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Laser surface modification and polishing of additive manufactured metallic parts

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Abstract

The combination of additive manufacturing (AM) and subsequent laser polishing is a technical approach with high flexibility in comparison to conventional processes. AM parts often present the need of post-processing due to surfaces with roughness higher than the admissible for most applications. The laser polishing consists in ablation and melting of a small amount of material, through laser irradiation, which is redistributed to create a surface with low roughness and probably new functionalities. Besides the flexibility, laser polishing presents high processing speed and capability for localized surface treatment. In this study, the resulting characteristics of AM parts irradiated by laser sources with different technical features are investigated and discussed. The parameters applied were the pulse duration, scan speed, repetition rate and average laser power. To evaluate the impact of laser processing on the material the microstructure and surface roughness were analysed and correlated to the process parameters.

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Keywords: Additive manufacturing; post-processing; laser polishing; surface modification

1. Introduction

One of the main advantages of additive manufacturing (AM) is the possibility of creating complex geometries and internal features, which cannot be produced by traditional processes. Although, the quality of the surface obtained often are not suitable for specific applications [1,2].

Laser polishing is a flexible method that also provides high processing speed capability for localized surface treatment. It is considered as an alternative for post-processing of AM parts due to its known advantages [3]. The laser process induces ablation and/or remelting of the surface. The later one could lead to a planarization by material relocation. Macrostructures smoothing can be achieved by applying continuous wave (cw) laser radiation, while pulsed laser are used for polishing of features with a lateral scale down to the micrometer range [4].

In this work, we present an investigation of the resulting characteristics of AM parts irradiated by continuous wave (CW) and pulsed laser radiation as a post-process. Different laser parameters (pulse duration, scan speed, repetition rate and average laser power) were applied on the upper and side surfaces of the AM samples. The evaluation of the laser processing impact on the parts is achieved by comparing the surface roughness and the material's microstructure before and after treatment.

2. Experimental

2.1. Material

The material investigated in this work was 18Ni (300 grade) Maraging steel, manufactured with an EOS M270 SLM machine. The AM samples are solid bodies (Fig. 1(a)) with dimensions of 1.5 x 1.5 x 1.0 cm^3 and were not submitted to any heat treatment or post-process after the additive manufacturing. The laser processing was performed on both upper and side surfaces of the samples (Fig. 1(b) and

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1(c), respectively). The upper surface has an initial Ra roughness of 2.7 ± 0.6 µm, while the side surface presents an initial Ra of 6.4 ± 0.8 µm, the measuring methods are described on section 2.3. Additive manufacturing is known for higher surface roughness when compared to traditional manufacturing processes, the Ra roughness requirements for most applications is less than 0.5 µm. The reasons are specific characteristics of the process, e.g., powder adhesion to the surface and stair stepping effect.

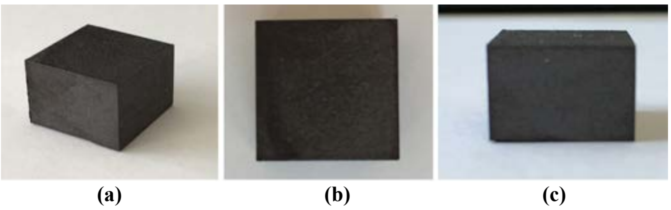

Fig. 1. AM sample: (a) geometry; (b) upper surface; (c) side surface.

2.2. Laser system set-up

For laser polishing we used a solid state laser radiation source (SPECTRON Laser Systems SL300, Nd:YAG, wavelength λ=1064 nm) which operates either in Q-switch (pulse duration 200 ns) or in cw (continuous wave) mode. The laser beam is focused onto the sample surface by an objective lens (f=160 mm or 100 mm) and can be scanned over the sample surface via deflection mirrors up to speeds of 2000 mm/s. This enables us to process an area of 110x110mm^2 (f=160 mm) or 65x65 mm^2 (f=100 mm).

A first approach consisted on varying the process parameters in a wide range while performing single-track experiments, for both types of laser operation, pulsed and cw mode. The goal was to identify a suitable process regime, which could result in an improvement of the surface quality of the parts. The parameters adopted are shown in Table 1.

