocomposites	33
2.4	Application of Polymers	33
2.4.1	Application of Commodity Polymers.....	33
2.4.1.1	Polyethylene.....	34
2.4.1.2	Polypropylene	34
2.4.1.3	Polyvinylchloride	35
2.4.1.4	Polystyrene.....	35
2.4.2	Applications of Engineering Polymers.....	35
2.4.2.1	Polyamides	35
2.4.2.2	Polybutylene Terephthalate.....	35
2.4.2.3	Acrylonitrile Butadiene Styrene	36
2.4.2.4	Polyoxymethylene or Polyacetals.....	36
2.4.3	Polymers for Specialty Applications.....	36
2.4.3.1	Polymers in Electronic Applications.....	37
2.4.3.2	Biomedical Applications	37
2.4.3.3	Polymers in Sensor Applications.....	37
2.5	Conclusion	37
	References.....	37
3	Printing Ink Formulations	41
	<i>Alexandra Pekarovicova and Veronika Husovska</i>	
3.1	Introduction.....	41
3.2	Individual Ink Components	42
3.2.1	Pigments.....	42
3.2.2	Polymers/Resins.....	44
3.2.3	Solvents.....	46
3.2.4	Additives	47
3.3	Inks Manufacture	47
3.4	Selected Inks for Individual Printing Processes.....	48
3.4.1	Inkjet Ink.....	48
3.4.2	Flexographic Inks.....	49
3.5	Functional Inks	50
3.6	Summary	52
	References.....	52

4 Additives for Ink Manufacture.....	57
<i>Zuzanna Żółek-Tryznowska</i>	
4.1 Definition of an Additive.....	57
4.2 Surfactants: Wetting and Dispersing Agents.....	58
4.2.1 Antifoaming Agents.....	59
4.3 Adhesion Promoters.....	59
4.4 Waxes.....	60
4.5 Driers.....	61
4.6 Rheology Modifier.....	61
4.7 Other Additives.....	61
4.7.1 Antioxidants and Antiskinning Agents.....	62
4.7.2 Alkalis.....	62
4.7.3 Biocides and Fungicides.....	62
4.7.4 Chelating Agents.....	62
4.7.5 Deodorants.....	62
4.8 Additives for Radiation-Curing Inks.....	62
4.9 Performance Additives.....	63
4.9.1 Ionic Liquids.....	63
4.9.2 Hyperbranched Polymers.....	63
References.....	65
5 Advanced Nanoscale Materials for Ink Manufacture	67
<i>Bin Bao, Fengyu Li and Yanlin Song</i>	
5.1 Introduction.....	67
5.2 Nanoscale Materials for Ink Manufacture.....	68
5.2.1 Functional Polymer Inks.....	68
5.2.1.1 Monodispersed Polymer Nanoparticle Latexes.....	68
5.2.1.2 Semiconductive and Conductive Polymer Suspensions.....	70
5.2.2 Inorganic Nonmetallic Inks.....	72
5.2.2.1 Ceramic Nano-Inks.....	73
5.2.2.2 Semiconductor Quantum Dot Inks.....	74
5.2.2.3 MOF Inks.....	76
5.2.2.4 Carbon Family Nano-Inks.....	76
5.2.3 Metal Nanomaterials.....	80
5.2.3.1 Metal Nanoparticle Inks.....	80
5.2.3.2 Metal Nanowire Inks.....	81
5.3 Conclusions and Outlook.....	82
References.....	82
6 Rheology of Printing Inks.....	87
<i>Zuzanna Żółek-Tryznowska</i>	
6.1 Newtonian and Non-Newtonian Fluids.....	87
6.1.1 Newtonian Fluids.....	87
6.1.2 Non-Newtonian Fluids.....	88
6.1.2.1 Shear-Thinning Flow Behavior.....	88
6.1.2.2 Shear-Thickening Flow Behavior.....	89

