

Adjustment of Selective Laser Melting (SLM) parameters as function of different geometries of metallic components to improve dimensional and surface quality

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Abstract

Selective Laser Melting (SLM) is an effective process for creating small parts with intricate geometries. Even though this process is largely studied, still the surface roughness and feasibility of different materials presents a major limitation for the applicability on some precision industries. Four different key metallic materials (SS 316L, TS H13, SS 420 and Copper), are optimized in SLM process in order to attain the best surface quality, without need of complementary finishing operations. By other hand there is a need to adjust the final dimensions to the design. Cube, semi-sphere, quadrangular pyramid geometries, with different dimensions are selected to evaluate the best parameters to attain a net shape. Infinite Focus Microscopy (IFM) shown that, for each geometry, there is an optimal adjust of parameters to the different geometries/dimensions to achieve the best surface quality and dimensional adjustments possible. Also, the different reductions in area between the STL file and the resulting parts, obliges the design to compensate this dimensional discrepancy, with this being highly dependent on the material used and the phases transformation that occur mid-process. A standard 316L austenitic stainless steel, with no mid-process phase change, was used as comparison. This study is a significant contribute to adjust the experimental conditions to the modelling.

Selective Laser Melting (SLM); Stainless Steel; SS 316L; SS 420; Tool Steel; TS H13; Copper; Surface quality; Geometries; Infinite Focus Microscopy; Dimensional Accuracy; Phase Transformation

1. Introduction

As additive manufacturing (AM) becomes a mainstream process in industrial applications, selective laser melting affirms itself as one of the powder-based processes with more potential to produce high-quality metallic components [1], [2]. However, surface quality has been an issue regarding precision technologies, as is the mould industry [3]. As of previous work, it is largely studied the process parameters to produce overhanging surfaces and minimal surface roughness in a standard geometry, for different metallic materials [4]–[8]. This work pretends to explore and demonstrate that these optimal conditions are not to be generalized to every geometry, choosing different but very basic geometries, as is the cube, semi-sphere and quadrangular triangle. In section 2 we dwell on some SLM surface quality influential factors, transitioning to section 3 methods used for this work. Section 4 resumes some of the results obtained along this work with discussion and comparison with previous work. Section 5 will state some conclusions that can be taken from this work.

2. Surface quality influential factors

2.1. Process parameters

Surface quality is driven by many factors in Selective Laser Melting fabrication [6]. Figure 1 shows that there are at least 4 big influential factors that are dependent on other sub-factors. In this work, it was chosen certain parameters that are varied: bulk energy density and laser power.

Energy density, as stated by EPMA is calculated in the following manner:

$$E = \frac{P}{e \cdot h \cdot v} \text{ [J/mm}^3\text{]} \quad (1)$$

Where E is the energy density, P is the input laser power, e is the layer thickness, h is the hatch spacing and v is the scanning velocity. It represents the fundamental input values for SLM, allowing comparisons between very different works in SLM for each material and it's the driving force for this work chosen parameters. Laser power influences greatly the pool melt dynamics, altering the response of the material to the energy input, becoming one other parameter of great importance for surface quality.

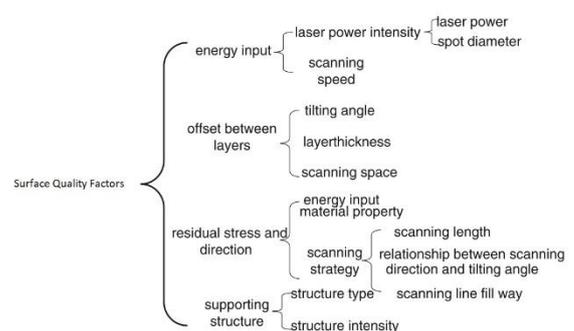


Figure 1. Influential process parameters for surface quality (adapted from [6])

2.2. Material

Different materials will have different responses in terms of SLM process parameters. Different melt temperatures, mid-process phase changes are great differentiating factors for each material. So, for each material, optimal values will be achieved for different energy densities and laser power [2]. These

factors, including initial powder characteristics will have great influence on the final surface quality for each geometry in each material [9].

In this work four different materials were used and characterised. It was studied the 4 S's (Shape, Structure, Size and Size distribution) recurring to different technologies. This lays the ground bases to any characterization done posteriorly.

