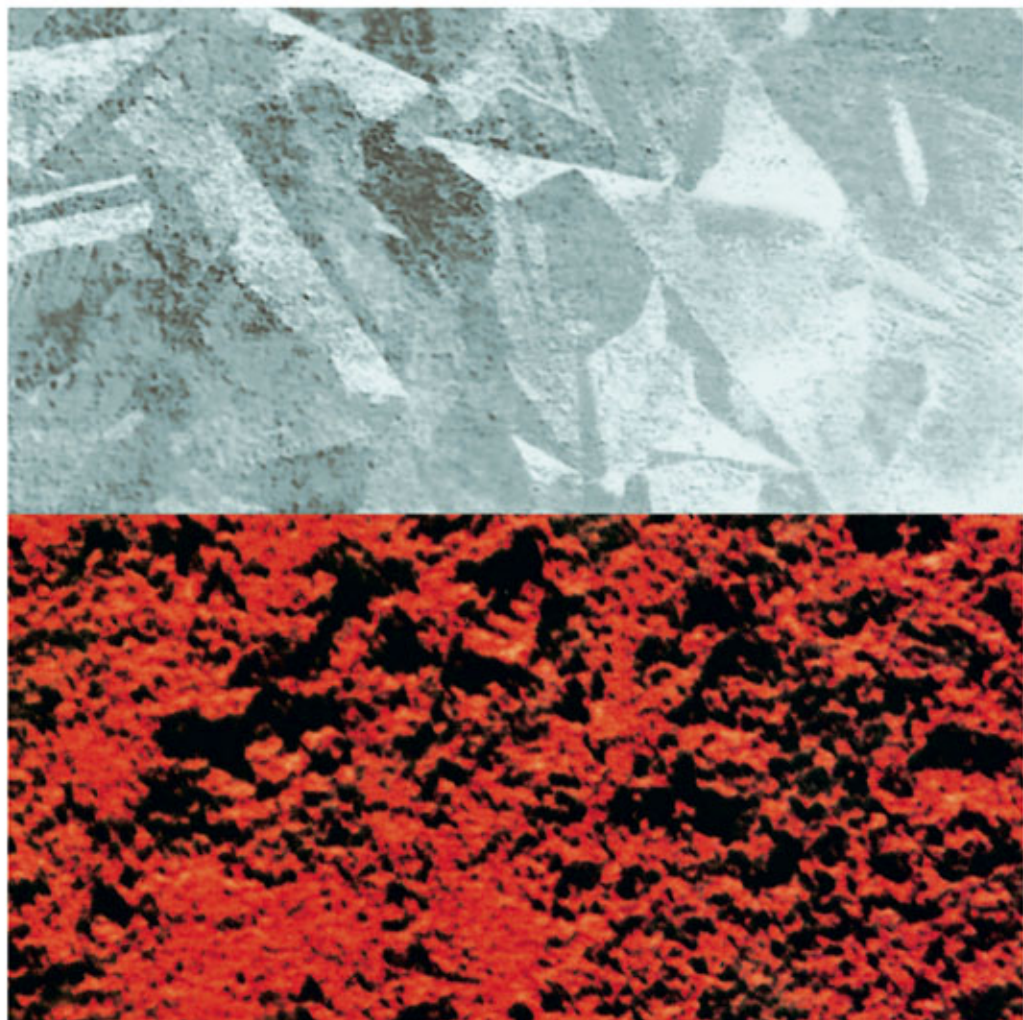


Edited by Peter Maass  
and Peter Peissker

 WILEY-VCH

# Handbook of Hot-dip Galvanization





*Edited by*  
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## **Handbook of Hot-dip Galvanization**



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## Contents

<b>Preface to the Third German Edition</b>	<i>XVII</i>
<b>Acknowledgment</b>	<i>XIX</i>
<b>Preface to the Second German Edition</b>	<i>XXI</i>
<b>List of Contributors</b>	<i>XXIII</i>

<b>1</b>	<b>Corrosion and Corrosion Protection</b>	<b>1</b>
	<i>Peter Maaß</i>	
1.1	Corrosion	1
1.1.1	Causes of Corrosion	1
1.1.2	Types of Corrosion	2
1.1.3	Corrosion Phenomena	3
1.1.4	Corrosive Stress	4
1.1.4.1	Atmospheric Corrosion	5
1.1.4.2	Corrosion in the Soil	5
1.1.4.3	Corrosion in Water	6
1.1.4.4	Special Corrosive Stress	7
1.1.4.5	Avoidance of Corrosion Damages	7
1.2	Corrosion Protection	7
1.2.1	Procedures	7
1.2.1.1	Active Procedures	7
1.2.1.2	Passive Procedures	9
1.2.2	Commercial Relevance	10
1.2.3	Corrosion Protection and Environmental Protection	18
	Appendix 1.A	18
<b>2</b>	<b>Historical Development of Hot-dip Galvanizing</b>	<b>21</b>
	<i>Peter Maaß</i>	
	References	27
<b>3</b>	<b>Surface-preparation Technology</b>	<b>29</b>
	<i>Peter Peißker</i>	

