JLMN-Journal of Laser Micro/Nanoengineering Vol. 5, No. 1, 2010

Technical Communication

Controlling the Hydrophobic Properties of Material Surface Using Femtosecond Ablation

Martti SILVENNOINEN, Jarno KAAKKUNEN, Kimmo PAIVASAARI, Pasi VAHIMAA and Timo JAASKELAINEN

Department of Physics and Mathematics, University of Joensuu, P.O. Box 111, 80101 Joensuu, FINLAND

E-mail: martti.silvennoinen@joensuu.fi

The wetting properties of the material can be altered by changing the surface topography. We have demonstrated the controlling of the wetting properties of the metal surface by texturing it using femtosecond laser ablation. Contact angles well above 150 degrees can be obtained to the steel sample using self-organized structures generated by the laser-matter interaction. The combination of micro- and nano-sized structures, obtained using specific laser parameters, changes the stainless steel surface to water repellant.

DOI: 10.2961/jlmn.2010.01.0020

Keywords: Self-organized structures, femtosecond ablation, functional surfaces, wettability, super-hydrophobic surfaces.

1. Introduction

The control over wetting properties of the material surface has various applications in the chemical, biological and medical sciences as well as in our everyday life. Simple example is self-cleaning surfaces, or so called Lotus-leaf effect, where by combining specific micro- and nanostructures superhydrophobic surfaces are obtained [1,2,3]. The hydrophobic/philic properties of the surface can also have a major role in the biomaterial adsorption at interfaces [4,5]. Controlling these properties can be used to enhance desired effects, for example, cell adherence and cell migration, both important aspects of the development of biocompatible materials.

Femtosecond laser ablation is a versatile tool for generation of both, self-organized or directly written, nano-, micro- and macrostructures. When ablating target surface with consecutive high fluence femtosecond pulses various self-organized structures start appearing to the sample surface. Usually these structures are considered as an undesired side-effect degrading the surface finish when using femtosecond laser for micromachining [6]. The self-organized micro-structures consist of randomly distributed deep holes connected with ravine type formations. Average feature size of the microstructure can be controlled by laser fluence and pulse number. Note that the microstructures can be covered with self-organized nanostructures. Similar structures can be made to large selection of material including metals, alloys and semiconductors.

We have manufactured large uniform area of the super-hydrophobic surfaces using combination of the self-organized micro- and nanostructures on stainless steel. We believe that such metal surfaces can have applications in enhancing the biocompatibility of the biomedical implants. Also applications requiring large surface-to-volume ratio, for example, catalysts in chemical reactions can benefit from femtosecond laser ablated surfaces.

2. Experimental

Material for experiments was stainless steel W720 manufactured by Böhler. Samples were cut into a round discs and polished to the optical quality. Before texturing samples were purified with ultra-sonic bath. Texturing of the sample was done by using Quantronix Integra-C-3.5 laser providing energy of 3.5 mJ per pulse, 120 fs pulse length, 790 nm center wavelength and 1 kHz repetition rate. 3D motion controller from Micos was used to move the sample.

The focused laser beam was Gaussian and it was scanned over the sample surface with scanning speed of 15 mm/s. Scanning was performed so that each scanned line overlapped well with previous one to ensure uniform structuring over the sample area. Diameter of the laser spot was 640 μm and each point of the surface received 1000 laser pulses. Fluence was 1.8 J/cm^2. Producing of 1 cm^2 area of such structured surface takes approximately 4 minutes. Scanning electron microscope pictures with various magnifications from the generated microstructures are presented in Figure 1. First of all, it can be seen that large area of uniform surface structures can be generated (Fig. 1 a)). The average size of the generated features is around 15 μm. The size can be controlled from approximately 1 μm to tens of microns by combination of fluence and pulse number. It can be also seen from Fig. 1 d) that micro-structures are covered with laser induced periodic surface structures (LIPSS) [7].

Changes in hydrophobic properties of the structured surfaces were determined with static contact angle measurement using the KSV-CAM 200 optical contact angle and surface tension meter. Immediately after ablation the steel surface is highly hydrophilic due to the