6.1.2.3	Power-Law Model.....	89
6.1.2.4	Shear Viscosity	89
6.1.2.5	Thixotropy.....	89
6.1.2.6	Viscoelasticity	90
6.1.3	Measurements of Flow Behavior.....	90
6.1.3.1	Flow Time	91
6.1.3.2	Flow Curve.....	91
6.1.3.3	Rational Rheometers with Concentric Cylinder Geometry	92
6.1.3.4	Rational Rheometers with Cone to Plate Geometry.....	92
6.1.4	Tack of Paste Inks.....	93
6.1.5	Low-Viscosity Printing Inks	93
6.1.5.1	Flexographic Printing Inks	93
6.1.5.2	Gravure Printing Inks	96
6.1.5.3	Inkjet Printing Inks	97
6.1.6	Paste Inks	97
6.1.6.1	Offset Printing Inks.....	97
6.1.6.2	Screen Printing Inks.....	97
6.1.6.3	Pad Printing Inks.....	98
6.1.7	Flow Behavior and Printability	98
	References.....	98
7	Low-Pressure Plasma-Assisted Polymer Surface Modifications.....	101
	<i>Alenka Vesel and Miran Mozetič</i>	
7.1	Low-Pressure Oxygen Plasma.....	101
7.2	Reactive Plasma Species and their Interaction with Polymers for Printing.....	104
7.2.1	UV Radiation	104
7.2.2	Free Electrons and Negatively Charged Ions.....	105
7.2.3	Positively Charged Molecular and Atomic Ions	105
7.2.4	Neutral Oxygen Atoms	105
7.2.5	Metastables and Ozone	105
7.2.6	Fluxes or Reactive Particles onto Polymer Surface.....	106
7.3	Flowing Afterglow	107
7.4	Peculiarities of Particular Polymers	108
7.4.1	Polyethylene Terephthalate (PET).....	109
7.4.2	Polystyrene (PS).....	112
7.4.3	Polypropylene (PP) and Polyethylene (PE)	113
7.4.4	Polyvinyl Chloride (PVC)	114
7.4.5	Polyamide (PA6)	115
7.5	Etching, Nanostructuring, and Wettability	116
7.6	Concluding Remarks.....	118
	References.....	118
8	Corona Treatment.....	123
	<i>Joanna Izdebska</i>	
8.1	Corona Discharge Treatment: Introduction.....	123
8.1.1	Treatment	125
8.1.2	Factors Influencing the Course and Effectiveness of Treatment	126

8.1.3	Changes in the Upper Layer.....	127
8.1.4	Methods Controlling the Correctness of the Upper Layer Modification	128
8.2	Surface Changes, Film Wettability, and Printability.....	129
8.2.1	Topography and Morphology	129
8.2.2	Surface Chemistry.....	130
8.2.3	Contact Angle	130
8.2.4	Printability.....	132
8.3	Peculiarities of Particular Polymers	133
8.3.1	Polypropylene	133
8.3.2	Polyethylene.....	135
8.3.3	Polyethylene Terephthalate.....	136
8.3.4	Polyvinyl Chloride.....	136
8.3.5	Ethylene Vinyl Acetate.....	137
8.3.6	Polystyrene.....	137
8.3.7	Poly lactide.....	137
8.4	Aging Process of Corona-Treated Films	138
8.5	Concluding Remarks.....	139
	References.....	139
9	Polymer Surface Modifications by Coating	143
	<i>Kazuhisa Tsuji, Tomoki Maeda and Atsushi Hotta</i>	
9.1	Organic Modifications of Polymer Surface.....	143
9.1.1	Photo-Grafting Polymerizations by Photo-Initiators.....	144
9.1.2	Initiated Chemical Vapor Deposition	146
9.1.3	UV-Curable Polymer Coating.....	146
9.1.4	Photo-Grafting Polymerization from the Layer of Photo-Iniferters	147
9.1.5	Applications of Organic Modifications	148
9.2	Inorganic Coating	149
9.2.1	Plasma-Enhanced Chemical Vapor Deposition.....	149
9.2.2	Magnetron Sputtering	150
9.2.3	Diamond-Like Carbon, SiO _x , and Oxide Coatings.....	150
9.2.4	Wettability and Other Properties for the Industrial Applications.....	151
9.3	Metallurgical Coating	153
9.3.1	Chemical Electro-Less Plating Techniques.....	153
9.3.2	Vapor Plating Techniques	153
9.3.3	Additional Properties by Metallurgical Coatings on Polymers	153
	References.....	154
10	Other Methods of Polymer Surface Modifications	161
	<i>H.Y. Zheng, Y.C. Guan, K. Liu, Z.K. Wang and S.M. Yuan</i>	
10.1	Introduction.....	161
10.2	Laser Beam Processing for Polymer Surface Modifications	162
10.2.1	Femtosecond Laser Textured PMMA Surfaces for Wettability Modification.....	162
10.2.1.1	Laser-Induced Surface Hydrophilicity and Hydrophobicity.....	162
10.2.1.2	Laser-Induced Wettability Modification of Microfluidic Channels for Fluid Flow Control.....	164
10.2.2	Ar ⁺ Laser-Induced Surface Relief Gratings on Azo-Polymers.....	166
10.2.3	Laser Micromachining Silicon Surface for Replication on Polymer Surface.....	168

