

# Contents

- 1 Overview of Runners, Gates, and Gate Positioning ..... 1
  - 1.1 Primary Parting Plane Runners ..... 1
  - 1.2 Sub Runners ..... 2
    - 1.2.1 Cold Sub Runners ..... 2
    - 1.2.2 Hot Sub Runners ..... 2
  - 1.3 Hybrid Sub-Runner and Parting Line Runner ..... 3
  - 1.4 Gate Designs ..... 3
  
- 2 Rheology of Plastics ..... 5
  - 2.1 Laminar vs. Turbulent Flow ..... 5
  - 2.2 Fountain Flow ..... 7
  - 2.3 Factors Affecting Viscosity ..... 7
    - 2.3.1 Common Viscosity Models ..... 8
    - 2.3.2 Non-Newtonian Fluids ..... 10
    - 2.3.3 Temperature ..... 11
    - 2.3.4 Pressure ..... 12
  - 2.4 Melt Compressibility ..... 12
  - 2.5 Melt Flow Characterization ..... 13
  
- 3 Filling and Packing Effects on Material and Molded Part ..... 17
  - 3.1 Process Effects on Material Viscosity ..... 17
    - 3.1.1 Melt Thermal Balance – Conductive Heat Loss vs. Shear Heating ..... 17
    - 3.1.2 Development of a Frozen Boundary Layer ..... 19
  - 3.2 Factors Affecting Plastic Material Degradation ..... 20
    - 3.2.1 Excessive Shear ..... 20
    - 3.2.2 Excessive Temperature ..... 22
  - 3.3 Effects of Mold Fill Rate on Fill Pressure ..... 23
  - 3.4 Post Filling or Packing Phase ..... 24
    - 3.4.1 Thermal Shrinkage as Plastic Cools ..... 24
    - 3.4.2 Compensation Flow to Offset Volumetric Shrinkage ..... 25
    - 3.4.3 Pressure Distribution During the Post Filling Phase ..... 26
    - 3.4.4 Gate Freeze-Off ..... 26
  - 3.5 Melt Flow Effects on Material and Molded Parts ..... 27
    - 3.5.1 Shrinkage ..... 27
      - 3.5.1.1 Volumetric Shrinkage ..... 28
      - 3.5.1.2 Orientation-Induced Shrinkage ..... 29

3.5.2	Development of Residual Stresses and Warpage .....	33
3.5.2.1	Warpage and Residual Stress from Side-to-Side Shrinkage Variations ..	33
3.5.2.2	Warpage and Residual Stress from Global/Regional Shrinkage Variations	34
3.5.2.3	Warpage and Residual Stress from Orientation-Induced Shrinkage Variations	34
3.5.3	Physical Properties as Effected by Orientation .....	35
3.6	Annealing a Molded Part .....	35
3.7	Summary .....	35
<b>4</b>	<b>Gate Positioning and Molding Strategies .....</b>	<b>39</b>
4.1	Gate Positioning Considerations .....	39
4.2	Design and Process Strategies for Injection Molding .....	41
4.2.1	Maintain Uniform Wall Thicknesses in a Part .....	41
4.2.2	Use Common Design Guidelines for Injection Molded Plastic Parts with Caution	42
4.2.3	Avoid Flowing from Thin to Thick .....	43
4.2.4	Establish a Simple Strategic Flow Pattern within a Cavity .....	44
4.2.5	Avoid Picture Framing .....	46
4.2.6	Integral Hinges .....	47
4.2.7	Balanced Filling Throughout a Mold .....	50
4.2.7.1	Gating Position(s) Within a Cavity .....	50
4.2.7.2	Multi-Cavity Molds .....	53
4.2.8	Provide for Uniform Temperatures (Mold and Melt) .....	55
4.2.9	Eliminate, Strategically Place, or Condition Welds .....	56
4.2.10	Avoiding Flow Hesitation .....	57
4.2.11	Managing Frictional Heating of the Melt .....	58
4.2.12	Minimize Runner Volume in Cold Runners .....	59
4.2.13	Avoid Excessive Shear Rates .....	60
4.2.14	Avoid Excessive, and Provide for Uniform, Shear Stresses .....	62
<b>5</b>	<b>The Melt Delivery System .....</b>	<b>65</b>
5.1	Runner Design Fundamentals .....	65
5.2	Overview of Runner/Melt Delivery System .....	66
5.2.1	Machine Nozzle .....	67
5.2.1.1	Nozzle Filter .....	68
5.2.1.2	Static Mixers .....	68
5.2.2	Sprue .....	68
5.2.3	Runner .....	69
5.2.4	Gate .....	69
5.3	Melt Flow Through the Melt Delivery System .....	69

