Investigation of the physical and mechanical characteristics of the applied corrosion-resistant powder coating

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Abstract. This article presents the results of experimental work on the development of a laser complex for micro- and nanomodification of metal surfaces using hybrid technologies. As an alloying material, a corrosion-resistant composite powder of the national brand was chosen, which is used in industry to prevent the occurrence of corrosion formations on the working surfaces of the executive parts of machines. One of the most used national grades of structural carbon steels was chosen as the substrate. The parameters of the laser radiation varied in two parameters: scanning speeds in the range of 12-15 mm/sec and radiation power in the range of 3-5 kW. As a result of the work carried out under various power modes, prototypes were obtained. On their basis, tabular data on the obtained values of microhardness, wear resistance and friction coefficients are compiled. The description of the obtained results is given and the direction of further work is indicated.

1. Introduction
Conducting experimental work in this direction is associated with the high interest of the scientific community and industrial figures in the field of alternative methods of processing materials. This interest is primarily associated with the high degree of efficiency of the products obtained when processing with a laser, plasma or other energy sources. Moreover it is much more cheaper use of the energy consumed by the equipment [1]. Do not forget about the wide range of new properties obtained and the improvement of existing properties of parts after this kind of processing.

During the work carried out, special interest was paid to improving the wear-resistant characteristics of metal surfaces. In addition, it was necessary to find out how the increase in wear resistance affects the hardness parameter of the coating. A wide range of powder compositions available on the market, both foreign and national manufacturers, is suitable for these properties. But in this experiment, powders of only national brands participated, due to the desire to achieve maximum economic efficiency.

The structural carbon steel of the national brand, which is common in the production of bushings, plates, gears and other products, was chosen as the substrate material.

The expected results of the experiment were an increase in the hardness of the initial metal surface and increased wear resistance values. Of particular interest was the comparison of the obtained friction coefficients for the obtained coatings and the initial surface.
2. Materials and methods
The initial steel samples were small rectangular plates with a wall thickness of about 4 mm. Before the experiment, the surface of the samples was sanded and treated with a degreasing compound [2]. The experiment involved several plates, each of which was processed under different power modes. Three (3) powder tracks were applied to each of the plates. Only the scanning speed of the laser beam was varied within one plate. When switching to the next plate, the radiation power increased in increments of 1 kW. A total of 9 tracks were applied [3].

The application parameters used are shown in Table 1. The values of the powder feed rate and the focal length of the laser head remained unchanged during the experiment [4].

| №  | Power, kW | Feed rate of powder, l/min | Speed of scanning, mm/sec | Focal length, mm |
|----|-----------|----------------------------|---------------------------|-----------------|
| 1  | 3         |                            | 12                        |                 |
| 2  | 3         |                            | 13                        |                 |
| 3  | 3         |                            | 15                        |                 |
| 4  | 4         |                            | 12                        |                 |
| 5  | 4         | 9                          | 13                        | 30              |
| 6  | 5         |                            | 15                        |                 |
| 7  | 5         |                            | 12                        |                 |
| 8  | 5         |                            | 13                        |                 |
| 9  | 5         |                            | 15                        |                 |

The coatings obtained on the substrate were captured in photographs. It should be noted that the coatings with the specified power parameters of 3 kW and the beam scanning speed in the range of 12-15 mm / sec did not give a satisfactory result, in which the fusion with the substrate would be strong [5], and the coating structure would be able to withstand external mechanical influences. This result was noted and presented in figure 1 below the text.

![Figure 1](image)

Figure 1. Coatings obtained at a power of 3 kW and scanning speeds of 12, 13, and 15 mm / sec from top to bottom, respectively.

The coatings obtained by increasing the power to 4 and 5 kW and varying the speed within the same limits showed much more effective results. The powder successfully fused with the substrate in both cases [6], and the formation of coagulated powder granules was minimized [7]. The results are shown in figures 2 and 3.
Figure 2. Coatings obtained at a power of 4 kW and scanning speeds of 12, 13 and 15 mm/sec from top to bottom, respectively.

Figure 3. Coatings obtained at a power of 5 kW and scanning speeds of 12, 13 and 15 mm/sec from top to bottom, respectively.

The obtained samples were carefully cut out of the substrate for the convenience of further research [8]. The end surfaces of the samples were carefully sanded, polished and etched in a special chemical composition.

