

Index

a

absorptivity/backscattering coefficient
117

additive manufacturing (AM) 1

- alloy design methodology 125–139
- alloy development 96–97
- available alloys 97–99
- double cantilever beam 232–235
- extraction of ISs for L-PBF process
225–229
- governing equations, MIS-based
sequential analysis 229–232
- melting and cooling processes and
associated defects 110–125
- metal-based additive manufacturing
94–96
- MIS method 220–225
- simulation-driven design for L-PBF
process 235–260

adipose-derived stem cells (ASCs) 56

Aerosint SA company 190

alginate microspheres 49–50

alloy design methodology, AM

- balling defects 127–128
- creep resistant Ni-based superalloy
135–136
- evaporation 126–127
- high strength Co-based superalloy
136–139
- keyhole formation 125–127
- modifications to solidification
behaviour 131–133
- solid-state defects 129–130
- solidification cracking models
128–129

- Ti-based alloys for medical applications
133–135

AlSi10Mg 108–109, 111, 123, 132, 174,
182

American Society for Testing and
Materials (ASTM) 3, 93, 98, 156,
236

Anisimov's model 288, 294, 295, 297

ANSYS Mechanical Enterprise 232

b

balling defects 115, 127–128, 134

balling phenomenon 115, 301–304

bifurcated alginate/cellular constructs
62–64

bifurcated construct printing 62, 63

bilayer SMPs 13–14

binder jetting 3, 94, 159, 261, 339

bioprinting technologies 44–46

body centred tetragonal (BCT) crystal
100

buoyant support fluids 65, 66

c

Calculation of Phase Diagrams
(CALPHAD) 131, 135, 136, 165,
194

Carbopol-enabled two-step gelation
approach 68

Carbopol microgels 68, 69, 71

Cauchy stress 358

cell-embedded or “bottom-up” 3D
printing-based tissue engineering
approach 43

cell-laden bioinks 43–86

- cell-laden droplet formation 53
- cell-laden microspheres 50, 53
- CNTs/PA12 composite 367, 368
- coaxial feeding 160, 161
- coefficient of restitution 272, 343
- coefficient of thermal expansion (CTE) 124, 225, 355, 359, 361
- cohesion effect 275, 278, 282, 284
- composite powder particles 340, 341, 343–348, 351, 352, 373
- compositional changes 98, 105, 115
- Computational Fluid Dynamics (CFD) 181, 270, 285, 299, 310, 311, 313–316, 322, 334
- computed axial lithography (CAL) 76, 77
- computer-aided design (CAD) software 2, 74, 85, 159, 245, 267
- continuous coaxial powder feeding 162–163
- continuous inkjet (CIJ) bioprinting 46
- continuous liquid interface production (CLIP) 5, 75–77
- continuous pre-curing digital light processing (DLP) printing
 - introduction 74–77
 - photocurable materials 77–78
 - pre-curing digital light processing (DLP) printing 81–82
- core-skin printing mode 225, 226
- counter-rotating roller-type recoating system 339
- crack-free Zr-modified Al7075 131
- crack susceptibility parameter 130
- creep resistant Ni-based superalloy 135–136

- d**
- damping coefficients 271, 342–343
- denudation 114, 269, 323, 326–329, 331, 333
- Derjaguin–Muller–Toporov (DMT) model 343
- Design A 242, 244
- Design B 242, 244
- DFLUX subroutine 360
- differential scanning calorimetry (DSC)
 - analysis 357, 367
- digital materials 5, 12, 15, 25

- direct(ed) energy deposition (DED)
 - process 3, 93–95, 156–158, 188, 225, 260–261, 267
- direct-ink-writing (DIW) 3–6, 9–10, 17–23, 25
- direct joining method
 - Al–Al bimetal 174–175
 - Al–Cu bimetal 174
 - Fe–Cu bimetal 173–174
 - Fe–Fe bimetal 175
 - Ti–Ti bimetal 174
- Direct Metal Laser Sintering (DMLS) 93, 222, 225, 237–238, 249–252
- discrete coaxial powder feeding 163
- discrete element method (DEM)
 - 181–182, 269–271, 273–274, 284, 299, 309, 323, 326, 327, 340–341, 344, 346, 373
- discrete element modeling of the powder recoating process
 - coefficient of restitution 343
 - composite powder particles 345–346
 - contact force model 342
 - damping coefficients 343
 - Derjaguin–Muller–Toporov (DMT) model 343
 - Johnson–Kendall–Roberts (JKR) model 343
 - Mohr–Coulomb failure criterion 342
 - non-linear Hertz–Mindlin theory 342
 - polymer powder particles 343–345
 - powder flowability 346–347
 - recoating quality of powder bed 347–353
- DMLS process parameters 225
- double cantilever beam 223–224, 232–235, 247–250
- double-ellipsoidal heat source model 226
- drop-on-demand (DOD)-based inkjet printing
 - bioink preparation and experimental setup 47–48
 - cell distribution within microspheres 50–54
 - free-standing microvessels 47
 - representative droplet formation
 - observations 49
 - schematic diagram 47