3.1	As-delivered Condition	30
3.1.1	Basic Material	30
3.1.1.1	Steel Composition	30
3.1.2	Surface Finish	31
3.1.2.1	Similar Contaminants	31
3.1.2.2	Dissimilar Contaminants	32
3.1.2.3	Defects on Steel Substrates	34
3.1.3	Steel Surface Roughness	35
3.2	Mechanical Surface-preparation Methods	35
3.2.1	Blast Cleaning	35
3.2.2	Barrel Finishing	36
3.3	Chemical Cleaning and Degreasing	37
3.3.1	Alkaline Cleaner	40
3.3.1.1	Composition	40
3.3.1.2	Water	41
3.3.1.3	Working Conditions	42
3.3.1.4	Analytical Control, Service Life, Recycling	44
3.3.2	Biological Cleaning	48
3.3.3	Pickle Degreasing	49
3.3.4	Other Cleaning Methods	51
3.4	Rinsing of the Parts	51
3.4.1	Carryover	52
3.4.1.1	Surface Data	52
3.4.1.2	Withdrawal, Dripping	52
3.4.1.3	Carryover	52
3.4.2	Calculation of Rinsing Processes	53
3.4.3	Rinsewater Recirculation	56
3.5	Pickling	57
3.5.1	Material and Surface Condition	58
3.5.1.1	Structure of the Oxide Layer	58
3.5.1.2	The Material Steel	58
3.5.1.3	Topography	60
3.5.2	Hydrochloric-acid Pickle	61
3.5.2.1	Composition	62
3.5.2.2	Pickling Conditions	64
3.5.2.3	Inhibition and Hydrogen Embrittlement	71
3.5.2.4	Analytical Control, Recycling, Utilization of Residual Material	75
3.5.3	Preparation of Cast Materials	79
3.5.4	Dezincification	80
3.6	Hot-dip Galvanizing Fluxes	81
3.6.1	Fluxes on ZnCl <sub>2</sub> /NH <sub>4</sub> Cl Basis	81
3.6.1.1	Dry Galvanizing	82
3.6.1.2	Wet Galvanizing	83
3.6.2	The ZnCl <sub>2</sub> /NaCl/KCl System	84
3.6.3	Flux-induced Residues	84



References	85
Standards	89
Lifting Devices	90

<b>4</b>	<b>Hot-dip Galvanizing and Layer-formation Technology</b>	<b>91</b>
	<i>W.-D. Schulz and M. Thiele</i>	
4.1	Process Variants	91
4.1.1	Continuous Hot-dip Galvanizing of Steel Strips and Steel Wire	91
4.1.2	Batch Galvanizing	94
4.1.2.1	Dry Galvanizing Process	94
4.1.2.2	Wet Galvanizing Process	94
4.1.3	Special Processes	97
4.2	Layer Formation in Hot-dip Batch Galvanizing Between 435°C and 620°C	98
4.2.1	General Notes	98
4.2.1.1	Low-silicon Range (<0.035% Si)	100
4.2.1.2	Sandelin Range (0.035–0.12% Si)	101
4.2.1.3	Sebisty Range (0.12–0.28% Si)	101
4.2.1.4	High-silicon Range (>0.28% Si)	101
4.2.2	Influence of Melting Temperature and Immersion Time on Layer Thickness	102
4.2.3	Influence of Heat Treatment of Steels Prior to Galvanizing	106
4.2.4	High-temperature Galvanizing above 530°C	107
4.2.5	Structural Analyses	108
4.2.5.1	Crystalline Structure in the Temperature Range of 435–490°C	108
4.2.5.2	Crystalline Structure in the Temperature Range of 490–530°C	110
4.2.5.3	Crystalline Structure in the High-temperature Range of 530–620°C	111
4.2.6	Holistic Theory of Layer Formation	114
4.2.6.1	Normal Temperature Range between 435 and 490°C	114
4.2.6.2	Temperature Range between 490°C and 530°C	115
4.2.6.3	High-temperature Range between 530°C and 620°C	115
4.2.7	Influence of Alloying Elements of the Melt on Layer Formation	117
4.2.7.1	Conventional Zinc Melts	117
4.2.7.2	Alloyed Zinc Melts	117
4.3	Liquid-metal-induced Embrittlement (LME)	120
4.4	After-treatment	122
	References	122
<b>5</b>	<b>Technical Equipment</b>	<b>125</b>
	<i>R. Mintert and Peter Peißker</i>	
5.1	Preliminary Planning	125
5.1.1	Preliminary Study	125
5.1.2	Intensive Study	125
5.1.3	Application for Approval	126

