DOI: 10.2507/34th.daaam.proceedings.xxx

ENHANCING HYDROPHOBIC PROPERTIES THROUGH LASER-INDUCED SURFACE STRUCTURING

Simon Syrovatka, Pavel Kozmin & Ondrej Marsalek

This Publication has to be referred as: Syrovatka, S[imon]; Kozmin, P[avel] & Marsalek, O[ndrej] (2023). Enhancing hydrophobic properties through laser-induced surface structuring, Proceedings of the 34th DAAAM International Symposium, pp.xxxx-xxxx, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-xx-x, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/34th.daaam.proceedings.xxx

Abstract

This paper explores the use of lasers with a focus on surface engineering. Its primary aim is to generate surface structures capable of influencing the characteristics of the material that is tested. Mainly the wettability of the surface, more particularly the enhancement of hydrophobic properties. A laser machine with ultrashort pulses was used to produce hydrophobic surface structures. This paper concludes by evaluating the surface structures and describing the aspects that influence the genesis and proposed functions of these surface structures.

Keywords: wettability; laser; surface structure; contact angle; hydrophobic structure

1. Introduction

Laser machining is beginning to be a more and more common type of machining process. It can be divided into a lot of groups such as laser welding, cutting, machining, surface structuring, etc [1], [2], [3]. Each of these groups of technologies is very interesting and has already been discussed in academic works. This article focuses especially on surface structuring, and the main goal of this article is to describe possibilities of laser surface structuring which could lead to the change of its wettability.

Creating surface structures using a laser can lead to a modification of the inherent properties of the given surface. Laser structuring allows for the alteration of factors beside the surface wettability such as surface roughness, optical properties, tribology and so on. Wettability is the ability of a liquid to adhere to the surface of solid substances. This capability depends on the surface structure of the solid material, which affects the size of the contact angle between the liquid and the solid surface. Surfaces can be categorized in terms of wettability as hydrophilic, hydrophobic, and superhydrophobic– the differences between these types of surfaces are illustrated in Fig. 1, based on the magnitude of the contact angle, which can be measured using numerous methods.

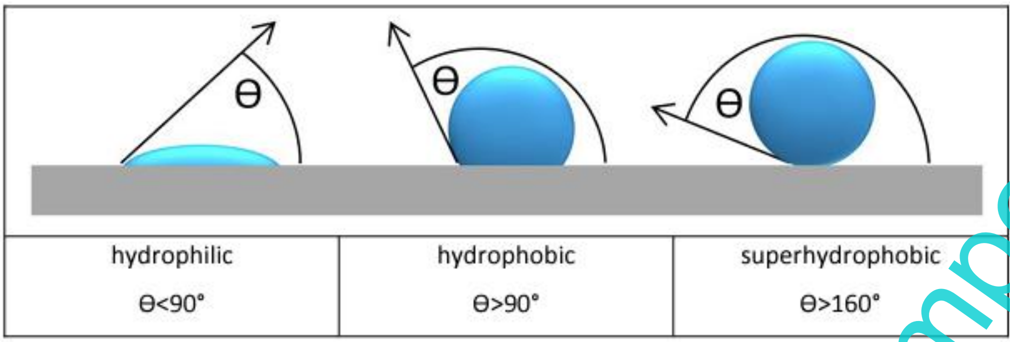


Fig. 1. Categorization of surfaces according to contact angle [4]

Contact angles could be measured by multiple methods of measuring. These methods include for example Young-Laplace method, the circle and polynomial fitting, the mask method, etc [5].

In the available academic publications, there are two main views on the designing of hydrophobic surface structures. The first one consists of known geometrical shapes such as cubes, dots, and grooves [4], [5]. These elementary shapes are often combined with special structures called LIPSS (laser-induced periodical surface structures).

