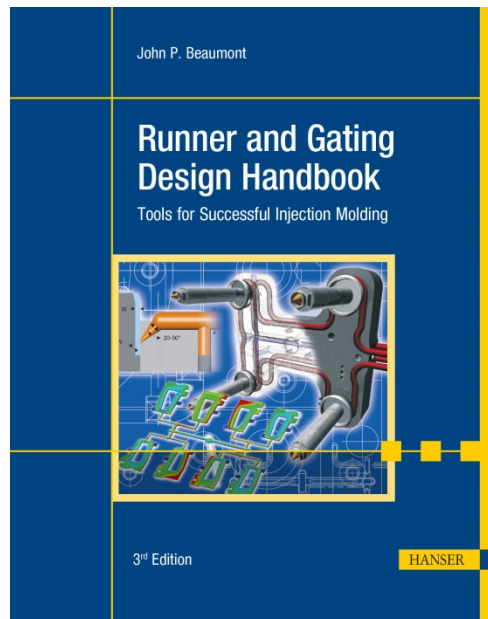


HANSER



Sample Pages

Runner and Gating Design Handbook

John P. Beaumont

ISBN (Book): 978-1-56990-590-6

ISBN (E-Book): 978-1-56990-591-3

For further information and order see

www.hanserpublications.com (in the Americas)

www.hanser-fachbuch.de (outside the Americas)

© Carl Hanser Verlag, München

Preface

Quality management methods, such as *Design for Six Sigma*, stress the critical review of fundamentals in order to identify and eliminate potential problems before they take their toll on the manufacturing process. In developing a mold design to produce an injection molded plastic part, one of the most fundamental and influential components is its melt delivery system. It also turns out that the melt delivery, or runner, system is probably the most underappreciated and misunderstood component of the injection mold. This makes it a prime candidate for critical review, particularly for the conscientious molder striving to improve his/her bottom line.

The melt delivery system begins with the injection molding machine's nozzle and continues into the mold, progressing through the sprue, runner, and gate. Though the melt may only experience these flow channels for a fraction of a second, their effects are dramatic and result in the most extreme conditions experienced by the plastic melt in any phase of nearly any plastics processing method. Shear rates in gates commonly exceed $100,000 \text{ s}^{-1}$ and localized melt temperature in high shear laminates can spike at as much as $200 \text{ }^\circ\text{C}$, at rates that can exceed $1000 \text{ }^\circ\text{C/s}$. Due to the extremity of these conditions, the actual effect of these conditions on the melt is not well understood. Most material characterization methods do not even come close to measuring melt conditions under these extremes. Viscosity vs. shear rate data are generally developed at a maximum of $10,000 \text{ s}^{-1}$, DSC data at less than $32 \text{ }^\circ\text{C/min}$, and PVT data at less than $3 \text{ }^\circ\text{C/min}$. As a result of the limitations of material characterization methods as well as solution modeling and meshing issues, today's injection molding and fluid flow simulation programs are still struggling to accurately predict the extreme non-homogeneous asymmetric melt conditions developed in a branching runner. The challenge of dealing with these conditions has generally been underestimated.

The influences of these extreme melt conditions developed in the runner are just beginning to be understood. One of the most significant is the realization that the combination of laminar flow and high perimeter shear in a runner results in extreme non-homogeneous melt conditions across a runner. Not only can a $200 \text{ }^\circ\text{C}$ variation in melt temperature exist but, as a result of the non-Newtonian characteristics of the melt, the viscosity may easily vary 100-fold from the zero shear conditions in the center of a flow channel to the extreme shear conditions around the perimeter. This creates significantly asymmetric melt conditions when the melt branches in a runner or part-forming cavity. The conditions developed in the runner continue into the part, corrupting the expected filling pattern and influencing how the part is packed, its mechanical properties, shrinkage, and warpage. These are all factors that are hardly known by most in the molding industry and their dramatic effects are rarely fully appreciated. The

influence can be particularly acute in two-stage injection processes such as gas assist, structural foam, MuCell[®], and co-injection.

As stated earlier, the melt delivery system consists of the molding machine's nozzle, sprue, runner, and gate. Each of these components, or regions, can have a significant influence on both the process and the molded part. Process effects include the ability to fill and pack the part, the injection fill rate, the clamp tonnage, and the cycle time. Effects on the part include size, weight, mechanical properties, and variations in these characteristics between parts formed in different cavities within a multi-cavity mold.

Despite the significant influence that the melt delivery system has on the molding process, its various components are generally poorly designed relative to the time, effort, and cost put into the other components/regions of a mold and molding machine. This book bridges the critical gap left by other publications dealing with injection molding, which generally touch only briefly on the design of the melt delivery system and its relationship to successful injection molding. In particular, the lack of information on cold runners needed to be addressed. Though a fair amount of published data on hot runners are available, these data are generally heavily influenced by the bias of companies that sell these systems. There are over 50 companies offering hot runner systems and components commercially, while there is no company at all offering cold runner systems. As a result, one can imagine the lackluster image of cold runners, as there is no company commercially promoting them.

Evidence of the lack of understanding of runners includes the fact that the significant effects of shear-induced flow imbalances in runners were not documented, or clearly understood, until 1997 when I published the first journal article on this phenomenon. For the first time, it became obvious that the industry standard "naturally balanced" runners were creating significant imbalances. Melt filling imbalances, developed from shear-induced melt variations, were found to be the norm in most of the industry standard geometrically balanced runner designs being used. This phenomenon was being overlooked by the entire molding industry for both cold and hot runner molds. In addition, the industry's leading state-of-the-art mold-filling simulation programs had been developed without the realization of the shear-induced imbalance. As a result, these programs did not predict the imbalance and left the analyst with a false impression that these runners provided uniform melt, filling, and packing conditions. The problem still exists today and should be considered when using analysis programs.

Of particular interest is the evolution of the runner from a basic necessity required to connect the injection unit and the mold's cavity to its emergence as a significant process tool. Newer melt rotation technologies, such as MeltFlipper[®] and iMARC[™], have introduced the concept of 3D injection molding.

This book takes an independent view of both hot and cold runners, trying not to make a judgment as to which is best for a given application. Rather, it addresses some of the critical design issues unique and common to both. The early chapters lay a foundation for designing runners by establishing an understanding of the rheological characteristics of plastic melt and how the influence of runner design and gating positions can affect the molded part. Chapter 4 provides important strategies for runner designs and gating position, which are critical to the successful molding of a plastic part. Chapter 5 provides an overview of the melt delivery system, followed by Chapter 6 and 7, which teach the development and solutions to shear-induced imbalances. These three chapters (5, 6, and 7) address issues which are common to both cold and hot runners, blending basic geometrical channel issues with melt rheology.

Chapter 8 focuses on cold runner designs including specific guidelines for runner and a wide variety of gate designs. Chapters 9 through 13 provide a close look at the design of hot runner systems and their unique capabilities and challenges. Chapter 14 provides a summary on the process of designing and selecting a runner system. Finally, the book concludes with an extensive troubleshooting chapter with contributions from John Bozzelli and David Hoffman.

This 3rd edition of *Runner and Gating Design Handbook* includes numerous updates and new instructional figures that are scattered throughout each of the 15 chapters. Chapters 6 and 7 include additional information and examples to aid in the understanding of critical shear induced melt variations that are developed in the runners of all injection molds. Autodesk Moldflow analyses and related discussions were added to help further understand the complexities of this phenomenon. Chapters 9 through 12 have expanded on all aspects of hot runners, including the design of manifolds, nozzles, gate tip designs, valve gated nozzles, and valve gate actuation. A new Chapter 15.3, "Injection Molding Process Development", written by Dave Hoffman of the American Injection Molding Institute (AIM Institute), was added.

This book is intended to provide the reader with a better understanding of the critical role the runner plays in successful injection molding. It is hoped that this understanding should go a long way toward reducing mold commissioning times, improving product realization, increasing productivity, improving customer satisfaction, and achieving quality goals such as Six Sigma.

Contents

Preface	V
Acknowledgments	IX
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	4
1.3 Hybrid Sub-Runner and Parting Line Runner	5
1.4 Gate Designs	5
2 Rheology and Melt Flow in an Injection Mold	7
2.1 Laminar vs. Turbulent Flow	8
2.2 Fountain Flow	10
2.3 Factors Affecting Viscosity	10
2.3.1 Common Viscosity Models	12
2.3.2 Non-Newtonian Fluids	14
2.3.3 Temperature	17
2.3.4 Pressure	17
2.4 Melt Compressibility	18
2.5 Melt Flow Characterization	19
2.5.1 Melt Flow Index	19
2.5.2 Capillary Rheometers	20
2.5.3 Nozzle Rheometers	25
2.6 Melt Flow in a Mold	26
2.6.1 Spiral Flow Molds	27
2.6.2 Injection Molding Simulation	28
2.6.3 Moldometer	30

3	Filling and Packing Effects on Material and Molded Part	33
3.1	Process Effects on Material Flow Characteristics	33
3.1.1	Melt Thermal Balance – Conductive Heat Loss vs. Shear Heating ..	33
3.1.2	Development of a Frozen Boundary Layer	36
3.2	Factors Affecting Plastic Material Degradation	42
3.2.1	Excessive Shear	42
3.2.2	Excessive Temperature	44
3.3	Effects of Mold Fill Rate on Fill Pressure	46
3.4	Post Filling or Packing Phase	47
3.4.1	Thermal Shrinkage as Plastic Cools	47
3.4.2	Compensation Flow to Offset Volumetric Shrinkage	48
3.4.3	Pressure Distribution During the Post Filling Phase	49
3.4.4	Gate Freeze-Off	50
3.5	Melt Flow Effects on Material and Molded Parts	51
3.5.1	Shrinkage	51
3.5.1.1	Volumetric Shrinkage	52
3.5.1.2	Orientation-Induced Shrinkage	54
3.5.2	Development of Residual Stresses and Warpage	58
3.5.2.1	Warpage and Residual Stress from Side-to-Side Shrinkage Variations	58
3.5.2.2	Warpage and Residual Stress from Global/Regional Shrinkage Variations	59
3.5.2.3	Warpage and Residual Stress from Orientation-Induced Shrinkage Variations	60
3.5.3	Physical Properties as Effected by Orientation	60
3.6	Annealing a Molded Part	61
3.7	Summary	61
4	Gate Positioning and Molding Strategies	65
4.1	Gate Positioning Considerations	65
4.2	Design and Process Strategies for Injection Molding	67
4.2.1	Maintain Uniform Wall Thicknesses in a Part	67
4.2.2	Use Common Design Guidelines for Injection Molded Plastic Parts with Caution	70
4.2.3	Avoid Flowing from Thin to Thick	71
4.2.4	Establish a Simple Strategic Flow Pattern within a Cavity	72
4.2.5	Avoid Picture Framing	76
4.2.6	Integral Hinges	78

4.2.7	Balanced Filling throughout a Mold	81
4.2.7.1	Gating Position(s) within a Cavity	82
4.2.7.2	Multi-Cavity Molds	86
4.2.8	Provide for Uniform Temperatures (Mold and Melt)	89
4.2.9	Eliminate, Strategically Place, or Condition Welds	90
4.2.10	Avoiding Flow Hesitation	91
4.2.11	Managing Frictional Heating of the Melt	93
4.2.12	Minimize Runner Volume in Cold Runners	93
4.2.13	Avoid Excessive Shear Rates	94
4.2.14	Avoid Excessive, and Provide for Uniform Shear Stresses	96
5	The Melt Delivery System	99
5.1	Runner Design Fundamentals	99
5.2	Overview of Runner/Melt Delivery System	100
5.2.1	Machine Nozzle	101
5.2.1.1	Nozzle Filter	102
5.2.1.2	Static Mixers	103
5.2.2	Sprue	103
5.2.3	Runner	103
5.2.4	Gate	104
5.3	Melt Flow through the Melt Delivery System	104
5.3.1	Melt Preparation – The Injection Molding Machine	104
5.3.1.1	Pressure Development from a Molding Machine	105
5.3.1.2	Flow through a Runner Channel	106
5.3.2	Effect of Temperature on Flow	107
5.3.2.1	Melt Temperature	107
5.3.2.2	Mold Temperature	109
5.3.3	Cold vs. Hot Runners	110
5.3.4	Pressure Drop through the Melt Delivery System (Nozzle vs. Sprue vs. Runner vs. Gate vs. Part Forming Cavity)	110
5.4	Use of Mold Filling Analysis	111
5.5	Runner Cross-Sectional Size and Shape	113
5.5.1	The Efficient Flow Channel	113
5.5.2	Pressure Development in the Runner	113
5.5.2.1	Flow through a Hot Runner vs. a Cold Runner	117
5.5.3	Runner Effect on Cycle Time	117
5.5.3.1	Cold Runner and Sprue Cooling Time	117
5.5.3.2	Hot Runner	118
5.5.4	Constant Diameter vs. Graduated Diameter Runners	118

