

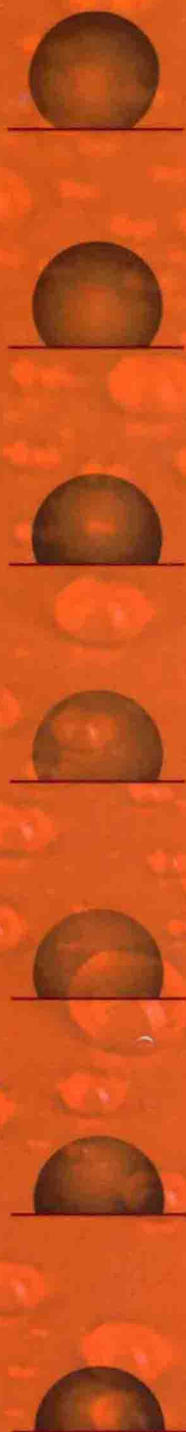


Surface Treatment of Materials for Adhesive Bonding

Second Edition

Sina Ebnesajjad

Assisted by Cyrus F. Ebnesajjad

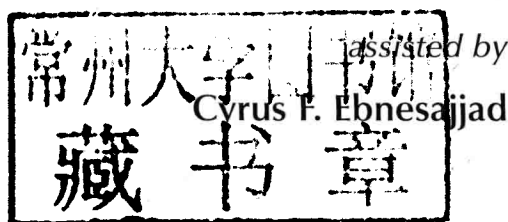


Surface Treatment of Materials for Adhesive Bonding

Second Edition

Sina Ebnesajjad, PhD

President, FluoroConsultants Group, LLC



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
225 Wyman Street, Waltham, MA 02451, USA

First published 2006

Second edition 2014

Copyright © 2014, 2006 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 arrangement 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.

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

ISBN: 978-0-323-26435-8

For information on all William Andrew publications
visit our website at store.elsevier.com

Printed and bound in the United States

Transferred to Digital Printing, 2013



**Working together
to grow libraries in
developing countries**

www.elsevier.com • www.bookaid.org

Surface Treatment of Materials for Adhesive Bonding

Preface

The first edition (2006) of this book was received well by the practitioners of adhesion, thus prompting a second edition. The second edition is an expansion of the first book. Three new chapters have been added to describe the effect of additives on surface properties and adhesion, surface treatment of ceramics, and adhesion promoters.

Chapter 6 of the first edition describes, dealing with surface treatment methods and techniques. It has been divided into two chapters to focus and devote more space to plasma treatment methods. Both plasma treatment techniques under vacuum and at atmospheric pressure have been covered. These techniques are gaining popularity because they are “dry.” The term dry means plasma treatment does not require wet chemicals, which often generate toxic chemical waste that needs disposal. The necessity of reducing the environmental impact of surface treatment operations has generated a great deal of research and development in the area of plasma technologies. Even though plasma treatment techniques require small amounts of gases, they are considered environmentally safe and friendly.

Chapter 10, dealing with the effect of additives on surface treatment of plastics, delves into the impact of additives on surface tension, and the fact that adherability of a material can be positive, neutral, or negative. Some additives actually enhance the bondability of a surface, some have little or no effect, and finally some including silicones and fluoropolymers reduce the ability of a surface to form a bond using an adhesive.

Chapter 11, dealing with surface treatment of ceramics, focuses on the surface treatment of this important group of materials. Ceramics have innumerable applications in industry, dental restorations, consumer products, and art. In addition to ceramics which occur naturally, many new ceramics have been (and continue to be) developed for special applications. By and large, developments in dental restoration have led to the creation of the largest number of ceramics.

Chapter 12, dealing with adhesion promoters, authored by Dr. Peter Pape, sheds light on the use of silanes and other adhesion promoters. Adhesion promoters, or coupling agents, are chemicals that act at the interface between an organic polymer and an inorganic substrate to enhance adhesion between the two materials.

Some readers have commented about the space devoted to the discussion of fluoropolymers. The answer is that fluoropolymers are simply the most difficult plastics to bond. Traditionally, sodium etching has been used to

render the surface of prefluoropolymers such as polytetrafluoroethylene bondable. These plastics represent one extreme type of material because of their unique low surface energy (<40 dynes/cm) and nonwetting characteristics. The other end of the spectrum of materials include metal oxides and metals which have high surface energy (>100 dynes/cm). In spite of the relatively small volume of fluoropolymer consumption, as compared to say polyolefins, they play extremely important roles in human life. Applications include medical devices such as pacemakers, automotive applications, fuel and hydraulic hoses in aerospace, chemical processing, semiconductor fabrication, pharmaceuticals, biopharmaceuticals, and food and beverages.

