

# ASM Handbook®

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## Volume 5B Protective Organic Coatings

Prepared under the direction of the  
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# Foreword

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*ASM Handbook*, Volume 5B, *Protective Organic Coatings* is a wholly new entry in the esteemed *ASM Handbook* series. Volume 5B grew out of an article, “Organic Coatings and Linings,” by Kenneth B. Tator, P.E., published in 2003 in *ASM Handbook*, Volume 13A, *Corrosion: Fundamentals, Testing, and Protection*. Mr. Tator and ASM International identified a need for an entire book dedicated to industrial protective coatings, based on the engineering and economic significance of the industry. To fill the reference publications gap in the materials field, the decision was made to include the book as a Volume in the *ASM Handbook* series, industry’s most comprehensive source of information on materials technology.

Volume 5B, like every Volume of the *ASM Handbook* series, was written by recognized industry experts, reviewed by groups of their peers, and edited by professionals dedicated to developing reference publications of the highest technical and editorial quality. This results in authoritative, reliable sources of information in every area of materials specialization, now including protective organic coatings.

ASM International is grateful for the hard work and dedication of its many volunteer authors and reviewers who gave of their expertise and time to make Volume 5B possible, particularly Kenneth B. Tator, P.E., KTA-Tator, Inc., Volume Editor and author of numerous articles in the Volume.

*ASM Handbook*, Volume 5B, *Protective Organic Coatings* is comprised of five divisions, which offer introductory material, an in-depth presentation of specific coating materials, practical information on surface preparation and coating application, coverage of coating use by various industries, and detailed discussion of coating analysis and evaluation methods. Volume 5B authors provided the latest information on the many industry standards that must be adhered to in the preparation, application, and testing of protective coatings.

Volume 5B includes full-color printing of all of its figures, including all photographs. ASM International thanks Kenneth B. Tator, P.E., and KTA-Tator, Inc., a corrosion and coatings consulting and inspection firm, for their generous contributions that have allowed the photographs in this book to be reproduced in color.

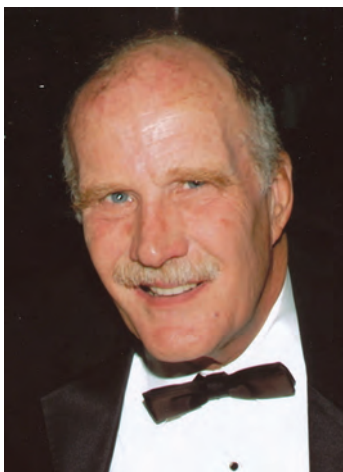
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# Preface

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**Kenneth B. Tator, P.E.**  
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Corrosion is a phenomenon of nature involving the deterioration of a material (usually a metal) due to a chemical or electrochemical reaction with the environment.

In accord with this definition, virtually every material object around us corrodes or can be expected to corrode. Metallic corrosion is most evident, and that of steel is most familiar to even casual observers because it results in a brown-colored rust that leads to pitting and ultimate loss of structural strength. Of course, other metals deteriorate to varying degrees on exposure to certain environments, although the deterioration may not be as evident. Corrosion of nonmetals also occurs, and that of wood and concrete is also of great concern. This destructive material deterioration occurs

to transportation vehicles (automobiles, trucks, railroad cars, etc.), bridges, pipelines of all types (water and wastewater, oil, gas, etc.), private homes and public buildings, even home appliances, electronic equipment, and—heaven forbid—personal computers and cell phones. Corrosion is all-pervasive in most environments in every region, country, and continent around the world!

ASM International has three comprehensive volumes on corrosion in its *ASM Handbook* series: Volume 13A, *Corrosion: Fundamentals, Testing, and Protection*; Volume 13B, *Corrosion: Materials*; and Volume 13C, *Corrosion: Environments and Industries*. Corrosion carries significant costs, estimated in 2013 to be more than \$450 billion annually in the United States and \$2.2 trillion worldwide, according to NACE International, the global authority on corrosion.