5.6	Designing Runners for Shear- and Thermally-Sensitive Materials	121
5.7	Runner Layouts	122
5.7.1	Geometrical Balanced Runners	122
5.7.2	Non-Geometrically Balanced Runners	125
5.7.3	Fishbone Runners vs. Geometrically Balanced Runners	125
5.7.3.1	Flow Balance Ratio	127
5.7.3.2	Melt Variation in Unbalanced Molds	128
5.7.3.3	Artificial Balancing of Runners	128
5.7.3.4	Do the Artificially Balanced Runners Reduce Runner Volume?	131
5.7.4	Family Molds	135
6	Filling, Melt, and Product Variations Developed in Multi-Cavity Molds	137
6.1	Sources of Product Variation in Multi-Cavity Molds of Mold Filling Imbalances	138
6.1.1	Product Variations Resulting from the Runner Design	138
6.1.2	Product Variations Resulting from Non-Runner Layout Issues	140
6.2	Imbalance Effects on Process, Product, and Productivity	144
6.2.1	Artificial Balancing of Runners	148
6.3	Shear-Induced Melt/Molding Variations from Geometrically Balanced Runners	150
6.3.1	Development and Stratification of Melt Variations Across a Runner Channel	150
6.3.2	Laminate Separation in Branching Runners Causing Cavity-to-Cavity Product Variations	152
6.3.3	Shear-Induced Melt Imbalances in Stack Molds	157
6.3.4	Development of Intra-Cavity Variations and Influence on Residual Stresses and Warpage	158
6.3.4.1	Warpage	164
6.3.4.2	Core Deflection	166
6.3.4.3	Effect on Concentric Parts (Gears, Fans, and Others)	167
6.3.5	Alternative Theories of the Cause of Mold Filling Imbalances	168
6.3.5.1	Cooling Variations	169
6.3.5.2	Plate Deflection	169
6.3.5.3	Corner Effect of Branching Runners	170
6.3.5.4	Melt Pressure as the Cause of Filling Imbalance	172
6.4	Runner Layouts	172
6.4.1	Identification of Various Flow Groups in Common Geometrically Balanced Runners	173

6.4.2	Apparent Geometrically Balanced Runner Layouts	175
6.5	Effect of Shear-Induced Melt Variations on Two-Stage Injection Processes ..	176
6.5.1	Gas Assist Injection Molding	176
6.5.2	Co-Injection Molding	179
6.5.3	Structural and Microcellular Foam Molding	181
6.6	The Cost of Melt Imbalances	182
7	Managing Shear-Induced Melt Variations for Successful Molding	185
7.1	Static Mixers	186
7.2	Artificial Balancing	188
7.2.1	Varying Sizes of Branching Runners or Gates to Achieve a Filling Balance	188
7.2.2	Varying Temperatures to Control Filling Balance	189
7.3	Melt Rotation Technology	190
7.3.1	Melt Rotation Technology in Hot Runner Molds	197
7.3.2	Melt Rotation Technology in Cold Runner Molds	198
7.3.3	Melt Rotation for Intra-Cavity Imbalances	199
7.3.4	Multi-Axis Melt Symmetry	200
7.3.5	In-Mold Adjustable Rheological Control (iMARC™)	202
7.3.5.1	3D Molding	203
7.4	Melt Rotation for Controlling Two Stage Injection Processes	207
7.5	Controlling Warpage through Melt Rotation Technology	209
7.5.1	Development of Warpage Potential	211
7.5.2	Controlled Warpage through Melt Rotation Technology	214
7.5.3	New Application for 3D Molding	216
7.6	MeltFlipper® Melt Rotation Technologies	217
7.6.1	Important MeltFlipper Patent Issues	217
7.6.2	Melt Rotation in Cold Runner Molds	218
7.6.3	Melt Rotation Technology in Hot Runner Molds	220
7.6.4	Multi-Axis Melt Symmetry	220
7.6.5	In-Mold Adjustable Rheological Control (iMARC™)	222
8	Cold Runner Molds	225
8.1	Sprue	226
8.1.1	Cold Sprue	227
8.1.2	Hot Sprue	232
8.2	The Cold Runner	233

8.2.1	Important Machining Considerations	235
8.2.2	Sizing of Runners	235
8.2.3	Venting	236
8.2.4	Runner Ejection	237
	8.2.4.1 Sprue Puller	237
	8.2.4.2 Secondary Sprue/Cold Drop	238
	8.2.4.3 Runner	238
8.2.5	Cold Slug Wells	239
8.3	Runners for Three-Plate Cold Runner Molds	240
8.4	Gate Designs	244
	8.4.1 Sprue Gate	245
	8.4.2 Common Edge Gate	246
	8.4.3 Fan Gate	247
	8.4.4 Film Gate or Flash Gate	248
	8.4.5 Ring Gate	249
	8.4.6 Diaphragm (Disk) Gate	250
	8.4.7 Tunnel Gate	252
	8.4.8 Cashew or Banana Gate	254
	8.4.9 Jump Gate	255
	8.4.10 Pin Point Gate	256
	8.4.11 Chisel Gate	257
	8.4.12 Overflow Gate	257
8.5	Effects of Gate Diameter in Multi-Cavity Molds	258
	8.5.1 Study 1	258
	8.5.2 Study 2	259
	8.5.3 Measuring Tolerances	262
9	Hot Runner Molds	267
9.1	Overview	267
	9.1.1 Advantages and Disadvantages of Hot Runner Systems	268
	9.1.1.1 Advantages of Hot Runners	268
	9.1.1.2 Disadvantages of Hot Runners	270
	9.1.1.3 Summary of Attributes of Different Runner Systems	271
9.2	Overview of Multi-Cavity Hot Runner Systems (Contrasting Systems)	272
	9.2.1 Externally Heated Manifold and Drops/Nozzles	273
	9.2.2 Externally Heated Manifold with Internally Heated Drops	274
	9.2.3 Internally Heated Manifold and Internally Heated Drops	275
	9.2.4 Insulated Manifold and Drops	276
9.3	Stack Molds	278

10	Hot Runner Flow Channel Design	281
10.1	Layout for Balanced Molding	282
10.2	Cross-Sectional Shape	284
10.3	Corners	284
10.3.1	Drilled Runner Channels	285
10.3.2	Machined Laminate Plate Runner Channels	287
10.4	Effect of Diameter	287
10.4.1	Pressure	287
10.4.2	Shot Control	290
10.4.3	Color Change	291
10.4.4	Material Change	294
11	Hot Runner Drops, Nozzles, and Gates	295
11.1	Hot Drops	296
11.1.1	Externally Heated Hot Drops (Nozzles)	297
11.1.2	Internally Heated Hot Drops	298
11.1.3	Heat Conducting Nozzles	299
11.2	Restrictive/Pin Point Gates	300
11.3	Gate Design Considerations	302
11.3.1	Gate Freeze-Off	302
11.3.2	Stringing/Drooling	303
11.3.3	Packing	304
11.3.4	Nozzle Tips for Hot Runner Thermal Gates	305
11.3.4.1	Ported Tips	306
11.3.4.2	Torpedo-Style Tips	308
11.3.5	Mechanical Valve Gates	309
11.3.5.1	Consideration of Valve Pin Flow Restrictions	312
11.3.5.2	Sequential Valve Gates	313
11.3.5.3	Valve Pin Movement Control for Sequential Gating	315
11.3.6	Thermal Shut-Off Gates	321
11.3.7	Hot Edge Gates	322
11.3.8	Multi-Tip Nozzles	323
11.4	Special Nozzle Arrangement	324
12	Thermal Issues of Hot Runner Systems	327
12.1	Heating	327
12.1.1	Coil (Cable) Heaters	328
12.1.2	Band Heaters	328
12.1.3	Tubular Heaters	329

12.1.4	Cartridge Heaters	330
12.1.5	Heat Pipe Technology	330
12.2	Heater Temperature Control	331
12.2.1	Thermocouples	331
12.2.2	Temperature Controllers	332
12.3	Power Requirements	334
12.4	Thermal Isolation of the Hot Runner	335
12.5	Gate Temperature Control	338
12.5.1	Gate Heating	340
12.5.2	Gate Cooling	340
13	The Mechanics and Operation of Hot Runners	341
13.1	Assembly and Leakage Issues	341
13.1.1	System Design	342
13.1.2	Hot Runner System Machining and Assembly	347
13.2	Mold and Machine Distortions	353
13.3	Startup Procedures	355
13.4	Color and Material Changes	355
13.5	Gates	356
13.5.1	Vestige	356
13.5.2	Clog	356
13.5.3	Wear	357
13.6	Maintenance	357
14	Process of Designing and Selecting a Runner System (Gate and Runner) – A Summary	359
14.1	Number of Gates	359
14.2	Gating Position on a Part	359
14.2.1	Cosmetic	359
14.2.2	Effect on Shrinkage, Warp, and Residual Stress	360
14.2.2.1	Orientation	360
14.2.2.2	Volumetric Shrinkage (Regional)	360
14.2.2.3	Unbalanced Filling	361
14.2.3	Structural Issues	361
14.2.3.1	Gate Stress	361
14.2.3.2	Flow Orientation	361
14.2.4	Gating into Restricted, or Otherwise Difficult to Reach Locations ...	362

14.3	Cavity Positioning	362
14.4	Material	362
14.5	Jetting	362
14.6	Thick vs. Thin Regions of the Part	363
14.6.1	Volumetric Shrinkage	363
14.6.2	Hesitation	363
14.7	Number of Cavities	363
14.8	Production Volume	363
14.9	Precision Molding (Precision Size, Shape, Weight, Mechanical Properties, and Consistency)	364
14.10	Color Changes	364
14.11	Material Change	365
14.12	Regrind of Runners	365
14.13	Part Thickness	365
14.13.1	Thin Part	365
14.13.2	Thick Part	366
14.14	Part Size	366
14.15	Labor Skill Level	366
14.16	Post Mold Handling	367
14.17	Part/Gate Stress Issues	367
14.18	Hot and Cold Runner Combinations	367
14.19	Two-Phase Injection Processes	367
15	Troubleshooting	369
15.1	Flow Grouping Mold Diagnostics	369
15.1.1	Shear-Induced Flow Imbalance Developed in a Geometrically Balanced Runner	370
15.1.2	Steel Variations in the Mold	371
15.1.3	Cooling Effects	371
15.1.4	Hot Runner Systems	371
15.1.5	Summary of Test Data	371
15.1.6	Flow Grouping: Method of Application	372
15.2	Injection Molding Troubleshooting Guidelines for Scientific Injection Molding	375
15.3	Injection Molding Process Development	418
15.3.1	The Molding Process	418

15.3.1.1	Mold Cooling	419
15.3.1.2	Clamp Unit - Initial Settings	420
15.3.1.3	Injection Unit - Initial Settings	422
15.3.1.4	Fill Time Scan - Evaluating First Stage Flow Rate	424
15.3.1.5	Pack Scans - Evaluating Second Stage Pack Pressure and Pack Time	430
15.3.1.6	Evaluate Cushion, Cooling Time, and Cycle Time	434
15.3.2	Process Monitoring and Process Documentation	436
15.4	List of Amorphous and Semi-Crystalline Resins	440
Index	443

1

Overview of Runners, Gates, and Gate Positioning

In many cases, the mold design dictates the gating position, although ideally, the optimum gate position should be determined based on part requirements and afterwards the mold design selected to provide for the desired gate position. Available gating positions, and gate designs, are significantly influenced by whether the runner travels along the primary parting plane of the mold (the parting plane where the part forming cavity is defined) or whether it *does not* travel along this plane.

This chapter provides only a brief introduction and orientation of basic runner types and their influence on gate design and gating location. More detail on each of these subjects is presented later in the book.