The authors hope that the second edition of the book is helpful to those who deal with surface treatment of materials and adhesion bonding.

None of the views or information presented in this book reflect the opinion of any of the companies or individuals that have contributed to the book. If there are errors, they are oversights on the part of the authors. A note indicating the specific error to the publisher, for the purpose of correction of future editions, would be most appreciated.

Sina Ebnesajjad
Cyrus F. Ebnesajjad
2013

Preface to First Edition

A basic industrial process is the bonding of alike and different materials to each other. Adhesion using an *adhesive* has proven to be an effective means of material bonding. This book describes treatment methods that must be applied to a material surface before successful adhesive bonding is possible. There are numerous examples ranging from wallpaper in a house and paint on surfaces, to parts used in the construction of aircraft.

The aim of this text is to explain, in a simple yet complete manner, all that is required to achieve successful adhesion bonding of different materials. Fundamental material considerations have been given priority to enable the use of the contents of this book in different industries. The book is both a reference and a source for learning the basics, and is useful for all involved in the product value chains. The book also offers information helpful to engineers, chemists, students, and all others involved in material adhesion and processing.

This book is intended to be a handbook for reference of processes and techniques, but it is written with a technical tone. This approach increases the availability of the whole text to readers with a college level background in mathematics and chemistry, but an in-depth knowledge of adhesion technology is not necessary. Chapters 6 through 8 can be used by almost anyone interested in surface treatment of materials and do not require college level background.

The book is organized in two parts. The first five chapters discuss definitions, surface characterization and analysis, surface energy measurement methods, adhesion mechanisms, and failure modes. Chapters 6 through 8 provide extensive information about surface treatment of materials. Chapter 6 is focused on surface preparation and treatment of metals and plastics to render surfaces bondable and to enhance the strength and durability of the bond. This chapter also includes the surface treatment techniques for fluorinated polymers, which are resistant to most techniques. Chapter 7 reviews the techniques applied to specific metals to make them bondable. Chapter 8 describes the surface preparation methods for plastic, thermosetting, and elastomeric materials. Some of the materials in Chapters 7 and 8 are updated from the excellent reference and classic Noyes publication, *Adhesives Technology Handbook*, by Arthur H. Landrock (1985), now out of print.

Attempt has been made throughout the text to balance the practical with the theoretical. Every chapter has been arranged so that it can be studied independently. For those who are interested in in-depth information, content

and references have been provided for surface, adhesion, and polymer science in Chapters 1 through 5. The reader interested only in the practical information can directly consult Chapters 6 through 8. The references listed at the end of each chapter serve as both a bibliography and source for additional reading. Review papers are helpful as a starting point for finding additional sources for concentrated reading in a selected area.

The sole purpose of surface treatment in the present context is to render surfaces adherable. It is virtually impossible to understand or achieve adequate surface preparation and treatment without an intimate knowledge of the science and practice of adhesion.

None of the views or information presented in this book reflects the opinion of any of the companies or individuals that have contributed to the book. If there are errors, they are oversights on the part of the authors. A note indicating the specific error to the publisher, for the purpose of correction of future editions, would be much appreciated.

Sina Ebnesajjad
Cyrus F. Ebnesajjad
2006

Acknowledgments

No massive undertaking can be completed without the contributions of many people and organizations. Many companies and individuals have contributed information and data to this book. The authors are grateful to each company and individual for their contributions. Diligent attempts have been made to acknowledge every contributor. Any oversight errors brought to the attention of the publisher or the authors will be corrected in future editions.

The authors wish to offer their sincere appreciation to companies whose information and data appear in this book. It is thanks to the contributions of these companies that the contents of this book are connected to the real world of practice and applications.

We would like to especially thank our friend, Dr. Laurence W. McKeen, for his support with the development of the first edition. He made an in-depth review of the manuscript, suggestions, and corrections, and contributed the section on the grit blasting of metals. We are indebted to Larry for his friendship and care.

