

NEED FOR SUPPORT STRUCTURES DEPENDING ON OVERHANG SIZE

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DOI: 10.17973/MMSJ.2016_12_2016192

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This paper is focused on 3D printing of metal parts and the limitations of this method. There are numerous methods currently used for 3D printing, for example, DMLS, SLS, CLADDING, etc. This paper is limited to 3D printing using DMLS (Direct Metal Laser Sintering). The method works with metal powder, which is applied to a building platform in thin layers. The shape of a part is sintered using a laser beam in each layer. The part is built layer by layer. The material used for the experiment was maraging steel 1.2709. Laser sintering was undertaken using the EOSINT M 290. We used the process parameters recommended for this powder by the equipment manufacturer. The measurements were carried out on a Blicke Multicheck PC500 microscope. The goal of the experiment was to find the size of the overhang which does not show signs of degradation of the geometry of the overhang.

KEYWORDS

3D print, DMLS, MS1 – 1.2709, Overhanging ends, Geometry

1 INTRODUCTION

Additive manufacturing (AM) is one of the most frequently discussed topics in manufacturing processes. AM covers many principles of producing products and prototypes. However, AM is not only used for the production of prototypes, but may be used for mass production, for example, manufacturing of drills with inserts by Mapal. AM methods can be divided according to different criteria. The kind of material used is one of the basic criteria. It is possible to print from many kinds of material, for example sands, ceramics, plastics and even metals. It is possible to print from metals, for example aluminium, stainless steel, maraging steel, etc. DMLS (Direct Metal Laser Sintering) allows printing from these metal materials, therefore it was used for the experiment in this work. The principle of this method is based on the application of thin layers of powder, which are sintered by a laser beam. The part is cut into individual slices, while the distance of individual cuts depends on the thickness of the applied layer of the powder. The shape of the part is sintered using a laser beam in each layer. The parts are built layer by layer. [Thomas 2009], [Capkova 2015], [Hanzl 2016], [Hanzl 2015]

This technology is presented as being capable of almost anything, but this is not entirely true. The technology can solve various issues regarding the manufacturability of parts, but there are cases when it is not possible to create a part using this method. Even this technology has its limitations, which can be split between those arising from the principle of the technology, and geometric limitations. The main limitations arising from the principle of the technology are print accuracy, the necessity of support structures, roughness, building direction, internal stress and necessary post-processing. But these are not the only limitations, because there are also

geometrical limitations. The limitations can be the size of the part, maximum length, overhang angle, overhangs, wall thickness, holes and internal cavities, etc. Although this technology has quite a few limitations, it is possible to create parts, which are not manufacturable using other technologies. [Thomas 2009], [Kucerova 2016], [Fousova 2015], [Capkova 2015]

This paper focuses on geometric limitations, especially issues of overhanging ends. The geometries of overhanging ends are perpendicular and they are situated parallel to the building platform. The aim of this study is to find the size of overhanging ends which are printed with the required geometry without signs of geometry degradation.

The material used for the experiment is maraging steel 1.2709 with the commercial marking MS1. The material achieves excellent mechanical properties after printing: for example, tensile strength up to 1200MPa and hardness of approximately 36HRC. An advantage of this steel is that it can be subjected to heat treatment, thereby making it possible to reach two material states. The first state is achieved by annealing to eliminate internal stress. The material achieves great mechanical properties in terms of toughness after this heat treatment. The second state is achieved by age-hardening. The material achieves excellent mechanical properties after this heat treatment, for example tensile strength up to 2000 MPa and hardness up to 55 HRC. The printed part can be machined, spark-eroded, welded, sandblasted, polished and coated. [EOS 2016], [Capkova 2015].

