Influence of the composition of the metal-ceramic coating on wear resistance

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Abstract. The work is devoted to the development of a wear-resistant coating, combining the hardly compatible properties of high hardness and plasticity. The proposed composite coating has a nickel-chrome corrosion-resistant matrix, providing high plasticity, and hardening phase Al₂O₃, which can significantly increase the hardness of the coating and wear resistance. The use of laser radiation to melt the coating allows to crush Al₂O₃ grain to 0.05 ... 1.0 мкм, which significantly increases the operational properties of the coating under the influence of variable loads on the friction assembly. Investigations of the frictional properties of wear-resistant coatings PG-10N-01 + 15% Al₂O₃ weld by a laser showed that when lubricated with hydraulic fluid AMg-10, the friction coefficient paired with Br.AJN 10-4-4 at a load of 5 ... 40 MPa and a sliding speed of 0.05 m / s is less than with solid electrolytic chromium. Wear rate Br. AZH 10-4-4 at a load of 10 MPa and a sliding speed of 0.25 and 1.0 m / s in friction pair with coating PG-10H-01+15%Al₂O₃ is 14 ... 20 times less than in a pair with solid electrolytic chrome coated respectively. The wear-resistant coating PG-10N-01 + 15% Al₂O₃, weld by laser, can be an alternative to replace hard electrolytic chrome plating. The developed technology for producing wear-resistant ceramic-metal coatings with an ultrafine hardening phase can be applied to create friction pairs of heavily loaded tribocouplings assemblies.

1. Introduction
Wear-resistant coatings represent a new technology that relates to local heat treatment methods. Local impact on the surface of concentrated energy and locality allow processing only the surface area without violating its structure and properties of the part as a whole. The control of technological parameters of laser processing and the composition of the processed materials in a wide range of values allows to obtain qualitatively new wear-resistant coatings. Laser melting of wear-resistant coatings makes it possible to obtain properties unattainable with traditional processing methods in local volumes of the surface layers of materials. This allows to purposefully control the chemical composition of the weld wear-resistant coating [1]. In the process of laser surface melting, due to large temperature gradients, intense hydrodynamic flows occur in the melt pool, which accelerate the mass transfer processes throughout the melting zone. This allows to perform a well-regulated process of producing surface coatings. Due to convective mixing of the melt as it moves away from the surface, there is no transition from phases with a higher concentration of the alloying element to phases with a lower concentration. All phases in the doped zone are mixed approximately uniformly in depth [2]. Laser cladding of wear-resistant coatings, due to its advantages, creates surface layers having properties that can compete with
coatings made of solid electrolytic chromium plating [3]. The chrome plating technology is widely used as a technological method of increasing the wear resistance of steel products in various fields of technology, especially in aviation [4]. Chrome is characterized by high hardness, high adhesion to steel and chemical resistance. The technical parameters of chrome coatings largely depend on the mode of deposition of chromium, so the wear resistance of the coating can vary several times [5]. Despite all the advantages of hard chrome plating, the future of this technology is currently in doubt, since chromium trioxide (CrO₃) used in most bathtubs for chrome plating is a carcinogen [6].

The purpose of the work is to investigate the influence of the composition of a ceramic-metal coating weld by a laser on wear resistance.

The development of new hardening technologies is inextricably linked with the creation of new materials. Wear-resistant coating material should have a plastic matrix based on nickel or cobalt alloys, fine grain, high hardness of the finely dispersed hardening phase. Eutectic alloys of the Ni-Cr-B-Si system have high physical and mechanical properties [7]. As the hardening phase, carbides, borides, nitrides, and metal oxides are used [8]. When concentrated laser radiation acts on the strengthening phases in the coating: carbides, borides, nitrides, which are intensively oxidized and decompose at high temperatures. Oxides Al, Cr, Ti, and others are high hardness, wear resistance, chemical resistance, and low cost, which makes them the most promising for use [9]. The percentage of the hardening phase in the coating depends on the operating conditions of the heavily loaded friction units should not exceed 20 ... 40%, mass. [10]. At a higher concentration, the wear rate decreases, but at the same time, such indicators as impact strength, tensile strength and endurance, and reliability decrease [11].