■ 1.1 Primary Parting Plane Runners

In the dominant runner type used in the industry the runner and part forming cavities are located along the same primary parting plane. Primary parting planes, often referred to as the parting lines, are where the mold opens and closes to allow ejection of the molded part and/or of the runner. The primary parting plane is the one where the molded part is formed and ejected. The *primary parting plane runner* is used in *two plate cold runner molds*. A cold runner mold is defined as a mold in which the plastic material in the runner is cooled and ejected from the mold during each mold cycle. Molten plastic material is injected through the runner, the gate, and then into the part-forming cavity. This molten plastic is then cooled by the mold, and when sufficiently solidified, the mold opens and the runner, gate, and part are ejected along the same primary parting plane. Figure 1.1 illustrates the position of the runner within the mold and its ejection from the primary parting plane. Notice that the part and runner are formed and ejected along the same parting plane.

After the molded part and runner are ejected, the mold again closes, creating a flow channel (runner path) between the injection molding machine nozzle to the part forming cavity. As the primary parting plane runner is located along the same parting plane as the part forming cavity, gating into the part is limited to its perimeter, or very near its perimeter. Sub gates, such as the tunnel, cashew, and jump gates, allow gating to be positioned within a short distance from the actual perimeter of the part (for gate designs see Section 8.4).

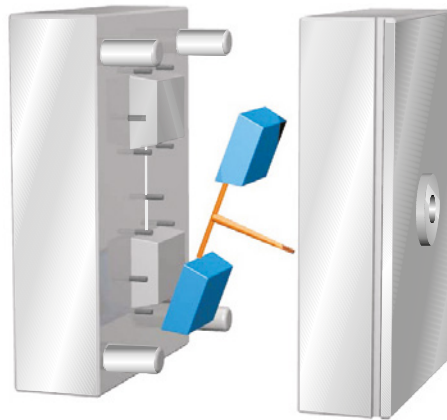


Figure 1.1 2-plate mold open and ejecting parts and runner

■ 1.2 Sub Runners

A second runner type does not travel along the primary parting plane of the mold. This *sub-runner* generally travels parallel to the primary parting plane, but not along it. The sub-runner can be used in either a cold runner or a hot runner mold.

1.2.1 Cold Sub Runners

In a cold runner mold, the sub-runner travels along a second parting plane other than the primary parting plane where the part is formed. The two parting planes are normally parallel to each other and are separated, and partially defined, by at least one mold plate. The sub-runner and part forming cavities are connected by an extension of the sub-runner referred to as a *secondary sprue*. The bridging secondary sprue passes through the at least one separating mold plate and connects to the part-forming cavity through a small gate opening. The secondary sprues are normally parallel to the opening direction of the mold and perpendicular to the sub-runner (see Figure 1.2).

During molding, after the plastic melt in the runner and part forming cavity solidify, the mold will open along the two parting planes. The part is ejected from the opened primary parting plane and the runner (which includes the secondary sprue and gate) is ejected from the opened second parting plane as seen in Figure 1.3.

This type of mold is commonly referred to as a *three-plate cold runner mold*. The terms two-plate and three-plate cold runner molds refer to the minimum number of mold plates required to form and to allow removal of both the part and the solidified runner. With the two-plate cold runner mold, the part and runner are formed and removed between at least a first and second mold plate. With the three-plate cold runner mold, the part is formed and removed between at

3

Filling and Packing Effects on Material and Molded Part

The flow of thermoplastics through an injection mold and its relationship to the molded part is quite complex. This chapter focuses on the development of melt conditions within a part-forming cavity and their relationship to the molded part. This will help the reader establish an optimum gating and molding strategy.

■ 3.1 Process Effects on Material Flow Characteristics

In Chapter 2, the basic behavior of thermoplastic materials was discussed and the relationships between a thermoplastic's viscosity, temperature, and shear rate were explained in detail. The initial viscosity of the melt entering a mold is determined by the melt temperature, as delivered from the molding machine, and the injection rate. High melt temperatures and high injection rates result in low viscosities for the plastic melt. This combination of high temperature and flow rate can result in lower fill pressures; however, pressure can begin to increase at extreme fast or slow fill rates. High melt temperatures are normally limited by potential degradation and longer mold cooling times. It is often desirable to perform a predictive mold filling analysis, such as with Autodesk Moldflow®, to determine the optimum balance of melt temperature, processing conditions (primarily injection rate), and runner diameter that will produce a quality product for a given part design. On the shop floor, use of molding techniques such as *Scientific Molding* [1] is commonly practiced to determine a target fill time for an existing mold. More recent methods for targeting an optimized injection molding process have been developed and are explained in Chapter 15 [2-4].

3.1.1 Melt Thermal Balance – Conductive Heat Loss vs. Shear Heating

The actual temperature of a melt in a mold is extremely complex. It not only varies along the length of a channel but can vary significantly across the channel. It is interesting to note that despite all of the scientific and technical advancements that have occurred since the introduction of injection molding, including putting a man on the moon and replacing the human heart over 50 years ago, we still cannot accurately measure the temperature of a melt in the

mold. In recent years the best method to determine melt temperature is to calculate it using mold filling simulation programs. However, recognize that as we cannot measure the melt temperature, we cannot confirm the accuracy of the program's calculations.

During injection, a hot thermoplastic is forced into a relatively cold mold. As the melt travels through cold portions of the mold, heat is continually being drawn from the plastic material. Plastic directly adjacent the cold mold walls will freeze almost immediately. The thickness of the frozen layer is dependent on the balance between heat lost to the mold through conduction and heat gained from shear. If the injection rate into a mold for a thermoplastic material is too slow, the thickness of the frozen layer builds up to a point where material can no longer be fed into the cavity and a short-shot is created.

A short-shot is the extreme outcome when the injection rate is not adequate to keep the thermoplastic melt temperature elevated enough for molding. At faster fill rates, frictional heating can overcome the heat lost through conduction and allow the material to remain molten during filling of the entire cavity. Figure 3.1 shows the result of a series of mold filling analyses of a simple rectangular plaque at three different fill rates. The plaque is 50 mm wide by 150 mm long and 2 mm thick. It is edge-gated as indicated (along the bottom edges of the figures) and molded with an ABS and a melt temperature of 255 °C. Note the change in melt temperature and frozen layer variations in each of the figures dependent on flow rate. At the fastest flow rate, it can be seen that the melt temperature at the end of fill is actually 10 °C higher than the injection temperature.

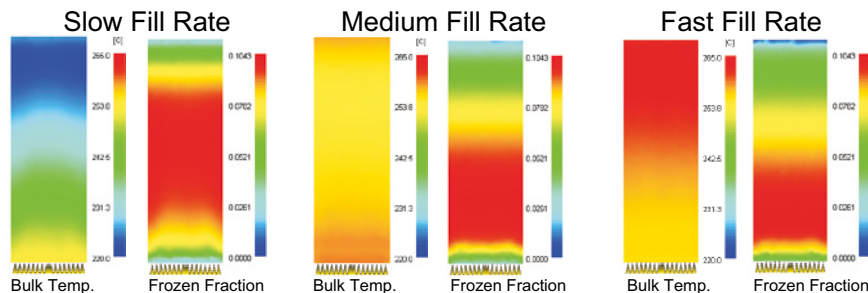


Figure 3.1 Effects of injection rate on bulk melt temperature and frozen material fraction as predicted by Moldflow's MPI

Control of frictional heating during mold filling can sometimes be difficult to achieve. With most parts, the geometry does not allow for the flow velocity of the melt to be constant without profiling the injection. Varying flow front velocities will result in a variation in the development of the frozen layer. A common example is the center gating of a disk-shaped part. At a constant injection rate from the injection molding machine, the flow front speed near the gate will be relatively high, but continually decreases as the melt progresses into the expanding cavity (see Figure 3.3). This will cause a high amount of shear heating near the gate, but as the melt front progresses, it slows down and will begin to lose more heat to the mold than it is gaining from possible shear heat. This effect can be minimized by utilizing an injection profile with an initial slower fill rate and then gradually increasing the injection rate. However, most molding is performed without the use of profiles.

Variations in wall thickness within a part can create significant variations in flow rate and the resultant thermal balance. Thin regions will create a resistance to the flow front and cause the melt to *hesitate* as it fills other thicker regions. The hesitating melt will quickly lose heat and potentially freeze off. This is discussed in more detail in Section 4.2.10.

A newer method (*Therma-flo*TM) for mapping the injection molding characteristics of plastic materials can evaluate the effect of wall thickness, flow rate, melt temperature, mold temperature and length of flow [4]. A feature of this method includes the ability to determine a cavity fill rate at which the melt temperature from gate region to end of fill is uniform. This considers the thermal balance within the melt as a result of heat gain from shear versus the heat loss to the mold by condition. The red line in Figure 3.2 shows the change in the bulk flow front temperature of a PBT (Sabic Valox 420SEO) in a 2 mm (0.08 inch) thick channel after flowing 75 mm (3 inch). In this case it is shown that at a melt front flow velocity of 2 inch/sec, the melt temperature drops nearly 20 °F as it flows 3 inches, and increases by nearly 20 °F at a melt flow velocity of 25 in/sec. In this case, a thermal balance occurs at an in-cavity flow velocity of 4.1 inch/sec (10.4 cm/sec).

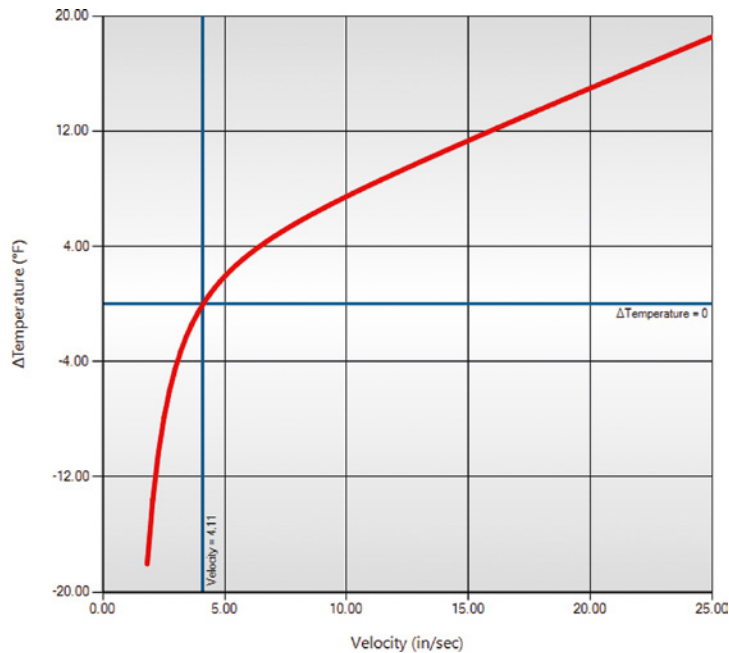


Figure 3.2 Thermal balance for a PBT in a 2.0 mm thick mold channel is shown to be occurring at a flow velocity of 4.11 in/sec (10.4 cm/sec)

There are many factors that contribute to the development of the frozen layer thickness in a molded part. The primary factors are:

- The thermoplastic's thermal properties (thermal conductivity, specific heat, and no-flow temperature, or transition temperature);
- The melt and mold temperature;
- The mold material's thermal properties;
- The local flow rate; and
- The residence time of the melt.

Figure 3.5 illustrates the distribution of frozen layer thicknesses that might occur between the gate and end of flow within a part having a diverging flow channel width such as a center gated disk. The frozen layer near the gate can be very thin because of the high shear rates and the constant supply of molten thermoplastic through the region of the part nearest the gate. The frozen layer is at its maximum thickness between the gate region and the flow front, and then again becomes relatively thin at the flow front due to the short time that the melt has been in contact with the cold cavity wall.

