Contents

	Contributor contact details	*xiii*
	Preface	*xvii*
1	**Metal powder injection molding (MIM): key trends and markets**	**1**
	R. M. GERMAN, San Diego State University, USA	
1.1	Introduction and background	1
1.2	History of success	2
1.3	Industry structure	4
1.4	Statistical highlights	6
1.5	Industry shifts	9
1.6	Sales situation	10
1.7	Market statistics	12
1.8	Metal powder injection molding market by region	13
1.9	Metal powder injection molding market by application	14
1.10	Market opportunities	15
1.11	Production sophistication	21
1.12	Conclusion	23
1.13	Sources of further information	23
Part I	**Processing**	**27**
2	**Designing for metal injection molding (MIM)**	**29**
	D. F. HEANEY, Advanced Powder Products, Inc., USA	
2.1	Introduction	29
2.2	Available materials and properties	31
2.3	Dimensional capability	35
2.4	Surface finish	35
2.5	Tooling artifacts	35
2.6	Design considerations	40

2.7	Sources of further information	49
3	**Powders for metal injection molding (MIM)**	**50**
	D. F. HEANEY, Advanced Powder Products, Inc., USA	
3.1	Introduction	50
3.2	Ideal MIM powder characteristics	51
3.3	Characterizing MIM powders	55
3.4	Different MIM powder fabrication techniques	57
3.5	Different alloying methods	61
3.6	References	62
4	**Powder binder formulation and compound manufacture in metal injection molding (MIM)**	**64**
	R. K. ENNETI, Global Tungsten and Powders, USA and V. P. ONBATTUVELLI and S. V. ATRE, Oregon State University, USA	
4.1	Introduction: the role of binders	64
4.2	Binder chemistry and constituents	66
4.3	Binder properties and effects on feedstock	70
4.4	Mixing technologies	84
4.5	Case studies: lab scale and commercial formulations	88
4.6	References	89
5	**Tooling for metal injection molding (MIM)**	**93**
	G. SCHLIEPER, Gammatec Engineering GmbH, Germany	
5.1	Introduction	93
5.2	General design and function of injection molding machines	94
5.3	Elements of the tool set	96
5.4	Tool design options	98
5.5	Special features and instrumentation	104
5.6	Supporting software and economic aspects	106
5.7	Sources of further information	108
6	**Molding of components in metal injection molding (MIM)**	**109**
	D. F. HEANEY, Advanced Powder Products, Inc., USA and C. D. GREENE, Treemen Industries, Inc., USA	
6.1	Introduction	109
6.2	Injection molding equipment	110
6.3	Auxiliary equipment	115
6.4	Injection molding process	116
6.5	Common defects in MIM	129

6.6 References 131

7 Debinding and sintering of metal injection molding (MIM) components 133

S. BANERJEE, DSH Technologies LLC, USA and C. J. JOENS, Elnik Systems LLC, USA

7.1 Introduction 133
7.2 Primary debinding 136
7.3 Secondary debinding 144
7.4 Sintering 147
7.5 MIM materials 161
7.6 Settering 167
7.7 MIM furnaces 169
7.8 Furnace profiles 176
7.9 Summary 176
7.10 Acknowledgements 178
7.11 References 178

Part II Quality issues 181

8 Characterization of feedstock in metal injection molding (MIM) 183

H. LOBO, DatapointLabs, USA

8.1 Introduction 183
8.2 Rheology 186
8.3 Thermal analysis 190
8.4 Thermal conductivity 193
8.5 Pressure–volume–temperature (PVT) 194
8.6 Conclusions 195
8.7 Acknowledgments 196
8.8 References 196

9 Modeling and simulation of metal injection molding (MIM) 197

T. G. KANG, Korea Aerospace University, Korea, S. AHN, Pusan National University, Korea, S. H. CHUNG, Hyundai Steel Co., Korea, S. T. CHUNG, CetaTech Inc., Korea, Y. S. KWON, CetaTech, Inc., Korea, S. J. PARK, POSTECH, Korea and R. M. GERMAN, San Diego State University, USA

