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Laser-assisted post-processing of additive manufactured metallic parts

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Abstract
Laser-assisted additive manufacturing (AM) is the process of successively melting thin layers of material using a laser source to produce a three dimensional device or product. From the many technologies available, only a few can produce metallic parts that fulfil the requirements of industrial applications. Ultrafast laser machining is a new and promising technical approach for post-processing AM parts since laser ablation and surface modification processes could be applied with high accuracy for trimming shape and functionality, i.e., edge quality and wettability. The impact of different ultrafast laser parameters is evaluated for AM samples, which are examined for surface roughness before and after the laser-assisted post-processes. For all the parameters tested, the use of ultrafast laser resulted in a homogeneous material ablation of the samples' surfaces. For the investigated parameter range, the AM building tracks were still maintained even after ultrafast laser post-processing. The achieved results showed the formation of self-organized porous structures at low laser scan velocities leading to an enhanced surface roughness. For higher scan velocities characteristic nano ripples might be induced having no significant impact on the measured surface roughness.

Keywords: Laser finishing, ultrafast laser ablation, additive manufacturing, selective laser melting

1. Introduction

Additive manufacturing (AM) is an established technology based on the material deposition layer-by-layer to produce a part or device [1]. It is an alternative for customization and personalization with little impact on manufacturing complexity. Also for reducing material waste, time and costs [2]. On the other hand, the AM process typically results in rough surface finish which make the parts unsuitable for many applications [3].

The laser post-processing is an alternative of AM post-processing for being a contactless method and for presenting great flexibility (wide range of systems, parameters and technologies available) [4]. By a defined control of laser parameters such as wavelength, pulse length, laser fluence, repetition rate, and scan speed, versatile processing for each type of material becomes possible including thermal processing, surface modification, and cold ablation.

It is characteristic for ultrafast laser machining that the used laser energy will induce no, or only a small, heat-affected zone in comparison to conventional laser with pulse lengths in the nanosecond regime. Other benefits of this process can be achieved by sub-micrometer ablation selectivity during machining. Furthermore, different processing strategies are available with a single laser source including cutting, drilling, ablation and surface smoothing [5].

In the present work the surface roughness of AM parts is examined after a laser-assisted finishing process. The impact on the surface quality of different laser process parameters, such as repetition rate and scan velocity, is investigated.

2. Experimental

2.1. Material

The material used in this study was 18 Maraging 300 steel, manufactured with an EOS M270 SLM machine. The AM samples

have simple cubic geometry with dimensions of 1.5 x 1.5 x 1.0 cm. The laser processing was performed on the top surface of the samples that have initial Ra roughness of 2.7 ± 0.6 µm. The chemical composition of the material is shown in Table 1.

Table 1. Chemical composition (wt%) for Maraging steel used in this study

Ni	Mo	Co	Fe	Ti	Al	O	C
13.5	4.6	6.6	50.3	1.2	0.4	18.8	4.6

2.2. Laser system

For this work an ultrafast fiber laser system (Tangerine, Amplitude Systèmes, France) was used. The scan velocity (v) and the repetition rate (f), which can be related to the pulse overlap and to the energy density of the laser, were varied, while the wavelength (λ), pulse duration (τ), beam diameter (D), line offset distance (OD) and average laser power (P) were kept constant. The process parameters are presented in Table 2.

Table 2. Laser process parameters

wavelength (λ)	1030 nm
pulse duration (τ)	400 fs
beam diameter (D)	0.06 mm
average power (P)	9.4 W
line offset distance (OD)	0.03 mm
scan velocity (v)	200 - 2000 mm s^{-1}
repetition rate (f)	500 - 2000 kHz

2.3. Analytical methods

To measure the roughness of the laser processed parts, a white light profilometer (MicroProf®, Fries Research & Technology GmbH, Germany) was used. The profile measurements were performed in two different directions: orthogonal to the building tracks (90°) and with a 45° angle (X and Y). For selected processing parameters areal measurements will be presented (not shown here).

3. Results and discussion

The change of the surface roughness of the samples as function of laser parameters is presented in Figure 1.

