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OPTIMIZATION OF SUPPORT STRUCTURES FOR LASER POWDER BED FUSION OF STAINLESS STEEL

RUOSTUMATTOMAN TERÄKSEN JAUHEPETISULATUKSEN TUKIRAKENTEIDEN PARAMETRIEN OPTIMOINTI

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TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto
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Ruostumattoman teräksen jauhepetisulatuksen tukirakenteiden parametrien optimointi

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Tämän kandidaatintyön tavoitteena oli selkeyttää teräksen jauhepetisulatuksessa (L-PBF) käytettävien tukirakenteiden nykytilanne kirjallisuuskatsauksen avulla. Tukirakenteet ja niiden parametrit tulisi optimoida tähdäten tuotteen parempaan laatuun minimoimalla samaan aikaan lopuksi poistettavien tukirakenteiden käyttöä.

Lähtökohtana on minimoida sekä tukirakenteiden että tulostettavan kappaleen sisäisiä lämpökuormia ja niistä aiheutuvia taipumia, vääristymiä ja muita virheitä, joita esiintyy usein varsinkin ohuissa ja kaltevissa rakenteissa. Vaakasuorien muotojen tulostuksen optimoinnin ohella on hyödyllistä soveltaa tasaisille pinnoille helpommin löydettäviä tukirakenteiden arvoja myös kalteville sekä pyöreille pinnoille.

Lämpökuormiin liittyvät ongelmat, kuten taipuminen ja etenkin haastavampien kulmien tulostaminen, joka helposti johtaa tulostuksen keskeytymiseen, voitaisiin kenties ratkaista laskemalla tulostusnopeutta tulostusalueen erityisvaatimusten mukaisesti.

Ohuemman metallikerroksen tulostaminen kriittiselle alueelle voisi myös toimia ratkaisuna suuriin lämpökuormituksiin. Helposti irrotettavien tukien käyttäminen tällaisille alueille on tärkeää, johtuen ohuiden rakenteiden mekaanisesta haavoittuvuudesta. Tukien kehittämiseksi tulee tutkia ja optimoida tukirakenteiden kokoa, pituutta sekä muotoa eri tilanteissa.

ABSTRACT

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Optimization of support structures for powder bed fusion of stainless steel

Bachelor's thesis

2019

38 pages, 18 figures and 2 tables

Examiner: D.Sc. (Tech) Heidi Piili

Advisor: D.Sc. (Tech) Heidi Piili

Keywords: Additive manufacturing, 3D printing, laser powder bed fusion, support structure, optimization, stainless steel, 316L

The aim of this Bachelor thesis was to clarify the usage of support structures in laser powder bed fusion (L-PBF) based on a literature survey. Support structures and their parameters should be optimized with the aim for better product quality while minimizing the use of otherwise unnecessary supports in general. The starting point is to minimize excessive thermal loads, bending and distortion of both the support structure and the printed object, as well as other errors which often occur especially with thinner and overhanging structures.

Along with the optimization of printing a flat piece, it should be useful to apply the parameters of support structures that have been well-found on flat surfaces for inclined and circular surfaces. Problems related to thermal loads such as bending, and in particular the bending of more challenging angles resulting printing interruption, could possibly be solved by lowering the printing speed according to the specific requirements of the printable area.

Printing a thinner metal layer in critical areas could also work as a solution to high thermal loads. Additionally, using easily detachable supports to such areas is possible although it

may be hard, due to the mechanically fragile nature of thin features. In order to develop and optimize supports, it is essential to investigate the size, shape and the length among other dimensions of support structures.

AKNOWLEDGEMENTS

I would like to thank Heidi Piili for active guidance with my thesis. The subject was initially new to me, and so the data research and writing of this work was a great way to learn more about metal additive manufacturing. I would also like to thank people at work for covering for me while I took some time off for writing this thesis among other school work.

Markus Särkkä
Helsinki 30.11.2019

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ABSTRACT

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LIST OF SYMBOLS AND ABBERVIATIONS

AM	Additive manufacturing
CAD	Computer aided design
FEA	Finite element analysis
L-PBF	Laser powder bed fusion
SLM	Selective laser melting
SLS	Selective laser sintering

1 INTRODUCTION

Additive manufacturing (AM), also known as 3D printing, is a relatively new manufacturing area with a lot of potential as a growing fabrication technology when compared to conventional machining methods. This is because many types of 3D printing technologies are getting more affordable and easily accessible for both consumers and industries. For materials such as metals, plastics and ceramics, additive manufacturing gives an opportunity for users to accurately create objects based on their design without having to master difficult and expensive conventional manufacturing methods and tools. AM also allows for easy customization, personalization, marking etc. as well as previously difficult or unachievable features such as hollow spaces, thin walls and complex geometries. (Gonzales-Gutierrez et. al. 2018, pp. 1-3.)

The possibilities and development potential of additive manufacturing has quickly attracted interest from both academic and industrial parties. The main hindering factor in development of metal additive manufacturing is that many new discoveries stay within the researching engineering department of companies. However, due to the fast development of AM and rapid appearing of new 3D printing technologies, comprehensive standards, guidelines and design principles have been rapidly developing in the last few years but there is still much room for further research. (Morgan, Agba and Hill 2017, p. 820.)

1.1 Goal and research problem

The goal for this thesis is to further plan the optimization of parameters in previously well-found support structure types and to adopt them into printing of inclined and round surfaces. This thesis is done as a literature survey and it includes the following research questions:

1) Which support types are best to be applied to printing stainless steel objects?
2) Why these support types are best?
3) What is effect of material to optimization of supports?
4) How can support parameters be optimized to make printing of inclined objects easier?
5) How can support parameters be optimized to minimize defects and flaws in the printed result?

This thesis will have industrial importance as support structures are the main problem of most additive manufacturing techniques. Rapidly developing printing techniques, parameters, structure models and knowledge of material behavior in different scenarios are essential to the development of L-PBF. Solutions that could solve heat related bending and shrinkage especially in metal additive manufacturing would be very beneficial. This is why support structure research has gotten so much attention as of late.

1.2 Limitations of the thesis

This study will make use of new research data springing from the rapidly developing AM and technology and L-PBF techniques. This thesis concentrates on L-PBF and the usage of stainless steel. The aim of the literary review is also to find the needed data, which can be applied to further researching L-PBF support parameters, heat related problems, distortions and general build quality.

1.3 Research methods

This research is a theoretical case study in which a specific area of a manufacturing method is brought under observation. The study is done by cross referencing recent scientific sources regarding the use of support structures in laser powder bed fusion. A qualitative analysis is done to reach a summary on how specific support structure types are best used in common L-PBF scenarios.

The databases used were LUT Finna and Scopus. Both offered good research tools for finding the newest available scientific data regarding the metal additive manufacturing methods reviewed in this thesis. Scopus was mainly used as a searching tool and LUT Finna served as both a search engine and the main source of scientific publications.

2 LITERATURE REVIEW

This literature review is a compilation of the main methods and parameters used in the additive manufacturing of metals. Laser powder bed fusion, which is the main manufacturing method in metal AM, has gotten a lot of attention in the last few years with a rapidly growing amount of scientific publications released. Figure 1 gives an overview of how much L-PBF has gained scientific interest between 2010-2019.