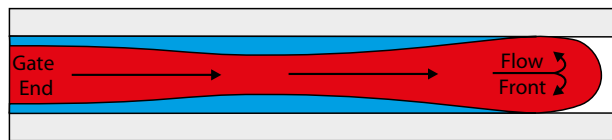


Figure 3.5 Development of frozen layer along the length of a polymer

Figure 3.6 is a summary plot from the Therma-flo™ moldometer showing the behavior of a polycarbonate (Covestro Makrolon 6455) [4]. Here pressure vs. flow front velocity at multiple wall thicknesses is shown. The results allow one to observe the contrasting impact of non-Newtonian shear thinning and the thermal exchange between melt and mold (including frozen layer development) vs. injection rate on mold filling pressures. Pressure (y -axis) is normalized by expressing it as pressure per length of flow (psi/inch). Velocity (x -axis) is the directly measured flow front velocity (inch/sec) of the melt in the monitoring channel. Note the pressure's reaction to flow velocity for each of the thicknesses shown (top to bottom curves represent cavity wall thicknesses of 0.06", 0.080", 0.100", and 0.140", respectively). Note that as flow velocity increases (left to right on the curve), pressure initially decreases as the melt benefits from non-Newtonian shear thinning, frictional heating, and reduction of frozen layer. As flow velocity continues to increase, there is a diminishing benefit of the non-Newtonian shear thinning and frictional heating. At some point the fundamental influence of the increasing melt flow rate of a pressure driven flow, and related flow velocity, becomes dominate and we see the pressure rise. The velocity at which the pressure is at a minimum is dependent on wall thickness and can be seen in this graph.

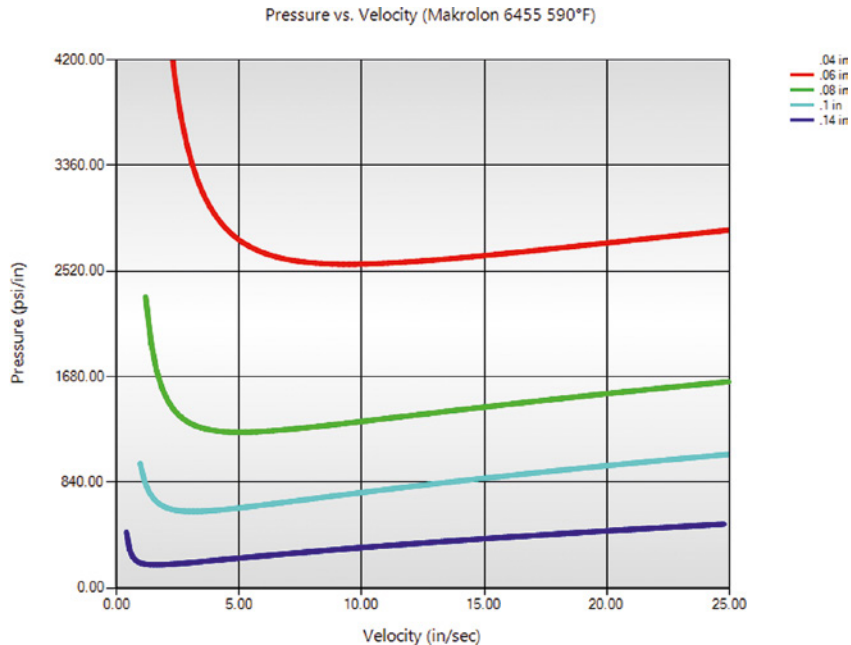


Figure 3.6 Mold filling pressure vs. flow front velocity at four different wall thicknesses (0.06", 0.080", 0.10", and 0.120")

Figure 3.7 contrasts the same PC as above to a PC/ABS at a wall thickness of 0.100" using the Moldometer. Note that increased shear thinning attributes of the ABS in the PC/ABS alloy decreases rate of the pressure rise at the faster fill velocities.

Figure 3.8 contrasts viscosity vs. shear rate data developed from a traditional capillary rheometer vs. the moldometer. Unlike a traditional capillary rheometer, the boundary of the moldometer is cooled to the same mold temperatures used during conventional injection molding. Therefore, the moldometer data includes the effect of the melts thermal exchange with the mold, including the development of a frozen layer. At the high shear rates, frictional heating is dominant with all wall thicknesses resulting in the viscosity data for all wall thicknesses beginning to converge. At these higher shear rates the frozen layer is minimized and therefore the data also begins to closely match the conditions measured in a traditional heated die capillary rheometer. However, at decreasing shear rates, the influence of the cold mold on melt temperature and a growing frozen layer can be seen. At these lower shear rates, a thin walled part is more heavily influenced by developing frozen layer than a thicker wall part. Also, at these lower shear rates we can see how differently a melt actually behaves in a mold vs. the conditions developed in a traditional capillary rheometer. Note that the viscosity data from the moldometer is not available at the lowest shear rates as the plastic material will freeze due to insufficient shear heating to offset heat lost to the cold mold.

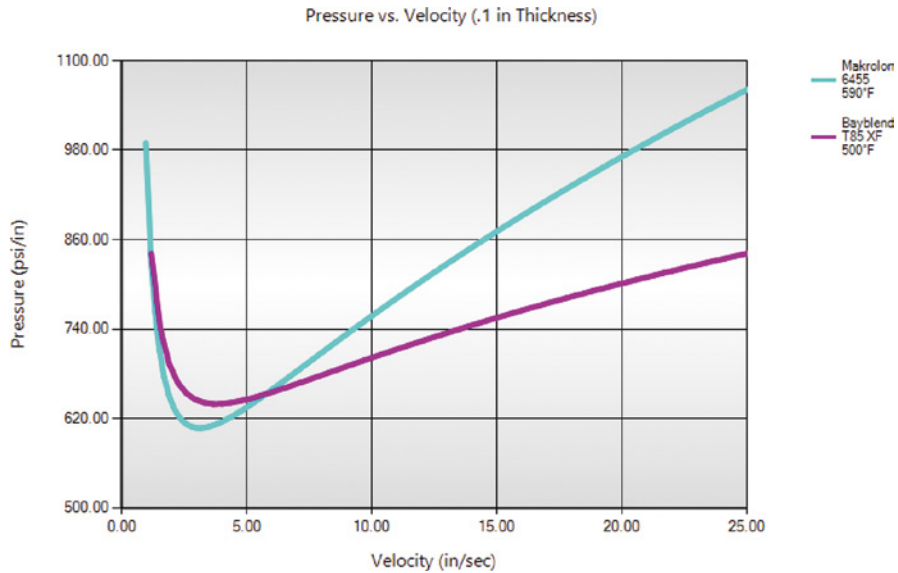


Figure 3.7 Contrasting the influence of injection rate on a PC versus a PC/ABS

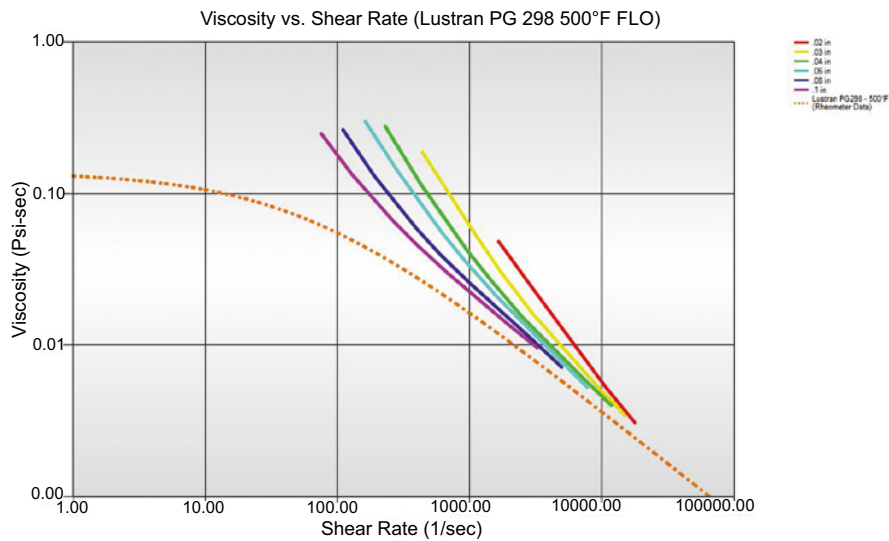


Figure 3.8 Viscosity vs. shear rate characteristics of a polymer when characterized in a conventional rheometer vs. how a polymer behaves when flowing through cooled channels .02 in (red), .03 in (yellow), .04 in (green), .06 in (blue), .08 in (violet), .1 in (purple), Lustran PG298-500°F (Rheometer Data) (dotted)

the runner and machine nozzle pressure was 10,800 psi. As the machine was capable of 20,000 psi, the high pressure loss in the runner did not create a problem.

It should be obvious now that performing a mold filling analysis without considering the nozzle and runner system could result in significant misjudgments about the ability to fill a part.

■ 5.4 Use of Mold Filling Analysis

Injection mold filling analysis programs by companies like Autodesk Moldflow Inc. and Core-Tech Systems Co. provide an excellent tool for sizing runner systems. These programs provide information on pressure, melt temperature, and shear rate at various fill rates. Though shear rate can be determined using simple hand calculations, fill pressure and melt temperature at various fill rates require much more sophisticated solution methods and detailed characterization of the polymer. Of particular interest to most molders is determining if their mold will fill with a given runner and gate design and a given gating location on their part. To determine this, the melt delivery system and the part forming cavity must be modeled. To size runners, a skilled analyst does not require a detailed model of the cavity. Often they can use simplified geometries that represent the volume of the cavity and a flow length and thickness representative of the most difficult flow path through the cavity [4]. Early 2-D injection molding simulation programs used this method successfully for years. The advantage of this older 2-D method is that the modeling and analysis can take as little as a half an hour for a skilled analyst. These programs used a simple 1-D beam for runners, and although they did not provide any graphical feedback, they did provide good information on pressure, temperature, shear rate, and shear stress on the melt during mold filling. The risk of this technology originated mostly in poor application by the user. The modeling of the part required good interpretive skills and good ability to realize what the program could and could not provide.



Figure 5.8 2½-D mold filling analysis output of fill pattern

Most of these early programs have been replaced by much more sophisticated 2½-D and 3-D programs that can provide much more detailed information on flow through the cavities (see

Figure 5.8). Detailed information on cavity conditions can be provided in easy to interpret colorized contour plots. Though these new programs present the impression that they are easier to use, they are significantly more complicated and compute-intense. They still require a skilled analyst to assure that the geometry and mesh is representing the critical regions to be analyzed. If sizing a runner and evaluating a gate design are the issue, these programs can be an over-kill and a waste of engineering time. This is particularly the case when many analysts still use the same 1-D beams to represent their runners as the older 2-D programs. The primary advantages of the newer programs are studying the filling patterns and melt conditions throughout a cavity and for the further analysis of mold cooling, part shrinkage, warpage, and structural performance.



Some cautionary remarks regarding the use of any of the standard 1-D, 2-D, 2½-D, and 3-D injection molding programs:

1. Mold filling analysis can provide good information on how small a runner can be while still allowing the mold to fill. With a cold runner, be careful that the size provided from a mold filling analysis is not too small to allow for the cavity to be properly packed out during compensation/packing phase. It is generally expected that the cold runner diameters should be no less than 1.5 times larger than the thickness of the part. Smaller diameters are possible but are more prone to packing issues. (Part requirements and design must be considered.)
2. One should be careful when trying to analyze an insulated or internally heated hot runner system. Most programs do not calculate the development of a frozen layer in these applications. Check with the software provider on how these conditions are handled.
3. The 1-D beams used in the 2-D and 2½-D filling analysis programs cannot pick up the shear-induced filling and melt imbalance in multi-cavity molds. Therefore, they also will not be able to pick up their influence on the part's shrinkage, warpage, and residual stresses.
4. At this time, all of the newer 3-D filling analysis programs struggle to predict the magnitude of the shear-induced filling and melt imbalances in multi-cavity molds (see Chapters 6 and 7 for details on shear induced melt variations developed in runners). Without careful meshing, these programs may only predict a small fraction of the melt variation and the influence it has on the part. Filling imbalances of less than 5% are often being predicted where the actual imbalance may be over 30%. Intra-cavity influences on filling patterns, shrinkage, residual stresses, and warpage are also commonly under-predicted.
5. Mold filling analysis is commonly used to artificially balance the filling of a fish-bone type runner layout. These programs can significantly reduce the effort required to manually balance these molds. However, a molder should realize that an artificial filling balance will not balance melt condition, shrinkage, warpage, or packing.

