

Contents

Preface — VII

Acknowledgements — IX

1 Introduction — 1

- 1.1 The big picture — 1
- 1.2 Introduction to injection moulding — 1
- 1.3 The injection moulding process — 3
 - 1.3.1 Piston injection unit — 4
 - 1.3.2 Reciprocating screw machine — 5
 - 1.3.3 Breaking down the injection moulding cycle — 7
 - 1.3.3.1 Plastication — 7
 - 1.3.3.2 Filling — 7
 - 1.3.3.3 Packing and Solidification — 8
- 1.4 Comparison with other moulding methods — 8
 - 1.4.1 Extrusion — 8
 - 1.4.2 Compression moulding — 10
 - 1.4.3 Transfer moulding — 10
 - 1.4.4 Blow moulding — 11
 - 1.4.5 Film blowing — 13
 - 1.4.6 Injection-compression — 14
 - 1.4.7 Additive manufacturing — 15
- 1.5 Conclusion — 16
- Suggested further reading — 16

2 Introduction to plastics — 19

- 2.1 Introduction — 19
- 2.2 Structure and typical properties of polymers — 21
- 2.3 Formation of macromolecules — 23
- 2.4 Molecular weight — 24
- 2.5 Plastics — 24
 - 2.5.1 Thermoplastic — 25
 - 2.5.2 Thermosets — 26
 - 2.5.3 Elastomers — 27
 - 2.5.3.1 Thermoplastic elastomers — 27
 - 2.5.4 The formulation of plastics — 29
 - 2.5.5 The binding structure of plastics — 30
- 2.6 The effects of processing on thermoplastics — 30
 - 2.6.1 Rheology — 31
 - 2.6.2 Heat and heat transfer — 32

2.6.3	Physical and chemical change —	32
2.6.4	Fountain flow —	33
2.7	Conclusion —	35
	Reference —	35
3	Injection moulding machinery —	37
3.1	Injection units —	38
3.2	Piston (plunger) injection unit —	38
3.3	Reciprocating screw injection unit —	39
3.3.1	Shot capacity —	40
3.3.2	Plasticising capacity —	40
3.3.3	The feeding hopper —	40
3.3.4	The injection cylinder —	41
3.4	Selection of the injection unit —	41
3.5	Length/diameter ratio —	43
3.5.1	Mixing screws for additives and fast cycling machines —	46
3.5.1.1	Mixing elements —	46
3.5.1.2	Extended plasticising cylinder —	46
3.5.2	Non-return valve —	48
3.6	General information on wear and tear —	48
3.7	Unit hardening treatment —	49
3.8	The nozzle —	49
3.9	Clamping units —	51
3.9.1	Differential piston system —	56
3.9.2	Mould weights —	57
3.10	Selection of the clamping unit —	57
3.11	Mould clamping force —	59
3.11.1	Mould clamping force level —	59
3.11.2	Mould clamping force and mould rigidity —	60
3.11.3	Setting mould closing and clamping force —	61
3.11.3.1	The clamping force —	61
3.11.3.2	Second clamping force —	61
3.12	Data for mould closing —	62
3.13	Other considerations —	64
3.14	International standard for the designation of injection moulding machines —	65
3.15	Injection moulding machine: drive technology —	67
4	Injection mould tooling basics —	69
4.1	Types of moulds —	69
4.1.1	Two-plate mould —	69
4.1.2	Stripper mould —	69

