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WEAR RESISTANCE OF COATINGS FROM SELF-FLUXING ALLOYS AFTER LASER DOPING UNDER DRY FRICTION CONDITIONS

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The wear resistance of Ni–Cr–B–Si–C coatings after laser treatment with a doping covering under dry friction conditions has been investigated. The microstructure of coatings after fusion by a gas burner and a laser beam and the roughness and waviness parameters of the friction surfaces before and after wear have been investigated.

The modern engineering industry is characterized by a steady growth in the power and capacity of machines, leading to increasing in unit loads in friction assemblies and more stringent requirements placed on the reliability and longevity of rubbing parts. One way to meet these requirements is to use wearproof coatings in the production of machine elements.

There exists a very wide range of materials used as such coatings. Coatings based on nickel self-fluxing alloys have found wide application [1]. They represent a multicomponent Ni–Cr–B–Si–C system and are characterized by the following features:

1) in the fusion process, they are capable of restoring oxide films formed by deposition due to the fluxing action of boron and silicon;

2) they have a relatively low melting temperature (1200–1300 K) due to the formation in the melt of low-melting-point eutectics, mainly γ–Ni + Ni_3B;

3) they exhibit a high corrosion and wear resistance due to both the high chrome and nickel content and the formation of the strengthening carbide-boride phase in the matrix solution.

The operational possibilities of these coatings can be widened by modifying their compositions with additional elements and compounds. The use of laser doping technologies in the processes of fusion of self-fluxing alloys makes it possible to considerably widen the field of application of the technology of reclaiming and reconditioning of worn machine elements as well as to raise the level of physico-mechanical and operational properties of coatings formed.

The question of choosing doping components is important. In the known investigations on the development of composite materials based on nickel alloys [2, 3], an improvement of their properties is achieved mainly by introducing carbide-boride additives, such as WC, TiB_2, Cr_3C_2, etc. Analysis of the influence of each component and their combinations on the properties of self-fluxing alloys gives reason to believe that an effective improvement of the properties of a coating can be achieved by introducing new elements. Therefore, it has been recognized that it is expedient to use, as doping composite additives, elements B, Cr, C, and Si and their compounds. Strengthening a given component of the alloy, one can vary over the required range the properties of the coating on the whole.

Proceeding from the foregoing, amorphous boron was used as a doping covering component [4]. The reason for such a choice was the fact that boron performs a double function: it serves to deoxidize oxide films formed in the process of deposition and is the basis for the formation of the strengthening boride phase.

Methods of Investigation. For the investigations, we used PG-KhN80SR3 powder containing 12–15% of Cr, 3% of B and Si each, and 0.8% of C; the basis was Ni. The coating hardness was 50–55 HRC, and the basic material was steel 45. Deposition of a coating layer was carried out on a UPU 3D plasma sprayer by a PP-25 plasmatron. The

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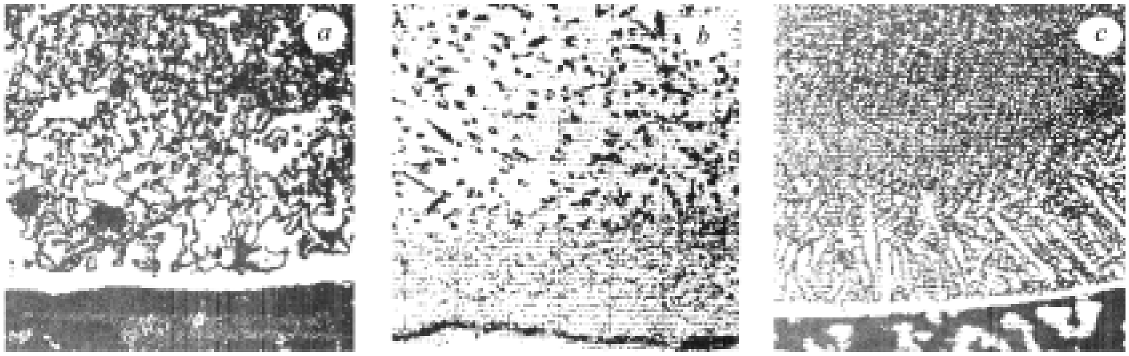

Fig. 1. Microstructure of the PG-SR3 coating: a) after fusion by a gas burner; b) at the boundary with steel 45 without melting of the basis; c) with guaranteed melting of the basis. × 800.

spraying conditions were as follows: a current strength of 220 A and a voltage of 90 V. The plasma-forming gas was nitrogen. Coatings were fused by a gas acetylene burner (with comparative analysis of the microstructure) and on technological laser facilities based on a continuous LGN-702 laser of power 800 W and a "Kometa-2" of power 1200 W. The melting conditions were as follows: the velocity of travel of the beam was 200 mm/min, and the beam diameter was 3 mm in processing on the LGN-702 facility and 3.5 mm — on the "Kometa-2" facility. To realize the laser doping processes, the same laser facilities were used.