Table 1. Laser process parameters for single-track experiments.

Parameter	cw	pulsed
Wavelength (nm)	1064	1064
Pulse duration (ns)	-	200
Beam diameter (mm)	0.1	0.1
Average power (W)	5 - 35	5 - 25
Scan speed (mm s^{-1})	10 - 500	25 – 2000
Repetition rate (kHz)	-	5 - 60

After analyzing the effects of the selected parameters on the material, a new parameter range was stablished for subsequent experiments applied to larger areas (5 x 5 mm^2). For this second step, it was necessary to define the pitch distance in addition to the parameters previously mentioned. The selected pitch distances were 25 and 50 µm. The processing of the larger area was performed by applying five repetitions with rotation by 72º of the laser scan direction between each repetition.

2.3. Analytical methods

A white light profilometer (MicroProf®, FRT, Germany) was used for profile measurements of the surfaces. The measurement direction was orthogonal to the AM building tracks.

3. Results and discussions

3.1. Single-track aspects

The aspects of the lines obtained by processing the samples with cw and ns lasers were very different from each other (Fig. 2 and Fig. 3, respectively).

For the experiments with the cw laser five different average powers were used along with scanning speed varying from 10 to 500 mm s^{-1}. The use of the lowest average power (5 W) caused no relevant effect on the surfaces in any speed range analyzed (Fig. 2 (a)). The increase of power to 15 and 20 W resulted in cracks on the surfaces for speeds from 10 to 100 mm s^{-1}. Cracks were also detected for higher average powers (25 and 35 W) but in a smaller range of speeds (10 to 40 mm s^{-1} and 10 to 20 mm s^{-1}, respectively). Above the mentioned speed ranges, for all average powers analyzed, the occurrence of laser ablation was observed (Fig 2(c)).

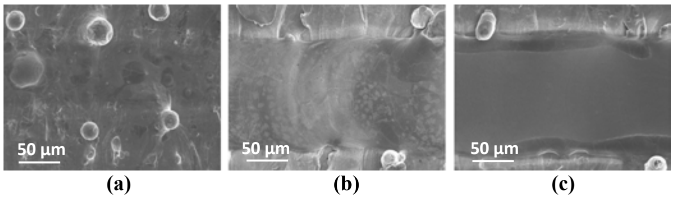

Fig. 2. SEM images of surfaces treated with cw laser: (a) 5 W and 90 mm s^{-1}: no significant effect on the surface; (b) 20 W and 20 mm s^{-1}: presence of cracks; (c) 25 W and 90 mm s^{-1}: laser ablation.

The use of ns laser on the AM samples resulted in melted material, differently from the cw, but not every range of parameters is promising for improvement of surface quality in terms of reduction of the roughness. Five repetition rates were adopted, along with four different average laser powers and scanning speeds varying from 150 to 2000 mm s^{-1}. For every combination of power and speed, the use of 5 kHz as a repetition rate resulted in excessive spatters and material removal (Fig. 3(a)). When increasing the repetition rate to 10 and 30 kHz, the same excessive spatters and material removal, plus melt pool instabilities, were observed for average power higher than 12 W, independently from the scanning speed adopted. Stable melt pools could be observed for the same repetition rates by using lower average power of 5 W (Fig. 3(b)). For the highest repetition rates (50 and 60 kHz) the combination of high speed and low power caused no significant effect on the surface. Stable melt pools were presented when combining low power and low speed. No excessive spatters or material removals were present when high repetition rates were applied, but the combination of high power and low speed, along with the combination of high power and high speed, caused melt pool instabilities (Fig. 3(c)).

The selection of the variation range of the laser parameters for the processing of larger areas was assisted by the single-track experiments. Only the cw mode was selected for further experiments since no results from the ns single-tracks presented a perception of surface roughness improvement. Two average laser powers were selected, being 25 and 50 W, while the scanning speed varied from 50 to 200 mm s^{-1} for the lower power and from 100 to 400 mm s^{-1} for the higher power. Despite not being in the analyzed range during the single-track experiments, the average power of 50 W was also selected for the areal processing as it was considered a prospective improvement on the surface quality if higher powers were applied.