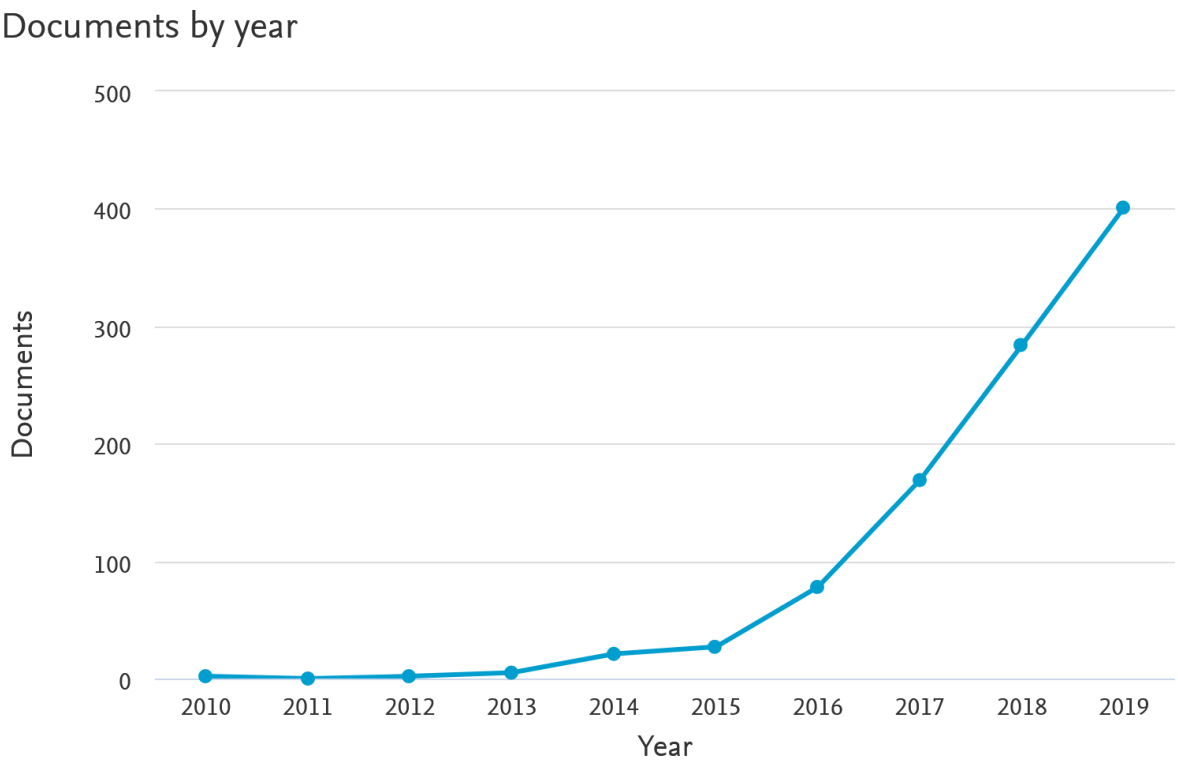

Figure 1. The annual growth of interest for laser powder bed fusion according to Scopus.

Figure 1 shows that ever since 2013, when the subject first started to get more attention, the interest for L-PBF has grown by more than 100 annual documents released every year. This growth is very significant considering that 10 years ago the technique was nearly unheard of. The annually growing publishing rate indicates that L-PBF is starting to become very relevant in the world of metal additive manufacturing.

2.1 Metal additive manufacturing

Even though additive manufacturing has developed rapidly during recent years, most of the methods used today were already invented in the 1980s. Even as the methods have existed for quite some time and are now constantly growing in popularity, there can be limitations of information available when it comes to designing and manufacturing newer objects and structures. Designing and the use of supporting structures of components form an important and often problematic area when it comes to AM and laser powder bed fusion of metals. (Morgan, Agba & Hill 2017, p. 819.

Due to their chemical composition and process parameters, metallic materials in AM go through a complex thermal process involving directional heat extraction combined with several phases of melting and solidification. Unlike in conventional manufacturing such as most machining techniques, this causes an impact on the material microstructure. High cooling rates often result in smaller grain size, porosity and less than optimal surface finish which are likely to affect fatigue properties negatively. However, after being mechanically finished, in many cases metallic components manufactured by AM can have mechanical properties as good as those made by conventional manufacturing methods. (Frazier 2014, p. 1926.)

2.2 Laser powder bed fusion

Laser powder bed fusion (L-PBF) is an AM process which uses a scanned laser beam to melt metal powder, usually based on a 3D model. After one layer is melted, the powder bed is lowered and the recoater or so-called rake/roller spreads a new even powder layer on top of the printed component. The process starts again and gradually forms the object layer by layer. Support structures are printed at the same time as the part itself for support during the process. The whole process takes place inside of a chamber. The L-BPF process can be seen in Figure 2. (Frazier 2014, p. 1918.)

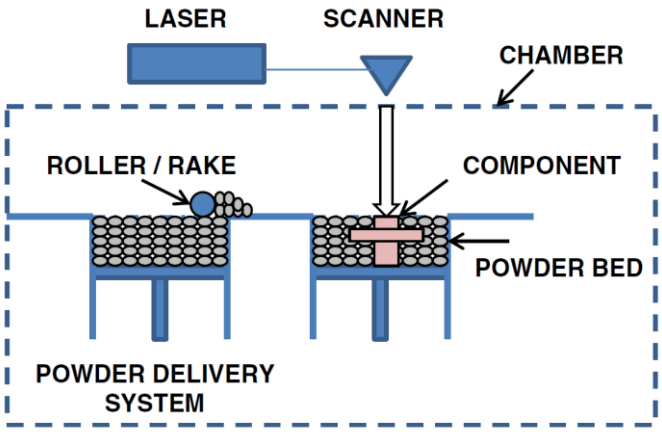

Figure 2. The basic principle of laser powder bed fusion. (Frazier 2014, p. 1919.)

Figure 2 is a generic illustration of the laser powder bed fusion process. The method allows for one or multiple laser beams to simultaneously fuse metallic powder layer by layer with relatively good accuracy. L-PBF allows for complex parts to be printed quickly without excessive lead time or wasted material. due to the accuracy of the process, L-PBF allows for printing lightweight thin structures such as lattices as well as completely solid objects. It is one of the most important processes in additive manufacturing of metals. (Wang et al. 2018, pp. 27-28.) The idea of layer-based manufacturing can be seen in Figure 3.

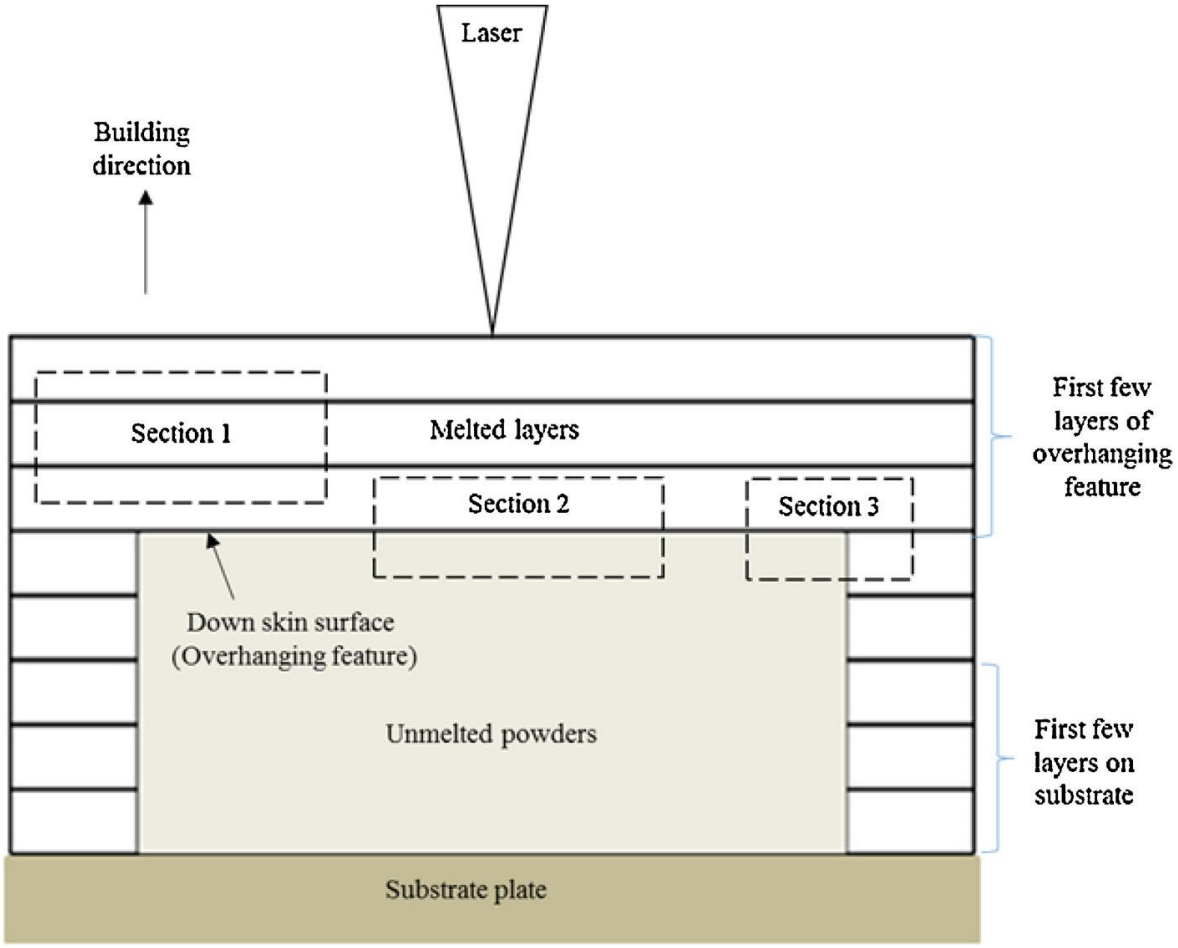

Figure 3. Layer schematic illustrating terms used in the L-PBF process. (Gan & Wong 2016, p. 476.)

