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# Part surface roughness on laser sintering and milling of maraging steel 300

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## Abstract

The additive manufacturing of metal parts provides new opportunities to freely design of molds with conformal cooling channels, which enhances the productivity of injected plastic parts. In contrast to this manufacturing process, the surface quality of laser sintering parts is limiting the application of such technology on mold manufacturing. This work intends to investigate the surface roughness of maraging steel 300 samples produced by direct metal laser sintering (DMLS) and post-processed with end milling. Based on a set of experiments, combining different laser sintering build directions and milling process the measurement of the resulting surface roughness expresses how these process parameters impact on the final surface quality.

Keywords: Direct metal laser sintering (DMLS), milling, surface roughness, maraging steel 300.

## 1. Introduction

The additive manufacturing process of metal parts provides greater autonomy for tooling design with complex geometry and, thus, allows the manufacture of molds with integrated cooling channels (conformal cooling) reducing the injection molding cycle time [1]. Maraging steels are known to combine good mechanical properties, such as high strength, high tenacity, good weldability and dimensional stability [2]. Prior studies show that the mechanical properties and the part quality directly depend on parameters used during the sintering process [3][4]. Yasa et al. [4] studies investigated the selective laser melting (SLM) process in maraging steel 300 parts. The same study showed that a higher scan speed for layers with 60  $\mu\text{m}$  thickness induced lower roughness values (30  $\mu\text{m}$  Ra). The parameter range of the SLM process of maraging steel-manufactured samples led in different roughness after the surface milling [5]. The roughness obtained by laser sintering does not meet the requirements of mold surface finishing for applying in injection molding. To improve the surface quality the polishing post process is required, a difficult to handle and costly operation and your suppression could lead to improve mold productivity. In this regard, this study investigates the surface roughness of maraging steel 300 samples obtained by direct metal laser sintering (DMLS) process and post processed with end milling.

## 2. Experimental set-up

Figure 1 shows the operation principle of DMLS technology where a laser beam melts the powder layer by layer according to the build direction defined to slice the 3D CAD model.

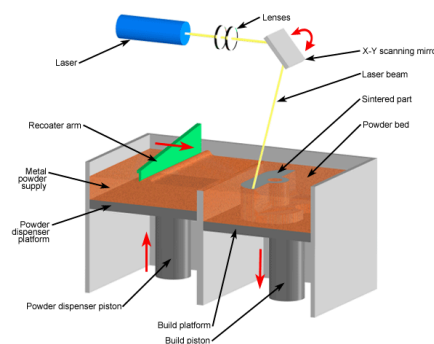


Figure 1: Operation principle of DMLS technology [2].

The Table 1 shows the machine specification and the parameters used in this study.

Machine	EOSINT M 280
Technology	DMLS

Laser type	Yb-fibre
Laser power [W]	170
Material	Maraging steel 300
Building platform [mm]	250 x 250 x 325
Preheating platform [°C]	40
Hatch distance [mm]	0.1
Environment gas	Nitrogen
Speed [mm/s]	1250
Stripe width [mm]	5
Layer thickness [mm]	0.02
Laser focus [mm]	0.1
Laser beam offset [mm]	0.015
Scan strategy	Line

Table 1 – Machine specification [7] and process parameters.

The build direction was changed in the sintering process. Fig. 2a shows the geometry developed for test specimens. Furthermore, the Fig. 2b shows the angles in which the parts were built, and the highlighted surfaces show the places of the roughness measurement.

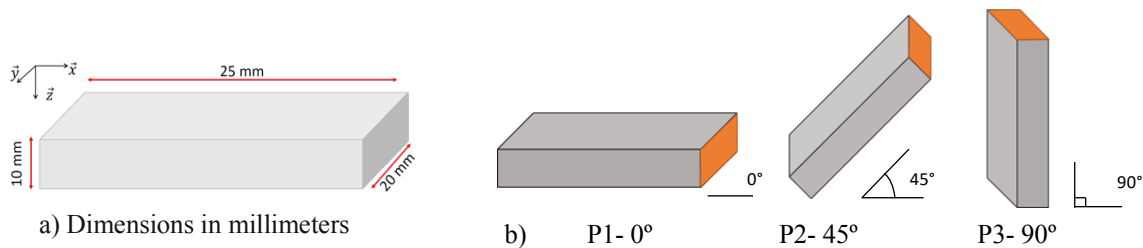


Figure 2 - Test part dimensions and building: a) Geometry b) Build direction.

The surface roughness was measured in a parallel direction to the building lines using Surtronic S-218 Taylor Hobson (set to measure the average roughness  $R_a$  with 0.80 mm cutoff). After chemical attack (Nital 5% for 5 minutes) Olympus BX51M, an electronic microscope, and a scanning electron microscope (SEM) Jeol were used to observe the microstructure and the milled surface. The sintered surface milling was performed under dry conditions in the machining center Romi D600 with end milling tool with  $\varnothing$  63 mm and 6 carbide inserts (OAKU 060508SR-R50) (see Fig.3) with the following cutting speeds  $V_{c1} = 100$  m/min and  $V_{c2} = 200$  m/min, feed per tooth  $f_z = 0.08$  mm and cutting depth  $a_p = 0.25$  mm.



Figure 3 - Milling tool and insert format.