2. Materials and equipment

The development of technology for producing wear-resistant ceramic-metal coatings was carried out on the basis of physical and mathematical modeling of plasma deposition and laser melting of the coating, taking into account the dependence of thermophysical parameters on temperature [12]. For preliminary application of powder compositions, an optimized plasma spraying process was used. Wear-resistant coatings on the working surfaces were applied by a supersonic plasma generator developed at IMASH RAS. Powder material was supplied to the subsonic region of the plasma flow. Alloys of the Ni – Cr – B – Si system were used as a plastic matrix [13]. As a hardening phase, Al₂O₃ powders of a fraction of 5 ... 20 μm. were used. The concentration of the hardening phase varied within 15 ... 20% (weight). Coating was melted on an automated laser technological complex LTK-01 with a continuous radiation power of 3.5 ... 4.5 kW, processing speed (2.0 ... 8.0) * 10⁻³ m / s [14]. The scanning frequency of the laser beam was 200–250 Hz; the frequency was selected to create Lissajous figures [15.17]. The technological post has a programmed movement of the laser beam relative to the part in three coordinates, a rotating table and equipment that allows to process the outer and inner cylindrical surfaces [18]. The mechanical properties of the surface layer were determined from the indentation diagram of the Vickers diamond pyramid on a CSM kinetic microhardness tester (microindentation system based on the compact platform CSM-instruments MHT - Z - AE - 000). The methodology for assessing the plasticity of the material was in accordance with the International Standard “Metallic Materials - Instrumented Indentation Test for Hardness and Materials Parameters” ISO / DIS 14577. Tribological tests were carried out on a machine for testing materials for friction and wear of UMT1. The wear was determined by the weighing method on an electronic laboratory analytical balance Shinko Vibra HTR-220 CE.

To test the technology for applying ceramic-metal coatings and study the frictional properties of the coating, samples of steel 30KhGSA with a size of 90 x 20 x 10 mm were used. A thermal spray coating was applied to the prepared surface. Alloys of the Ni-Cr-B-Si system were used as a plastic matrix. The powder composition of the Ni-Cr-B-Si system was used (PG-10N-01 powder, composition, %: C-0.6 ... 1.0; B-2.8 ... 3.4; Si-4 ... 4.5; Cr-14 ... 20; Fe-34; Ni base) and hardening additive 15% Al₂O₃. At the second stage, laser melting of the coating was carried out. The coating thickness after finishing was 0.35 ... 0.40 mm, the grinding allowance was 0.25 ... 0.35 mm. According to the results of metallographic studies, it was found that the transition zone coating base was approximately 30 μm.
3. The results of the experiment and the discussion

The efficiency of the friction unit depends on the properties of materials and contacting surfaces. One of the methods for assessing the mechanical characteristics of the surface layer of a material is the kinetic indentation method [18, 19]. Vickers microhardness assessment of wear-resistant coating materials is made on average of 5 measurements of the print diameter. The average Hv value of the weld coating is 7.794 GPa. To compare the parameters of a laser-deposited coating, the results of indentation of an electrolytic chromium coating are presented. Almost the only method for assessing the elastic and plastic properties of the material of the surface layers is the method of determining the kinetic microhardness, based on the continuous recording of the parameters of the indentation process, namely, the load on the indenter and its immersion depth. When assessing the mechanical properties of coatings, the following characteristics were measured: E — elastic modulus; Hv - Vickers microhardness; Wtotal - the total work spent on the indentation; Wpl. - the plastic part of the overall work; Kp - coefficient of irreversible deformations. The results of measurements during kinetic indentation are presented in table 1.

Table 1. The average values of the parameters of the mechanical properties of the coatings and counterbody.

| Coating                              | $E$ (ГПа) | $H_v$ (ГПа) | $W_{pen}$ (мкДж) | $W_{pl}$ (мкДж) | $K_r$  |
|--------------------------------------|-----------|-------------|------------------|----------------|-------|
| Coating PG-10H-01+15%Al₂O₃           | 1496      | 7794        | 0.39             | 0.15           | 0.38  |
| Electrolytic chrome plating          | 809       | 3615        | 0.57             | 0.32           | 0.56  |
| Counterbody - Br.AJN 10-4-4          | 408       | 2341        | 0.65             | 0.35           | 0.54  |