Method 2: Method 2 solves the pressure through the annular gap without having to derive an equivalent rectangular shaped flow path.

$$\text{Given: } \eta = m \dot{\gamma}^{n-1}; m = 0.179 \text{ psi} \cdot \text{sec}; n = 0.681$$

$$\begin{aligned} \dot{\gamma}_{\text{AnnularFlow}} &= \frac{6Q}{\pi(R_{\text{Bore}} + R_{\text{Heater}}) \cdot (R_{\text{Bore}} + R_{\text{Heater}})^2} \\ &= \frac{6 \cdot 2}{\pi(0.4 + .3125) \cdot (0.4 - 0.3125)^2} = 697 \text{ sec}^{-1} \end{aligned}$$

$$\eta = m \dot{\gamma}^{n-1} = 0.179 \cdot 697^{0.681-1} = 0.0222$$

$$\begin{aligned} \Delta P_{\text{AnnularFlow}} &= \frac{12Q \eta l}{\pi(R_{\text{Bore}} + R_{\text{Heater}}) \cdot (R_{\text{Bore}} - R_{\text{Heater}})^3} \\ &= \frac{12 \cdot 2 \cdot 0.0222 \cdot 10}{\pi(0.8 + 0.625) \cdot (0.8 - 0.625)^3} = 3,526 \text{ psi} \end{aligned}$$



Note that in the above examples, pressure drop as determined by both methods are essentially the same. Also note that the pressure drop through the annular flow channel is nearly 8 times that found in an equivalent full-round flow channel. In actual applications, this will vary as the frozen layer development along the outside diameter of the internally heated annular channel is not considered.

5.5.2.1 Flow through a Hot Runner vs. a Cold Runner

For the most part, the pressure development in the runner system is the same for hot and cold runners. Both types of systems experience laminar flow and fountain flow, which means there is no flow at the mold wall. In other words, there is no slip of the melt at the wall of the mold as the plastic is being injected.

Hot runner molds typically have slightly larger diameter runners because there is no concern with runner regrind or concern with its cooling time. These larger diameters allow for reduced pressure drops through the runner. Despite the surrounding cold mold in a cold runner, the bulk temperature of the melt is very similar in both hot and cold runner systems due to the significant shear heating developed in a runner. This shear heating also minimizes the development of a frozen layer during mold filling in a cold runner.

5.5.3 Runner Effect on Cycle Time

5.5.3.1 Cold Runner and Sprue Cooling Time

The cooling time of the sprue and runner has the ability to affect the overall cycle time. Although the sprue and runner do not have to be frozen completely, they must cool long

enough that they may be easily ejected. This rarely becomes an issue unless when molding thin walled parts. If the sprue puller region, which is normally the thickest area in the melt delivery system, is forcing the cycle time to be extended, a hot sprue may be a good replacement.

5.5.3.2 Hot Runner

Hot runners have a clear advantage over cold runners in most high speed thin walled molding applications. Time is saved as less material must be plasticated and injected to fill the runner, clamp stroke is reduced, runner ejection time and handling are eliminated, as well as eliminating additional cooling time that might be required for the cold runner. However, the hot runner can potentially extend cycle time in some cases, as it not only adds heat to the mold but restricts the location of cooling channels. This is particularly true in the gate region. Here the hot drop reaches directly to the part. The addition of cooling to this area is physically obstructed by the hot drop itself. Though cooling can be designed and machined in special channels around the drop tip, this is commonly left out by the designer due to cost and complexity. In addition, direct gate cooling can potentially cause premature gate freeze.

5.5.4 Constant Diameter vs. Graduated Diameter Runners

It is common practice, with geometrically balanced runners, to decrease the runner diameter at each branch as it progresses from the sprue (see Figure 5.12). This is a practice that is often blindly performed without understanding its purpose, or the potential negative effects.

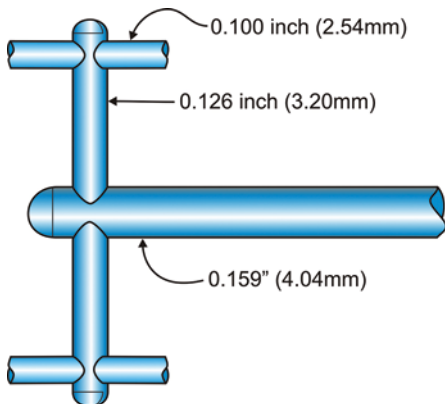


Figure 5.12 A graduated runner showing progressively increasing diameters from tertiary to secondary to primary runner sections



When sizing a cold runner, its minimum diameter must allow for proper packing of the part. Therefore, if a runner is to have progressive runner branches with varying diameters, it must be designed from the gate back to the sprue. The smallest diameter runner would be attached to the gate and each successive branch back toward the sprue would be increased.

6.3.4.2 Core Deflection

Core deflection is caused by unbalanced pressures developed from the melt on a core. The location of the gate has a significant impact on core deflection. Figure 6.28 shows two cores with three different gating locations. Gate locations 1 and 2 will both result in high pressure developing on the side of the core near the gate. This will cause the core to bend away from the gate. Gate location 3 is preferred when gating concentric parts. Not only will gate location 3 reduce the potential for core bending, it should also help prevent air traps, weld lines, and non-concentricity. However, despite this apparently ideal center gating location, filling patterns in center-gated parts in multi-cavity molds are almost always unbalanced. Shear-induced melt variations again will create side-to-side filling and packing variations, which can deflect the mold core forming the part.

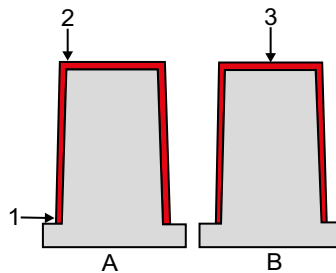


Figure 6.28 Gating locations 1 and 2 will cause core deflection. Gating location 3 should not contribute to core deflection as long as the melt entering the cavity has symmetrical temperature and shear conditions. However, if fed by a traditional 2nd generation branching runner (2 or more cavities), cavity filling will be unbalanced

Figure 6.29 illustrates the development of a side-to-side filling variation that can develop in a simple four-cavity, three-plate cold runner or hot runner mold. The highly sheared laminates, developed from the machine's nozzle and sprue, are split at the primary runner. This creates a bottom to top (sprue side to core side) melt variation in the primary runner, which continues into the part forming cavity. This can potentially deflect the core during both the filling and the packing stages and result in variations in wall thickness within the part. This wall thickness variation can then cause the part to warp. The resulting wall thickness variations and warpage can often be traced to be directly related to the expected position of the high and low sheared materials. Interestingly, it is often found that the actual core deflection is away from the low sheared material side of the core. This is analogous to the condition where the last filling cavities in an unbalanced mold can sometimes end up producing the largest and heaviest parts.

Even if the core does not deflect, significant problems can develop from the melt variations entering a cavity. Figure 6.30 shows a small, center-gated canister molded in a 16-cavity hot runner mold. Despite the ideal center gating location, a significant filling imbalance can be seen. The lead flow on the side of the part is fed from the high sheared regions of the runner. The flow in this case actually races down one side, around the flange at the open end, and creates a gas trap along the side of the part.

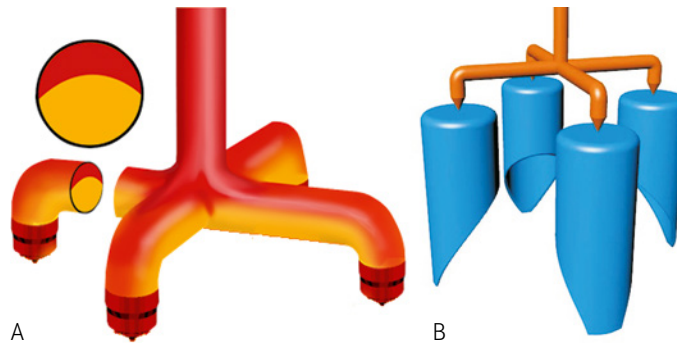


Figure 6.29 Top figure (A) illustrates the development of asymmetric melt conditions in a simple 4-cavity mold. The bottom figure (B) illustrates the potential intra-cavity filling imbalance that can be expected to result in core deflection and side to side shrinkage variations causing warpage



Figure 6.30 Center-gated canister molded in a 16-cavity hot runner. Asymmetric melt conditions resulted in the intra-cavity filling imbalance shown

6.3.4.3 Effect on Concentric Parts (Gears, Fans, and Others)

The continuation of unmanaged shear-induced melt variations into any centrally-gated part can create significant challenges that are commonly misunderstood. This is particularly the case with high precision parts such as gears and fans. Both of these require excellent concentricity. Figure 6.31 is an illustration based on an actual industrial automotive case of a large fan produced in a two-cavity, hot-to-cold runner system. Each drop of the two-drop hot runner is feeding a wagon wheel cold runner with 10 spokes, each directly feeding the fan. Despite the perfectly geometrically balanced runner system, each cavity was filling eccentrically. The half of each cavity toward the edges of the mold was filling before the half in the center of the mold. The resulting eccentric filling and packing caused a disabling imbalance in the finished molded part. The part weight imbalance was severe enough that the part had to be hand balanced using weights following molding. Initially, it was thought that the mold's cores were deflecting outward from the mold, thus opening the flow channel and reducing the pressure drop in those areas. However, it was found that when one cavity was shut off, the parts filled

■ 8.5 Effects of Gate Diameter in Multi-Cavity Molds

Mold filling imbalances in multi-cavity molds are particularly sensitive to variations in gate sizes. Even gates designed within common machining tolerances can result in unexpected and undesirable filling imbalances. As the cross sectional size of the gate decreases, the process becomes more sensitive to slight variations in the gate diameter size.

Through use of the flow grouping and mold balance diagnostics method presented in Section 15.1, the impact of mold filling imbalances, as effected by dimensional variations in mold steel, can be isolated and quantified. Using this method in numerous commercial applications, it was found that significant mold filling imbalances could be attributed to very small variations in a gate diameter. Often, these imbalances were occurring despite the fact that the gates were sized within the designer's tolerances. Gates on the high versus low end of the tolerance were a common source of the problem. The problem has been observed in both hot and cold runner molds. This led to a couple of studies using mold filling simulation to help isolate and quantify the effect of gate diameter variations as compared to the resulting filling imbalances. As the purpose of the study was to evaluate gate size influences, simple 1D beam runners and gates were used in order to eliminate any influence of shear induced melt variations.

8.5.1 Study 1

The first study was to evaluate the effect of small changes in gate diameter on pressure. The changes were based on tolerances that might be considered very tight to fairly loose. These tolerances are ± 0.005 mm (0.0002 in.), ± 0.0127 mm (0.0005 in.), ± 0.0254 mm (0.001 in.), and ± 0.05 mm (0.002 in.). The high and low limits of these tolerances were applied to a 0.762 mm (0.030 in.) inch long gates with diameters of 0.51 mm (0.020 in.), 1.02 mm (0.040 in.), 1.52 mm (0.060 in.), 2.03 mm (0.080 in.), and 2.54 mm (0.100 in.). The results are summarized in Table 8.1.

As seen in Table 8.1, the smaller the gate, the more significant the impact of variations in gate diameters. With a 2.54 mm (0.100 in.) diameter gate, a variation of ± 0.0254 mm (0.001 in.) has an 8% effect on pressure, whereas the same tolerance on a 0.51 mm (0.020 in.) diameter gate will have a 49% effect on pressure. These small diameter gates are commonly used in high tolerance parts, including those used for manufacturing electrical connectors.

Table 8.1 Pressure Variation Based on Gate Diameter Tolerance (Dimensions in mm)

Gate Dia	Tolerance			
	± 0.00508	± 0.0127	± 0.0254	± 0.0508
	% P Var	% P Var	% P Var	% P Var
0.508	8%	22%	49%	123%
1.106	4%	11%	22%	49%
1.524	3%	7%	14%	31%
2.032	2%	5%	11%	22%
2.54	2%	4%	8%	17%

8.5.2 Study 2

The second study looks at the effect on mold filling imbalance in an eight-cavity geometrically balanced cold runner mold. Again mold filling simulation was used. The part was a simple flat plaque having a volume of 2.419 cm³ (0.1476 in.³). The runner had a standard round channel with a 3.175 mm (0.125 in.) diameter. The parts were gated using a pinpoint gate with a 0.762 mm (0.030 in.) length. Three gate diameters were used, 0.762 mm (0.030 in.), 1.02 mm (0.040 in.), and 1.27 mm (0.050 in.). The gate diameters of the four inside and four outside cavities were varied to the upper and lower limits of a specified tolerance and the results were analyzed. The tolerance values that were used are; ± 0.0127 mm (0.0005 in.), ± 0.0254 mm (0.001 in.), ± 0.05 mm (0.002 in.), and ± 0.102 mm (0.004 in.).

