9th International Conference on
Photonic Technologies LANE 2016

Industrial Paper

Design of a hydraulic component for additive manufacturing of stainless steel

Mikko Hovilehto[a,*], Lauri Jokinen[b], Pasi Holopainen[b], Antti Salminen[a,c], Heidi Piili[a]

[a]*Lappeenranta University of Technology, Laboratory of Laser Processing, Lappeenranta, Finland.*
[b]*Metso Minerals, Tampere, Finland*
[c]*Machine Technology Centre Turku Ltd, Turku, Finland*

Abstract

Additive manufacturing (AM) of stainless steel is a technology that enables fabrication of structures too complicated for any traditional methods. This freedom of design can be exploited by designing parts that improve the performance of both, the part and the system as a whole. Traditionally, hydraulic blocks are designed to be manufactured with traditional methods. The aim of this study was to re-design a hydraulic component to be manufactured with AM to improve the functionality and reduce the weight of it. 3D modelling software used in the study was Solidworks 2015 and AM system used in this study was a modified research machine representing EOSINT M-series. The material used was EOS SS 316L stainless steel. It was concluded that the weight reduction of the part was significant. It was also noticed that components (valves etc.) designed for AM manufactured hydraulic blocks should be available to get even more benefit from AM.

Keywords: additive manufacturing; design for additive manufacturing; powder bed fusion

1. Introduction

Additive manufacturing of metals has been studied extensively in recent years. The SLM (selective laser melting) has become a manufacturing method widely used by several industries such as automotive and aerospace (Yadroitsev et al. 2015). The layer wise functional principle and development of additive manufacturing has enabled the use of additive manufacturing for designing products with geometries, which would be impossible to produce with traditional fabrication methods (Zhang et al. 2014; Moylan et al. 2012). The potential of AM in reducing weight and enhancing parts functionality is nowadays widely accepted (Ponche et al. 2014). Powder bed fusion (PBF) of metals is the most challenging fabrication method from perspective of design for additive manufacturing (DFAM) due to the multiple design rules concerning PBF of metals.

The DFAM differs completely from the traditional design for manufacture and assembly DFMA concept as the designer can forget the constraints of conventional manufacturing methods. The fact that CAD programs are designed for designing parts for conventional manufacturing techniques is complicating the work of DFAM designers (Bourell et al. 2009). Design for additive manufacturing was studied by Vayre et al. 2012 by proposing a pattern for design process of a part to be manufactured utilizing additive manufacturing (analysis of the specifications, initial shape, definition of a set of parameters, parametric optimization and validation of the shape). During literature survey it was noticed that there is a lack of published studies about utilizing DFAM. This has been the main motivation for authors to carry out this survey regarding design for additive manufacturing and thus it is the interest of the authors to present the design process and the results of the study.

The aim and purpose of the study is to redesign a hydraulic block to be manufactured with metallic powder bed fusion and to present how the design process was performed. The hydraulic block was chosen to be redesigned because of the potential of weight reduction and improvement in functionality.

* Corresponding author. Tel.: +358-401-523-580 .
E-mail address: mikko.hovilehto@lut.fi

2. Research methodology

The research was conducted by first creating a pattern for the design process. The CAD software used in the study was Solidworks 2015 and it was used for all of the 3D modelling done during the study. The model was reviewed several times during the design process in co-operation with engineers of case company to find out possible problems and design improvements.

3. Results and discussion

A systematic way was created to perform the design process in organized and logical way. The design process was performed according to the pattern shown in Figure 1.

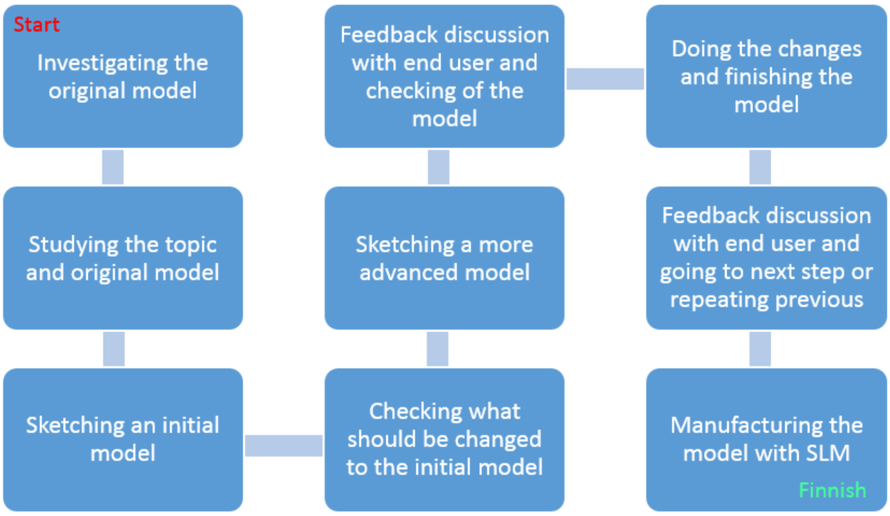

Fig. 1. Flowchart of the design process.