5.2	Layout Variants of Plants	126
5.2.1	Linear Arrangement	126
5.2.2	U-Shaped Arrangement	126
5.2.3	Mounting Area	130
5.2.4	Frames, Crossbeams, Auxiliary Devices	130
5.2.4.1	Feeding Devices	133
5.2.4.2	Typical Examples for Frames and Crossbeams	134
5.2.5	Automatic Batch Galvanizing Plant	136
5.3	Pretreatment Plant	137
5.3.1	Pretreatment Units	137
5.3.2	Pickling Housing	139
5.3.3	Heat Supply of Pretreatment Baths	140
5.3.4	Favorable Tank Covers	142
5.4	Drying Furnaces	142
5.5	Galvanizing Furnaces	145
5.5.1	Immersion burners for heating of ceramic bath for zinc and zinc/ aluminum	145
5.5.2	Galvanizing Furnaces with Circulating Heating	146
5.5.3	Galvanizing Furnaces with Surface Heating	146
5.5.4	Galvanizing Furnaces with Impulse Burner Heating	148
5.5.5	Galvanizing Furnace with Induction Heating	148
5.5.6	Galvanizing Furnace with Resistance Heating	149
5.5.7	Galvanizing Furnaces with Channel Inductor	149
5.5.8	Service Plan: Galvanizing Kettle	150
5.6	Galvanizing Kettle	155
5.7	Zinc Bath Housings	155
5.7.1	Transverse Housing, Stationary	157
5.7.1.1	Housing with Hinged or Sliding Covers	157
5.7.2	Transverse Housing, Crane Displaceable	158
5.7.3	Longitudinal Housing	159
5.8	After-treatment	159
5.9	Unloading Area	160
5.10	Crossbeam Return	160
5.11	Crane Units	160
5.11.1	Adaptation of Crane Systems to the Galvanizing Operation	161
5.11.2	Equipment Overview	161
5.12	Filtration Plants	163
5.13	Semiautomatic Galvanizing Lines for Small Parts	164
5.14	Galvanizing Furnace with Ceramic Trough	165
5.15	Automatic Galvanizing Line for Small Parts	169
5.15.1	Fully Automatic Galvanizing Plants for High-Precision Bolts	169
5.15.2	Automatic Robot-operated Centrifugal Galvanizing Line	170
5.16	Pipe Galvanizing Line	170
5.17	Application of Vibrators	172
5.18	Energy Balance	174

- 5.19 Commissioning and Decommissioning of a Hot-dip Galvanizing Kettle, Kettle Change, Method of Operation 176
- 5.19.1 Hot-dip Galvanizing Kettles and Galvanizing Furnaces 176
- 5.19.2 Commissioning 177
- 5.19.3 Optimum Operation 179
- 5.19.4 Efficient Energy Consumption and Service Life of the Kettle 180
- 5.19.5 Decommissioning 181
- 5.19.6 Galvanizing Kettle Failure 182
- References 183

## **6 Environmental Protection and Occupational Safety in Hot-dip Galvanizing Plants 185**

*C. Kaßner*

- 6.1 Rules and Measures Concerning Air-pollution Control 185
- 6.1.1 Rules 185
- 6.1.2 Authorizations 187
- 6.2 Measures for the Control of Air Pollution 188
- 6.2.1 Ventilation Equipment in the Hot-dip Galvanizing Industry 188
- 6.2.1.1 Ventilation Systems 189
- 6.2.1.2 Collection Systems 191
- 6.2.1.3 Restraint Systems 196
- 6.2.1.4 Induced Draft Fans 207
- 6.2.1.5 Discharge of Emissions 208
- 6.3 Measuring Systems 210
- 6.3.1 Emission Measurement 210
- 6.3.2 Measurement in the Working Area 210
- 6.3.3 Trend Measuring 211
- 6.4 Waste and Residual Materials 211
- 6.4.1 General Notes 211
- 6.4.2 Oily Wastes/Residual Materials from Degreasing 213
- 6.4.2.1 Oily Waste /Residues from Degreasing Bathes 213
- 6.4.2.2 Oil- and Grease-containing Sludge and Concentrates 213
- 6.4.3 Spent Pickling Solutions 213
- 6.4.4 Wastes/Flux Treatment Residues 214
- 6.4.4.1 Spent Flux Baths 214
- 6.4.4.2 Iron-hydroxide Sludge 215
- 6.4.5 Wastes/Galvanizing Residues 215
- 6.4.5.1 Dross 215
- 6.4.5.2 Zinc Ash 215
- 6.4.5.3 Spattered Zinc 216
- 6.4.6 Further Wastes/Residues 216
- 6.5 Noise 216
- 6.5.1 General Notes 216
- 6.5.2 Noise Protection in Hot-dip Galvanizing Plants 218
- 6.5.2.1 Personal Protection Equipment 218

