The International Journal Of Engineering And Science (IJES)
|| Volume || 3 || Issue || 12 || December - 2014 || Pages || 14-19 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Design for Additive Manufacturing – DFAM

Esa Hietikko
Department of Mechanical Engineering, Savonia University of Applied Sciences

ABSTRACT

Additive Manufacturing (AM) known as well as rapid prototyping or 3D printing is popular discussion subject at a moment. It is called to be the third industrial revolution and also forecasted to widely replace the traditional industrial manufacturing methods. By using AM it is possible to produce effectively parts that are very difficult or even impossible to manufacture using traditional methods. However, AM has limitations that put challenges to the design of such parts.

The hype around additive manufacturing is partly understandable. There are still several drawbacks that must be kept in mind. For example when talking about heavy steel parts AM cannot compete against traditional manufacturing methods in terms of costs and processing time unless the parts are redesigned for AM. The development of the AM technology is fast and more efficient solutions should be able to see after some years.

Keywords *- 3D-printing, additive manufacturing, design rules, engineering design, rapid prototyping.*

Date of Submission: 28 November 2014 Date of Accepted: 10 December 2014

I. INTRODUCTION

Additive Manufacturing (AM) known as well as rapid prototyping or 3D printing is popular discussion subject at a moment. It is called to be the third industrial revolution and also forecasted to widely replace the traditional industrial manufacturing methods. By using AM it is possible to produce effectively parts that are very difficult or even impossible to manufacture by traditional methods. However, AM has limitations that put challenges to the design of such parts.

Additive Manufacturing is a method that can be used to build a part by adding material layer by layer. While most of traditional manufacturing methods remove material and produce waste, this method only adds material with minimum or no waste. There are several techniques used in AM. All of them share a common feature of adding material layer by layer.

Engineers use nowadays widely the principles of DFMA (Design for Manufacturing and Assembly) when designing parts and assemblies. The design rules of DFMA are based on the limitations of traditional manufacturing methods and materials. For example sheets, beams and shafts are common shapes of billets. These also guide strongly the definition of shapes of designed parts and assemblies. Traditional manufacturing methods and materials lead engineers to design simple geometrical shapes like straight lines and circles. Also the traditional structural analysis theories are mainly based on simple geometrical shapes.

Because AM gives the possibility to use more free forms in produced parts and assemblies, the engineers must change their way of thinking [1]. The focus must be moved from the billets and manufacturing methods to the optimal shape of part. One fact that makes this change of thinking more difficult is that design software packages favor traditional geometrical shapes (e.g. lines, rectangles and circles) and the 3D models including free form shapes are more difficult or even impossible to produce with them.

Design has a significant role in optimizing the use of material and improving the usability and easiness of assembly of AM parts [2][3][4][5]. Maybe the most important goal of the use of AM is to reduce the use of material and masses of the parts. This can be done by optimizing the forms of parts and include for example hollow or honeycomb like cross sections. Also the time used to assemble parts together can be reduced by combining several parts together and improving the shapes of parts to make the assembly operations easier. One important goal is to form the internal features of parts used for example in hydraulic or cooling applications to make the float smoother and reduce the pressure drops in them. [6]

This paper presents three most important design rules to be used when designing AM parts and assemblies. They should also be used to redirect the engineering education and change the thinking and attitudes of design engineers.

II. THREE MOST IMPORTANT DESIGN RULES FOR AM

Nature has formed human during times. Therefore it is impossible to find straight lines from human body. The bone cross sections are arbitrary and change along the length. Also the inside structure of bones is not solid. However the traditional parts designed by engineers are straight and homogenous, because the manufacturing of them would otherwise be too slow and expensive. If you compare a human bone and a corresponding part produced by engineers with traditional methods, the latter will lose in both costs as well as in mass and mass/strength ratio.

By looking around it is easy to notice the things that have involved engineering design. They often have 90 degree corners which are mainly caused by the use of machining tools. Also the design applications (CAD-programs) encourage engineers to use straight lines and 90 degree angles because they are easier to realize and measure. When using AM the designer don’t need to think about manufacturing tools or billets.[1]

Even if it is very easy to produce free form parts by AM, there are still some limitations. Most important of things that must be kept in mind are:

1. The dimensions and shape of the printed part
2. The layer based structure
3. Printing orientation

The maximum part sizes of 3D-printers are not very large. Common printing space is about 250x250x250 mm. Probably the most important aspect about the printing size is the fact that the printing time and also costs will be increase radically when the size of the printed part increases. Fig. 1 shows an example of printing times of boxes of different dimensions with plastic 3D-printer. The prices of 3D-printers that use plastic as the printing material are correspondingly cheap. Still the printing time will compose main part of the costs of the printed part. Therefore it is important to design parts that have low material volume.