- ductile-to-brittle transition (DBT)
 temperature 113
- ductility dip cracking (DDC) 113
- dynamic wall effects 276–277, 282
- e**
- effective laser energy 367
- elastic strain 220–222, 228, 231, 322,
 358, 361, 370
- elastic stress tensor 231
- electron beam PBF (EB-PBF) 94–96,
 102, 103, 111, 115, 138, 139, 267,
 269, 301, 302, 323
- endothelial colony-forming cells (ECFCs)
 56
- energy absorbing layer (EAL)-assisted
 laser printing 55
- energy consumption efficiency 367–369
- enthalpy of melting 117–119
- EOS M290 DMLS system 238, 252
- evaporation model 285, 288–291, 294,
 309
- extended finite element method (XFEM)
 26
- extracellular matrix (ECM) 43, 44, 67, 85
- extreme high-speed laser material
 deposition (EHLA) technology
 161
- f**
- fiber loading effect 352
- fiber-reinforced polymer composite
 powder particles 340
- fibroblast-laden gelatin-alginate
 microvascular network 74
- finite element analysis (FEA) 225, 227,
 230–232, 239, 247
- finite element method (FEM) approach
 270, 285, 310–311, 313–316, 322,
 373
- finite element modeling of SLS process
 finite element simulation
 360–361
- flowchart 353, 355
- heat source models 356–357
- process parameter optimization
 366–369
- recrystallization phenomenon
 359–360
- recrystallization, strain, and stress
 results 369–373
- temperature distribution 363–366
- thermo-elastic-viscoplastic constitutive
 model 358–359
- thermo-elasto-viscoplastic model
 361–363
- transient heat transfer model 357
- 4D printing
 definition 1
- flowchart 1–2
- modeling guided design 24–26
- primary materials 2
- shape memory polymers (SMPs) 2
- shape programmable materials 7–24
- shape-shifting performance 3
- Fraunhofer Institute for Laser Technology
 (ILT) 161, 169
- freeform drop-on-demand laser printing
 61–62
- functionally graded materials (FGMs)
 159, 170, 184
- fused filament fabrication (FFF) 3–6, 8,
 10, 11, 13, 14, 179, 180
- fusion-based additive manufacturing
 (AM) 139, 155
- g**
- gas pores 114–125
- gelatin-based cellular construct
 fabrication 72–74
- GelMA bioink 77, 84
- GelMA/PEGDA bioink 77
- genetic algorithms (GA) 24
- global-local analysis 239, 242
- governing equations for MIS-based
 sequential analysis 229–232
- h**
- Hastelloy X 98, 104–106
- hatching distance 305–306, 309
- heat-affected zone (HAZ) 113, 173, 181,
 187–188, 221, 223, 224, 226, 286
- heat capacity 112, 117–119, 125, 286, 357
- heat source models 286, 356
- of electron beam 287–288
- of laser beam 286–287
- Hertz–Mindlin contact model 271
- high strength Co-based superalloy 136