4.1.3	Slide mould —	69
4.1.4	Three-plate mould —	70
4.2	The feed system —	72
4.2.1	Introduction —	72
4.2.2	The runner —	72
4.2.3	Runner shape —	74
4.2.4	Runner layout —	75
4.2.4.1	Standard-runner —	75
4.2.4.2	Cold-runner —	76
4.2.4.3	Hot-runner —	76
4.3	Gate design —	81
4.3.1	Sprue gate —	81
4.3.2	Restricted gate —	81
4.3.3	Side or edge gate —	82
4.3.4	Flash gate —	83
4.3.5	Fan gate —	83
4.3.6	Tab gate —	84
4.3.7	Diaphragm gate —	85
4.3.8	Spider gate —	85
4.3.9	Ring gate —	85
4.3.10	Hot tip gating —	86
4.4	Mould temperature control —	87
4.5	Ejection systems —	90
4.6	Venting —	92
4.7	Conclusion —	92
	Suggested further reading —	93
5	Process control systems —	95
5.1	Introduction —	95
5.2	Explanation of the different concepts in control and regulation technology —	95
5.2.1	Hydraulic or electric systems? —	95
5.2.1.1	Pump —	95
5.2.2	Motor —	96
5.2.3	Cylinder —	96
5.2.4	Directional valves —	96
5.2.5	Pressure valves —	98
5.2.6	Flow-regulator valves —	100
5.2.7	Location and setting of proportional valves —	100
5.2.7.1	Valve bodies —	101
5.2.7.2	Function of the volume proportional valve —	101
5.2.7.3	Function of the pressure proportional valve —	102

5.2.8	Check valves —	103
5.2.9	Receivers —	103
5.3	General information regarding control units, regulators, position regulation and injection process regulation —	104
5.3.1	Control unit —	104
5.3.2	Regulator —	105
5.3.3	Screw with position regulator —	105
5.3.4	Injection process regulation —	106
5.4	Electrical systems —	109
5.5	Hybrid machines —	111
5.6	The user interface —	112
6	Amorphous and semi-crystalline thermoplastics —	115
6.1	Introduction —	115
6.2	Amorphous plastics —	116
6.2.1	Overview and common properties —	117
6.2.2	Standard polystyrene homopolymer —	117
6.2.3	Styrene copolymers —	119
6.2.4	Modified polyphenylene oxide —	120
6.2.5	Polyvinyl chloride —	121
6.2.6	Cellulose materials —	123
6.2.7	Polymethyl methacrylate —	123
6.2.8	Polycarbonate —	124
6.2.9	Polyacrylates —	128
6.2.10	Polysulfones —	129
6.2.11	Polyetherimide —	130
6.2.12	Polyamide imide —	132
6.3	Semi-crystalline plastics —	132
6.3.1	Overview and common properties —	133
6.3.2	Polyethylene —	136
6.3.3	Polypropylene —	136
6.3.4	Polyamides —	138
6.3.5	Polyacetals —	139
6.3.6	Polyterephthalates (linear polyesters) —	142
6.3.7	Polyphenylene sulfide – typical characteristics and applications —	143
6.3.8	Polyfluorolefins —	144
6.3.9	Polyacrylic acid and polyarylamide —	146
6.3.10	Polyacryl and ether ketones —	148
6.3.11	Liquid crystalline polymers —	149
6.4	Conclusion —	152

- 7 Processing thermoset, liquid silicone rubber and ceramic materials — 153**
 - 7.1 Thermosets — 153**
 - 7.1.1 Overview and common properties — 153**
 - 7.1.2 Materials for screw injection moulding machines — 154**
 - 7.1.3 Processing procedures for thermoset plastics — 156**
 - 7.1.3.1 Compression moulding — 156**
 - 7.1.3.2 Injection moulding — 156**
 - 7.1.4 Screw injection machines for thermosets — 157**
 - 7.1.5 Mould — 158**
 - 7.1.6 Guide values for cylinder and mould temperature settings — 158**
 - 7.1.7 The injection unit for granulated thermosets — 160**
 - 7.1.8 The injection unit for processing moist polyester — 160**
 - 7.1.9 Nozzle temperature (if Nozzle Heating is Applied) — 161**
 - 7.1.10 Common thermoset materials: Properties and applications — 161**
 - 7.1.10.1 Phenol formaldehyde compounds — 161**
 - 7.1.10.2 Urea formaldehyde compounds — 162**
 - 7.1.10.3 Melamine formaldehyde compounds — 163**
 - 7.1.10.4 Unsaturated polyester — 164**
 - 7.1.10.5 Epoxide compounds — 165**
 - 7.2 Elastomer injection moulding compounds — 167**
 - 7.2.2 Processing procedures for elastomeric materials — 167**
 - 7.2.2.1 Compression moulding — 167**
 - 7.2.2.2 Injection moulding — 167**
 - 7.2.2.3 Injection moulding machines for rubber compounds — 168**
 - 7.2.2.4 Peripheral device — 168**
 - 7.2.2.5 Mould — 168**
 - 7.2.3 Silicone elastomers – liquid silicone rubber systems — 168**
 - 7.2.3.1 Classification — 169**
 - 7.2.3.2 Crosslinking — 170**
 - 7.2.3.3 Processing of two-component liquid silicone rubber — 170**
 - 7.2.3.4 Advantages of processing liquid silicone rubber materials — 171**
 - 7.2.3.5 Injection process — 171**
 - 7.2.3.6 Configuration of injection moulding machines and processing data — 171**
 - 7.2.3.7 Specific properties — 173**
 - 7.2.3.8 Crosslinking reaction — 173**
 - 7.2.3.9 Structural viscosity — 174**
 - 7.2.3.10 Vulcanisation — 176**
 - 7.2.3.11 Internal mould pressure — 176**
 - 7.2.3.12 Shrinkage — 176**
 - 7.2.3.13 Tempering — 176**