In choosing the optimum thickness of the doping covering, the following was taken into account. A coating thickness that is too small (less than 0.1 mm) does not provide an appreciable increase in the quantity of the strengthening phase and the required effect. If the coating layer has a considerable thickness (over 0.15 mm), then, as a result of the low heat conductivity of the deposited coating, under the action of the laser beam a considerable superheating followed by evaporation and oxidation arises in it. In so doing, an unjustifiably large portion of the energy supplied will be expended in heating the doping coat, which decreases the melting efficiency of the coating. As a result of the investigations made [4], it has been established that an increase in the covering thickness leads to an increase in the mean microhardness of the fused zone. At a covering thickness of over 0.15 mm the increase in the microhardness becomes negligible and there is a decrease in the melting-zone depth. Therefore, a thickness of 0.1 mm was taken as the optimum value.

Comparative studies of the wearing of steel 45 samples with a PG-SR3 coating of hardness HRC 55 upon laser fusion and doping and of samples of tool steel NC10 (analog of steel U10) of hardness HRC 60 were made on an Amster A-135 friction machine, which permitted registration of the frictional torque at constant rotation frequency and load and calculation of the friction work. As a counterbody, flat samples of an S30 hard alloy (approximate analog — TT8K6 alloy) were used. By the measurement data the mean and instantaneous coefficients of friction were calculated:

$$\bar{\mu} = \frac{A}{\pi P D n} \quad \text{and} \quad \mu = \frac{2M_{\mathrm{t}}}{PD} .$$

Microstructure of Coatings upon Laser Doping. As in all processes accompanied by the action of a concentrated energy source, in laser treatment the chief factors influencing the microstructure formation are the high heating and cooling rates of the surface coating. This leads to an incomplete proceeding of the diffusion processes, the formation of a large number of nuclei, and the formation of a highly dispersed and nonequilibrium structure. In the process of laser treatment with melting of the basis material, the picture is complicated because of the vigorous mixing of materials in the melt bath.

The foregoing is also true for the formation of the structure of laser-radiation-fused self-fluxing alloys. It should be noted that since in the process of laser doping of coatings from self-fluxing alloys no new components are introduced, upon laser doping the structure morphology undergoes no qualitative changes in the previously obtained properties. Figure 1a shows the structures of the PG-SR3 alloy upon fusion by a gas burner and in the laser radiation. From Fig. 1 it is seen that the character of the structures obtained by these techniques of coating fusion differs con-

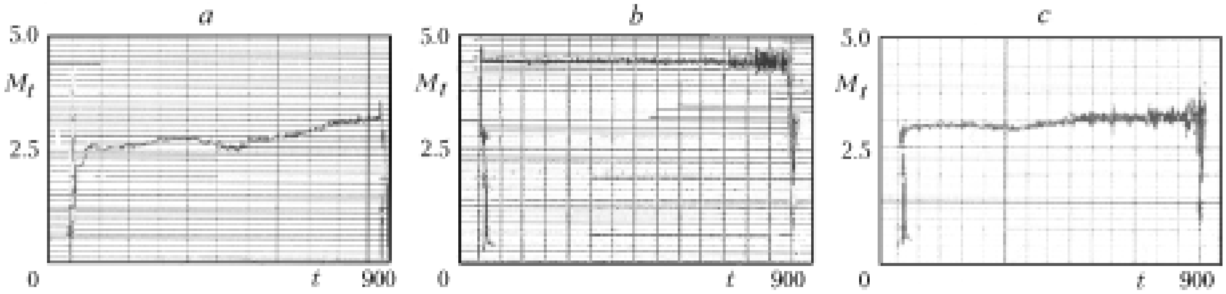

Fig. 2. Changes in the frictional torque with time: a) coating, P = 500 N; b) coating, P = 1000 N; c) steel NC10, P = 500 N; consequences of rubbing are noticeable.

