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Application of an Ultrashort-pulsed Laser for Generation of Super-hydrophobic Surfaces

Abstract: Hydrophobic surfaces have gained a vast attention in different fields of biomedical applications over the last few years. Laser treatment has been shown as a promising technology for the generation of functional, inter alia, superhydrophobic surfaces. In this study a picosecond Yb-YAG laser was assigned for the generation of superhydrophobic characteristics on a steel alloy with application in surgical instrumentation. Regarding the ablation energy threshold of about 6 μJ for the given pulse width and laser beam characteristics and by assigning a suitable combination of microstructure kinematics and laser processing conditions a persistent hierarchical pattern is mapped over the laser-radiated surfaces. The average measured contact angle on the laser-radiated surfaces was about 150° , which indicates their superhydrophobic properties.

Keywords: ultrashort-pulsed laser, superhydrophobic properties, hierarchical microstructures, medical instrumentation.

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1 Introduction

Inspired from nature, hydrophobic properties, frequently referred as the “Lotus effect” have gained a wide application domain in different fields of biomedical applications over the last few years [1,2]. The most outstanding potentials are found in the medical implants with self-cleaning features [3], controlled cellular interaction [4], protein adsorption [5], bacterial growth [6], and in the medical instrumentation as in drug delivery devices, diagnostic, and surgery tools [7]. The artificial preparation of the hydrophobic effect relies on the modification of surface energy in the contact interface of a fluid medium with a solid boundary [1] which is most commonly

performed by the direct induction of multi-scale structures in micro and nano ranges or by different coating techniques.

Laser treatment has been shown as a promising technology for the generation of functional, inter alia, superhydrophobic surfaces. These surfaces are considered as a sub-category of laser-induced periodic surface structures (LIPSS), which are generally aimed to mimic functional biological surfaces [8].

As a novel representative of laser technology for preparation of functional parts, ultrashort-pulsed lasers provide the highest controllability in the processing of a wide range of medical materials ranging from synthetic resins to metal alloys and ceramics [9–11]. However, the generation of desired functional characteristics requires a deep understanding and deployment of the influential process parameters.

In this study a picosecond Yb-YAG laser was assigned for the generation of superhydrophobic characteristics on a steel workpiece with application in surgical instrumentation. By assigning a suitable combination of microstructure pattern shape and spacing with laser pulse energy density and scanning speed a superhydrophobic surface with a static contact angle of about 150° was achieved, which exhibited a multi-scale hierarchical microstructure pattern.

2 Methods and experiments

A picosecond Yb-YAG laser (Trumpf TruMicro 5050) was assigned for the generation of superhydrophobic characteristics on the matching surfaces of a suture scissor made of a steel alloy. The laser system offers a pulse duration of < 10 ps and a maximum average power of 50 W, while the pulse repetition frequency is fixed at 400 kHz. This allows for a maximum pulse energy of about 125 μJ . A 2D-scanning head with a f-theta focusing lens were used to achieve fast beam deflection and therefore high scanning speeds. A schematic of the experimental setup is presented in Figure 1. The steel sample is placed within the focal point of the focused laser beam with a focused spot size of about 80 μm . The vertical (along the laser beam) and the horizontal adjustment of the sample position is performed by the mechanical axes z and x, y, respectively. After positioning the sample, as the mechanical axes do not possess a high dynamic capacity, the laser conditioning is performed only by means of the laser scanner.

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Figure 1: Image of the experimental setup. Red lines illustrate the laser beam path

The surface of the workpiece samples was uniformly sand-blasted before the experiments. The microstructure analysis of the processed parts was done with scanning electron microscope (SEM) and confocal images. The characterisation of the prepared samples was subsequently performed by injecting microdroplets of a constant volume on the samples and measuring the static contact angle using a light microscope.

