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Enhancing surface finish of additively manufactured titanium and cobalt chrome elements using laser based finishing

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Abstract

Additive manufacturing (AM) offers the possibility of creating a complex free form object as a single element, which is not possible using traditional mechanical machining. Unfortunately the typically rough surface finish of additively manufactured parts is unsuitable for many applications. As a result AM parts must be post-processed; typically mechanically machined and/or and polished using either chemical or mechanical techniques (both of which have their limitations). Laser based polishing is based on remelting of a very thin surface layer and it offers potential as a highly repeatable, higher speed process capable of selective area polishing, and without any waste problems (no abrasives or liquids).
In this paper an in-depth investigation of CW laser polishing of titanium and cobalt chrome AM elements is presented. The impact of different scanning strategies, laser parameters and initial surface condition on the achieved surface finish is evaluated.

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1. Introduction

In recent past additive manufacturing (AM) has become a very intriguing solution for a lot of different areas of life due to its capability to overcome construction constraints that limit traditional manufacturing techniques as

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additive manufacturing is capable of creating three dimensional, free form surfaces. Unfortunately the surface finish produced by additive manufacturing might not be sufficient for certain specific applications, such as medical implants need that require a smooth surface to limit bacteria growth and prevent tissue damage. Currently AM parts are polished using either mechanical or electrochemical polishing, but both of those methods have their limitations. When considering mechanical polishing it struggles with highly complex free form parts and electrochemical polishing is insufficiently selective for creating highly customized microscale polished areas. Moreover both of these methods produce debris like abrasives or fluids. Laser polishing offers a potential solution without these limitations hence a number of research groups have investigated laser polishing of parts created with different additive manufacturing techniques as selective laser melting, sintering and laser metal deposition (Dadbakhsh, Hao, & Kong, 2010; J. A. Ramos; Lamikiz, Sanchez, et al., 2007; Lamikiz, Sánchez, López de Lacalle, & Arana, 2007; Rosa, Mognol, & Hascoët, 2015; Yasa, Deckers, & Kruth, 2011). In our research we present an investigation to determine optimal parameters of laser polishing of titanium and cobalt chrome parts created using selective laser melting. The influence of different laser parameters, various scanning strategies and initial surface condition is assessed.

2. Experimental setup

The laser used for polishing was a fibre laser manufactured by SPI, G3 40WH operating at the wavelength of 1064 nm with maximum operating power is 40 W. The beam profile is a type H (near flat top) with a beam quality factor, $M^2 = 3.1$. The beam is focused using an f-theta lens with focal length of 160 mm, generating a 40 µm diameter focal spot. However, during all of the experiments this beam was used out of focus to provide a divergent beam of 80 µm diameter. To prevent oxidization during the process, the samples were placed in a gas cell filled with argon. After processing, the samples were investigated using either a white light interferometer (Zygo NewView 5000), a surface profilometer (Alicona Infinite Focus) or an optical microscope (Leica DM6000 B). To eliminate waviness during the analysis, the surface was investigated in the different spatial frequency domains: (i) macro- ($\lambda \geq 80$ µm); (ii) meso- (80 µm > λ > 10 µm); and (iii) micro-roughness ($\lambda \leq 10$ µm).

3. Experimental work

Experimental work focused on poslishing of lat surfaces of two different materials: titanium alloy – Ti6AL4V and cobalt chromium – CoCr. All of the parts were build using Renishaw AM250 SLM machine. Powder diameter was 10 – 20 µm with layer thickness of 30 µm. During the experimental work different scanning strategies were investigated to find the optimal scanning parameters for polishing of additively manufactured parts.

3.1. Ti6Al4V

An initial set of experiments was focused on testing whether an ablative process used before the laser polishing process provides any improvement to the processed part. The concept is to remove larger scale structures and as a result decrease the value of macro-roughness. To compare the influence of such a process both samples (with and without ablative process) were polished using continuous wave (CW) laser radiation using 1,2 and 3 polishing cycles (1 cycle = 4 laser polishing passes, at different angles (18°, 71°, 0°, 45°). Ablation process consisted of 8 laser passes - 250 ns pulse duration, 40 W power, 80 µm spot size and 75% pulse and live overlap. Laser polishing was carried out with 40 W laser power, 7.1 kJ/cm^2 energy density, 75% line overlap with 80 µm spot size. Fig. 1 shows values of roughness for each processed area and Fig. 2**Fig. 1** shows optical microscopy images of processed areas.