

Contents

1. Introduction	1
2. State of the Art	5
2.1. Conventional Manufacturing Techniques	5
2.2. Additive Manufacturing Techniques	7
2.2.1. Stereolithography	9
2.2.2. Laminated Object Manufacturing	11
2.2.3. Fused Deposition Modeling	12
2.2.4. 3D-Printing	14
2.2.5. Direct Inkjet Printing	15
2.2.6. Selective Laser Sintering	16
2.2.7. Further Additive Manufacturing Techniques	19
2.3. Preliminary Conclusion	20
3. SLM for Ceramics	23
3.1. Principle	23
3.2. Process Parameters	24
3.3. Experimental Setup Stationary CO ₂ Laser Preheating	26
3.4. State of the Art in SLM of Ceramics	28
4. Applied Materials	31
4.1. Material Properties	31
4.1.1. Alumina	31
4.1.2. Zirconia	32
4.1.3. The System Al ₂ O ₃ / ZrO ₂	33

4.2. Powder Characteristics	35
4.2.1. Size Distribution and Particle Shape	35
4.2.2. Flowing Ability	39
4.3. Preliminary Conclusion	41
5. Characterization of Optical Properties	43
5.1. Fundamentals	43
5.2. Spectroscopic Analysis	49
5.2.1. Methods	49
5.2.2. Results and Discussion	50
5.3. Online Measurement	52
5.3.1. Methods	52
5.3.2. Results and Discussion	56
5.4. Preliminary Conclusion	61
6. Machinery Development for High-Temperature SLM of Ceramics	63
6.1. Motivation	63
6.2. Inductive Preheating	65
6.2.1. Concept	65
6.2.2. Heating Source	66
6.2.3. Design of the Inductive Heating Device	66
6.2.4. Implementation of Machinery Equipment	72
6.3. Selective Laser Preheating	73
6.3.1. Concept	73
6.3.2. Laser Sources	74
6.3.3. Optical Design	75
6.3.4. Implementation of Machinery Equipment	81
6.4. Preliminary Conclusion	82
7. Temperature Distribution	85
7.1. Methods	85
7.2. Results and Discussion	88
7.2.1. Inductive Preheating	88
7.2.2. Selective Laser Preheating	91
7.2.3. Stationary CO ₂ Laser Preheating	95
7.3. Preliminary Conclusion	97

8. Preheating Strategies and Resulting Property Profiles	101
8.1. Fundamentals	101
8.1.1. Mechanisms of Crack Formation	101
8.1.2. Microstructural Formation	103
8.1.3. Phase Distribution	105
8.2. Methods	106
8.3. Results and Discussion	108
8.3.1. Inductive Preheating	108
8.3.2. Selective Laser Preheating	118
8.3.3. Stationary CO ₂ Laser Preheating	126
8.4. Preliminary Conclusion	133
9. Surface Quality Analysis	135
9.1. Methods	135
9.2. Single Track Analysis	139
9.2.1. Variation of Preheating Temperature	139
9.2.2. Variation of Mean Particle Size and Layer Thickness	145
9.2.3. Variation of Focused Spot Size	146
9.3. Volumetric Part Analysis	147
9.3.1. Variation of Scan Sequence	147
9.3.2. Variation of Contour Hatch Distance	148
9.3.3. Variation of Scan Delay	150
9.3.4. Dimensional Accuracy Measurements	153
9.4. Preliminary Conclusion	155
10. Conclusion and Outlook	157
Bibliography	161
A. Applied Laser Sources	181
B. Absorptivity Measurements	183
C. Dimensioning of the Inductive Preheating	185
C.1. Fundamentals	185
C.2. Constructive Design	186
C.3. Cooling Element	187
C.3.1. Temperature Distribution Insulation	187

C.3.2. Cooling Capacity of the Cooling Element	193
C.4. Thermal Radiation of Preheated Area	195
D. Dimensioning of the Selective Laser Preheating	197
D.1. Dichroitic Mirror	197
D.2. Estimated Spot Size of the SLM Laser	198
D.3. Estimated Spot Size of the Preheating Laser	199
D.4. Estimated Laser Power for the Preheating Laser	200
D.5. Raw Beam Intensities of the Applied Laser Sources	201
E. Simulative Analyses	203
E.1. Approach and Material Constants	203
E.2. Heat source	204
E.3. Model and Element Size	205
F. Measurement of Surface Roughness	207
F.1. Fundamentals	207
F.2. Diagrams	209
F.2.1. Variation of Preheating Temperature Standard Deviations	209
F.2.2. Parameter Variation for Mean Particle Size and Layer Thickness	210
Glossary	227
Acronyms	231
Latin Symbols	235
Greek Symbols	239