## Contents

5.3.1	Melt Preparation – The Injection Molding Machine . . . . .	69
5.3.1.1	Pressure Development from a Molding Machine . . . . .	70
5.3.1.2	Flow Through a Runner Channel . . . . .	71
5.3.2	Effect of Temperature on Flow . . . . .	72
5.3.2.1	Melt Temperature . . . . .	72
5.3.2.2	Mold Temperature . . . . .	73
5.3.3	Cold vs. Hot Runners . . . . .	73
5.3.4	Pressure Drop through the Melt Delivery System (Nozzle vs. Sprue vs. Runner vs. Gate vs. Part Forming Cavity) . . . . .	74
5.4	Use of Mold Filling Analysis . . . . .	75
5.5	Runner Cross Sectional Size and Shape . . . . .	76
5.5.1	The Efficient Flow Channel . . . . .	76
5.5.2	Pressure Development in the Runner . . . . .	77
5.5.2.1	Flow through a Hot Runner vs. a Cold Runner . . . . .	79
5.5.3	Runner Effect on Cycle Time . . . . .	80
5.5.3.1	Cold Runner and Sprue Cooling Time . . . . .	80
5.5.3.2	Hot Runner . . . . .	80
5.5.4	Constant Diameter vs. Varying Diameter Runners . . . . .	80
5.6	Designing Runners for Shear- and Thermally-Sensitive Materials . . . . .	82
5.7	Runner Layouts . . . . .	83
5.7.1	Geometrical Balanced Runners . . . . .	84
5.7.2	Non-Geometrically Balanced Runners . . . . .	84
5.7.3	Fishbone Runners vs. Geometrically Balanced Runners . . . . .	85
5.7.3.1	Flow Balance Ratio . . . . .	86
5.7.3.2	Melt Variation in Unbalanced Molds . . . . .	87
5.7.3.3	Artificial Balancing of Runners . . . . .	87
5.7.3.4	Does the Artificially Balanced Runners Reduce Runner Volume? . . . . .	88
5.7.4	Family Molds . . . . .	90
<b>6</b>	<b>Filling and Melt Imbalances Developed in Multi-Cavity Molds . . . . .</b>	<b>93</b>
6.1	Source of Mold Filling Imbalances . . . . .	93
6.1.1	Imbalances Developed from the Runner . . . . .	93
6.1.2	Imbalance Caused by Non-Runner Layout Issues . . . . .	95
6.2	Imbalance Effects on Process, Product, and Productivity . . . . .	98
6.3	Shear-Induced Melt/Molding Imbalances in Geometrically Balanced Runners . . . . .	102
6.3.1	Development and Stratification of Melt Variations Across a Runner Channel . . . . .	102
6.3.2	Laminate Separation in Branching Runners Causing Cavity-to-Cavity Filling Imbalances. . . . .	103
6.3.3	Shear Induced Melt Imbalances in Stack Molds . . . . .	105