The metal printing process in L-PBF means melting thin metal layers on top of each other to eventually achieve the desired shape. As it can be seen from Figure 3, a fiber laser heats the powder above the melting point of the specific material which induces a liquid phase fusion. After this phase, the substrate plate is lowered by a cylinder mechanism so that the just printed layer is lowered as well. Substrate layers are the basis of both the geometrical features of the printed parts and the disposable support structures. Section 2 represents the first layer of an overhanging portion, which needs to be supported by the vertical section seen below section 3. The non-melted powder is simply raw material temporarily left in the crevice due to it not being melted along with the first 5 layers displayed on both sides. (Gan & Wong 2016, p. 474.)

L-PBF can be used to directly print complex three-dimensional metal structures and components with the help of CAD models. The L-PBF process has proven to produce detailed lattice structures with good accuracy, suitable strength for most purposes and few defects. This means potential for lightweight structures desired by aerospace, automotive and medical engineering industries. (Zhong et al. 2019, p. 2.)

2.2.1 Stainless steel as raw material in laser powder bed fusion

The most common stainless steel grades used in L-PBF are 304, 304L and 316L. However, 316L is the only grade which has been commercialized by systems manufacturers as of 2019. (Zitelli, Folgarait, Di Schino 2019, p. 10.) Due to their chemical and microstructural features resulting in material properties in both low and high temperatures, stainless steels are widely used. For L-PBF, an optimal composition for printing can be maintained with the right kind of storage and chemical manipulation of the raw material powder. Microstructural properties, like grain size as seen in Figure 4, and phases are determined by the parameters of the L-PBF process such as the heat flow direction, grain growth, and laser scanning strategy. (Zitelli, Folgarait, Di Schino 2019, p. 9.)

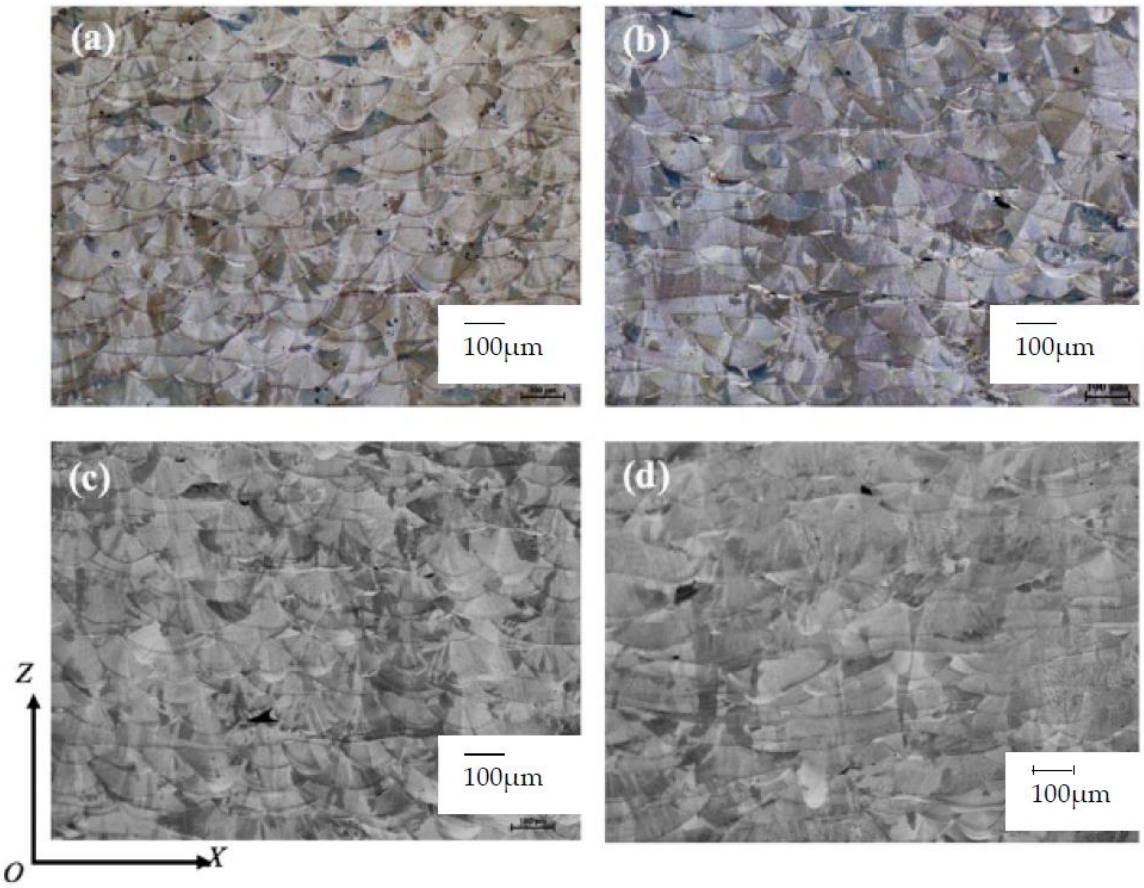

Figure 4. The microstructure of 316L fabricated at 200w laser power achieved by using different scanning strategies. (Zitelli, Folgarait, Di Schino 2019, p. 12.)

Figure 4 shows different microstructures achieved for 316L at 200w laser power using different scanning strategies. 4a is the result of the Meander strategy, 4b from Stripe strategy, 4c from a Chess strategy with 5mm x 5mm islands and 4d is the result of a Chess strategy using. 1mm x 1mm islands. As long as the laser scanning power used stays the same, the grain size is entirely dependent on the scanning strategy. (Zitelli, Folgarait, Di Schino 2019, p. 12.) The four scanning strategies used can be seen in figure 5.