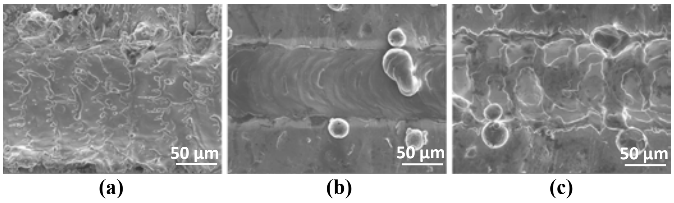

Fig. 3. SEM images of surfaces treated with nanosecond laser: (a) 25 W, 5 kHz and 165 mm s^{-1}: excessive spatter and material removal; (b) 5 W, 30 kHz and 20 mm s^{-1}: more stable melt pools; (c) 19 W, 60 kHz and 90 mm s^{-1}: melt pool instabilities.

3.2. Surface and microstructure

The different cw laser parameters applied on the surfaces of the AM samples presented a variety of surface modifications (Fig. 4 and Fig. 5). Although, despite the significant difference in their initial roughness, no significant difference occurred when processing the upper or side surfaces with the same laser parameters.

No major change was observed on the quality of the surface when applying average power of 25 W and a pitch distance 50 µm (Fig. 4(a)). However, the decrease of the pitch distance to 25 µm resulted in a decrease in the surface roughness for the highest speed applied (200 mm s^{-1}) (Fig. 4(b)).

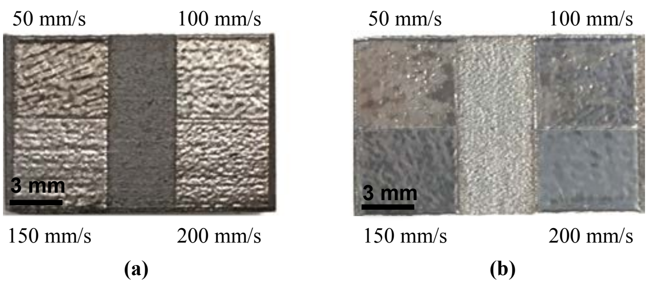

Fig. 4. Photography images of areas processed with cw laser and average power of 25 W: (a) pitch distance of 50 µm; (b) pitch distance of 25 µm.

A more significant improvement of the processed surfaces was achieved when the average power of 50 W was applied. From an optical view, it is assumed that oxidization took place for both pitch distances and speeds of 100 mm s^{-1} and 200 mm s^{-1}. For the higher speeds (300 and 400 mm s^{-1}) an improvement of the surface quality was observed, the original topography is almost vanished and no substantial oxidation is observed (Fig. 5(a) and (b)).

The surface microstructures obtained with 50 µm of pitch distance and 25 W average laser power present several irregular marks or surface defects that can be related to the original surface after ablation (Fig. 6(a) and (b)). The surface obtained with 25 µm pitch distance is flat, while oxidation are identified for lower scanning speeds (Fig. 6(c) and (d)).

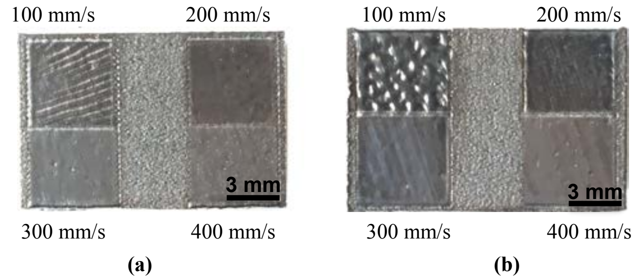

Fig. 5. Photography images of areas processed with cw laser and average power of 50 W: (a) pitch distance of 50 µm; (b) pitch distance of 25 µm.