Reference [Thomas 2009] provides very substantial information about the geometrical limitations of 3D printing using DMLS. This study includes the very latest research and describes the rules for the creation of parts optimized for 3D printing using DMLS. The experiments were carried out with stainless steel with commercial marking 316L, but this is not so important because the rules are almost identical. The listed rules are verified in the experimental section of this study. The verification of the rules focuses especially on construction units, for example holes, threads, gaps between parts, thin walls, overhanging ends, etc. Reference [Kucerova 2016] provides much information about the metallography of printed steel 1.2709 with commercial marking MS1. This reference provides useful information about this printed material and gives an idea of the metallographic composition of the material and its properties. Reference [Hanzl 2015] gives information about the influence of processing parameters on the mechanical properties of SLM parts. The author describes individual parameters which influence the mechanical properties of a part. Significant parameters are laser power, scan speed, hatching, building direction and layer thickness. References [EPMA 2016] and [Matilainen 2012] also deal with geometric limitations for 3D printing using DMLS. These references give information about what it is possible to print and what complications we might expect.

2 POWDERED MATERIAL MS1

The material used for additive manufacturing is maraging steel with the commercial marking MS1. The conventional European standard designation is 1.2709 and, according to DIN, is X3NiCoMoTi 18-9-5. This kind of steel is characterized by having very good mechanical properties, and being easily heat-treatable using a simple thermal age-hardening process to obtain excellent hardness and strength. The material is characterized by good machinability, weldability, and it is suitable for polishing and coating. The material composition is shown in Table 1. [EOS 2016], [Kucerova 2016], [Hanzl 2016]

Table 1. Material composition [EOS 2016]

Fe	Ni	Co	Ti	Al
Balance	17-19	8.5 -9.5	4.5 - 5.2	0.6 - 0.8
Cr	Cu	C	Si	S, P
≤0.5	≤0.5	≤0.03	≤0.1	≤0.01

The steel for 3D printing using DMLS is supplied in powder form. There are several kinds of powder with different shapes of particles, which primarily depend on the principle of production. The powder is made by atomization using gas. The powders made by this method are spherical, which is useful for better filling of the air gaps in the powder. The powder particles have different diameters. Different sizes of particles lead to a better volume fraction of the metal. The diameter of particles ranges from 10 to 40 micrometres. [EOS 2016], [Kucerova 2016], [Hanzl 2016]

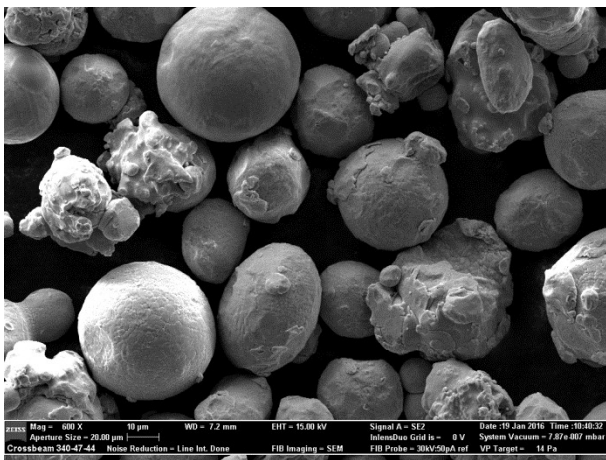


Figure 1. The powder particles

3 EXPERIMENT

The EOS M290 printer was used for manufacturing the experimental samples. This printer allows fast, flexible and cost-effective production from various metal materials. A 400-watt fibre laser provides an exceptionally high beam quality combined with stable performance. The scanning speed can be up to 7m/s. The building volume is 250 x 250 x 325 mm.

The test sample is created as one piece, which is composed of several samples with different sizes of overhanging ends. The size of the base is 65 x 15 x 10mm. The overhanging ends are built 5mm above the base. The overhanging ends are from 0.6 mm up to 1.6 mm with a step of 0.2mm. The overhanging ends are printed without support structures to find the size of the overhanging end with adequate geometry and good quality. The test sample is shown in Fig. 2.

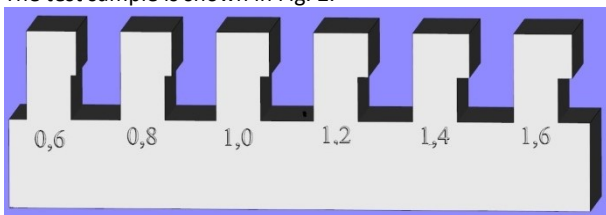


Figure 2. Test sample

The test samples were situated with different orientations on the building platform. The influence of the position on the size and quality of the overhanging ends was investigated. The first sample was oriented in the X axis and the second in the Y axis.