Table 1: Process parameters for the generation of hydrophobic samples

Parameter	Values
Average laser power [W]	2.5; 3.5; 5.0; 7.0
Scanning speed [mm/s]	500; 1000; 2000
Hatch distance [μm]	30; 50; 60; 100
Number of repetitions [-]	40; 80; 160

3 Results

In order to define the proper laser pulse energy for the conditioning of the workpiece samples different pulse energy levels were tested. As a result, the threshold average laser ablation power was found to be about 2.5 W, which corresponds to a pulse energy of approximately 6 μJ for the given pulse width. With considerably larger pulse energy values of up to 17.5 μJ the samples were structured in micro-level. However, these microstructures lack the multiscale feature and as can be expected, do not exhibit hydrophobic properties. Conversely, the measured contact angle was less than 20° , which can be characterized as hydrophilic rather than hydrophobic. Multiscale microstructures and accordingly hydrophobic properties were attained by a pulse energy of about 8.75 μJ , which is slightly above the ablation threshold and corresponds to the average laser power of 3.5 W. Not only the laser pulse energy, but also the scanning speed, pattern hatch distance and

the number of repetitions were shown to be determining in the generation of a hierarchical microstructure. Accordingly, the most significant multiscale microstructure was attained with a laser power of 3.5 W, scanning speed of 1000 mm/s, hatch distance of 30 μm and after a repetition of 160 times. Figure 2 presents 2 SEM images of the corresponding sample, where a large-scale pattern period corresponding to the hatch distance (30 μm) is accompanied by a small-scale pattern in sub-micrometre range. Four laser paths are also illustrated.

Figure 2: SEM images of a hierarchical microstructure in large and small scales

The assigned pattern repetitions are required for achieving the sufficient structure depth and the degree of polarization required for the small-scale micro/nano-structure. Godoy et al. have studied the influence on large scale line spacing on the surfaces hydrophobicity [12] and concluded that too small hatch distance will counteract the hydrophobic surface properties. Unlike the small-scale patterns, the large-scale features can be clearly distinguished by means of confocal microscopy as presented in Figure 3. Nevertheless, the large-scale pattern alone will not initiate hydrophobic properties. Secondary small-scale

micro/nano-structures that are generated by the laser beams polarization induce the crucial surface texture. These features can be distinguished as the so-called laser induced periodic surface structures (LIPSS) and are shown in the lower part of Figure 2. Gemini et al. [13] have proven that samples that had a combination of the nanoscale LIPSS and larger surface structures result in larger contact angles in comparison to those textured with LIPSS only.

Figure 3: Confocal image of a multiscale structured sample

The super-hydrophobic properties of the surface structure achieved with the above-mentioned parameters were characterized by microscopic measurement of the static contact angle of the inserted water droplets. The effect of ambient atmosphere on the functional characteristics of laser -treated surfaces is already addressed in the literature [12,13]. However, the effects of atmosphere gas as well as the transition time were not investigated in this study and the samples were prepared under normal atmosphere and the contact angle measurements were performed after a single post-processing time of about 24 hours. Afterwards three contact angle measurements were performed for each sample and the average value was taken for the characterization of the samples. The largest value, which was associated with the selected sample presented in Figure 2 was about 150° as shown in Figure 4.

Figure 4: Microscopic image of contact angle measurement

4 Conclusion

A picosecond laser in combination with a fast 2D scanning head and a f-theta optical lens have been successfully applied to generate super-hydrophobic surfaces on a steel surgical instrument. Even though, the intended hydrophobic characteristics were attained by generating a multiscale micro/nano-structure, the processing condition window for this application is yet very small. Promising results required the application of a pulse energy slightly above the ablation threshold of the workpiece material. Further influential parameters were pattern spacing and energy density. The effects of surrounding atmosphere gas and the transition time were not explicitly investigated, which imply that a deep understanding of the physical effects within the laser processing with ultrashort-pulsed lasers is essential to generate robust, long-lasting hierarchical surface microstructures, that do not need a long transition time to become super-hydrophobic.

Author Statement

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