10.3	Micromachining	169
10.3.1	Conventional CNC Micromachining	170
10.3.2	Ultra-Precision Micromachining	171
10.4	Other Energy Beam Processing Techniques	176
	References.....	177
11	Flexographic Printing.....	179
	<i>Joanna Izdebska</i>	
11.1	Fundamentals of Flexographic Printing	179
11.1.1	Basic Principle	179
11.1.2	Printing Plates	179
11.1.3	Anilox Rollers.....	183
11.1.4	Printing Units	186
11.1.5	Printing Machines	187
11.2	Production Materials.....	189
11.2.1	Inks.....	189
11.2.1.1	Water-Based Ink.....	190
11.2.1.2	Solvent-Based Ink.....	190
11.2.1.3	UV-Curable Ink.....	191
11.2.2	Plastic Substrates	191
11.2.2.1	Films.....	192
11.2.2.2	Laminates	192
11.2.3	Requirements for the Plastic Substrate	193
11.3	Flexographic Printing Benefits	193
11.4	Flexographic Market and its Future	194
	References.....	195
12	Gravure Printing.....	199
	<i>Rozalia Szentgyörgyvölgyi</i>	
12.1	Market of Gravure Printing	199
12.2	Printing Process	200
12.3	Gravure Printing Inks	202
12.4	Gravure Cylinder Manufacturing	204
12.4.1	Electromechanical Engraving	206
12.4.2	Direct Processing of Copper with a Pulsed Laser	208
12.4.3	Direct Laser System with a Zinc Layer	209
12.4.4	Cylinder Manufacturing with Etching, with Laser-Made Masks	210
12.5	Structure of Gravure Printing Presses	210
12.6	Applications and Further Developments	213
	References.....	215
13	Offset Printing.....	217
	<i>Živko Pavlović, Sandra Dedijer, Srđan Draganov, Igor Karlović and Ivana Jurić</i>	
13.1	Fundamentals of Offset Printing	217
13.1.1	Basic Principle	217
13.1.2	Conventional Wet Offset Printing	218
13.1.3	Waterless Offset Printing.....	218