TABLE 1. Coefficients of Dry Friction

Friction coefficient	Material	
	alloy PG-SR3	steel NC10
Mean	0.105	0.146
Instantaneous	0.28	0.31

siderably. In the case of fusion by a gas burner, the coating remains in the molten state for 5–15 sec. In so doing, volume heating of the element takes place, and crystallization and complete cooling occur under equilibrium conditions at low cooling rates. This leads to the formation of a low dispersed globular structure, whose basis is formed by the grains of a solid solution of nickel. Against their background, primary precipitations of the carbide-boride phase with eutectic colonies of γ-Ni + Ni$_3$B of a grayer color between them are clearly defined. The formation of a transition zone between the coating and the basis up to 20 μm wide is characteristic. This transition zone is a doped solid solution of iron in nickel arising from the diffusive processes at the liquid–solid interface.

In the case of laser fusion, the microstructure can be characterized as a thin conglomerate of phases (Fig. 1b, c). A two-to-threefold decrease in the transition zone thickness compared to the coating fused by a gas burner is characteristic. This is due to the short liquid–solid contact time and the formation in the melt adjacent to the bath boundary of a zone of dendrites of the solid solution of nickel oriented in the direction of heat removal. Analysis of the microstructure has shown that the basis metal is γ-Ni crystallized in the form of dendrites with 2nd- and 3rd-order axes. Between the dendrite axes a highly dispersed boride eutectics is crystallized. The carbide phase is rejected from the melt primarily in the form of hexahedrons changing at high cooling rates into dendrites with branches positioned at 60^{o} from one another. The fusion conditions strongly influence the character of the structure formation of self-fluxing nickel alloys. An increase in the energy density upon laser fusion leads to the melting of the basis, which causes partial mixing of the basis material with the coating material and a change in the coating morphology. In this case, there is a globular rejection of solid solutions of nickel with iron, at whose boundaries carbide-boride eutectics is formed.

Wear Resistance of Laser Coatings under Dry Friction Conditions. As mentioned above, coatings based on nickel alloys feature a high wear resistance. Below, the results of the investigations of the wear resistance of coatings under dry friction conditions are given.

It can easily be seen that the friction conditions on the coating surface (Fig. 2) are more favorable compared to steel NC10. The dry friction coefficients in the first case are somewhat lower (Table 1).

After 15 min of work at a load of 500 N the wear of the samples with a coating was 2.7 mg and that of the steel samples — 4.8 mg, i.e., higher by a factor of 1.8. In so doing, after 8 min of work, on the steel sample traces of rubbing and after 15 min a catastrophic wear were noted (Fig. 2). The counterbodies had wears of 2.0 and 6.0 mg, respectively, i.e., the wear intensity was three times higher. And the total wear resistance in the case of using a coating after laser deposition was two-to-three times higher compared to hardened steel.

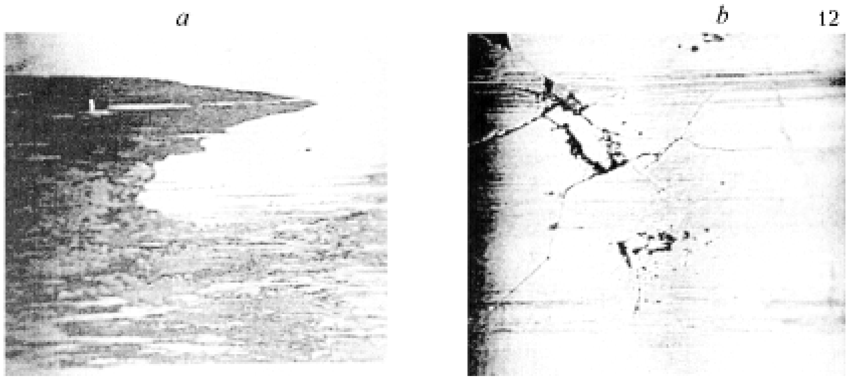

Fig. 3. Worn surfaces of steel NC10 (a) and alloy PG-SR3 (b) samples. × 10.