The Y axis is parallel to the recoater blade and the X axis is perpendicular to the recoater blade. Samples were printed using support structures, but the support structures were used only under the base. The height of the support structures was 6 millimetres. The height of the support structures has to allow the parts to be cut off from the building platform using a band saw. Two types of support structures were used: block and cone. The support structure of the block was set as follows: Hatching 0.65 x 0.65mm, Hatching teeth – Height 1.0mm, Top length 0.35mm, Base length 0.8mm and Base interval 0.15mm, Fragmentation 5.2 x 5.2mm and separation width 0.65mm. The cones were situated in each corner and in the middle of the part. The support structure of the Cone was set as follows: Contact to part (r1) 0.8mm, Contact to platform (r2) 2mm, Upper a lower Z Offset 0.25mm. The cones ensure better rigidity of the support structures.

The test samples were printed using parameters recommended by the manufacturer. The basic parameters include the intensity of the laser power, scanning speed, beam offset, overlap, hatching, skywriting, etc., as shown in Fig. 3. The manufacturer claims excellent properties in various types of printed parts using the predefined process parameters. These parameters are universal and they can be used for printing high-volume parts or thin-walled parts. However, each of these parts have different specifics and therefore it is possible to find better process parameters for certain parts. Finding the process parameters is a very demanding activity and therefore the vast majority of users of 3D printers use the process parameters recommended by the manufacturer. The universal process parameters are locked and therefore the size of each parameter cannot be determined. EOS uses three types of universal process parameters: EOS_Direct_Part, EOS_Direct_Tools and EOS_Support_Structures. EOS_Direct_Part is used for building the parts which are printed with a support structure, but the support structure is set as EOS_Support_Structures. The parts printed without support structures have to be printed directly on the building platform and they are set as EOS_Direct_Tools. The parameters of individual settings are different. The layer thickness is 40 micrometres.

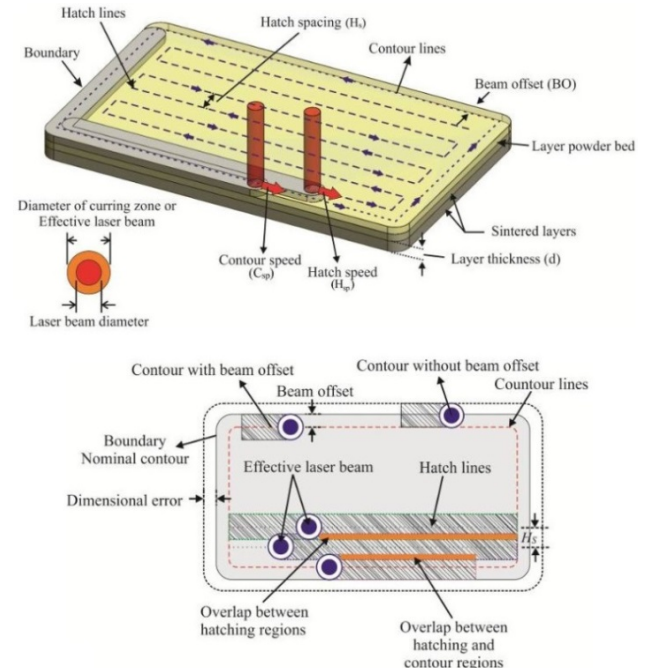


Figure 3. Parameters of 3D print [Bineli 2011]

4 HATCHING

Hatching means the paths of the laser beam. The hatching is composed from several sectors, and the size of each sector can be edited. The basic hatching is composed from three sections: Downskin, Inskin, and Upskin. There are also other types such as Inner Skin, etc. Fig. 4. explains what they mean and where individual sections are used.

