15th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2011, Prague, Czech Republic, 12-18 September 2011

RESEARCH ON HOW TO IMPROVE THE MECHANICAL PROPERTIES OF THE METALLIC PARTS MADE BY SELECTIVE LASER MELTING (SLM)

Pacurar Razvan, Berce Petru, Dura Mihai
Technical University of Cluj-Napoca
B-dul Muncii no. 103-105, Cluj-Napoca
Romania

ABSTRACT
Within the Selective Laser Melting (SLM) process, there are a number of input parameters that can be controlled and modified in order to obtain different characteristics of the selective laser melted parts. Some of this input factors pertain to the laser (e.g. laser power, laser scan spacing, etc.), while others refers to the metallic powder properties (e.g. particle size, percentage composition of the constituent materials, etc.) or to the melting parameters (e.g. layer thickness, scanning speed, etc). Output parameters of interest might be hardness, density, strength, porosity, etc. The current paper is focusing mainly on the density and porosity issue. Theoretical and experimental methods for improving the mechanical properties of the metallic parts made by SLM from Stainless Steel 316L powder are revealed. A solution for controlling the porosity of the SLM metallic parts is also presented in the paper.
Keywords: Additive Manufacturing, Selective Laser Melting, Stainless Steel 316L, Mechanical Properties

1. INTRODUCTION
Over the last decade, the Selective Laser Melting (SLM) process has gained a wide acceptance as a Rapid Prototyping (RP) technique [1]. Due to the technical improvements, a better process control and the possibility to process all kind of metals, a shift to firstly Rapid Tooling (RT) and secondly Rapid Manufacturing (RM) came up in recent years [2]. Many applications could take advantage of this evolution by using the SLM not only for visual concept models and onetime functional prototypes, but also for tooling moulds, tooling inserts and end-use functional parts with long-term consistency [3]. In order to turn the SLM process into a production technique for real components, some conditions have to be fulfilled. Firstly, manufacturing applications increase the requirements on material and mechanical properties [4]. The process must guarantee consistency on the entire product life cycle. Secondly, process accuracy, surface roughness and the possibility to fabricate geometrical features like overhanging surfaces and inner structures become very important for manufacturing. Finally, the breakthrough of the SLM process as a RM technique will depend on its reliability, performance and economical aspects like production time and cost. The presented work investigates if the SLM process fulfills these manufacturing requirements, mainly on mechanical properties, trying to show opportunities of new applications of direct metal manufacturing by means of SLM [5].

2. RESEARCH ON HOW TO IMPROVE THE MECHANICAL PROPERTIES OF THE METALLIC PARTS MADE BY SLM

2.1. The SLM process parameters
There are several parameters having influence on the mechanical properties of the selective laser melting (SLM) process, such as the laser power, the scanning speed, the layer thickness, the lens focus

position or the powder bed temperature. There is a limit for these parameters, according to the MCP Realizer SLM 250 equipment manufacturer recommendations, like for example 100-200 Watts for the Laser Power, 0.1-0.5 m/s for the scanning speed, 100-200 °C for the powder bed temperature, depending on the metallic powder we are using for the manufacturing process. Beside the specified parameters in the MCP Realizer II manufacturing software package, an important step consists in correct part orientation. This step it is very important because it will determine how the building supports will be generated. This step will not only influence the total time of the part to be manufactured on the machine, but also it will influence its mechanical strength.