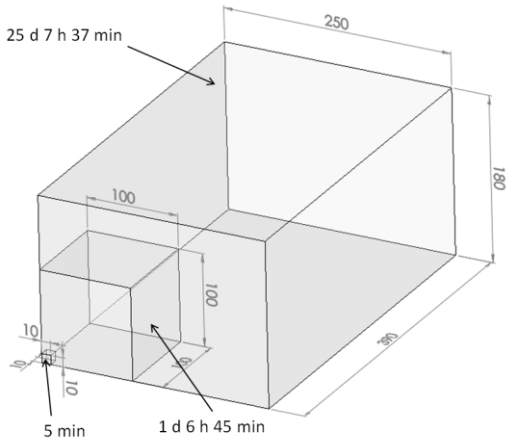

Figure 1. Printing time comparizon with boxes of different dimensions.

The shape of the printed part can be quite freely selected. Therefore the strength and for example flow properties of parts can be optimized easier. In Figs. 2 and 3 there are examples of simulated fluid flows in an original and redesigned test parts. It is clear that smoother forms will produce smoother flow.

As told earlier the straight line is probably the most common geometrical shape used in engineering design. Another shape with strong traditions is circle. Circle is mostly used when engineers design holes, which are almost always produced using a drilling method. In it the circle and a straight line produce the hole. When using the AM method, the horizontal circular hole is in fact one of the difficult shapes because of the overhang. If possible, the circle should be replaced with triangle, polygon or drop.

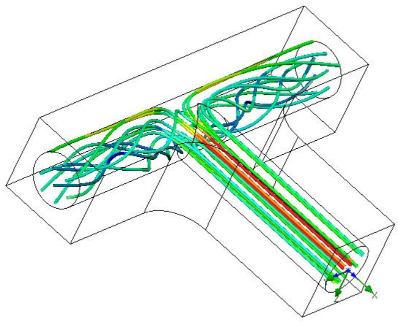

Figure 2. The fluid flow will be disturbed in traditionally shaped (= drilled) holes.

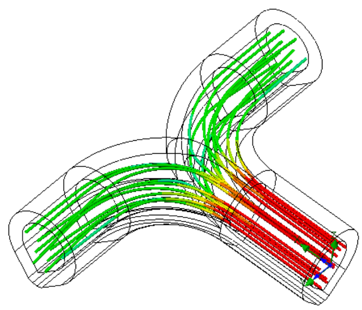

Figure 3. Smoother form causes smoother flow.

Because of the layer structure the surface quality and accuracy of part dimensions may cause difficulty and the surfaces of the parts must often be smoothened after printing. The common layer thicknesses may vary from 0,05 mm to 0,2 mm. It is clear that smaller layer thickness will cause longer printing time. It is also essential to recognize that the accuracy of the surfaces may vary if examined it in horizontal or vertical direction. The layer thickness may be, for example, 0,1 mm but the size of the fuse used to extrude plastic could be 0,5 mm. Fig. 4 shows an experimental case of printed plastic test part. The accuracy of dimensions is between +/- 0,2 mm.

Most of the printing methods are not able to print over empty space without massive support structures that must be removed after printing. Therefore it is wise to avoid hanging forms also called overhangs when designing AM parts.

The printing direction is an important decision, because it can be used to avoid overhangs. The height of the printed part is also important because it defines the printing time and has therefore strong effect on the printing costs. Fig. 5 presents some alternatives for printing direction. The orientation C is bad because of large overhangs. Also the printing time is relatively long (about 4 hours 49 minutes with plastic printer). Orientation B is better because there are overhangs only in the horizontal holes. Also printing time is much smaller (2 hours 49 minutes). The orientation A is best in terms of the overhangs. The estimated printing time for orientation A is 2 hours 43 minutes. This orientation still may face difficulties because there are horizontal circular holes in it.

These difficulties can be reduced by forming the horizontal hole differently. In AM there are no reasons to use circular holes. Polygons or drop forms are as easy to produce. Therefore for example the part presented in Fig. 6 is much better for AM.

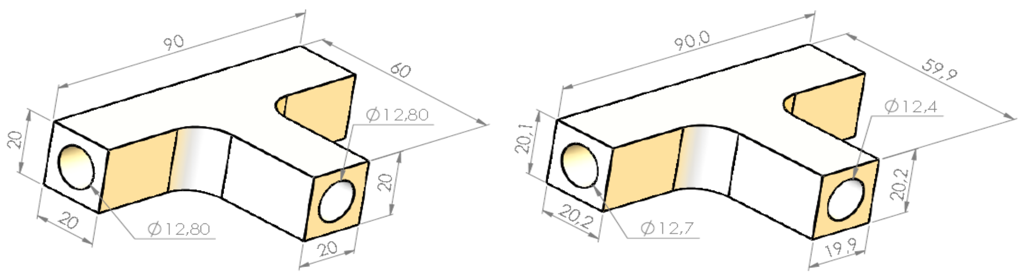

Figure 4. The accuracy of test part dimensions.