13.1.4	Offset Printing Plates	219
13.1.4.1	Structure of Offset Printing Plates	219
13.1.4.2	CtP Technology.....	219
13.2	Offset Inks.....	220
13.2.1	Oxidation Dried Inks and Drying Method	221
13.2.2	UV Wet Offset and Waterless Offset Inks and Drying Method	222
13.3	Construction of Printing Presses for Offset Printing	223
13.3.1	Sheet-Fed Printing Presses	224
13.3.1.1	Feeding Unit, Transport of Substrate, and Delivery Unit.....	224
13.3.1.2	Inking Unit.....	224
13.3.1.3	UV-Curing Systems	225
13.3.1.4	Waterless Offset Presses	225
13.3.2	Web-Fed Offset Printing Presses	226
13.4	Print Quality Control in Waterless Offset on Polymer Materials.....	226
	References.....	228
14	Inkjet Printing.....	231
	<i>Atasheh Soleimani-Gorgani</i>	
14.1	Fundamentals of Inkjet Printing Technology	231
14.1.1	CIJ Printing Systems.....	232
14.1.2	Drop on Demand Inkjet Printing Systems	232
14.1.2.1	Thermal Inkjet Printing	233
14.1.2.2	Piezoelectric Inkjet Printing	233
14.1.2.3	Electrostatic Inkjet Printing.....	234
14.1.2.4	Acoustic Inkjet Printing.....	236
14.2	Physical and Chemical Properties of Inkjet Printing Inks.....	236
14.2.1	Viscosity.....	236
14.2.2	Surface Tension.....	237
14.2.3	Particle Size	237
14.2.4	Solute Properties	238
14.3	Droplet Ink Behavior on the Substrate.....	239
14.4	Polymer in Inkjet Ink Formulation.....	240
14.5	Polymers as Inkjet Printing Substrate	240
14.6	Future in Inkjet Printing	241
	References.....	241
15	Screen Printing.....	247
	<i>Dragoljub Novaković, Nemanja Kašiković, Gojko Vladić and Magdolna Pál</i>	
15.1	Fundamentals of Screen Printing	247
15.2	Stencil/Plate Making.....	249
15.2.1	Screen Printing Mesh.....	249
15.2.2	Screen Printing Frame	251
15.2.2.1	Screen Printing Frame Materials.....	251
15.2.3	Screen Printing Squeegee	252
15.2.3.1	Squeegee Types.....	252
15.2.4	Screen Printing Emulsion	254

15.3	Imaging, Hand-Cut Stencils, Photostencils, Computer to Screen Systems.....	254
15.3.1	Hand-Cut Stencils	255
15.3.2	Photostencils	255
15.3.3	“Computer to Screen” Systems	257
15.4	Printing Process	258
15.4.1	Flatbed Screen Printing	258
15.4.2	Rotary Screen Printing.....	259
15.4.2.1	Drying Equipment.....	259
15.4.3	Polymer Substrates and Inks	260
15.5	Screen Printing Industry	260
	References.....	261
16	Pad Printing.....	263
	<i>Raša Urbas, Urška Stankovič Elesini, Tomislav Cigula and Sanja Mahović Poljaček</i>	
16.1	History.....	263
16.2	Basics of Pad Printing	264
16.2.1	Printing Form.....	264
16.2.2	Pad.....	264
16.2.3	Printing Ink	264
16.2.4	Pad Printing Machines.....	265
16.3	Basic Elements of Pad Printing.....	265
16.3.1	Printing Form	265
16.3.1.1	Engraving of Printing Forms	265
16.3.1.2	Use of Screen Ruling.....	266
16.3.1.3	Types of Printing Forms	267
16.3.2	Printing Pad.....	270
16.3.2.1	Characteristics of a Printing Pad	270
16.3.3	Printing Inks.....	271
16.3.3.1	Composition of Pad Printing Inks	272
16.3.3.2	Types of Pad Printing Inks	272
16.3.4	Technology of Printing Machines	273
16.3.4.1	Drive Type of Printing Machines	274
16.3.4.2	Inking System of Printing Machines.....	274
16.3.4.3	Multicolor Pad Printing Machines.....	275
16.3.4.4	Special Machine Designs.....	276
16.3.4.5	Accessories of Pad Printing Machines	277
16.4	Application of the Pad Printing.....	277
	References.....	278
17	Embossing Process.....	279
	<i>Shiwei Lin</i>	
17.1	Fundamentals of Embossing.....	279
17.2	Hot Embossing Modes.....	280
17.2.1	P2P Hot Embossing	280
17.2.2	R2P Hot Embossing.....	281
17.2.3	R2R Hot Embossing	282

