Contents

The Author ..... **V**

Preface ..... **VII**

1 The Injection Molding Process **1**

1.1 Process Flow 1

1.2 The Machine and Plant Technology 3

1.2.1 Clamping Unit 4

1.2.2 Injection Unit 6

1.2.3 Drive 6

1.2.4 Controls 7

2 Technical Jargon **9**

2.1 Injection Molding Machine 9

2.2 Mold 14

2.3 Injection Molding Process 24

2.4 Plastic Material 30

3 Setting the Process Variables **33**

3.1 Basic Information for the Initial Settings 35

3.1.1 Shot Weight 36

3.1.2 Flow Path Length 36

3.1.3 Average Wall Thickness 37

3.1.4 Plastic to Be Processed 38

3.1.5 Class of Molded Part 38

3.1.6 Projected Area of the Molded Part . . . 38
3.2 Initial Setting . . . 39
3.2.1 Temperature . . . 39
3.2.1.1 Melt Temperature, Processing Temperature . . . 40
3.2.1.2 Mold Temperature . . . 42
3.2.1.3 Nozzle Temperature/Hot Runner Temperature . . . 42
3.2.2 Metering . . . 43
3.2.3 Injection and Holding Pressure . . . 48
3.2.3.1 Injection Process . . . 48
3.2.3.2 Switchover to Holding Pressure . . . 50
3.2.3.3 Holding Pressure Process . . . 52
3.2.4 Cooling Time . . . 54
3.3 Correcting the Initial Settings . . . 55
3.3.1 First Correction Step (without Holding Pressure) . . . 55
3.3.2 Second Correction Step (with Holding Pressure) . . . 56
3.4 Optimization of the Initial Settings . . . 57
3.4.1 Incomplete Cavity Filling . . . 58
3.4.2 Sink Marks . . . 59
3.4.3 Flash . . . 60
3.4.4 Visible Weld Lines . . . 61
3.4.5 Jetting . . . 61
3.4.6 Grooves (Vinyl Record Effect) . . . 62
3.4.7 Surface Streaks . . . 63
3.4.8 Burn Marks (Diesel Effect) . . . 64
3.4.9 Dull Spots Near the Gate . . . 65
3.4.10 Differences in Surface Gloss . . . 65

4 Plastic Properties Relevant to Injection Molding . . . 67

4.1 Flow Properties of Plastics . . . 67
4.1.1 Relationship between Pressure and Velocity (Hagen-Poiseuille) . . . 67
4.1.2 Viscosity . . . 68
4.1.2.1 Influence of the Shear Rate on the Viscosity . . . 70
4.1.2.2 Influence of Temperature on Viscosity . . . 70
4.1.3 Combined Influence of Speed and Temperature (Bathtub Curve) . . . 71
4.1.4 Fountain Flow . . . 72
4.1.5 Troubleshooting with Flow Trace Analysis . . . 74

4.2 Process Sequence for Injection and Holding Pressure 74
4.2.1 Relationship between Specific Pressure, Volume and Temperature (pvT Diagram) 74
4.2.2 Pressure-Time Graph, Pressure Curves 77
4.2.3 Injection Speed 83
4.2.4 Holding Pressure Phase 85
4.2.4.1 Holding Pressure Time 85
4.2.4.2 Holding Pressure Level 86
4.3 Design of Molded Parts 89
4.3.1 Flow-Path/Wall-Thickness Ratio 89
4.3.2 Filling Pattern 89
4.3.2.1 Weld Lines and Flow Lines 92
4.3.2.2 Folds 93
4.3.2.3 Burners/Diesel Effect 94
4.3.2.4 Poorly Filled Areas 94
4.4 Inner Properties of Plastics 95
4.4.1 Orientations 95
4.4.2 Stresses 96
4.4.3 Crystallization 98
4.5 Temperatures and Heat Processes in Plastics 100
4.5.1 Cooling (Calculation) 100
4.5.2 Cooling Properties, Weld Line Strength 105
4.5.3 Influence of Mold Temperature on Molded Part Dimensions 107
4.5.4 Temperature Equilibrium 109
4.5.5 Melting Temperature, Processing Temperature 110
4.5.6 Influence of Temperature on Demolding and General Demolding Problems 112
4.5.7 Dwell Time and Material Degradation 113

