

Contents

1	Materials for Injection Molds	1
1.1	Steels	2
1.1.1	Summary	2
1.1.2	Case-Hardening Steels	6
1.1.2.1	Treatment	6
1.1.3	Nitriding Steels	7
1.1.4	Through-Hardening Steels	7
1.1.5	Heat-Treated Steels for Use as Supplied	9
1.1.6	Martensitic Steels	10
1.1.7	Corrosion-Resistant Steels	10
1.1.8	Refined Steels	11
1.2	Cast Materials	12
1.2.1	Steel Casting	12
1.3	Nonferrous Metallic Materials	14
1.3.1	Copper Alloys	14
1.3.1.1	Beryllium-Copper Alloys	14
1.3.2	Zinc and its Alloys	15
1.3.3	Aluminum Alloys	17
1.3.4	Bismuth-Tin Alloys	18
1.4	Materials for Electrolytic Deposition	19
1.5	Surface Treatment of Steels for Injection Molds	20
1.5.1	General Information	20
1.5.2	Heat Treatment of Steels	21
1.5.3	Carburizing	22
1.5.4	Nitriding	22
1.5.5	Boriding	23
1.5.6	Electrochemical Treatments	
	Chrome and Nickel Plating	23
1.5.6.1	Chrome Plating	24
1.5.6.2	Nickel Plating	24
1.5.6.3	NYE-CARD Process	24
1.5.6.4	Hardalloy Coating	24
1.5.6.5	Final Note	24
1.5.7	Coating at Reduced Pressure	25
1.5.7.1	The CVD Process	25
1.5.7.2	The PVD Process	26
1.6	Special Hardening Procedures	27
1.6.1	Laser Hardening	27
1.6.2	Electron-Beam Hardening	27

1.7	Materials and Procedures to Make Prototype Molds for Small Numbers of Molding	27
1.7.1	Casting Resins	28
1.7.2	Ceramic Casting Materials	28
1.8	Materials for Mold Bases and Functional Components (Mold Standards)	31
	References	32
2	Mold Making Techniques	35
2.1	Casting	36
2.1.1	Casting Processes	36
2.1.2	Sand Casting	36
2.1.3	Precision Casting – Ceramic Casting	37
2.1.4	Die Casting	38
2.2	Metal Spraying	40
2.3	Electrolytic Deposition	41
2.4	Hobbing	45
2.5	Machining and Other Material Removing Operations	47
2.5.1	Forming by Operations – Machining	47
2.5.2	Surface Treatment (Finishing)	48
2.5.2.1	Grinding and Polishing (Manual or Assisted)	48
2.5.2.2	Vibratory Finishing	49
2.5.2.3	Sand Blasting (Jet Lapping)	51
2.5.2.4	Pressure Lapping	51
2.5.2.5	Electrochemical Polishing	51
2.5.2.6	Electric-Discharge Polishing	51
2.5.3	Integration of Computerized Design and NC Programming	52
2.6	Electric-Discharge Forming Processes	55
2.6.1	Electric-Discharge Machining (EDM)	55
2.6.2	Cutting by Spark Erosion with Traveling-Wire Electrodes	58
2.7	Electrochemical Machining (ECM)	59
2.8	Chemical Material Removal – Etching	59
2.9	Surfaces Processed by Spark Erosion or Chemical Dissolution (Etching)	62
2.10	Molds for Arbitrary Shapes of Hollow bodies Shell Technique – Fusible-Core Technique	63
2.11	Stereo-Planographic Process for Making Prototypes and Patterns	66
	References	67
3	Procedure for Estimating Mold Costs	71
3.1	General Outline	71
3.2	Procedures for Estimating Mold Costs	71
3.3	Cost Group I: Cavity	75
3.3.1	Computation of Working Hours for Cavities	75
3.3.2	Time Factor for Machining Procedure	76
3.3.3	Machine Time for Cavity Depth	76
3.3.4	Time Consumption for Cavity Surface	77
3.3.5	Time Factor for Parting Line	77