- hiHep cell-laden GelMA/dECM bioink 77
 - hot isostatic pressing (HIP) 99, 106, 138
 - human umbilical vein endothelial cells (HUVECs) 56, 57
 - human umbilical vein smooth muscle cells (HUVSMCs) 56, 57
 - hybrid blocks 236, 238, 241
 - hydrogels 2, 7, 16–19, 22, 23, 26, 43–44, 46–48, 55, 65–66, 72, 74, 84–85
- i**
- Inconel 718 106–107, 164–166, 225–226, 229, 237
 - inherent strain (IS) method 219–261
 - inkjet 3D printing 4
 - inkjet print micro-fluidic chips 46–47
 - intermediate state 222, 228
 - International Organization for Standardization (ISO) 3, 93, 98
 - interpolation algorithms 239
- j**
- Jacobs working curve 77–81
 - jetting angle 331, 332
 - J*-integral 235–243, 261
 - Johnson-Kendall-Roberts (JKR) model 272, 343
- k**
- Kear-Wilsdorf lock 103
 - keyhole formation 112, 115, 125–126, 295, 296
 - keyhole porosity 108, 115
- l**
- lack-of-fusion porosity 114
 - Laponite 71
 - nanoclay yield-stress colloid 71
 - nanosilicates 72
 - Laser Cusing, Direct Metal Printing (DMP) 93
 - laser heat source model 356, 360
 - laser powder bed fusion (LPBF) 93, 94, 98, 169, 172, 174, 177–178, 180–183, 187, 189, 220, 222–223, 225–232, 235–260, 267, 326
 - laser printing
 - freeform drop-on-demand laser printing 61–64
 - introduction 54–56
 - living cells effects 56–61
 - laser scanning path design
 - compliance minimization 253–255
 - concurrent optimization for scanning path and structural shape 257–260
 - description of 253
 - stress minimization 255–257
 - laser scanning strategy 225–226, 261
 - Laser-Engineered Net Shaping (LENS™) 93, 223
 - L-DED of Ti-ceramic material system 167–168
 - liquation cracks 112, 113
 - liquid crystal elastomers (LCEs)
 - multi-materials 21
 - single-material 20
 - liquid-state sintering 323, 324
 - longitudinal 226–227
- m**
- Mach number 291
 - magnetic shape memory polymer (M-SMP) 23, 24
 - magnetoactive soft materials
 - Marangoni effect 120, 295, 305–307, 316, 323
 - multi-material 23–24
 - single material 22–23
 - material extrusion 3, 20, 44, 71, 94
 - material jetting 3, 44, 94
 - MATLAB toolbox 25
 - melting and cooling processes, AM
 - absorptivity/backscattering coefficient 117
 - balling phenomena 115
 - boiling temperature & volatility 122–123
 - compositional changes 115
 - enthalpy of melting 117–119
 - gas pores 114–115
 - heat capacity 117–119
 - keyhole porosity 115
 - lack-of-fusion porosity 114
 - liquation cracks 113
 - process 110
 - residual stress 113
 - solid-state cracks 113–114
 - solidification cracks 112

surface tension 120–121
 thermal conductivity 119–120
 thermal expansion and contraction 123–125
 melt pool dynamics 120, 268
 melt-pool formation in LPBF 110–112
 metal additive manufacturing (AM)
 background 267–269
 modeling of 323–333
 powder melting 284–309
 powder spreading 269–271
 thermal stress 309–323
 metal-based additive manufacturing 94–96
 method of moving asymptotes (MMA) 247
 microcracks 175, 319, 367
 MicroFab Jet Driver 48
 MicroFab nozzle dispenser 48
 micro-reactive inkjet printing (MRIJP) 47, 48
 micro-voids 367
 micro-welding phenomenon 229
 modified inherent strain (MIS) method 219
 based sequential analysis 229–232, 234
 based simulation 220, 233–242, 253
 IS method, remarks 222–225
 theory for modification 220–222
 Mohr-Coulomb failure criterion 342
 molten track profile 295
 multi-jet fusion (MJF) 339–340
 multi-material AM (MMAM) 156
 components design 158–159
 in multi-material L-DED and L-PBF 190, 193, 194
 in multi-material WAAM 194–196
 potential applications of 188–190
 multi-material AM technologies 187–188
 multi-material L-DED
 advantage 161
 material feeding mechanism
 continuous coaxial powder feeding 162–163
 discrete coaxial powder feeding 163
 simultaneous wire and powder feeding 163

materials and characteristics in
 L-DED of Fe–Cu bimetal 167
 L-DED of Ni–Cu bimetal 164–165
 L-DED of Ni–SS bimetal 165–166
 L-DED of Ti–Al bimetal 166
 L-DED of Ti–ceramic material system 167–168
 L-DED of Ti–Ni FGM and Ti–SS FGM with diffusion barrier layers 166–167
 multi-material L-PBF
 hybrid metal/ceramic materials 177–178
 hybrid metal/polymer materials 178–181
 material deposition mechanism in
 hybrid methods for discrete powder deposition 171–172
 spatial material composition variation 170–171
 unidirectional material composition variation 170
 metallic materials
 direct joining method 173–175
 gradient path method 175–176
 intermediate section method 176–177
 modelling and simulation of 181–183
 schematic diagram of 169
 multi-material 3D printing 2, 5–6
 multi-material WAAM
 computer numerical control (CNC) system 183
 material feeding mechanism of 184
 materials and characteristics in
 Cu-involved multi-metals 187
 Fe–Al bimetals 186
 Fe–Ni bimetals 186–187
 SS–Fe/SS bimetals 185
 SS–Ni bimetals 185
 Ti–Al bimetals 185
 multiphase flow model 326–327

n

nanoclay suspension 66, 71–74
 nanofibrillated cellulose (NFC) composite inks 18
 nanosilicates 71, 72
 NIH 3T3 mouse fibroblast-laden bioink 47, 56, 69