Credit goes to later Arthur H. Landrock for the materials updated (found in Chapters 7 and 8 of this book) from his excellent *Adhesives Technology Handbook* (Noyes Publications, 1985).

We honor the memory of our deceased friend Bill Woishnis, the cofounder of William Andrew Publishing (acquired by Elsevier in 2009), for his support of the authors in the development of the first edition of the book.

We would like to thank Matthew Deans, the Senior Publisher of William Andrew, for his leadership and invaluable support. Thanks to Matthew's wisdom and guidance, William Andrew continues to grow in both the number of titles and the breadth of subject matters it offers. David Jackson, Associate Editor in William Andrew, is not only brilliant, but a most pleasant and hardworking young man. We appreciated his support throughout the revision of this book. Ms. Lisa Jones' support during the typesetting and production of this book was invaluable.

Our special thanks go to our assistant Brenna Kirby for her editorial support and assistance with manuscript preparation.

We dedicate this book to our family members, who patiently supported us throughout the entire revision process. Without their generosity and devotion this revision would have not been possible.

Sina Ebnesajjad
Cyrus F. Ebnesajjad

Preface	xiii
Preface to First Edition	xv
Acknowledgments	xvii

Part I

Background and Theory

1. Introduction to Surface Preparation	3
1.1 Definition of Surface Preparation, Adhesives, and Adhesive Bonding	3
1.2 Introduction to Surface Treatment	4
1.2.1 Degreasing	5
1.2.2 Abrasion	5
1.2.3 Chemical Treatment	6
References	6
2. Surface Tension and Its Measurement	7
2.1 Introduction	7
2.2 What is an Interface?	7
2.3 Surface Tension	8
2.4 Surface Free Energy	9
2.4.1 Surface Energy of Solids	10
2.4.2 Work of Adhesion	11
2.5 Contact Angle (Young's Equation)	11
2.6 Laplace's Equation	13
2.7 Effect of Temperature on Surface Tension	14
2.8 Surface Tension Measurement	14
2.8.1 Measurement for Liquids: Du Nouy Ring and Wilhelmy Plate Methods	17
2.8.2 Measurement for Solids: Liquid Homolog Series	18
References	23
3. Surface Energy of Solids and Its Measurement	25
3.1 Introduction	25
3.2 Determining the Surface Energy of Solids	25
3.2.1 Fractional Polarity	26

3.3 Equation of State	26
3.4 Surface Tension Components	28
3.5 Polymer Melt Method	31
3.6 Critical Surface Tension	31
3.7 Other Methods for Estimation of Surface Tension of Molten Polymer	34
3.7.1 Grunberg and Nissan's Relationship	34
3.7.2 Hildebrand and Scott's Equation	34
3.7.3 McGowan's Equation	35
3.8 Shuttleworth's Equation	35
References	36

4. Surface and Material Characterization Techniques	39
4.1 Introduction	39
4.2 Surface Analysis Techniques	39
4.3 Optical (Light) Microscopy	41
4.4 Infrared Spectroscopy	45
4.5 Raman Spectroscopy	46
4.6 Scanning Electron Microscopy (SEM)	47
4.7 Rutherford Backscattering Theory (RBS)	48
4.8 Energy Dispersive X-Ray Spectroscopy (EDS)	49
4.9 Transmission Electron Microscopy (TEM)	50
4.10 Electron Spectroscopy for Chemical Analysis (ESCA)	50
4.11 Auger Electron Spectroscopy (AES)	53
4.12 Ion Scattering Spectroscopy (ISS)	53
4.13 Secondary Ion Mass Spectroscopy (SIMS)	54
4.14 Time-of-Flight Secondary Ion Mass Spectroscopy (TOF-SIMS)	55
4.15 Mass Spectroscopy or Spectrometry (MS)	55
4.16 Atomic Force Microscopy (AFM)	56
4.17 Electron Energy Loss Spectroscopy (EELS)	59
4.18 Gas Chromatography (GC)	59
4.19 Nuclear Magnetic Resonance (NMR)	60
4.20 Differential Scanning Calorimetry (DSC)	62
4.21 Differential Thermal Analysis (DTA)	64
4.22 Dynamic Mechanical Analysis (DMA)	65
4.23 Thermogravimetric Analysis (TGA)	68
4.24 Adhesive Bond Testing	68
4.24.1 Tensile	70
4.24.2 Shear	72
4.24.3 Peel	73
References	74