5 Special Injection Molding Processes 115

5.1 Injection Molding with Blowing Agents 115
5.1.1 Thermoplastic Foam Injection Molding (TFI) 117
5.1.2 Gas Counter-Pressure Process 120
5.1.3 System Equipment for Blowing Agent Injection Molding 121
5.2 Gas-Assisted Injection Technique (GIT) 122
5.2.1 Pressure Curve for the Internal Gas Pressure Technique 123

5.2.2 Standard GIT Process 125
5.2.2.1 Design of GIT Parts 127
5.2.2.2 Process Engineering for the Standard GIT Process 129
5.2.3 Blow-Out Process 131
5.2.3.1 Secondary Cavity Process 133
5.2.3.2 Melt Push-Back Method 134
5.2.4 Troubleshooting the GIT Process 135
5.3 External Gas Pressure Technique 138
5.4 Injection Compression Molding 140
5.4.1 General Information on the Process 140
5.4.2 Large-Area Injection Compression Molding 141
5.4.3 Partial Injection Compression Molding 142
5.4.4 Passive Injection Compression Molding 143
5.4.5 Process Control for Large-Area Injection Compression Molding 145
5.4.6 Process Control for Injection Compression Molding with Displacement Cores 146
5.4.7 Process Control for Passive Injection Compression Molding 147
5.5 Multi-Component Injection Molding 147
5.5.1 Overmolding 148
5.5.1.1 General 148
5.5.1.2 Material Combination for Multi-Component Injection Molding 151
5.5.1.3 Special Process Engineering Knowledge 153
5.5.2 Sandwich Molding 154
5.5.2.1 General 154
5.5.2.2 Injection Sequence in the Sandwich Process 154
5.5.2.3 Special Product-Related Knowledge 159
5.5.2.4 Process Technology 161
5.5.2.5 Standard Sandwich Technology 162
5.5.2.6 Mono-Sandwich Technology 165
5.5.2.7 General Troubleshooting 166
5.6 Plasticizing with Degassing 166

6 Optimization of Quality 169

6.1 Documentation and Monitoring 173
6.1.1 Continuous, Chronological Monitoring 173

6.1.1.1 The Significance of Individual Actual Process Parameters . 174
6.1.1.2 Possible Defect Frequency 179
6.1.2 Statistical Process Control (SPC) 182
6.1.2.1 Documentation with Statistical Parameters 183
6.1.2.2 Control Charts 186
6.1.2.3 Strategy for Regulating Quality 187
6.1.2.4 Parameter Selection 188
6.1.3 Monitoring with Process Models 189
6.2 Optimization with External Intelligence 189
6.2.1 Design of Experiments (DOE) 190
6.2.2 Evolutionary Operation (EVOP) 196
6.2.3 Comparison of EVOP and DOE 201
6.3 Special Process Strategies 201
6.3.1 *pvT* Strategy 202
6.3.2 Adaptive Process Control 203
6.3.2.1 Correlation Analysis 204
6.3.2.2 Adaptive Machine Control 205
6.3.2.3 Flow Rate Control 207
6.3.2.4 APC and IQ Weight Control 209

7 Sustainability in Injection Molding 213
7.1 Use of Recycled Materials 215
7.2 Reduction in Energy Requirements 218
7.2.1 Saving Drive Energy 219
7.3 Saving Heating Power 222
7.4 Use of Blowing Agents 224

8 Procedure for Standardized Presetting of an Injection Molding Machine 227
8.1 Basic Molded-Part Data 227
8.2 Settings 228
8.3 Tables and Diagrams 229

9 Further Reading 239

Index 241