6.3.4	Development of Intra-Cavity Variations .....	106
6.3.4.1	Warpage .....	107
6.3.4.2	Core Deflection .....	107
6.3.4.3	Effect on Concentric Parts (Gears, Fans, and Others) .....	108
6.3.5	Alternative Theories of the Cause of Mold Filling Imbalances .....	109
6.3.5.1	Cooling Variations .....	109
6.3.5.2	Plate Deflection .....	109
6.3.5.3	Corner Effect .....	110
6.3.5.4	Melt Pressure as the Cause of Filling Imbalance .....	110
6.4	Runner Layouts .....	111
6.4.1	Identification of Various Flow Groups in Common Geometrically Balanced Runners .....	111
6.4.2	Apparent Geometrically Balanced Runner Layouts .....	112
6.5	Effect of Shear-Induced Melt Variations on Two-Stage Injection Processes .....	113
6.5.1	Gas Assist Injection Molding .....	113
6.5.2	Co-Injection Molding .....	114
6.5.3	Structural and Microcellular Foam Molding .....	115
6.6	The Cost of Melt Imbalances .....	116
<b>7</b>	<b>Managing Shear-Induced Melt Variations for Successful Molding .....</b>	<b>119</b>
7.1	Static Mixers .....	119
7.2	Artificially Balancing .....	121
7.2.1	Varying Sizes of Branching Runners or Gates to Achieve a Filling Balance .....	121
7.2.2	Varying Temperatures to Control Filling Balance .....	122
7.3	Melt Rotation Technology .....	122
7.3.1	Melt Rotation Technology in Hot Runner Molds .....	127
7.3.2	Melt Rotation Technology in Cold Runner Molds .....	128
7.3.3	Melt Rotation for Intra-Cavity Imbalances .....	129
7.3.4	Multi-Axis Melt Symmetry .....	130
7.3.5	n-Mold Adjustable Rheological Control (iMARC™) .....	132
7.3.5.1	3D Molding .....	132
7.4	Melt Rotation for Controlling Two Stage Injection Processes .....	135
7.5	Controlling Warpage Through Melt Rotation Technology .....	136
7.5.1	Development of Warpage Potential .....	139
7.5.2	Controlled Warpage through Melt Rotation Technology .....	140
7.5.3	New Application for 3D Molding .....	142

<b>8</b>	<b>Cold Runner Molds</b>	145
8.1	Sprue	146
8.1.1	Cold Sprue	146
8.1.2	Hot Sprue	149
8.2	The Cold Runner	149
8.2.1	Important Machining Considerations	151
8.2.2	Sizing of Runners	152
8.2.3	Venting	153
8.2.4	Runner Ejection	153
	8.2.4.1 Sprue Puller	153
	8.2.4.2 Secondary Sprue/Cold Drop	154
	8.2.4.3 Runner	155
8.2.5	Cold Slug Wells	155
8.3	Runners for Three-Plate Cold Runner Molds	156
8.4	Gate Designs	158
8.4.1	Sprue Gate	159
8.4.2	Common Edge Gate	160
8.4.3	Fan Gate	161
8.4.4	Film Gate or Flash Gate	162
8.4.5	Ring Gate	162
8.4.6	Diaphragm Gate	163
8.4.7	Tunnel Gate	164
8.4.8	Cashew or Banana Gate	165
8.4.9	Jump Gate	166
8.4.10	Pin Point Gate	166
8.4.11	Chisel Gate	166
8.4.12	Tab Gate	167
8.5	Effects of Gate Diameter in Multi-Cavity Molds	167
8.5.1	Study 1	167
8.5.2	Study 2	168
8.5.3	Measuring Tolerances	169
<b>9</b>	<b>Hot Runner Molds</b>	173
9.1	Overview	173
9.1.1	Advantages and Disadvantage of Hot Runner Systems	174
	9.1.1.1 Advantages of Hot Runners	174
	9.1.1.2 Disadvantages of Hot Runners	176
	9.1.1.3 Summary of Attributes of Different Runner Systems	178
9.2	Overview of Multi-Cavity Hot Runner Systems (Contrasting Systems)	179

9.2.1	Externally Heated Manifold and Drops/Nozzles .....	180
9.2.2	Externally Heated Manifold with Internally Heated Drops .....	181
9.2.3	Internally Heated Manifold and Internally Heated Drops .....	182
9.2.4	Insulated Manifold and Drops .....	182
9.3	Stack Molds .....	183
<b>10</b>	<b>Hot Runner Flow Channel Design .....</b>	<b>185</b>
10.1	Layout for Balanced Molding .....	185
10.2	Cross-Sectional Shape .....	186
10.3	Corners .....	187
10.4	Effect of Diameter .....	188
10.4.1	Pressure .....	188
10.4.2	Shot Control .....	190
10.4.3	Color Change .....	191
10.4.4	Material Change .....	194
<b>11</b>	<b>Hot Runner Drops, Nozzles and Gates .....</b>	<b>195</b>
11.1	Hot Drops .....	196
11.1.1	Externally Heated Hot Drops (Nozzles) .....	196
11.1.2	Internally Heated Hot Drops .....	197
11.1.3	Heat Conducting Nozzles .....	197
11.2	Restrictive/Pin Point Gates .....	198
11.3	Gate Design Considerations .....	199
11.3.1	Gate Freeze-Off .....	199
11.3.2	Stringing/Drooling .....	200
11.3.3	Packing .....	200
11.3.4	Mechanical Valve Gates .....	202
11.3.4.1	Sequential Valve Gates .....	204
11.3.5	Thermal Shut-Off Gates .....	205
11.3.6	Hot Edge Gates .....	205
11.3.7	Multi Tip Nozzles .....	206
<b>12</b>	<b>Thermal Issues of Hot Runner Systems .....</b>	<b>207</b>
12.1	Heating .....	207
12.1.1	Coil (Cable) Heaters .....	208
12.1.2	Band Heaters .....	208
12.1.3	Tubular Heaters .....	209
12.1.4	Cartridge Heaters .....	209
12.1.5	Heat Pipe Technology .....	210

