Investigation of functional properties of metal surfaces after laser treatment

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Abstract. This article presents the results of the study of the processes of formation of the metal surface, which has different hydrophysical properties and high chemical resistance to acidic media. The dependence of the contact angle of the surface ($\theta$) on various parameters of laser processing material, the density of arrangement of the scanning vectors, the depth of the heated layer, the presence of oxide layer, etc. Determined optimum modes of laser processing, with which it is possible to obtain the greatest hydrophobicity, and maximum adhesion to the metal surface.

1. Introduction
The interaction of water and water vapor with the surface of various materials has a great influence on the functional and operational properties of objects. In particular, water and water-forming media contribute to the active corrosion of metals. For example, the mechanism of repulsion of water drops has long been used in nature. More than 200 species of plants (the well-known "Lotus effect") and various living organisms have surfaces whose microrelief is able to prevent interaction with water. A good illustration of the natural use of structured micro roughness is the leaf of the Tarot plant (Colocasia esculenta). The property of hydrophobicity of these species of plants and animals occurs due to the special geometric structure of their surface (figure 1).

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{figure1a}
\includegraphics[width=0.4\textwidth]{figure1b}
\caption{(a, b). Examples of natural and artificial hydrophobic surfaces (a) Lotus leaf surface; (b) artificially created water repellent surface [1].}
\end{figure}
In this connection, no less effective way to protect the metal from corrosion is the creation of hydrophobic surfaces with using laser radiation. Laser micromachining is a relatively new method of manufacturing micrelief of the surface but is already actively used in modern and innovative manufacturing enterprises. The main research on the creation of hydrophobic surfaces is carried out on pico- and femtosecond lasers (\(\lambda=1030\) nm and \(\lambda=800\) nm). Despite the significant amount of work on the creation of hydrophobic surfaces, today there are a number of unresolved problems that limit the widespread use of these technologies: insufficient wear resistance of microgeometry, the need for the use of consumables, weak chemical resistance of hydrophobic layers. In some cases, the created surface microstructures and coatings are characterized by insufficient mechanical strength. Therefore, reducing the rate of degradation of the hydrophobic state as a result of interaction with water molecules during underwater and underground operation of materials remains an urgent task.

The aim of the study is the possibility of forming a surface with high adhesion and hydrophobicity properties by a fiber nanosecond laser. This work is a continuation of the authors’ research [2-7] on the creation of anticorrosive coatings using fiber laser radiation.

2. Experiment and results

In our work we used a fiber nanosecond laser (operating in pulse-periodic mode) with the wavelength of 1070 nm and power up to 18, 4 W (figure 2). The power density of laser radiation was varied in the range from \(q_0=0,1*10^8\) W/cm\(^2\) to \(q_0=2*10^8\) W/cm\(^2\). The density of the vectors was from 1 to 20 line/mm. As a test sample, steel grade was used 10X18H10T. Surface treatment of metal was held at a room temperature of 23°C and a relative humidity of air of 55%.

The analysis of the obtained results allows us to conclude that laser irradiation of the surface of steel with a fiber nanosecond laser can serve as an alternative to expensive lasers with ultrashort pulse durations in the creation of microstructured surfaces. Figure 3 and 4 show microphotography of the steel surface with the best wetting angle and the best adhesion properties.
Studies have shown that the greatest hydrophobicity of the surface corresponding to the highest wetting angles $\theta$, measured immediately after the surface treatment with laser radiation, is obtained at a pulse duration $\tau = 4$ ns, pulse repetition frequency $f = 20$ kHz and scanning speed $V$ to 100 mm / s. Increasing the repetition frequency of laser pulses $f$ from 20 kHz to 100 kHz, increasing their duration $\tau$ to 100...200 ns, and a decrease in the scanning speed $V$ to 150 mm / s leads to a sharp decrease in the wetting angle $\theta$, which indicates a decrease in hydrophobicity – an increase in the hydrophilicity of the metal surface.

Figure 5 shows how the degree of wetting of the surface changed (the wetting angle of the untreated surface is indicated by a solid line). Some modes, such as increasing the fill density (Lin./mm) and increased scanning speed (V), give a positive hydrophobic result. At the same time, there is a set of parameters at which the value of the wetting angle could not be measured practically, since the angle $\theta < 10^\circ$. Such a value of the wetting angle indicates the complete absorption of the surface of the water drop is achieving a high adhesive ability.

Figure 3(a, b). Microphotography (a) maximum wetting angle of the sample surface; (b) linear metal surface fill vectors.

Figure 4(a, b). Microphotography (a) sample with the best adhesive properties; (b) linear metal surface fill vectors.
The samples were tested a month after the experiment. As can be seen from the results (figure 6), the picture changes over time. Some of the experiments carried out with high scanning speed and a low pulse repetition rate gave a positive hydrophobic effect. The wetting angle in them exceeds 120°, which allows them to be classified as hydrophobic surfaces (over 150° superhydrophobic surfaces). It is suggested that this change over time is due to the slow oxidation of the metal surface under normal storage conditions.

As can be seen from figures 5 and 6, a month later the total degree of hydrophobicity increased, which is confirmed by both experiments and literature [8]. Several modes of laser treatment allowed to approach the values of the wetting angle θ≈140°, which characterizes the metal surface as hydrophobic.

Figure 5. Graph of the dependence of the wetting angle θ of the treated surface on the successive changes in the various values of the laser system parameters q, V, f, τ, the number of passes N and the density of the fill immediately after the formation of the surface microtopology.
Figure 6. Graph of the dependence of the wetting angle θ of the treated surface on the successive changes in the various values of the laser system parameters q, V, f, τ, the number of passes N and the density of the fill in a month after the formation of the surface microtopology.

Table 1 presents the laser processing parameters for best results.

|  | θ | τ, ns | V, mm/s | q, W/cm² | f, HGz | N, line/mm | Repeat | Type | θ₀ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 9.1 | 4 | 25 | 2*10⁸ | 20 | 20 | 1 | lin | 139 |
| 2 | 7.9 | 4 | 25 | 2*10⁸ | 20 | 10 | 6 | lin | 25 |

3. Conclusion
The article presents an experimental possibility of obtaining surfaces with a high degree of hydrophobicity immediately after laser treatment and over time. By adjusting the parameters of the laser system, it is possible to produce a metal surface, which in its properties will simulate the hydrophobic surface of the Lotus leaf. Despite the fact that the experimental setup used can not provide the accuracy of the surface roughness control of the material necessary to obtain superhydrophobic surfaces, it allows to produce surfaces whose total stochastic roughness leads to an increase in the hydrophobicity of the surface, which was demonstrated in the article. In this connection, the widespread fiber nanosecond laser can serve as an alternative to expensive lasers with ultrashort pulse durations in the production of microstructured surfaces.
Studies have shown that the greatest hydrophobicity of the surface corresponds to the greatest wetting angles $\theta$. It is also worth noting that the properties of manufactured surfaces with high hydrophobicity and a high degree of adhesion, change over time under the influence of changing environmental conditions. This phenomenon requires additional observations taking into account the time parameter. In addition, the obvious dependence of the wetting angle $\theta$ on the laser radiation parameters has not yet been detected. It is only possible to determine the nature of the change in the desired angle from the increase or decrease of a particular parameter of the laser system. The investigated technology of creation of a microrelief is not capable to replace all available methods of processing of a surface of metals but will help to solve a number of problems connected with a change of properties of a surface. In the future, it is planned to conduct research on mechanical stability and service life.

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