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Laser polishing - enhancing surface quality of additively manufactured cobalt chrome and titanium components

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Abstract

Additive manufacturing (AM) allows construction of complex, free surface structures that cannot be produced as lone parts using traditional mechanical manufacturing. A commonly-used AM process is selective laser melting (SLM) where a high intensity laser beam selectively scans a powder bed according to the computer-aided design of the component to be produced and the powder metal particles are melted into the required pattern. Unfortunately AM components show poor surface quality, in particular due to partially fused particles from the metal powder used in the AM process. As a result post processing of AM parts is essential to improve the quality of the surface to suit specific industrial needs.

Currently SLM manufactured parts are chemically or mechanically polished, but both of these methods have their drawbacks. Mechanical polishing is limited by the complexity of the AM structure, whereas electrochemical polishing struggles if selective polishing of small areas is desired. The laser polishing process is based on the melting and subsequent solidification of a micro-layer of material, using a laser beam as the heat source for a smooth topography. As a result laser polishing offers a highly repeatable, short duration process that is capable of selective polishing of microscale areas.

We are therefore presenting the possibility of using both pulsed and CW lasers to improve the surface quality of titanium and cobalt chrome alloy AM parts to provide tailored aesthetic and tribological requirements. A range of different scan strategies, employing different scanning directions, energy densities and speeds, also different laser powers and spot diameters are investigated.

Keywords: additive manufacturing, selective laser melting, laser polishing, laser finishing

1. Introduction

Additively manufactured (AM) parts overcome many of the limitations of traditional manufacturing processes, allowing construction of highly complex three dimensional parts. Unfortunately the as-manufactured surfaces of AM parts are unsuitable for many applications and hence a post-processing step is essential. Currently AM parts are polished using chemical or mechanical polishing, but both of these methods have their drawbacks, e.g.: repeatability, slow speed, waste material and an inability to selectively generate different degrees of surface finish on different regions of a part. Laser polishing presents an intriguing option as it offers the capability to overcome many of these limitations. Recently times many research groups have investigated a possibility of using laser based finishing of AM structures to improve surface quality [1-4]. In this paper we investigate different approaches of laser polishing of AM cobalt chrome and titanium parts.

2. Experimental setup

During experiments two different SPI fibre lasers were used: (i) SPI G3 40WH operating at 40W laser power with a spot size of 80 µ; (ii) SPI redPOWER R4 at 100W laser power with a spot size of 400 µm. During laser processing samples were placed in a chamber filled with Argon to prevent oxidation. After laser processing surface roughness (S_a) of samples was measured and analysed using Alicona InfiniteFocus surface profilometer (ISO 11562/25178/1278).

3. Titanium

The first set of experiments was focused on comparing the influence of different scanning patterns to the surface roughness of Ti6Al4V AM parts. Three different scanning patterns were tested: (i) raster scanning (0°, 0°, 0°, 0°); (ii) perpendicular scanning directions (0°, 90°, 0°, 90°); and (iii) pattern imitating halftone printing angles (18°, 71°, 0°, 45).

Table 1 Values of surface roughness (S_a) after 1 full laser polishing cycle (4 laser passes) at constant energy density of 7.1 kJ/cm^2. Initial surface S_a = 4.47 µm.

Scanning pattern	Raster scanning	Perpendicular directions	Halftone printing angles
Surface roughness (S_a)	2.12 µm	2.01 µm	1.86 µm
Improvement	53%	55%	58%

The best results were obtained with the pattern imitating halftone printing angles – see Table 1. Parameters used: power of 40 W; spot size of 80 µm; energy density of 7.1 kJ/cm^2 and line overlap of 90%.

Consequently the next set of experiments investigated the impact of using an ablative process before the main polishing process in order to remove larger scale structures and hence improve surface macro roughness. Figure 1 shows optical microscopy images of surfaces after 3 consecutive scanning cycles (1 cycle = 4 laser passes at halftone printing angles - 18°, 71°, 0°, 45°) with and without the ablative process before the main polishing CW process. It was found that by using an ablation process to remove larger scale structures it was possible to improve the laser polishing process by 27% and decrease the value of S_a by 72% Results of the measurements are plotted in figure 2. The energy density used for this experiment was 7.1 kJ/cm^2, line overlap of 75%, and spot size of 80 µm and power of 40W.

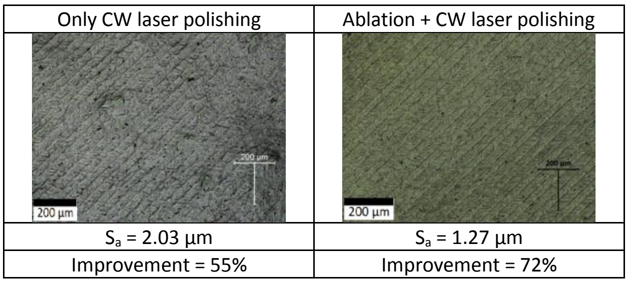

Figure 1. Optical microscopy images of surface obtained by CW laser polishing (3 cycles - 12 scans at halftone printing angles) with and without ablation before main process. Initial surface S_a = 4.47 µm.