3. Method

3.1. Experimental Equipment

For the characterization of powder structure and final part structure, it was used a X-ray diffraction technique, in a Philips X'Pert MPD with a cobalt cathode. For the evaluation of shape, a FEI Quanta 400FEG ESEM/EDAX Genesis X4M system was used. For the granulometry of the powders, it was used a Mastersizer Hydro 3000E.

For the characterization of the final parts, the already refered DRX and SEM was used, along with Archimedes for the calculation of density. Infinite Focus Microscopy was done with a Alicona Infinite Focus from Alicona Infinite Imaging complying with ISO 4287 and 4288.

3.2. Metallic Powders

Stainless Steel 316L (AISI/SAE) and Tool Steel H13 (AISI) were provided from SLM Solutions GmbH. Stainless Steel 420 (AISI/SAE) and Copper were provided from Sandvik Materials Technology.

3.3. Selective Laser Melting

The apparatus used was a SLM 125HL from SLM solutions with a maximum laser power of 400 W, with a continuous wavelength of 1,070 nm Ytterbium fiber laser and a 70 μm beam diameter. The build envelope is 125x125x125 mm. Argon was used for the powder processing within the chamber and the process only begins with less than 0.1% of O_2 in the chamber. A layer thickness of 30 μm was used. Table 1 resumes the most important characteristics.

Component	Characteristic	SLM 125 HL
Laser	Laser type	Ytterbium
	Maximum output	400 W
	Wavelength	1070 nm
	Laser beam diameter	70-100 μm
Base	Size	125x125(mmxmm)
	Pre-heating Temperature	200°C
Process	Layer thickness	20-75 μm
	Build Velocity	25 cm^3/h
	Minimum Wall Size	140 μm
Atmosphere	Type	Argon (99.992%)
	O_2	<0.2%
	Relative Pressure	1-1.2 kPa

Table 1. SLM 125 HL Machine Characteristics

As for the parameters used, they were built around an accepted literature or machine standard value, the conditions used in each production are resumed in Table 2. No supports were used as to not introduce another variable.

Production conditions		
SS 316L/ SS 420	Base	316L
	Time between Layers	10-15 s
	Layer thickness	30 μm
	Hatch Distance	120 μm
	Scanning Angle	45° Islands (with 90° increments)
TS H13	Base	H13
	Time between Layers	10-15 s
	Layer thickness	30 μm
	Hatch Distance	120 μm
	Scanning Angle	45° Islands (with 90° increments)
Copper	Base	H13
	Time between Layers	90 s
	Layer thickness	30 μm
	Hatch Distance	120 μm
	Scanning Angle	45° Islands (with 90° increments)

Table 2. Production Conditions

The group test were 9x9 parts distributed along the base with different parameters as to access the best parameters combo for each geometry. A second production of bigger parts intended to have a comparing factor for the influence of size. Figure 2 shows the final part in two sizes.

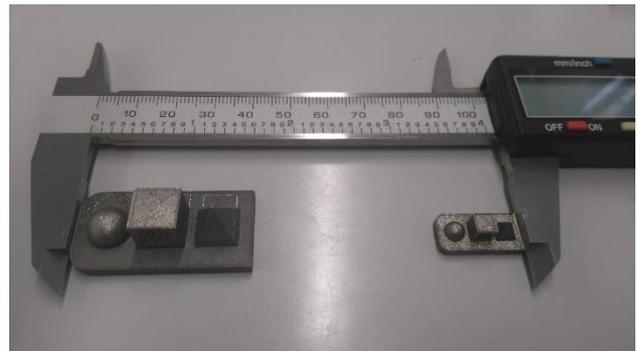


Figure 2. Example of the parts with different geometries

4. Results and discussion

4.1. Powder Characterization

The powders have been characterized in relation to the 4 S's. As to shape, all the powders present a round shape typical to atomization. In case of structure, the SS 316L present an austenitic phase with some vestiges of martensite. The SS 420 has a predominant ferritic phase with some austenite. The TS H13 is mostly martensitic with some vestigial austenite. Copper presented a unique phase.

As for size distribution 316L as a $d_{10} = 22.7 \mu\text{m}$, a $d_{50} = 32.4 \mu\text{m}$ and a $d_{90} = 45.2 \mu\text{m}$, 420 as a $d_{10} = 14.8 \mu\text{m}$, a $d_{50} = 24.5 \mu\text{m}$ and a $d_{90} = 39.20 \mu\text{m}$. H13 as a $d_{10} = 21.2 \mu\text{m}$, a $d_{50} = 32.1 \mu\text{m}$ and a $d_{90} = 48.3 \mu\text{m}$. Copper as a $d_{10} = 30.7 \mu\text{m}$, a $d_{50} = 46.7 \mu\text{m}$ and a $d_{90} = 69.0 \mu\text{m}$.

