

Contents

Preface	XV
The Authors	XVII
The Editor	XVII
The Co-Authors	XVIII
1 Introduction	1
<i>Dr. Ruben Schlutter</i>	
1.1 Defect Patterns in Injection Molding	2
1.2 Preparation of a Specification Sheet and Functional Specification Sheets	4
2 Tool Steels and Their Coatability	9
<i>Markus Pothmann</i>	
2.1 Introduction	9
2.1.1 Definition of Tool Steels	9
2.1.2 Development of Tool Steels	10
2.1.3 Types of Tool Steels	10
2.2 Injection Molding Tool Steels	12
2.2.1 Introduction	12
2.2.2 Properties of Injection Molding Tool Steels	13
2.2.3 Composition of Injection Molding Tool Steels	14
2.2.4 Heat Treatment of Injection Molding Tool Steels	17
2.2.5 Surface Treatment of Injection Molding Tool Steels	18
2.2.6 Maintenance and Care of Injection Molding Tool Steels	19

2.3	Selection of Injection Molding Tool Steels	21
2.3.1	Factors that Influence the Choice of Material for Injection Molding Tool Steels	21
2.3.2	Challenges in the Selection of Injection Molding Tool Steels	21
2.3.3	Selecting Materials for Injection Molding Tool Steels	22
2.3.4	Future Development of Injection Molding Tool Steels	24
3	Fundamentals of Coating Technologies	27
3.1	Electrolytically Deposited Metallic Layers and Hybrid Systems	27
	<i>Dr. Orlaw Massler</i>	
3.1.1	Background and Challenges	27
3.1.2	Galvanic Layers	28
3.1.2.1	Challenges and Actions	30
3.1.3	Electroless Separation	31
3.1.3.1	Electroless Nickel Plating	31
3.1.3.2	Principle of Electroless Nickel Plating	32
3.1.3.3	Electroless Nickel Coatings with Solid Additives (Dispersion)	32
3.1.3.4	Dispersion Layers as a Special Case	33
3.1.3.5	Friction-Increasing Layers	33
3.1.3.6	Sensor- and Indicator Layers	33
3.1.4	Loading Types	34
3.1.5	Coating-Compatible Design	35
3.2	Physical Vapor Deposition	38
	<i>Dr. Ruben Schlutter</i>	
3.2.1	Introduction	38
3.2.2	Process Variants	38
3.2.2.1	Evaporation	39
3.2.2.2	Sputtering	40
3.2.2.3	Ion Plating	42
3.2.3	Layer Growth and Adhesion Mechanisms for PVD Coatings	42
3.2.4	Multilayer Coating Systems	45
3.3	Chemical Vapor Deposition	48
3.3.1	Metalorganic Chemical Vapor Deposition	48
	<i>Vanessa Frettlöh</i>	
3.3.1.1	Classification of the Technology	48
3.3.1.2	Processes during MOCVD-coating	49

3.3.1.3 Requirements for Organometallic Precursors	51
3.3.1.4 Structure of an MOCVD System	52
3.3.1.5 Gap mobility and 3D capability of the coatings	54
3.3.2 Solid-Based Chemical Vapor Deposition	58
<i>Dr. Ruben Schlutter</i>	
3.3.2.1 Basics of CVD with Solid Precursors	58
3.3.2.2 Transport of the Solid Precursor	61
3.3.3 Plasma-Based Chemical Vapor Deposition	65
<i>Patrick Engemann</i>	
3.3.3.1 Plasmas	65
3.3.3.2 Plasma-Activated Chemical Vapor Deposition	66
3.3.4 Precursors – Molecular Sources for Functional Materials	68
<i>Prof. Dr. Sanjay Mathur, Dr. Veronika Brune, and Dr. Thomas Fischer</i>	
3.3.4.1 Chemical Strategies in Material Synthesis	72
3.3.4.2 Outlook	82
3.4 Simulation of Layer Deposition	89
<i>Ameya Kulkarni</i>	
3.4.1 Introduction	89
3.4.2 Theoretical Principles and Experimental Setup	91
3.4.3 The Equations of State	93
3.4.4 Experimental Procedure and Results	94
3.4.5 Results of the Simulations	97
3.4.6 Conclusion	102
4 Measurement Technology for Coating Characterization	103
4.1 Crater Grinding Method	103
<i>Dr. Ruben Schlutter</i>	
4.1.1 Determination of the Coating Thickness	104
4.1.2 Determination of Wear Resistance	107
4.2 Scanning Electron Microscopy	110
<i>Dr. Ruben Schlutter</i>	
4.2.1 Introduction	110
4.2.2 Instrument Setup	112
4.2.3 Preparation of the Sample	117
4.2.4 Sensors in a Scanning Electron Microscope	117
4.2.4.1 SE Sensor	117