Filling analyses were performed, using Moldflow's MPI 6.0 software, running DuPont's Zytel nylon and GE's Cycolac ABS, with a set injection time of 1 second for all simulations. The gate diameters for flow group #2 (outside cavities) were set to the upper limit of the tolerance, where the gate diameters for flow group #1 (inside cavities) were set to the lower tolerance limit. Comparisons between the flow rates through the gates of the different flow groups were made, and a percent difference was calculated to find the percent flow imbalance. The flow rates directly correspond with the fill time of the cavities.

As with Study 1, it was found that the smaller the gate, the greater the impact of varying gate diameter. For instance, a 0.762 mm (0.030 in.) gate will see more of a percent imbalance over its tolerance range with varying gate diameter than a 1.02 mm (0.040 in.) diameter gate. As well as the larger the tolerance the greater the imbalanced experienced. The graph in Figure 8.43 shows several important factors of gate size and variation in the nominal gate size. The y-axis represents the percent imbalance, where the x-axis represents the tolerance limit set for the specific gate. For example, varying the 0.762 mm (0.030 in.) gate to the upper and lower ends of the ± 0.0254 mm (0.001 in.) tolerance limits (gate diameters of 0.7874 mm (0.031 in.) and 0.737 mm (0.029 in.)) resulted in an imbalance of nearly 17% between the two flow groups. This reinforces the idea that small deviations from a nominal gate size can and will have significant effects on the flow imbalance and overall process window. As the deviation from the nominal gate diameter increases, the percent imbalance will grow.

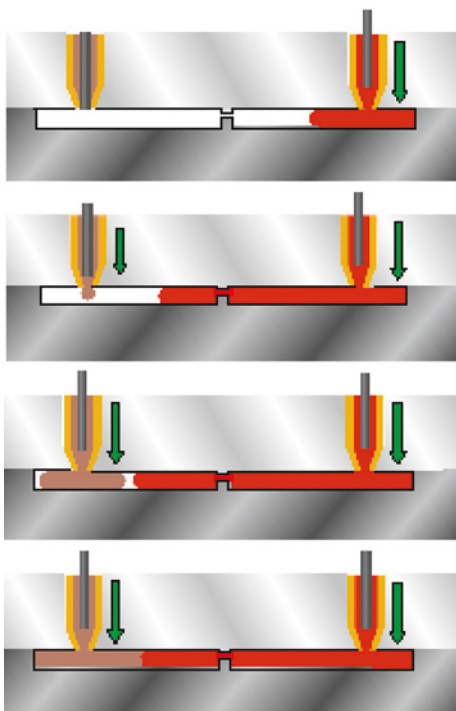


Figure 11.24 Use of sequential valve gating to assure good strength across the hinge and good packing on either side of the hinge

11.3.5.3 Valve Pin Movement Control for Sequential Gating

Until recent years, most all valve pin movements have been limited to providing a single fast speed open, to a fully open position, and a single fast speed close to a full close position. This type of control can work well in many applications. However, when using cascading sequential valve gating, when progressive gates are opened during mold filling, a sudden change in flow front velocity results that can often cause flow mark on the surface of the part. This is particularly acute with glossy part surfaces.

In response to this issue, hot runner manufacturers have been developing systems that provide a higher level of control of the opening stroke, and some also providing a similar high level of control to the closing stroke. Essentially these systems can profile the opening and closing stroke of the pin rather than the more conventional one fast speed to one position open and one fast speed to one position closed, with all pins set to the same high speed. The ability of the molder to profile the opening stroke allows them to discretely control the introduction of melt from each progressive gate in order to eliminate surges in flow front velocity, and thereby address the resultant cosmetic issues.

Figure 11.25 is a plot of an automotive part being fed by five gates using cascading sequential valve gates. The left side of the top figure, and the corresponding close-up bottom left, show the flow lines resulting from traditional quick full open valve gates. This is contrasted to the right side of the top figure, and corresponding close-up on the bottom right where the valve opening has been profiled using a servo driven valve gate to eliminate the flow lines.



Figure 11.25 Automotive part where the left side was molded with a traditional fast-opening valve gate versus the right side that was molded using a profiled servo driven valve gate (Courtesy: HRSflow)

The newer systems with the more controlled opening and closing motions are still mostly based on hydraulic drives. However there are also electronic servo driven and pneumatic systems. With hydraulic and pneumatic systems, speed can be controlled by manually adjusting flow control valves. The valves can be located downstream of the pin's hydraulics (return to tanks side of the circuit) in order to maintain positive control of the pin movement. This type of system may only provide a single slowed opening stroke of the valve pin to a single fully open position, while some may have further profiling capabilities. In application, an operator may progressively throttle down the speed of an opening gate while observing a pressure versus time curve and comparing this to the visual inspection of the part. Once the cosmetic issue has been eliminated at the second gate, the operator would then repeat the process at each of the progressive gates until their objective has been met. Figure 11.26 is an illustration of the valve gate opening and a corresponding valve pin position (y-axis) vs. time (x-axis) achieved with a controlled slow speed hydraulic system during the opening stroke. The controlled time to open is established as described above.

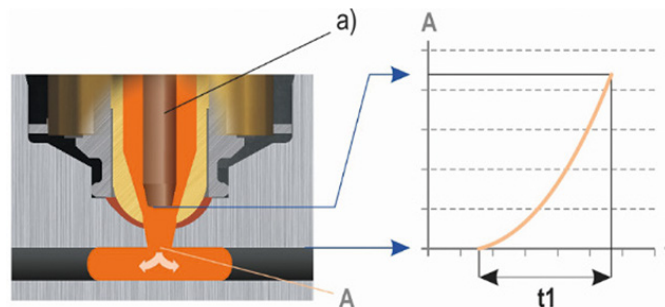


Figure 11.26 Controlled valve pin (a) opening with corresponding response curve of position (y-axis) vs. time (x-axis) (Courtesy: INCOE)



Figure 15.22 Record grooves or orange peel

Possible causes	Possible remedies
Mold build up or deposits	Check for residue or deposits on the mold/cavity surface. If there are mold deposits, see "Mold buildup."
Mold surface finish	Check surface of cavity for proper polish or finish and whether it is clean. Repair and clean.
Slow filling	Increase injection rate, this decreases resin viscosity and allows more pressure to be transferred to the cavity. If 1 st to 2 nd stage switchover is < 0.1 s, ensure velocity is not pressure-limited.
Low cavity pressure	Increase 2 nd stage pressure. Increase 2 nd stage time, and if possible remove the same amount of time from the cooling or mold closed timer to keep cycle time constant.
Mold temperature	Increase mold temperature. Decrease mold temperature.
Melt temperature	Check melt temperature, adjust to within the manufacture's guidelines if temperature is outside limits. Try higher end and lower end of resin supplier's guidelines.
Uneven filling of a single cavity	Balance flow path with flow leaders if possible. Increase injection rate.
Unbalanced filling in multi-cavity molds	Adjust runner size to balance filling. Do not adjust gate size to balance filling; this will provide various gate seal times and vary part dimensions, weight, etc.

Pinking of the Part

Relatively rarely it happens that parts will turn pink while in storage. The cause is usually carbon monoxide gas reacting with components of the plastic.

Possible causes	Possible remedies
Carbon monoxide	Minor amounts for carbon monoxide are known to discolor certain resins. Remove parts to open area and see if discoloration disappears. Exposing the part(s) to sunlight can accelerate the disappearance of the discoloration. If discoloration reverses, remove all gas fueled lifts etc. from storage area. Improve storage area ventilation. Go to battery operated fork lifts.

Pitting

Possible causes	Possible remedies
Trapped gases dieseling	See “Burns.” If it is due to dieseling, do not run the mold, further damage will result.
Corrosion or chemical attack by the resin or additive on the steel	Check for resin compatibility with the steel of the mold. If acid gases are possible, a more chemically resistant surface may be required. A different steel or coating of the existing surface should be specified.
Abrasive wear, erosion	Highly filled resins can pit and erode a mold’s surface finish. Change gate location, coat cavity with a wear resistant finish. Rebuild tool with appropriate hardened steel.

Poor Color Mixing

See also “Color Mixing”

Race-Tracking, Framing, or Non-Uniform Flow Front

The flow front should be a continual half-circle fill from the gate.

Possible causes	Possible remedies
Non-uniform wall thickness	Thicker sections of part fill preferentially due to lower melt pressures required to fill. Plastic flow will accelerate in thicker sections and hesitate filling a thin section. This may allow the plastic to “race-track” around the perimeter or section of a part and trap air or volatiles. Try faster injection rates but it is unlikely this will solve the problem as you are fighting a law of physics. Round the edge or taper the junction between the nominal wall change. The correct fix is to redesign with a uniform nominal wall.
Gate location	Gate into the thick area and provide flow leaders to the thin areas to provide uniform filling.
Hot surface or section in the mold	Allow the mold to sit idle until mold is at uniform temperature. Make and save first shot for 99% full. If flow path is different than in later shots, it is a tool-steel temperature and cooling issue. Check mold for hot spots. Get uniform cooling.

Record Grooves, Ripples, Wave Marks

These are concentric grooves or lines usually at the leading edge of flow. The flow front is hesitating, building up pressure then moving a short distance and hesitating again. This is almost always related to lack of adequate pressure at the flow front or slowing of injection velocity.

Possible causes	Possible remedies
Pressure limited 1 st stage or lack of velocity control	Double check that the pressure during 1 st stage is 200–400 hydraulic psi lower than the set first stage limit. Make sure there is enough pressure differential (delta P) between the highest pressure during 1 st stage and the set pressure limit for 1 st stage. First stage pressure limit should be higher than the pressure used during 1 st stage.
Incorrect position transfer	Take 2 nd stage pressure to 300 psi plastic pressure or if the machine does not allow this, take 2 nd stage time to zero. The part should be 95–99% full. If this is a thin-walled part, the part should be full with only slight underpack near the gate. Adjust position transfer to provide appropriate fill volume.
Melt temperature too low	Check melt temperature via the hot probe technique or appropriate IR sensor. Make sure it is within the resin supplier's recommended range.
Poor 1 st to 2 nd stage switch-over response	Note response of hydraulic pressure at switch-over. It should rise to the transfer point, then drop rapid to the set 2 nd stage pressure. If hydraulic pressure drops much below set 2 nd stage pressure, the flow front may be hesitating and building a high viscosity. Repair machine.
Low pack rate or volume	Increase pack rate or volume of oil available for 2 nd stage.
Low mold temperature	Increase mold temperature 20–30 °F. Decrease cycle time. This will raise steel temperature in the mold.

Screw Recovery, Slow Recovery, Screw Slips or Does Not Feed

The metering section of the screw pumps plastic forward, which pushes the screw back.

Possible causes	Possible remedies
Feed throat temperature	Run throat temperature at 110 to 140 °F for most resins. For high-end engineering resins you may want to go higher. Do not run feed throat at 60–80 °F. Feed throat should be PID temperature-controlled.
Feed problems	Check size of granules and flow through hopper and feed throat. Ensure that material gravity-feeds correctly when resin is being loaded into the hopper. Vacuum loading may interrupt normal gravity-feeding, especially with single shot loaders. If coloring at the press, check recovery without colorant. Certain color concentrate carriers can increase recovery times, too much wax or oil.
Heavily carbonized or blocked flights	Standard general purpose screws are notorious for dead spots behind flights. These can have large carbon or other deposits that block plastic flow. Check screw for clean polished flights.
Worn screw and/or barrel	Worn screws and barrels will provide better mixing but slow recovery rates as plastic back flushes over flights. Flights should be sharp, screw root should be highly polished, no nicks or scratches.
Moisture	Check moisture content of plastic, check feed throat for cracks leaking water.
Granule size	Plastic granules should be uniform in size and shape. A wide range in granule size, fines and small granules along with large chunks of regrind will cause feeding problems. This includes large and small pellets in virgin.
High back pressure	Target 1,000 to 1,500 psi melt back pressure. Try lower back pressure.