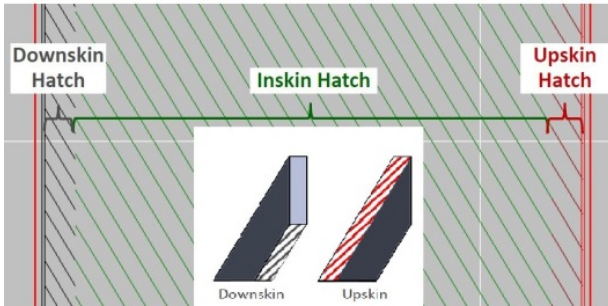


Figure 4. Hatching [EOS 2016]

It is evident from the name that Upskin is located on the upper side part and Downskin is located on the underside of the component. The default setting for the size of the Downskin and Upskin areas is set at 4 layers. Downskin and Upskin are not used for vertical walls. Downskin hatching is denser than other hatching methods. A better surface quality is achieved using this method of hatching. [EOS 2016]

The paths of the laser are changed in each successive layer to improve the properties of the part. The best angle for rotation of successive layers was determined as 67°. Fig. 5 shows four successive layers with an overhang size of 1.6 mm. [EOS 2016]

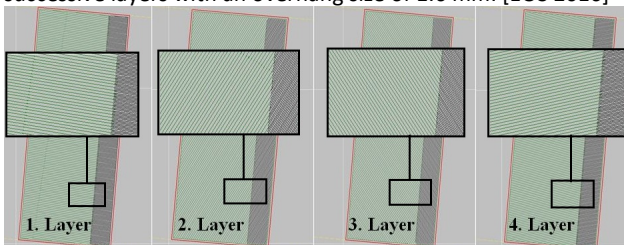


Figure 5. Hatching - four successive layers

5 PRINTING

The printing of the test samples proceeded without obvious problems or complications only to the height when the test sample did not have overhanging ends. The problem started when the printing of the overhanging ends began. Excessive heating of the thin walls occurred during printing. During the sintering of successive layers "lighting up" areas of the overhanging ends occurred. This was caused by enormous heating due to poor heat removal, which accumulated in the small cross-section. This enormous heating was observed only in the first few layers. The phenomenon decreased until it completely disappeared. This phenomenon had a visible impact on the geometric accuracy of the overhanging ends, as shown below.

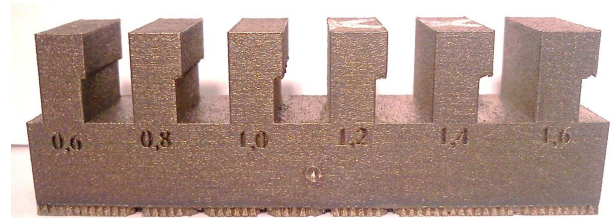


Figure 6. Printed test sample

6 EVALUATION

The sizes of the overhanging ends were evaluated using a Multicheck PC 500 optical microscope. This microscope is primarily designed for measurement of tool wear. The accessories include additional lighting and especially clamping systems. The microscope is equipped with an automatic exchange of lenses and allows a maximum magnification up to 200 times. This device is capable of measuring to an accuracy of up to 0.005 mm. The overhanging ends were measured using 20 and 120 times magnification. Twenty times magnification was for informative purposes only.



Figure 7. Microscope Multicheck PC 500

All measured overhanging ends are grouped here into one image for clarity. The differences between overhanging ends are clearly visible in this picture. The geometry of overhanging ends with size 1.4 and 1.6mm is not adequate as can be seen with the naked eye.

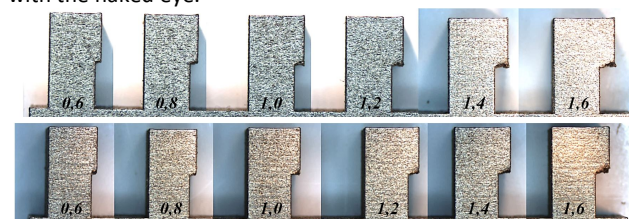


Figure 8. Measuring using 20x zoom - the first row with orientation X, the second row orientation Y

Observation of the overhanging ends was very surprising but higher magnification, because none of the overhanging ends achieved rectangular geometry. The overhanging end 0.6 mm printed in the X axis was the closest, but all the other overhanging ends deviated from rectangular geometry to a greater or lesser extent. The deviation increases with the larger size of the overhanging ends. Figure 9. shows overhanging ends with sizes of 0.6mm in X axis, 0.8mm in Y axis, 1.2 mm in Y axis and 1.6 mm in X axis.