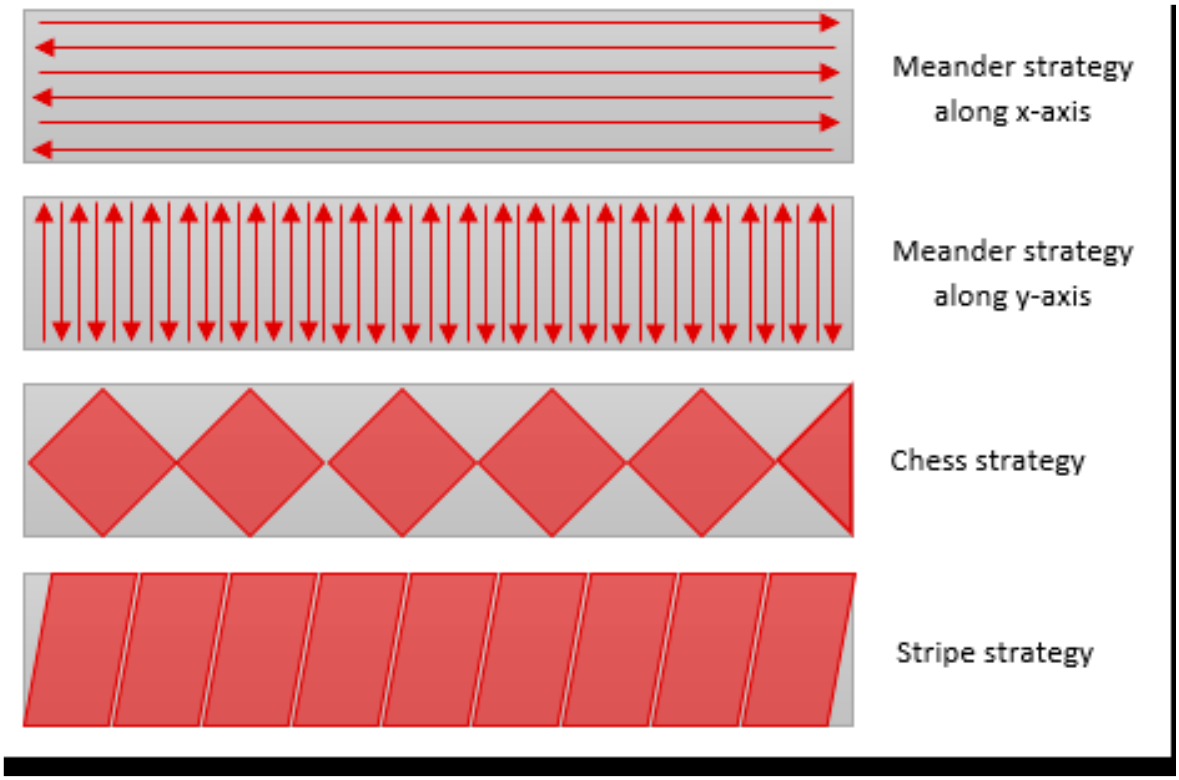

Figure 5. Examples of different laser scanning strategies. (Zitelli, Folgarait, Di Schino 2019, p. 7.)

The four scanning strategies presented in Figure 5 are a Meander strategy, in which the laser travels unidirectionally or bidirectionally along a selected axis. Chess strategies divide the scanned area into smaller sections, or islands. Stripe strategies are similar to Chess strategies except for the scanning phases being longer in shape. Using different scanning angles in sectors of the printed object help with reducing thermal gradients on the printed layer which results in reduced residual stress. (Zitelli, Folgarait, Di Schino 2019, p. 6.)

Cooling rates for stainless steels usually range between 105–106 K/s. This cooling rate results in fine solidification microstructure and is caused by the surrounding gas, the unfused powder and the already solid material underneath the molten surface. (Zitelli, Folgarait, Di Schino 2019, p. 9.) Table 1 shows the chemical composition of stainless steel grade 316L, a very popular corrosion resistant raw material.

Table 1. Chemical composition of 316L stainless steel powder (wt%). (Yu et al. 2019, p. 23)

Cr	Mo	Ni	Mn	C	Si	P	N	Fe
17.49	2.36	12.84	0.47	0.01	0.41	0.013	0.09	Bal.

Due its wide range of compatibility and usage in industrial and medical sectors, 316L is among the most researched stainless steels used for L-PBF. It has the mechanical and chemical properties (composition in table 1.) such as corrosion resistance to make it a suitable material for many applications in these sectors. (Sun et al. 2016, pp. 197-198).

2.3 Support structures in laser powder bed fusion

In metal additive manufacturing, support structures as seen in Figure 6 are essential for all L-PBF processes. When the printed part cannot be orientated to completely avoid overhangs, support structures are needed. These printed structures usually do not bring anything to the part itself and need to be removed after printing, but they are needed because they work as anchors, dissipate heat and most importantly prevent warping of part structures such as overhangs. (Gan & Wong 2016, p. 474.)

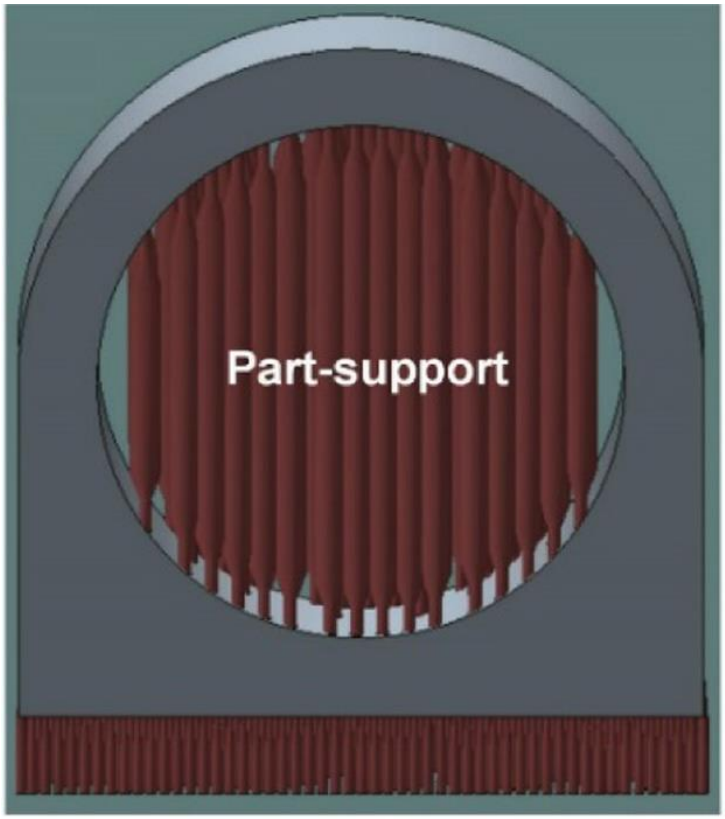

Figure 6. CAD model of basic pin supports (in red) used in printing a ring-like metal object. (Han et al. 2018, p. 1085.)

Support structures, like the red colored pin supports in Figure 6, are often required in L-PBF, especially when creating parts with thin walls and overhangs as seen above the red supports. They are a critical supportive component in the manufacturing process because the product itself can easily be distorted due to the excess heat left in the piece before cooling down. This is why especially the riskier parts such as horizonal and or thin structures must be supported to prevent bending. (Han et al. 2018, p. 1081.) Overhanging part structures that represent less than a 45-degree vertical angle as seen in Figure 7, have a high risk of deformation without the use of support structures. Angles over 45 degrees tend to have a much lesser risk for errors. **(**Hussein et al. 2013, p. 1019)

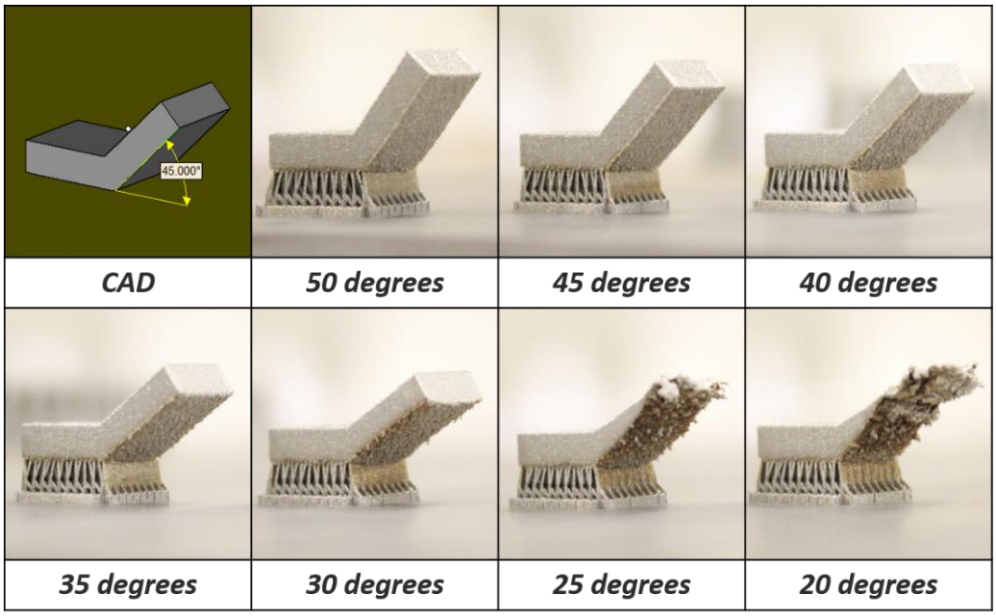

Figure 7. the effect of the angle without support structures (The Digital Thread 2018).

Figure 7 shows that below 45 degrees, overhangs can no longer support themselves and need external support. Otherwise they quickly start to distort and bend. After 40 degrees the flaws are already noticeable and going from 35 to 25 degrees the geometry is often completely unprintable. This happens because of the excessive thermal load combined with the lack of support below the printed structure. (Han et al. 2018, p. 1081.)