6.5.2.2	Operational Measures	218
6.6	Occupational Safety	219
6.6.1	General Notes	219
6.6.1.1	Legal Foundations	219
6.6.1.2	Accidents in Hot-dip Galvanizing Companies	219
6.6.1.3	Accident Costs	220
6.6.2	Equipment of the Hot-dip Galvanizing Company	221
6.6.2.1	General Notes	221
6.6.2.2	Workrooms and Working Areas	221
6.6.2.3	Open Baths	221
6.6.2.4	Feeding Devices	222
6.6.3	Operating Instructions/General Instructions	223
6.6.4	Personal Protection Equipment	223
6.6.5	Personal Rules of Conduct	223
6.6.6	Handling of Hazardous Substances	227
6.6.7	Safety Marking at the Workplace	228
6.6.8	Statutory Representative for Environmental and Labor Protection	228
6.7	Practical Measures for Environmental Protection	230
	References	234
	Further References	237

## **7 Design and Manufacturing According to Hot-dip Galvanizing Requirements** 239

*G. Scheer and M. Huckshold*

7.1	General Notes	239
7.2	Requirements Regarding Surface Quality of the Basic Material	241
7.2.1	General Notes	241
7.2.2	Removal of Dissimilar Layers	241
7.2.2.1	Oils and Greases	241
7.2.2.2	Welding Slag and Welding Tools	241
7.2.2.3	Blasting, Abrasive Residues	242
7.2.2.4	Paint, Old Coatings, Markings	242
7.2.3	Surface Roughness	243
7.2.4	Shells, Scales, Overlaps	243
7.3	Dimensions and Weights of Material to be Galvanized	244
7.3.1	General Notes	244
7.3.2	Bath Dimensions, Piece Weights	244
7.3.3	Bulky Parts, Oversized Parts	245
7.3.4	Suspensions	246
7.4	Containers and Tubular Constructions (Hollow Bodies)	247
7.4.1	General Notes	247
7.4.2	Tubular Constructions	247
7.4.3	External Galvanizing of Tubes and Containers	248
7.4.4	Containers	249
7.5	Steel Profile Constructions	251

7.5.1	Materials/Material Thickness/Stress	251
7.5.2	Surface Preparation	251
7.5.3	Overlaps	252
7.5.4	Free Punches and Flow Apertures	252
7.6	Steel Sheet and Steel Wire	255
7.6.1	Sheet Steelware	255
7.6.1.1	Joining Methods	255
7.6.1.2	Design	255
7.6.2	Wire Products	257
7.7	Constructions of Hot-dip Galvanized Semifinished Products	257
7.7.1	Requirements	258
7.7.2	Processing	259
7.8	Avoidance of Distortion and Crack Formation	260
7.8.1	Coherences	260
7.8.2	Remedies	262
7.8.3	Reduction of Distortion/Crack Risk in Large Steel Constructions	263
7.9	Welding Before and After Hot-dip Galvanizing	265
7.9.1	Welding Before Hot-dip Galvanizing	265
7.9.1.1	General Notes	265
7.9.1.2	Sources of Defects	265
7.9.1.3	Welding Practice	266
7.9.2	Welding After Hot-dip Galvanizing	268
7.9.2.1	General Notes	268
7.9.2.2	Welding Practice	268
7.10	Hot-dip Galvanizing of Small Parts	270
7.10.1	Methods	270
7.10.2	What are Small Parts?	271
7.10.3	Appearance and Surface Quality	271
7.10.4	Products	271
7.10.4.1	Fasteners	271
7.10.4.2	Nails, Pivots, Discs, Hooks, etc.	272
7.10.4.3	Small Parts of Sectional Steel, Bar Steel and Sheet	272
7.10.4.4	Chains	273
7.11	Reworking and Repair of Zinc Coatings	273
7.11.1	Zinc Ridges, Drainage Runs	273
7.11.2	Hinges and Thread Bolts	273
7.11.3	Imperfections and Damages	274
7.12	Hot-dip Galvanizing of Cast Materials	276
7.13	Local Avoidance of Zinc Adherence	277
7.14	Standards and Guidelines	278
7.14.1	DIN EN ISO 1461 and National Supplement 1 (Notes)	278
7.14.2	DIN EN ISO 14713	281
7.14.3	Further Standards	281
7.15	Defects and Avoiding Defects	282
7.15.1	Extraneous Rust	282

