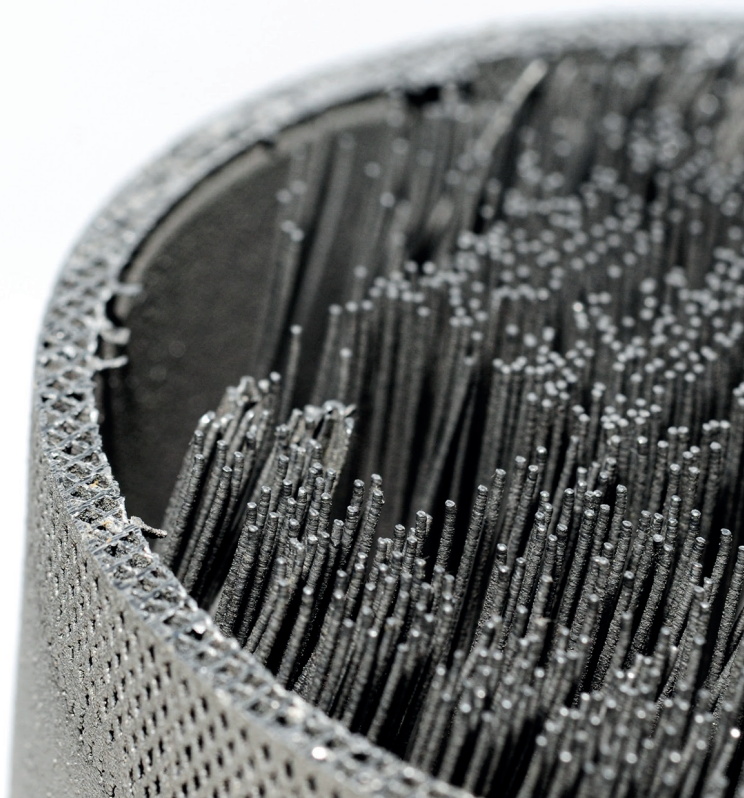


Support Structure Design in Additive Manufacturing

A parametric approach on support structure design
for the laser-based powder bed fusion of metals



Sebastian Weber



Produktentwicklung

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Preface

The dissertation at hand on the support structure design in metal additive manufacturing (AM) emerged from a research project on the re-design of spare parts for AM. Samples manufactured for this project demonstrated the need for an increased knowledge of support design to diminish build failures, leading to the topic of this dissertation. Due to the limited resources of the university regarding AM machines at this time, AM process simulations played a huge role in this study.

First of all, I would like to thank my supervisor and former head of the Institute for Technical Product Development (ITPE) *Prof. Dr.-Ing. Kristin Paetzold* for her excellent guidance throughout my time as a doctoral student and for her support on decisions made concerning my dissertation. At this point, I also want to thank my second reviewer *Prof. Dr.-Ing. Dieter Krause* for his commitment and dedication.

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Sebastian Weber
Augsburg, February 25th, 2022

Abstract

Additive manufacturing (AM) is known for the ability to create complex features, commonly referred to as *design freedom*. Especially for the laser-based powder bed fusion of metals, support structures are often still required for printability reasons or increased process reliability. Currently, there is a lack of knowledge about support structure design, leading to the risk of build failures or increased material consumption.

The primary aim of this study was the development of an approach for the design of tree-like support structures to help designers achieve the best mechanical behavior of an additively manufactured part. For this, experimental studies on the printability, geometrical accuracy and strength of thin struts were performed and an AM process simulation model was set up for four generic overhang geometries. This model was then used for parameter optimization to determine support structure design parameters, resulting in Pareto optimal support designs regarding the support volume and the part's deformation. Based on these results, recommendations were derived to further increase the understanding of support structure design. Measurements of printed samples were used to verify simulation results and the suitability of tree-like support. In addition, two case studies on the additive manufacturing of discontinued spare parts were used for an initial validation of the approach and derived recommendations.

This research was the first to consider thermal and structural loads in a parameter optimization for the design of support structures with the objective of an increased mechanical behavior of the part. The potential of the presented approach to achieve a successful print on the first attempt was shown by a case study. In addition, the optimization results showed a reduced warping of the part for an increased diameter at the upper section of the support structure. The understanding of support structure design was further enhanced by the identified effect of the diameter on the geometrical accuracy of thin struts. The presented approach forms the basis for fully automated support generation tools, which require little to no user input.

Kurzfassung

Die additive Fertigung (AM) ist dafür bekannt, die Herstellung komplexer Strukturen zu ermöglichen, was allgemein als Gestaltungsfreiheit bezeichnet wird. Dennoch sind, insbesondere beim laserbasierten Pulverbettsschmelzverfahren von Metallen, häufig Stützstrukturen erforderlich, um die Druckbarkeit zu gewährleisten oder die Prozesssicherheit zu verbessern. Derzeit existiert ein Wissensdefizit in der Gestaltung von Stützstrukturen, was zu einem erhöhten Materialverbrauch oder sogar zu Fertigungsabbrüchen führt.