4. Cobalt-Chrome

AM cobalt-chrome parts were also investigated. In this case, using only scanned CW laser radiation with various scanning strategies, laser powers and beam diameters it was possible to achieve a significant decrease of surface roughness. Four different scanning approaches were tested: (i) raster scan with alternating direction (0°, 180°, 0°, 180°, 0°); (ii) perpendicular scanning directions (0°, 90°, 0°, 90°, 0°); (iii) scanning with increasing angle (0°, 45°, 90°, 135°, 180°); and (iv) halftone printing angles (18°, 71°, 0°, 45°, 0°). Initial experiment were done using 40W laser power, 80 µm spot size, an energy density of 3 kJ/cm^2 and scanning speed of 16.5 mm/s. The best results were obtained when using the halftone printing approach and 4 consecutive scanning passes. The surface roughness (S_a) was reduced by 77% - see Table 2. Figure 4 shows areal maps laser polished surface.

Table 2 Value of surface roughness (S_a) after four laser scans at halftone printing angles for constant energy density of 3 kJ/cm^2.

	Pre-processing	Post-processing	Improvement
Surface roughness (S_a)	22.84 µm	5.23 µm	77%

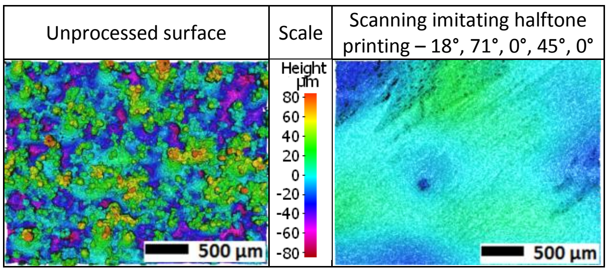

Figure 4. Areal maps unprocessed and processed (4 consecutive laser passes) cobalt-chrome AM part. Focused spot size of 80 µm, power of 40 W, energy density of 3 kJ/cm^2 and 90% live overlap.

Different energy densities were also investigated. By adjusting scanning speed (20, 16.5, 10 and 8 mm/s) and having constant power (40W) energy densities of 2 - 5 kJ/cm^2 were tested- see Table 2.

Table 2 Surface roughness (S_a) after four laser scans at halftone printing angles using different energy densities. Initial value of S_a = 22.84 µm.

Energy density	2 kJ/cm^2	3 kJ/cm^2	4 kJ/cm^2	5 kJ/cm^2
Surface roughness (S_a)	7.26 µm	5.23 µm	8.44 µm	5.59 µm
Improvement	68%	77%	63%	75%

Same scanning pattern, imitating halftone printing angles 18°, 71°, 0°, 45°, 0, and parameters – 3kj/cm^2, 90% line overlap were used for polishing with a bigger spot dimeter of 400 µm. To maintain a constant value of energy density – 3 kJ/cm^2 - a power of 100 W and scanning speed of 8.33 mm/s were used – see Figure 5. The surface roughness (S_a) was reduced by 95% - see Table 3. The big improvement, compared to the results obtained with smaller beam size, was a result of higher laser power hence a larger melt depth which was more successful in removing larger scale structures

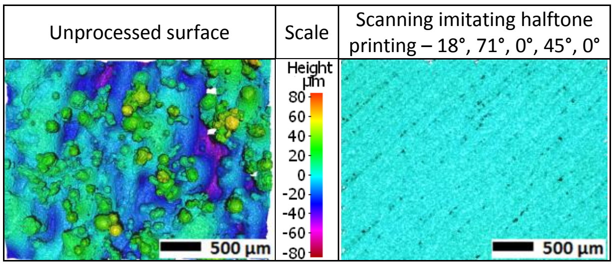

Figure 5 Areal maps unprocessed and processed (4 consecutive laser passes) cobalt-chrome AM part. Focused spot size of 80 µm, power of 40 W, energy density of 3 kJ/cm^2 and 90% live overlap.

Table 3 Value of roughness (S_a) after four laser scans at halftone printing angles.

	Pre-processing	Post-processing	Improvement
Surface roughness (S_a)	14.35 µm	691 nm	95%

5. Conclusions

This work presents initial results of laser polishing of titanium and cobalt-chrome AM parts using laser radiation. By using both laser ablation and CW laser polishing a 72% improvement in surface roughness (S_a) for Ti6Al4V AM part was achieved. For AM cobalt-chrome parts a surface roughness (S_a) reduction of 95% was achieved by introducing a larger beam size and a more powerful laser that was capable of melting larger scale structures. The results demonstrate the potential of laser-based polishing of AM parts.

Acknowledgements

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