7.15.2	Grinding Sparks	284
7.15.3	Cracks in Workpieces	284
7.15.4	Dissimilar Layers on the Steel Structure	284
7.15.5	Thermal Impacts	286
7.15.6	Damages through Straightening Work	287
7.15.7	Galvanizing Defects through Air Inclusions	287
7.15.8	Unprotected Fasteners	287
	References	288
<b>8</b>	<b>Quality Management in Hot-dip Galvanizing Companies</b>	<b>291</b>
	<i>G. Halm</i>	
8.1	Why Quality Management?	291
8.2	Important Criteria	292
8.3	Structure of the QM System according to DIN EN ISO 9001:2000	292
8.4	Short Description of QM Elements Sections 4–8	294
8.4.1	Documentation Requirements Section 4	294
8.4.2	Management Responsibilities Section 5	295
8.4.3	Resource Management Section 6	295
8.4.4	Product Realization Section 7	295
8.4.5	Measuring, Analysis and Improvement Section 8	296
8.5	Introduction of QM Systems	300
8.6	Trends	300
	Acknowledgment	301
	References	301
<b>9</b>	<b>Corrosion Behavior of Zinc Coatings</b>	<b>303</b>
	<i>H.-J. Böttcher, W. Friehe, D. Horstmann, C.-L. Kruse, W. Schwenk, and W.-D. Schulz</i>	
9.1	Corrosion–Chemical Properties	303
9.1.1	General Notes	303
9.1.2	Basic Principles of Corrosion in Waters	305
9.1.3	Thermodynamic Fundamentals	309
9.1.4	Bimetallic Corrosion	312
9.1.5	Thermal Resistance	313
9.1.6	Mechanical Resistance	314
9.2	Corrosion Caused by Atmosphere	314
9.2.1	General Notes	314
9.2.2	Corrosion Caused by Natural Weathering	315
9.2.2.1	Corrosion Caused by Natural Weathering without Rain Protection	316
9.2.2.2	Corrosion in Natural Weathering with Rain Protection	319
9.2.3	Indoor Corrosion	320
9.2.3.1	Interior Rooms without Air Conditioning	320
9.2.3.2	Interior Rooms with Air Conditioning	321

9.2.4	White-rust Formation	321
9.2.5	Corrosion Due to Drain Water	324
9.3	Corrosion through Water	324
9.3.1	Drinking Water	324
9.3.2	Swimming-pool Water	326
9.3.3	Open Cooling Systems	326
9.3.4	Closed Heating and Cooling Systems	327
9.3.5	Wastewater	327
9.3.5.1	Rainwater	327
9.3.5.2	Domestic Wastewater	327
9.3.5.3	Wastewater Treatment Plants	328
9.3.6	Seawater	328
9.3.6.1	Cover-layer Formation	329
9.3.6.2	Blistering	329
9.3.6.3	Duplex-Systems	330
9.4	Corrosion in Soils	330
9.4.1	Free-corrosion Behavior	331
9.4.2	Potential Dependence of the Corrosion Rate	332
9.4.3	Reaction to Element Formation and Stray Current Impact	333
9.4.4	Reaction to the Impact of Alternating Current	333
9.5	Corrosion Resistance to Concrete	334
9.6	Corrosion in Agricultural Facilities and Caused by Agricultural Products	336
9.6.1	Buildings and Barn Equipment	337
9.6.2	Storage and Transport	337
9.6.3	Foodstuffs	338
9.7	Corrosion through Nonaqueous Media	338
9.8	Corrosion Protection Measures at Defective Spots	340
9.8.1	General Notes	340
9.8.2	Repair Methods	340
9.8.2.1	Thermal Spraying with Zinc	341
9.8.2.2	Application of Coating Materials	341
9.8.2.3	Application of Solders	341
9.9	Examination of Corrosion Resistance and Quality Test	342
9.9.1	Appearance	342
9.9.2	Layer Thickness	342
9.9.3	Adhesiveness	343
	References	343
<b>10</b>	<b>Coatings on Zinc Layers–Duplex-Systems</b>	<b>349</b>
	<i>A. Schneider</i>	
10.1	Fundamentals, Use, Main Fields of Application	349
10.2	Definitions of Terms	352
10.3	Protection Period of Duplex-Systems	353
10.4	Special Features of the Constructive Design of Components	353

10.5	Quality Requirements for the Zinc Coating for Protective Paint Layers	355
10.6	Surface Preparation of the Zinc Coating for the Protective Paint	356
10.6.1	Contaminations on the Zinc Coating	356
10.6.2	Surface-preparation Methods	357
10.6.3	Description of Practically Applied Surface-preparation Methods	359
10.6.3.1	Sweep-blasting	359
10.6.3.2	High-pressure Water Jet or Steam Blasting	360
10.6.3.3	Grinding with Abrasive Fleece	361
10.6.3.4	Chemical Conversion	362
10.6.4	Classification of Surface Preparation and Protective Paint Coating in the Manufacturing Technology	363
10.6.4.1	Protective Paint Systems with Liquid Coating Materials	363
10.6.4.2	Protective Paint Systems with Powder Coating Materials	364
10.7	Coating Materials, Protective Paint Systems	364
	References	369
<b>11</b>	<b>Economic Efficiency of Hot-dip Galvanizing</b>	<b>371</b>
	<i>Peter Maafß</i>	
	References	377
<b>12</b>	<b>Examples of Use</b>	<b>379</b>
	<i>Peter Maafß</i>	
12.1	Building Construction	380
12.2	Civil Engineering	383
12.3	Traffic Engineering	385
12.4	Sport/Leisure	388
12.5	Plant Engineering	389
12.6	Mining	390
12.7	Energy Supply	391
12.8	Agriculture	393
12.9	Component Parts/Fasteners	394
12.10	Environmental Protection	396
12.11	Handicraft	397
12.12	Art	399
12.13	Continuous-sheet Galvanizing	400
12.14	Conclusion	401
<b>13</b>	<b>Appendix</b>	<b>403</b>
	<i>Peter Maafß</i>	
	Appendix A Defect Occurrence on Zinc Coatings and at Hot-dip Galvanized Workpieces	403
13.1	Requirements for the Zinc Coating	403
13.1.1	Design	403