4.2. Parts Characterization

Some final results are shown in the following images.

Figure 3 to 5 shows the IFM image obtained.



Figure 3. Example of the IFM image obtained from semi-sphere geometry

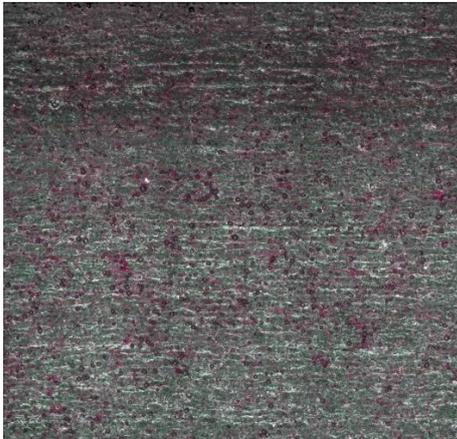


Figure 4. Example of the IFM image obtained from cube geometry

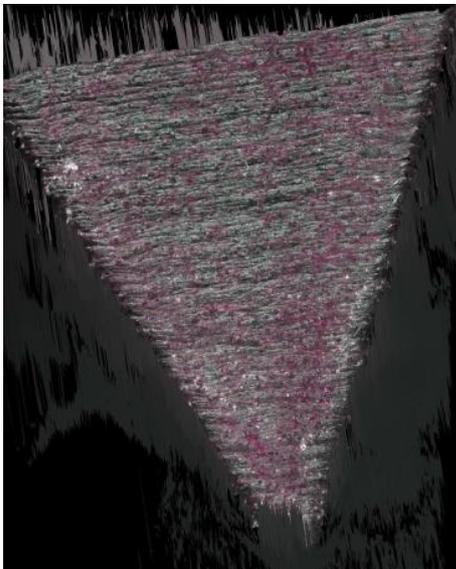


Figure 5. Example of the IFM image obtained from pyramid geometry

The comparison between average surface roughness, mean-squared surface roughness and peak-valley for H13 are shown in the Figures 6-8 below.