3.3.6	Time Factor for Surface Quality	78
3.3.7	Machining Time for Fixed Cores	78
3.3.8	Time Factor for Tolerances	79
3.3.9	Time Factor for Degree of Difficulty and Multifariousness	79
3.3.10	Time Factor for Number of Cavities	80
3.3.11	Computation of Working Hours for EDM Electrodes	80
3.4	Cost Group II: Mold Bases	81
3.5	Cost Group III: Basic Functional Components	82
3.5.1	Sprue and Runner System	82
3.5.2	Runner System	84
3.5.3	Hot-Runner Systems	84
3.5.4	Heat-Exchange System	85
3.5.5	Ejector System	85
3.6	Cost Group IV: Special Functions	85
	References	86
4	The Injection Molding Process	89
4.1	The Molding Cycle	89
4.1.1	Injection Molding of Thermoplastics	91
4.1.2	Injection Molding of Curable Plastics	91
4.1.2.1	Injection Molding of Elastomers	91
4.1.2.2	Injection Molding of Thermosets	92
4.2	Terms Used in Connection with Injection Molds	92
4.3	Classification of Molds	92
4.4	Functions of the Injection Mold	93
4.4.1	Criteria for Classification of Molds	95
4.4.2	Basic Procedure for Mold Design	98
4.4.3	Determination of Mold Size	98
4.4.3.1	Maximum Number of Cavities	104
4.4.3.2	Clamping Force	104
4.4.3.3	Maximum Clamping Area	104
4.4.3.4	Required Opening Stroke	105
4.4.4	The Flow Length/Wall Thickness Ratio	105
4.4.5	Computation of Number of Cavities	107
4.4.5.1	Algorithm for the Determination of the Technically and Economically Optimum Number of Cavities	110
4.4.5.2	Costs for Sampling, Setup and Maintenance	120
4.5	Cavity Layouts	123
4.5.1	General Requirements	123
4.5.2	Presentation of Possible Solutions	123
4.5.3	Equilibrium of Forces in a Mold During Injection	123
4.5.4	Number of Parting Lines	125
	References	126
5	Design of Runner Systems	129
5.1	Characterization of the Complete Runner System	129
5.2	The Sprue	130

5.3	Concept and Definition of Runners	133
5.3.1	Standard Runner Systems	133
5.3.2	Hot-Runner Systems	133
5.3.3	Cold-Runner Systems	134
5.3.4	Demands on the Runner System	134
5.3.5	Classification of Runner Systems	134
5.3.6	Design of Runners	138
5.4	Design of Gates	140
5.4.1	Position of the Gate at the Part	145
5.5	Runners and Gates for Reactive Materials	148
5.5.1	Thermosets	148
5.5.2	Elastomers	148
5.5.3	Computing the Pressure Loss in a Runner System for Reactive Plastics	149
5.5.4	Effect of Gate Position for Reactive Plastics	149
5.6	Qualitative (Filling Image) and Quantitative Computation of the Filling Process of a Mold (Simulation Models)	150
5.6.1	Introduction	150
5.6.2	The Filling Image and its Significance	150
5.6.3	Using the Filling Image for Preparing a Simulation of the Filling Process	152
5.6.4	Theoretical Basis for Producing a Filling Image	153
5.6.5	Practical Proceeding for Graphically Producing a Filling Image	154
5.6.5.1	Drawing the Flow Fronts	154
5.6.5.2	Radius Vectors for the Presentation of Shadow Regions	154
5.6.5.3	Areas with Differences in Thickness	157
5.6.5.4	Filling Images of Ribs	161
5.6.5.5	Filling Images of Box-Shaped Moldings	162
5.6.5.6	Analysis of Critical Areas	163
5.6.5.7	Final Comments	163
5.6.6	Quantitative Analysis of Filling	165
5.6.7	Analytical Design of Runners and Gates	166
5.6.7.1	Rheological Basis	166
5.6.7.2	Viscosity of the Thermoplastic Melt	166
5.7	Thermosets	172
5.7.1	Pressure Computation for Straight Channels	173
5.7.2	Points of Discontinuity	174
5.8	Elastomers	177
5.8.1	Common Design	177
5.8.2	Effect of Processing Characteristics on the Basis of Processing Windows	178
5.8.3	Critical Comments on the Model of a Processing Window	180
5.9	Estimating Pressure Losses with Thermoplastics	182
5.9.1	Pressure Drop in Elbows and Branching	182
5.9.2	Pressure Drop from Unsteady Cross-Sectional Transitions	183
5.9.3	Pressure Drop in Runners	184
5.9.4	Special Phenomena with Multiple Gating	185
	References	187