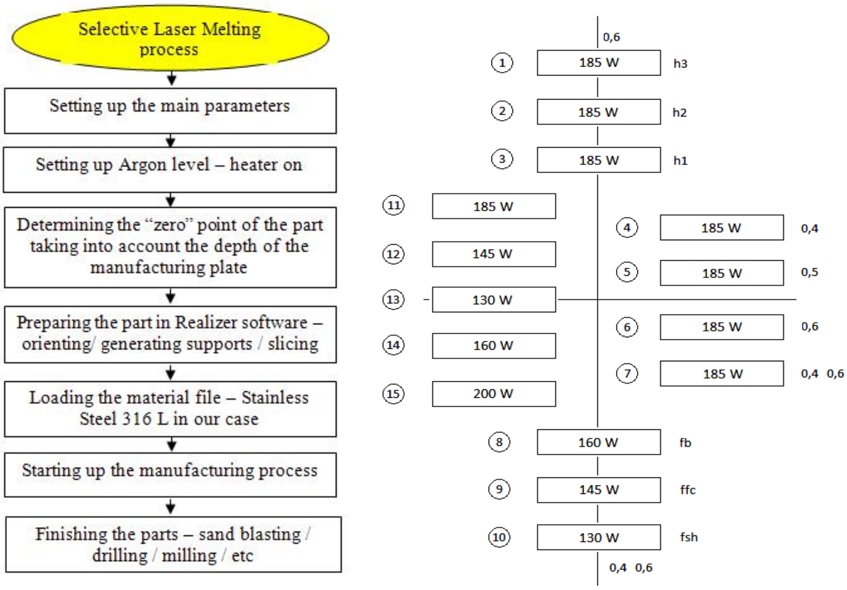

Figure 1. The SLM process and our experimental organizing plan for the SLM process

For setting up the machine several steps needs to be followed as illustrated in Figure 1. If the preparing procedure looks quite simple at one first look, the SLM process control it is not so simple, especially when the total manufacturing time is more than 24 hours of effective work. It is not the laser system, which could cause problems in this case, as it is the temperature control during the process. The manufactured part accumulates heat in time, so shrinkage phenomena occur during the SLM manufacturing process. If we consider that the machine is in the right focus position and the layer thickness we work with is set to the minimum value, we could consider that the SLM process is mainly influenced by the scanning speed, calculated as the minimum point distance over the exposure time and the laser power we use during the manufacturing process. As illustrated in Figure 1, our experimental organizing plan consisted in varying of the laser power and scanning speed we are working with in order to observe how these two parameters influences the mechanical properties of the manufactured parts (samples), such as the density/ porosity of the parts. The material we have worked with was Stainless Steel 316L powder material.

2.2. Samples manufactured by SLM and porosity/density calculus

Several samples as the ones illustrated in Figure 2 were manufactured at the Technical University of Cluj-Napoca (TUC-N) on the MCP Realizer II SLM 250 equipment, according to the experimental plan presented in Figure 1. The technological parameters, such as layer thickness – 0.05 mm, build chamber temperature - 180˚C, oxygen level inside the build chamber – 0.1 %, were the same for all the manufactured samples. Only two parameters - the laser power (in Watts) and the scanning speed (in meters/seconds) were varied according to our experimental plan presented in Figure 1.

Figure 2. Samples manufactured at the Technical University of Cluj-Napoca on the SLM equipment

The samples manufactured by SLM were afterwards analyzed with an electronic microscope as illustrated in Figure 3. As could be observed by analyzing the cross sections of the samples from the electronic microscope images, in the case, when 185 W laser power was used, the obtained density of the manufactured part has been closed to 100 %. Remaining porosities are clearly visible as black spots in these images (see Figure 3). Only little amount of pores appears in the last image thanks to the beneficial effect of the available preheating system. Slower cool down rates allow gas inclusions to escape from the melt pool before solidification of the material. The micro-hardness is rather high because the melt pool cools down very rapidly when the laser beam has passed.

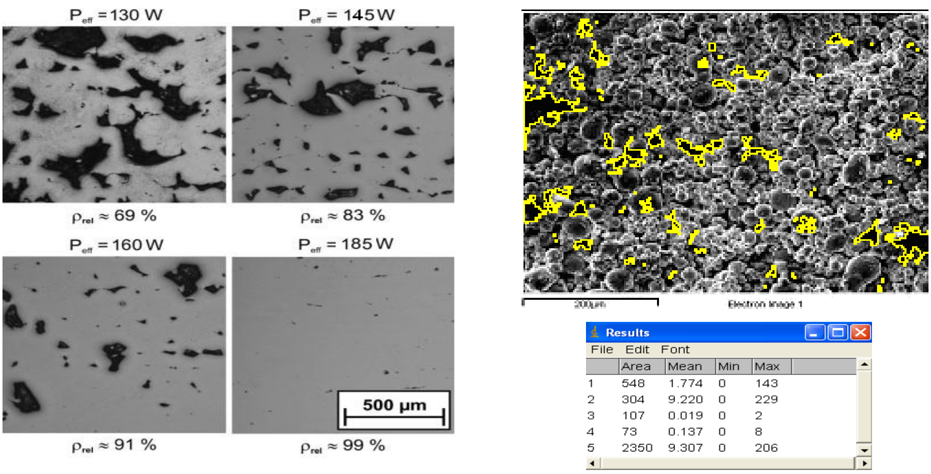

Figure 3. Samples analyzed on the electronic microscope from the TUC-N and ImageJ software