Possible causes	Possible remedies
High RPM	Try lower screw rotate speeds; better melt uniformity and mixing are obtained with slow screw speeds. Use all but ~ 2 seconds of the cooling time for plasticating. Do not lengthen the cycle.
Incorrect barrel temperature settings	Start by setting front and center zones to the center of the resin suppliers recommended range. Set rear zone at the minimum of the range. Back pressure set at 1,000 melt psi. Average recovery time for 10 cycles. Repeat with rear zone 10 °F higher until you have reached the rear zone setting at the maximum recommended by the resin supplier. Pick the temperature that gives you the minimum recovery time.
Poor screw design	See “Color mixing” and “Screw design”

Screw Slip

See also “Screw Recovery”

Screw Design

Possible causes	Possible remedies
Standard general purpose screw	These are known to produce unmelt due to solids bed break up. They should be replaced with melt-uniformity screws: Minimum L/D is 20/1. This is an industry problem; most (99%) of general purpose screws do not provide uniformly melted polymer coming out of the nozzle.
Screw and barrel metals	Recommend: bimetallic or hardened barrels and soft screws like stainless steel. Chemically resistant screw material is especially critical for clear resins. Screw should be polished with sharp edges on flights with the back of the flights rounded with a large radius to prevent dead spots and carbon buildup. Screw root and flight channels should be highly polished with no nicks or scratches. A modified barrier should lead from the transition zone to the metering zone.
Barrier flights	Generally not recommended, unless short and at the end of the transition zone or beginning of the metering section. Often cause severe degradation and overheating.
Vented barrels	Vented barrels, though uncommon, do have their purpose. They provide excellent melt uniformity and process resins that are not subject to hydrolysis more uniformly. Unfortunately, their design is often poor. The two-stage screw must be designed with a continuous flight through the decompression section. The first stage should be cut such that it cannot overpump the second stage. Vented barrels require near zero back pressure to prevent vent flooding. This presents purging and residence time problems. See Figure 15.10, Figure 15.17, and Figure 15.23.

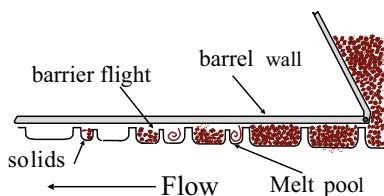


Figure 15.23 Barrier screw

Shorts or Short Shots or Non-Fill

Part is short or some section of the part, such as a rib is not completely filled out.

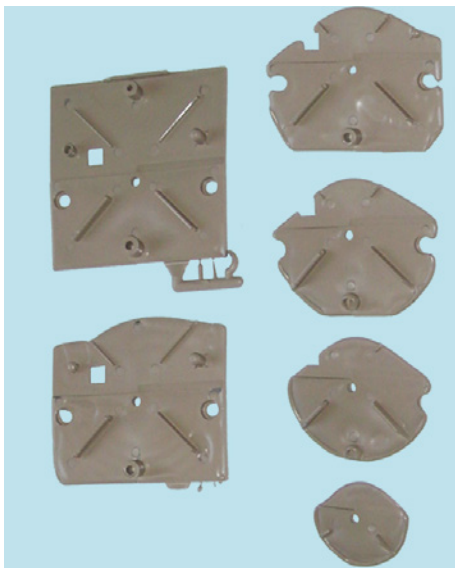


Figure 15.24 Short shot series filling a part; the part is center-gated

Possible causes	Possible remedies
Consistent short shots	
Incorrect shot size	Take 2 nd stage pressure to 300 psi plastic pressure or lower ; if the machine does not allow this, take 2 nd stage time to zero. The part should be 95–99% full. If this is a thin walled part, then the part should be full with only slight under-pack near the gate. Adjust position transfer to provide appropriate shot size or 1 st stage volume. Do not use 1 st stage pressure-limit to adjust the amount of plastic that enters the cavity on 1 st stage.
Pressure-limited 1 st stage or lack of velocity control	Double check that the pressure during fill or 1 st stage is 200–400 hydraulic psi lower than the set first stage limit. Make sure this is enough pressure differential, delta P, across the flow control valve.
Injection rate	Increase injection rate to decrease viscosity.
Non-return valve or barrel worn or broken	Check non-return valve and barrel, are they in specification? If the non-return valve is OK, double check barrel for wear and ovality. Repair or replace as needed. Note: non-return valve should not have mating angle between seat and sliding ring. This should be a stepped angle for positive shut off.
Large pressure drop	Perform a short shot analysis for pressure loss. Note pressure at transfer for shots making: 1) 99% full part, 2) Sprue, runner and gate, 3) sprue and runner only, 4) purge full shot through the nozzle into the air. This is best done using one velocity during first stage. Use intensification ratio to calculate pressure drop for a) nozzle, acceptable range 200–4,000 psi b) sprue and runner, acceptable range 200–5,000 psi c) gate, acceptable range 200–5,000 psi d) part, acceptable range 200–40,000 psi. Evaluate where largest pressure drop is and remedy. A restriction of flow will be discovered with this method.

Possible causes	Possible remedies
Trapped gas or air	Progressively short shoot the mold using shot size or position transfer to make 10, 20, 40, 60, 70, 80, 95% full parts. Note if there is any sign of the plastic flow front coming around on itself. Is there a racetrack effect? This includes jetting. Note if ribs are covered before completely filling. This test cannot be done correctly if you reduce 1 st stage pressure or velocity. You must be velocity-controlled for 1 st stage. The concept is to find where the gas is coming from and eliminate its source. Vent the tool properly or use porous steel to eliminate gas traps. Jetting can cause gas and air to be trapped. Check for moisture, steam is a gas. Change gate location. Pull a vacuum on the mold cavity during fill.
Insufficient 2 nd stage pressure	Make sure 1 st stage is at the right shot volume; part should be 95–99.9% full at the end of 1 st stage. If OK, raise 2 nd stage pressure.
No cushion	Ensure adequate cushion to allow for transfer of packing or 2 nd stage pressure.
Melt temperature	Verify that melt is within the resin supplier's recommended range.
Mold temperature	Try higher mold temperatures and or faster cycle times.
Resin viscosity	Change resin to a higher melt flow rate. Be careful as properties may decrease due to lower molecular weight. Parts must be fully tested in the application for correct performance.
Long flow length	For every mm of flow there is a pressure drop. Long flow lengths have large pressure drops. Add gates or flow leaders. Last resort increase nominal wall.
Check balance if a multi-cavity tool	See text for the Flow Grouping mold diagnostics process for determining mold balance.
Thin nominal wall	Add flow leaders if possible. Increase nominal wall if all other avenues fail. Thicker nominal wall will reduce pressure loss.
Intermittent short shots	
Non-return valve or barrel worn or broken	Check non-return valve and barrel, are they in specification? If the non-return valve is OK, double check barrel for wear and ovality. Repair or replace as needed. Note: non-return valve should not have mating angle between seat and sliding ring. This should be a stepped angle for positive shut-off.
Cushion not holding	Note cushion repeatability, if varying by more than 0.200 in. or 5 mm, check non-return valve as above. Try a larger decompression stroke to help "set" the check valve. Be careful not to suck air into the nozzle and cause splay.
Contaminated material	Check gates and parts for foreign material. Check quality of regrind. See introduction to "Color mixing."
Check balance if a multi-cavity tool	See text for Flow Grouping method for determining mold balance.
Melt temperature	Verify that melt is within the resin suppliers recommended range.
Mold temperature	Try higher mold temperatures and or faster cycle times.
Unmelt	Look for unmelted granules in the part, color streaks, see "Screw design" and introduction to "Color mixing". Provide uniform melt to the gate.
Cold slug	Occasionally it is possible for a cold slug from the nozzle to go beyond the sucker pin and plug a gate. Check nozzle for cold slug formation. See "Nozzle drool."
Insufficient 2 nd stage pressure	Raise 2 nd stage pressure.
Trapped gas	See above, see also "Bubbles."

Index

Symbols

- 1-D beam 111
- 2½-D programs 111
- 2-D injection molding simulation programs 111
- 3D molding 203, 216
- 3-D programs 111

A

- Abrasive Flow Machining (AFM) 281
- Adjustable Thickness Overflow Molding (ATOM) 135
- air bubbles 376
- amorphous 52, 57
- anisotropic shrinkage 66, 360
- annular flow 114
- annular flow channel 114
- artificial balance 126, 129
- artificial balancing 126, 188
- assembly 351
- Autodesk Moldflow Inc. 111
- automatic degating 247, 249, 252
- axial power rating (APR) 331

B

- back flow 361
- back pressure 435
- Bagley correction 22
- balance 376, 396, 403, 408, 410, 413, 414
- balancing melt conditions 219
- ball check valve 376
- banana gate 254
- band heaters 328
- barrier flights 406
- basic edge gate 257

- bending forces 353
- black specks 376, 378, 379, 381, 391, 394, 402, 414
- black streaks 376, 384, 386, 391
- blisters 380, 392
- blooming 381
- blush 381, 382, 396, 397, 414
- bridging 382
- brittleness 382, 383, 390
- bubbles 376, 380, 383, 408, 409, 414
- burns 384, 386, 404

C

- capillary rheometer 20, 24
- carbon monoxide 403, 404
- cartridge heaters 330
- cascading injection 313
- cashew gate 43, 254
- check ring 377, 387, 393, 400, 402
- chemical bonds 17
- chisel gate 257
- clamp tonnage 66
- clamp unit 420
 - clamp tonnage 420
 - ejection settings 421
 - mold filling simulation 421
 - mold open stroke 421
- clogging 356
- closed-loop systems 332
- cloudiness in clear parts 386
- coil heaters 328
- co-injection 207
- co-injection molding 179
- cold drop 238
- cold runner 99, 198, 233, 235
- cold runner mold 225

cold slug 402
 cold slug well 229, 237, 239
 cold sprue 227
 color change 291, 292, 355, 364
 color concentrate 387, 388
 color dispersion 103
 color mixing 378, 390, 391, 394, 404, 406, 408, 414
 color shift 389
 compensation phase 49, 71, 304
 compressible 290
 compression fit 345
 concentric parts 166
 conduction 34, 335
 constant diameter runner 120
 controlled mechanical valve gates 313
 converging flows 61
 cooling 58, 371
 cooling circuits 169
 cooling rate 52, 54
 cooling time 48, 117, 435
 core deflection 66, 166
 core pin bending 389
 core shift 158, 389, 390
 core shifting 201
 CoreTech Systems Co. 111
 corner effect 170
 corner plugs 342
 corners 284
 cosmetic 359
 costs 182
 covalent bonds 17, 51
 cracking 390
 crazing 387, 391, 413
 crystalline structure 52
 crystallization temperature 52
 cushion 434
 cycle time 93, 148, 435
 cycle time too long 391

D

dark streaks 391
 dead flow regions 361, 364
 deflection 354
 deformed parts 391
 degradation 42, 44, 95, 110, 406
 degree of crystallinity 392, 393, 409
 delamination 392

designing a runner system 359
 diameter of a flow channel 287
 diaphragm gate 250
 differential shrinkage 68
 dilatant 14
 dimensional variations 392
 directional shrinkage 66, 67
 directional shrinkage variations 67
 direct thread 345
 disk gate 250
 distortion 353, 354
 diverging flow fronts 61
 draw polish 412
 drying temperatures 44
 dynamic forces 353

E

edge gate 247
 ejection 238
 ejector pins 238
 electrical discharge machining (EDM) 349
 electric molding machines 105
 electrostatic forces 51
 entropy 15
 equivalent hydraulic radius 114
 expanding flow fronts 61
 extensional flow 55
 extensional flow effects 54
 externally heated drops 273, 274, 297
 externally heated manifold and drops 272
 externally heated manifolds 273
 externally heated manifold with internally heated drops/nozzles 272
 externally heated systems 273, 292

F

fan gate 247
 fiber-filled materials 57, 72, 90
 filler 54
 fillers 57
 filling 62
 filling imbalances 82, 258
 fill pressure 46
 fill rate 89
 fill speed 156
 Fill Time Scan 424
 - delta P 429