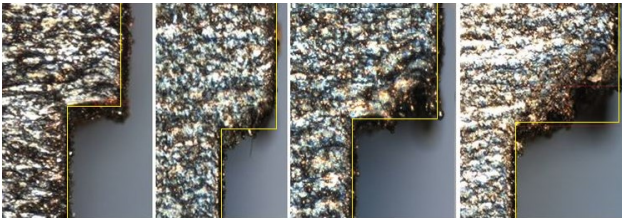


Figure 9. Detailed view of real geometry

7 THE SURFACE OF OVERHANGING ENDS

Very poor surface quality was detected on all the overhanging ends. This fact is confirmed in Fig. 10, which shows the overhanging ends from the underside. The ends with a size bigger than 1mm have very bad surface quality, which is formed by big craters and "burns". The surface shows signs of colouring, which confirms that the intensity of the heat was disproportionate in a given location. The ends with a size smaller than 0.8 mm have slightly better surface quality. The surface is formed by more regular and considerably smaller "burns" and craters.

A decrease of volume was observed at the end of the overhanging ends with sizes bigger than 1.0 mm. This reduction of the end is caused by sintering of a bigger volume of powder due to poor removal heat at this point. The bad heat removal is caused by the absence of support structures. Sintering a large volume of the material leads to the formation of large blocks and "burns".

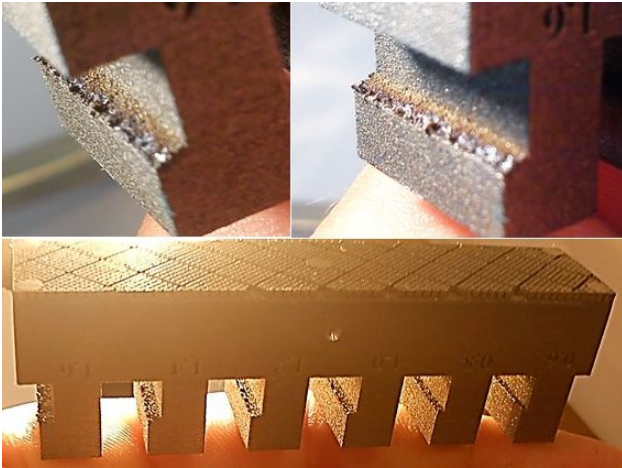


Figure 10. The surface of the overhanging ends

8 CONCLUSIONS

This paper presents the results of experiments conducted on overhanging ends made by 3D printing using the DMLS method. The results were evaluated experimentally. The experiment focused on printing overhanging ends without support structures.

A problem with printing overhanging ends was detected during the printing, however this problem did not endanger the safety of printing. Enormous heating of the thin overhanging ends was caused due to poor removal of heat energy. This fact leads to 'lighting up' of the overhanging ends. The intensity of the added energy was increased by densification of the paths of laser. The paths of the laser were compressed by using the Downskin hatching method. It would be better not to use Downskin in this case, which would lower the intensity of the energy input and result in better results for the overhangs. Nevertheless, when using hatching without Downskin for complex parts, if only the size and geometry of the overhangs were not evaluated, worse results would be acquired.

The printed series of overhanging ends was designed based on the information from the research activities. Despite the research activities, the interval was not perfect, because only one overhanging end was printed adequately. The 0.6 mm overhanging end printed in the X axis was closest to this geometry. All the other overhanging ends differed in their rectangular geometry to a greater or lesser extent. The deviation increased with the larger size of the overhanging ends. It would be appropriate to choose lower sizes for overhanging ends with smaller steps between individual ends for further research.

Very bad surface quality can be observed among the overhanging ends bigger than 1.0 mm. These ends were influenced by heat. The surface quality of all the overhanging ends is relatively bad.

The different orientation of test samples on the building platform showed no significant effect on the size or geometry of the overhanging ends.

ACKNOWLEDGEMENTS

The present contribution has been prepared under the project LO1502 'Development of the Regional Technological Institute' under the auspices of the National Sustainability Programme I of the Ministry of Education of the Czech Republic aimed at supporting research, experimental development and innovation.

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