EVALUATION OF CHOSEN PARAMETERS OF SURFACE ROUGHNESS (MICROGEOMETRY) ON THE SAMPLES FROM STAINLESS STEEL 316L AND MANUFACTURED BY THE ADDITIVE TECHNOLOGY SLM

PAGÁČ Marek[1], MALOTOVÁ Šárka[1], ZLÁMAL Tomáš[1], PETRŮ Jana, KRATOCHVÍL Jiří[1]

[1]*VSB - Technical University of Ostrava, Ostrava, Czech Republic, EU*

Abstract

The article deals with the evaluation of chosen parameters of surface roughness on the square section samples from stainless steel 316L (1.4404), manufactured by the additive technology with using Selective Laser Melting method (SLM). As part of the experiment was measured (scanned) and compared of chosen parameters of surface roughness on plane area of the samples printed in the same process parameters with a difference of power of the laser. One set of samples was printed during half power machine (200 W), the second during maximum power (400 W). The samples were oriented in the building chamber in the same way. The plane areas of blocks were parallel with plane XZ and YZ of coordinate system of 3D printer Renishaw AM400. The measuring of parameters of surface roughness was evaluated by optical microscope Alicona Infinite Focus5.

Keywords: 3D printing, additive technology, renishaw, surface roughness, alicona microscope

1. INTRODUCTION

Additive manufacturing (AM) replace conventional technology and currently is used for production the prototypes and functional samples, when CAD models are source data. The additive process is characterized by the coating of material layer in axis Z. This technology is opposite of conventional machining, when the cutting tool takes away the machined material. Internal structure and material properties of powder have an influence on the mechanical properties of produced component. The additive technology of production are the most used for manufacturing prototypes for the purpose of biomedicine, design and in the aviation, cosmic and automotive industry.

The results could be the new shapes emphasizing modern look and construction solution, where is used topological optimization, which can be achieved saving of material with regard to strength and district conditions. Due to high purchase cost not only machine, but material of the powder is necessary maximal usability and the effort to achieve the best parameters of building. The using of additive technologies in mechanical engineering is developing and to serve for purpose rapid prototyping. The main advantages is finding errors in documents and concepts, verification of manufacturability, assessment of the appearance, verification of suitability for series production and last but not least reverse engineering [1, 2].

2. SELECTIVE LASER MELTING

The Additive technology is classified by the standard ISO/ASTM 52900:2015 Additive Manufacturing - General Principles - Terminology. Distribution of technologies can be defined according to the input material and energy supply. The technology of sintering powder layers (Powder Bed Fusion) is process of rating individual layers of metal powder on the basic table with the same chemical composition as metal powder. This technology (according to producer SLM - Selective Laser Melting) works on the principle high power laser, when the basic material is melted - metal powder, which is coated on the platform in very thin layer and by scanning of laser beam is created 3D object in axis Z. Primarily, profile is harden after application of the metal powder and then the building is finished. The building chamber is filled up by inert gas - argon (some machine uses nitrogen). [3]

The models created by SLM technology achieve sufficient strength, mechanical and chemical resistance. The technology replaces forms for plastic injection molding due to the excellent mechanical properties. These forms are called like as forms for comfort cooling. Its big disadvantage is porosity. The buildings could be separated by wired electro erosive machining or saw. The production process of SLM is influenced by process parameters, which are dependent on each other [4, 5].

- **Powder** - distribution, size and shape of grain, distribution of particles, material properties.
- **Laser** - power, beam distribution, speed of material rating, influence of protective atmosphere, time and frequency of pulse.
- **Temperature** - temperature of building platform, temperature of feeder, thermal conductivity.
- **Production strategy** - scan speed, distance of hatches, thickness of coated layer, scan strategy of laser beam - chessboard, stripes, total fill and meander **(Figure 1)** [6].