6 Design of Gates	191
6.1 The Sprue Gate	191
6.2 The Edge or Fan Gate	193
6.3 The Disk Gate	195
6.4 The Ring Gate	196
6.5 The Tunnel Gate (Submarine Gate)	197
6.6 The Pinpoint Gate in Three-Plate Molds	200
6.7 Reversed Sprue with Pinpoint Gate	202
6.8 Runnerless Molding	205
6.9 Insulated-Runner Molds	207
6.10 Temperature-Controlled Runner Systems – Hot-Runner Molds/Cold-Runner Molds	208
6.10.1 Hot-Runner Systems	209
6.10.1.1 Concepts of Hot-Runner Molds and Comparison With Competing Systems	211
6.10.1.2 Design of a Hot-Runner System and its Components	213
6.10.1.3 Nozzles for Hot-Runner Molds	214
6.10.1.3.1 Open Nozzles	214
6.10.1.3.2 Nozzles with Shut-Off Probes	227
6.10.1.4 The Hot Manifold	231
6.10.1.4.1 Basic Configurations	231
6.10.1.4.2 Design and Manufacturing Details	231
6.10.1.5 Melt Supply	235
6.10.1.6 Heating of a Hot-Runner System	236
6.10.1.6.1 Heating of Nozzles	238
6.10.1.6.2 Heating of Manifolds	238
6.10.1.6.3 Computing of Power Output	241
6.10.1.7 Temperature Control in Hot Manifolds	241
6.10.1.7.1 Placement of Thermocouples	241
6.10.1.7.2 Controllers	242
6.10.1.8 Design of Hot-Runner Molds	242
6.10.1.9 Economics of Hot-Runner Molds	243
6.10.2 Cold-Runner Molds	245
6.10.2.1 Cold-Runner Systems for Elastomers	245
6.10.2.2 Cold-Runner Molds for Thermosets	250
6.11 Special Mold Concepts	252
6.11.1 Stack Molds	252
6.11.2 Injection Molds for Compact Disks	255
6.11.3 Molds for Manufacturing Cans	256
6.11.4 Molds for Reactive Materials	257
6.11.4.1 Thermosets	257
6.11.5 Molds for Two-Component Injection	258
6.11.6 Molds for Producing Compound with Sheet Metal (Outsert Technique, Rubber-Metal Combination)	259
6.11.7 Molds for Multicolor Injection Molding	259
References	260

7 Venting of Molds	265
References	270
8 The Heat Exchange System	271
8.1 Cooling Time	272
8.2 Thermal Diffusivity of Several Important Materials	274
8.2.1 Thermal Diffusivity of Elastomers	276
8.2.2 Thermal Diffusivity of Thermosets	276
8.3 Computation of Cooling Time of Thermoplastics	277
8.3.1 Estimation	277
8.3.2 Computation of Cooling Time with Nomograms	277
8.3.3 Cooling Time with Asymmetrical Wall Temperatures	279
8.3.4 Cooling Time for Other Geometries	280
8.4 Heat Flux and Heat Exchange Capacity	282
8.4.1 Heat Flux	282
8.4.1.1 Thermoplastics	282
8.4.1.2 Reactive Materials	286
8.4.1.2.1 Thermosets	286
8.4.2 Design of Heat-Exchange System Based on the Specific Heat Flux (Overall Design)	293
8.4.3 Method of Calculation	303
8.4.3.1 Overall Calculation	303
8.4.3.2 Analytical Thermal Calculation	303
8.4.3.3 Calculation by Segmentation	306
8.5 Cooling of Critical Sections of a Molding	306
8.5.1 Empirical Correction for Cooling a Corner	307
8.5.2 Refined Design by Segmentation	308
8.5.2.1 Thermal Conductance of Segments	308
8.5.2.2 Thermal Transfer Resistance of Cooling Elements	311
8.5.2.3 Uniformity	313
8.5.2.4 Flow Rate of Coolant	314
8.5.2.5 Pressure Drop	315
8.6 Empirical Compensation of Corner Distortion from Heat-Flux Differences	316
8.6.1 Cold Core and Warm Cavity	316
8.6.2 Modification of Corner Configuration	317
8.6.3 Local Adjustment of Heat Fluxes	318
8.7 Practical Design of Cooling Lines	319
8.7.1 Heat-Exchange Systems for Cores and Parts with Circular Cross Section	319
8.7.2 Cooling Systems for Flat Parts	324
8.7.3 Sealing of Cooling Systems	327
8.8 Calculation for Heated Molds for Reactive Materials	328
8.9 Heat Exchange in Molds for Reactive Materials	329
8.9.1 Heat Balance	329
8.9.2 Temperature Distribution	332
8.10 Practical Design of the Electric Heating for Thermoset Molds	333
References	334