ImageJ software was used in order to determine the porosity of the samples manufactured by SLM. The porosity in this case (by the experimental point of view) was calculated by using the following formula:

$$p = \frac{\sum Ai}{Atot} \tag{1}$$

where A_i represents each granule area and Atot is the entire image area.
By the theoretical point of view, there is also a possibility to calculate the porosity of the samples, by using the formula:

$$p = 100 \cdot (1 - \frac{\rho}{\rho_T}) \qquad (2)$$

where ρ is the apparent density and ρ_T is the theoretical density provided by the MCP Realizer SLM 250 equipment manufacturing company (8 g/cm^3 for Stainless Steel 316L material).
The apparent density ρ was calculated by using formula (3):

$$\rho = \frac{m}{V} \qquad (3)$$

where m is the sample's weight, in grams and V is the sample's volume, in *cm^3*.
By analyzing all the images with ImageJ software analyzer and by calculating the porosity using formulas (1) and (2), the results were comparable in both cases, by the theoretical and the experimental point of view. A very interesting phenomena it has been observed, consisting in the fact that the porosity has been decreased from 31 % when 130 W laser power has been used to less than 1 % in the last case when 185 W laser power has been set up for manufacturing the part on the MCP Realizer II SLM 250 system. When 200 W laser power is being set-up on the machine, we have obtained less than 1 % of pores inside the material structure, but shrinkage phenomena severely occurred, because too much energy is being applied on a very thin melted surface. As regarding the scanning speed we had worked with, we observed that at the same laser power we worked with, like, if the scanning speed is decreased from 0,6 m/s to 0,4 m/s, the relative density of manufactured material will be significantly increased, so in consequence the porosity of the material will be significantly decreased to less than 1 %.

3. CONCLUSION

In conclusion of our theoretical approach and made experiment, we could state that if the laser power is increased and the scanning speed is decreased, the relative density of manufactured part by SLM will be significantly increased, so in consequence the porosity of the material will be significantly decreased. The best result was obtained when a laser power of 185 W and a scanning speed of 0,4 m/s were used to manufacture several samples made by Stainless Steel 316L material using the MCP Realizer SLM 250 equipment. Future research still needs to be done in the future regarding the part's roughness, heat transfer and the influence of the powder bed temperature on the manufactured parts made on the SLM equipment, issues that severely affects not only their accuracy, but also their mechanical properties, such as the fracture strength, elongation, hardness, etc.

4. ACKNOWLEDGMENT

This paper was supported by the project "Development and support of multidisciplinary postdoctoral programmes in major technical areas of national strategy of Research Development - Innovation" 4D-POSTDOC, contract no. POSDRU/89/1.5/S/52603, project co-funded by the European Social Fund through Sectorial Operational Programme Human Resources Development 2007-2013."

5. REFERENCES

[1] Wohlers T, Wohlers Report 2010, State of the Industry, Annual Worldwide Progress Report, http://www.wohlersassociates.com
[2] Branner G, Zaeh MF, Groth C, Coupled-Field Simulation in Additive Layer Manufacturing, Proceedings of the 3rd International Conference on Polymers and Moulds Innovations, Gent, Belgium, 2005
[3] Kruth, J. P. et al., Benchmarking of Different SLS/SLM Processes as Rapid Manufacturing Techniques, Proceedings of the Polymers and Moulds Innovations (PMI), paper 525, Gent, Belgium, April 2005
[4] Dewidar M., Lim, J.K., Dalgarno, K.W, A Comparison Between Direct and Indirect Laser Sintering of Metals, Journal of Materelias Science and Technolgy, 2008
[5] Vandenbroucke B, Kruth JP, Selective Laser Melting of Biocompatible Metals for Rapid Manufacturing of Medical Parts, Rapid Prototyping Journal, 2007