Although support structures are useful and necessary during the manufacturing process, they are useless afterwards and most times require burdensome mechanical removal as seen in figure 8. The problem of finding a balance between adequate supportive properties and removability remain a problem in additive manufacturing of metals. Both industry and academia are working towards optimizing these key problems related to laser powder bed fusion. (Morgan, Agba & Fill 2017, p. 820.)

Figure 8. Manual removal of metal support structures (Swiss Plastic Platform 2018.)

Figure 8 represents manual support removal which can be time consuming and difficult. Easier removal by way of lighter structures and smaller amounts of used material for these supports will both reduce material costs and shorten post-manufacturing time. Both of these problems need to be tackled by optimizing the design of support structures. (Lindecke et al. 2018, p. 53.)

Table 2 shows the general definitions of L-PBF related to raw material powders, support structures and their functions. More intricate builds can have specific supportive needs which automated design processes might not yet recognize. Even though the simulation of working support structures has developed, predefined supports still needs some attention and optimization. Different parts of the product often demand different support types and so in order to succeed, different support shapes and sizes among other variables will need to be considered in the manufacturing of a single product. (Lindecke et al. 2018, p. 53.)

Table 2, modified based on Jiang, Xu and Stringer (2018, p. 5)

					Functions of the Support Structure		
3D Printing Category (ISO, 2015)	Definition	Technologies	Material used	Does This Technique Need Support Structures?	For thermal dissipation	For printability	For part balance
Powder Bed Fusion	Thermal energy selectively fuses regions of a powder bed.	Melting processes	Powder materials, including stainless steel, tool steel, cobalt chrome, titanium and aluminum	Yes	√	√	√

As it can be seen from table 1, in L-PBF, supports structures are needed for thermal dissipation caused by the direct heat from the process laser. Supports are also needed as a foundation to print on and to anchor the object during printing. As of now the generally established material groups for LPB-F are stainless steel, tool steel, cobalt chrome, titanium and aluminum. These are the overall restrictions of metal melting processes within L-PBF. (Jiang, Xu and Stringer (2018, p. 5)

2.3.1 Cellular lattice supports

Cellular supports, which are usually generated through mathematical models, are designed to be lightweight while still being able to support the manufactured object and overhangs. The process of designing cellular supports seen in Figure 9 is divided into two phases: first, the orientation for least support volume needed is identified. Secondly, the support microstructure is optimized to further reduce the printed volume. Structure density is determined by the printed objects need for weight support. (Strano et al. 2013, pp. 1247-1248.)

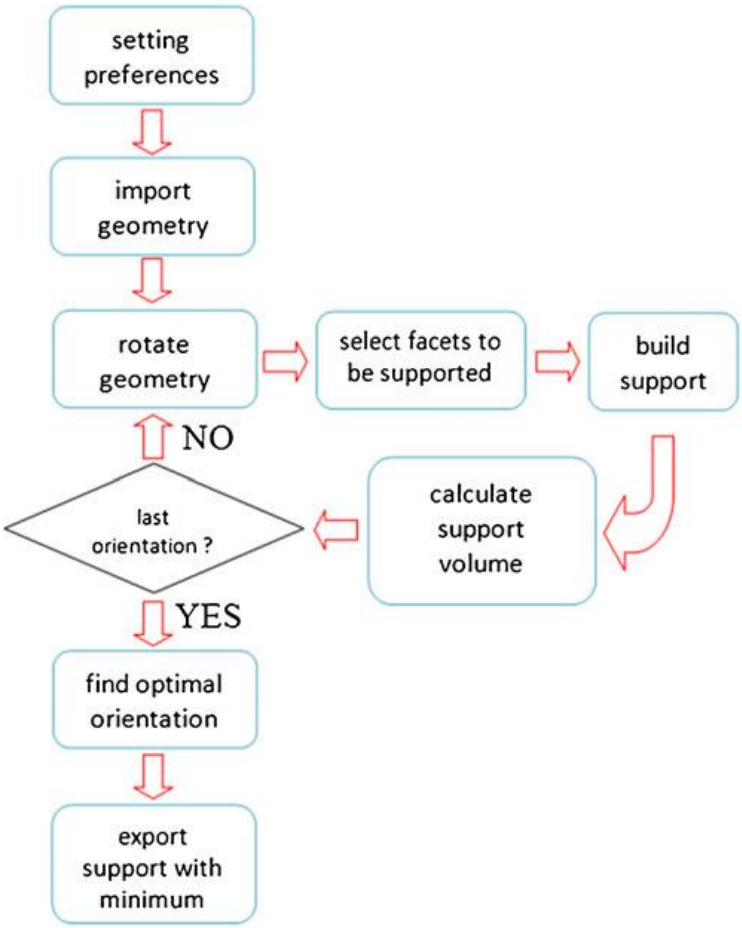

Figure 9. Systematic designing of support structures (Strano et al. 2013, p. 1249.)

As seen in Figure 9, systematic support design is a step by step process where the optimal part orientation and support structure geometry are simulated several times. Results are analyzed for further optimization in the next round and the process is repeated until a suitable part orientation and support construction are achieved for printing. Cellular supports were originally designed by traditional commercial CAD packages, but this method has proven to be unsuitable due to the vast amount of Boolean operations needed. A computationally lighter method to build cellular supports such as Schwartz cells, seen in Figure 10, is based on using periodic implicit functions to create gyroid shaped microstructures. By using a more advanced grading algorithm to make cellular supports, implicit functions can be used to create cellular supports in a more flexible way depending on the printed object. The modelled support mesh is transferred into an STL file which is then printed to support the object. (Strano et al. 2013, p. 1248-1249.)

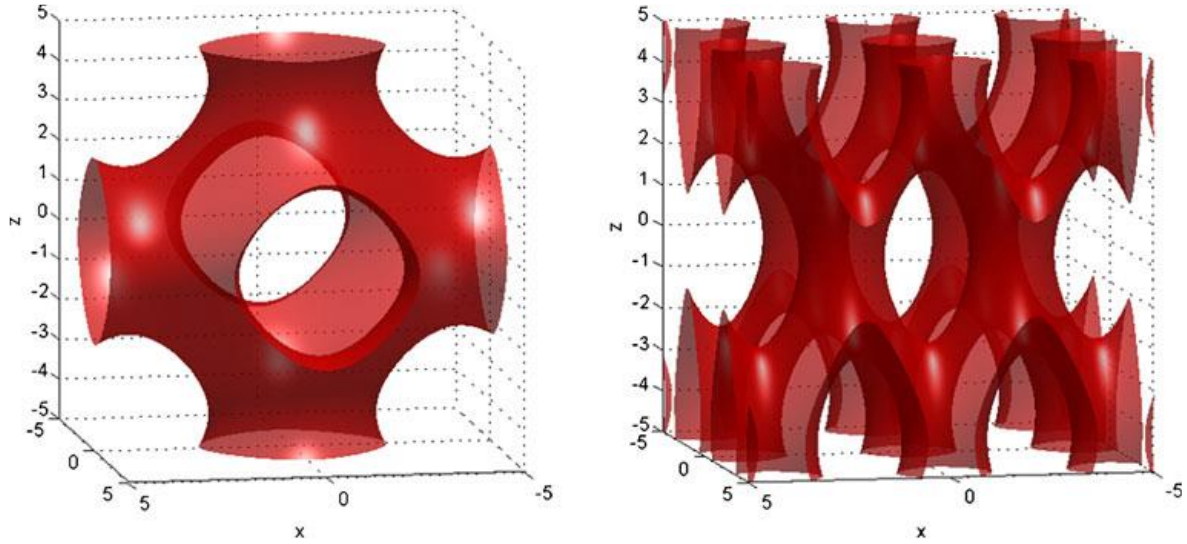

Figure 10. Schwartz cells used in lightweight lattice support structures (Strano et al. 2013, p. 1251)

Figure 10 illustrates lightweight Schwartz cells used in cellular lattice supports. Depending on the printed object surface, the need for support can change sensitively. Figure 11 explains the optimization process for support orientation. By trying out multiple angles for the same object, an optimal orientation for the object and its supports can be found. By doing this, support volume can be minimized resulting in reduced weight and material costs. (Strano et al. 2013, pp. 1249-1250.)