4.2.4.2 UVD Sensor	118
4.2.4.3 BSE Sensor	120
4.2.4.4 EDX Sensor	123
4.3 Laser Microscopy	130
<i>Dr. Stefan Svoboda</i>	
4.3.1 Basic Principle	130
4.3.2 Taking a Picture	131
4.3.3 Application Examples	137
4.3.3.1 Crack Network in Sol-Gel Coating	137
4.3.3.2 Representation and Evaluation of Crater Grinding	139
4.3.3.3 Roughness Measurement on a Plastic Sample	140
4.3.3.4 Evaluation of a Wear Test	141
4.4 White Light Interferometry	143
<i>Dr. Andreas Balster</i>	
4.4.1 Introduction	143
4.4.2 Roughness as a Measured Variable	144
4.4.3 White Light Interferometry method	147
4.4.3.1 Measuring Principle of White Light Interferometry	147
4.4.3.2 Applications of White Light Interferometry	149
4.4.3.3 Limitations of White Light Interferometry	151
4.5 Infrared Spectroscopy	152
<i>Dr. Andreas Balster</i>	
4.5.1 Introduction	152
4.5.2 Physical Basics	152
4.5.3 The Application of FTIR Spectroscopy to Polymers: Material Identification	155
4.5.4 Identification and Structure Clarification	156
4.5.5 Quantification of Components	159
4.5.6 Metrological Aspects of FTIR Spectroscopy	160
4.5.7 ATR-FTIR Spectroscopy	161
4.5.8 Application in Molding Tool Technology	163
4.6 X-Ray Fluorescence Analysis	165
<i>Dr. Martin Ciaston</i>	
4.6.1 Introduction	165
4.6.2 Physical Principles of X-Ray Fluorescence	165
4.6.3 Instrumental Aspects of X-Ray Fluorescence Spectroscopy	168

4.6.4	Applications of X-Ray Fluorescence Spectroscopy in Material Analysis	169
4.6.5	Quantitative Aspects of X-Ray Fluorescence Spectroscopy	170
4.6.6	Summary and Outlook	172
4.7	Electrochemical Impedance Spectroscopy	174
	<i>Dr. Anatoliy Batmanov</i>	
4.7.1	Introduction	174
4.7.2	Basics of EIS	175
4.7.3	Presentation of EIS Measurement Results	180
4.7.4	EIS Investigation of Protective Coatings	181
4.7.5	The Test Setup for EIS Measurements	186
4.7.6	Conclusion	187
4.8	Nanoindentation	189
	<i>Dr. Ruben Schlutter</i>	
4.8.1	Introduction	189
4.8.2	Experimental Setup for Measurement using a Nanoindenter	191
4.8.3	Common Test Methods	195
4.8.3.1	Determination of the Indentation Hardness	195
4.8.3.2	Determination of the Indentation Modulus	197
4.8.3.3	Determination of the Penetration Creep	198
4.8.3.4	Determination of the Penetration Relaxation	198
4.8.3.5	Determination of the Plastic and Elastic Part of the Indentation Work	199
4.8.4	Test Methods for Coatings	200
4.8.4.1	Penetration Modulus of the Coating	202
4.8.4.2	Penetration Hardness of the Coating	203
4.9	Determination of the Thermal Diffusivity of Coatings	206
	<i>Patrick Engemann</i>	
4.9.1	Influence of the Mold Wall Temperature on the Injection Molding Process	206
4.9.2	Contact Temperature	207
4.9.3	Time-Domain Thermoreflectance (TDTR)	208
4.9.4	3-Omega	209
4.9.5	Test Setup for Measuring the Contact Temperature	210
4.9.6	Test Procedure for Measuring the Contact Temperature	211

4.10	Determining the Demolding Force during Injection Molding	214
	<i>Dr. Ruben Schlutter</i>	
4.10.1	Introduction	214
4.10.2	State of the Art	214
4.10.3	Experimental Setup for Analyzing Static and Dynamic Friction ...	216
4.10.3.1	Experimental Setup	217
4.10.3.2	Carrying out the Experiment	219
4.10.3.3	Qualification of the Injection Mold in the Long-Term Test	220
4.10.4	Summary	221
4.11	Determination of Emissions in Plastics Processing	223
	<i>Dr. Andreas Balster and Matthias Korres</i>	
4.11.1	Introduction	223
4.11.2	Gas Chromatography/Mass Spectrometry (GC/MS)	223
4.11.3	Emission Formation in Plastics Processing	230
4.11.4	Process-Dependent Emission Formation	231
4.11.4.1	Material Drying	231
4.11.4.2	Material Processing	233
4.11.5	Summary	238
4.12	Wear Tests in Plastics Processing	240
	<i>Marko Gehlen</i>	
4.12.1	Introduction	240
4.12.2	Definition of Wear	240
4.12.3	The Importance of Wear for the Industry	241
4.12.4	State of the Art and Measurement Methods	241
4.12.5	Wear during Injection Molding and in the Injection Molding Tool	243
4.12.6	Investigation of the Wear Behavior in Injection Molding	244
4.12.7	Outlook	246
4.12.8	Summary	247
4.13	Adhesion Assessment of Coatings	249
	<i>Dr. Orlaw Massler</i>	
4.13.1	Rockwell Test (DIN 4856)	251
4.13.2	Thermal Shock Test	252
4.13.3	File Test	252
4.13.4	Cross-Section Method	252