However, by utilizing existing corrosion-prevention technologies, the cost can be drastically reduced, perhaps by one-third or more. What are those technologies? They include proper corrosion design and maintenance; the use of more resistant construction materials, such as corrosion-resistant alloys and plastics; the use of corrosion inhibitors; anodic and cathodic protection; metallic coatings; and the use of organic protective coatings. This last technology is the subject of this Volume. It is an important subject because organic protective coatings are by far the most widely used means of corrosion protection. The application and use of organic protective coatings, including zinc-rich coatings, accounted for 88.3% of all monies spent for corrosion protection in the United States, as estimated by the report “Corrosion Cost and Preventive Strategies in the United States,” FHWA-RD-01-156, issued by the Federal Highway Administration in 2002. Adjusted to the 2013 estimated cost of corrosion in the United States of \$450 billion utilizing the same ratios of corrosion cost to coating protection expense used in 2002, the money spent for protective coating corrosion abatement in the United States would exceed

\$175 billion, or over \$545 for every man, woman, and child in the United States, at the end of 2014—not a trifling sum!

This printed Volume is but a snapshot in time regarding coatings. It is not all-inclusive, as there are other areas where coatings are used and some specific types of coatings that are not covered herein. Moreover, like everything else in life these days, change is constant, and the rate of technological improvement is accelerating at an ever-increasing rate. Coatings, like all materials, have benefited greatly from the advent of nanotechnology, and superior coatings are being introduced to the market on an almost daily basis. ASM International is releasing this book not only in printed form but also in a digital format, available on the ASM International website. This makes possible future updates and additional content, so our coverage keeps pace with technology. I absolutely encourage readers to assist ASM International in keeping this Volume’s digital version current with updated technology.

This Volume is organized into five divisions: Introduction (consisting of four articles); Coating Materials (nineteen articles); Surface Preparation and Coating Application (seven articles); Industrial Uses (nine articles); and Coating Analysis and Evaluation (six articles). A total of 50 authors wrote the Volume’s 45 articles. I am most grateful to those authors, and their employer corporations and organizations, for the contribution of the considerable time and expertise necessary to write articles for this Volume. What a remarkable group of professionals!

I’d also like to thank Patty Conti, Production Coordinator; Kate Fornadel, Senior eProduction Coordinator; Diane Whitelaw, Production Coordinator; and Madrid Tramble, Manager, Production at ASM International for publishing this first *ASM Handbook* totally in color. A color production requires a lot more attention to detail than a black-and-white production, and Patty and the ASM group have pulled it off—congratulations! Others at ASM International who deserve special thanks are Steve Lampman, Senior Content Developer; Karen Marken, Senior Managing Editor; and Scott Henry, Director, Content and Knowledge-Based Solutions.

I’m indebted to Amy Nolan, Content Developer at ASM International, for helping to obtain authors and reviewers and for nagging authors (mostly me) to get their articles written on schedule. Without her, this book could not have been written.

I would also like to thank my employer, KTA-Tator, Inc., for so graciously allowing me the time to work on this Volume, as I conducted much of my work at home—although they likely felt they were better off without me at the office.

Finally, and perhaps most importantly, I would like to thank my wife Maureen who put up with my computer rage and other frustrations while I was working at home. She is the love of my life, and, as a result of my Handbook effort, while always a beautiful woman, Maureen now has exemplary patience, resilience, and tolerance—I am truly blessed!

Ken Tator  
Editor

# Policy on Units of Measure

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By a resolution of its Board of Trustees, ASM International has adopted the practice of publishing data in both metric and customary U.S. units of measure. In preparing this Handbook, the editors have attempted to present data in metric units based primarily on *Système International d'Unités* (SI), with secondary mention of the corresponding values in customary U.S. units. The decision to use SI as the primary system of units was based on the aforementioned resolution of the Board of Trustees and the widespread use of metric units throughout the world.

For the most part, numerical engineering data in the text and in tables are presented in SI-based units with the customary U.S. equivalents in parentheses (text) or adjoining columns (tables). For example, pressure, stress, and strength are shown both in SI units, which are pascals (Pa) with a suitable prefix, and in customary U.S. units, which are pounds per square inch (psi). To save space, large values of psi have been converted to kips per square inch (ksi), where 1 ksi = 1000 psi. The metric tonne ( $\text{kg} \times 10^3$ ) has sometimes been shown in megagrams (Mg). Some strictly scientific data are presented in SI units only.

To clarify some illustrations, only one set of units is presented on artwork. References in the accompanying text to data in the illustrations are presented in both SI-based and customary U.S. units. On graphs and charts, grids corresponding to SI-based units usually appear along the left and bottom edges. Where appropriate, corresponding customary U.S. units appear along the top and right edges.