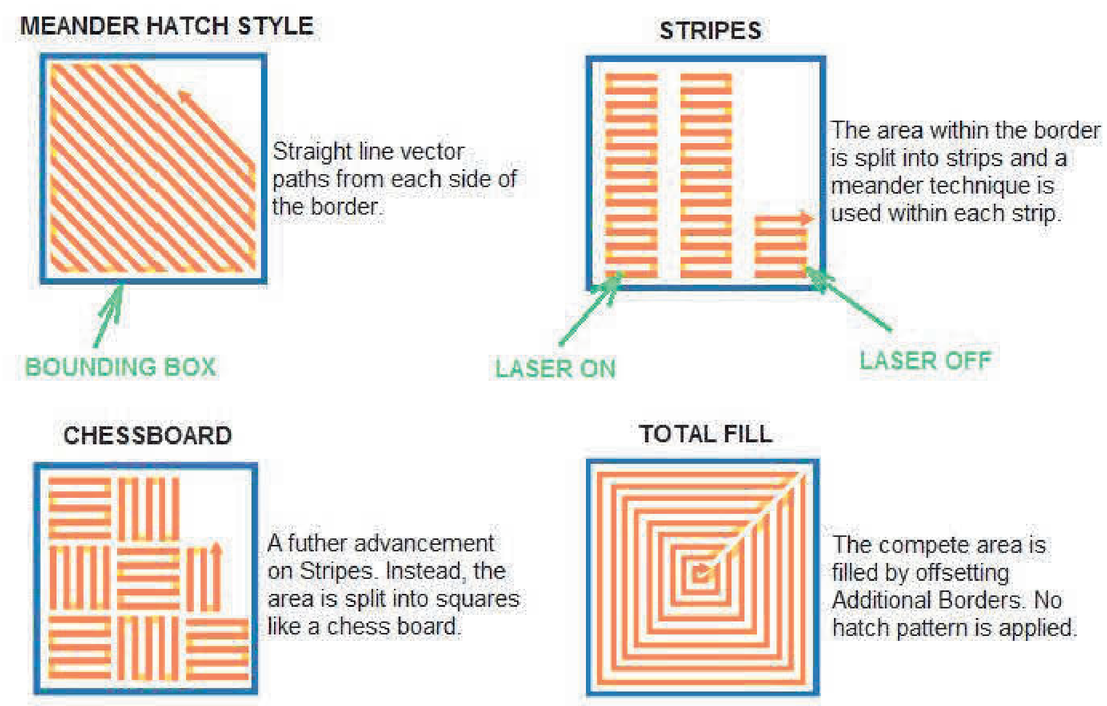

Figure 1 Types of hatch styles [7]

3. DESIGN OF EXPERIMENT

3.1. Experimental equipment

This experiment was realized with using 3D printer Renishaw AM 400 **(Figure 2)** in the Laboratory of Additive Manufacturing, at Department of Machining, Assembly and Engineering Metrology, Faculty of Mechanical Engineering, VSB-TU Ostrava. The machine allows fast air suction from working space, which is then filled up inert atmosphere - argon gas. It is equipped filtering system, which doesn't allow to operator contact with emission. Part of the machine is software Quant AM for preparing production of components, inserting and editing of CAD model, change of geometry and settings of process parameters.

Figure 2 3D Printer Renishaw AM 400

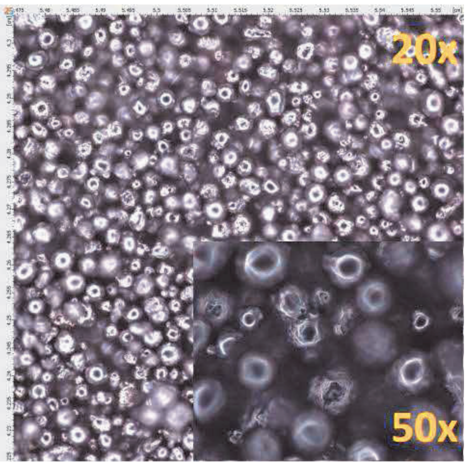

Figure 3 Magnification of metal powder 316L

3.2. Metal powder

The samples were printed from stainless steel 316L. It is se o an austenitic stainless steel which comprises iron alloyed with chromium of mass fraction up to 18 %, nickel up to 14 % and molybdenum up to 3 %, along with other minor elements. Material properties are high hardness, toughness, high corrosion resistance, high machine-ability. Magnification of powder 316L is shown in F**igure 3** by Alicona Infinite Focus microscope. [8]

3.3. Design and printing of samples

For evaluation the chosen parameters of surface roughness were proposed three samples of the square section about dimension (10 × 10 × 70) mm. The prisms were organized on the platform (250 × 250 × 15) mm in one row and they were printed during power of machine 200 and 400 W. Planar surfaces of the blocks were parallel with XZ and YZ planes of 3D coordinate system of printer. During the printing process, thin layer of 50 μm of metal powder was coated from rear towards the front of the building chamber. The samples were printed by strategy Meander, when the laser beam melted metal powder from left side of chamber to right (against the stream argon). The platform has moved about fixed value in Z axis and he laser beam turned about 67° before the next layer was created for each sintering (**Figure 4**). The platform was preheated to 170 °C..