17.3	Influence of Polymer Performance on Embossing Features.....	282
17.3.1	Thermal Behavior of Polymeric Materials.....	282
17.3.2	Polymer Deformation under Embossing.....	283
17.4	Application Example: R2R Hot Embossing Holographic Images on BOPP Shrink Film.....	284
17.5	Outlook.....	289
	References.....	289
18	3-D Printing.....	293
	<i>Daniel J. Thomas and Timothy C. Claypole</i>	
18.1	Introduction.....	293
18.2	Fundamentals of 3-D Printing.....	295
18.2.1	Fused Deposition Manufacturing.....	295
18.2.2	Stereo Lithography.....	296
18.2.3	Selective Laser Sintering.....	298
18.3	Applications.....	299
18.4	3-D-Printing Process.....	300
18.5	3-D Printable Materials.....	301
18.5	Electrically Conductive Polymers.....	302
18.6	3-D Bioprinting.....	302
18.7	Conclusions.....	305
	References.....	305
19	Theory, Modeling, and Simulation of Printing.....	307
	<i>Ludovic G. Coppel</i>	
19.1	Introduction.....	307
19.2	Measuring and Modeling Reflection Properties for Color Prediction.....	308
19.3	Light Scattering and Absorption.....	308
19.3.1	Surface Scattering.....	309
19.3.2	Bulk Scattering.....	310
19.3.3	Fluorescence.....	312
19.3.4	Monte Carlo Methods.....	314
19.4	Spectral Reflectance Prediction Models for Colored Halftones.....	314
19.4.1	Murray–Davis Model.....	314
19.4.2	Yule–Nielsen Model.....	315
19.4.3	Spectral Neugebauer Model.....	315
19.4.4	Probabilistic Models.....	316
19.4.5	Cellular Implementation.....	317
19.4.6	Fluorescence.....	318
19.4.7	Dot Surface Coverage and Ink Spreading.....	319
19.5	Multilayer Constructions.....	320
19.6	Surface and Interface Reflections.....	321
19.7	Transparent and Translucent Substrates.....	322
19.8	Conclusions.....	324
	Acknowledgment.....	324
	References.....	324

20	Characterization of Print Quality in Terms of Colorimetric Aspects	329
	<i>Michael Dattner and Daniel Bohn</i>	
20.1	Colorimetric Aspects	329
20.1.1	Color Perception	329
20.1.2	Color Measurement.....	333
20.1.3	Spectral Data to CIE Lab Data.....	335
20.1.4	Color Deviation Formulas	336
20.2	Characterization of Print Quality	337
20.2.1	Homogeneity of Unprinted Substrate.....	338
20.2.2	Influence of Ink Transfer	338
20.2.3	Different Materials, Different Perception.....	343
20.2.4	Inline Spectral Measurements for Continuous Quality Control in Terms of Color.....	343
	References.....	344
21	Characterization of Mechanical Properties of Prints.....	347
	<i>Marta Gajadhur</i>	
21.1	Introduction.....	347
21.2	Ink Abrasion Resistance of Polymer Substrates	347
21.2.1	Different Methods of Polymers Abrasion Resistance Testing.....	348
21.2.2	Evaluation Methodology of Printed Polymers Abrasion Resistance.....	349
21.3	Scratch Resistance of Polymer Substrates	351
21.4	Summary	352
	References.....	352
22	Aging and Degradation of Printed Materials	353
	<i>Joanna Izdebska</i>	
22.1	Aging and Degradation: Definitions.....	353
22.2	Models of Artificial Aging	354
22.2.1	Radiation	355
22.2.2	Thermal Aging	356
22.2.3	Chemical Aging	356
22.2.4	Complex Aging.....	356
22.3	Degradation of Polymer Materials	356
22.3.1	Radiation Degradation	356
22.3.2	Chemical Degradation	357
22.3.3	Oxidative Degradation	357
22.3.4	Thermal Degradation	358
22.3.5	Mechanical Degradation	358
22.3.6	Biodegradation	358
22.4	Methods of Testing the Aging Process and Degradation	359
22.4.1	Tests of Polymeric Materials	359
22.4.2	Prints Tests.....	361
22.5	Polymeric Substrate Degradation	362
22.5.1	Polyethylene.....	362
22.5.2	Polypropylene	363
22.5.3	Poly(ethylene terephthalate)	364