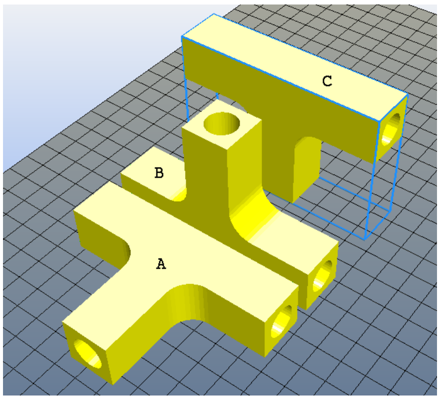

Figure 5. Printing orientation alternatives.

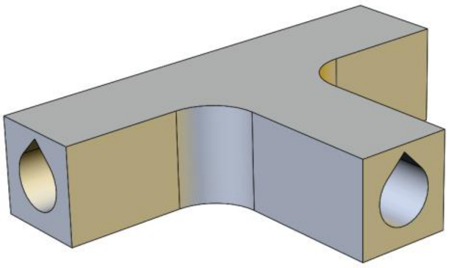

Figure 6. The shape of holes can be selected freely in AM.

The inner structures of AM parts can be generated to a honeycomb like structures. Normally the 3D-printer operation software will make this automatically. The user still has to select the amount of material used inside the parts. This is often a percentage between 0 and 100%. 0% means completely hollow structure and 100 % is a solid part. The Fig. 7 shows an example of inner structure.

The outside surfaces can also be redesigned. The Figs. 8 and 9 show a redesigned part that has both inner and outer surfaces reshaped.

In order to optimize the use of material in parts it is wise to use modern computerized methods in estimation of the stresses and deformations. Fig. 10 shows an example of part, its strength analysis and optimized version of it with strength analysis. The stresses and deformations are practically same, but the use of material is reduced in the latter case. While the optimization of the material use may not be important in terms of that single part, you must always remember the well-known principle of mass multiplication. Think about an airplane, for example. The reduction of mass of single part may be meaningless in terms of the whole airplane. But if you think further, you understand that it will influence many other things in an airplane. A little bit smaller engine is needed, smaller fuel tank is needed, smaller wing area is needed and so on.

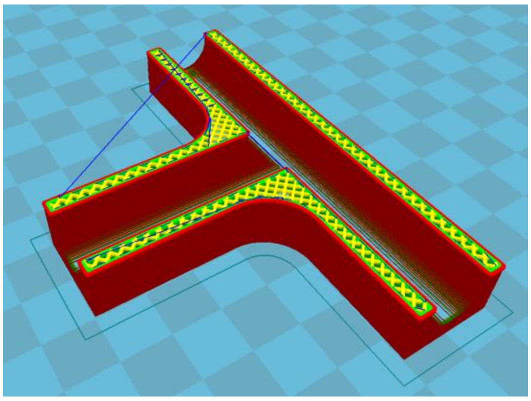

Figure 7. Example of the inner structure of a 3D part.

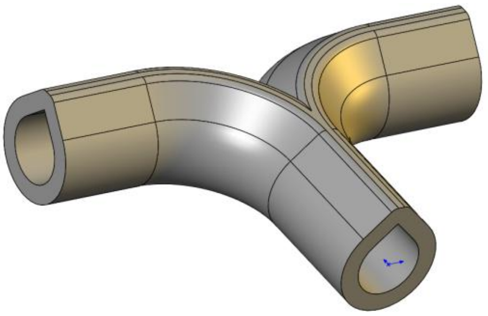

Figure 8. The reshaped inner and outer parts .

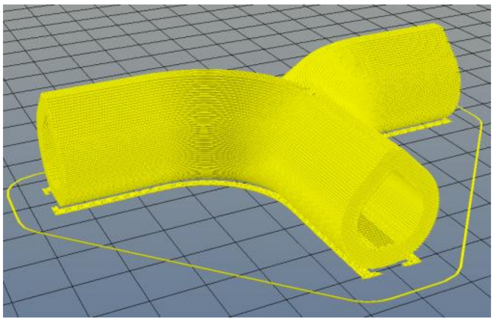

Figure 9. The minimal support structures needed to print the test part.

