

Contents

Acknowledgments	VII
Preface	IX
About the Author	XI
Foreword by Glenn Beall	XIII
Foreword by Louis Maresca	XV
Foreword by Joe McFadden	XIX
1 Introduction	1
1.1 Causes of Plastics Failure	1
1.2 The Holistic Approach	2
1.2.1 The Four Wheels	4
1.2.1.1 Material	4
1.2.1.2 Design	5
1.2.1.3 Processing	5
1.2.1.4 Tooling	6
1.2.2 Assembly and Secondary Operations	6
1.3 References	6
2 Plastic Materials	7
2.1 Introduction	7
2.2 Polymer Fundamentals	7
2.2.1 Polymer	8
2.2.2 Polymer Chain	8
2.2.3 Thermoplastics and Thermosets	9

2.2.3.1 Thermoplastic Types—Amorphous and Semicrystalline	9
2.2.3.2 Thermosets	10
2.2.4 Thermoplastic Molecular Arrangements	12
2.2.4.1 Blends, Alloys, and Copolymers	13
2.2.4.2 Commercial Plastics—Not Just Polymers	13
2.2.5 Average Molecular Weight of Plastic Resins	14
2.2.5.1 Molecular Weight	14
2.2.5.2 Molecular Weight and Mechanical Properties	16
2.2.5.3 Molecular Weight and Viscosity	17
2.2.5.4 Melt Flow Rate	18
2.2.6 Injection Molding of Thermoplastic Materials	19
2.2.6.1 Heating Amorphous and Semicrystalline Materials	19
2.2.6.2 All Materials Are Amorphous During Injection	20
2.2.6.3 Degradation	20
2.2.7 Plastic Properties	21
2.2.7.1 A Word of Caution about Using MFI to Predict Flow	21
2.2.8 Color Fundamentals	23
2.2.8.1 Color Measurement	24
2.3 “Plastics Are Not Metals”	30
2.3.1 Color, Gloss, and Aesthetics	30
2.3.2 Long Term Stress	33
2.3.3 Plastics and Chemical Resistance	34
2.3.3.1 Physical Effect	36
2.3.3.2 Chemical Resistance	36
2.3.4 Physical Properties—Plastics vs. Metals	38
2.3.4.1 Temperature Dependent Behavior of Plastics vs. Metals	39
2.3.5 Latent Defects	40
2.4 Choosing the Right Plastic for Your Application	41
2.4.1 The Commercial Plastics Family	41
2.4.2 Material Selection Process	42
2.4.2.1 Morphology	44
2.4.2.2 Thermal and Mechanical Properties	45
2.4.2.3 Special Properties	45
2.5 Thermoplastic Elastomers and Overmolding	48
2.5.1 TPE Family	48
2.5.2 Compatible Materials	50
2.6 References	50

3 Design	53
3.1 Introduction	53
3.2 Robust Design	54
3.2.1 Cost	54
3.2.1.1 Legitimate Costs	54
3.2.1.2 Avoidable Costs	55
3.2.1.3 Beyond Avoidable Costs	55
3.2.2 Performance, Manufacturability, and Costs	57
3.2.3 Purely Physical Requirements	58
3.2.4 Chemical and Environmental Requirements	58
3.2.5 Agency and Regulatory Requirements	59
3.2.6 Tooling and Molding Related Requirements	59
3.2.6.1 Wall Thickness	59
3.2.6.2 Knit or Weld Lines	76
3.2.6.3 Boss and Rib Height Considerations	80
3.3 Plastics Structural Calculations	83
3.3.1 Stress or Strain?	83
3.3.2 Long Term Strains	87
3.3.2.1 Warpage	89
3.3.2.2 Plastic Screws	89
3.3.2.3 Force Fit Assemblies	91
3.3.2.4 Tolerance Stack Up Issues	92
3.3.3 Change in Physical Properties with Rate of Loading	95
3.3.4 Metal Inserts	95
3.3.5 Draft	101
3.3.6 Gate Location and Effect of Location	103
3.3.7 Orientation	105
3.3.8 Wear of Plastics	108
3.4 Thin Walls, Structural Foam, and Gas Assisted Molding	109
3.4.1 Thin Wall Molding	109
3.4.1.1 Wall Thickness Variation	111
3.4.1.2 Rib Thickness	112
3.4.2 Structural Foam Molding	112
3.4.3 Gas Assisted Molding	113
3.5 References	113