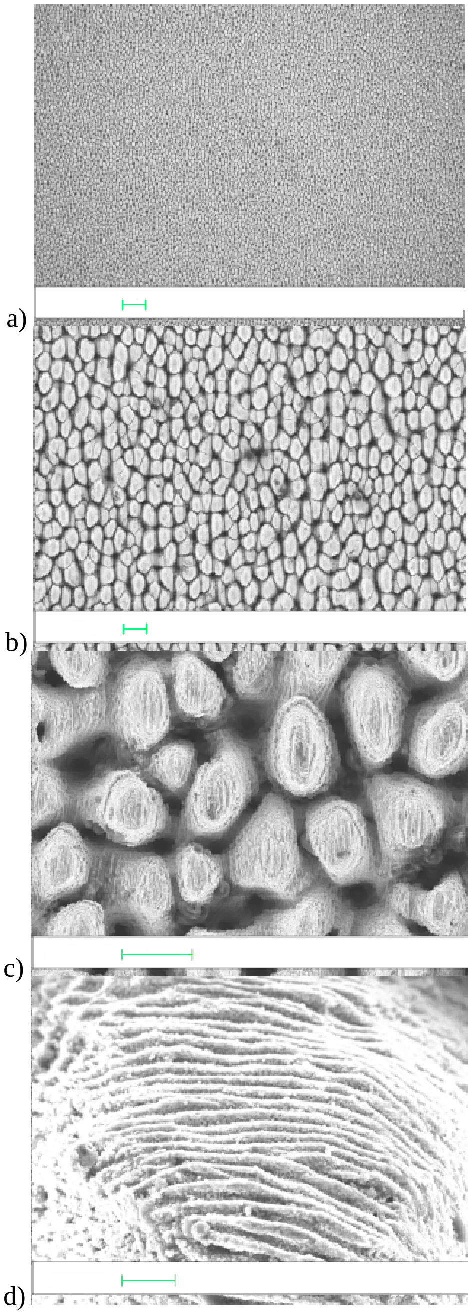

Fig. 1. Sem-images of the structured surface on stainless steel. The scale bar is 100, 20, 10 and 1 μm in a, b, c and d, respectively.

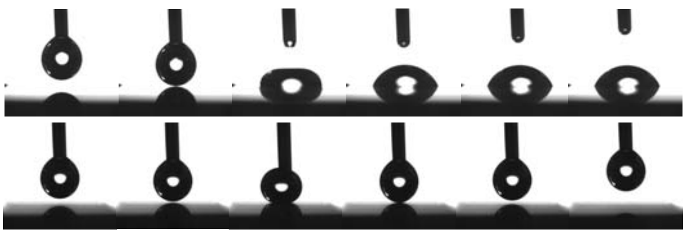

Fig. 2. Two series of pictures from the contact angle measurements. Top row polished stainless steel surface. Bottom row textured stainless steel surface.

ablation debris in form of the small particles. In order to get rid of the detached particles from the surface, samples were treated with 1 hour of ultra-sonic bath in acetone and subsequent chemical treatment called silanization. In Fig. 2 are two series of pictures from the contact angle measurements made from polished and structured steel surface. In the case of polished surface the water droplet is detached from the needle immediately after contact with metallic surface forming a static contact angle of 80°. However, for the structured surface the water droplet refuses to detach from the needle. The structured surface is highly hydrophobic with contact angle of 170°. The reason for such an enhancement of the hydrophobic properties is the reduced area fraction of the liquid-solid contact when changing the topography of the surface. The very low contact angle hysteresis and tilt angle indicates the self-cleaning properties for the surface.

3. Conclusions

Superhydrophobic surfaces were manufactured to the stainless steel samples. Topographical changes in form of the combined micro- and nanostructures result enhanced hydrophobic properties of the surface. Contact angle values of 170° were obtained for structured surface in contrast to 80° for polished steel surface.

Acknowledgments

The authors would like to acknowledge the Finnish Agency for Technology and Innovation (TEKES).

References

[1] T. Sun, L. Feng, X. Gao and L. Jiang, “Bioinspired surfaces with special wettability”, Acc. Chem. Res. **38** (2005), 644-652.

[2] Y. Jung and B. Bhusnan, “Contact angle, adhesion and friction properties of micro- nanopatterned polymers for superhydrophobicity”, Nanotechnol. **17** (2006), 4970-4980.

[3] E. Puukilainen, T. Rasilainen, M. Suvanto and T. A. Pakkanen, “Superhydrophobic polyolefin surfaces:controlled micro- and nanostructures”, Langmuir **23** (2007), 7263-7268.

[4] R. D. Tilton, C. R. Robertson and A. P. Gast, “Manipulation of hydrophobic interactions in protein adsorption”, Langmuir **7** (1991), 2710-2718.

[5] X. Zhang, F. Shi, J. Niu, Y. Jiang and Z. Wang, “Superhydrophobic surfaces: from structural control to functional application”, J. Mater. Chem., **18** (2008), 621-633.

[6] P. T. Mannion, J. Magee, E. Coyne, G. M. O’Connor and T. J Glynn, “The effect of damage accumulation behaviour on ablation thresholds and damage morphology in ultrafast laser micro-machining of common metals in air”, Appl. Surf. Science, **233** (2004), 275-287.

[7] A. Borowiec and H. K. Haugen, “Subwavelength ripple formation on the surfaces of compound semiconductors irradiated with femtosecond laser pulses”, Appl. Phys. Lett. **82** (2003), 4462-4464.

(Received: July 6, 2009, Accepted: December 23, 2009)