The pattern in Figure 1 enables a design process that utilizes the expertise of both the DFAM designer and the engineers from the case company. This way also provides information to flow freely from phase to phase, an open communication and an innovative approach to design, which all are needed in this kind of case.

3.1. Investigating the original model, studying the topic and the original model

The original model was a traditional hydraulic block with several unnecessary drillings and excess weight due to constraints of traditional manufacturing technique used (machining). As the model designed for machining suffers from the limitations caused by the manufacturing method, it was not desirable to try to mimic the design of the original model. At this point, all rules for conventional manufacturing had to be forgotten. Therefore instead of studying the original model, the schematic diagram was taken under closer investigation. However the components and their operation principle was studied and the installation orientation of the components was checked. The original model had drillings of various diameters and it was decided to use one diameter for the channels and holes in the AM model.

3.2. Sketching an initial model

Sketching an initial model was started by mimicking the original schematic diagram. Main constraints of the design (presented in Figure 2a) are that the attachment points cannot be altered (blue arrows) and the side with the output connection (red arrow) needs to be free of other components. It was decided that the design could consist of small blocks connected to each other with pipes to exploit the benefits of additive manufacturing. The internal diameter of the pipes was set to 8 mm by the engineers of the case company to enable sufficient fluid flow of the hydraulic system. Because of the complexity of the system, the orientation of the pipes could not be only parallel to building direction or perpendicular to building direction. Building round pipes with 8 mm internal diameter perpendicular to building direction would lead to building deformations. Thus the pipes were designed to be shape of a droplet to avoid building deformations, such as sagging. The self-supporting geometry designed for the pipes was tested and proved to be successful. The self-supporting geometry is presented in Figure 2b.

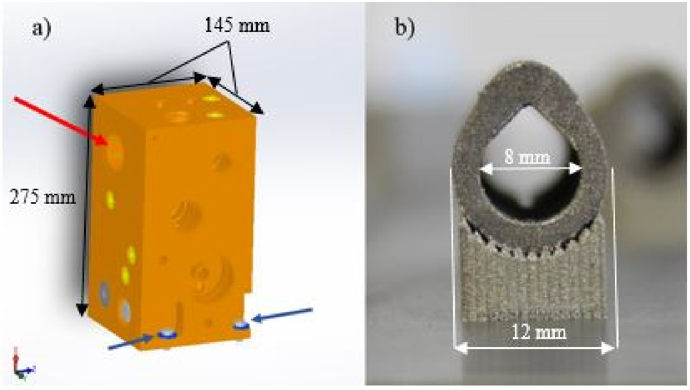

Fig. 2. a) Constraints of design b) Self-supporting pipe geometry.

3.3. Feedback discussion with end user, locating design problems and improving the model

The design process took several iteration loops before the design was satisfactory. The model was regularly investigated with the engineers of the case company to point out problems and things to improve in the design. Designing of the blocks for the hydraulic components proved to be the most challenging task and the expertise of the engineers of the case company was needed especially at this point. In this kind of cases, it is crucial to know the functionality of part designed thoroughly so that all points can be taken into account. Minimum dimensions for the small blocks to withstand the forces from cavity machining were checked from the component manufacturers and the blocks were designed using this information. The attachment points of the block were consolidated in the design to reduce weight and building time. DFAM was used to save material and reduce weight and building time by removing excessive material from the model. The model was built by adding material where it is needed instead of the principle of machining, which is removing material where it is not needed. Designing of the final outside geometry of the small blocks was performed as one of the last phases of the design process. External supports for supporting the model against the forces caused by the cavity machining after the SLM manufacturing process, were added before the shaping of the blocks. This was noticed to be unnecessary because the attachment points of the external supports were modified or moved at the outer geometry design phase and the external supports needed to be designed again after it.

3.4. Final design and comparison to the original model

The weight and dimensions of the conventionally manufactured hydraulic block were 36 kg and 145x145x275 mm. The weight and dimensions of the additively manufactured block will be 9.7 kg and 197.5x208.5x115 mm. Weight of the additively manufactured model will be increased by the support structures built for the manufacturing process. However the cavity machining will remove material from the model so the increase of the weight of the model will not be significant. The weight reduction achieved with the new design is 72 % and it is illustrated in Figure 3.