Data pertaining to a specification published by a specification-writing group may be given in only the units used in that specification or in dual units, depending on the nature of the data. For example, the typical yield strength of steel sheet made to a specification written in customary U.S.

units would be presented in dual units, but the sheet thickness specified in that specification may be presented only in inches.

Data obtained according to standardized test methods for which the standard recommends a particular system of units are presented in the units of that system. Wherever feasible, equivalent units are also presented. Some statistical data may also be presented in only the original units used in the analysis.

Conversions and rounding have been done in accordance with IEEE/ASTM SI-10, with attention given to the number of significant digits in the original data. For example, an annealing temperature of 1570 °F contains three significant digits. In this case, the equivalent temperature would be given as 855 °C; the exact conversion to 854.44 °C would not be appropriate. For an invariant physical phenomenon that occurs at a precise temperature (such as the melting of pure silver), it would be appropriate to report the temperature as 961.93 °C or 1763.5 °F. In some instances (especially in tables and data compilations), temperature values in °C and °F are alternatives rather than conversions.

The policy of units of measure in this Handbook contains several exceptions to strict conformance to IEEE/ASTM SI-10; in each instance, the exception has been made in an effort to improve the clarity of the Handbook. The most notable exception is the use of  $\text{g/cm}^3$  rather than  $\text{kg/m}^3$  as the unit of measure for density (mass per unit volume).

SI practice requires that only one virgule (diagonal) appear in units formed by combination of several basic units. Therefore, all of the units preceding the virgule are in the numerator and all units following the virgule are in the denominator of the expression; no parentheses are required to prevent ambiguity.

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# Contents

<b>Introduction</b> . . . . .	<b>1</b>	<b>Acrylic Coatings</b>	
Elemental Chemistry Introduction		<i>Leo J. Procopio</i> . . . . .	48
<i>Kenneth B. Tator</i> . . . . .	3	Acrylic Polymer Chemistry . . . . .	48
Elements . . . . .	3	Acrylic Polymers for Solventborne Coatings . . . . .	50
Creation of Elements. . . . .	4	Acrylic Polymers for Waterborne Coatings . . . . .	51
Atoms . . . . .	5	Film Formation of Acrylic Latex Polymers . . . . .	52
Valence Electrons . . . . .	5	Types of Chemistries Available in Waterborne Acrylic Latex Coatings . . . . .	53
Assembly of Polymers from Atoms . . . . .	7	Types of Waterborne Acrylic Coatings . . . . .	54
Functional Groups . . . . .	7	Benefits and Challenges of Waterborne Latex Coatings. . . . .	57
Chemical Bonding Structures. . . . .	7	Industrial Maintenance Applications Using Latex Coatings . . . . .	57
Composition of a Paint Coating		Advances in Waterborne Latex Coatings for Industrial Maintenance. . . . .	58
<i>Chrissy Stewart</i> . . . . .	10	Conclusions . . . . .	60
Pigments . . . . .	11	<b>Epoxy Resins and Curatives</b>	
Resin. . . . .	12	<i>Kenneth B. Tator</i> . . . . .	63