Das Hauptziel dieser Studie war die Entwicklung eines Ansatzes für die Gestaltung baumartiger Stützstrukturen, um Konstrukteuren zu erleichtern, das beste mechanische Verhalten eines additiv gefertigten Teils zu ermöglichen. Zu diesem Zweck wurden experimentelle Versuche zur Druckbarkeit, geometrischen Genauigkeit und Festigkeit dünner Stäbe durchgeführt und ein Simulationsmodell des AM-Prozesses für vier generische Überhanggeometrien erstellt. Dieses Modell wurde anschließend zur Parameteroptimierung verwendet, um Parameter der Stützstruktur zu bestimmen, die zu Pareto-optimalen Ergebnissen bezüglich des Stützstrukturvolumens und der Bauteilverformung führen. Auf Basis dieser Ergebnisse wurden Empfehlungen abgeleitet, die den Wissensstand über die Auslegung von Stützstrukturen weiter verbessern. Messungen an gedruckten Proben dienten zur Verifizierung der Simulationsergebnisse und Überprüfung der Eignung von baumartigen Strukturen als Stützstrukturen. Darüber hinaus wurden zwei Fallstudien zur additiven Fertigung von nicht mehr verfügbaren Ersatzteilen für eine erste Validierung des Ansatzes und der abgeleiteten Empfehlungen verwendet.

In diesem Forschungsprojekt wurden erstmals thermische und strukturelle mechanische Lasten in einer Parameteroptimierung berücksichtigt, die der Auslegung von Stützstrukturen mit dem Ziel eines verbesserten Bauteilverhaltens dient. Das Potenzial des vorgestellten Ansatzes, im ersten Versuch einen erfolgreichen Druck zu erzielen, wurde durch eine Fallstudie bewiesen. Die Ergebnisse der Parameteroptimierung zeigten einen reduzierten Bauteilverzug bei größeren Durchmessern an der Spitze der Stützstruktur. Neue Erkenntnisse wurden auch über den Einfluss des Durchmessers von dünnen Stäben auf die geometrische Genauigkeit erlangt. Mit dem vorgestellten Ansatz wird die Grundlage für vollautomatische Tools zur Erzeugung von Stützstrukturen geschaffen, die wenig bis gar keine Benutzereingaben erfordern.

Contents

List of Figures	IX
List of Tables	XI
Symbols	XIII
Acronyms	XV
1 Introduction	1
1.1 Additive manufacturing and current trends	1
1.2 Motivation	4
1.3 Aims & structure	7
2 Theoretical background	11
2.1 Metal additive manufacturing technologies	12
2.1.1 Powder Bed Fusion	12
2.1.2 Directed Energy Deposition	13
2.1.3 Material Extrusion	14
2.1.4 Binder Jetting	15
2.2 Support structure	16
2.2.1 The role of the support structure	16
2.2.2 Support structure types	17
2.3 Fundamentals of Design for AM	19
2.3.1 DfAM for additive manufactured parts	20
2.3.2 DfAM for support structures	21
2.4 Additive manufacturing simulation	21
2.4.1 Meshing	22
2.4.2 Boundary conditions	24
2.4.3 The inherent strain method	25
2.4.4 Thermo-mechanical modeling	26
3 Current state in research: A literature study	27
3.1 Support structure design	28
3.1.1 Design approaches	29
3.1.2 Design parameters	31

3.1.3	Topology optimized support	32
3.1.4	Design for enhanced removability	34
3.2	The effect and properties of a support structure	34
3.3	Towards support-free printing	36
3.4	Determination of research needs	37
4	Methodology and methods	39
4.1	Research methodology	39
4.1.1	DRM: Design Research Methodology	40
4.1.2	Delimitation against other methodologies	42
4.2	Methods and tools	43
4.2.1	Literature study	43
4.2.2	Axiomatic design	43
4.2.3	Modeling & simulation	44
4.2.4	Case studies	44
5	Parametric support structure design approach	45
5.1	General strategy	46
5.2	Delimitation	48
5.2.1	Material selection	48
5.2.2	Machine selection	49
5.2.3	Support structure type selection	49
5.3	Parameter determination	50
5.3.1	Decomposing support structure design	51
5.3.2	Derivation of geometric design parameters	52
5.3.3	Constraints on parameters	54
5.3.4	Parameter significance	55
5.4	Tool for creating parametric support structure	56
5.4.1	User-defined parameters	57
5.4.2	Overhang detection and seed planting	58
5.4.3	Support branch creation	59
5.5	Parameter boundaries and support properties	61
5.5.1	Geometric accuracy of thin struts	61
5.5.2	Tensile properties of thin struts	63
5.6	AM simulation & optimization	66
5.6.1	Geometry of interest	66
5.6.2	AM simulation model	68
5.6.3	Meta-model creation	70
5.6.4	Parameter optimization	72
5.7	Derivation of recommendations	76
6	Model and result verification	81
6.1	Simulation and design verification	81
6.1.1	Strain scaling factor verification	82
6.1.2	Tree-like support design verification	83

6.2	Tree-like support applied to AM spare parts	85
6.2.1	Case study I: Re-design of a piston	85
6.2.2	Case study II: Re-design of an exhaust manifold	90
7	Discussion	93
7.1	Result interpretation	94
7.2	Implications of the approach	96
7.3	Limitations of the approach	98
7.4	Future research needs	99
8	Conclusion	101
	Bibliography	105
	Appendix	117
A	Parameter matrix references	119
	Author's Publications	121