5 Application of Functional Coatings	255
5.1 Hard Coatings	255
<i>Marko Gehlen</i>	
5.1.1 Introduction	255
5.1.2 Definition and Properties of a Hard Coating	255
5.1.3 Areas of Application	256
5.1.4 Requirements and Coating Structure	256
5.1.5 Process for Applying Hard Coatings	257
5.1.6 Characteristic Values for Evaluating Wear Resistance	258
5.1.7 Achieved Abrasion Comparison Values and Hardness	259
5.1.8 Summary	260
5.2 Tribological Coatings and Wear Protection Coatings	261
<i>Dr. Orlaw Massler</i>	
5.2.1 Types of Wear	261
5.2.2 Friction Reduction	262
5.2.3 Galvanic Coatings	263
5.2.3.1 Hard Chrome Plating	263
5.2.3.2 Nickel Plating	264
5.2.4 Electroless Nickel and Dispersion Coatings	265
5.2.4.1 Dispersion Coating	266
5.2.4.2 SiC Dispersion Coatings	266
5.2.4.3 BC Dispersion Coatings	266
5.2.4.4 hBN Dispersion Coatings	266
5.2.5 Tribological PVD and PACVD Coatings	266
5.2.6 Hybrid Coatings	267
5.3 Corrosion-Protective Coatings	270
<i>Dr. Anatoliy Batmanov</i>	
5.3.1 Definition of Corrosion	270
5.3.2 Basic Strategies for Preventing Corrosion	272
5.3.3 Requirements for Corrosion Protection Coatings	273
5.3.4 Development of a Corrosion-Protective Coating against Hot Gas Corrosion	276
5.3.5 Development of a Corrosion-Protective Coating against Aqueous Corrosion	279

5.4	Thermal Barrier Coatings	282
	<i>Vanessa Frettlöh</i>	
5.4.1	Understanding Thermal Barrier Coatings	282
5.4.2	Influence of Temperature in the Injection Molding Process	282
5.4.3	Application and Properties of Thermal Barrier Coatings	284
5.4.4	Functionality of Thermal Barrier Coatings	285
5.4.5	Application of Thermal Barrier Coatings in the Injection Molding Process	287
5.4.6	Use of Thermal Barrier Coatings in Thin-Wall Injection Molding ..	290
5.5	Coatings for Plaque Reduction	295
	<i>Mattias Korres</i>	
5.5.1	Introduction	295
5.5.2	Plaque in the Injection Molding Tool	296
5.5.3	Process Optimization	298
5.5.4	Optimization of the Injection Molding Tool	300
5.5.5	Coatings for Plaque Reduction	301
5.6	Coatings to Reduce Demolding Force	304
	<i>Dr. Ruben Schlutter</i>	
5.6.1	Introduction	304
5.6.2	State of the Art	304
5.6.3	Possible Applications and Potentials	308
5.6.3.1	Material Selection of the Thermoplastic Material	308
5.6.3.2	Addition of Additives	309
5.6.4	Modification of the Cavity Surface	310
5.6.5	Summary	311
5.7	Thin-Film Sensor Technology	313
	<i>Dr. Angelo Librizzi</i>	
5.7.1	Introduction	313
5.7.2	State of the Art Sensors	314
5.7.2.1	Pressure Measurement in the Injection Mold	314
5.7.2.2	Temperature Measurement in the Injection Mold	316
5.7.3	Measuring Principle for Temperature-Sensitive Thin Films	318
5.7.4	Coating Structure	320
5.7.5	Coating Production	320
5.7.6	Characterization of the Thermoelectric Behavior of the Thin-Film Sensors	323

5.7.7 Calculation of the Response Dynamics	324
5.7.8 Sensor Integration and Application in an Injection Mold	326
5.7.9 Summary	328
5.8 Heating Coatings	330
<i>Dr. Martin Ciaston</i>	
5.8.1 Introduction	330
5.8.2 Basics of Near-Contour Heating Layers	330
5.8.3 Requirements for a Coating System for an Application as a Heating Conductor in the Injection Molding Process	331
5.8.4 Application of Heating Coatings in Injection Molding Processes ...	332
5.8.5 Summary and Outlook	333
Index	335