5. Theories of Adhesion	77
5.1 Introduction	77
5.2 Mechanical Theory	77
5.3 Electrostatic (Electronic) Theory	78
5.4 Diffusion Theory	79
5.5 Wetting Theory	80
5.6 Chemical Bonding	81
5.6.1 Acid–Base Theory of Adhesion	83
5.7 Weak Boundary Layer Theory	85
5.8 Definition of Failure Modes	86
5.9 Mechanisms of Bond Failure	88
References	90

Part II

Surface Treatment Methods and Techniques

6. Material Surface Preparation Techniques	95
6.1 Introduction	95
6.2 General Considerations	95
6.3 Surface Treatment of Metals	96
6.4 Cleaning (Degreasing) Metals	99
6.4.1 General Sequence of Cleaning	100
6.5 Priming	107
6.6 Sol-gel Process	108
6.7 Surface Treatment of Plastics	109
6.7.1 Effect of Treatment on Plastic Surfaces	110
6.7.2 Surface Cleaning	112
6.7.3 Mechanical Treatment (Surface Roughening)	113
6.7.4 Corona Treatment	113
6.7.5 Flame Treatment	124
6.8 Sodium Etching of Fluoroplastics	128
6.9 Methods for Evaluating Effectiveness of Surface Preparation	130
6.9.1 Dyne Liquids	131
6.9.2 Water-Break Test	133
6.9.3 Contact-Angle Test	133
6.10 Surface Exposure Time (SET)	133
References	136
 7. Surface Preparation of Metals	 139
7.1 Introduction	139
7.2 Aluminum	139

7.2.1 Sol-gel Process	140
7.2.2 Immersion Etch (Optimized FPL Process)	143
7.2.3 FPL Paste Etch	144
7.2.4 Chromate-Free Etch Process	145
7.2.5 Anodization	146
7.2.6 Brush Plated Etch (Stylus Method)	153
7.2.7 Ciba Laser Pretreatment (CLP)	153
7.3 Beryllium	154
7.4 Brass	155
7.5 Bronze	155
7.6 Cadmium	156
7.7 Copper and Copper Alloys	156
7.7.1 Nitric Acid–Sodium Chlorite (Black Oxide)	156
7.7.2 Nitric Acid–Ferric Chloride	156
7.7.3 Nitric Acid	157
7.7.4 Acid Etch (Sulfuric Acid–Dichromate–Ferric Sulfate)	157
7.8 Gold	158
7.9 Magnesium and Magnesium Alloys	158
7.9.1 Alkaline-Detergent Solution	158
7.9.2 Hot Chromic Acid	159
7.9.3 Sodium Hydroxide–Chromic Acid	159
7.9.4 Anodic Treatments	160
7.9.5 Conversion Coatings and Wash Primers	160
7.10 Nickel and Nickel Alloys	160
7.10.1 Abrasive Cleaning	160
7.10.2 Nitric Acid Etch	160
7.10.3 Sulfuric–Nitric Acid Pickle	160
7.10.4 Cleaning and Treatment of Plated Parts	161
7.10.5 Nickel-Base Alloy Treatments	161
7.11 Platinum	162
7.11.1 Abrasive Cleaning	162
7.11.2 Abrasive Scouring	162
7.12 Silver	162
7.12.1 Chromate Conversion Coating	162
7.12.2 Degrease/Abrade/Prime	162
7.13 Steel	163
7.13.1 Acid Treatment	164
7.13.2 Potassium Iodide–Phosphoric Acid Method	164
7.13.3 ASTM Suggested Methods	165
7.14 Stainless Steel	165
7.14.1 Acid Etch (for Types 301 and 302 Stainless Steel)	166
7.14.2 Oxalic–Sulfuric Acid Process for Maximum Heat Resistance	167
7.14.3 Bromophosphate Treatment	167
7.14.4 ASTM Suggested Methods	168