7.2.3.14	Preparation of liquid silicone rubber —	177
7.2.4	Processing components for liquid injection moulding —	177
7.2.4.1	Dosing equipment for liquid silicone rubber —	177
7.2.4.2	Machine technology —	180
7.2.4.3	Injection unit —	182
7.2.4.4	Cylinder module —	182
7.2.4.5	Non-return valve —	181
7.2.4.6	Auxiliary heating control circuits —	182
7.2.4.7	Interface for brush and cleaner units —	182
7.2.4.8	Handling interface —	182
7.2.4.9	User-programmable inputs/outputs —	183
7.2.4.10	Air blast equipment with pressure reducer —	183
7.2.4.11	Control unit for vacuum pump —	183
7.2.4.12	Hydraulic/pneumatic cold-runner control —	183
7.2.4.13	Protective screens made of polycarbonate —	183
7.2.4.14	Simple cold-runner nozzle —	183
7.2.4.15	Cold-runner head —	184
7.2.4.16	Mould technology —	185
7.2.5	Application of liquid silicone rubber parts in food production —	190
7.2.6	Summary —	191
7.3	Processing of ceramic and metal powder materials —	193
7.3.1	Introduction —	193
7.3.2	Binder —	194
7.3.3	Processing —	195
7.3.3.1	Compression moulding —	195
7.3.3.2	Injection moulding —	196
7.3.4	Configuration of injection moulding machines —	196
7.3.4.1	Peripheral devices —	196
7.3.4.2	Mould —	196
7.3.4.3	Wear —	197
7.3.5	Process requirements —	197
7.3.5.1	Debinding and sintering —	197
7.4	A growing market for moulders —	197
	Further reading —	199
	Reference —	199
8	Guide values and processing instructions for the most important thermoplastic injection moulding compounds —	201
8.1	Predrying material —	201
8.2	Examples of the moulding parameters of selected materials —	201
8.3	Parameters of the injection moulding process and the quality of moulded parts —	202

8.4	Injection and mould cavity pressure —	207
8.5	Injection pressure and injection time —	211
8.6	General information on filling speed —	211
8.6.1	Initial injection speed —	211
8.7	Filling speed and orientation —	212
8.8	Effects of excessive filling speed —	213
8.9	Setting the initial injection speed —	214
8.10	Plasticising —	215
8.10.1	Compound temperature – general information —	215
8.10.2	Cylinder temperatures —	216
8.10.3	Nozzle temperature —	217
8.10.4	Temperature profile guideline for the plasticising cylinder —	218
8.10.4.1	Horizontal —	218
8.10.4.2	Ascending —	218
8.10.4.3	Descending —	219
8.10.4.4	Ascending and descending at the nozzle —	219
8.10.5	Temperatures for the cylinder and mould —	219
8.10.6	Measuring the compound temperature —	222
8.10.7	Screw speed —	223
8.10.8	Back pressure —	223
8.11	The injection stage —	226
8.11.1	Filling to packing —	226
8.11.2	The mould —	226
8.11.2.1	Mould temperature: general information —	226
8.11.2.2	Mould temperature levels —	229
8.11.2.3	Uniformity of mould temperatures —	229
8.11.2.4	Mould temperature patterns —	230
8.11.2.5	Temperature control devices —	231
8.11.2.6	Matching temperature control units and mould maintenance —	233
8.11.2.7	Measuring the mould temperature – checking the uniformity of the mould temperature control —	234
8.12	Recommended values for holding pressure time and remaining cooling time —	234
8.13	Cycle time —	235
8.14	Setting the injection moulding machine —	236
9	Practical applications using injection moulding technology —	239
9.1	Introduction —	239
9.2	Troubleshooting and guidance —	239
9.2.1	Detection and classification of defects —	240
	Physical Cause —	241
9.2.2	Flow diagrams for troubleshooting —	241

