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Laser modification of surface properties – surface finish and wettability

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Abstract

The highly localised heating that can be provided by an industrial laser is ideal for modifying surfaces via melting and/or ablation of thin surface layers, whilst leaving the bulk of the material unchanged. In recent research we have concentrated on two applications (i) improving surface finish of additively manufactured (AM) parts via a 'laser polishing' process and (ii) the generation of hydrophobic surfaces using laser texturing. Both processes have application in many industries including aerospace, medical implants, and food.
Laser polishing of AM parts is based on the creation of a shallow melt pool, with flow under surface tension resulting in localised smoothing. This can provide different surface finishes on different areas of a surface, often a requirement. We focus on polishing CoCr and Ti6Al4V AM parts, using both cw and nanosecond pulsed lasers.
Nanosecond laser pulses of higher energy density, meanwhile, may be used to generate hydrophobic surfaces. Such effects are demonstrated on brass and copper.

Keywords: Laser polishing; Laser texturing; Hydrophobicity; Surface roughness

1. Introduction

In many industries laser surface processing has enabled a lot of new applications that are not possible with more traditional subtractive machining. Through laser texturing it is possible to change many of the functional surface properties such as: wettability (Ta et al., 2015), increase or reduce surface friction (Dunn, 2016; Kang, Park, Kim, & Seo, 2015; Schille et al., 2015), hardness (Fang et al., 2009) or alter the aesthetics e.g. laser polishing (Gora et al., 2016; Nüsser, Kumstel, Kiedrowski, Diatlov, & Willenborg, 2015). In this paper we present laser polishing of additively manufactured (AM) parts for medical application as well as nanosecond laser created superhydrophobic surfaces and their potential chemical applications.

2. Laser polishing of AM structures

Powder based additive manufacturing is growing in popularity as a manufacturing method in many industries e.g. aerospace, medical, mould tooling or automotive. The surface quality of the as-built parts is rarely good enough for final application without post processing. Currently parts are post-processed using electrochemical or mechanical (abrasive) polishing methods. Unfortunately these methods have certain limitations and so laser polishing is an interesting option as it offers shorter processing times, higher repeatability, selective processing of microscale areas and does not generate any debris.

In laser based polishing the laser beam is scanned across the surface creating a localized melt pool. Consequently, melted material flows directed by the surface tensions leading to a smoothed surface. Although the process itself is conceptually simple there are many factors that contribute to the complexity of developing an

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optimal and robust solution. In this paper we present laser polishing of both flat and curved CoCr and Ti6Al4V AM parts. Both of these materials are used for various medical implants. CoCr is used in the production of bespoke dental abutments (part of a dental implant, Fig. 1a) and titanium alloy is used in production custom cranial implants (Fig. 1b). When considering dental abutments laser polishing would be beneficial as an abutment requires two types of different finish: a smooth surface for the parts that sits in a gum; and a rough finish for the top part onto which the crown is adhesively bonded. Titanium cranial implants, meanwhile are currently post-processed using abrasive polishing method, which is a time consuming process that requires a highly skilled worker to achieve sufficient surface finish – and there is always the danger of excessive material removal which would cause the part to be scrapped. Laser polishing, meanwhile, can be fairly easily automated and hence provide consistent, highly repeatable results.

Fig. 1(Left) Bespoke AM dental abutments (Renishaw); (Right) Bespoke AM cranial implant (Renishaw).

2.1. Experimental setup

Polishing was carried out using an SPI SP-100C fibre laser, wavelength 1064 nm and a maximum power of 100 W. The beam (M^2<1.3) was manipulated using a galvanometer scan head with an f-theta lens of focal length 160 mm. This provided a spot size diameter of 35 µm, however this was defocused to a diameter of 400 µm and was scanned across the sample surface using a galvanometer scan head. During laser processing the samples were placed in a gas cell filled with argon to prevent oxidation. The surface roughness (S_a) of the samples was measured before and after polishing using an Alicona Infinite Focus surface profilometer (ISO 11562, 25178 and 1278).