## Contents

12.2	Heater Temperature Control	210
12.2.1	Thermocouples	210
12.2.2	Temperature Controllers	211
12.3	Power Requirements	212
12.4	Thermal Isolation of the Hot Runner	213
12.5	Gate Temperature Control	215
12.5.1	Gate Heating	216
12.5.2	Gate Cooling	216
<b>13</b>	<b>The Mechanics and Operation of Hot Runners</b>	<b>217</b>
13.1	Assembly and Leakage Issues	217
13.1.1	System Design	218
13.1.2	Hot Runner System Machining and Assembly	220
13.2	Mold and Machine Distortions	223
13.3	Startup Procedures	225
13.4	Color and Material Changes	225
13.5	Gates	226
13.5.1	Vestige	226
13.5.2	Clog	227
13.5.3	Wear	227
13.6	Maintenance	227
<b>14</b>	<b>Process of Designing and Selecting a Runner System (Gate and Runner) –</b>	
	<b>A Summary</b>	<b>229</b>
14.1	Number of Gates	229
14.2	Gating Position on a Part	229
14.2.1	Cosmetic	229
14.2.2	Effect on Shrinkage, Warp, and Residual Stress	230
14.2.2.1	Orientation	230
14.2.2.2	Volumetric Shrinkage (Regional)	230
14.2.2.3	Unbalanced Filling	231
14.2.3	Structural Issues	231
14.2.3.1	Gate Stress	231
14.2.3.2	Flow Orientation	232
14.2.4	Gating into Restricted, or otherwise Difficult to Reach Locations	232
14.3	Cavity Positioning	232
14.4	Material	232
14.5	Jetting	233
14.6	Thick vs. Thin Regions of the Part	233

14.6.1	Volumetric Shrinkage .....	233
14.6.2	Hesitation .....	233
14.7	Number of Cavities .....	233
14.8	Production Volume .....	234
14.9	Precision Molding (Precision Size, Shape, Weight, Mechanical Properties and Consistency) .....	234
14.10	Color Changes .....	234
14.11	Material Change .....	235
14.12	Regrind of Runners .....	235
14.13	Part Thickness .....	235
14.13.1	Thin Part .....	235
14.13.2	Thick Part .....	236
14.14	Part Size .....	236
14.15	Labor Skill Level .....	236
14.16	Post Mold Handling .....	237
14.17	Part/Gate Stress Issues .....	237
14.18	Hot and Cold Runner Combinations .....	237
14.19	Two-Phase Injection Processes .....	237
<b>15</b>	<b>Troubleshooting .....</b>	<b>239</b>
15.1	The 5 Step Process™ .....	239
15.1.1	Shear-Induced Flow Imbalance Developed in a Geometrically Balanced Runner .....	239
15.1.2	Steel Variations in the Mold .....	240
15.1.3	Cooling Affects .....	240
15.1.4	Hot Runner Systems .....	241
15.1.5	Summary of Test Data .....	241
15.1.6	The 5 Step Process: Method of Application .....	241
15.2	Injection Molding Troubleshooting Guidelines for Scientific Injection Molding .....	243
15.3	Two Stage Molding Set-Up .....	290
15.4	Intensification Ratio (Ri) .....	301
15.5	Characterizing Flow Behavior in an Injection Mold .....	302
15.6	List of Amorphous and Semi-Crystalline Resins .....	302