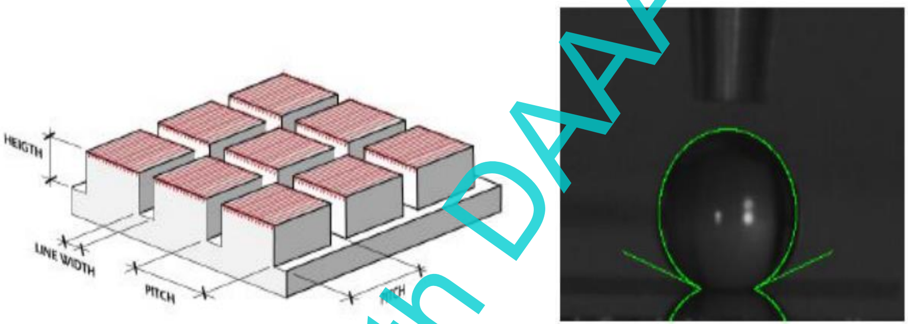


Fig. 2. Metrix structure with LIPSS and measured contact angle of this structure [7]

The second view of designing surface structures is inspired by nature. The shapes are more loose and whole structures are more complex. The best example of a hydrophobic surface structure is the surface of the lotus leaf.

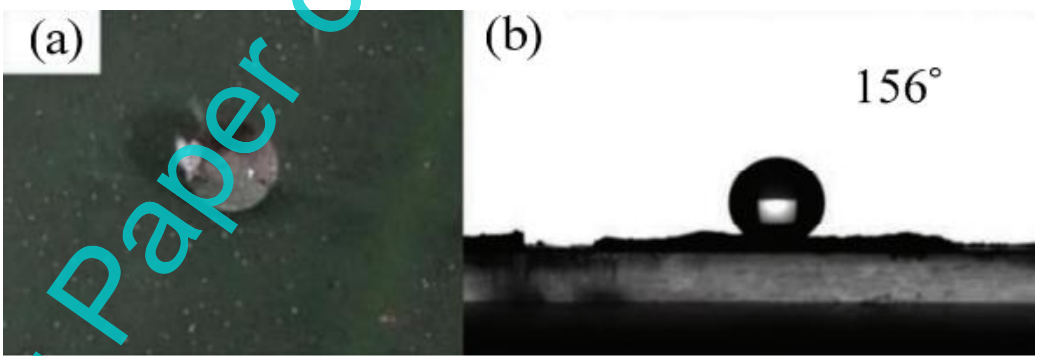


Fig. 3. The water droplet on the lotus leaf (a), the contact angle of the droplet [8]

Controlled wettability of the surface can play a crucial role in engineering in the development of new functional surfaces, the design of innovative machining technologies involving cutting fluids, or the production of workpieces with precisely defined surface properties. For instance, in the aviation industry, a significant challenge is the formation of ice, which detrimentally affects the operations and flight safety of aircraft and helicopters [6]. The complexity of surface structure laser fabrication and their overall effect on surface wettability are investigated in the experiment of this article.

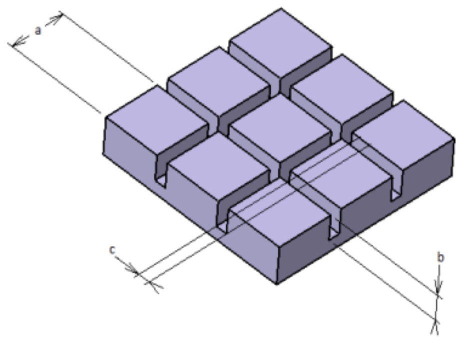
2. Experiment

As the tested material the austenitic chromium-nickel steel stabilized with titanium (X6CrNiTi18-10) was used. This material holds significant prominence in numerous industrial domains that concentrate on laser surface structuring and its subsequent applications. The surfaces of the samples have been ground and the final roughness of the surface was approximately R_a = 0,4 µm this value of surface roughness was crucial for the rest of the experiment to measure only the effect of the manufactured surface structures on the wettability of the surface.

Before the fabrication process the design of possibly hydrophobic structures was made.

1. *Cube*

This surface structure was modified to the 5 variants which dimensions can be seen in the picture bellow.

