

Contents

Acknowledgments	V
Preface	VII
1 Overview of Plastics Molding	1
<i>Che-Ping (Barton) Lin</i>	
1.1 Introduction to Injection Molding	1
1.1.1 The Systems of Injection Molding	3
1.1.1.1 The Cycle of Injection Molding	3
1.1.1.2 Injection Machine	4
1.1.2 Defects in Injection Molded Products	10
1.1.2.1 Short Shot	10
1.1.2.2 Warp	11
1.1.2.3 Flash	11
1.1.2.4 Sink Mark and Void	12
1.1.2.5 Air Trap	13
1.1.2.6 Burn Mark	13
1.1.2.7 Delamination	14
1.1.2.8 Fish Eye	14
1.1.2.9 Flow Mark	14
1.1.2.10 Stress Mark	15
1.1.2.11 Hesitation	15
1.1.2.12 Jetting	16
1.1.2.13 Splay	16
1.1.2.14 Weld Line	17

1.2	Core Values of Molding Simulation	18
1.2.1	Application of CAE Technology in Injection Molding	19
2	Material Properties of Plastics	23
	<i>Chen-Chieh (Jye) Wang</i>	
2.1	Overview	23
2.2	Rheological Properties	25
2.2.1	Viscosity	26
2.2.1.1	Effects of Non-Newtonian and Molecular Conformation	27
2.2.1.2	Effects of Shear Rate	28
2.2.1.3	Effects of Temperature	30
2.2.1.4	Effects of Pressure	31
2.2.1.5	Theoretical Models	31
2.2.1.6	Viscosity Properties of Plastics	33
2.2.2	Viscoelastic Fluids	35
2.2.2.1	Viscoelastic Behavior	35
2.2.2.2	Theoretical Models	37
2.2.2.3	Measurement of Viscoelasticity	41
2.3	Thermodynamic and Thermal Properties	46
2.3.1	Specific Heat Capacity	46
2.3.2	Melting Point and Glass Transition Temperatures	48
2.3.3	PVT Equation of State	49
2.3.3.1	Definition	49
2.3.3.2	Data Interpretation	50
2.3.3.3	Theoretical Models	51
2.3.3.4	Effects of Non-Equilibrium State on PVT	54
2.3.4	Thermal Conductivity and Heat Transfer Coefficient	56
2.3.4.1	Definition	56
2.3.4.2	Theoretical Models	57
2.3.4.3	Data Interpretation	57
2.3.4.4	Mold-Melt Contact and Heat Transfer Coefficient (HTC)	58

2.4	Mechanical Properties	59
2.4.1	Stress and Strain of Plastics	59
2.4.2	Solid-Like Viscoelasticity	60
2.4.3	Theoretical Model	61
2.4.4	Data Interpretation	62
2.5	Kinetic Properties	64
2.5.1	Crystalline	64
2.5.2	Theoretical Models	64
2.5.3	Effects of Cooling Rate on Crystallization	65
2.6	Curing Kinetics	66
2.6.1	Curing Phenomenon	66
2.6.2	Theoretical Models	67
2.6.3	Curing Effect on Viscosity	68
2.6.4	Data Interpretation	70
3	Part and Mold Design	73
	<i>Tsai-Hsin (Sam) Hsieh, Yao-Chen (Cloud) Tsai, Yao-Wei (Willie) Chuang</i>	
3.1	Part Design	73
3.1.1	Golden Rule: Uniform Wall Thickness	73
3.1.2	Wall Thickness versus Flow Length	76
3.1.3	Radius/Fillets and Chamfer Angle	78
3.1.4	Rib and Boss	79
3.1.5	Draft Angle	84
3.1.6	Design for Manufacturing (DFM)	85
3.1.7	Summary	86
3.2	Mold Design	87
3.2.1	Basics	88
3.2.2	Gate Design	91
3.2.2.1	Gate Number	91
3.2.2.2	Gate Location	92
3.2.2.3	Gate Types	95
3.2.3	Runner Design	97
3.2.3.1	Runner Shape and Dimension	98
3.2.3.2	Multi-Cavity Runner Design	99