9 Shrinkage	337
9.1 Introduction	337
9.2 Definition of Shrinkage	337
9.3 Tolerances	338
9.4 Causes of Shrinkage	344
9.5 Causes of Anisotropic Shrinkage	345
9.6 Causes of Distortion	347
9.7 Effect on Shrinkage from Processing	347
9.8 Supplementary Means for Predicting Shrinkage	349
References	352
 10 Mechanical Design of Injection Molds	 353
10.1 Mold Deformation	353
10.2 Analysis and Evaluation of Loads and Deformations	353
10.2.1 Evaluation of the Acting Forces	354
10.3 Basis for Describing the Deformation	355
10.4 The Superimposition Procedure	356
10.4.1 Coupled Springs as Equivalent Elements	356
10.4.1.1 Parallel Coupling of Elements	357
10.4.1.2 Elements Coupled in Series	358
10.5 Computation of the Wall Thickness of Cavities and their Deformation	358
10.5.1 Presentation of Individual Cases of Loading and the Resulting Deformations	359
10.5.2 Computing the Dimensions of Cylindrical Cavities	360
10.5.3 Computing the Dimensions of Non-Circular Cavity Contours	361
10.5.4 Computing the Dimensions of Mold Plates	362
10.6 Procedure for Computing Dimensions of Cavity Walls under Internal Pressure	364
10.7 Assumptions of Loads	364
10.7.1 Estimating Additional Loading	364
10.7.1.1 Effects from Mold Making	364
10.7.1.2 Thermal Effects During Operation of the Mold	365
10.7.1.3 Effects from Molding Machines	365
10.8 The Admissible Deformation as Basis for Computing Dimensions	365
References	366
 11 Shifting of Cores	 367
11.1 Estimating the Maximum Shifting of a Core	367
11.2 Shifting of Circular Cores with Lateral Pinpoint Gate at the Base (Rigid Mount)	368
11.3 Shifting of Circular Cores with Lateral Pinpoint Gate at the Tip (Rigid Mount)	370
11.4 Shifting of Rectangular Cores with Lateral Pinpoint Gate at the Base (Rigid Mount)	371
11.5 Shifting of Cores Related to Mounting (Exemplified by a Circular Core Laterally Gated at the Base)	371