22.5.4 Polyamide.....	364
22.5.5 Polystyrene.....	364
22.5.6 Poly(vinyl chloride).....	365
22.5.7 Poly(ethylene-co-vinyl acetate) Copolymer.....	365
22.5.8 Biodegradable Polymers.....	365
22.6 Impact of Radiation Artificial Aging on Print.....	366
22.7 Summary.....	368
References.....	368
23 Applications of Printed Materials.....	371
<i>Joanna Izdebska</i>	
23.1 Introduction.....	371
23.2 Packaging.....	372
23.2.1 Flexible Packaging.....	372
23.2.2 Rigid Packaging.....	375
23.2.3 Food Packaging.....	376
23.2.4 Pharmacy and Personal Care Packaging.....	377
23.2.5 Industrial Packaging.....	379
23.2.6 Packaging Trends.....	379
23.3 Labels.....	380
23.3.1 Glue Applied.....	381
23.3.2 Pressure Sensitive.....	381
23.3.3 In-Mold Labels.....	381
23.3.4 Sleeve Labels.....	382
23.4 Printed Electronics.....	382
23.5 Household Equipment.....	384
23.6 Promotional Gifts and Materials.....	384
23.7 Others.....	384
References.....	385
24 Microcapsules in Printing.....	389
<i>Urška Stankovič Elesini and Raša Urbas</i>	
24.1 Introduction.....	389
24.2 Microcapsules and Microspheres.....	389
24.3 Types of Release Mechanism.....	391
24.4 Microencapsulation.....	392
24.5 Application of Microcapsules in Graphic and Paper Industry.....	393
References.....	395
25 Environmental and Safety Issues of Polymers and Polymeric Material in the Printing Industry.....	397
<i>Kirsten Radermacher</i>	
25.1 Introduction.....	397
25.2 Sustainable Development.....	398
25.2.1 Model of Sustainable Development.....	398
25.2.2 Methods of Ecological, Economic, and Social Sustainability.....	399
25.2.3 Complex or Simple Information.....	401

25.3	Life-Cycle Assessment	401
25.3.1	Structure of the LCA	401
25.3.2	Opportunities and Limitations of LCA	403
25.4	LCA and Toxic Risk Assessment	403
25.4.1	Toxic Risk Assessment Methods	404
25.4.2	Opportunities and Limitations of Risk Assessment within LCA	405
25.5	Printing Industry and Sustainability	406
25.5.1	Energy	406
25.5.2	Materials	407
25.5.3	Hazardous Waste	408
25.6	Assessment of Polymers and Polymeric Materials	408
25.6.1	Example: LCA of Polymeric Films	408
25.6.2	Example: Risk Assessment of UV Printing Varnishes	410
25.7	Summary	411
	References	411
	Index	417

Contributors

Bin Bao Beijing National Laboratory for Molecular Sciences (BNLMS), Key Laboratory of Green Printing, Key Laboratory of Organic Solids, Institute of Chemistry, Chinese Academy of Sciences, Beijing, China

Daniel Bohn Bergische Universität Wuppertal, Wuppertal, Germany

Tomislav Cigula Faculty of Graphic Arts, University of Zagreb, Zagreb, Croatia

Timothy C. Claypole College of Engineering, Swansea University, Swansea, UK

Ludovic G. Coppel The Norwegian Color and Visual Computing Laboratory, Gjøvik, Norway

Michael Dattner Innovation Management, BST eltromat International GmbH, Bielefeld, Germany

Sandra Dedijer Department of Graphic Engineering and Design, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

Srdan Draganov Department of Graphic Engineering and Design, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

Urška Stankovič Elesini Faculty of Natural Sciences and Engineering, University of Ljubljana, Ljubljana, Slovenia

Marta Gajadhur Department of Printing Technology, Institute of Mechanics and Printing, Faculty of Production Engineering, Warsaw University of Technology, Warsaw, Poland

Y.C. Guan Beihang University, Beijing, P.R. China

Atsushi Hotta Department of Mechanical Engineering, Keio University, Yokohama, Japan

Veronika Husovska Western Michigan University, Chemical and Paper Engineering, College of Engineering and Applied Science, Kalamazoo, USA

Joanna Izdebska Department of Printing Technology, Faculty of Production Engineering, Mechanics and Printing Institute, Warsaw University of Technology, Warsaw, Poland

Ivana Jurić Department of Graphic Engineering and Design, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

Igor Karlović Department of Graphic Engineering and Design, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

Nemanja Kašiković Department of Graphic Engineering and Design, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