Additives. . . . .	13	Epoxy History . . . . .	63
Solvent . . . . .	13	Epoxy Resins . . . . .	63
Volatile Organic Compounds. . . . .	14	Epoxy Hardeners/Curatives/Co-Reactants/Co-Polymers . . . . .	68
Film-Forming Mechanisms of Various Coating Types. . . . .	15	Concerns regarding the Use of Epoxy Coatings . . . . .	76
Coating Systems Defined. . . . .	16	<b>Polyvinylidene Fluoride-Based Coatings Technology</b>	
Qualification Testing for Coating System Selection		<i>Robert A. Iezzi</i> . . . . .	80
<i>William D. Corbett</i> . . . . .	17	Fluoropolymer Background . . . . .	80
Methods for Qualifying Coating Systems . . . . .	17	General Properties of Polyvinylidene Fluoride . . . . .	80
Independently Generated Data versus Coating-Manufacturer- Generated Data . . . . .	18	Polymerization of Polyvinylidene Fluoride . . . . .	81
Standard Laboratory Test Procedures for Qualifying Coating Systems . . . . .	18	Polyvinylidene Fluoride Resin Types . . . . .	81
Establishing Minimum Performance Requirements . . . . .	31	Coating Formulation of Polyvinylidene Fluoride . . . . .	82
Overview of Quality and the Standards, Programs, and Certifications Used in the Coatings Industry		Application of Polyvinylidene Fluoride-Based Coatings . . . . .	83
<i>Alison B. Kaelin</i> . . . . .	32	Coating Properties of Polyvinylidene Fluoride . . . . .	83
Defining Quality, Quality Assurance, Quality Control, and Quality Management . . . . .	32	Typical End Uses of Polyvinylidene Fluoride-Based Coatings . . . . .	85
Evolution of Quality Control/Quality Assurance in Coatings. . . . .	33	Opportunities for Improvement. . . . .	85
Standards, Quality Programs, and Certifications in the Coatings Industry . . . . .	34	Health and Safety Considerations of Polyvinylidene Fluoride . . . . .	85
Conclusion. . . . .	35	Summary . . . . .	86
<b>Coating Materials</b> . . . . .	<b>37</b>	<b>Fluoroethylene Vinyl Ether Resins for High-Performance Coatings</b>	
Alkyd Resins		<i>Robert Parker and Kristen Blankenship</i> . . . . .	88
<i>Kenneth B. Tator and Michael G. Koehler</i> . . . . .	39	The Chemistry of FEVE Resins . . . . .	88
Alkyd History . . . . .	39	FEVE Resin Types . . . . .	89
Alkyd Resin Chemistry . . . . .	40	Methods of Formulation for FEVE Resins. . . . .	89
Drying Oil . . . . .	42	FEVE Coating Properties. . . . .	91
Drying Reactions . . . . .	42	Applications of FEVE-Based Coatings . . . . .	93
Alkyd Production . . . . .	43	Concerns When Formulating and Using FEVE Coatings. . . . .	94
Coating Formulations . . . . .	43	Health and Safety . . . . .	95
Driers . . . . .	43	Summary . . . . .	95
Solvents. . . . .	44	<b>Phenolic Coatings</b>	
Oil Content . . . . .	44	<i>Kenneth B. Tator</i> . . . . .	96
Alkyd Modification. . . . .	45	History of the Development of the Phenolic Resin . . . . .	96
Application Methods. . . . .	45	Chemistry and Varieties of Phenolic Resins. . . . .	96
Commercial Products . . . . .	45	Coatings Based on Phenolic Resol Resins . . . . .	98
Concerns about Using Alkyd Coatings . . . . .	46	Concerns when Using Phenolic Coatings. . . . .	99
Summary . . . . .	46	<b>Polyester and Vinyl Ester Coatings</b>	
		<i>Kenneth B. Tator and William R. Slama</i> . . . . .	100
		History . . . . .	100
		Polyester Coating Applications. . . . .	101
		Strengths of Polyesters and Vinyl Esters . . . . .	101