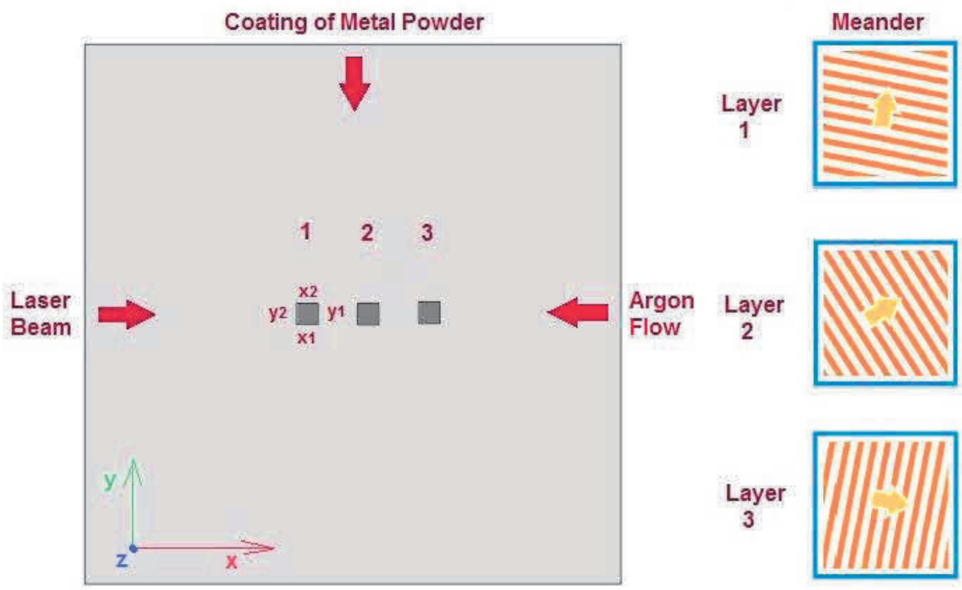

Figure 4 Layout of samples during printing

Rotating the beam is eliminated the ability to scan individual lines continuously at the top of the sample and is reduced the porosity of the structure. The strategy of Meander is characterized, that the residual heat is accumulated in the lower left and upper right corners, which is substantially larger than in the middle part, where is longer time to create the next track. This strategy is fast and effective, especially for building samples with small cross section. The printed samples are shown in **Figure 5**, which were printed in maximum and half power.

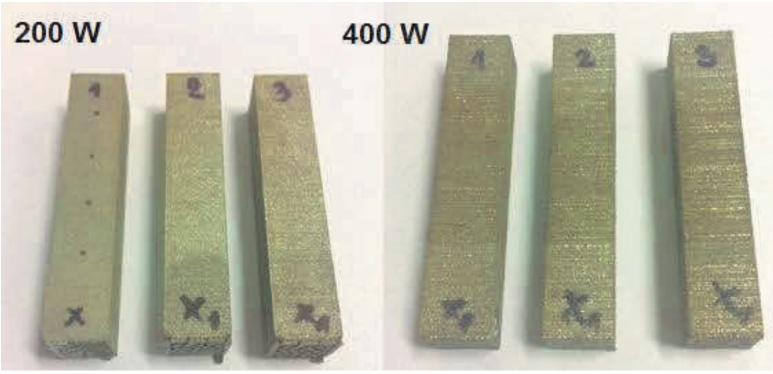

Figure 5 The printed samples from material 316L at different machine performance

4. EVALUATION OF THE RESULTS

The chosen parameters of surface roughness individual sample were measured and evaluated based optical contactless microscope Alicona Infinite Focus 5 (**Figure 6**). The main part of the whole system is portable optics containing the objectives, which allow the measurement with different distinction. The advantage the whole microscope is wide range of measurable areas, using of optimized LED light and coaxial lightning. The device ensures the high accuracy and repeatability of the whole measurement. The results each measurement is protocol with the required parameters of measurement including input conditions and graphical view scanned surface of component.