- NMVCM cell-laden GelMA bioink 77
 non-ideal jetting behaviors 59, 61
 nonlinear curve fitting method 368
 non-linear Hertz-Mindlin theory 341, 342
 normalized mass flow rate NMFR 278
- o**
- organ building blocks (OBBs)/ECM bath 67
 overhang construct fabrication 62
- p**
- PA12 powder particles 343–346, 352, 353
 particle shape effect 352–353
 percolation effect 275, 278, 280, 282, 284
 phase-field Model 323–324
 photocurable materials 77–81
 piezoactuator-attached inkjet dispenser 46
 piezoactuator-based inkjet process 49
 Poisson effect 228, 229
 Poisson's ratio 247, 272, 340
 polyacrylic acid (PAA) 17
 poly aryl ether ketone (PAEK) powder 356, 364, 365
 poly-ether ether ketone (PEEK) 180, 343–345, 348
 PolyJet technology 5
 polymer powder-based additive
 manufacturing
 discrete element modeling of the powder recoating process 341–353
 finite element modeling of the SLS process 353–373
 polymer powder particles 340, 343–345, 348, 357, 373
 powder bed fusion (PBF) process 94–97, 102, 106, 108, 114–117, 119, 126, 135, 136, 139, 156–158, 171, 188, 267–270, 277, 286, 288, 299, 301, 302, 309, 320, 322, 331
 powder flowability 341, 345–347, 352
 powder layer thickness effect 282, 304, 307, 340, 341, 348–350, 356, 373
 powder melting
 coupling with powder spreading model 295, 299
 evaporation and recoil pressure 288–292
 governing equations 285–286
 heat source models 286–288
 model verification and validation 292–295
 porosity reduction and optimization 308–309
 powder recoating 339–341, 349, 373
 powder sintering in EB-PBF 323–326
 powder spattering and denudation phenomena 326
 powder spreading 269
 governing equations 271–273
 guidance for design and optimization 282–284
 model validation 273–275
 spreading and deposition mechanisms 275–282
 pre-curing digital light processing (DLP) printing 81–86
 printed active composites (PACs) 1, 11, 12
 “printing-then-gelation” approach 69, 70
 extrusion 3D printing method 68
 printing-then-solidification 65
 extrusion of alginate and cellular structures 68–71
 of liquid materials in nanoclay suspension 71–74
- r**
- rake-type powder spreading 275–279
 rake-type spreader model 273
 Rayleigh critical time-step criterion 273
 realistic heat inputs 292–293
 recoating quality of powder bed 339, 347–353
 recoating velocity effect 349–352
 recoil pressure 110, 122, 285, 286, 288–292, 294, 295
 recrystallization phenomenon 355, 356, 359
 region of interest (ROI) 239, 242, 282
 residual stress 113
 estimation 247–251
 level of 113–114
 resultant powder layer model 299
 reversibly self-healing hydrogels 65, 66
 roller powder dynamics 279
 roller-type powder spreading 279–282