Additives for Both Unsaturated Polyester and Vinyl Ester Coatings . . . . .	102	Silicates and Siliconates . . . . .	179
Polyester and Vinyl Ester Linings, Coatings, and Flooring for Chemical-Resistant Industrial Applications . . . . .	103	Silicone Fluids . . . . .	179
Chemistry of Polyester Polymer Systems . . . . .	105	Silicone Resins . . . . .	179
Saturated Polyesters . . . . .	105	Applications . . . . .	180
Unsaturated Polyesters . . . . .	107	Silicon-Base Additives . . . . .	183
Chemistry of Vinyl Ester Resins . . . . .	109	Summary . . . . .	183
<b>Polyurethane Coatings</b>		<b>Polysiloxane Hybrid Coatings</b>	
<i>Steven Reinstadtler, C. Todd Williams, and Ahren Olson</i> . . . . .	111	<i>Gerald L. Witucki</i> . . . . .	185
Introduction to Polyurethane . . . . .	111	Introduction . . . . .	185
Polyurethane Chemistry Basics . . . . .	111	Industrial Maintenance Topcoats . . . . .	185
Polyurethane Coatings Overview . . . . .	112	Architectural Coatings . . . . .	187
Types of Polyurethane Coatings . . . . .	112	Automotive Clear Coats . . . . .	188
Health Effects of Isocyanates . . . . .	116	Closing Remarks . . . . .	188
<b>Polyurea-Based Coatings</b>		<b>Smart Coatings and Nanotechnology Applications in Coatings</b>	
<i>Dudley J. Primeaux II</i> . . . . .	118	<i>Todd Hawkins, Jorma Virtanen, Charles Simpson, and Joshua Armstrong</i> . . . . .	189
Polyurea Systems . . . . .	118	Smart Coatings . . . . .	189
A Brief History of Polyurea Development . . . . .	118	Nanotechnology Applications in Coatings . . . . .	190
Polyurea Chemistry and Formulation . . . . .	119	Nanomaterials . . . . .	190
Performance Issues . . . . .	123	Nanofilms . . . . .	194
Application Processing Considerations . . . . .	124	Synthesis Techniques . . . . .	194
Real-World Problems and Concerns . . . . .	127	Specific Applications in Coatings . . . . .	194
Safety Practices . . . . .	130	Characterization and Manipulation of Nanomaterials . . . . .	197
Conclusion . . . . .	130	Environmental and Health Considerations . . . . .	197
<b>Polyaspartic Coatings</b>		<b>Bitumens—Coal Tar and Asphalt Coatings</b>	
<i>Edward P. Squiller and Steven Reinstadtler</i> . . . . .	132	<i>Kenneth B. Tator</i> . . . . .	200
History . . . . .	132	Asphalts . . . . .	200
Polyaspartic Esters and their Chemistry . . . . .	132	Coal Tar . . . . .	201
Fast Curing Corrosion Protection Coating Systems . . . . .	134	Comparison of Asphalt and Coal Tar Coatings . . . . .	202
Polyaspartic Floor Coatings . . . . .	136	Health and Environmental Concerns Regarding Asphalt and Coal Tar . . . . .	203
Health Effects of Isocyanates . . . . .	137	<b>Wax-Based Coating Systems</b>	
Conclusion . . . . .	137	<i>Charles Kennedy and Frank Rampton</i> . . . . .	205
