Ref. 668.412 PRE

Contents

List of Contributors V

Dedication VII

Preface IX

1 Precision Injection Molding: Overview and Scaling Considerations 1
J. Greener. R. Wimberger-Friedl

1.1 Introduction 1
1.2 The M-Chain of Precision Molding 1
1.3 Dimensional Integrity 4
1.3.1 Pressure History 5
1.3.2 Cooling Stresses 7
1.3.3 Shrinkage 8
1.3.4 Warpage 9
1.4 Dimensional Stability 9
1.5 Simulation 12
1.6 Summary 14

2 Instabilities in Dimensions and Shape 17
L. C. E. Struik

2.1 Introduction 17
2.2 Creep-Recovery; Isothermal 17
2.3 Creep-Recovery; Nonisothermal 18
2.4 Nonisothermal Creep Recovery Accompanied by Physical Aging 21
2.5 Complicated Loading Patterns During Shaping 22
2.6 Predicting Long-Term Dimensional Instability from Short-Time Tests 24
2.7 Discussion 24
2.7.1 Applicability of the Linear Viscoelastic Theory 24
2.7.2 Factors Determining Instabilities 25
2.7.3 Related Phenomena 26
2.7.4 Volume Relaxation and Cooling Stresses 26

3 Dimensional Accuracy in Injection Molding: State of the Art and Open Challenges 29
R. Pantani. G. Titomanlio

3.1 Introduction 29
3.2 Generalities on Shrinkage and Thermal Stresses 29
3.3 Parameters Affecting Shrinkage 30
3.4 Some Aspects of Injection Molding of Interest for Shrinkage Predictions 31

3.5 State of the Art of Shrinkage Modelling. 32
3.5.1 PVT Approach 32
3.5.2 Statistical Approach 34
3.5.3 Thermomechanical Approach 34
3.6 Elastic Modeling of Shrinkage 36
3.6.1 The Physical Basis of the Model 36
3.6.2 Definitions and Main Equations 38
3.6.3 Derivation of Shrinkage Equations 40
3.7 A Viscoelastic Approach to Shrinkage 44
3.8 A Reliable Solidification Criterion and Relaxation in the Solid State 47
3.8.1 Relevance of Solidification Criterion on Stresses and Shrinkage 50
3.9 Shrinkage and Thermal Stresses of Semicrystalline Polymers 52
3.10 Dimensional Instability After Molding 54

4 Birefringence Modeling in Optical Discs 59
T. H. Kwon, Y. B. Lee

4.1 Introduction 59
4.2 Thermal Stress and Birefringence. 60
4.3 Stress-Optical Behavior 63
4.3.1 Stress-Optical Law and Photoelasticity. 63
4.3.2 Linear Viscoelasticity and Photoviscoelasticity 64
4.3.3 Time-Temperature Superposition. 65
4.3.4 Photoviscoelasticity Experiment 66
4.3.5 Volume Relaxation Phenomena with Free Volume Theory 67
4.4 Material Data 70
4.5 Birefringence in Injection Molded Center-Gated Disks 73
4.5.1 Physical Model 73
4.5.2 Residual Stresses and Birefringence 77
4.5.3 Numerical Modeling 78
4.5.4 Numerical Simulation Results and Discussion 85
4.6 Concluding Remarks 100

5 Shrinkage of Injection Molded Material 105
P. K. Kennedy, R. Zheng

5.1 Introduction 105
5.2 Filling and Packing Analysis 105
5.2.1 Material Properties 106
5.2.2 Geometric Considerations 108
5.2.3 Simplification by Mathematical Analysis 108
5.2.4 Solution of the Governing Equations 110
5.3 Cooling Analysis 111
5.4 Shrinkage and Warpage Prediction 111
5.4.1 Residual Strain Methods 112
5.4.2 Residual Stress Models. 113

5.5 The Material Data Problem 115
5.6 Hybrid Model 116
5.6.1 The Contracted Notation 117
5.6.2 Prediction of the b_i 119
5.6.3 Using the Model 121
5.7 Results for Unfilled Polypropylene 122
5.8 Results on Other Materials 125
5.8.1 ABS 125
5.8.2 PC 125
5.8.3 PC+ABS Blend 128
5.8.4 PBT 128
5.9 Filled Materials 128
5.9.1 Glass Reinforced PA66 131
5.9.2 Talc Filled PBT 131
5.10 Conclusion 131