4 Tooling Considerations	115
4.1 Introduction	115
4.2 Injection Molding Tool Family	115
4.2.1 Two Plate Molds	116
4.2.2 Three Plate Molds	118
4.3 Mold Elements	120
4.3.1 Steel Selection	120
4.3.2 The Feed and Vent System	123
4.3.2.1 Sprue and Sprue Bushing	123
4.3.2.2 Runner	123
4.3.2.3 Gates	132
4.3.2.4 Vents	136
4.3.3 Creating Undercuts	140
4.3.3.1 By Pass Shut Off	140
4.3.3.2 Angle Pin or Finger Cam	141
4.3.3.3 Hydraulic Cylinders or Solenoids	142
4.3.3.4 Floating "A" Plate	142
4.3.3.5 Collapsible Core	143
4.3.3.6 Lifters	143
4.3.3.7 Loose Piece Insert	144
4.3.3.8 General Notes on Side Action	144
4.3.4 The Ejector System	145
4.3.4.1 Ejector Pins and Blades	145
4.3.4.2 Ejector Sleeves	146
4.3.4.3 Stripper Plate Ejection	147
4.3.4.4 Air Poppet Valve	147
4.3.4.5 Factors Influencing Ease of Ejection	148
4.3.4.6 Guided Ejection	148
4.3.5 Special Case: Reverse Mold	149
4.3.6 Thermal Management	150
4.3.6.1 Cooling Insert and Baffles	152
4.3.6.2 Bubblers	152
4.3.6.3 Thermal Pin	153
4.3.6.4 Coolant Flow Requirements	154
4.4 Steel Safe Condition	156
4.5 Reviewing Mold Designs	156
4.5.1 Information Needed	156
4.5.2 Title Block	157
4.5.3 Core Plan View	157
4.5.4 Cavity Plan View	157

4.5.5 3D Rendering of Part	159
4.5.6 Mold Design Checklist	159
4.6 References	159
5 Processing	161
5.1 The Molding Machine	161
5.1.1 Injection Molding Machine Components	162
5.1.2 The Feed System	162
5.1.2.1 Screw Details	164
5.1.2.2 Clamp Tonnage and Capacity	165
5.1.2.3 Intensification Ratio	166
5.2 The Injection Molding Cycle	167
5.2.1 Filling or Velocity Stage	168
5.2.2 Packing	168
5.2.3 Cooling and Ejection	168
5.3 Process Capability	169
5.4 Basic Controls in Injection Molding	169
5.4.1 Drying Time, Temperature, and Drying of Air	169
5.4.1.1 Background	169
5.4.1.2 The Drying Process	171
5.4.1.3 Control of Drying Time	173
5.4.1.4 Control of Dryness	173
5.4.2 Melt Temperature	174
5.4.3 Mold Temperature	175
5.4.4 Fill Time and Shear Rate	176
5.4.5 Packing Pressure and Time	177
5.4.6 Gate Freeze Time	178
5.4.7 Cooling Time	178
5.4.8 Residence Time	178
5.5 Common Processing Issues	180
5.5.1 Poor Drying	181
5.5.2 Hesitation	181
5.5.3 Knit Line Strength and Appearance	184
5.5.3.1 Venting	185
5.5.3.2 Melt Temperature	186
5.5.3.3 Injection Speed	186
5.5.3.4 Packing Pressure	186
5.5.3.5 Mold Temperature	186
5.5.3.6 Mold Surface	187
5.5.3.7 Material	187
5.5.3.8 Putting It All Together through a DOE	187

5.5.4 Jetting	190
5.5.5 Poor Venting	192
5.5.6 Poorly Designed Gates, Runners, and Sprue	193
5.5.7 Mold Heating	196
5.5.7.1 Ignorance	196
5.5.7.2 Poor Controls and Monitoring	197
5.5.7.3 Intentional Overriding of Established Process Parameters	197
5.5.7.4 Effects of Running the Mold Too Hot	197
5.5.7.5 Effects of Running the Mold Too Cold	198
5.5.8 Gate Blush	200
5.5.9 Flow Marks, Gloss, and Texture Variation	202
5.5.10 Record Grooving	204
5.5.11 Warping	205
5.5.11.1 Non-Uniform Shrinkage	205
5.5.11.2 Poor Ejection	206
5.5.12 Flashing and Short Shots	206
5.5.13 Sink Marks	207
5.5.14 Scuffing	207
5.5.15 Read Through and Shadows	208
5.5.16 Unequal Shrinkage in Cross Direction	208
5.5.17 Use of Shrink Fixture	209
5.6 Scientific Molding	209
5.6.1 Traditional Molding vs. Scientific Molding	209
5.6.2 Details of the Process	210
5.6.3 Establishing the Optimum Process	212
5.6.3.1 Step 1: The Viscosity Curve and the Injection Speed	212
5.6.3.2 Step 2: Balancing the Cavities	213
5.6.3.3 Step 3: Pressure Drop Study	214
5.6.3.4 Step 4: Setting the Pack and Hold Pressures	215
5.6.3.5 Step 5: Setting the Hold Time	216
5.6.3.6 Step 6: Setting the Cooling Time	217
5.7 Putting It All Together—Processing Parameters Recording	218
5.7.1 Proper Recording of the Process	218
5.7.2 Ongoing Control of the Process	220
5.7.3 Allowable Changes to the Processing Parameters	224
5.8 References	224