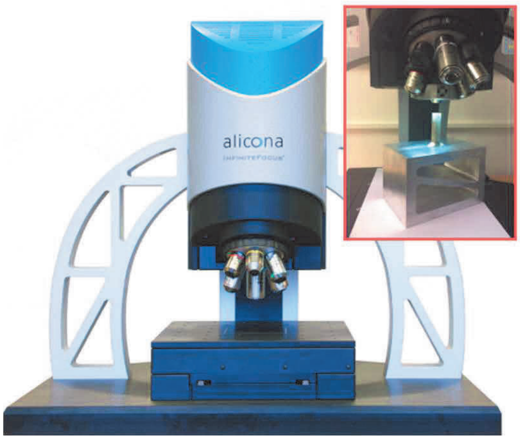

Figure 6 Alicona Infinite Focus 5 microscope

Samples were situated on the preparation under the objective (**Figure 6**). The measurement was realized with LED light, the objective with distinction 10× for power 200 W and the objective with distinction 5× for 400 W. For each sample were measured parameters of surface roughness of all four walls and upper base for the both power of the printer. The samples were not heat, chip and surface treatment. After measurement were evaluated average arithmetic deviation *Ra* [μm] and maximum profile height *Rz* [μm]. The each area was measured five times and statistical processed results all samples are shown in **Table 1**. At the **Figure 7** are shown scanned surfaces for the both power of machine, where the resulting roughness with the use of the color spectrum is shown there. At 200 W, the surface is created by a much smaller amount tops or hollows than with using maximum power of printer.

Table 1 The Evaluation of parameters of surface roughness in 200 W and 400 W of machine

200 W	Sample 1		Sample 2		Sample 3	
Area	*Ra [μm]*	*Rz [μm]*	*Ra [μm]*	*Rz [μm]*	*Ra [μm]*	*Rz [μm]*
X_1Z	13.86 ± 0.19	93.81 ± 0.86	12.88 ± 0.22	85.03 ± 0.78	13.81 ± 0.39	97.04 ± 0.45
Y_1Z	14.45 ± 0.25	91.02 ± 0.45	13.24 ± 0.35	92.20 ± 0.96	11.93 ± 0.43	81.59 ± 0.79
X_2Z	8.48 ± 0.09	48.62 ± 0.21	7.01 ± 0.31	54.25 ± 0.79	9.12 ± 0.07	66.23 ± 0.67
Y_2Z	8.25 ± 0.10	58.03 ± 0.26	10.1 ± 0.33	74.78 ± 0.76	10.73 ± 0.11	73.17 ± 0.98
Base	7.93 ± 0.06	60.79 ± 0.45	8.52 ± 0.26	64.84 ± 0.61	8.63 ± 0.09	56.16 ± 0.47
400 W	Sample 1		Sample 2		Sample 3	
Area	*Ra [μm]*	*Rz [μm]*	*Ra [μm]*	*Rz [μm]*	*Ra [μm]*	*Rz [μm]*
X_1Z	3321 ± 0.21	218.19 ± 1.63	35.85 ± 0.45	219.37 ± 1.06	36.67 ± 0.78	240.55 ± 0.83
Y_1Z	36.81 ± 0.37	229.26 ± 1.07	30.89 ± 0.50	226.84 ± 0.81	32.61 ± 0.22	217.08 ± 0.71
X_2Z	27.35 ± 0.49	187.32 ± 0.99	22.02 ± 0.87	179.22 ± 0.34	26.53 ± 0.49	179.33 ± 0.45
Y_2Z	23.84 ± 0.47	164.44 ±1.01	27.29 ± 0.22	188.84 ± 0.74	28.34 ± 0.16	186.59 ± 0.63
Area	4.76 ± 0.27	25.44 ± 0.68	3.38 ± 0.06	19.15 ± 0.12	5.16 ± 0.45	25.63 ± 0.11

The each area was measured five times and statistical processed results all samples are shown in **Table 1**. At the F**igure 7** are shown scanned surfaces for the both power of machine, where the resulting roughness with the use of the color spectrum is shown there. At 200 W, the surface is created by a much smaller amount tops or hollows than with using maximum power of printer.

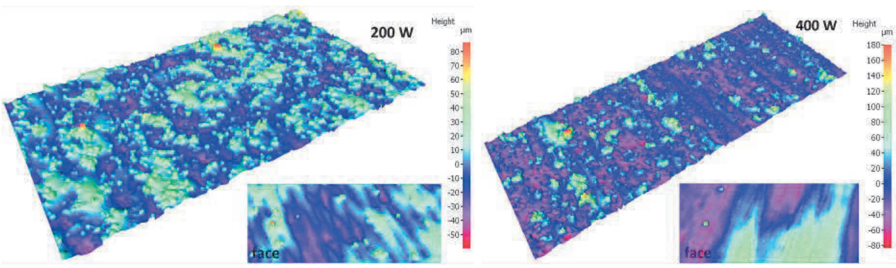

Figure 7 Magnified surface of samples at 200 and 400 W

The exceptions are the areas of the upper base, on which was evaluated surface roughness as the best of all values for the both power. From the measured results and the visual inspection it was pronounced that better is used half machine power (200 W) to print prototype samples. Surface roughness of these samples was up to 60 % better. However, their quality was not ideal for functionality, which is typical for parts manufactured by the additive technology. Currently, unfortunately, any available technologies exist, which ensures to made shape and dimensionally accurate model with high surface quality requirements.