- 13.1.2 Workpiece Properties 404
- 13.1.3 Coating Properties 404
- 13.1.4 Layer Thickness 404
- 13.1.5 Repairs 404
- 13.1.6 Adhesiveness 405
- 13.2 Assessment Criteria for Hot-dip Galvanized Coatings on Steel Structures 405
- 13.3 Major Defects in the Zinc Coating or at the Hot-dip Galvanized Workpiece 406
  - 13.3.1 Defects Originating from the Design of the Workpiece 406
    - 13.3.1.1 Accumulations (Zinc Build-up) 406
    - 13.3.1.2 Blocked Boreholes 407
    - 13.3.1.3 Metal Embrittlement 407
    - 13.3.1.4 Flash 407
    - 13.3.1.5 Closed Hollow Bodies 407
    - 13.3.1.6 Burned Castings 408
    - 13.3.1.7 Distortion 408
    - 13.3.1.8 Efflorescence of Salts 408
    - 13.3.1.9 Inclusions of Pickle and Flux Residues 408
  - 13.3.2 Defects Originating from Surface Coverings on the Workpiece 409
    - 13.3.2.1 Defects due to Paint, Oil Crayon, Tar, etc. 409
    - 13.3.2.2 Defects due to Grease and Oil 409
    - 13.3.2.3 Defects due to Welding Slag 409
    - 13.3.2.4 Black Areas 409
  - 13.3.3 Defects Arising due to the Process Engineering Applied in Hot-dip Galvanizing 409
    - 13.3.3.1 Ash, Flux 409
    - 13.3.3.2 Thick Zinc Coating 410
    - 13.3.3.3 Thin Zinc Coating 410
    - 13.3.3.4 Peeling 410
    - 13.3.3.5 Sticking Points 410
    - 13.3.3.6 Pimples 411
    - 13.3.3.7 Rough Surface 411
    - 13.3.3.8 Formation of Tears and Sags 411
    - 13.3.3.9 Drainage Runs, Drops, Points 411
  - 13.3.4 Defects Caused by Transport, Storage and Assembly 412
    - 13.3.4.1 Extraneous Rust 412
    - 13.3.4.2 White Rust 412
    - 13.3.4.3 Flaking 413
    - 13.3.4.4 Brown Staining 413
    - 13.3.4.5 Blistering 413
  - 13.3.5 Handling and Assembly of Hot-dip Galvanized Components 414
- Appendix B Information Centers in the Federal Republic of Germany 416

Appendix C Hot-dip Galvanizing Companies in Germany as of  
15/8/2005 Source: Institut für Feuerverzinken GmbH 419  
Appendix D Worldwide Galvanizing Associations 439

**Index** 443

## Preface to the Third German Edition

As the second German edition of the “Handbuch Feuerverzinken”, published in 1993, has been out of print for some time, a third, completely revised edition became necessary. With its publication we would like to thank all authors, some of them new to this edition, for their valuable contributions.

The following modifications and additions have been made:

- In the revision the new Euro- and ISO standards are considered, in particular DIN EN ISO 1461.
- The chapter on surface preparation technology now covers new processes that take into account the trend towards environmentally friendly technologies.
- The layer formation technology is explained on an entirely new footing, based on the investigations of the Institute for Corrosion Protection, Dresden, and the Institute for Steel Engineering, Leipzig, and includes high temperature galvanization.
- The chapters on technical equipment, design and manufacturing according to hot-dip galvanizing requirements as well as on occupational safety and quality management have been updated.
- The commercially important method of powder coating is now covered in the sections on the post-treatment of zinc coatings.
- All chapters take into account the vastly expanded range of hot-dip galvanized products, e.g., truck frame parts.
- After eight years of intense discussions with the responsible government departments, trade associations and the IG Metall (Industrial Union of Metal Workers) the method of hot-dip galvanization, since August 2005, has been integrated into the job description of a Surface Coating Specialist. Therefore, for the first time, a Germany-wide recognized trade for hot-dip galvanization specialists exists.

We hope that the third edition of the “Handbuch Feuerverzinken” will continue to meet interest in the professional circles and will constitute a ready reference for the hot-dip galvanization industry.

Critical remarks conducive to the book's content will be much appreciated. We would like to thank the publisher Wiley-VCH, notably Dr. Ottmar and Dr. Münz, who sympathetically supported us in our wish to publish this third edition and unbureaucratically also undertook some of the editors' work.