3.2.4	Cooling Design	100
3.2.5	Others	102
3.2.5.1	Ejector System	102
3.2.5.2	Venting Design	102
4	Process Conditions	105
	<i>Chuan-Wei (Arvid) Chang</i>	
4.1	Introduction to the Injection Molding Cycle	105
4.1.1	Brief Introduction to Injection Molding Machine Units	105
4.1.2	Injection Molding Cycle	107
4.1.3	Molding Window	110
4.1.4	PVT Variations during Injection Stages	111
4.2	Plasticizing Conditions	122
4.2.1	Nozzle Temperature and Cylinder Temperatures	122
4.2.2	Back Pressure, Screw rpm, Suck Back, and Metering Stroke ..	123
4.3	Filling Conditions	129
4.3.1	Filling Time versus Injection Velocity	129
4.3.2	Injection Pressure	133
4.3.3	VP Switch	136
4.4	Packing Conditions	138
4.5	Cooling Conditions	140
4.5.1	Cooling Time	140
4.5.2	Coolant Flow Rate	141
4.5.3	Mold Temperature	141
4.6	Connecting Smart Design to Smart Manufacturing	142
4.6.1	Machine Characterization	143
4.6.2	The CAE Setting Mode in Combination with Injection Machine on Site	148
4.6.3	Case Study	150
5	Molding Simulation Methodology	157
	<i>Hsien-Sen (Ethan) Chiu</i>	
5.1	The Goal of Molding Simulation	157
5.1.1	Design Verification and Optimization	158

5.1.1.1	Overview of Design for Manufacture (DFM)	158
5.1.1.2	CAE and DFM: A Practical Case Study	160
5.1.2	Process Conditions Optimization	167
5.1.2.1	Molding Stability	167
5.1.2.2	Real Case	169
5.2	Basics of Simulation Equations	173
5.2.1	Governing Equations	174
5.2.2	Numerical Approximation	175
5.2.2.1	Finite Difference Method (FDM)	175
5.2.2.2	Finite Volume Method (FVM)	178
5.2.2.3	Finite Element Method (FEM)	180
5.3	What Is Molding Simulation?	182
5.3.1	Brief History of Molding Simulation	182
5.3.2	Simulation Workflow	189
6	Flow Consideration versus Part Features	193
	<i>Wen-Hsin (Debbie) Weng</i>	
6.1	Basics	193
6.1.1	Flow Behavior of Plastic Melt in the Cavity	193
6.1.2	Effects of Filling Time	198
6.1.3	Flow Rate versus Injection Pressure	199
6.1.3.1	Flow Rate Curve Setting	199
6.1.3.2	Relationship of Injection Rate and Injection Pressure	203
6.1.4	VP Switch and Cavity Pressure	209
6.1.5	Effects of Part Thickness	218
6.1.6	Material Viscosity an Flow Behaviour	223
6.1.7	Summary	227
6.2	Practical Applications	228
6.2.1	CAE Solution to Stress Mark in a Phone Shell	228
6.2.2	Flow Rate Effect on Injection Pressure of Laptop Product	232
6.3	CAE Case Study	234

7	Runner and Gate Design	239
	<i>Yao-Chen (Cloud) Tsai, Yao-Wei (Willie) Chuang</i>	
7.1	Basics	239
7.1.1	General Design Guide of Runners	239
7.1.2	General Design Guide of Gates	244
7.1.3	Gate Sealing	256
7.1.4	Flow Balance	258
7.2	Practical Applications	265
7.2.1	CAE Verification on MeltFlipper® Design	265
7.2.2	CAE Verification of Multi-Cavity Systems	271
7.3	CAE Case Study	275
8	Cooling Optimization	279
	<i>Hung-Chou (Kent) Wang</i>	
8.1	Basics	279
8.1.1	Heat Transfer Mechanism	280
8.1.2	Design Golden Rule: Uniform Mold Temperature	283
8.1.3	General Design Guide of Cooling Channel	287
8.1.4	Cooling Efficiency: Coolant Flow Consideration	291
8.1.5	Cooling Time Estimate	294
8.1.6	Use CAE Cooling Analysis	296
8.1.7	Conformal Cooling Application	299
8.2	Practical Applications	303
8.2.1	Digital Camera Cover	303
8.2.2	Cartridge	308
8.3	CAE Case Study	312
9	Warpage Control	315
	<i>Shih-Po (Tober) Sun, Wen-Hsin (Debbie) Weng</i>	
9.1	Basics	315
9.1.1	The Causes of Warpage	318
9.1.2	Material Effects	321
9.1.3	Geometrical Effects	324
9.1.4	Process Condition Effects	326

9.1.5	Criteria of CAE Warp Analysis	328
9.1.6	Methods to Minimize Warpage	332
9.2	Practical Applications	338
9.3	CAE Case Study	343
10	Fiber Orientation Control	347
	<i>Huan-Chang (Ivor) Tseng</i>	
10.1	Basics	348
10.1.1	Process Principle	350
10.1.2	Theory Models	351
10.1.3	Advantages and Challenges	361
10.2	Practical Applications	362
10.2.1	Using the iARD-RPR Model for an Injection Molded Center-Gated Disk with Fiber-Reinforced Thermoplastics	362
10.2.2	Comparison of iARD-RPR Models under GNF Decoupling and IISO Coupling	366
10.2.3	The Influences of Material Flow and Fiber Interaction on Fiber Orientation and Product Quality during Injection Molding	369
10.3	CAE Case Study	374
11	Hot Runner Optimization	379
	<i>Tsai-Hsin (Sam) Hsieh</i>	
11.1	Basics	379
11.1.1	Process Principle	380
11.1.2	Temperature Control in a Hot Runner System	384
11.1.3	Advantages and Challenges	386
11.2	Practical Applications	395
11.2.1	CAE Verification on a Single-Gate Hot Runner System	395
11.2.2	CAE Pin Movement Control of Valve Gate	404
11.3	CAE Case Study	408