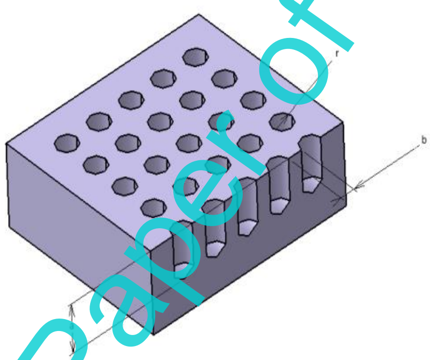


variant	a [µm]	b [µm]	c [µm]
I	50	5	20
II	50	10	20
III	50	10	10
IV	50	20	20
V	50	20	13

Fig. 4. Design and dimensions of structure Cube (a – side of a cube; b – depth; c – pitch)

2. *Hole*

This surface structure was modified to the 5 variants which specifications can be seen in the picture bellow.



variant	r [µm]	a [µm]	b [µm]
1	10	12	20
2	10	12	10
3	15	12	20
4	15	12	10
5	15	12	5

Fig. 5. Design and dimensions of structure Hole (r – radius of a hole; a – depth; b – pitch)

Once the design of the individual structures was created, it was possible to proceed to their production. A laser system with ultrashort pulses was used for it, the parameters of which are:

- Wavelength = 532 nm
- Laser pulse length = 13 ps
- Repetition rate = 200 – 1000 kHz
- Average laser power < 12 W

It was necessary to used specific laser parameters for the manufacturing of all designed surface structures.

3. Results

After the production of the designed structures (it was produced 10 types of structures), each structure was scanned and measured by an optical microscope (Alicona Infinite Focus) to verify the fabrication of the correct dimension (Fig. 6 and Fig. 7).

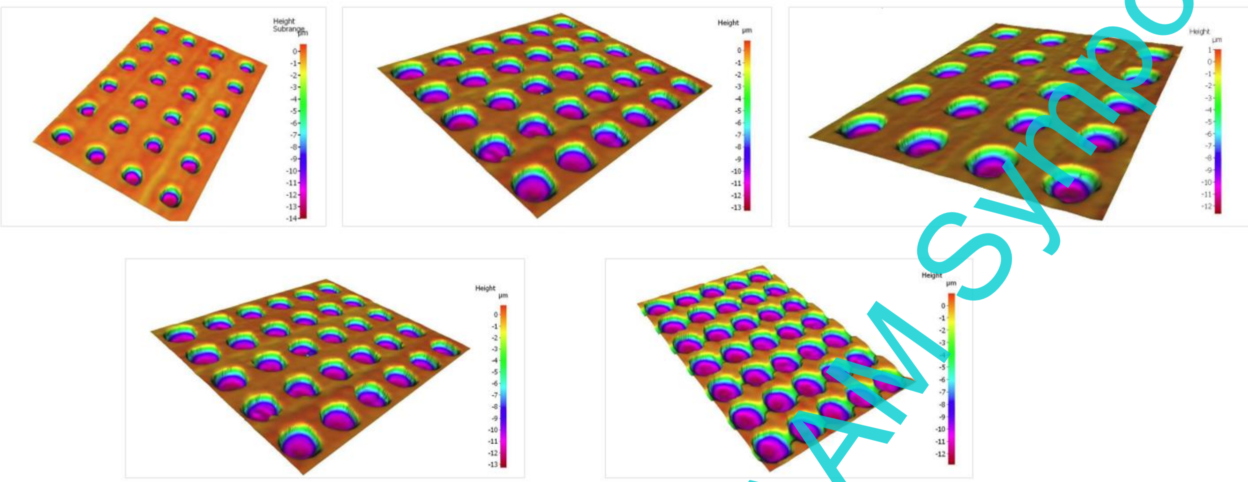


Fig. 6. Scans of fabricated surface structures type Hole (variant 1 – 5)