During the experiment, Wmelt is determined - the irreversible energy loss during indentation, equal to the area of the hysteresis loop in the indenter indentation diagram, i.e. energy absorbed in the load-unload cycle and Wtotal - mechanical work of indentation, equal to the sum of elastic and plastic energy. According to the results of the experiment, the coefficient of irreversible energy losses during indentation of Kp was determined, which is often called the literature plasticity coefficient. The term irreversible energy loss more accurately reflects the essence of the process, because irreversible energy loss also includes energy loss due to cracking. This coefficient is determined by the ratio $K_r = W_{pl.}/W_{tot}$. The plasticity of materials to a large extent determines their crack resistance, the higher the plasticity is, the higher the coefficient of crack resistance is [20]. PG-10N-01 + 15% Al2O3 coating is inferior in crack resistance to electrolytic chromium coating. When the coating is melted by a concentrated laser source with an optimized radiation density, as a result of the thermohydraulic processes that occur in the liquid melt bath, the hardening phase Al2O3 disperses from its initial size to 0.05 .. 1.0 μm.

The study of the tribological characteristics of the PG-10N-01 + 15% Al2O3 coating and coatings with electrolytic chrome was carried out on a UMT1 friction machine. The friction pattern of the samples is the end face of the ring sample (counterbody) along the coated plane. The overlap coefficient of 0.5, lubrication - hydraulic fluid AMg-10. The linear velocity was 0.05 m / s, the friction path was L = 105 m. The material of the counterbody Br.AJN 10-4-4, the hardness of the samples was Hv = 2341MPa. An electrolytic chrome coating with a hardness of Hv = 3615 MPa was used as a reference for comparison. The test results of the coatings are shown in figure 1. To compare the test results, the dependences of the friction coefficient on the composition of the coating with additives of the strengthening phase 17% and 20% Al2O3 are given [2, 21]. Over the entire load range, the friction coefficient of PG-10N-01 + 15% Al2O3 coating is less than that of solid electrolytic chromium. With an increase in the hardening phase of Al2O3 in the coating composition, the friction coefficient decreases.

The performance of the friction unit depends on the mating materials in the friction pair. The weak link in the friction unit is antifriction material, in this case it is a counterbody in the form of alloy Br.AJN 10-4-4. Dependence of the wear rate of Br.AJN 10-4-4 paired with coatings is shown in figure 2.
Wear rate Br.AJN 10-4-4 paired with PG-10H-01 + 15% Al2O3 coating in the speed range 0.25 ... 1.0 m / s varies from 14 to 20 times compared with the chrome coating. Friction pair Br.AJN 10-4-4 coated with PG-10H-01 + (15 ... 20%) Al2O3 has obvious advantages both in terms of low friction coefficient and wear rate of counterbody- Br.AJN 10-4-4 in comparison with hard electrolytic chrome coating.

The adhesion with the base is an important characteristic of the weld coating. An increase in the diffusion zone leads to an increase in adhesive strength. The degree of dissolution of the base in the weld layer, in the interface, has a great influence on the strength of the bond between them. The higher the degree of dissolution is, the higher the bond strength is. But the penetration zone, its depth, should be optimal, since the intense interaction of the coating with the base in the presence of a liquid phase leads to a change in its composition, which is not always desirable.

Figure 1. The dependence of the friction coefficient on the load at a speed of 0.05 m / s for coatings: 1-chrome, 2-PG10H-01+20%Al2O3, 3-PG10H-01+17%Al2O3, 4-PG10H-01+15%Al2O3.

Figure 2. Dependence of the wear rate of Br.AJN 10-4-4 on speed at a load of 10 MPa with friction with: 1- PG-10N-01 + 20% A1203, 2- PG-10N-01 + 17% A1203, 3- PG-10N-01 + 15% A1203, 4-solid electrolytic chrome.

4. Conclusions
The research of the frictional properties of wear-resistant coatings PG-10N-01 + 15% A1203 weld by laser has shown that when lubricated with hydraulic fluid AMg-10, the friction coefficient paired with Br.AJN 10-4-4 at a load of 5 ... 40 MPa and a sliding speed of 0.05 m / s is less than with solid electrolytic chrome. Wear rate Br.AJN 10-4-4 at a load of 10 MPa and a sliding speed of 0.25 and 1.0 m / s in friction pair with PG-10N-01 + 15% Al2O3 coating is 14 ... 20 times less than in pair with solid electrolytic chrome coating respectively. Wear-resistant coating PG-10N-01 + 15% A1203, weld by laser, can be an alternative to replace hard electrolytic chrome plating. The developed technology for
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