TABLE 2. Roughness and Waviness Parameters of Frictional Surfaces before and after Wear

Parameters (according to IOS 4287-99 specifications)	Measurement data, μm			
	surface before wear		surface after wear	
	I	II	I	II
Maximum height of profile hills	0.490	0.059	0.456	0.102
Maximum depth of profle valleys	0.576	0.078	0.640	0.119
Largest height of profile over 10 points	1.066	1.137	1.095	0.221
Mean height of profile	0.286	0.103	0.335	0.188
Total height of profile	1.721	1.017	1.673	0.834
Mean arithmetic duration of profile	0.121	0.032	0.166	0.061
Asymmetry coefficient of profile	–0.150	0.01	–0.451	0.094
Tilt coefficient of profile	3.919	2.164	3.242	2.163
Mean step of profile asperities	32.7	349.8	43.81	204.9
Mean step of profile asperities over peaks	8.41	43.34	6.52	29.19

Note: I — calculation by the roughness profile; II — calculation by the waviness profile.

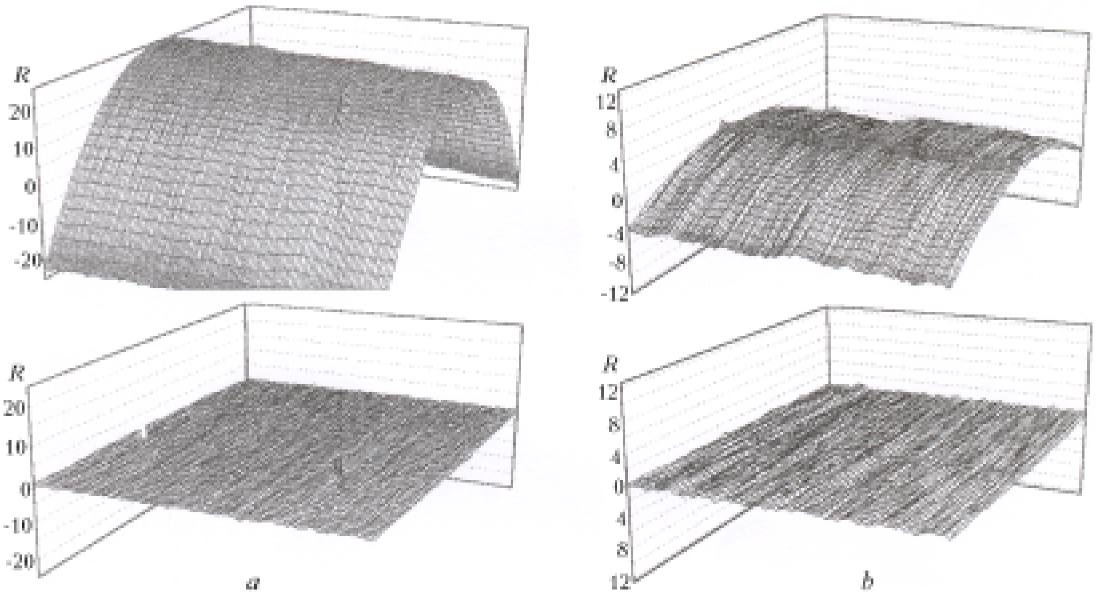

Fig. 4. Stereometry of the surfaces of samples with a laser coating before (a) and after (b) wear.

As the load was increased to 1000 N, the wear intensity increased considerably (almost three times), and, in so doing, microcracks on the friction surface were observed (Fig. 3). Apparently, this is due to the redistribution of internal stresses in the transition zone under the action of high pressures and temperatures.

The topography of worn surfaces was investigated on a PGM-1C device (Table 2). The three-dimensional images of the friction surfaces before and after wear are given in Fig. 4. It can be easily seen that in the wear process the stereometry of the contact surface has worsened.

Thus, under dry friction conditions the chief factor determining the wear resistance of an element is the hardness of the doped layer and its chemical composition. A positive effect on the operating characteristics of the surface is produced by the content in the surface layer of amorphous boron, which is responsible for the formation of secondary structures separating the friction surfaces and preventing setting. With increasing influence of the rate factor a higher wear resistance is displayed by samples with a stable state of the solid solution and a lower level of residual stresses.

The wear resistance of surfaces subjected to laser strengthening and doping under dry friction conditions exceeds the wear resistance of the surfaces of hardened steel elements.

NOTATION

A, work of friction, N·m; D, sample diameter, m; M_t, frictional torque, N·m; P, load on the sample, N; n, number of revolutions made by the sample during testing; μ, friction coefficient; t, time, sec.

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