Abrasive wear of metal surface modified with mineral particles

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Abstract. The resistance of mineral coatings created on the surface of specimens of 20X13 steel (Russian analogue of steel 20Cr13 (EU)) modified with ultradispersed mineral particles to abrasive wear during friction against fixed particles was determined, and the wear parameters of layers modified with mineral particles were compared with the parameters of surface layers created by laser cladding of alloys of different compositions. The studies were carried out on an experimental setup for testing abrasive wear under a static load of 60 N and 160 N and determined the weight wear, the average wear rate and the average wear rate of the surface layer of three samples with different mineral coatings. According to the results of measurements at a pressure on the wear surface of 0.5 MPa, a sample was determined with an indicator of weight wear comparable to a coating made of cobalt alloy, created by the method of laser cladding and about four times inferior in this indicator, to a coating of a nickel alloy, created by the method of laser cladding and tool steel. The practical use of various methods of protecting parts from abrasive wear is determined, along with the physical and technical characteristics of the layers, by the economic feasibility in specific operating conditions.

1. Introduction
The creation of protective films, coatings and modified layers with properties that differ from those of the main part is one of the promising areas of material science [1]. Evaluation of the practical benefits of the creation of films or layers traditionally consists in determining the degree of protection from the external environment (thermal cycling loads, abrasive, water, acids, alkalis, etc.) and is characterized by a set of properties and measured parameters (hardness, coefficient of friction, resistance to corrosion, wear resistance, etc.) [2-3].

Interest in modified layers enriched with microparticles of various minerals is due to their prospects as wear-resistant, corrosion-resistant, extreme pressure, antifriction coatings created on the surface of friction pairs of various metals - steels [4-6], titanium [7], aluminum [8], working in an aggressive environment - abrasive, sea water, in the presence of gases, acid solutions, under thermal cyclic loads [9, 10]. The special properties of mineral coatings, as well as such characteristics of the technology of their creation, such as the locality of deposition of coatings, low temperatures during their production, high speed of creation of coatings, give the technology additional marketing advantages in the market of wear-resistant coatings [4, 6]. Entry into the market of metallurgical, mining, construction equipment traditionally precedes research in independent laboratories and operational tests at the sites of corporate partners. The resource of equipment, machine assemblies and individual parts operating
at enterprises of these industries strongly depends on abrasive wear, which occurs when parts of mechanisms are rubbed against the processed material, as well as in friction pairs operating in a fine abrasive medium [11-13].

For the equipment of enterprises in these industries, the study of the properties of coatings or protective layers created on metal parts under conditions of abrasive wear is especially relevant [14]. Until now, based on the results of the use of mineral coatings under abrasive wear conditions, created on various parts, there have been exceptionally high-quality assessments of wear resistance [4, 6]. The purpose of this article is to determine the resistance of mineral coatings created on the surface of samples of steel 20X13 (Russian analogue of steel 20Cr13 (EU)), modified with ultrafine particles of minerals, to abrasive wear when rubbing against fixed particles and to compare the wear parameters of layers modified with mineral particles with parameters of surface layers created by laser cladding of alloys of different composition.

2. Materials and methods

The essence of testing surface layers modified with mineral particles for abrasive wear when rubbing against fixed abrasive particles is that the surface of the test sample interacts for some time at a fixed load with fixed abrasive particles (abrasive bar) [3]. Before and after the end of each test cycle, the test sample is weighed and the wear resistance of the surface layer is determined.

The study was carried out on cylindrical metal samples 10 mm in diameter and 25 mm in length. On the end surface of the samples under study, layers modified with ultradispersed particles of minerals were created using the basic technology of S&PA “Geoenergetika” [4]. In total, three types of layers were created, differing in the types of mineral mixtures, under the same technological conditions, which implied a difference in tribological parameters, including the wear resistance of the samples. During the research, one sample of each type of layers was used.

The samples were studied on an experimental setup for testing abrasive wear during friction against a fixed abutment with a sample loading system consisting of a loading rod with a socket for fixing a mandrel and a rod for creating a pressure load using weight weights. The tests were carried out under the action of a static load of 60 N and 160 N, the relative error in determining the load did not exceed ±1%.

To determine the weight wear, the test sample was weighed before and after each test cycle. When measuring weight wear, we used an electronic balance HTR-120CT with a Tuning Fork sensor, weighing range from 0.01 g to 120 g with a discreteness of not more than 0.0001 g, with a verification scale mark of at least 0.001 g and an accuracy class according to GOST 24104-2001 special (I) (RU).

