Formation of antifriction surface-periodic nanostructures under the action of ultrashort laser pulses

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Abstract. In this paper, we studied the method of forming of periodic surface structures resulting by the action of femtosecond laser radiation. The dependence of the formed structure pulsations period on the orientation angle of the sample was established. Studies of the formed periodic surface structures resulting by the action of femtosecond laser radiation were made on the basis of the obtained images from a scanning electron microscope. A study of the coefficient of friction of the sample before and after processing on the tribometer was carried out. It was concluded that LIPSS created on the surface of molybdenum reduced the friction coefficient by half.

1. Introduction

Laser-induced periodic surface structures (LIPSS) are a unique phenomenon that can be observed on almost any material after irradiating it with linearly polarized laser beams, especially when using femtosecond laser radiation [1-3]. Over the past few years, research activities in the field of LIPSS have increased significantly, since their generation in a one-step process provides a simple method of nanostructuring and surface functionalization for controlling optical, mechanical or chemical properties. After exposure to metal by femtosecond radiation, the sample surface acquires a lower coefficient of friction and wear, which underlines the huge potential of LIPSS in tribological applications. The coefficient of friction is reduced by more than two times [4].

The frictional qualities depend on the microstructure of the surface, namely on a certain degree of roughness or porosity, in which the oil is retained in the cavities and pores. The appearance of antifriction properties under dry friction conditions is facilitated by the presence of such components in the material, which themselves have a lubricating effect and are present on the friction surface and provide low friction [5, 6]. A widely used approach is to reduce the coefficient of friction through the use of lubricants. Due to the grooves and roughness available on the surface, the lubricant remains in the grooves. This effect allows the lubricant to stay longer between the pipes.

2. Experimental work

The femtosecond laser system TETA-10 was used as a radiation source in this work. The parameters of the laser radiation were the following: the duration of the radiation pulse $\tau = 300$ fs, the energy per pulse $\varepsilon = 150$ $\mu$J. The sample was a round molybdenum plate. The sample prepared for the experiment was subjected to laser processing. The dependence of the period of the formed structure of the pulsations on
the angle of orientation of the sample was established [7]. The power value was 1.2 W, and the sample displacement speed was 1 mm/s.

Using the motorized rotary translator Standa 8MR151, the sample was set to: $\Theta = 0; 5; 15; 25; 35$; and 45 degrees, then laser radiation passes through the focusing lens, and then strokes begin to form. The scheme of this experiment is shown in Figure 1.

**Figure 1.** Diagram of the experimental setup for the formation of PSS by changing the angle of the sample

The principal trajectory of the surface scan is presented in the implemented scheme in Figure 2. The speed of movement of the sample is $\upsilon_1 = 1$ mm/c; $\upsilon_2 = 2$ mm/c; $\upsilon_3 = 3$ mm/c.

**Figure 2.** The principal trajectory of the movement of laser radiation and the formation of surface-periodic structures in the implemented scheme

3. Research

The studies of the formed periodic surface structures resulting from the action of femtosecond laser radiation were made on the basis of the obtained images of the scanning electron microscope Quanta 200 3D. The criterion for determining the best treatment regimes was the formation of periodic structures without any pronounced defects in the form of exfoliating melt ablation or a phase explosion.
Figure 3. SEM images of the obtained PPP at a speed of 1 mm/s and angle of inclination: a) $\theta = 0^\circ$; b) $\theta = 5^\circ$; c) $\theta = 15^\circ$; d) $\theta = 25^\circ$; e) $\theta = 35^\circ$; f) $\theta = 45^\circ$.

Figure 3 (a) shows the formed surface-periodic structures that were obtained as a result of laser exposure to a molybdenum sample. The angle of the sample was 0 degrees. The period is $\Lambda = 419.56$ nm. In Figure 3 (b), one can see that with an increase in the angle of inclination of the sample one can see an increase in the PSS period. With an increase in the angle by 5°, the period of the PSS increased to an average value of $\Lambda = 475.87$ nm. Figure 3 (c) also shows an increase in the period with increasing angle of inclination of the sample. The PSS period, with a speed of 1 mm/s and a tilt angle $\theta = 15^\circ$, on average reaches $\Lambda = 515.81$ nm. In Figure 3 (d), the PSS period, with an increase in the angle to 25°, has already grown to an average value of $\Lambda = 532.11$ nm. In Figure 3 (e), after increasing the angle to 35°, the PSS period became equal on average to $\Lambda = 546.20$ nm. As the angle increases to 45°, as shown in Figure 10 (f), the surface-periodic structures appear less intense, and their period is on average $\Lambda = 567.26$ nm.

Figure 4. Graph of the PSS period versus angle. 1 - values obtained by the formula. 2 - values obtained experimentally.

There are differences in the dynamics of the growth of the PSS period in comparison with the data obtained as a result of calculation by the formula and from experimental data [8]. The growth trends of the PSS period with a change in the orientation angle of the sample to laser radiation described in
the literature persist [9]. The difference in growth dynamics can be explained by several factors: 1) the effect of a laser-induced plasma torch formed on the surface of the sample during processing; 2) some inaccuracy when setting the position of the sample relative to the focal plane of the focusing system; 3) factors not specified in the literature that have a certain influence on the result.

The study of the coefficient of friction on the surface of molybdenum before and after treatment was carried out on the CSM tribometer. The specimen was mounted on a movable table, a movable rod was adjusted, and a steel ball was fixed as a counter-body. The force with which the counter-body acted on the sample was 10 N. Between the counter-body and the sample was a lubricant - industrial oil [10]. In the work program, the parameters were set for the speed and distance that the counter-body would travel by moving along the model. The speed was equal to 10 cm / s, and the distance was 40 m. After making all the parameters, tests were carried out, during which graphs of the friction coefficient were plotted in the working window of the program (Fig. 5).

![Figure 5. Graph of the coefficient of friction of the surface of molybdenum: 1 - untreated by laser radiation, 2 - treated with laser radiation.](image)

In Figure 5A, the friction of the counter body against the surface of untreated molybdenum using oil occurred. The friction coefficient here was about 0.11. After molybdenum was treated with laser radiation, the coefficient of friction of the counter body on the surface of the sample under study decreased by a factor of 2 and became equal to 0.055. This graph can be seen in Figure 5B. It can be concluded that LIPSS formed on the surface of molybdenum helps to reduce the friction coefficient by 50%. This is due to the fact that LIPSS are alternating grooves in which oil is retained in the grooves, which in turn provides low friction, and this effect can be achieved by reducing the area of the contacting surface due to the formation of some roughness.

4. Conclusion

The laser-induced periodic surface structures created on the surface of molybdenum reduced the friction coefficient by half. After exposure to the metal by femtosecond laser radiation, the sample surface acquired a lower coefficient of friction and wear, which underlines the enormous potential of periodic surface structures caused by a laser in tribological applications. The developed surface micro-relief, in addition to the lubrication retention functions, helps to reduce the contact area on contact of mated friction pairs. The considered method for the formation of periodic surface structures can be used in industry in the treatment of friction pairs to increase the antifriction properties.

5. Bibliography

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