Leipzig, December 2007

*Peter Maaß*  
*Peter Peißker*

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## Preface to the Second German Edition

Hot-dip galvanization was invented in 1742 by the French chemist Paul Jacques Malouin, but first found wide-spread use in 1836 after a patent on its practical application was issued to the French chemist Stanislas Sorel. Decades of alchemy and chemistry combined with craftsmanship led the way to a productive, efficient and modern industry.

The increasing importance of structural engineering with its varied application fields on the one hand and the demands for low-maintenance or maintenance-free corrosion protection on the other hand have spurred the development of process technology and installation engineering of hot-dip galvanization.

The essential groundwork on the topic was laid in the landmark publication “Das Feuerverzinken” (Hot-dip Galvanization) by Prof. Bablik, the eminent expert of process technology, published in 1941. The book “Das Feuerverzinken”, the first German edition of “Handbuch Feuerverzinken” by the editors, published in 1970, and its second edition will provide readers and practitioners with the possibility to gain an understanding of the historical and technological development of hot-dip galvanization and will hopefully help to bring it to fruition in practical applications.

Corrosion and corrosion protection, notably hot-dip galvanization, are nowadays integral parts of quality management of products and of environmental protection because corrosion is caused by environmental influences. By limiting and preventing corrosion, hot-dip galvanization as a prime method of corrosion protection helps to

- protect natural resources
- conserve values
- increase the quality of living
- enhance security.

If reference books could be written by few individual authors in the past, the sheer complexity of process technology and installation engineering necessitates a joint effort of an assembly of experts from various disciplines. Critical remarks conducive to the book’s content will be much appreciated. We thank the publisher which supported us in every respect.

Leipzig, July 1993

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# 1

## Corrosion and Corrosion Protection

Peter Maaß

### 1.1

#### Corrosion

##### 1.1.1

##### Causes of Corrosion

All materials or products, plants, constructions, and buildings made of such materials are subject to physical wear during use.

A general overview of different kinds of wear caused by mechanical, thermal, chemical, electrochemical, microbiological, electric, and radiation-related impacts is shown in Figure 1.1.

The technical and economic mastering of physical wear is difficult, since several causes are intertwined and mutually influence each other. The interaction with certain media of the environment results in undesired reactions of the materials that trigger corrosion, weathering, decaying, embrittlement, and fouling.

While mechanical reactions lead to wear, chemical and electrochemical reactions cause corrosion. Such processes emanate from the materials' surfaces and lead to modifications of the material properties or to their destruction. According to DIN EN ISO 8044, corrosion is defined as:

“Physical interaction between a metal and its environment which results in changes of the metal's properties and which may lead to significant functional impairment of the metal, the environment or the technical system of which they form a part.”

Note: *This interaction is often of an electrochemical nature.*

From this definition, included in the standard, further terms are derived:

- **Corrosion system:** A system consisting of one or several metals and such parts of the environment that affect corrosion.
- **Corrosion phenomenon:** Modification in any part of the corrosion system caused by corrosion.

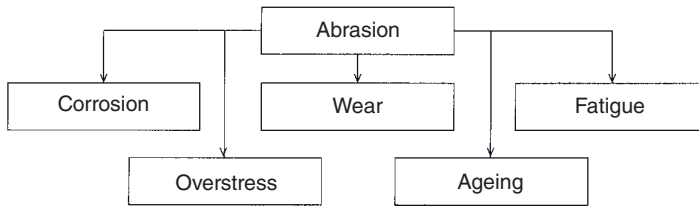


Figure 1.1 Types of wear of materials.

- **Corrosion damage:** Corrosion phenomenon causing the impairment of the metal function, of the environment or of the technical system of which they form a part.
- **Corrosion failure:** Corrosion damage characterized by the complete loss of operational capability of the technical system.
- **Corrosion resistance:** Ability of a metal to maintain operational capability in a given corrosion system.

When unalloyed or alloyed steel without corrosion protection is exposed to the atmosphere, the surface will take on a reddish-brown color after a short time. This reddish-brown color indicates rust is forming and the steel is corroding. In a simplified way, the corrosion process of steel progresses and is chemically based on the following equation:



The corrosion processes begins when a corrosive medium acts on a material. Since (energy-rich) base metals recovered from naturally occurring (low-energy) ores by means of metallurgical processes tend to transform to their original form, chemical and electrochemical reactions occur on the material's surface.

Two kinds of corrosion reactions are distinguished:

- **chemical corrosion**  
Corrosion excluding electrochemical reaction,
- **electrochemical corrosion**  
Corrosion including at least one anodic and one cathodic reaction.