7.15 Tin	170
7.16 Titanium	170
7.16.1 Stabilized Phosphate–Fluoride Treatment	171
7.16.2 Alkaline Cleaning	172
7.16.3 Alkaline Etch	173
7.16.4 Pasa-Jell [®] Treatment	173
7.16.5 VAST Process	173
7.16.6 Alkaline-Peroxide Etch (RAE Etch)	174
7.16.7 ASTM Suggested Methods	175
7.16.8 Sol-gel Process	176
7.17 Tungsten and Alloys	176
7.17.1 Hydrofluoric–Nitric–Sulfuric Acid Method	176
7.18 Uranium	176
7.18.1 Abrasive Method	177
7.18.2 Acetic Acid–Hydrochloric Acid Method	177
7.18.3 Nitric Acid Bath	177
7.19 Zinc and Alloys	178
7.19.1 Abrasion (for General-Purpose Bonding)	178
7.19.2 Acid Etch	178
7.19.3 Sulfuric Acid–Dichromate Etch	178
7.19.4 Conversion Coatings	178
7.20 Weld Bonding Metals	179
7.20.1 Vapor Honing/Pasa-Jell [®] 107M Procedure	180
7.21 Conclusions	180
References	180

8. Surface Preparation of Thermoplastics, Thermosets, and Elastomers	185
8.1 Introduction	185
8.2 Thermoplastics	185
8.2.1 Acetal Copolymer (Celcon [®])	186
8.2.2 Acetal Homopolymer (Delrin [®])	186
8.2.3 Acrylonitrile–Butadiene–Styrene (ABS)	187
8.2.4 Allyl Diglycol Carbonate (CR-39 [®] by PPG Industries)	189
8.2.5 Cellulosics [Cellulose Acetate, Cellulose Acetate Butyrate (CAB), Cellulose Nitrate, Cellulose Propionate, Ethyl Cellulose]	189
8.2.6 Ethylene–Chlorotrifluoroethylene Copolymer (ECTFE)	190
8.2.7 Ethylene–Tetrafluoroethylene Copolymer (ETFE)	190
8.2.8 Ethylene–Vinyl Acetate (EVA)	190
8.2.9 Fluorinated Ethylene–Propylene Copolymer (FEP)	190
8.2.10 Ionomer	190
8.2.11 Nylon (Polyamide)	191
8.2.12 Perfluoroalkoxy Resins (PFA)	191

8.2.13	Phenylene-Oxide-Based Resins (Noryl [®] Polyaryl Ethers by GE Plastics)	192
8.2.14	Polyarylate (Ardel [®] by BP plc)	192
8.2.15	Polyaryl Sulfone (Astrel [®] 360 plastic)	192
8.2.16	Polycarbonate	193
8.2.17	Polychlorotrifluoroethylene (PCTFE)	195
8.2.18	Polyester (Saturated)	195
8.2.19	Polyetheretherketone (PEEK)	196
8.2.20	Polyethersulfone (PES) (Victrex plc)	196
8.2.21	Polyetherimide (Ultem [®] from GE Plastics)	196
8.2.22	Polyethylene (PE)	197
8.2.23	Polymethylmethacrylate (PMMA) (Plexiglas [®] — Arkema Corporation)	198
8.2.24	Polymethylpentene (TPX [®])	198
8.2.25	Polyphenylene Sulfide (PPS) (Ryton [®] — Chevron Phillips Chemical Co.)	199
8.2.26	Polypropylene (PP)	199
8.2.27	Polystyrene (PS)	200
8.2.28	Polysulfone (Udel [®] — Solvay Advance Polymers)	201
8.2.29	Polytetrafluoroethylene (PTFE)	202
8.2.30	Polyvinyl Chloride (PVC)	202
8.2.31	Polyvinyl Fluoride	203
8.2.32	Polyvinylidene Fluoride (PVDF)	203
8.2.33	Styrene—Acrylonitrile (SAN) (Tyril [®] — Dow Chemical Co.)	203
8.3	Thermosets	203
8.3.1	Diallyl Phthalate (DAP)	204
8.3.2	Epoxiest	204
8.3.3	Melamine—Formaldehyde (Melamines)	205
8.3.4	Phenol—Formaldehyde (Phenolics)	205
8.3.5	Polyester	205
8.3.6	Polyimide	205
8.3.7	Polyurethane	206
8.3.8	Silicone Resins	207
8.3.9	Urea—Formaldehyde (U-F)	207
8.4	Reinforced Plastics/Thermosets	208
8.4.1	Tear-Ply (Peel-Ply) Method	208
8.4.2	Sanding	208
8.4.3	Grit-Blasting	208
8.4.4	Manual Scouring	209
8.4.5	Solvent-Soak and Abrading	209
8.5	Reinforced Thermoplastics (Glass-Reinforced)	210
8.6	Plastic Foams	210
8.7	Surface Preparation of Rubbers	210
8.7.1	Neoprene (Polychloroprene) (CR)	212