Fengyu Li Beijing National Laboratory for Molecular Sciences (BNLMS), Key Laboratory of Green Printing, Key Laboratory of Organic Solids, Institute of Chemistry, Chinese Academy of Sciences, Beijing, China

Shiwei Lin College of Materials and Chemical Engineering, Hainan University, Haikou, People's Republic of China

K. Liu Singapore Institute of Manufacturing Technology, Singapore, Singapore

Tomoki Maeda Department of Mechanical Engineering, Keio University, Yokohama, Japan

Miran Mozetič Jozef Stefan Institute, Ljubljana, Slovenia

Dragoljub Novaković Department of Graphic Engineering and Design, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

Magdolna Pál Department of Graphic Engineering and Design, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

Živko Pavlović Department of Graphic Engineering and Design, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

Alexandra Pekarovicova Western Michigan University, Chemical and Paper Engineering, College of Engineering and Applied Science, Kalamazoo, USA

C.V. Pious International and Interuniversity Center for Nanoscience and Nanotechnology, Mahatma Gandhi University, Kottayam, India

Sanja Mahović Poljaček Faculty of Graphic Arts, University of Zagreb, Zagreb, Croatia

Kirsten Radermacher Department of Print and Media Technologies, University of Wuppertal, Wuppertal, Germany

Atasheh Soleimani-Gorgani Department of Printing Science and Technology, Institute for Color Science and Technology, Tehran, Iran

Yanlin Song Beijing National Laboratory for Molecular Sciences (BNLMS), Key Laboratory of Green Printing, Key Laboratory of Organic Solids, Institute of Chemistry, Chinese Academy of Sciences, Beijing, China

Rozalia Szentgyörgyvölgyi Institute of Media Technology, Obuda University, Budapest, Hungary

Daniel J. Thomas College of Engineering, Swansea University, Swansea, UK

Sabu Thomas International and Interuniversity Center for Nanoscience and Nanotechnology, Mahatma Gandhi University, Kottayam, India

Kazuhisa Tsuji Department of Mechanical Engineering, Keio University, Yokohama, Japan

Raša Urbas Faculty of Natural Sciences and Engineering, University of Ljubljana, Ljubljana, Slovenia

Alenka Vesel Jozef Stefan Institute, Ljubljana, Slovenia

Gojko Vladić Department of Graphic Engineering and Design, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

Z.K. Wang Singapore Institute of Manufacturing Technology, Singapore, Singapore

S.M. Yuan Beihang University, Beijing, P.R. China

H.Y. Zheng Singapore Institute of Manufacturing Technology, Singapore, Singapore

Zuzanna Żolek-Tryznowska Department of Printing Technology, Faculty of Production Engineering, Mechanics and Printing Institute, Warsaw University of Technology, Warsaw, Poland

Preface

The purpose of this book is to prepare a comprehensive, structured publication gathering together both scattered knowledge and the results of studies in the field of polymeric materials conducted in the research centers all around the world.

I met Prof. Sabu Thomas during the Third International Multicomponent Polymer Conference (Third IMPC) in India in 2012. From the beginning, we knew that the areas of our interests complement each other very well. We immediately understood each other well and felt that by combining mutual knowledge and interests we can establish a successful and long-lasting cooperation.

Last year, Prof. Sabu Thomas as a visiting professor lectured at the Warsaw University of Technology, Faculty of Engineering, where I am currently working. It was then when we have decided to coauthor a book. Professor's experience in the field of polymeric materials in combination with my knowledge in printing and inks enabled us to outline the book, which just came to your hands. With the help of our scientist friends from around the world, working in the field of printing, materials science and physical–chemical processes, we were able to prepare this publication. We would like to thank all of them for the excellent cooperation and the knowledge that they wanted to share.

There are books about printing available on the market, but ours is exceptional in a sense that it is entirely dedicated to printing on plastics, both classic and biodegradable. These materials are becoming increasingly important as printing substrates, and their application is growing in the recent years. Furthermore, polymers are replacing other materials

used so far in many different areas, such as packaging, agriculture, or automotive industry. Properly selected plastics can substitute other materials such as metal, paper, and glass.