12	Co-/Bi-Injection Molding	411
	<i>Chih-Chung (Jim) Hsu, Yu-Sheng (Tim) Chou</i>	
12.1	Basics	412
12.1.1	Process Principle	412
12.1.2	Advantages and Challenges	415
12.1.3	Theory Models	417
12.2	Practical Applications	418
12.2.1	Co-Injection Molding of Fork Model	418
12.2.2	Co-Injection Molding: Core Breakthrough and Flow Imbalance	420
12.2.3	Co-Injection Molding: Fiber Orientation Predictions	424
12.2.4	CAE Case of Bi-Injection Molding	426
12.3	CAE Case Study	430
13	Gas-/Water-Assisted Injection Molding	433
	<i>Chih-Chung (Jim) Hsu, Yu-Sheng (Tim) Chou</i>	
13.1	Basics	433
13.1.1	Process Principle	434
13.1.1.1	Short-Shot Process	434
13.1.1.2	Full-Shot Process	436
13.1.2	Advantages and Challenges	438
13.2	Practical Applications	446
13.2.1	CAE Verification on GAIM	446
13.2.2	CAE Verification on WAIM	449
13.2.3	CAE Verification on GAIM: Fingering Effect	452
13.3	CAE Case Study	454
14	Foam Injection Molding	457
	<i>Yuan-Jung (Dan) Chang, Li-Yang (Robert) Chang, Chih-Wei (Joe) Wang</i>	
14.1	Basics	457
14.1.1	Microcellular Process Principle	458
14.1.2	Advantages and Challenges	462
14.1.3	Theory Models	464

14.2	Practical Applications	466
14.2.1	CAE Verification on Microcellular Injection Molding: Case 1 ..	466
14.2.2	CAE Verification of Microcellular Injection Molding: Case 2 ..	473
14.2.3	CAE Verification on Chemical Foaming Injection Molding	480
14.2.4	CAE Verification of Polyurethane Reactive Foaming Molding ..	483
14.2.5	Summary	491
14.3	CAE Case Study	492
15	Powder Injection Molding	495
	<i>Huan-Chang (Ivor) Tseng</i>	
15.1	Basics	495
15.1.1	Process Principle	496
15.1.2	Advantages and Challenges	497
15.1.3	Theory Models	500
15.2	Practical Applications	505
15.3	CAE Case Study	508
16	Resin Transfer Molding	511
	<i>Hsun (Fred) Yang, Yu-He (Zoe) Chen</i>	
16.1	Basics	512
16.1.1	Process Principle	516
16.1.2	Advantages and Challenges	520
16.2	Theory Models	521
16.2.1	2.5D Analysis	521
16.2.2	3D Analysis	523
16.2.3	Measurement of Permeability	525
16.2.4	Porosity	528
16.2.5	Measurement of Chemorheological Properties	529
16.2.6	Simulation Parameters	530
16.3	Practical Applications	531
16.3.1	CAE Verification on Edge Effects	531
16.3.2	CAE Verification on Thickness-Direction Flow	533
16.3.3	CAE Verification on a Wind Turbine Blade	538
16.3.4	CAE Verification on Mat Effects	540

16.3.5	CAE Verification on Flybridge	543
16.4	CAE Case Study	547
17	Integrated Circuit Packaging	549
	<i>Chih-Chung (Jim) Hsu, Chia-Peng (Victor) Sun, Chen-An (Jennan) Wang, Yu-En (Joseph) Liang</i>	
17.1	Basics	549
17.1.1	Process Principle	554
17.1.2	Advantages and Challenges	557
17.1.3	Theoretical Models	559
17.2	Practical Applications	563
17.2.1	CAE Verification on Void Prediction	563
17.2.2	Fluid-Structure Interactions: Wire Sweep Analysis	567
17.2.3	Fluid-Structure Interactions: Paddle Shift and Chip Deformation Analysis	569
17.2.4	Warpage Prediction for a Bilaminate	577
17.2.5	Warpage Prediction for a Bi-Material Component Model	580
17.2.6	Warpage of Bi-Material Strip	583
17.2.7	The Effect of Dispensing Control and Creeping Behavior on the Underfill Process	586
17.3	CAE Case Study	591
Index		595