To carry out the relative wear resistance of the surface layer of the samples under study, abrasive material 12 CT 1 (RU) with an electrocorundum grinding grain with a hardness of at least R or S (hard) according to GOST 52587 (RU) and a grain size of 63-50 μm according to GOST 52381 (RU) was used. The contact surface area of the sample is 314 mm².

The tests were carried out by rubbing the end surface of the sample against the surface of the abrasive bar. The friction path for one test cycle was determined empirically and was constant within the entire test series. The linear velocity of the relative movement of the sample over the abrasive surface was 0.313 m s⁻¹. The choice of the magnitude of the load and the speed of movement was determined by the need to avoid heating the end surface of the samples, which affects the properties of the surface layer and the capabilities of the installation.

According to the test results, the following indicators of wear resistance were determined:

- weight wear - change in sample weight during testing, defined as the difference between the initial and final weight of the sample in each test cycle, mg;
- average wear rate - the ratio of the weight wear value to the time interval during which it arose, is defined as the ratio of weight wear to the duration of one test cycle, mg·s⁻¹;
- average wear rate - the ratio of the weight value to the conditioned path, on which wear occurs, is determined as the ratio of the weight wear of the sample to the actual friction path traveled in one test cycle, mg·m⁻¹.
3. Results and discussion

The results of testing the surface layers of three samples modified with different mixtures of mineral particles are presented below in tables 1-3.

Table 1. Test results of sample No. 1 for abrasive wear when rubbing against monolithic abrasive.

| No. cycle | Initial weight (g) | Final weight (g) | Friction path (m) | Test time (s) | Weight wear (g) | Average wear rate (g·s⁻¹) | Average wear rate (g·m⁻¹) |
|-----------|-------------------|-----------------|------------------|-------------|----------------|----------------------|----------------------|
|           | Load 60 H         |                 |                  |             |                |                      |                      |
| 1         | 29.908            | 29.9            | 9.39             | 30          | 0.008          | 0.00027              | 0.00085              |
| 2         | 29.9              | 29.898          | 9.39             | 30          | 0.002          | 0.00007              | 0.00021              |
| 3         | 29.898            | 29.895          | 9.39             | 30          | 0.003          | 0.00010              | 0.00032              |
| Load 160 H|                   |                 |                  |             |                |                      |                      |
| 4         | 29.895            | 29.874          | 9.39             | 30          | 0.021          | 0.00070              | 0.00224              |
| 5         | 29.874            | 29.858          | 9.39             | 30          | 0.016          | 0.00053              | 0.00170              |
| 6         | 29.858            | 29.844          | 9.39             | 30          | 0.014          | 0.00047              | 0.00149              |
| 7         | 29.844            | 29.818          | 9.39             | 30          | 0.026          | 0.00087              | 0.00277              |
| 8         | 29.818            | 29.795          | 9.39             | 30          | 0.023          | 0.00077              | 0.00245              |
| 9         | 29.795            | 29.271          | 9.39             | 30          | 0.054          | 0.00180              | 0.00575              |

By the end of cycle no. 6 the abrasive block was very “greasy” that is it lost its original roughness and was replaced with a new one. On test cycle No.8 the base metal appeared. Average values of weight wear over the thickness of sample No. 1 were 4.3 mg at a load of 60 N and 20 mg at a load of 160 N.

The test results of sample No. 2 are presented in table 2.

Table 2. Test results of sample No. 2 for abrasive wear when rubbing against monolithic abrasive.

| No. cycle | Initial weight (g) | Final weight (g) | Friction path (m) | Test time (s) | Weight wear (g) | Average wear rate (g·s⁻¹) | Average wear rate (g·m⁻¹) |
|-----------|-------------------|-----------------|------------------|-------------|----------------|----------------------|----------------------|
|           | Load 60 H         |                 |                  |             |                |                      |                      |
| 1         | 29.84             | 29.828          | 9.39             | 30          | 0.012          | 0.00040              | 0.00128              |
| 2         | 29.828            | 29.819          | 9.39             | 30          | 0.009          | 0.00030              | 0.00096              |
| 3         | 29.819            | 29.809          | 9.39             | 30          | 0.01           | 0.00033              | 0.00106              |
| Load 160 H|                   |                 |                  |             |                |                      |                      |
| 4         | 29.809            | 29.722          | 9.39             | 30          | 0.087          | 0.00290              | 0.00927              |
| 5         | 29.722            | 29.632          | 9.39             | 30          | 0.09           | 0.00300              | 0.00958              |

It should be noted that the actual wear of the surface layer enriched with minerals occurred at a load of 60 N. During the test cycle No. 4 the base metal appeared on the surface of the sample No. 2. The average weight wear at a load of 60 N was 10.3 mg.