3. Results
The microhardness study was carried out in accordance with the state standard "Measurement of microhardness by indentation of diamond tips" on a microhardness meter of the PMT-3 model [9]. The method consisted in awarding individual zones of the coating structure with a load weighing 100 gs, which left prints with a certain shape of geometry on the surface. Further, these prints were studied on microscopic equipment and, using the geometric parameters of the print diagonals, were transformed by the formula into Vickers hardness parameters [10]. The results of the performed measurements are shown in table 2.

Table 2. The results of measurements of the microhardness of samples at the specified processing parameters.

| Sample mode | Place of measurement | Number of measurements | The arithmetic mean of the diagonal | The arithmetic mean of the obtained hardness, HV | The arithmetic mean of the obtained hardness, HRC |
|-------------|----------------------|------------------------|-------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 4 kW/12 mm/sec | Deposited layer | 2                      | 18.5                                | 541.7092768                                   | 51.8                                          |
|             | Main material       | 2                      | 25.7                                | 280.706919                                    | 27.3                                          |
| 4 kW/13 mm/sec | Deposited layer | 2                      | 17.2                                | 626.6901028                                   | 56.5                                          |
|             | Main material       | 2                      | 24.1                                | 319.20938                                     | 32.2                                          |
| 4 kW 15 mm/sec | Deposited layer | 2                      | 19.15                               | 505.5593807                                   | 49.5                                          |
|             | Main material       | 2                      | 25.3                                | 289.6467684                                   | 28.5                                          |
| 5 kW 12 mm/sec | Deposited layer | 2                      | 17.65                               | 595.1416029                                   | 54.8                                          |
|             | Main material       | 2                      | 26.2                                | 270.0891556                                   | 25.9                                          |
The obtained results are displayed visually in figure 4. The hardness values are given in the HRC system [11]. The modes are assigned with an indication of the power used and the scan speed through the separator character «/».

![Figure 4. Histogram of the microhardness values of the obtained layers (orange column) versus the hardness of the substrate material (blue column).](image)

Table 3. The values of the friction coefficients obtained during tests on the tribometer.

| Marking of the sample /№ diagram | Friction before running-in | Friction after running-in | Total coefficient of friction |
|----------------------------------|---------------------------|---------------------------|------------------------------|
| 4 kW-10 mm*sec/1                 | 0.379                     | 0.416                     | 0.4                          |
| 5 kW-10 mm*sec/2                 | 0.58                      | 0.66                      | 0.63                         |
| 4 kW-13 mm*sec/3                 | 0.45                      | 0.56                      | 0.55                         |
| 5 kW-13 mm*sec/4                 | 0.57                      | 0.62                      | 0.61                         |

The dynamics of the change in the coefficient of friction of the sample surfaces is visually displayed in figure 6. It shows a graph that takes into account the friction before/during and after the indenter is applied to the surface of the material.

4. Discussing
The process of selecting laser treatment modes for various materials and applications is a rather time-consuming and complex process. Many of the results obtained during such tests may not be sufficient, or even not at all satisfy the needs of the consumer and the application industry. The implementation of a series of numerous experiments, during which a wide range of available controlled laser parameters will be tested, can neutralize failures and help achieve a positive result.
Figure 5. Diagrams of changes in the coefficient of friction during tests on a tribometer.

Figure 6. Image of the results of measuring the friction coefficients of the obtained samples.

This work demonstrates exactly such an excerpt of the process of selecting the necessary processing mode. The results obtained in this work are nevertheless promising, due to the obtained
microhardness characteristics and wear resistance coefficients. The values of microhardness, based on the obtained data, are able to reach values twice as large as their original ones. However, an absolutely solid material is also not an ideal option for solving emerging problems, since due attention should be paid to the values of impact strength, plasticity and fatigue.

The increase in the coefficient of friction of the samples, based on the graph, is associated with an increase in the radiation power and the processes occurring on the sample surface during the melting of the base and the reinforcing substance. So, at reduced capacities, the coefficient of friction varies within 0.37-0.52, and at increased capacities within 0.6-0.64. The measurement error is caused by irregularities formed when powder granules are deposited on the surface of the product. It is worth noting that in order to achieve a high degree of protection against abrasive wear, it is necessary to keep the coefficient of friction within the limits not exceeding 0.8 values.

The overall result should be noted the effectiveness of the laser-hybrid processing method and its effect on the internal structure of the steel material. In future works, a larger range of the studied parameters will be investigated.

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