### 3. Results and discussions

#### 3.1. Surface analysis

Figure 4 shows the results obtained from surface roughness samples measurements. The arithmetic average roughness ( $R_a$ ) is  $3 \mu\text{m}$  for build direction of  $90^\circ$ . When the part was rotated to  $0^\circ$ , the roughness increased to  $10.1 \mu\text{m}$ . Finally, when it was built in  $45^\circ$ , the roughness result was  $11.36 \mu\text{m}$ . The direct comparison between the samples shows that the roughness values are better to the sample with build direction  $90^\circ$ , showing the build direction changes the part roughness. It is important to emphasize the machine changes the scan strategy in the last sintered layers. The sintered surface milling provided significant improvement in the roughness. The maximum roughness value obtained was  $0.6 \mu\text{m}$  with cutting speed 200 m/min. It was noted that the change of the build direction changes the part roughness after milling. The best surface roughness obtain after milling is the test part that have the worse surface roughness directly after sintering. However, the change of the cutting speed

to 100 m/min results the lower roughness value 0.37  $\mu\text{m}$  (see Fig. 4) and changing cutting speed to 200 m/min not causes significant impact on surface roughness.

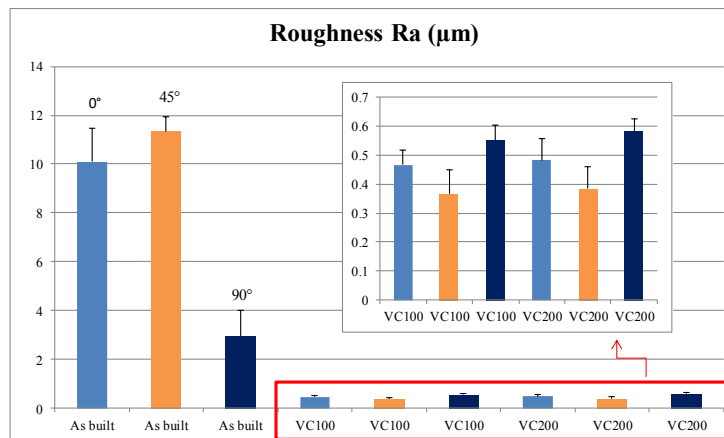


Figure 4 – Surface roughness comparison.

The milled surface analysis in SEM showed that are inclusions (see Fig. 5a) and micropores (see Fig. 5b), which can be related to fusion failures in the sintering process and shows the need to improve the process.

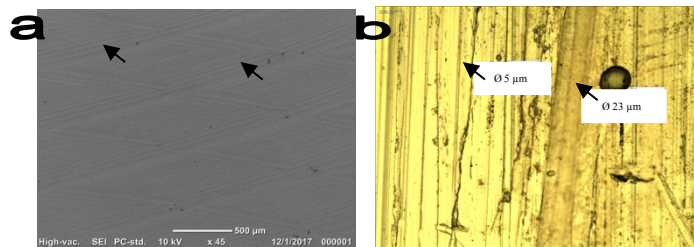


Figure 5 – Milled surfaces after laser sintering: a) amplification 45x b) amplification 200x.

### 3.2. Microstructure

The microstructure analysis shows the change in the solidification shape of the laser melt pool. Fig. 6a (build direction 45°) shows a half ellipsoid solidification shape and Fig. 6b (build direction 90°) shows a smooth, elongated and cross ellipsoid solidification shape, evidencing the effect of the scan strategy in the part solidification. Fig. 6c (build direction 90°) shows formation of elongated acicular microstructures that were observed in all samples.

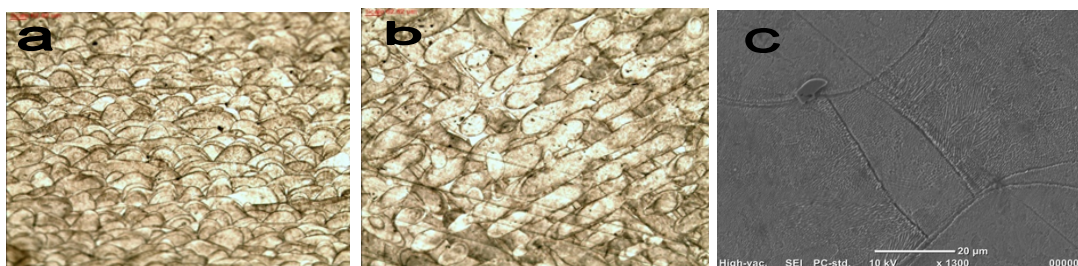


Figure 6 – Surface images: a) Amplification 10x b) Amplification 10x c) Amplification 1300x.

### 4. Conclusions

This study investigated the surface roughness of maraging steel 300 samples manufactured by the direct metal laser sintering (DMLS) process and post processed with end milling. The lower roughness obtained directly after the sintering process was 3  $\mu\text{m}$  (Ra) in the sample surface with direction of 90° (final surface of the part in plan X-Y parallel to building platform). For milled surfaces, the lower roughness was 0,37  $\mu\text{m}$  with cutting speed 100 m/min with part build direction of 45°. A slight influence of the build direction was noted. Moreover, as

supposed, the microstructure of the material is sensitive to process parameters, in particular the scan strategy. For future studies, we suggest the analysis of combination impact of other parameters (e.g.: scan speed, laser power, heat treatments etc.) in the part roughness after the milling.

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