The test results of sample No. 3 are presented in table 3.
Table 3. Test results of sample No. 3 for abrasive wear during friction against monolithic abrasive.

| No. cycle | Initial weight (g) | Final weight (g) | Friction path (m) | Test time (s) | Weight wear (g) | Average wear rate (g·s\(^{-1}\)) | Average wear rate (g·m\(^{-1}\)) |
|-----------|-------------------|------------------|------------------|--------------|----------------|-------------------------------|-------------------------------|
| Load 60 H |                   |                  |                  |              |                |                               |                               |
| 1         | 29.958            | 29.95            | 9.39             | 30           | 0.008          | 0.00027                       | 0.00085                       |
| 2         | 29.95             | 29.942           | 9.39             | 30           | 0.008          | 0.00027                       | 0.00085                       |
| 3         | 29.942            | 29.937           | 9.39             | 30           | 0.005          | 0.00017                       | 0.00053                       |
| Load 160 H|                   |                  |                  |              |                |                               |                               |
| 4         | 29.937            | 29.835           | 9.39             | 30           | 0.102          | 0.00340                       | 0.01086                       |
| 5         | 29.835            | 29.667           | 9.39             | 30           | 0.168          | 0.00560                       | 0.01789                       |

As in the tests of sample No. 2 the wear of the surface layer enriched with mineral particles of sample No. 3 occurred at the first stage at a load of 60 N. Therefore wear at the second stage at a load of 160 N fell on the transition zone and the base metal of the sample. The average weight wear at a load of 60 N was 7 mg.

Table 4 presents summary data on the wear characteristics of the investigated surface layers of samples No. 1-3 and surface layers obtained by laser cladding of alloys of different compositions [15-17] made by us earlier on this installation.

Table 4. Comparative data of wear characteristics of various materials.

| Layer material                  | Wear pressure. (MPa) | Weight wear (mg) | Average wear rate (mg·s\(^{-1}\)) | Average wear rate (mg·m\(^{-1}\)) |
|--------------------------------|----------------------|------------------|-----------------------------------|----------------------------------|
| Sample No.1 (mineral coating)  | 0.2                  | 4.3              | 0.14                              | 0.46                             |
| Sample No.2 (mineral coating)  | 0.5                  | 20.0             | 0.6                               | 1.8                              |
| Sample No.3 (mineral coating)  | 0.2                  | 7.0              | 0.23                              | 0.75                             |
| Martensitic stainless steel SS 410L | 0.5               | 40               | 0.67                              | 2.13                             |
| Austenitic stainless steel SS 316L | 0.5               | 170              | 2.83                              | 9.05                             |
| Cobalt alloy 2537-10            | 0.5                  | 13               | 0.22                              | 0.69                             |
| Tool steel M2                   | 0.5                  | 4                | 0.07                              | 0.21                             |
| Tin bronze CuSn11               | 0.5                  | 120              | 2.00                              | 6.39                             |
| Nickel alloy 1560-00            | 0.5                  | 4.5              | 0.08                              | 0.24                             |

As can be seen from the presented data the nickel-base alloy and tool steel have the highest wear resistance which show the minimum values of weight wear at a pressure of 0.5 MPa on the wear surface in the presented range of materials. Sample No. 1 shows comparable toughness to cobalt alloy. The wear resistance of the surface layer of sample No. 3 is approximately two times worse than that of sample No. 1. The least resistance of the three samples under study has the surface of sample No. 2, the wear of which is comparable to the wear of the surface of martensitic stainless steel. However the use of certain methods of protecting parts from abrasive wear is determined along with the physical and technical characteristics of the layers by the economic feasibility in specific operating conditions.

4. Conclusion
A comparative study of the surface of three different samples (steel 20Cr13) modified with ultradispersed particles of various minerals was carried out under conditions of abrasive wear when
rubbing against fixed particles under the action of a static load of 60 N and 160 N. According to the results of measurements at a pressure on the wear surface of 0.5 MPa of the three samples studied the highest resistance to wear abrasive action is possessed by sample No. 1 which shows an indicator of weight wear comparable to a coating made of cobalt alloy created by laser cladding and is inferior in this indicator approximately four times to coatings made of a nickel alloy created by laser cladding, and tool steel. The wear resistance of the surface layer of sample No. 3 is approximately two times worse than that of sample No. 1. The least resistance of the three samples under study has the surface of sample No. 2 the wear of which is comparable to the wear of the surface of martensitic stainless steel.

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