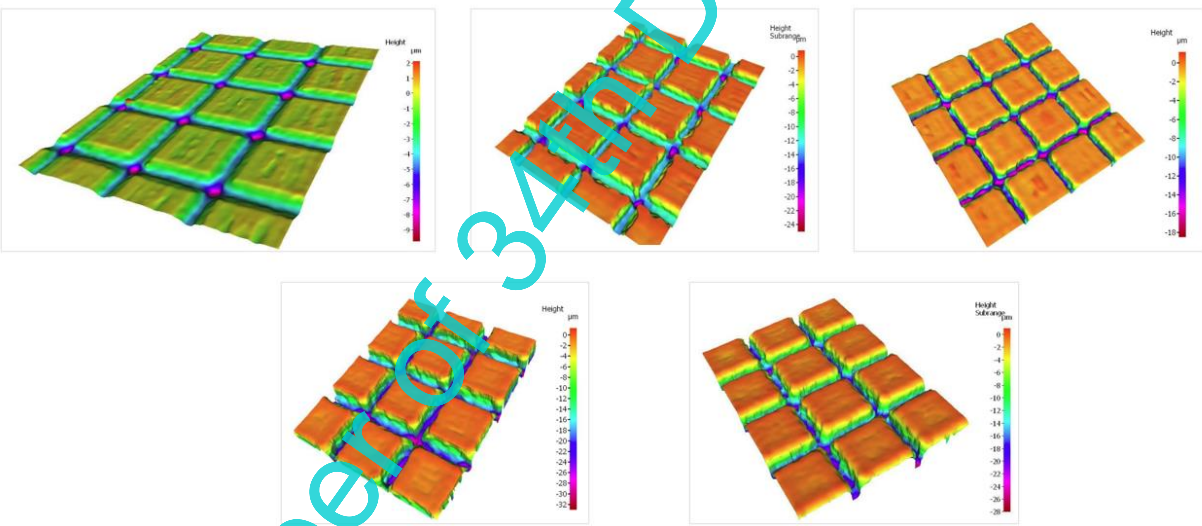


Fig. 7. Scans of fabricated surface structures type Cube (variant I – V)

All surface structures were produced with maximal dimensional deviation of 5 µm.
The next step in the experimental process was to examine the influence of structures on the wettability of the surface (measurement of the contact angle). The method of Sessile drop (static contact angle for the surface) was used for the evaluation of the wettability. For this measurement, the Drop Shape Analyzer (DSA30E) was used. The actual test of wettability was conducted for each produced surface structure. Based on the research study, water droplets with a volume of 3.5 µl were chosen [6]. The wettability angles were measured twice for each sample – first immediately after landing

on the created surface structure and secondly, 10 seconds after landing on the surface structure. The measurements took place approximately two weeks after the fabrication of the surface structures using the picosecond laser system.

Based on these measurements, it was found that the most hydrophobic structure from the type Hole was variant no. 5 and the least hydrophobic was variant no. 3. Regarding the surface structures type Cube the most hydrophobic was variant no. II and the least hydrophobic was the variant no. III.

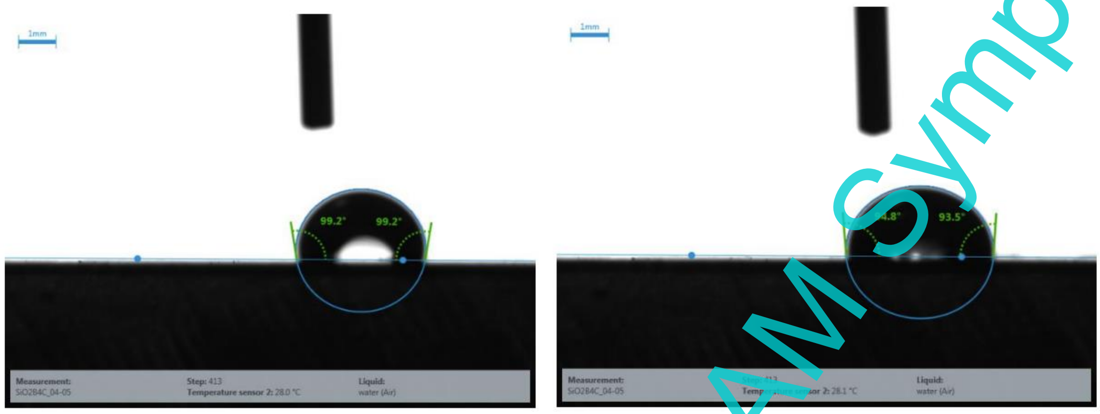


Fig. 8. The measured contact angle of surface structure Hole variant no. 5 (right – just after landing of the droplet on the structure, left – 10s after landing of the droplet on the structure)

Fig. 9. The measured contact angle of surface structure Cube variant no. III (right – just after landing of the droplet on the structure, left – 10s after landing of the droplet on the structure)

4. Conclusion

Several surface structures whose purpose is to change the wettability of treated surfaces were designed based on published articles on a similar topic. These structures are the structures of recurring cubes and recurring holes. It was designed with five variations from each group. All 10 surface structures were manufactured using a picosecond laser system and their dimensional accuracy was verified using an optical microscope. After the fabrication, the contact angle of every structure was measured and based on which the wettability was determined. It was found that the contact angle of the most hydrophobic structure - type Hole was 99,2° (which is 3,8 degrees more than the non-treated surface). Regarding the structures - type Cube the biggest measured contact angle was 120,8° (which is 25,4 degrees more than the non-treated surface).