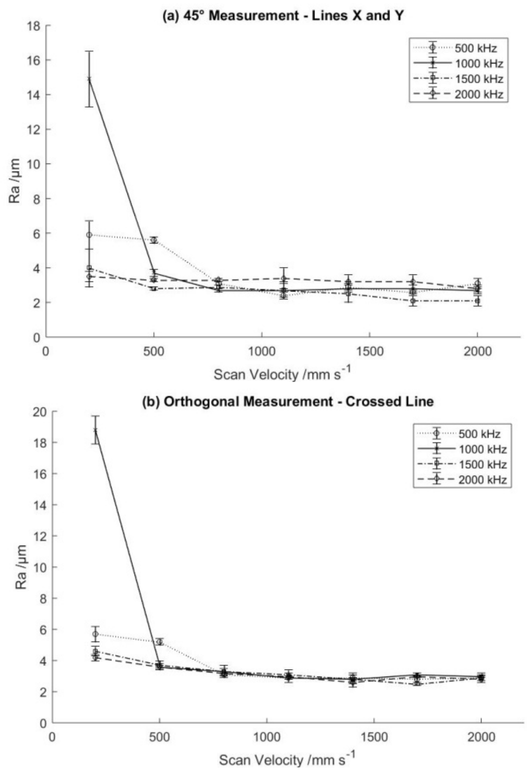

Figure 1. Roughness Ra as function of scan velocity and repetition rate. Ra was measured in 45° (a) and 90° (b) to the building tracks.

The highest surface roughness Ra was observed for the lowest scan velocity (200 mm s^{-1}) and for the repetition rate of 1000 kHz, in both measurement directions 45° and 90°, being 14.9 ± 1.6 µm and 18.8 ± 0.9 µm, respectively. The high values observed for these parameters are due to laser-induced self-organized porous surface. The pores observed presented diameters up to 20 µm. This structure can indicate the occurrence of selective material removal from the parts. The comparison of the surface texture and their microstructure is shown in Figure 2.

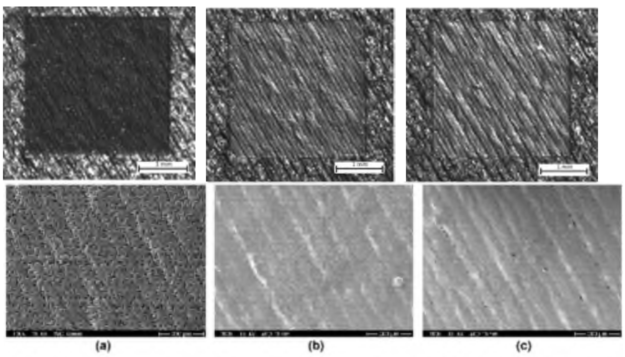

Figure 2. SEM of laser processed surface. (top) survey view (3x3mm^2) and (bottom) detail view showing the micro texture: (a) 500 kHz and 200 mm s^{-1}; (b) 500 kHz and 1100 mm s^{-1}; (c) 500 kHz and 2000 mm s^{-1}

The roughness decreased, in all cases, with the increasing of the scan velocity to 500 mm s^{-1}. Beyond this point, the roughness tended to vary in the small range of 2 to 3 µm, which is very similar to the surface roughness of the parts as-built.

The microstructures obtained when scan velocities from 1100 to 2000 mm s^{-1} are applied, to all repetition rates, are very similar to each other, thus the low variation on the Ra values in the mentioned range. They present periodical ripples and occasional unmelted particles from the building process on the surface.

The surface modification mechanism observed during the ultrafast laser post-processing of the AM samples was mainly ablation, leading to an almost homogenous material removal. For the used process parameter range the tracks from the building process could not be planished out, which is indicated by the similarity of the roughness values when compared to the initial surface roughness of the part, as mentioned above.

Apart from the roughness values of the lowest velocity, no significant difference was observed between the two measuring directions (45° and 90°).

4. Conclusions

The influence of two laser parameters, scan velocity and repetition rate, on the surface roughness of additively manufactured parts was presented. By applying material ablation and surface modification by femtosecond laser radiation two types of surface roughness formation could be detected. For small laser scanning velocity the surface roughness increased due to a selective material ablation. With increasing scanning speed the surface roughness Ra is reaching values which are similar to the initial Ra values of the as-built AM part. Additionally, the formation of nano-ripples, so-called laser-induced periodical surface structures (LIPSS), could be observed for high scanning speeds. Due to the cold ablation mechanism, ultrafast laser processing is a useful technology for edge processing and selective particle ablation of AM parts. Furthermore, a combination of laser-assisted thermal polishing of AM building tracks and subsequent fs-laser for surface functionalization and edge processing will be studied in upcoming experiments in order to achieved an enhanced surface quality and functionality beyond state-of the art AM parts.

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