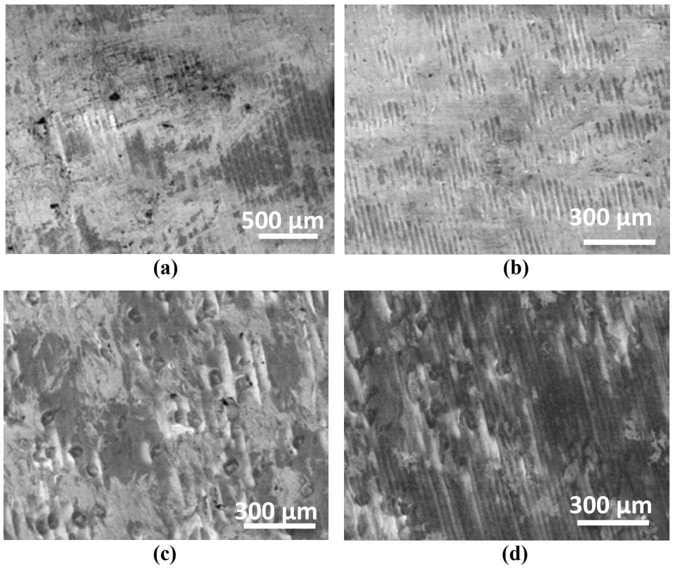

Fig. 6. SEM images of laser processed surfaces: (a) 25 W, 50 µm pitch distance and 50 mm s^{-1}; (b) 25 W, 25 µm pitch distance and 50 mm s^{-1}; (c) 25 W, 50 µm pitch distance and 200 mm s^{-1}; (d) 25 W, 25 µm pitch distance and 200 mm s^{-1}.

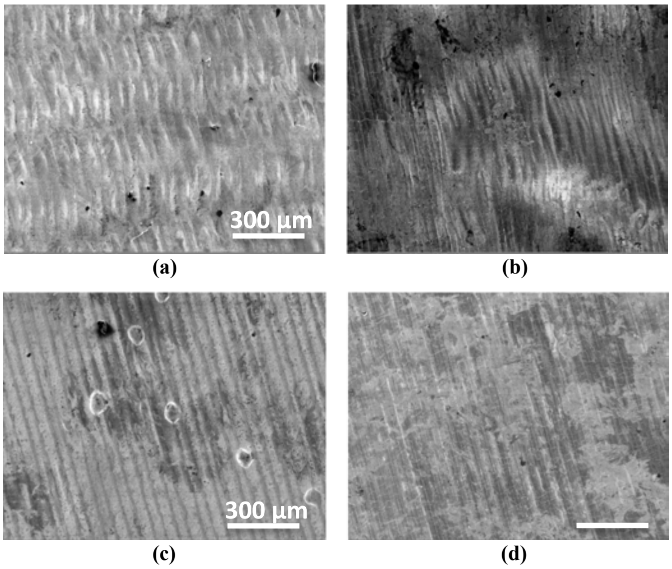

Fig. 7. SEM images of laser processed surfaces: (a) 50 W, 50 µm pitch distance and 100 mm s^{-1}; (b) 50 W, 25 µm pitch distance and 100 mm s^{-1}; (c) 50 W, 50 µm pitch distance and 400 mm s^{-1}; (d) 50 W, 25 µm pitch distance and 400 mm s^{-1}.

The microstructures obtained with 50 W average power and high speed are very similar for both pitch distances. For low speeds, the surfaces present several topographic irregularities (Fig. 7).

3.3. Roughness

The Ra roughness presented by the upper and side surfaces after the same laser processing are very similar to each other, even though their initial roughness have a significant difference.

The use of 25 W average laser power did not result in a substantial improvement of the surface quality for most speeds and both pitch distances. Surface roughness Ra under 1 µm (Ra of 0.7 µm) was obtained only with 25 µm pitch distance and 200 mm s^{-1}. The differences between Ra values achieved with different pitch distances varied for each speed and are related to the original topography of the surface and its oxidation after laser post-processing (Fig. 8).

Surface roughness Ra below 1 µm (minimum Ra of 0.6 µm) was obtained with both pitch distances by applying a cw laser source with 50 W average power and high speeds. The difference between Ra values obtained with different pitch distances are higher for lower speeds, higher oxidation and heat effects are observed for higher scan overlaps (Fig. 9).