9.1 Modeling and simulation of the mixing process 197
9.2 Modeling and simulation of the injection molding process 203

9.3	Modeling and simulation of the thermal debinding process	215
9.4	Modeling and simulation of the sintering process	224
9.5	Conclusion	230
9.6	References	231
10	**Common defects in metal injection molding (MIM)**	**235**
	K. S. HWANG, National Taiwan University, Taiwan, R.O.C.	
10.1	Introduction	235
10.2	Feedstock	236
10.3	Molding	238
10.4	Debinding	243
10.5	Sintering	250
10.6	Conclusion	251
10.7	References	252
11	**Qualification of metal injection molding (MIM)**	**254**
	D. F. HEANEY, Advanced Powder Products, Inc., USA	
11.1	Introduction	254
11.2	The metal injection molding process	255
11.3	Product qualification method	255
11.4	MIM prototype methodology	257
11.5	Process control	258
11.6	Understanding of control parameters	260
11.7	Conclusion	263
11.8	Sources of further information	263
12	**Control of carbon content in metal injection molding (MIM)**	**265**
	G. HERRANZ, Universidad de Castilla-La Mancha, Spain	
12.1	Introduction: the importance of carbon control	265
12.2	Methods of controlling carbon, binder elimination and process parameters affecting carbon control	267
12.3	Control of carbon in particular materials	276
12.4	Material properties affected by carbon content	297
12.5	References	297
Part III	**Special metal injection molding processes**	**305**
13	**Micro metal injection molding (MicroMIM)**	**307**
	V. PIOTTER, Karlsruhe Institute of Technology (KIT), Germany	

13.1 Introduction 307
13.2 Potential of powder injection molding for micro-technology 308
13.3 Micro-manufacturing methods for tool making 309
13.4 Powder injection molding of micro components 313
13.5 Multi-component micro powder injection molding 325
13.6 Simulation of MicroMIM 328
13.7 Conclusion and future trends 330
13.8 Sources of further information and advice 331
13.9 References 332

14 Two-material/two-color powder metal injection molding (2C-PIM) 338

P. SURI, Heraeus Materials Technology LLC, USA

14.1 Introduction 338
14.2 Injection molding technology 338
14.3 Debinding and sintering 341
14.4 2C-PIM products 344
14.5 Future trends 346
14.6 References 347

15 Powder space holder metal injection molding (PSH-MIM) of micro-porous metals 349

K. NISHIYABU, Kinki University, Japan

15.1 Introduction 349
15.2 Production methods for porous metals 351
15.3 Formation of micro-porous structures by the PSH method 354
15.4 Control of porous structure with the PSH method 360
15.5 Liquid infiltration properties of micro-porous metals produced by the PSH method 369
15.6 Dimensional accuracy of micro-porous MIM parts 374
15.7 Functionally graded structures of micro-porous metals 379
15.8 Conclusion 388
15.9 Acknowledgements 388
15.10 References 389

Part IV Metal injection molding of specific materials 391

16 Metal injection molding (MIM) of stainless steels 393

J. M. TORRALBA, Institute IMDEA Materials, Universidad Carlos III de Madrid, Spain

16.1 Introduction 393
16.2 Stainless steels in metal injection molding (MIM) 396

16.3 Applications of MIM stainless steels 403
16.4 Acknowledgements 409
16.5 References 410

17 Metal injection molding (MIM) of titanium and titanium alloys 415
T. EBEL, Helmholtz-Zentrum Geesthacht, Germany

17.1 Introduction 415
17.2 Challenges of MIM of titanium 416
17.3 Basics of processing 422
17.4 Mechanical properties 425
17.5 Cost reduction 432
17.6 Special applications 435
17.7 Conclusion and future trends 440
17.8 Sources of further information 441
17.9 References 441

18 Metal injection molding (MIM) of thermal management materials in microelectronics 446
J. L. JOHNSON, ATI Firth Sterling, USA

18.1 Introduction 446
18.2 Heat dissipation in microelectronics 447
18.3 Copper 451
18.4 Tungsten–copper 461
18.5 Molybdenum–copper 474
18.6 Conclusions 482
18.7 References 482

19 Metal injection molding (MIM) of soft magnetic materials 487
H. MIURA, Kyushu University, Japan

19.1 Introduction 487
19.2 Fe–6.5Si 489
19.3 Fe–9.5Si–5.5Al 497
19.4 Fe–50Ni 506
19.5 Conclusion 513
19.6 References 514

20 Metal injection molding (MIM) of high-speed tool steels 516

N. S. MYERS, Kennametal Inc., USA and D. F. HEANEY, Advanced Powder Products, Inc., USA

20.1 Introduction 516
20.2 Tool steel MIM processing 517
20.3 Mechanical properties 523
20.4 References 525

21 Metal injection molding (MIM) of heavy alloys, refractory metals, and hardmetals 526

J. L. JOHNSON, ATI Firth Sterling, USA, D. F. HEANEY, Advanced Powder Products, Inc., USA and N. S. Myers, Kennametal Inc., USA

21.1 Introduction 526
21.2 Applications 527
21.3 Feedstock formulation concerns 529
21.4 Heavy alloys 534
21.5 Refractory metals 544
21.6 Hardmetals 554
21.7 References 560

Index *569*