2.2. Experimental results

Initial experiments were focused on identifying the optimal scanning strategy for both CoCr and Ti6Al4V samples. After testing a number of different patterns the one that gave the best results was a scanning pattern imitating halftone printing angles consisting of 4 passes at different angles: 18°, 72°, 0°, 45°, to avoid moiré patterns. Another important parameter is line to line overlap, where it was found that the best results were achieved for an overlap between 60% and 70%. The influence of energy density on the surface roughness was also investigated. The best results for CoCr were achieved when using 3 kJ/cm^2 and 2 kJ/cm^2 for Ti6Al4V. Fig. 2 shows surface profiles of flat and cylindrical CoCr parts before and after laser polishing, demonstrating a reduction in surface roughness of a flat CoCr part by 38× and a cylindrical part by 11.5×.

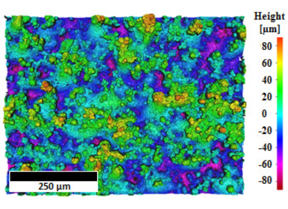
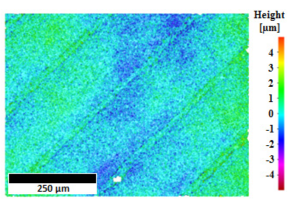
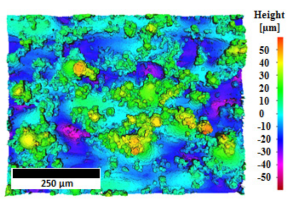
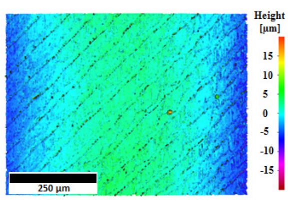
Flat surface		Curved surface	
			
S_a = 23 µm	S_a = 0.55 µm	S_a = 13 µm	S_a = 1.1 µm

Fig. 2. Surface profiles for flat and curved CoCr AM parts before and after laser polishing. Note different surface height scales.

Fig. 3 shows similar results for flat and cylindrical Ti6Al4V parts, demonstrating a reduction in surface roughness of flat Ti6Al4V part by 21.5× and a cylindrical part by 10×.

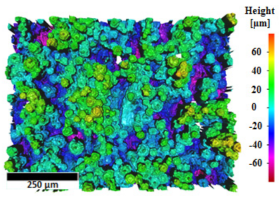
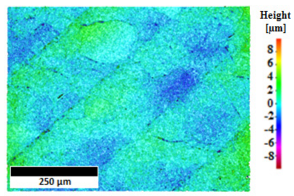
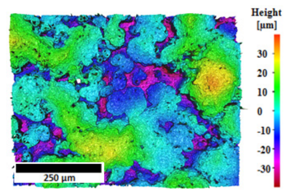
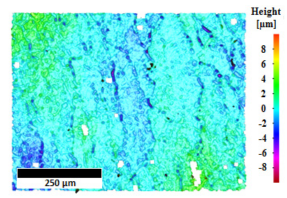
Flat surface		Curved surface	
			
S_a = 19 μm	S_a = 0.86 μm	S_a = 8.4 μm	S_a = 0.87 μm

Fig. 3. Surface profiles for flat and curved Ti6Al4V AM parts before and after laser polishing. Note different surface height scales.

3. Superhydrophobic surfaces on copper and brass

Precise control over the surface wettability is of interest to many industries, with applications including self-cleaning surfaces, corrosion resistance, drag reduction or microfluidics control (Blossey, 2003; Zhang, Shi, Niu, Jiang, & Wang, 2008). Although there are many techniques for creating superhydrophobic surface such as plasma treatment, chemical deposition, lithography, and ultrafast laser texturing and amid these laser texturing is a very promising manufacturing method due to low waste, quick processing times and single step processing. (Yan, Gao, & Barthlott, 2011). In this paper we present a nanosecond laser texturing process to generate superhydrophobic surfaces on both brass and copper using a cost-effective fibre laser.