9.2.3	Sink marks — 262 Physical cause — 262 Correcting sink marks — 262
9.2.4	Streaks — 262 Signs of burnt streaks — 263 Signs of moisture streaks — 264 Signs of air streaks — 266
9.2.4.1	Burnt streaks (brown or silver) — 266
9.2.4.1.1	Physical cause — 266
9.2.4.1.2	Correcting burnt streaks (brown or silver) — 266
9.2.4.2	Moisture streaks — 266
9.2.4.2.1	Physical cause — 266
9.2.4.2.2	Possible causes for moisture streaks — 267
9.2.4.2.3	Correcting moisture streaks — 267
9.2.4.3	Colour streaks — 267
9.2.4.3.1	Physical cause — 267
9.2.4.3.2	Correcting colour streaks — 268
9.2.5	Air streaks/air hooks — 268 Physical cause — 268 Correcting air streaks/air hooks — 269
9.2.6	Glass fibre streaks — 269 Physical cause — 269 Correcting glass fibre streaks — 269
9.2.7	Gloss/gloss differences — 269 Physical cause — 269 Correcting gloss/gloss differences — 270
9.2.8	Weld line (visible notch or colour change) — 270 Physical cause — 270 Improving a weld line (visible notch or colour change) — 273
9.2.9	Jetting — 273 Physical cause — 273 Correcting jetting — 274
9.2.10	Diesel effect (burns) — 275 Physical cause — 275 Correcting the diesel effect (burns) — 276
9.2.11	Record grooves effect — 276 Physical cause — 276 Correcting the record grooves effect — 278
9.2.12	Stress whitening/stress cracks — 278 Physical cause — 278 Correcting stress whitening/stress cracks — 279

9.2.13	Incompletely filled parts — 279
	Physical cause — 279
	Correcting incompletely filled parts — 280
9.2.14	Oversprayed parts (flashes) — 280
	Physical cause — 280
	Correcting oversprayed parts (flashes) — 281
9.2.15	Visible ejector marks — 281
	Physical cause — 282
	Correcting visible ejector marks — 282
9.2.16	Deformation during demoulding — 282
	Physical cause — 283
	Correcting deformation during demoulding — 284
9.2.17	Flaking of the surface layer — 284
	Physical cause — 285
	Correcting flaking of the surface layer — 285
9.2.18	Cold slugs/cold flow lines — 285
	Physical cause — 285
	Correcting cold slug/cold flow lines — 286
9.2.19	Entrapped air (blister formation) — 287
	Physical cause — 287
	Correcting entrapped air (blister formation) — 287
9.2.20	Dark spots — 287
	Physical cause — 287
	Correcting dark spots — 288
9.2.21	Dull spots near the sprue — 288
	Physical cause — 288
	Correcting Dull Spots Near the Sprue — 289
9.3	Data acquisition record — 289
9.3.1	Using the data acquisition record — 289
9.3.2	Data acquisition record for optimising moulded parts — 290
9.3.2.1	Moulded part data — 290
9.3.2.2	Machine settings and defect evaluation — 291
9.4	Experiences with injection moulded components — 295
9.4.1	Threaded connecting sleeves for ink-drafting apparatus — 295
9.4.2	Meter cases — 295
9.4.3	Wristwatch glass — 296
9.4.4	Alarm clock glass — 297
9.4.5	Glass cover for a digital gauge — 297
9.4.6	Plug boards with insert pins — 299
9.4.7	Hair slides — 299
9.4.8	Toothbrush components — 300
9.4.9	Screw cap with conical nipple — 302