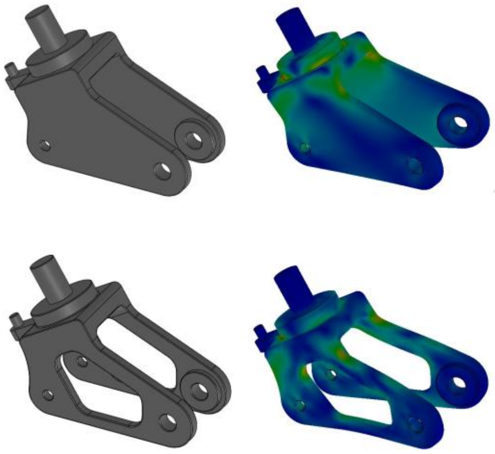

Figure 10. Optimized shape based on FEM-analysis.

III. DISCUSSION

It is clear that the use of AM will certainly reduce the use of material and waste. It is also clear that the bigger the produced part is the longer it will take to print. Because the processing time is essential in the costs structure of printed parts (especially if material is metal) the costs will increase radically when the volume (and height) of the part is growing.

Overhangs must be avoided by designing the parts without them or changing the printing direction to minimize the need of support structures. Horizontal circular holes are bad. Drop or polygon shapes should be used instead if possible.

Designing smooth forms may increase the mass/strength ratio of parts and the flow efficiency of channels radically. Internal structures should be designed to be hollow or honeycomb like. If the printed material is powder, you should always remember that the powder should be able to be removed from the internal hollow sections of the parts.

As a conclusion it could be said that the hype around additive manufacturing is partly understandable. There are still several drawbacks that must be kept in mind. For example when talking about heavy steel parts AM cannot compete against traditional manufacturing methods in terms of costs and processing time. The development of the AM technology is, however fast and more efficient solutions should be able to see after some years. [7][8]

IV. CONCLUSION

One of the most important goals of AM is to expand the efficiency and reliability of traditional manufacturing methods towards more customizable parts. Some of the parts made by AM are already cheaper compared to traditional manufacturing methods (for example implants). But looking widely around this is not true.

AM is at the moment clearly expensive way to produce parts if you think about broadly the manufacturing itself. The equipment and materials are very expensive. If you instead think about the whole life cycle of the product, it may turn out to be economic. For example a piece of airplane might cost 1000 € when manufactured using AM and 100 € when traditional manufacturing methods are used. But if it is possible to reduce the mass of the part for example 20 %, it may cause reduction of 10.000 € in operation and service costs during the 15 or 20 years lifecycle of that airplane. Also the soft values like the better usability or growing satisfaction among customers may have effect on costs.[8]

Maybe the worst barrier of the increasing use of AM is attitudes. ”We have always made it this way” or ”Why to repair something that is not broken”. These attitudes are often tightly connected to the cultures of companies. The well-known fact is that they are very difficult to change. It is true what someone have told: ”Culture will eat the strategy as a breakfast”.

ACKNOWLEDGEMENTS

This research has been supported by the European Structural Funds programme for Eastern Finland through the research project DeAdMan (Design for Additive Manufacturing).

REFERENCES

[1] C., B. Williams, C., C. Seepersad, Design for Additive Manufacturing Curriculum: a Problem- and Project Based Approach. http://utwired.engr.utexas.edu/lff/symposium/proceedingsarchive/pubs/manuscripts /2012/2012-05-williams.pdf

[2] I. Gibson, G. Goenka, R Narasimhan, N. Bhat, Design Rules for Additive Manufacture, http://utwired.engr.utexas.edu/lff/symposium/proceedingsArchive/pubs/Manuscripts/2010/2010-59-Gibson.pdf.

[3] R. PONCHE1 J.Y. HASCOET, O. KERBRAT, P. MOGNOL, A new global approach to design for additive manufacturing, *Virtual and Physical Prototyping 7, 2 (2012) 93-105*

[4] R Hague, I Campbell and P Dickens: Implications on design of rapid manufacturing, Proc. Instn Mech. Engrs Vol. 217 Part C, 2013

[5] Page Tom: Design for Additive Manufacturing – Guidelines for cost effective manufacturing, LAP LAMBERT Academic Publishing, Saarbrucken, 2011

[6] MINA ALIAKBARI: Additive Manufacturing: State-of-the-Art, Capabilities, and Sample Applications with Cost Analysis Master of Science Thesis, Production Engineering and Management, Department of Industrial Production, KTH, June 2012

[7] Ben Uglow, Nigel Coe, Rupinder S Vig, Adam Wood, Robert J Davies: MORGAN S TANLEY BLUE PAPER - Capital Goods: 3D Printing, MORGAN STANLEY RESEARCH Global, September 5, 2013

[8] Wohlers Report 2014, 3D Printing and Additive Manufacturing State of the Industry Annual Worldwide Progress Report, Wohlers Associates Inc., Colorado, USA, 2014.