After all, it could be said, based on the experiments carried out, that the picosecond laser system is a useful tool for the fabrication of surface structures that have an influence on the surface property especially on the wettability of the surface.

However, it is important to say that the wettability of a surface is not only affected by the morphology of the surface to determine the specific factors contributing to changes in surface wettability, but it would also be convenient to manufacture and test an even greater number of samples. Subsequently, the produced samples could be subjected to testing using an alternative method for measuring the contact angle of the liquid (such as the dynamic drop method) or employing a different measuring liquid (such as distilled water). This expanded scope of experimentation would enable a more comprehensive understanding of the underlying mechanisms affecting surface wettability. Also, for the next research work, it would be very interesting to manufacture and test the properties of some structures inspired by nature.

5. Acknowledgments

This article has been prepared under the project SGS-2022-007–Research and Development for Innovation in Engineering Technology–Machining Technology IV.

6. References

[1] Begic-hajdarevic, Derzija, Mugdim Pasic, Ahmet Cekic a Muhamed Mehmedovic (2016). Optimization of Process Parameters for Cut Quality in CO2 Laser Cutting Using Taguchi Method. In: Branko Katalinic, ed. *DAAAM Proceedings* [online]. 1. vyd. B.m.: DAAAM International Vienna, 2016 [vid. 2023-08-30], s. 0157–0164. ISBN 978-3-902734-08-2. DOI: 10.2507/27th.daaam.proceedings.024

[2] Topic, Angela, Branko Bauer, Zoran Kozuh a Nikola Knezovic (2016). Gas Composition Influence on the Microstructure and Geometry of Laser-Welded Joints in Duplex Stainless Steel. In: Branko Katalinic, ed. *DAAAM Proceedings* [online]. 1. vyd. B.m.: DAAAM International Vienna, 2016 [vid. 2023-08-30], s. 0734–0742. ISBN 978-3-902734-08-2. DOI: 10.2507/27th.daaam.proceedings.106

[3] Franz, Markus, Jens Bliedtner a Conrad Haupt (2014). Laser Metal Deposition Welding in the Field of Tool and Mould Making. *Procedia Engineering* [online]. 2014, **69**, 237–240. ISSN 18777058. DOI: 10.1016/j.proeng.2014.02.227

[4] Conrad, Daniel a Lars Richter (2014). Ultra-short Pulse Laser Structuring of Molding Tools. *Physics Procedia* [online]. 2014, **56**, 1041–1046. ISSN 18753892. DOI: 10.1016/j.phpro.2014.08.016

[5] Akbari, Raziyeh a Carlo Antonini (2021). Contact angle measurements: From existing methods to an open-source tool. *Advances in Colloid and Interface Science* [online]. 2021, **294**, 102470. ISSN 00018686. DOI: 10.1016/j.cis.2021.102470

[6] Xing, Wei, Zu Li, Haiou Yang, Xinlin Li, Xinyun Wang a Ning Li (2019). Anti-icing aluminum alloy surface with multi-level micro-nano textures constructed by picosecond laser. *Materials & Design* [online]. 2019, **183**, 108156. ISSN 02641275. DOI: 10.1016/j.matdes.2019.108156

[7] Li, Kewei, Nathaniel Myers, Grant Bishop, Yuxin Li a Xin Zhao (2022). Study of surface wettability on fused silica by ultrafast laser-induced micro/nano-surface structures. *Journal of Manufacturing Processes* [online]. 2022, **79**, 177–184. ISSN 15266125. DOI: 10.1016/j.jmapro.2022.04.035

[8] Yang, Fuchao a Zhiguang Guo (2015). Characterization of Micro-Morphology and Wettability of Lotus Leaf, Waterlily Leaf and Biomimetic ZnO Surface. *Journal of Bionic Engineering* [online]. 2015, **12**(1), 88–97. ISSN 1672-6529, 2543-2141. DOI:10.1016/S1672-6529(14)60103-7