For the both power, it was characterized that in X_2Z and Y_2Z planes were measured smaller values of parameters of surface roughness - better than in the other two planes. The values were around Ra = 10 μm for power 200 W. Their quality was compared with measured results for these bases. The surfaces, which were printed at maximum power, showed signs of a strong deterioration by compared to previous conditions. The value of parameter of surface roughness Ra was approaching to 40 μm.

5. CONCLUSION

The Additive technology allows manufactured form - complex components, which are unavailable for conventional technology of production. By adhering to the required quality of material, it becomes an integral part of the industry engineering. The aim of experimental activity was measured and evaluated the chosen parameters of surface roughness on the samples made from SLM method with using 3D printer Renishaw AM 400. Its results were compared of parameters of surface roughness measured on flats six samples. The both set of samples were printed in the same conditions, which were: situation and orientation of samples, direction of flow of protective gas, height of the layer of metal powder and used strategy (Meander). The one difference in input parameters was used power of machine: 200 and 400 W.

The experiment confirmed that the power of machine has an influence on the surface roughness quality of samples made from material 316L. Samples, which were printed with using a half power (200 W), showed better surface roughness then with using maximal power up to 60 %. This power is sufficient for building of prototypes and achieves better surface properties. The next difference during evaluation of surface roughness was orientation of individual samples in building chamber. Worse, higher values were measured on the walls of samples, which were built up in X_1Z and Y_1Z planes for the both using power. Precise results cannot be uniquely determined, so it is recommended to perform the experiment in the same conditions with using 200 W again and then reduce the power by 20 W (180 W) and repeat the whole experiment. Changing conditions can significantly influence the resulting print surface quality.

ACKNOWLEDGEMENTS

Article has been done in connection with projects Education system for personal resource of development and research in field of modern trend of surface engineering - surface integrity, reg. no. CZ.1.07/2.3.00/20.0037 financed by Structural Founds of Europe Union and from the means of state budget of the Czech Republic and by project Students Grant Competition SP2017/147 and SP2017/149 financed by the Ministry of Education, Youth and Sports and Faculty of Mechanical Engineering VŠB-TUO.

REFERENCES

[1] ABE, F. et al. The manufacturing of hard tools from metallic powders by selective laser melting. *Journal of Materials Processing Technology,* 2001, vol. 111, no. 1-3, pp. 210-213.

[2] KRUTH, J-P, et al. Binding mechanisms in selective laser sintering and selective laser melting. *Rapid Prototyping Journal,* 2005, vol. 11, no. 1, pp. 26-36.

[3] GUO, N., LEU, M.C. Additive manufacturing: technology, applications and research needs. *Fronties of Mechanical Engineering,* 2013, vol. 8, no. 3, pp. 215-243.

[4] Aditivní technologie: Zpráva o stavu 3D tisku pro Českou technologickou platformu STROJÍTENSTVÍ, o.s. *Česká strojírenská platforma* [online]. [cit. 2017-04-30]. Available from: www.ctps.cz/cs/uvodni-stranka/soubor-aditivni-technologie/85/.

[5] ILČÍK, J., KOUTNÝ, D. PALOUŠEK, D. Geometrical Accuracy of the Metal Parts Produced by Selective Laser Melting: Initial Tests. In: *Modern Methods of Construction Design*. Switzerland: Springer Int Publishing, 2014, pp. 573-582.

[6] YADROITSEV, I., BERTRAND, Ph., SMUROV, I. Parametric analysis of the selective laser melting process. *Applied Surface Science,* 2007, vol. 253, no. 19, pp. 8064-8069.

[7] Magics training: Material profile editing. *RENISHAW: apply innovation* [online]. United Kingdom: Renishaw, 2016 [cit. 2017-04-30]. Available from: renishaw.com.

[8] SS 316L - 047: Powder for additive manufacturing. *RENISHAW: apply innovation* [online]. United Kingdom: Renishaw, 2015 [cit. 2017-04-30]. Available from: renishaw.com/additive.