

Contents

Preface	V
Acknowledgments	VII
About the Authors	IX
1 Basics of 3D Printing Technology	1
1.1 Basic Terms and Definitions	2
1.1.1 Additive Manufacturing	2
1.1.2 The Principle of Layer-Based Processes	3
1.2 Application Levels	6
1.2.1 Direct Processes	7
1.2.1.1 Rapid Prototyping	7
1.2.1.2 Rapid Manufacturing	11
1.2.1.3 Rapid Tooling	14
1.2.2 Indirect Processes	18
1.2.2.1 Indirect Prototyping	19
1.2.2.2 Indirect Tooling	22
1.2.2.3 Indirect Manufacturing	24
1.3 Classification of Machines for Additive Manufacturing	27
1.3.1 Generic Terms for AM Machines	27
1.3.2 Classification of Machines and Properties of Parts	29
1.4 Conclusions	30
1.5 Questions	30
2 Additive Manufacturing Processes/3D Printing	33
2.1 Direct Additive Processes	33
2.1.1 Polymerization	36
2.1.1.1 Laser-Stereolithography (LS)	37

2.1.1.2	Polymer Printing and Polymer Jetting	39
2.1.1.3	Digital Light Processing	41
2.1.1.4	Micro Stereolithography	42
2.1.2	Sintering and Melting	43
2.1.2.1	Laser Sintering/Selective Laser Sintering (LS/SLS)	43
2.1.2.2	Powderbed Fusion (PBF), Selective Laser Melting (SLM)	47
2.1.2.3	Electron Beam Melting	48
2.1.3	Extrusion/Fused Layer Modeling	49
2.1.4	Powder-Binder Process	53
2.1.4.1	3D Printer – 3D Systems/Z Corporation	53
2.1.4.2	Metal and Sand Printer – ExOne	55
2.1.4.3	3D Printing System – Voxeljet	57
2.1.5	Layer Laminate Manufacturing (LLM)	58
2.1.5.1	Laminated Object Manufacturing (LOM)	58
2.1.5.2	Selective Deposition Lamination (SDL)	60
2.1.5.3	LLM Machines for Metal Parts	61
2.1.6	Hybrid Processes	61
2.1.6.1	Controlled Metal Buildup (CMB)	62
2.1.6.2	Direct Metal Deposition (DMD)	62
2.1.6.3	Extruding and Milling – Big Area Additive Manufacturing (BAAM)	63
2.1.7	Further Processes	65
2.1.7.1	Aerosol Printing	65
2.1.7.2	Bioplotter	66
2.2	Indirect Processes/Follow-Up Processes	66
2.3	Conclusions	68
2.4	Questions	68
3	The Additive Manufacturing Process Chain and Machines for Additive Manufacturing	71
3.1	Data Processing and Process Chains	71
3.1.1	AM Process Chain	71
3.1.1.1	Process Chain: Rapid Prototyping	73
3.1.1.2	Process Chain: Rapid Manufacturing	75
3.1.2	Data Structure, Errors, and Repair	76
3.2	Machines for Additive Manufacturing	80
3.2.1	Personal Printers	81
3.2.1.1	Fabber and Do-It-Yourself Printers (DIY)	81
3.2.1.2	Desktop Printers	84
3.2.2	Professional Printers	87

3.2.3	Production Printers	88
3.2.4	Industrial Printers	91
3.3	Conclusions and Outlook	97
3.4	Questions	97
4	Applications of Additive Manufacturing	101
4.1	Automotive Industry and Sub-Suppliers	102
4.1.1	Automobile – Interior Components	102
4.1.2	Automobile – Exterior Components	105
4.2	Aerospace Industry	107
4.3	Consumer Goods	109
4.4	Toy Industry	114
4.5	Art and History of Art	116
4.6	Mold and Die Making (Rapid Tooling)	119
4.7	Medical Engineering	121
4.8	Architecture and Landscaping	126
4.9	Miscellaneous Applications	131
4.9.1	Mathematical Functions	131
4.9.2	3D Decoration Objects and Ornaments	131
4.9.3	Aerodynamic and Freeform Objects	132
4.10	Conclusions	133
4.11	Questions	134
5	Perspectives and Strategies of Additive Manufacturing	137
5.1	Potential of Additive Manufacturing	137
5.1.1	Complex Geometries	139
5.1.2	Integrated Geometry	141
5.1.3	Integrated Functions	143
5.1.4	Multi-Material Parts and Graded Materials	149
5.2	Strategies of Additive Manufacturing Processes	152
5.2.1	Customized Mass Production	153
5.2.1.1	One-of-a-Kind and Small Batch Production	153
5.2.1.2	Individualization	154
5.2.1.3	Personalization	157
5.2.2	Personal Production	160
5.2.3	Distributed Individualized Production	162
5.3	Conclusions	163
5.4	Questions	164

6	Materials and Design	167
6.1	Materials	167
6.1.1	Anisotropic Properties	169
6.1.2	Isotropic Basic Materials	171
6.1.2.1	Plastics	173
6.1.2.2	Metals	176
6.1.2.3	Ceramic Materials	178
6.1.2.4	Composite Materials	179
6.1.2.5	Further Materials	180
6.1.3	Graded Materials and Composite Materials	181
6.2	Construction – Engineering Design	182
6.2.1	Tolerances – From the Digital Design to the Part	183
6.2.2	Design Freedom	183
6.2.3	Relative Fit	184
6.2.4	Flexures, Hinges, and Snap-Fits	184
6.2.5	Orientation and Positioning of Parts in the Build Space	185
6.2.6	Bores (Holes), Gaps, Pins, and Walls	186
6.3	Selection Criteria and Process Organization	189
6.4	Conclusions and Outlook	190
6.5	Questions	191
7	Glossary	195
	Index	203