S

- Saint-Venant's principle 239
- scaffold-based or "top-down" approach 43
- Scalmalloy® 98, 131
- Scheil solidification analysis 131
- selective laser melting (SLM) technology 93, 169, 267, 300, 317, 318
- selective laser sintering (SLS) 168, 339, 340, 343, 353–373
- selective powder deposition 170–171
- "shape memory effect" (SME) 4, 7–10, 12, 24
- shape memory polymers (SMPs) 1, 2, 7–16, 24, 26
- shape memory polymers and composites
 - multi-material 14–16
 - nanocomposites 10–11
 - printed active fiber-reinforced composites 11–13
 - single 8–10
- shape programmable materials for 4D printing
 - hydrogels and composites
 - multi-material hydrogels 18–19
 - single-material hydrogels and composites 17–18
 - liquid crystal elastomers (LCEs) 19–20
 - magnetoactive soft materials (MSM) 21–24
 - shape memory polymers and composites
 - bilayer SMPs 13–14
 - multi-material 14–16
 - nanocomposites 10–11
 - printed active fiber-reinforced composites 11–13
 - single SMP 8–10
- shrinkage-feeding model 128
- simulation-driven design for L-PBF
 - process
 - crack prevention
 - bearing bracket 242, 243
 - critical J-integral for solid/support interface 236–237
 - fracture sample with curved interface 241
 - fracture sample with flat interface 240
 - J-integral at solid/support interface 237–239
 - workflow description 235–236
 - laser scanning path design 253–260
 - support structure design based on
 - topology optimization
 - double cantilever beams 247–251
 - hip implants 251–252
 - residual stress estimation 247–251
 - topology optimization of the support structure 245–247
 - workflow description 245
- single-material LCE 20–21
- single-material 3D printing techniques 3–5
- single SMP 8–10
- sodium alginate concentration 47, 50–53
- solid-state cracks 98, 113, 135–137
- solid-state defects 129–131
- solid-state sintering 323–326, 331
- solidification cracking models 128–129
- solidification cracks 105, 106, 112, 128, 132, 135, 137, 196
- solution-dependent variables (SDVs) in UMAT 362, 363
- spatter 323, 326–328, 331
- stable silk fibroin-based construct 47
- Standard Tessellation Language (STL) 74, 245, 299, 344, 345
- static wall-effect 277
- stiffness coefficient 271
- strain aging cracking 113
- stress-dip phenomenon 276
- super layer 231
- superalloys 97–98, 103–104, 106, 135–138, 164
- support bath-enabled 3D bioprinting
 - introduction 65–68
 - printing-then-solidification extrusion of alginate and cellular structures 68–71
 - printing-then-solidification of liquid materials in nanoclay suspension 71–74
- surface energy density 273, 343
- surface tension 55, 58, 110, 112, 115, 120–121, 127, 133–134, 286, 295, 302–303, 305, 323

t

- thermal conductivity 118–120, 129–130, 167, 173, 176, 180, 188, 190, 196, 269, 285–286, 327, 355
- thermal cracking 267, 317–320
- thermal diffusivity 101, 112, 114, 125, 127, 129, 164, 167
- thermal expansion coefficient 108, 114, 124, 129–130, 156–157, 166, 178, 188, 195–196, 310, 322
- thermal strain 113–114, 124, 128–130, 133, 223, 231, 310, 323, 356, 358–359, 361, 370
- thermal stress
 - mitigation and tailoring of 322
 - model comparison and application 314–322
 - model construction 310–313
 - simulation case 313–314
 - stress concentrations 314, 315
- thermal-fluid flow model 285, 295, 299
- thermal stress-induced dislocation 320–322
- thermo-elastic-viscoplastic constitutive model 358
- thermo-elasto-viscoplastic model 356, 361–363
- thermomechanical cycles 235
- 3D alginate and cellular tubes 61–64
- 3D bioprinting of Y-shaped tubular structure 68–71
- 3D cell printing-based tissue engineering 44
- 3D printed shape + time 1
- 3D printing techniques
 - multi-material 5–6
 - single-material 3–5
- 3D printing-based tissue engineering approach 43
- 3D standard triangle language (STL) model 74, 245, 299, 344, 345
- 316L stainless steel 107, 273, 298, 300, 320, 334
- Ti-based alloys for medical applications 133
- Ti6Al4V (Ti64) 225
- Ti–6Al–4V 99–103, 115, 119–120, 122–123, 125–126, 294, 299, 313, 323, 334
- titanium alloys 93, 99–100, 133, 166, 174, 176, 184, 299
- topology optimization (TO) 25, 242, 245–252
- transient heat transfer model 219, 310, 356, 357, 361, 363–364
- tunable pre-curing DLP bioprinted hydrogels 85
- tunable pre-curing DLP printing approach 81–82
- twinning-induced plasticity (TWIP) 108
- two-dimensional (2D) lattice Boltzmann model 340
- 2D lattice structures 24
- two-layer deposition 226–227
- two-photon polymerization (TPP) 5, 17, 22–23

u

- un-melted zones 306, 367
- unrecoverable matrix baths 65
- UV absorber 80–81

v

- van der Waals cohesive force 271
- vat photopolymerization 2–5
- vat polymerization 44–45
- vapor jet 122, 323, 326–329, 331–333
- viscoplastic strain rate 358, 362
- volume of fluid (VOF) method 182, 286
- volumetric 3D printing 27, 76–77
- von Mises stress 372

w

- wall effects 275–278, 282, 284
- welding field 223
- wire and powder deposition by laser (WPDL) 163–165

y

- yield-stress fluids 65–66
- yield-stress support bath materials 66, 71
- Young's modulus of the powder particle 272
- Y-shaped alginate tubular constructs 62
- Y-shaped tubular structure 68–71