Wettability surface control on stainless steel by LIPSS formation

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Abstract. In this paper, laser-induced periodic structures are obtained on the surface of SS304 stainless steel when treated with femtosecond laser radiation. The dependence of the period of surface structures on the speed and power of laser radiation treatment is revealed. The wetting angle and the dependence of this angle on the processing speed are determined. It is shown that after femtosecond laser treatment, the surface became more hydrophilic.

1. Introduction

The rapid development of advanced energy technologies poses new challenges in creating functional surfaces and materials that can significantly optimize the processes of energy production and transmission. Much attention is paid to the development of functional surfaces that can be used to solve modern technical problems related to the creation of materials with an increased coefficient of solar radiation absorption, wear resistance and improved strength characteristics, catalytic activity, as well as the creation of materials with the effect of self-cleaning the surface and the ability to switch wetting modes from superhydrophobic to superhydrophilic state [1-3].

The interaction of laser radiation with solids leads to modification of the target surface layer and is accompanied by the release of micro- and nanoparticles into the environment. Changes in the morphology of the material can be expressed both in the formation of periodic microstructures due to the modulation of the melt by capillary waves, and in disordered microrelief caused by the redistribution of the melt under the influence of environmental vapors. Formation of laser-induced periodic surface structures (LIPSS) corresponding to a spatially modulated surface profile with a period of the order of the light wavelength is one of the most common phenomena that occur when laser radiation is applied to condensed media [4-7].

LIPSS can be useful for controlling friction and wetting. Functional surfaces created as a result of processing the initial technological surfaces with femtosecond laser pulses have a number of new properties that require careful interdisciplinary study. The number of technological applications of surfaces created by this method is growing every day, and their non-trivial properties give grounds for their promising application in various directions [8-12].

2. Experimental setup

The experiments of LIPSS formation were carried out using the pulsed femtosecond Yb:KGW laser system with the wavelength $\lambda = 1030$ nm, the energy of the pulse $E_{\text{max}} \approx 150$ $\mu$J, the pulse duration $\tau \approx 280$ fs. The pulse repetition rate was set to 10 kHz. For scanning the surface with laser radiation, we used a galvoscanator.
A polarizing attenuator is used to adjust the value of the laser pulse power. It is also necessary in order not to disable the optical elements. The transmitted beams are separated and their intensity is controlled by turning the quartz half-wave plate.

Studies of the formed laser-induced spatially periodic structures resulting from the effect of femtosecond laser radiation are performed on the basis of images obtained from Quanta 200 3D scanning electron microscope. Using a scanning microscope, we measured the values of the LIPSS period.

Low-carbon austenitic stainless steel 304 stainless steel (SS304) was used as the processed material. This steel grade is widely used in various fields of industry and agriculture.

The wetting angle was measured using the built-in function of the Altami Studio program. To register optical images, a high-speed Point-Grey Flea3 Color Vision camera with a Modular Zoom Lens System (Thorlabs) of variable multiplicity and optomechanical equipment was used.

Samples with the initial measurement of the wetting angle were processed by laser radiation at different speed values. The wetting angle of each treated area was measured immediately after laser processing.

3. Results and discussion

To form laser-induced periodic structures, a number of experiments were performed on the surface of SS304 stainless steel. Before the experiment, the sample surfaces were thoroughly cleaned. The samples were processed using a femtosecond THETA-10 laser system [13-15].

During a series of experiments, the laser power was 700 mW, 1000 mW, 1300 mW. The processing speed also changed from 100 to 2000 mm/s. The results of surface treatment were analyzed based on images obtained from a scanning electron microscope (SEM). Figure 1 shows surface images of processed samples obtained using a Quanta 200 3D SEM at various processing laser power and scanning speeds of 100 mm/s. Image analysis showed the dependence of changes in the nature of the formed structures on the scanning speed. The criterion for determining the best treatment mode was to obtain well-formed periodic structures, without any pronounced defects in the form of spall ablation of the melt or phase explosion.

The measurement of the period of laser-induced surface structures as a function of power and speed is shown in Figure 2. Based on the data obtained, it can be concluded that the period of laser-induced surface structures can vary in a fairly wide range of values depending on the parameters of laser radiation (from 205 to 972 nm).
The wetting edge angle was estimated using the sessile drop method, and distilled water was used. According to this method, a drop of solution was placed on a flat horizontal surface of the samples, and the camera integrated into the microscope focused on the drop, where its edges were clearly visible. Special tables were used to position the sample, allowing the sample to be moved along two coordinates with micrometer accuracy. The sample was installed on translators. An optical system of variable magnification with a digital camera was used to obtain images. Then the image of the deposited drop was displayed on the monitor screen.

The wetting angle is formed between a tangent drawn to the surface of the liquid-gas phase and a solid surface with a vertex located at the contact point of the three phases. The wetting angle of each treated area was measured immediately after laser processing (Figure 3).

The graph of the wetting angle dependence on the speed of laser radiation processing at the laser power of 700 mW, 1000 mW, 1300 mW is shown in Figure 4. The values of the wetting edge angle vary as the laser processing parameters change. Based on the data obtained, at small values of the edge angle, the liquid spreads over the surface of the treated material, which indicates that after femtosecond laser treatment, the surface properties of the material have changed. The surface became hydrophilic.

Following the obtained graph and comparing the images from microscopes, we can conclude that the wetting angle significantly decreases with a decrease in the processing speed, which is caused by a change in the received energy from laser radiation and the formation of micro- and nanostructures on the sample surface, as well as the formation of oxides with elements that are part of stainless steel.
Fig. 4. Graph of the wetting angle depending on the processing power and speed.

4. Conclusion
A series of experiments on processing stainless steel with femtosecond laser radiation at different scanning power and speed was performed. The wetting angle of the treated surface was evaluated using the sitting drop method. Based on the results of estimating this angle, a graph was drawn up of the dependence of the wetting edge angle on the processing speed, and the laser processing mode was selected, in which the surface property of the material changed. The surface became more hydrophilic after femtosecond laser treatment. The value of the edge angle is affected by laser radiation parameters such as processing speed and power.

References
[1] San-Blas A. et al. 2020 Applied Surface Science. 520 146328
[2] Gnilitskyi I. et al. 2019 Lubricants. 7(10) 83
[3] Florian C. et al. 2018 ACS applied materials & interfaces. 10(42) 36564
[4] Fraggelakis F. et al. 2018 Journal of Laser Micro Nanoengineering. 13(3) 206.
[5] Žemaitis A. et al. 2020 RSC Advances. 10(62) 37956
[6] Varlamova O. et al. 2017 Applied Physics A. 123(12) 725
[7] Aizawa T et al. 2020 Metals. 10(8) 1044
[8] Murzin S. P. et al. 2020 Coatings. 10(7) 606
[9] Bonse J. et al. 2014 Applied physics 117 (1) 103
[10] Hashida M. et al. 2016 Applied Physics A. 122 (4) 484
[11] Yao J. et al. 2012 Applied Surface Science. 258 (19) 7625
[12] Kochuev D. A. et al. 2020 Technical Physics Letters. 46 (8) 779
[13] Kochuev D. A. et al. 2020 Bull. Russ. Acad. Sci. Phys. 84 (3) 443
[14] Voznesenskaya A. et al. 2019 Journal of Physics: Conference Series.1164(1) 012002
[15] Khorkov K. S. et al. 2017 Bull. Russ. Acad. Sci. Phys. 81(12) 1438.