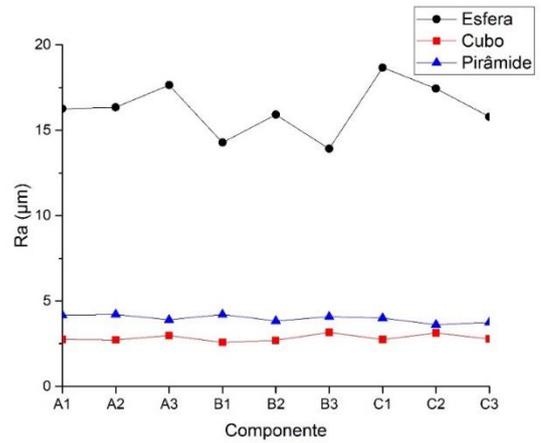


Figure 6. Values of average surface roughness

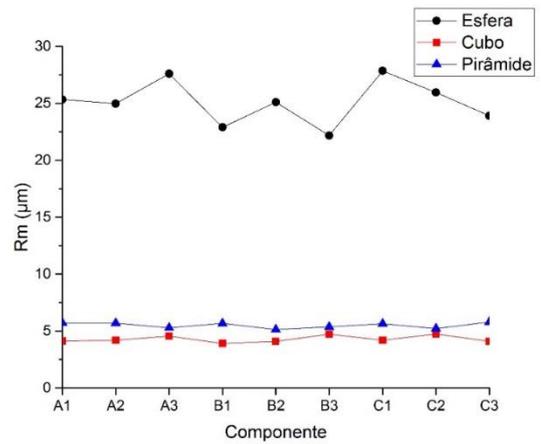


Figure 7. Values of root-mean squared surface roughness

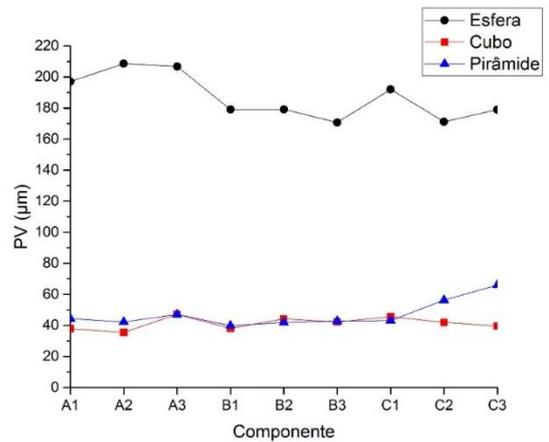


Figure 8. Values of peak-valley for each geometry

The pyramid, evaluated on its side wall, and the cube, evaluated on its vertical wall present similar results when compared to the semi-sphere geometry, which has much higher surface roughness, due to the stair stepping effect [4].

It can be seen also that different geometries are connected to different surface roughness. Due to layer per layer fabrication, geometries that concur the best with the next layer have better surface quality.

For the cube geometry, there are few superficial defects. The pyramids already show some stair effect that decreases the surface quality obtained from these parts.

Minimum values for H13 are around 4 μm for the parts produced. As this is a low value for SLM production, shot-peening can achieve even better surface quality [10].

There are evident optimal values for each geometry that are not coincident, which shows that the parameters must be adapted for each geometry.

The reduction in size was also evaluated for the semi-sphere, recurring to the 3D possibility of IFM characterization, as seen in Figure 9.

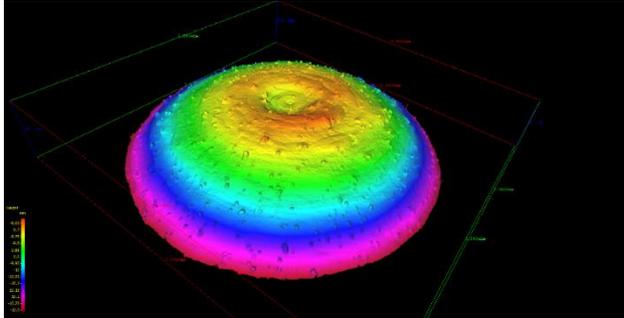


Figure 9. Example of the 3D IFM image obtained from semi-sphere geometry

The section was cut in half and evaluated for its sphericity, as can be seen on Figure 10 and 11.

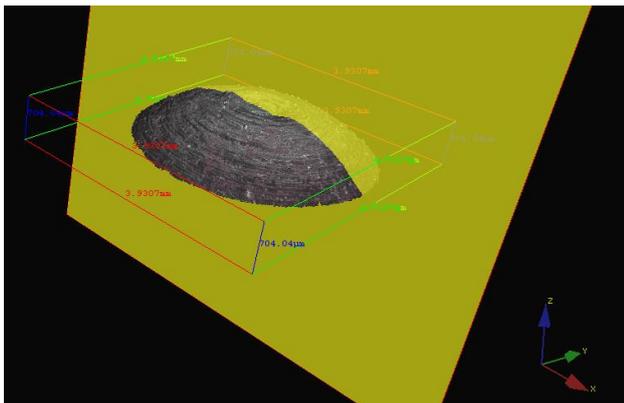


Figure 10. Example of the 3D IFM image cut from semi-sphere geometry

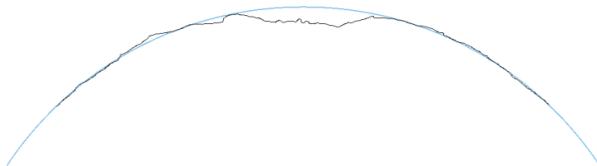


Figure 11. Example of the IFM sphericity evaluation capacity.

The reduction was about 1% for the case of H13. Different materials shown different dimensional contraptions and different confirmations to what is the perfect circle, shown in blue in Figure 11.

5. Conclusions

The present paper demonstrates the significant importance of parameters on the final surface quality, being that different geometries in the same material have different optimal values for energy density and laser power where the best surface roughness is optimal.

It was also compared a standard material, with no phase change with 3 different materials, one stainless steel but with phase change, one tool steel, and copper.

It was observed low dimension accuracy in the parts, being dependent on two important factors, size of the part and material.

The semi-sphere reveals itself as one of the most difficult geometries as of the ladder effect, amplified by the reduction in size of the part, and precision of the laser.

It was concluded that an adjustment in an initial CAD must be made to achieve the best dimensional accuracy.

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