- fill only shot weight 425
- fill time 424, 425, 428
- Fill Time Scan explanations 426
- Fill Time Scan procedure 425
- flow groups 429
- Hagen-Poiseuille equation 424
- mold filling simulation 429
- pressure drop 424
- pressure vs. fill time 427
- shear rate 424
- shear thinning 424
- transfer position 425, 426
- transfer pressure 425
- viscosity 424
- volumetric flow rate 424
- film gate 248
- filter nozzle 357
- finer 379, 386, 405, 410, 413
- fishbone 86, 125, 126, 283
- fishbone runner 125, 126, 128, 132
- fishbone type runner 138
- flash 395, 409
- flash gate 248
- flexural load 60, 73
- flexural loading 361
- flow angle 220
- flow balance ratio 127
- flow channel 36
- flow channels in hot runners 284
- flow front 49
- flow grouping diagnostic method 157
- Flow Grouping method 371
- flow groups 127, 150, 173, 202, 369, 370, 372
- flow length 66
- flow lines 396, 417
- flow pattern 72
- flow rate 34, 36, 46
- fountain flow 8, 106
- frictional heating 11, 16, 34, 151
- frozen layer 34, 36, 37
- frozen skin 110
- full round 113

G

- gas assist 207
- gas-assisted injection molding 176
- gas distribution 178
- gas trap 77, 166

- gate 244, 338
- gate blush 381, 396
- gate cooling 340
- gate freeze 303
- gate freeze-off 302
- gate freeze study 303
- gate freeze time 50
- gate insert 301
- gates 189
- gate seal 412
- gate unseal 413
- gate vestige 356
- gate wear 310
- gating 72, 359, 360
- gating location 65
- geometrically balance 126
- geometrically balanced runner 86, 88, 139
- gloss 381, 389, 397, 402, 414
- graduated diameter runner 119

H

- Hagen Poiseuille's Law 46
- haze in clear parts 386
- heat conducting hot nozzles 299
- heated bushing 297
- heated gate tip 301
- heated nozzle 297
- heaters 327
- heat pipes 101
- heat soak 355
- hesitate 35, 77, 91
- hesitation 79, 91, 148, 363
- high ejection forces 48
- high precision molding 364
- high watt density cartridge heaters 330
- hinges 78
- hot drop 118, 272, 295
- hot edge gates 322
- hot manifold 4
- hot runner manifolds 189
- hot runner mold 4, 202
- hot runners 99, 197, 380
- hot runners in general 272
- hot runner system 268, 335, 345, 348
- hot runner systems 45, 270
- hot sprue 225, 232
- hot tip stringing 397, 401
- hydraulic system 105

hydrostatic 49, 147
 hydrostatic pressure regions 82

I

iMARC™ 202, 215, 222
 imbalanced 86
 imbalanced filling 83
 impact loading 361
 INCOE Integrated System™ 357
 INCOE's Unitized™ 197
 indirect thread 345
 initial viscosity 33
 injection molding screws 104
 injection pressure 110
 injection profile 34
 injection rate 194
 injection unit 422

- back pressure 422, 423
- cooling time 424
- flow rate 423
- injection pressure limit 423
- injection time limit 423
- melt temperature 422
- pack pressure 423
- pack time 423
- safe start-up shot size 423
- screw RPM 422, 423
- transfer position 423

 insulated hot runner 272
 intensification ratio 105, 375, 407, 438
 internal forces 353
 internally heated drop 274, 275, 278
 internally heated hot drops 298
 internally heated hot runner system 292
 internally heated manifold 275
 internally heated manifold with internally heated drops/nozzles 272
 intra-cavity balance 199
 intra-cavity shear-induced imbalances 180
 intra-cavity shear-induced variations 178

J

jetting 66, 246, 362, 380, 384, 397, 398, 408, 417
 jump gate 255

K

Kenix mixer 186
 kinematic viscosity 8
 knit lines 398, 417

L

lapped edge gate 246
 leakage 341, 351
 leaking at the nozzle tip 350
 linear flows 61
 living hinges 398, 399
 low watt density cartridge 330

M

machining 235
 manifold 272, 342
 material changes 294, 365
 material shrinkage 56
 maximizing hinge strength 79
 mechanical properties 73
 mechanical shut-off gates 309
 melt 375
 melt compressibility 8
 MeltFlipper® 185, 190, 194, 199, 208, 219, 220
 MeltFlipper MAX™ 190, 200, 202, 222
 melt flow index 19
 melt fracture 43
 melt injection pressure 105
 melt pressure 105, 381
 melt rotation design 194
 melt rotation technology 184, 185, 190, 194, 196, 197, 209
 melt temperature 34
 melt temperature variation 146
 melt variation 128
 mica-insulated band heaters 329
 microcellular molding 181
 mineral-insulated band heaters 329
 mixing 186
 Modified Cross viscosity model 12
 modulus 58
 mold build-up 381, 397, 399, 414
 mold cooling 419

- mold filling simulation 420
- mold temperature 420
- Reynold's number 419

mold deflection 141
 mold steel variations 140
 mold temperature 36, 169, 403
 molecular orientation 51
 molecular weight degradation 382, 383, 390
 MuCell® 207, 367
 MuCell process 208
 multi-axis symmetry 200
 multi-cavity molds 258
 multi-tip nozzles 323

N

naturally balanced 122, 173
 naturally balanced runner 137
 Newtonian fluid 14, 22, 46
 nominal wall 383
 non-fill 400, 407
 non-Newtonian 106
 non-return valve 376, 377, 379, 380, 386, 387, 392, 393, 400, 401, 402, 407, 408
 non-uniform nominal wall 391
 notched edge gate 246
 nozzle 377, 379
 nozzle body 101
 nozzle drool 401, 402, 408
 nozzles 342
 nozzle stringing 402
 nozzle tip 101, 376, 377, 379, 401, 402, 412

O

O diameter (inlet diameter) 229
 odor 402
 open gated nozzle 4
 open-loop controllers 332
 open pin point gate 301
 Opti-Flo™ 220
 orange peel 402, 414
 orientation 11, 15, 54, 61, 360, 361
 orthotropic contraction (shrinkage) 52
 outlet sprue diameter 231
 overflow gate 257

P

packing 62, 304, 366
 pack pressure 50, 304
 Pack Pressure Scan 430

– cushion 431
 – mold filling simulation 431
 Pack Time Scan 431
 – cooling time 432
 – mold filling simulation 433
 – multi-cavity molds 433
 – pack time 432
 – profiled pack 433
 parabolic 113
 parting line 225
 parting planes 1
 part size 366
 PID (Proportional Integral Derivative) 332
 pin gauge 266
 pinking 403
 pin point gate 5, 43, 256
 pitting 404
 plastic pressure 375, 376, 389, 392, 395, 405, 407, 416
 plate deflection 169
 post-mold shrinkage 435
 potato chip warpage 60
 power law and viscosity model 12
 power-law fluid 14
 power law index 23
 power lost from surfaces 334
 power required for start-up 334
 power required for sustained operation 334
 power required to heat the manifold 334
 power requirement 334
 pressure 113, 117, 287
 pressure distribution 49, 146, 147
 pressure drop 15, 50, 233
 pressure gradient 59
 pressure history 53
 pressure loss 110, 111
 pressure losses 105
 primary parting plane 1
 primary parting plane runner 1
 primary runner 225
 process documentation 436
 – machine settings 436
 – mold filling simulation 438
 – plastic cooling rate 438
 – plastic flow rate 437
 – plastic melt temperature 437
 – plastic pressure 438
 – plastic variables 436
 process monitoring 436

- cushion 436
- cycle time 436
- fill time 436
- screw recovery time 436
- transfer pressure 436
- viscosity 436
- production volume 363
- pulled parts 391
- PVT 18, 47, 52

R

- Rabinowitsch correction 22
- race-track 404
- race-tracking 404
- Re# 8
- record grooves 402, 404
- recording 402
- regrinding 110, 226
- reground material 93
- relax 62
- relaxation 61
- residence time 45, 293
- residual stress 53
- residual stresses 61, 62
- Reynolds number 7
- rheology 7
- ribs 71
- ring gate 249
- ripples 404
- rotational rheometer 24
- runner designs 234
- runner diameter 235
- runner-induced melt variations 152
- runners
 - artificial balancing 128
- runner size 93
- runner sizing 119

S

- saddle warpage 60
- sandwich molding 179
- Scientific Injection Molding 369, 375, 386, 392
- Scorim™ 91
- screw 104, 377, 379
- screw design 406, 414
- screw recovery 405, 406
- screw recovery time 435

- screw RPM 435
- screw slip 405, 406
- secondary bonds 17
- secondary sprue 2, 238
- semi-crystalline 57
- semi-crystalline structure 52
- sensitivity 107, 108, 156, 194
- shape factor 233
- shear 54, 93
- shear circles 97
- sheared laminates 162
- shear-induced imbalances 173, 190, 373
- shear induced stress 54
- shear rate 10, 21, 54, 94, 95, 150, 288
- shear rate limits 43, 95
- shear rate profile 11
- shear rates 14, 106, 361
 - high 43
 - ultra high 43
- shear rate through a rectangular flow channel 94
- shear rate through a round channel 94
- shear-sensitive 42
- shear stress 21, 61, 96
- shear stresses 55, 361
- shear stress limits 95
- shorts 400, 407
- short shots 34, 407, 409
- shot control 290
- shrinkage 52, 53, 57, 58, 61, 62, 89, 214, 215, 360
- shrinkage variation 162
- side-to-side filling variation 166
- silvery streaks 410
- sink 410, 414
- sinks 49, 409, 410
- soft start 355
- spacer buttons 347
- specific volume 47, 51, 52
- splay 386, 410, 411
- sprue 226, 342
- sprue bar 279
- sprue bushing 227
- sprue cooling 230
- sprue gates 245
- sprue gating 245
- sprue length 231
- sprue O dimension 231
- sprue puller 229, 237

sprue sticking 412
 sprue taper 231
 stack molds 200, 278
 stagnant flow 355
 stagnant flow areas 284
 stagnant flow regions 276
 startup of a hot runner system 355
 static mixers 186, 187
 steel imbalances 373
 steel safe 104
 sticking 382, 390, 391
 sticking in mold 412
 stopped angle valves 401
 streaks 414
 stressed polymer molecules 61
 stress whitening 387, 394
 stringing 303, 340, 401
 structural foam 207
 style runner 86
 submarine gate 252
 surface finish 399, 402, 403, 414

T

tapered shut-off pins 310
 temperature controllers 332
 temperature gradient 211
 temperature sensitivity factor (T_b) 108
 tensile load 60, 73
 tensile loading 361
 thermal conductivity 109
 thermal contraction 62
 thermal degradation 44
 thermal expansion 189, 294, 342
 thermal history 106, 110
 thermal shut-off 340
 thermal shut-off gate 321
 thermoplastic materials 362
 thermoset 24
 thermoset injection 152
 thick part 366
 thin part 365
 three-plate cold runner 243, 272
 three-plate cold runner mold 2, 240
 three-plate molds 238
 tolerances 350
 transfer position 418
 – cut-off 418
 – switchover 418

– V-P (Velocity-Pressure) switchover 418
 transient flow 62, 82
 trapped air 386
 trapped gas 383, 384, 408
 tubular heaters 329
 tunnel gate 43, 252, 254
 two-plate cold runner 271
 two-plate cold runner mold 1, 225
 two-stage injection processes 207
 two-stage molding 418
 – first stage 418
 – second stage 418

U

UltraFlow 188
 unbalanced filling 62, 82, 361
 uniform cooling 89
 Unitized® 348
 Unitized System™ 357
 unmelt 408
 unmelted 408
 unmelted particles 414

V

vacuum voids 383, 384
 valve gated nozzle 4
 van der Waals 17
 variation in mold temperature 140
 variations in wall thickness 71
 varying diameter runner 120
 velocity 8, 106
 velocity controlled first stage 375
 velocity profile 11
 vent clogging 414
 venting 66, 236
 visco-elastic properties 58
 viscosity 8, 14, 17, 21, 107
 void 409
 voids 49, 414
 volumetric shrinkage 47, 48, 59, 67
 volumetric shrinkage variations 67

W

wall thickness 53, 67, 360
 wall thicknesses 49
 warp 62, 391, 409, 415, 416

warpage 51, 53, 56, 61, 164, 209, 213, 215
wave marks 404
wear 357
weld 396
weld lines 313, 398, 417
welds 90
wide gate 248
worm tracks 417

X

X branched runners 282

Z

zone temperatures 189