

# Contents

<b>Acknowledgments .....</b>	<b>V</b>
<b>Preface .....</b>	<b>VII</b>
<b>1      Overview of Plastics Molding .....</b>	<b>1</b>
<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
<b>2</b>	<b>Material Properties of Plastics .....</b>	<b>23</b>
	<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
<b>3</b>	<b>Part and Mold Design .....</b>	<b>73</b>
<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
<b>4</b>	<b>Process Conditions .....</b>	<b>105</b>
<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
<b>5</b>	<b>Molding Simulation Methodology .....</b>	<b>157</b>
<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
<b>6</b>	<b>Flow Consideration versus Part Features .....</b>	<b>193</b>
	<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

<b>7</b>	<b>Runner and Gate Design .....</b>	<b>239</b>
	<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
<b>8</b>	<b>Cooling Optimization .....</b>	<b>279</b>
	<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
<b>9</b>	<b>Warpage Control .....</b>	<b>315</b>
	<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
<b>10</b>	<b>Fiber Orientation Control . . . . .</b>	<b>347</b>
	<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
<b>11</b>	<b>Hot Runner Optimization . . . . .</b>	<b>379</b>
	<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

<b>12</b>	<b>Co-/Bi-Injection Molding</b>	<b>411</b>
<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
<b>13</b>	<b>Gas-/Water-Assisted Injection Molding</b>	<b>433</b>
<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
<b>14</b>	<b>Foam Injection Molding</b>	<b>457</b>
<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
<b>15</b>	<b>Powder Injection Molding .....</b>	<b>495</b>
	<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
<b>16</b>	<b>Resin Transfer Molding .....</b>	<b>511</b>
	<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
<b>17 Integrated Circuit Packaging .....</b>	<b>549</b>
<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
<b>Index .....</b>	<b>595</b>