6 Secondary Operations	225
6.1 Introduction	225
6.2 Ultrasonic Assembly	226
6.2.1 Theory	226
6.2.1.1 Hysteresis Heating	226
6.2.1.2 Energy for Ultrasonic Welding	227
6.2.2 Generation of Vibration	228
6.2.3 Ultrasonic Welding System Components	229
6.2.3.1 Control of Power and Total Energy Provided to the Welded Surface	230
6.2.3.2 Details of the Subcomponents	231
6.2.4 Types of Ultrasonic Welding	235
6.2.5 Welding Polymers	236
6.2.5.1 Other Factors Affecting Ease of Welding	238
6.2.6 Design Factors	239
6.2.6.1 Joint Types	239
6.2.6.2 Part Design	241
6.2.6.3 Fixture Design	244
6.2.6.4 Important Welding Parameters	245
6.3 Heat Staking	250
6.3.1 Heat Staking Machines	252
6.3.2 Insert Height and Required Torque	255
6.4 References	256
7 Part and Tool Costs	257
7.1 Introduction	257
7.2 Part and Assembly Costs	257
7.2.1 Elements of a Plastic Part Cost	257
7.2.1.1 Cost of Molded Parts	258
7.2.1.2 Cost of Bought Parts	258
7.2.1.3 Secondary Operations	258
7.2.1.4 Profit	258
7.2.2 Overall Cost to Customer	259
7.2.3 Determination of Shop Rates, Overhead Costs on Resin and Bought Parts, and Margin	260
7.2.4 Determination of Cycle Times	260
7.2.5 Putting It All Together	261
7.3 Tool Costs	263
7.3.1 Tool Specifications	263
7.3.2 Tool Costing Sheet	264

8 Six Sigma Techniques in Plastics	267
8.1 Introduction	267
8.2 Brief History	268
8.3 Evolution of Six Sigma	268
8.4 DMAIC	270
8.4.1 Define	271
8.4.2 Measure	271
8.4.3 Analyze	271
8.4.4 Improve	271
8.4.5 Control	272
8.5 Design for Six Sigma and DMADV	272
8.5.1 Define	272
8.5.2 Measure	274
8.5.3 Analyze	275
8.5.4 Design	275
8.5.4.1 Failure Mode and Effects Analysis (FMEA)	275
8.5.4.2 Poka Yoke	277
8.5.4.3 Conventional Tools Used in Design Phase: Simulation ..	277
8.5.4.4 Some Common Poka Yoke Tools for the Design Process ..	279
8.5.4.5 Some Other Commonly Used Tools	280
8.5.5 Verify	283
8.6 Going Beyond Just Making Good Products	283
8.6.1 Kano Analysis	283
8.6.2 Breaking the Paradigm	285
8.6.3 BHAGS (Pronounced “Be Hags”): Big Hairy Audacious GoalS ..	286
8.7 References	288
9 Further Reading and Reference Material	289
9.1 Introduction	289
9.2 Materials	289
9.2.1 Step 1: Search across Suppliers	290
9.2.2 Step 2: Search within Suppliers	291
9.2.3 RoHS, REACH, UL, and Other Standards	292
9.2.3.1 RoHS	292
9.2.3.2 REACH	292
9.2.3.3 UL 94 Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances	293
9.3 Design	293
9.3.1 Structural Calculations Including Snaps and Gears	293

9.3.2	High Performance Optical Parts	294
9.3.3	Living Hinge	294
9.3.4	Brittle and Ductile Failures	294
9.3.5	Thin Wall Molding	295
9.3.6	Structural Foam	295
9.3.7	Gas Assisted Molding	295
9.3.8	Two Shot Molding	296
9.3.9	Pad Stamping	296
9.3.10	Plating	296
9.3.11	In-Mold Decoration	297
9.3.12	Ultrasonic Welding	297
9.4	Tooling	297
9.4.1	Classes of Molds	297
9.4.2	Tool Polish	297
9.4.3	Texture	298
9.4.4	Total Tolerance	298
9.4.5	Sprue, Gate, and Vent Design	298
9.5	Processing	299
9.6	Simulation and Analysis	299
9.6.1	Simulation	299
9.6.2	Design Checking and Design for Performance	299
9.7	Failure Analysis Tools	300
9.8	Six Sigma and Statistics	301
9.8.1	Basic Statistics	301
9.8.2	Design of Experiments (DOE)	302
9.8.3	Process Capability	302
9.8.4	Six Sigma Tools	302
9.9	References	303
Index	305	