### 1.1.2

#### Types of Corrosion

Corrosion does not only occur as linear abrasion, but in versatile forms of appearance. According to DIN EN ISO 8044, important variants for unalloyed or alloyed steel are:

- **Uniform surface corrosion**  
General corrosion occurring on the entire surface at nearly the same rate.
- **Shallow pit corrosion**  
Corrosion with locally different abrasion rates; caused by the existence of corrosion elements.
- **Pitting corrosion**  
Local corrosion resulting in holes, that is, in cavities expanding from the surface to the inside of the metal.
- **Crevice corrosion**  
Local corrosion in connection with crevices occurring in or immediately adjacent to the crevice area, which has developed between the metal surface and another surface (metal or nonmetal).
- **Contact corrosion (aka dissimilar metal corrosion)**  
Occurs at contact surfaces of different metals; the acceleratedly corroding metal area is the anode of the corrosion element.
- **Intergranular corrosion**  
Corrosion in or adjacent to the grain boundaries of a metal.

The standard mentioned above describes altogether 37 types of corrosion. These types of corrosion result in corrosion phenomena.

### 1.1.3

#### **Corrosion Phenomena**

EN ISO 8044 defines corrosion phenomena by corrosion-causing modifications in any part of the corrosion system.

Major corrosion phenomena are:

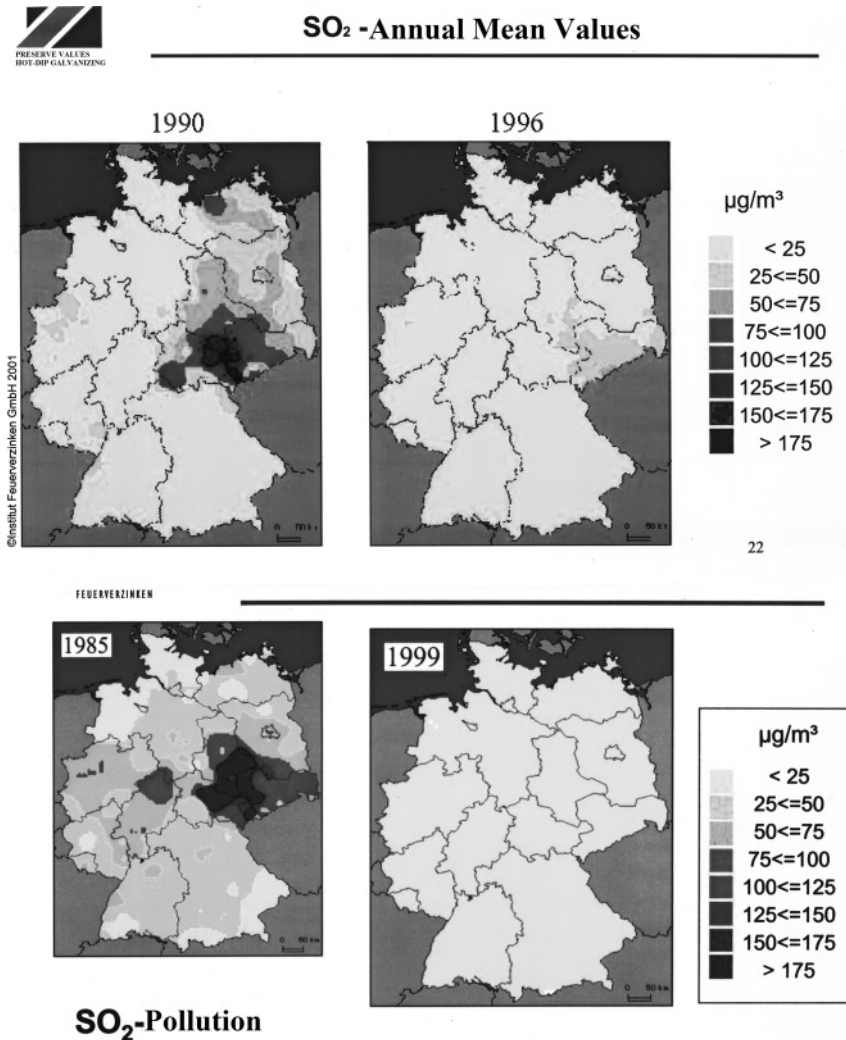
- **Uniform surface attack**  
A form of corrosion where the metal material is almost uniformly removed from the surface. This form is also the basis for the calculation of the mass loss ( $\text{g m}^{-2}$ ) or the determination of the corrosion rate ( $\mu\text{m y}^{-1}$ ).
- **Shallow pit formation**  
A form of corrosion with irregular surface attack forming pits with diameters much larger than their depth.
- **Pitting**  
A form of corrosion with crater-shaped or surface-excavating pits or pits resembling pin pricks. The depth of the pitting spots usually exceeds their diameter.

It is very difficult to differentiate between shallow pit formation and pitting.

1.1.4

**Corrosive Stress**

According to DIN EN ISO 12944-2: All environmental factors enhancing corrosion (see Figure 1.2).



**Figure 1.2** The reduction of SO<sub>2</sub> pollution in Germany over the last 20 years led to decisive reductions of the zinc-removal values (cf. Table 1.1).