6 Towards the Prediction of Structure Development in Injection Molded Semicrystalline Polymers 137
G. *Eder, H. Janeschitz-Kriegl, E. Ratajski*

6.1 Introduction 137
6.2 Phenomenology of Crystallization Patterns 138
6.3 Suitable Parameters for a Description of Underlying Processes 142
6.4 Fundamental Considerations for Quiescent Melts 145
6.5 Fundamentals of Flow-Induced Crystallization 148
6.6 Outlook 151

7 Deformation of Polycarbonate Optical Discs by Water Sorption and Aging 153
L. van der Tempel

7.1 Introduction 153
7.1.1 Water Sorption 155
7.1.2 Physical Aging 155
7.2 Disc Warpage by Water Sorption and Volume Relaxation 155
7.2.1 Experimental Introduction 155
7.2.2 Model 156
7.3 Water Sorption and Swell in Polycarbonate 158
7.3.1 Model 159
7.3.2 Measurement Methods for Swell and Diffusivity 161
7.3.3 Swell 162
7.3.4 Water Diffusion 163
7.4 Volume Shrinkage of Polycarbonate Substrates During Hot Storage 163
7.4.1 Measurements 164
7.4.2 Model 164
7.5 Conclusions 167

8 Injection Molding for Microfluidics Applications 169
L. J. Lee, L. Yu, K. W. Koelling, M. J. Madou

8.1 Introduction 169
8.2 Microfluidics 170
8.2.1 Basic Concepts 170
8.2.2 Micro- and Nanofluidic Functions 173
8.3 Mold (Master) Making 175
8.3.1 LIGA 176
8.3.2 UV-LIGA 184
8.3.3 Comparison of Various Mold-Making Methods 190
8.4 Microfeature Injection Molding Techniques and Applications 192
8.4.1 Molding of CDs and DVDs 192
8.4.2 Thermoplastic Microfeature Injection Molding 194
8.4.3 Reaction Injection Molding (RIM) 201
8.4.4 Demolding 204
8.4.5 Injection Molding with Nanostructures 204
8.5 Experimental Analysis of Microfeature Injection Molding 205
8.5.1 Experiments of Microfeature Injection Molding 205
8.5.2 Unidirectional Mold Filling with Microfeatures 210
8.6 Theoretical Analysis of Microfeature Injection Molding 212
8.6.1 An Analytic Model for Pressure Estimation 214
8.6.2 Simulation with Commercial Codes 215
8.6.3 Hybrid Numerical Simulation 222
8.6.4 Thermal Boundary Conditions 227
8.6.5 Test of the Hybrid Numerical Scheme and Thermal Boundary Conditions 228
8.6.6 Other Microfluidic Related Issues 232
8.7 Future Directions 233

9 Introduction to Micromolding 239
B. R. Whiteside, M. T. Martyn, P. D. Coates

9.1 Introduction 239
9.2 Technology 240
9.3 Tooling 245
9.4 Materials 248
9.5 Process Monitoring and Assessment 251
9.6 Product Property Measurement 257
9.7 Summary 262

10 Precision Process Control of Precision Injection Molding 265
D. Kazmer

10.1 Introduction 265
10.2 Fundamentals 266

10.2.1 Injection Molding Fundamentals 266
10.2.2 Process Control Fundamentals 269
10.2.3 Robust Design Fundamentals 271
10.3 Process Control Technologies 276
10.3.1 Machine Control 277
10.3.2 State Variable Control 278
10.3.3 Set-Point Control 279
10.4 Precision Process Control Development 281
10.4.1 Methodology 281
10.4.2 Example #1: Process Window Determination for DVD Manufacturing 285
10.4.3 Example #2: Dynamic Feed 289
10.5 Conclusions 292

11 Machine Hardware for Precision Injection Molding 299
J. Border

11.1 Introduction 299
11.2 Precision Injection Molding Machines 299
11.2.1 Hydraulic Control vs. Electric Control 299
11.2.2 Screw Shutoff 303
11.2.3 Melting Screws 304
11.2.4 Machine Layout 306
11.2.5 Special Material Processing 306
11.2.6 Automated Part Handling 307
11.2.7 Machine Sizes 308
11.2.8 Machine General 308
11.3 Molds 309
11.3.1 Mold Material Selection 309
11.3.2 Machining Precision 310
11.3.3 Plate Interlocks 310
11.3.4 Across the Parting Line 310
11.3.5 Mold Temperature Control 311
11.3.6 Mold Types 314
11.4 Summary 317

Index 319