Modern printing industry is very interdisciplinary and draws knowledge from multitude of disciplines. High-quality printing requires employment of knowledge of material science, physical–chemical phenomena, printing techniques, preparation of the polymers surface before printing, and factors affecting the printing process, among others. Print quality is today a key aspect of aesthetics and marketing, testifies to the quality of the product, distinguishes it, and may decide about its attractiveness or contribute to its individual character.

Authors and editors have made every effort to create a compendium of knowledge on application of polymer materials in printing that is at the same time practical, comprehensive, exhaustive, yet remains an accessible publication. Furthermore, the aim of the book is to be the source of the current information and latest developments in the field for the moment of publication. We have designed the book so that the reader may acquire not only broad and deep knowledge, but also find fundamentals and explanations of the basic phenomena that many times are difficult to explain and often overlooked. This book should become an invaluable help not only for students and lecturers, but also for printers, manufacturers of printing materials, and other industries associated with the use of printed plastics.

Joanna Izdebska
Warsaw, June 2015

13 Offset Printing

Živko Pavlović, Sandra Dedijer, Srđan Draganov, Igor Karlović and Ivana Jurić

Department of Graphic Engineering and Design, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

OUTLINE

13.1 Fundamentals of Offset Printing	217	13.3 Construction of Printing Presses for Offset Printing	223
13.1.1 Basic Principle	217	13.3.1 Sheet-Fed Printing Presses	224
13.1.2 Conventional Wet Offset Printing	218	13.3.1.1 Feeding Unit, Transport of Substrate, and Delivery Unit	224
13.1.3 Waterless Offset Printing	218	13.3.1.2 Inking Unit	224
13.1.4 Offset Printing Plates	219	13.3.1.3 UV-Curing Systems	225
13.1.4.1 Structure of Offset Printing Plates	219	13.3.1.4 Waterless Offset Presses	225
13.1.4.2 CtP Technology	219	13.3.2 Web-Fed Offset Printing Presses	226
13.2 Offset Inks	220	13.4 Print Quality Control in Waterless Offset on Polymer Materials	226
13.2.1 Oxidation Dried Inks and Drying Method	221	References	228
13.2.2 UV Wet Offset and Waterless Offset Inks and Drying Method	222		

13.1 Fundamentals of Offset Printing

13.1.1 Basic Principle

Lithographic printing was invented by Alois Senefelder at the end of the eighteenth century, with a stone as a printing form, which is the base of today's well-known offset printing. Since then, this printing technique has rapidly grown over the past decades. Although today's offset uses a metal-based printing plate as a form for printing, some of the physical–chemical properties are responsible for the quality of printing.

The word *offset* comes from the phrase *set-off*, which symbolically shows the way of getting the printed sample on the substrate (e.g., paper)—indirectly from a rubber blanket. Printed images are previously directly transferred from the printing plate to a rubber blanket (Figure 13.1).

Depending on the type, the differences between printing and nonprinting areas vary from approximately 0.5 to 2.0 μm above the grain of the printing

plate. Their height is almost the same, but they are distinguished by different physical–chemical surface properties (Langlais, 2011).

Offset printing has been a market leader for a long time, in terms of the highest speed of printing and

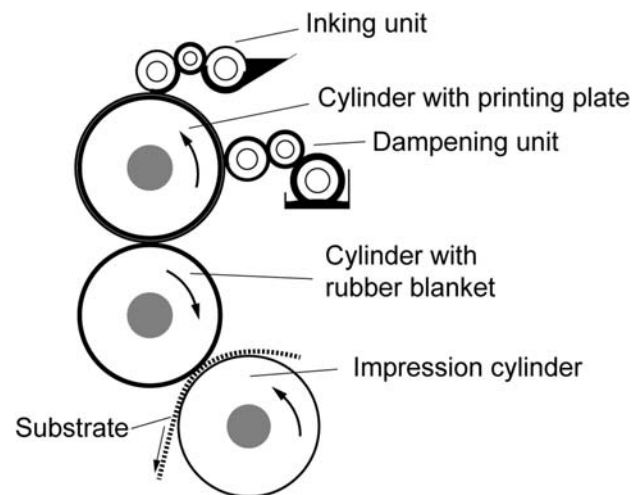


Figure 13.1 Components of the basic principle—offset printing unit.