11.6	Shifting of Circular Cores with Disk Gates (Rigid Mount)	373
11.6.1	Basic Examination of the Problem	373
11.6.2	Results of the Calculations	375
11.7	Shifting of Cores with Various Types of Gating (Rigid Mounts)	377
11.8	Design Examples for Core Mounting and Alignment of Deep Cavities	378
	References	379
12	Ejection	381
12.1	Summary of Ejection Systems	381
12.2	Design of Ejection Systems – Ejection and Opening Forces	385
12.2.1	General Discussion	385
12.2.1.1	Experience	387
12.2.2	Methods for Computing the Release Forces	388
12.2.2.1	The Estimation Method	389
12.2.2.2	Cylindrical Sleeves	393
12.2.2.3	Cylindrical Sleeves of Polystyrene	393
12.2.2.4	Rectangular Sleeves	396
12.2.2.5	Tapered Sleeves	396
12.2.3	Summary of Some Basic Cases	397
12.2.4	The Release Forces for Complex Parts Exemplified with a Fan	400
12.2.4.1	Contact Pressure on the Fan under Release Forces	402
12.2.4.2	Buckling of Ejector Pins under Cavity Pressure	403
12.2.5	Estimating the Opening Forces	403
12.2.5.1	Changes of State in a P-V-T Diagram for Molds with Different Rigidities	404
12.2.5.2	Indirect Opening Forces	405
12.2.5.3	Total Opening Force	405
12.2.5.4	The Coefficient of Static Friction and the Release and Opening Forces	405
12.3	Types of Ejectors	406
12.3.1	Design and Dimensions of Ejector Pins	406
12.3.2	Points of Action of Ejector Pins and Others Elements of Demolding	409
12.3.3	Ejector Assembly	413
12.4	Actuation of the Ejector Assembly	414
12.4.1	Means of Actuation and Selection of Places of Action	414
12.4.2	Means of Actuation	414
12.5	Special Release Systems	418
12.5.1	Double-Stage Ejection	418
12.5.2	Combined Ejection	418
12.5.3	Three-Plate Molds	418
12.5.3.1	Ejector Movement by Stripper Bolt	420
12.5.3.2	Ejector Movement by Latch	420
12.5.3.3	Reversed Ejection from the Stationary Side	422
12.6	Ejector Return	423
12.7	Ejection of Parts with Undercuts	426
12.7.1	Demolding of Parts with Undercuts by Pushing Them Off	427
12.7.2	Permissible Depth of Undercuts for Snap Fits	428

12.8 Demolding of Threads	430
12.8.1 Demolding of Parts with Internal Threads	430
12.8.1.1 Stripper Molds	430
12.8.1.2 Collapsible Cores	430
12.8.1.3 Molds with Interchangeable Cores	432
12.8.2 Molds with Unscrewing Equipment	432
12.8.2.1 Semiautomatic Molds	432
12.8.2.2 Fully Automatic Molds	433
12.8.3 Demolding of Parts with External Threads	441
12.9 Undercuts in Noncylindrical Parts	442
12.9.1 Internal Undercuts	442
12.9.2 External Undercuts	442
12.9.2.1 Slide Molds	443
12.9.2.2 Split-Cavity Molds	448
12.9.3 Molds with Core-Pulling Devices	452
References	453
13 Alignment of Molds – Changing of Molds	455
13.1 Function of Alignment	455
13.2 Alignment with the Axis of the Plasticating Unit	455
13.3 Internal Alignment and Interlocking	456
13.4 Alignment of Large Molds	459
13.5 Changing Molds	461
13.5.1 Systems for a Quick Change of Molds for Thermoplastics	461
13.5.2 Mold Exchanger for Elastomer Molds	466
References	468
14 Computer Assisted Mold Design	469
14.1 Introduction	469
14.2 Rheological Design	469
14.2.1 Two-Dimensional Procedures	469
14.2.2 Three-Dimensional Procedures	474
14.2.2.1 Determination of the Optimum Gate Location	475
14.2.3 Computation in Layers Along a Flow Path	485
14.2.3.1 Bases of Computation	486
14.2.3.2 Application to Molds for Thermoplastics	489
14.2.3.3 Application to Elastomer Molds	493
14.3 Thermal Design	494
14.3.1 Approximate Thermal Design	494
14.3.2 Examination of Results with a Section Through Mold and Molding	497
14.3.3 Thermal Computation with the Boundary-Integral Method	498
14.4 Mechanical Design	500
14.5 Education for Users of Simulation Programs	503
References	504

15 Maintenance of Injection Molds	507
References	509
16 Repair and Alterations of Injection Molds	511
References	514
17 Mold Standards	515
References	517
18 Temperature Controllers for Injection and Compression Molds	519
18.1 Function, Method, Classification	519
18.2 Control	521
18.2.1 Control Methods	521
18.2.2 Preconditions for Good Control Results	522
18.2.2.1 Controllers	523
18.2.2.2 Heating, Cooling and Pump Capacity	524
18.2.2.3 Temperature Sensors	524
18.2.2.4 Installation of Temperature Sensors in the Mold	525
18.2.2.5 Heat-Exchange System in the Mold	526
18.3 Selection of Equipment	527
18.4 Connection of Mold and Equipment – Safety Measures	528
18.5 Heat Carrier	528
18.6 Maintenance and Cleaning	529
19 Steps for the Correction of Molding Defects Caused by Improper Mold Design	531
References	534
Index	535