As an example, designing cellular supports for a complex diamond shape structure with a cylindrical trusses cell core frame was used as a case study done by G. Strano, L. Hao, R. M. Everson and K. E. Evans at the University of Exeter. At first, the optimal orientation was found out and after that, the cellular structure was mathematically optimized to fit the selected orientation of the object and support structure. Figure 11b shows that an unfavorable angle can mean a lot when designing support structures. (Strano et al. 2013, p. 1253.)

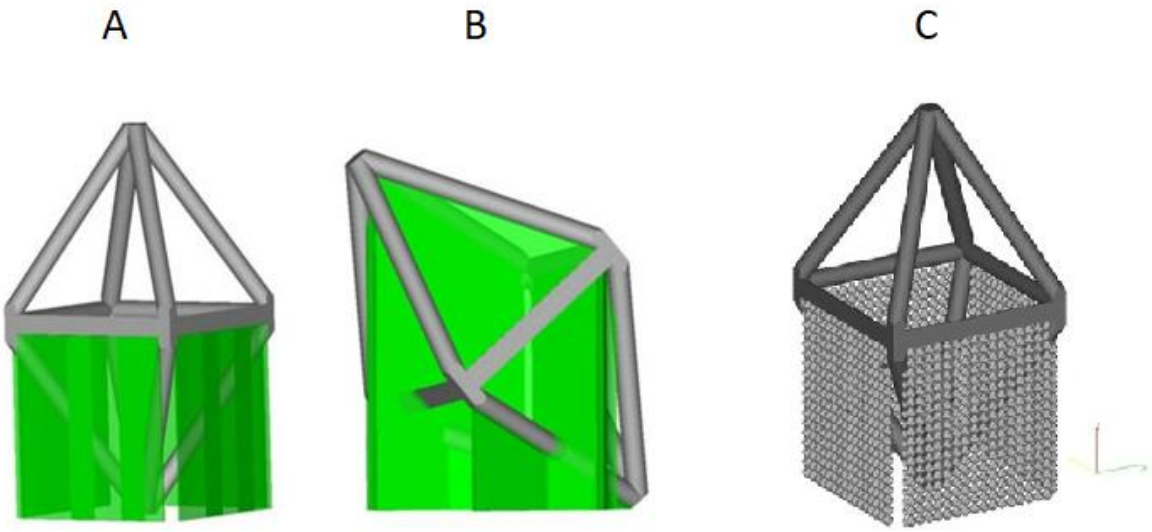

Figure 11. Simulation of different support orientations and the final cellular support model (Strano et al. 2013, p. 1253).

As it can be seen from Figure 11a, when the orientation is at a suitable angle, there is no need for supports above the centerline of the printed object. This is because the overhangs are at angles vertical enough and do not need support. Figure 11b shows that when the same part is at a less suitable angle, the printing process would require far more support structures to prevent the upper section of the part from deforming. Figure 11c shows the simulated shell support structure based on Figure 11a. The optimization process of support designing results in less printed volume meaning reduced weight, time and material costs. (Strano et al. 2013, p. 1253).

Lattice supports used in metal additive manufacturing are periodic cellular structures made by repeating a specific manufacturing pattern to achieve a strong and lightweight structure. Lattice supports allow for low mass resulting in lower material costs while maintaining the stability needed to support the printed object. This is due to the smart structure design that evaluates the stress in each printed section and is able to strengthen supports only where needed. This saves both material and energy. (Hussein et al. 2013, p. 1019-1020.) Metallic lattice structures consisting of continuous cells, as seen in Figure 12, show good mechanical properties along with high impact-energy absorption and low thermal conductivity. For these reasons, lattice structures have been well found not only in disposable supports but also inside of printed objects. (Wang et al. 2018, p. 27-28.)

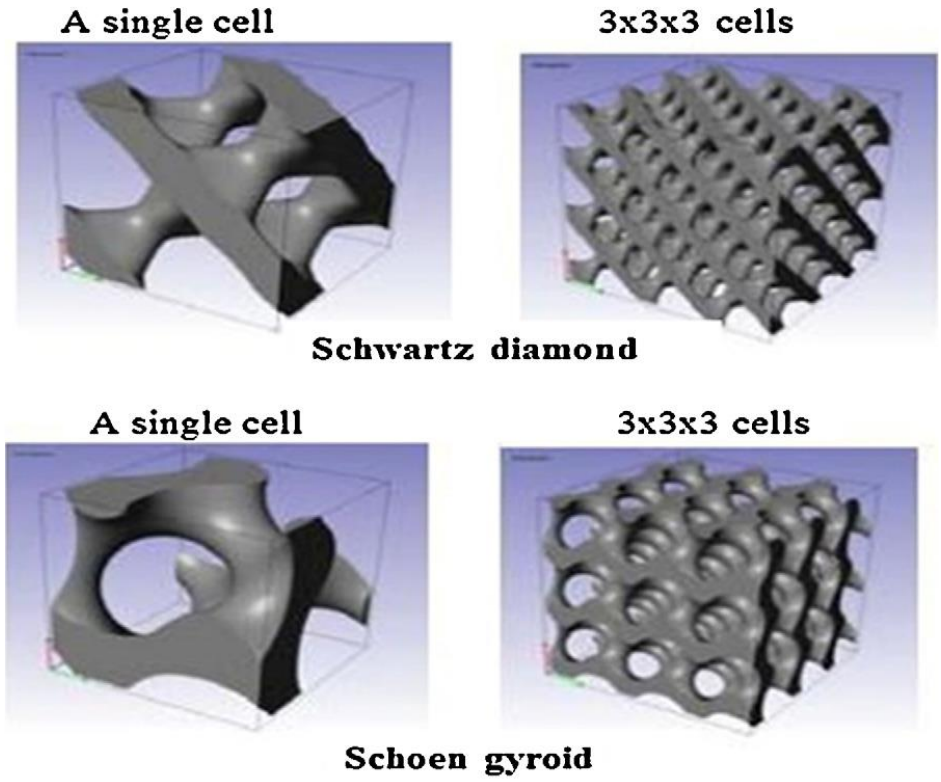

Figure 12. CAD model of gyroid and diamond lattice structures. (Hussein et al 2013, p. 1021)

Figure 12 illustrates different angles of a single shell Schoen gyroid structure and a larger 3x3x3 structure using the same basic single cell shape as building blocks. As it can be noticed from the Figure, the same cell support shapes can be continuously used in different sized external support structures and inside of printed parts.

2.3.2 Pin supports

Pin supports are support structures used in AM and L-PBF processed and are based on either single straight pin shaped pillars or different combinations of the same structure. As an example of these variations, three types of 316L stainless steel pin based supports called Pin, Y and inverted Y or IY(shown in Figure 13) were tested in a study carried out by M.X. Gan and C.H. Wong at the Nanyang Technological University. In these tests, most of the supports were successfully printed by L-PBF, except for some of the Y supports which started causing trouble due to excessive thermal loads and shrinkage resulting in deformation. (Gan & Wong 2016, p. 475.)