- 9.4.10 Switch housing — 302
- 9.4.11 Battery housing — 304

- 10 Advanced processing techniques — 305**
 - 10.1 Introduction — 305
 - 10.2 Multicomponent moulding — 305
 - 10.2.1 Co-injection moulding — 305
 - 10.2.2 Bi-Injection moulding — 305
 - 10.2.3 Interval injection moulding — 307
 - 10.2.4 Injection moulding/additive manufacturing hybrid processes — 307
 - 10.3 Assisted moulding — 308
 - 10.4 Multi-Shot moulding — 308
 - 10.5 Over-moulding — 308
 - 10.6 Micromoulding — 308
 - 10.7 Business trends — 309
 - 10.8 Material selection — 311
 - 10.9 Process technology — 315
 - 10.9.1 Multicomponent injection moulding — 315
 - 10.9.2 co-injection moulding — 315
 - 10.9.2.1 Material selection for co-injection moulding — 317
 - 10.9.2.2 Process sequence — 318
 - 10.9.2.3 Co-injection moulding: different techniques — 318
 - 10.9.2.4 Part design and tooling requirements for co-injection moulding — 324
 - 10.9.2.5 Rheology and mould filling: why and how co-injection moulding works — 325
 - 10.9.2.6 Setting optimum parameters — 328
 - 10.9.2.7 Co-Injection moulded application case studies — 329
 - 10.9.2.8 Recycling and legislation — 329
 - 10.9.2.9 Discussion and conclusions — 330
 - 10.9.3 Bi-Injection — 330
 - 10.9.4 Interval injection moulding — 331
 - 10.10 Assisted moulding — 332
 - 10.10.1 Gas injection moulding technology — 332
 - 10.10.2 Process technology — 333
 - 10.10.3 Patent situation — 333
 - 10.10.4 Advantages and disadvantages of gas injection moulding technology — 333
 - 10.10.5 Process Variations in the application of gas injection moulding technology — 335
 - 10.10.5.1 Gas injection through the machine nozzle — 335
 - 10.10.5.2 Gas injection through an injector module in the mould — 336

- 10.10.5.3 Gas injection in the moulded part — 336
- 10.10.5.4 Melt blow moulding technology — 337
- 10.10.5.5 Melt back pressure technology/gas injection in the moulded part — 337
- 10.10.5.6 Melt extrusion technology/gas injection in the moulded part — 338
- 10.10.5.7 Core pull technology — 338
- 10.10.5.8 Systems technology for the implementation of gas injection moulding technology — 342
- 10.10.5.9 Configuration guidelines for gas injection moulding technology — 343
- 10.10.6 KoolGas™ — 345
- 10.10.7 Water-assisted injection moulding process — 346
- 10.11 Multi-shot moulding — 346
 - 10.11.1 Machine technology — 348
 - 10.11.1.1 Injection unit configurations — 348
 - 10.11.2 Core back moulding — 349
 - 10.11.3 Rotating tool — 352
 - 10.11.4 Transfer moulding — 353
 - 10.11.5 Multi-shot using a single injection unit — 355
 - 10.11.6 Materials for multi-shot moulding — 357
 - 10.11.6.1 Material selection for multi-shot moulding — 357
 - 10.11.6.2 Material process order — 358
 - 10.11.6.3 Using thermoset materials — 358
 - 10.11.6.4 Liquid silicone rubber — 358
 - 10.11.6.5 Thermoplastic elastomers — 359
 - 10.11.7 Multi-shot application case studies — 360
 - 10.11.7.1 Trio knob — 360
 - 10.11.7.2 Stanley screwdriver — 361
 - 10.11.8 Limitations to multi-shot — 362
 - 10.12 Over-moulding — 362
 - 10.12.1 Insert moulding — 362
 - 10.12.2 Lost core moulding — 363
 - 10.13 A final word on energy efficiency — 364
 - 10.14 The future? — 365
 - References — 365
 - Further reading — 366

Abbreviations — 367

Appendix — 369

Index — 373