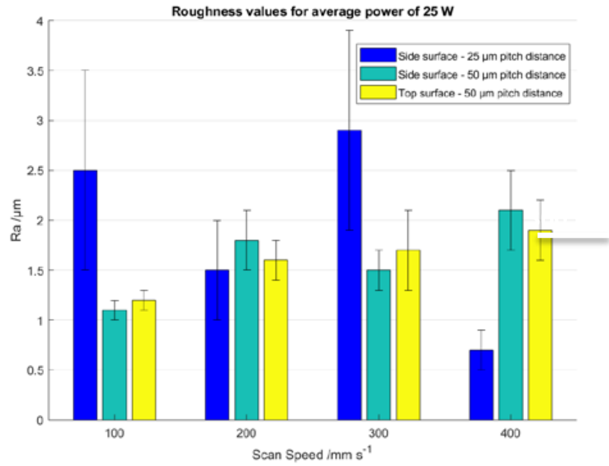

Fig. 8. Roughness Ra as function of scan speed and pitch distances for 25 W average laser power.

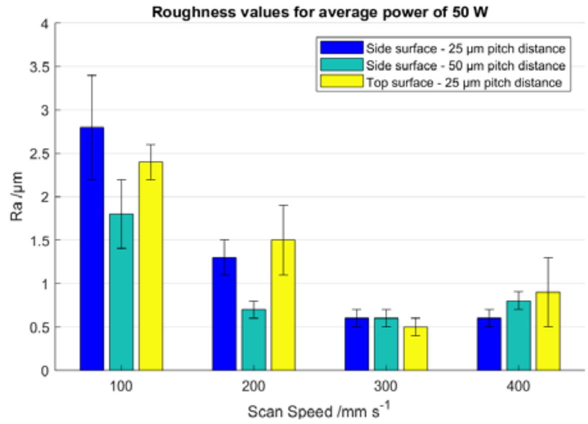

Fig. 9. Roughness Ra as function of scan speed and pitch distances for 50 W average laser power.

In most cases, the laser source adopted was able to remove the powder particles attached to the surface of the parts during the AM process (Fig. 10), which can reduce the Ra roughness in a small range. Therefore, a reduction on the Ra roughness for most parameters applied was achieved, when compared to the initial surface.

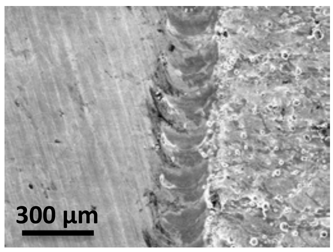

Fig. 10. SEM image of the material surface before (right) and after (left) laser post-processing.

4. Conclusions

The influence of the main laser parameters on the surface quality of additively manufactured parts was studied. A significant reduction of the surface roughness Ra was accomplished by using 50 W average power and scan speeds in the range of 300 mm s^{-1}. Continuous wave laser sources have the potential to remove particles attached to the part's surface by ablation, but the high surface temperatures achieved during the laser process can cause undesired modifications, such as oxidation. When processing larger areas, cracks were observed in all cases, even when they were not present on the single-track experiments, due to the number of repetitions, remelting of resolidified material, and the higher average temperatures caused by the laser scan overlaps. Further studies will be developed to select shielding gases, in order to reduce the oxidation during the post-process and to analyze the influence on the crack formation, along with the combination of different types of laser sources for new functionalities.

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References

[1] Townsend A et al. Surface texture metrology for metal additive manufacturing: a review. Precision Engineering 2016;46:34-47.
[2] Gora WS et al. Enhancing surface finish of additively manufactured titanium and cobalt chrome elements using laser based finishing. Physics Procedia 2016; 83:258-263.
[3] Bhaduri D et al. Laser polishing of 3D printed mesoscale components. Applied Surface Science 2017; 405:29-46.
[4] Temmler A, Willenborg E, Wissenbach K. Laser polishing. Proc. SPIE 2012; 8243.