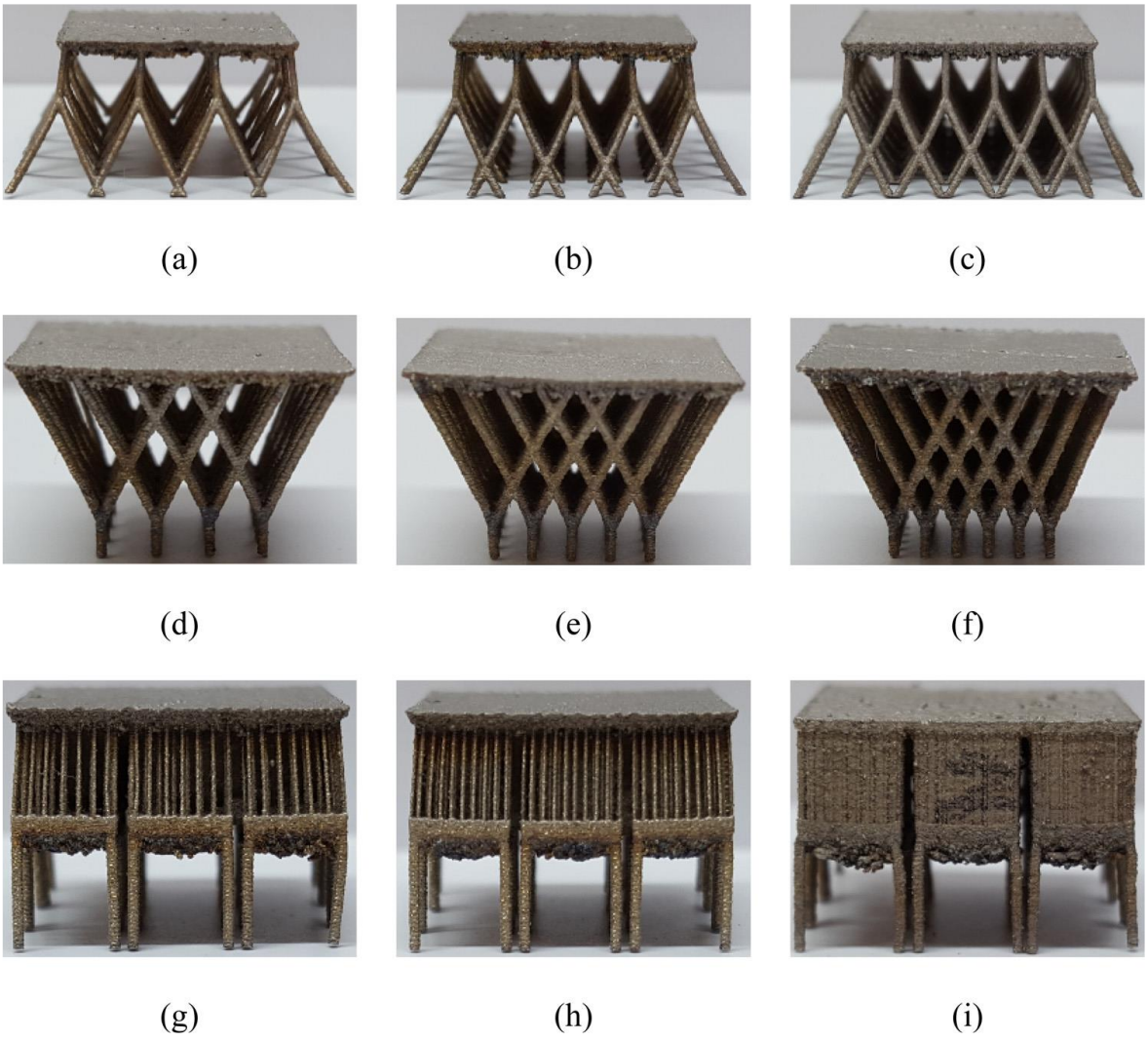

Figure 13. Different combinations of the IY, Y and Pin supports (Gan & Wong 2016, p. 479.)

Figure 13 shows the three different types of support structures used in these tests. While using these Y supports, shown in Figures 13d, 13e and 13f, for support, the thin printed plate started to suffer thermal warping and the printing had to be stopped. A surface profile analysis which can be seen in Figure 14 shows that the thermal warping was caused by non-uniformly spaced struts that caused different cooling rates between the center and the edges of the printed thin plate.

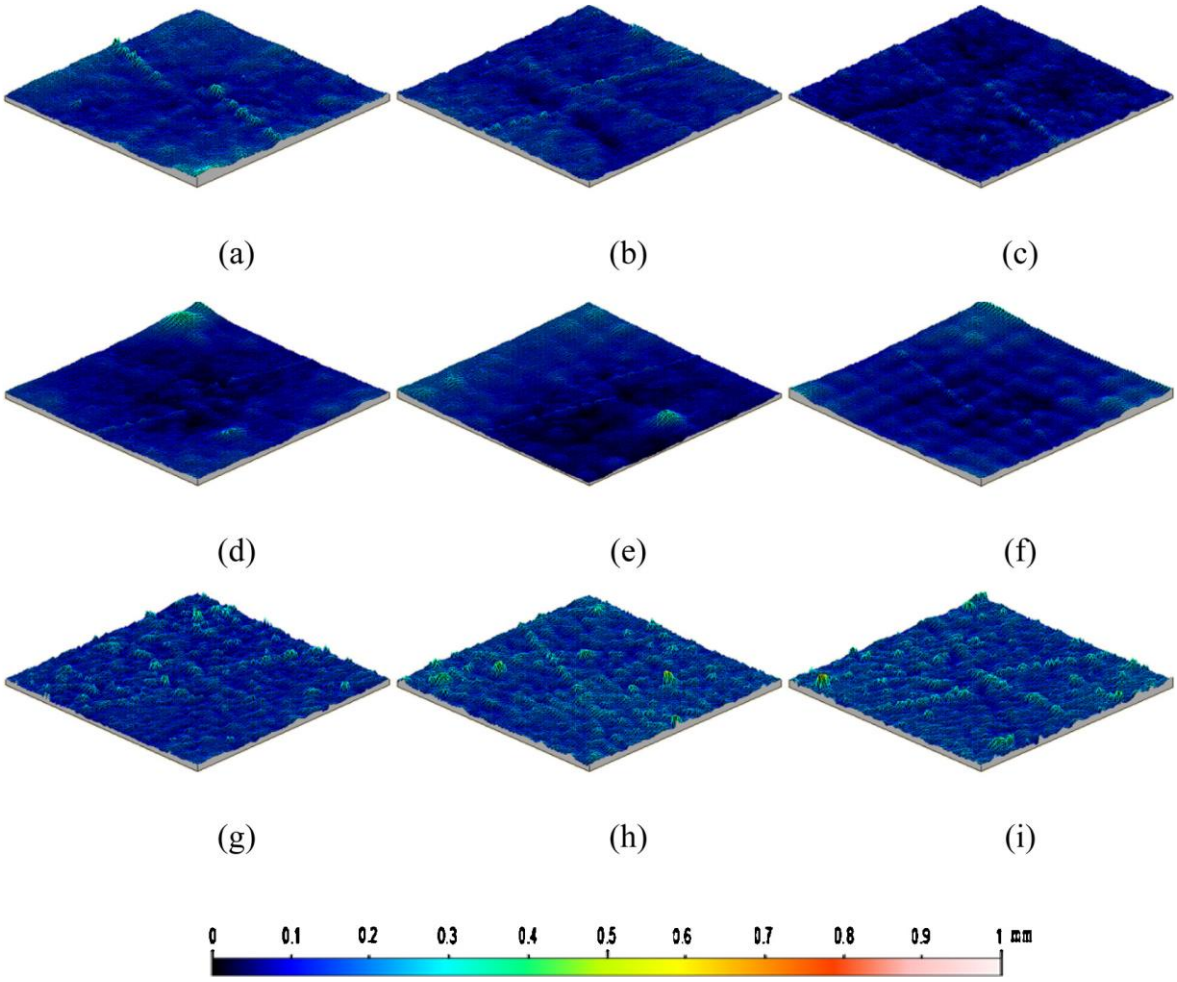

Figure 14. Top surface profiles of thin plates using different support types.

As it can be seen in Figure 14d, 14e, and 14f, the uneven heat dissipation of the Y supports caused different levels of shrinkage on the same printed layer, mostly in the middle plate. The height differences caused by this also caused the printed edges to curl upwards. For comparison, Figures 14a, 14b and 14c represent the printed surface achieved using IY supports. Figures 14g, 14h and 14i represent the pin supports used. (Gan & Wong 2016, p. 483.)

The inverted Y or so called IY supports showed better potential than the Y or simple pin supports. IY supports produced a rather levelled surface on the plate while using the least amount of overhang-support contact points per plate (25). For the IY supports, the contact area with the plate was only 2.2 % of the whole overhang-support contact area. However, better surface quality, geometrical accuracy and less shrinkage would be needed to achieve adequate printing results. Among these aspects there were thoughts on how to improve the

supporting further. One suggestion was to shorten the supports to increase heat flow and this way reduce shrinkage. The three main points to improve pin supports were to uniform heat dissipation, keeping the space between supports at a maximum of 5 mm and keeping the angle between the support and the shrinkage direction above 90°. (Gan & Wong 2016, p. 483.)

Based on these tests, especially the detachability of IY supports seen in Figures 11d, 11e and 11f is obviously better than that of Y and pin supports. With the supports taking only a small portion at the bottom of the part, separating them should be significantly easier.