<b>Polymeric Floor Coatings</b>		Petrolatum and Microcrystalline Wax . . . . .	205
<i>Frederick Gelfant</i> . . . . .	139	Petrolatum and Microcrystalline Tape Systems . . . . .	206
Polymeric Floor Coating Markets . . . . .	139	Marine Petrolatum-Based Pile Systems . . . . .	208
Service Conditions . . . . .	142	Cold-Applied Petrolatum-Based Paste Coating Systems . . . . .	209
Polymer Chemistries Used in Flooring . . . . .	142	Wax-Based Dips, Brushons, and Sprays . . . . .	209
Polymeric Flooring Systems . . . . .	143	Wax-Impregnated Fabrics and Wax-Coated Papers . . . . .	209
Properties and Testing . . . . .	144	Hot-Applied Microcrystalline Wax Flood Coating Systems . . . . .	210
Installation of Polymeric Floor Coatings . . . . .	146	Wax-Based Casing Fillers . . . . .	211
Regulatory Requirements . . . . .	147	<b>Zinc-Rich Coatings</b>	
Issues, Failures, and Solutions . . . . .	147	<i>Kenneth B. Tator</i> . . . . .	213
Summary . . . . .	149	History . . . . .	213
<b>Powder Coatings—Pipelines</b>		Galvanic Series . . . . .	214
<i>J. Alan Kehr</i> . . . . .	152	Types of Zinc-Rich Coatings . . . . .	215
Chemistries of FBE: Types of Resins and Curatives . . . . .	152	<b>Surface Preparation and Coating Application</b> . . . . .	<b>221</b>
Functional FBE Coating Systems: External, Three Layer, Internal, and Rebar . . . . .	153	<b>Surface Preparation</b>	
Fusion-Bonded Epoxy Functional Coatings—Problems and Problem Avoidance . . . . .	161	<i>Kenneth A. Trimber and William D. Corbett</i> . . . . .	223
<b>Powder Coatings—Other Industries</b>		Presurface-Preparation Inspection . . . . .	223
<i>Denis Grimshaw</i> . . . . .	168	Methods of Surface Preparation . . . . .	227
Advantages and Disadvantages of Powder Coating . . . . .	168	Surface-Cleanliness Standards . . . . .	231
Uses of Powder Coatings . . . . .	168	Conclusion . . . . .	235
Powder Coatings Formulation Components . . . . .	169	<b>Soluble Salts beneath Coatings</b>	
Manufacture of Powder Coatings . . . . .	170	<i>Kenneth B. Tator</i> . . . . .	236
Application of Powder Coatings . . . . .	171	Mechanisms of Coating and Corrosion Degradation by Soluble Salts . . . . .	236
Troubleshooting . . . . .	172	Salt Chemistry and Analysis . . . . .	238
Properties and Specifications . . . . .	175	Research Regarding Tolerable Levels of Salts beneath Coatings . . . . .	243
Selection of Coating Type for Typical Uses . . . . .	175	Tolerance Limits of Salts beneath Coatings . . . . .	247
Future Trends and Challenges for Powder Coatings . . . . .	175	What Does All This Mean? . . . . .	248
<b>Silicon-Based Technologies in Coatings</b>			
<i>Gerald L. Witucki</i> . . . . .	177		
Chemistry . . . . .	177		
Uses Of Alkoxy Silanes . . . . .	178		