3.1. Experimental setup

An SPI EP-S 20W fibre laser, λ = 1064 nm was used for surface structuring. This was operated at a repetition rate of 25 kHz, pulse length of 220 ns and was focused to a spot size of 21 μm diameter. A scanning speed of 75 mm/s was used. Experiments were carried out using a 5 μL droplet of deionized water and the contact angle was determined using FTA32 software. Fig. 4 presents the typical microgroove structure that was created on the surface of brass with a fluence of 65 J/cm^2 and line to line spacing of 75 μm.

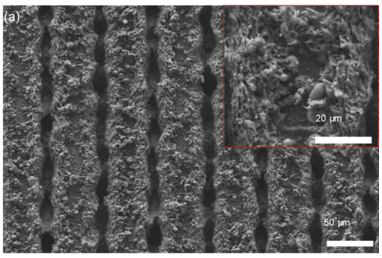


Fig. 4. SEM micrograph of the laser texture brass surface (65 J/cm^2, line spacing – 75 μm, spot diameter 21μm).

3.2. Experimental results

Immediately after laser texturing the surface is hydrophilic, but that state is not constant and its properties do change over the time. Fig. 5 shows the evolution of the contact angle over the time for both copper and brass for three different energy densities. Each measured point is the average of three measurements.

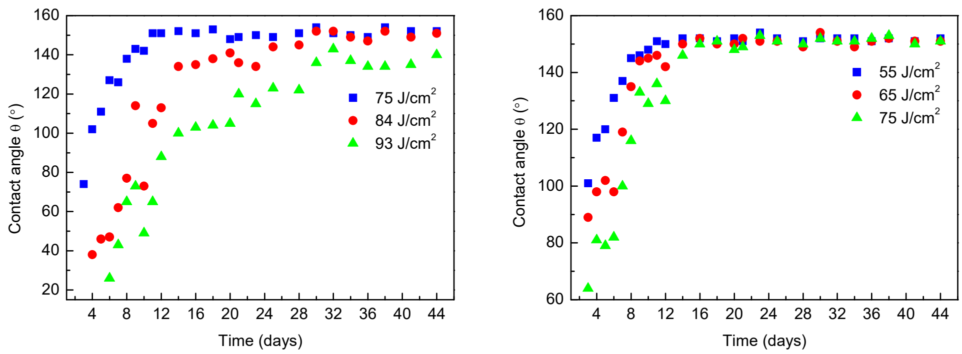


Fig. 5. Development of the contact angle over the time after laser texturing for (a) copper; (b) brass for three different energy densities.

For both copper and brass irradiated with 55 J/cm^2 it took ~11 days to reach a steady state of the contact angle. Both materials have successfully reached contact angles of slightly above 150°. During the maturing process samples were stored in standard laboratory conditions. A number of authors have sought to explain such changes of surface properties over time, such as adsorption of organic matter from the atmosphere, creation of hydrophobic groups and decomposition of carbon dioxide into carbon with active magnetite (Bizi-bandoki, Valette, Audouard, & Benayoun, 2013; Long, Zhong, Fan, Gong, & Zhang, 2015).

The contact angle of the droplet is not only dependent on the surface topography and surface chemistry, but on the solution that is in contact with the surface. As presented in (Ta et al., 2015), for contact angle measurement using a mixture of methanol and water, the contact angle depends on their relative concentrations. For a 0% methanol solution the contact angle is >150°, then for the concentration of ~30% contact angle drops to ~125° and for the concentration of 44% it drop all the way down to ~40°.

4. Conclusions

In this paper we have presented two surface modification processes; laser polishing of AM parts and laser surface texturing of brass and copper to create superhydrophobic surfaces. For an optimised laser polishing process we have successfully achieved surface roughness (S_a) reduction by 38× for flat and by 11.5× for cylindrical CoCr surface, and for Ti6Al4V a factor of 21.5× for flat and 10 for a cylindrical surface.

We were successful in nanosecond laser texturing of superhydrophobic surfaces on copper and brass using a cost-effective nanosecond laser. Initially after laser texturing, the surfaces were hydrophilic, but after ~11 days they started to exhibit hydrophobic properties, reaching a maximum contact angle of 152°. Such surfaces can be used to measure solutions, such as methanol and water mixture. Depending on the concentration of methanol the contact angle can differ significantly – for 0% contact angle is 152° and for 44% solution it drops to ~40°.

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