3 RESULTS AND DISCUSSION

In additive manufacturing of metals and specifically with stainless steels, there is no single support structure best found for all applications. However, some broad lines can be drawn. Lightweight automatically generated lattice structures offer versatile potential due to their ability to be designed and optimized rather accurately to give the right amount of support, anchorage, and heat dissipation combined with good detachability compared to heavy solid structures. Well placed thin and separate pin supports do not necessarily need a large amount of space below the printed parts and offer easy removal as well.

Support parameters for inclined and round surfaces can be optimized by using digital tools which are able to anticipate the heat and weight related problems of the metal material used for printing. CAD software are used to accurately model the desired objects and FEA tools combined with systematic support structure design practices allow for designing the supports around the printed objects while saving time and reducing material costs.

In traditional machining, products are cut out of raw material which results in swarf that has no use before being recycled. AM uses very little extra material except for necessary support structures. The excess metal powder us recycled and used for further printing.

Especially in industries with larger resources available, the flexibility of additive manufacturing can be useful: complex production lines could be partially replaced with additive manufacturing stations. Additive manufacturing is unlikely to ever completely replace conventional machining methods due to their proficiency and accuracy in so many applications, but it offers ways to effectively and economically create unique products with previously unavailable geometries. There are many commercial terms that fall under L-PBF, such as Selective Laser Melting (SLM) and Selective Laser sintering (SLS). The vast number of names for similar manufacturing processes might be confusing, but the general methods used in different processes are still very similar.

3.1 Support structure variations

As seen in Figures 15-18, different types of support structures and combinations can be found all around the additive manufacturing world in industry applications and scientific

studies. The use of previously well-found geometries with different advantages can combined to achieve the mechanical and thermal properties needed in the specific sections of printed parts which need external support.

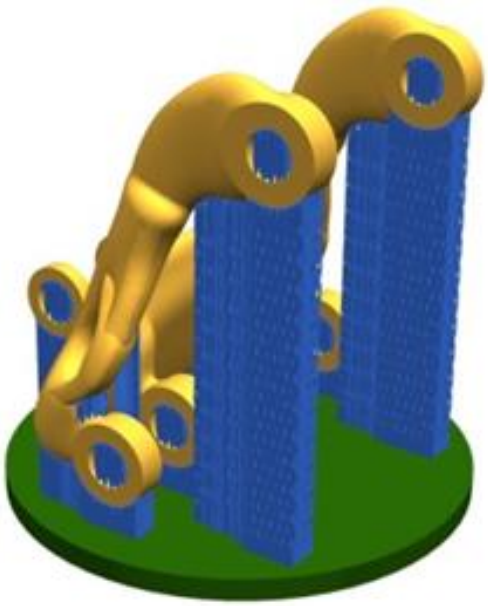

Figure 15. Automatically generated support structure mesh. (Siemens 2017)

Figure 16. Variating support structures and thickness. (Materialise 2017)

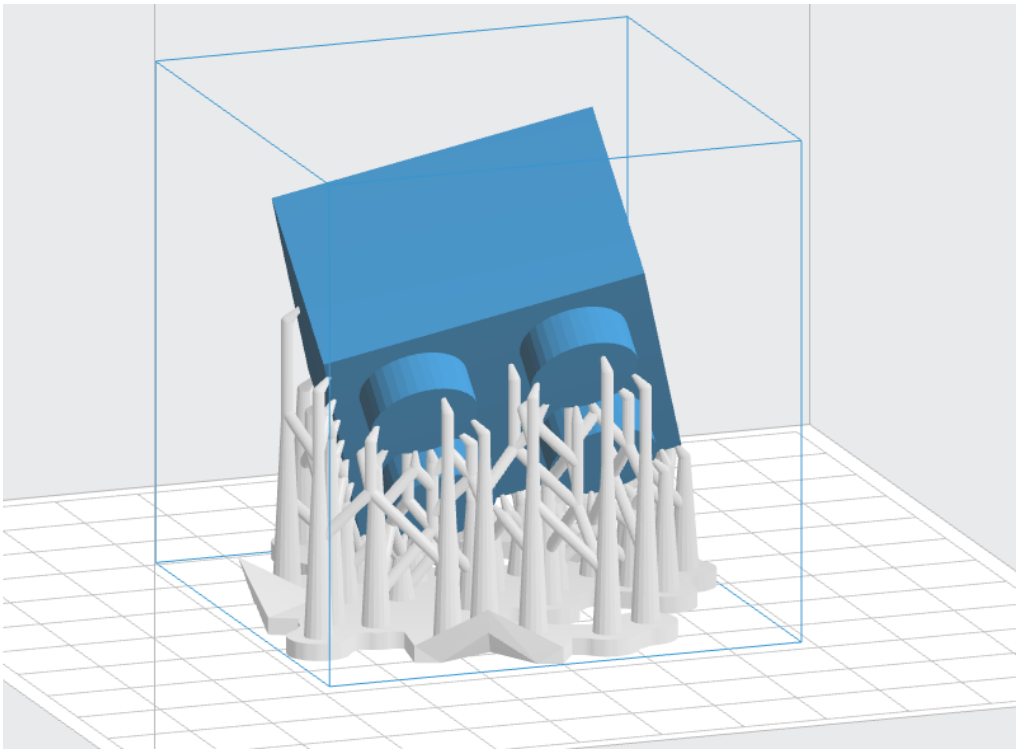

Figure 17. Tree-like supports. (Manufacturing Lounge 2018)

Figure 18. Long spiral supports and lattice supports. (Teknologix 2019)

As it can be seen in Figure 15, automatically designed lattice supports are a common way to create lightweight disposable structures to give anchorage and physical support during 3D printing. Figure 16 shows that supports do not need to have universal shape or density around the printed part. Supports can be intelligently placed only where needed and with the shape and density required in each section. This also helps with detaching after printing is done. Figure 17 Shows tree-like pin supports which can be used to support the part using several branches springing from initial base pins. Figure 18. Shows the use of narrow spiral-like supports with a solid base used for supporting a higher part of the printed object. Below the base of the part, sturdier Lattice supports are used combined with a more solid base and top.

4 CONCLUSION AND SUMMARY

This Bachelor thesis studied the usage and behavior of support structures in laser powder bed fusion by using new available research data. This thesis was done as a literature survey. For 3D printing stainless steel objects with vertical and inclined shapes in L-PBF, support structure optimization is very essential to achieve adequate support while maintaining detachability. Generally, all printing angles from 45 degrees towards completely horizontal surfaces require support structures to avoid distortion and especially thin structures are prone to deformation due to thermal loads. In the case of round or elliptical surfaces, each point on the surface has a tangent and generally any part angle below 45 degrees will need support.

Even while the use of supports is crucial, detachability and lightweight can be optimized towards a point where they do not cause excessive trouble or material costs. Lightweight cellular lattice supports and certain types of pin supports both have good detachability with variable thermal dissipation and support.

There is a compromise to be done between thick and heavy supports with good heat dissipation and lightweight supports where the dissipation of heat from printing the part is more challenging. Heavier structures such as pin supports with very dense positioning give good support and heat dissipation with the cost of more difficult detachability and additional material costs. Thin lightweight supports such as cellular lattice supports or different types of pin support structures like IY supports have the challenge of heat dissipation and part support but have a clear advantage when it comes to detachability.

Further optimization of support structures in the additive manufacturing of metals along with evolving manufacturing techniques and printing parameters are likely to enable more and more advanced structures with better mechanical properties in the future. There is no doubt that when manufacturing becomes more affordable and most of the printing problems are solved, laser powder bed fusion will become even more popular within all industries, scientific communities and the private sector.

5 FURTHER STUDIES

As continuation for this thesis the following study topics regarding the printing of stainless steels could prove useful:

- A study combining different types of support structures such as pin supports and lattice supports in the printing of metal parts with complex geometries. This could help with making supports even lighter.

- A study testing different printing speeds, laser power and powder layer thicknesses in sensitive printing sections such as thin overhangs. It would indicate how much these parameters could help with distortions.

- A study testing the minimum need for supports for round overhangs. It could give insight on how much a slowly changing angle changes the need for support by each increment.

- A study testing the detachability of different support structure types and final product quality after removal would give good insight on how the part-support connection could be optimized.

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