Coating Application Methods	
<i>James Machen</i> . . . . .	251
Factors to Consider when Selecting an Application Method . . . . .	251
Manual (Hand-Applied) Methods of Coating Application . . . . .	252
Spray Application Methods . . . . .	252
Spray Application Technique . . . . .	255
Shop and Field Quality Control and Quality Assurance	
<i>William D. Corbett</i> . . . . .	256
Defining Quality . . . . .	256
Quality Assurance . . . . .	256
Quality Control . . . . .	257
Duties of QA and QC Personnel . . . . .	257
Sequence of QC and QA Observations and Testing . . . . .	257
Quality Planning . . . . .	257
Overview of Surface Preparation . . . . .	258
Presurface-Preparation Inspection . . . . .	259
Abrasive Quality . . . . .	260
Abrasive Cleanliness . . . . .	261
Lighting . . . . .	261
Industry Standards for Assessing Surface Cleanliness . . . . .	261
Inspection of Surface Preparation . . . . .	263
Inspection of Wood and Concrete Surfaces . . . . .	267
Inspection of Coating Mixing, Thinning, and Application . . . . .	269
Calculation of Wet-Film Thickness . . . . .	271
Postcoating Application Inspection . . . . .	271
Documentation . . . . .	276
Worker Health and Environmental Hazards Associated with Coating Application and Removal	
<i>Dan O'Malley and Stanford T. Liang</i> . . . . .	277
Worker Health Hazards . . . . .	277
Controlling Exposure to Hazardous Coating Constituents . . . . .	281
Environmental Hazards . . . . .	285
Green Coatings	
<i>Barry Law</i> . . . . .	291
The History of Sustainable Development, Green Chemistry, and Green Coatings . . . . .	291
Green Coatings—Marketing and Procurement . . . . .	295
Conclusion . . . . .	298
Master Painters Institute 'Green Performance Standard' . . . . .	298
Master Painters Institute 'Extreme Green Performance Standard' . . . . .	299
Master Painters Institute 'Recycled Product Performance Standards' . . . . .	299
Intended Uses . . . . .	301
Testing Details . . . . .	301
Call-Up Testing and Listing Requirements . . . . .	301
GS-11-1993 . . . . .	302
GC-03—1997 . . . . .	302
GS-11 Edition 3.1—July 12, 2013 . . . . .	302
GS-43 . . . . .	303
EcoLogo Program Certification Criteria Document CCD-047 . . . . .	304
EcoLogo Program Certification Criteria Document CCD-048 . . . . .	304
LEED v3 . . . . .	305
LEED v4 . . . . .	306
Environment Canada Volatile Organic Compound Concentration Limits for Architectural Coatings Regulations . . . . .	307
Utah R307-361 . . . . .	310
Coating Various Substrates	
<i>Jayson L. Helsel</i> . . . . .	313
Preparing and Painting Steel . . . . .	313
Preparing and Painting Cast Iron . . . . .	315
Preparing and Painting Galvanizing . . . . .	316
Preparing and Painting Stainless Steel, Aluminum, and other Nonferrous Metals . . . . .	318
Preparing and Painting Concrete . . . . .	319
Preparing and Painting Wood . . . . .	322
<b>Industrial Uses . . . . .</b>	<b>325</b>
Pipeline Industry Coatings	
<i>E. Bud Senkowski</i> . . . . .	327
Why Do We Need Pipeline Coatings? . . . . .	327
How Long Have We Used Pipeline Coatings? . . . . .	327
Developments during 1930 to 1950 . . . . .	327
Developments during 1950 to 1970 . . . . .	327
Developments since 1970 . . . . .	328
The Evolution of Pipeline Coating Materials . . . . .	328
Factors Affecting Pipeline Coating Performance . . . . .	328
Current Usage Patterns of Pipeline Coating Materials . . . . .	332
Other Pipeline Coating Materials in Current Use . . . . .	332
Coating of Joints . . . . .	337
Marine Coatings	
<i>Mark Schultz, Timothy McDonough, Michael Eckart, and Mike Bentkjaer, Sherwin-Williams</i> . . . . .	340
The Vessel Interior—Ballast Tanks . . . . .	340
Common Issues Encountered when Coating Ballast Tanks . . . . .	341
Requirements Associated with Coating Ballast (and Associated) Tanks . . . . .	343
Advent of Ultra-High Solids Coatings Ballast Tank Technology . . . . .	345
Antifouling . . . . .	348
The Vessel Exterior: Freeboard, Topside, and Decks . . . . .	351
Conclusion . . . . .	353
Coatings Used in the Nuclear Industry	
<i>E. Bud Senkowski</i> . . . . .	354
Basic Designs of Nuclear Power Plants . . . . .	354
Coating Usage in Nuclear Plants . . . . .	355
The Design Basis Accident . . . . .	355
Design Basis Accident Testing . . . . .	356
Other Critical Coating Parameters . . . . .	357
Coating Selections in the Nuclear Plant . . . . .	359
Protective Coating Strategies in Generation III Plants . . . . .	360
Bridge Coatings	
<i>Greg Richards, Kimmer Cline, and Douglas Reardon</i> . . . . .	361
Bridge Deterioration . . . . .	361
Types of Bridge Designs . . . . .	361
Bridge Corrosion-Zone Environments . . . . .	362
Bridge Areas of Greatest Corrosion Concern . . . . .	365
Steel Bridge Coatings . . . . .	366
Concrete Bridges . . . . .	369
Application Methods . . . . .	372
Coating Condition Assessment . . . . .	372
Summary . . . . .	373
Transportation—Railcar Coatings	
<i>Jim Molnar</i> . . . . .	374
A Brief History of Rail Coatings . . . . .	374
The Rail Coating Environment . . . . .	374
Exposures and Logistics . . . . .	375
Exterior Rail Coatings . . . . .	376
Application of Exterior Coatings . . . . .	377
Interior Rail Coatings (Hoppers, Tanks, and Box) . . . . .	379
Application . . . . .	380
Rubber Linings (Tank Car Interiors) . . . . .	382
Coating Selection . . . . .	382
Regulatory Compliance (Tank Cars) . . . . .	383
Summary . . . . .	383
Appendix . . . . .	384

