Contents

Preface ---- VII

1	Introduction —— 1
1.1	A disruptive technology, additive manufacturing — 1
1.2	Advantages of AM over traditional manufacturing —— 2
1.2.1	Greater design ability —— 3
1.2.2	No tooling —— 3
1.2.3	On-demand manufacturing —— 4
1.2.4	Rapid <i>prototyping</i> —— 4
1.2.5	Customization —— 4
1.2.6	Minimal material waste —— 4
1.2.7	Low cost for small number of parts —— 4
1.3	Classification of AM technologies —— 5
1.3.1	Vat polymerization —— 5
1.3.1.1	Stereolithography — 7
1.3.1.2	Digital light processing — 7
1.3.1.3	Continuous liquid interface production — 7
1.3.1.4	Volumetric Vat manufacturing —— 8
1.3.2	Material jetting —— 9
1.3.3	Binder jetting —— 10
1.3.4	Material extrusion —— 11
1.3.4.1	Fused filament fabrication —— 11
1.3.4.2	Paste extrusion —— 12
1.3.5	Powder bed fusion —— 14
1.3.6	Directed energy deposition —— 15
1.3.7	Sheet lamination —— 16
1.4	Timeline/history of AM —— 19
2	Additive manufacturing of polymers —— 22
2.1	Classification of polymers —— 22
2.1.1	Thermoplastics —— 23
2.1.2	Thermosets —— 23
2.1.3	Elastomers —— 23
2.2	Selection of polymers for AM —— 24
2.3	AM of thermoplastic polymers —— 25
2.4	AM of thermosets —— 27
2.4.1	AM of photosensitive thermosets —— 27
2.4.2	AM of heat-sensitive thermosets —— 29
2.5	AM of elastomers —— 29



3	Additive manufacturing of polymer composites —— 31
3.1	Additive manufacturing of powder-doped polymer
	composites —— 31
3.2	Additive manufacturing of short fiber-doped composites — 34
3.2.1	Short fiber reinforced thermoplastic composites — 35
3.2.2	Short fiber reinforced thermoset composites —— 35
3.3	Prediction of mechanical properties of short fiber reinforced composites —— 38
3.4	Alignment of short fibers within additively manufactured composites —— 40
3.5	Additive manufacturing of continuous fiber reinforced composites —— 41
3.6	Mechanical performance comparison of additively manufactured polymer composites —— 45
4	Additive manufacturing of metals —— 47
4.1	Feedstock material fabrication for powder bed fusion —— 48
4.2	Feedstock materials used in metal AM —— 51
4.2.1	Titanium and titanium alloys —— 53
4.2.2	Aluminum alloys —— 53
4.2.3	Other metals —— 54
4.3	Design considerations in metal AM —— 54
4.3.1	Void formation —— 54
4.3.2	Residual thermal stresses —— 55
4.3.3	Surface roughness —— 55
4.3.4	Postprocessing —— 55
4.3.4.1	Stress relief — 56
4.3.4.2	Heat treatment —— 56
4.3.4.3	Hot isostatic pressing —— 56
4.3.4.4	Machining and surface treatments —— 56
4.4	Mechanical properties of additively manufactured metals —— 57
5	Additive manufacturing of ceramics —— 61
5.1	Powder-based ceramic additive manufacturing —— 62
5.1.1	Binder jetting of ceramics —— 63
5.1.2	Powder bed fusion of ceramics — 64
5.2	Slurry-based ceramic additive manufacturing —— 66
5.2.1	Vat polymerization of ceramics —— 66
5.2.2	Direct writing of ceramics —— 67
5.3	Bulk solid-based technologies —— 69
5.3.1	Sheet lamination —— 70

5.3.2	Fused filament fabrication —— 71
5.4	Additive manufacturing of polymer-derived ceramics — 73
5.5	Mechanical properties of AM ceramics —— 74
6	Bioprinting — 78
6.1	Bioprinting methods —— 78
6.2	Bioink types used in bioprinting —— 81
6.3	Bioprinting applications — 82
6.3.1	Bioprinting of blood vessels —— 84
6.3.2	Skin bioprinting — 85
6.3.3	Cartilage printing —— 85
6.3.4	Cardiac tissue bioprinting — 87
6.3.5	Kidney tissue bioprinting —— 88
6.4	Challenges and limitations of bioprinting functional organs — 88
6.5	Bioprinting in cancer research —— 89
7	Topology optimization —— 92
7.1	Topology optimization for additive manufacturing —— 93
7.2	Topology optimization methods —— 96
7.3	Solution of topology optimization problem using ANSYS finite
	element software —— 99
8	Advanced concepts in additive manufacturing —— 101
8.1	Hybrid additive manufacturing —— 101
8.1.1	Additive/subtractive hybrid manufacturing —— 101
8.1.2	Additive/additive hybrid manufacturing —— 102
8.1.3	Hybrid additive manufacturing/scaffolding technologies —— 104
8.2	Additive manufacturing of thermoelectric materials —— 106
8.3	Four-dimensional printing with smart materials —— 113
8.3.1	Four-dimensional printing materials —— 114
8.3.1.1	Four-dimensional-printed hydrogels —— 114
8.3.1.2	Shape-memory polymers —— 115
8.3.1.3	Elastomer actuators —— 117
8.3.2	Applications of 4D-printed structures —— 117
Referer	nces 121

Index ---- 135