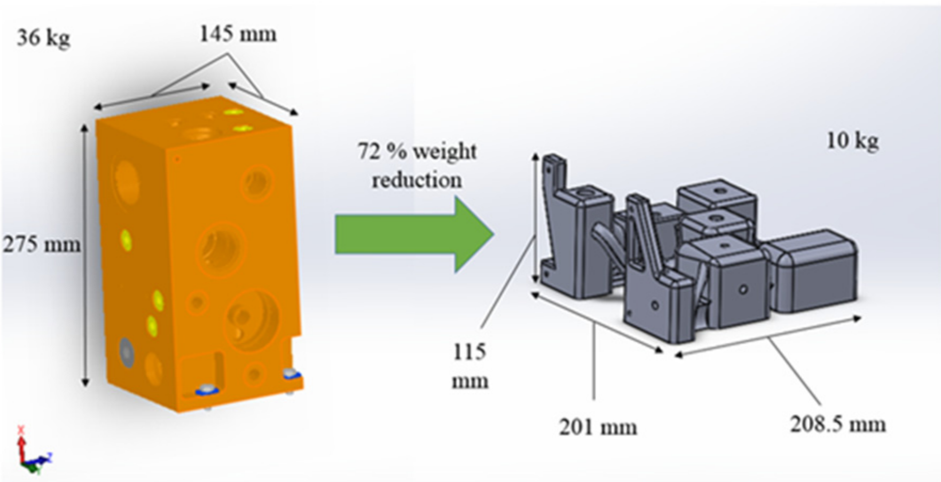

Fig. 3. Comparison between the old and the new model.

The channels and pipes inside the new design have no sharp angles and there are no unnecessary drillings in the system. On the contrary all the channels inside the original design have sharp angles due to the manufacturing method used. The amount of unnecessary drillings is reduced from 7 to 0, as 2 of the plugs are located in the sides hidden in the Figure 3. Therefore the fluid dynamics of the system should be improved from the original model. Part of these unnecessary drillings can be seen in the Figure 3, as they are clogged with yellow plugs.

3.5. Manufacturing of the model

To manufacture the model support structures were needed to be designed between the model and the building platform. Manufacturing of the model is under progress. The layer thickness used in the build is 20 µm. The current stage of manufacturing process is presented in Figure 4. Manufacturing of the model will be carried out also by using 40 µm as layer thickness using a different AM machine, as it will reduce fabrication time into half. This issue will be further studied.

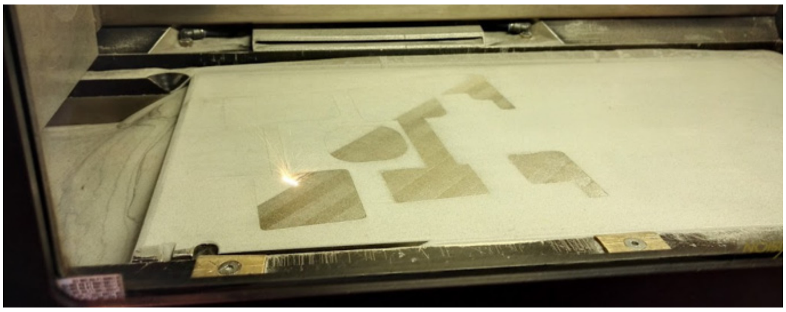

Fig. 4. Manufacturing of the model.

4 Conclusions

The aim and purpose for conducting this study was to re-design a hydraulic block to reduce the weight of the part, increase the functionality of the part and to enhance the performance of the part. The study was carried out in Laboratory of Laser Processing of Lappeenranta University of Technology. The study was conducted by planning the design process and designing the new part with Solidworks 2015 CAD software. The design process was partly conducted in co-operation with design engineers of the case company. It can be concluded that the achieved weight reduction of 72 % is remarkable. It can be also concluded that the performance of the hydraulic block should be improved as a result of absence of the unnecessary drillings and as a result of smoother geometry of the channels and pipes. The hydraulic components at the market at the present are designed to be installed in large hydraulic blocks instead of minimal AM hydraulic blocks. By reducing the size of the components and the material needed around them, this and other AM designed hydraulic blocks could be designed even more efficiently.

Acknowledgements

This study was carried out as a part of the Finnish Metals and Engineering Competence Cluster (FIMECC)'s program MANU - Future digital manufacturing technologies and systems and sub-project P6. Authors would like to thank all participants of MANU P6 project for their knowledge and input to this article. Authors would also like to acknowledge personnel of LUT Laser for their assistance to carry out this study.

References

Bourell, D. L., Leu, M. C., and Rosen, D. R., 2009. Roadmap for Additive Manufacturing: Identifying the Future of Freeform Processing, The University of Texas at Austin, Austin, TX.

Moylan S., Slotwinski J., Cooke A., Jurrens K. and Donmez M.A., 2012. Proposal for a standardized test artifact for additive manufacturing machines and processes, Proceedings of the 2012 Annual International Solid Freeform Fabrication Symposium 2012, pp. 6-8.

Ponche, R., Kerbrat, O., Mognol, P. and Hascoet, J., 2014. A novel methodology of design for Additive Manufacturing applied to Additive Laser Manufacturing process. Robotics and Computer-Integrated Manufacturing, 30(4), pp. 389-398.

Vayre, B., Vignat, F. and Villeneuve, F., 2012. Designing for Additive Manufacturing. Procedia CIRP, 3, pp. 632-637.

Yadroitsev, I., Krakhmalev, P. and Yadroitsava, I., 2015. Hierarchical design principles of selective laser melting for high quality metallic objects. Additive Manufacturing, 7, pp. 45-56.

Zhang, Y., Bernard, A., Gupta, R.K. and Harik, R., 2014. Evaluating the Design for Additive Manufacturing: A Process Planning Perspective. Procedia CIRP, 21, pp. 144-150.