Guidance for the Use of Protective Coatings in Municipal Potable Water Systems		Coating Failure Analysis	
<i>R.A. Nixon</i> . . . . .	385	<i>Rick Huntley</i> . . . . .	474
Water System Components . . . . .	385	Obtaining and Analyzing Background Information . . . . .	474
Water Treatment Plants . . . . .	386	Preliminary Determination of Site Conditions . . . . .	475
Elevated and On-Ground Storage Tanks, Towers, and Reservoirs . . . . .	388	Inspection Equipment Requirements . . . . .	475
Probable Corrosion Mechanisms . . . . .	390	Coating Failure Site Investigation . . . . .	477
Selection Criteria for Protective Coatings in Municipal Water Systems . . . . .	396	Sampling Techniques . . . . .	480
Commonly Used Generic Coating Systems in Water Applications . . . . .	398	Sample Chain of Custody . . . . .	482
Common Quality Watchouts . . . . .	398	Coordination with the Coatings Laboratory . . . . .	482
Protective Coatings for Corrosion Control in Municipal Wastewater Systems		Report Preparation . . . . .	482
<i>R.A. Nixon</i> . . . . .	403	Sample Retention . . . . .	482
Wastewater System Components . . . . .	403	Laboratory Testing	
Wastewater Treatment or Water Reclamation Plants . . . . .	405	<i>Cindy O'Malley, Carly McGee, and Valerie Sherbondy</i> . . . . .	483
Typical Corrosion Mechanisms in Municipal Wastewater Systems . . . . .	411	Visual and Microscopic Examination . . . . .	483
Selection Criteria for Protective Coatings in Municipal Wastewater Systems . . . . .	415	Fourier Transform Infrared Spectroscopy . . . . .	485
Commonly Used Generic Coating Systems in Wastewater Applications . . . . .	418	Differential Scanning Calorimetry . . . . .	487
Common Quality Watchouts . . . . .	420	Scanning Electron Microscopy-Energy Dispersive X-Ray Spectroscopy . . . . .	489
Guidelines for Maintenance Coating of Steel Structures in Pulp and Paper Mills		Chromatography . . . . .	489
<i>R.A. Nixon and D. Bennett</i> . . . . .	422	Electrochemical Impedance Spectroscopy . . . . .	492
Scope, Fundamental Elements, and Condition Assessments . . . . .	422	Test Cabinets and Standard Test Environments . . . . .	492
Pulp and Paper Mill Environments . . . . .	424	Nonstandard Testing for Simulation . . . . .	498
Surface-Preparation Requirements and Standards . . . . .	427	Coating Failures and Defects	
Coating Systems and Materials . . . . .	429	<i>Brendan Fitzsimons and Trevor Parry</i> . . . . .	502
Quality and Productivity . . . . .	431	Abrasion . . . . .	502
Special Considerations . . . . .	434	Adhesion Failure . . . . .	502
Coatings for Commercial Structures and Building Deficiencies that Affect Performance		Alligatoring (Crocodiling) . . . . .	503
<i>Kenneth A. Trimber, Kevin J. Brown and Kevin D. Knight</i> . . . . .	438	Bleeding . . . . .	503
Purposes of Coatings in Commercial Buildings . . . . .	439	Blistering . . . . .	503
Coating System Selection . . . . .	439	Bloom (Blush) . . . . .	503
Common Problems and Design Considerations for Masonry Coatings . . . . .	442	Bridging . . . . .	504
Conclusions . . . . .	448	Bubbles or Bubbling . . . . .	504
<b>Coating Analysis and Evaluation . . . . .</b>	<b>451</b>	Cathodic Disbonding . . . . .	504
Estimating the Cost of Industrial Painting Projects		Chalking . . . . .	504
<i>Michael P. Reina</i> . . . . .	453	Checking . . . . .	505
The Nature of Estimating . . . . .	453	Cobwebbing . . . . .	505
Estimating Methods . . . . .	453	Cissing . . . . .	505
Determining the Scope of Work . . . . .	455	Cracking . . . . .	505
Calculating Surface Area Takeoff . . . . .	456	Cratering . . . . .	506
Calculating Labor Quantities and Rates . . . . .	457	Cratering . . . . .	506
Calculating Material Quantities and Costs . . . . .	458	Crowsfooting . . . . .	506
Calculating Equipment Costs . . . . .	458	Crazing . . . . .	506
Remembering Forgotten Costs . . . . .	459	Delamination . . . . .	506
Conducting a Coating Condition Assessment . . . . .	459	Fading . . . . .	507
Putting It All Together and Determining the Selling Price . . . . .	460	Grinning . . . . .	507
Coating Deterioration		Flaking . . . . .	507
<i>Kenneth B. Tator</i> . . . . .	462	Heat Damage . . . . .	507
Variability within a Properly Applied Coating Layer . . . . .	462	Impact Damage . . . . .	508
Environmental Effects Resulting in Coating Deterioration . . . . .	463	Mud Cracking . . . . .	508
Conclusion . . . . .	472	Intercoat Contamination . . . . .	508
		Orange Peel . . . . .	508
		Peeling . . . . .	509
		Rippled Coating . . . . .	509
		Pinholes . . . . .	509
		Runs . . . . .	509
		Rust Rashing . . . . .	510
		Rust Staining . . . . .	510
		Rust Spotting . . . . .	510
		Sags . . . . .	510
		Settlement . . . . .	511
		Solvent Lifting . . . . .	511
		Skinning . . . . .	511
		Solvent Popping . . . . .	511
		Staining . . . . .	512
		Undercutting . . . . .	512

Stress Cracking . . . . .	512	Cementitious Linings . . . . .	515
Wrinkling . . . . .	512	Glass and Porcelain Enamels . . . . .	515
Overview of Other Protection Methods		Electroplating . . . . .	515
<i>Kenneth B. Tator</i> . . . . .	513	Thermal Spray Coatings . . . . .	515
Conversion Coatings . . . . .	513	Rubber Linings . . . . .	515
Hot Dip Galvanizing . . . . .	514	Index . . . . .	517