8.7.2	Ethylene–Propylene–Diene Terpolymer (EPDM)	214
8.7.3	Silicone Rubber (Polydimethylsiloxane)	214
8.7.4	Butyl Rubber (BR)	215
8.7.5	Chlorobutyl Rubber (CIIR)	216
8.7.6	Chlorosulfonated Polyethylene (Hypalon [®] – DuPont Co.)	216
8.7.7	Nitrile Rubber (Butadiene–Acrylonitrile) (NBR)	217
8.7.8	Polyurethane Elastomers	218
8.7.9	Synthetic Natural Rubber (Polyisoprene) (IR)	218
8.7.10	Styrene–Butadiene Rubber (SBR) (Buna S)	219
8.7.11	Polybutadiene (Butadiene Rubber)	219
8.7.12	Fluorosilicone Elastomers	220
8.7.13	Fluorocarbon Elastomers	220
8.7.14	Polysulfide Rubber (PTR)	221
8.7.15	Propylene Oxide Rubber	221
8.7.16	Polyacrylate (Polyacrylic Rubber)	222
8.8	Thermoplastic Elastomer	222
8.9	Painted Surfaces	223
8.10	Conclusions	224
	References	224
9.	Plasma Treatment of Polymeric Materials	227
9.1	Introduction	227
9.2	Plasma Reaction with Polymer Surfaces	229
9.3	Low Pressure Plasma Treatment (LPT)	231
9.3.1	Applications of Low Pressure Plasma Treatment to Polymers	232
9.3.2	Application of Low Pressure Plasma Treatment of Fluoropolymers	240
9.4	Atmospheric Pressure Plasma Treatment	251
9.4.1	Inline Plasma Treatment of Wire and Cable	260
9.5	Surface Treatment of Biopolymers	260
	References	266
10.	Effects of Additives on Surface Treatment of Plastics	271
10.1	Introduction	271
10.2	Laser Marking	273
10.3	Antistatic Additives	274
10.4	Anti-blocking Agents	274
10.5	Internal Lubricants	275
10.6	Additives for Wear and Friction Reduction	276
	References	280

11. Surface Treatment and Bonding of Ceramics	283
11.1 Industrial Ceramics	283
11.1.1 Alumina Ceramics	285
11.1.2 Steatite Ceramics	285
11.1.3 Zirconia Ceramics	285
11.1.4 Silicon Carbide	285
11.1.5 Cordierite Ceramics	286
11.1.6 Mullite	286
11.1.7 Silicon Nitride	286
11.1.8 Sapphire Ceramics	287
11.2 Treatment of Ceramics for Bonding	287
11.3 Treatments for Adhesive Bonding	288
11.3.1 Degreasing	289
11.3.2 Abrasion or Surface Roughening	289
11.3.3 Acid Etch	290
11.3.4 Silane Coupling Agents	291
11.3.5 Laser Treatment	294
11.3.6 Flame Treatment	295
11.4 Treatment for Cementation	295
11.5 Treatments for Brazing	295
References	298
 12. Adhesion Promoters	 301
12.1 General Concepts	301
12.2 Silane Adhesion Promoters	302
12.2.1 Typical Silane Coupling Agents	302
12.2.2 Silane Chemistry	304
12.3 Adhesion Promoter Mechanism with Silanes	305
12.3.1 The Interphase Region	305
12.3.2 Bonding to the Inorganic Substrate	306
12.3.3 Bonding to the Organic Polymer	307
12.4 Optimizing Coupling Agent Performance	308
12.5 How to Choose a Silane Coupling Agent	312
12.6 General Applications of Silane Coupling Agents	313
12.7 Industry and Utility	314
12.7.1 Surface Treatment of Fiberglass	314
12.7.2 Surface Treatment of Minerals in Plastics	317
12.7.3 Mineral Fillers in Rubber Reinforcement	322
12.7.4 Adhesion Promoters for PICA	324
12.8 Nonsilane Adhesion Promoters	326
12.9 Sources of Adhesion Promoters	327
References	327