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METALLOGRAPHIC AND DUROMETRIC INVESTIGATIONS OF WEAR SURFACES HARDENED BY LASER TREATMENT

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The effect of the technological regime of laser treatment on the microstructure and microhardness of composite powder coatings produced by fusion of modifying coverings is investigated. The optimum regimes for production of coatings with the most uniform distribution of modifying substances throughout the volume and the greatest microhardness are established.

Statement of the Problem and Investigation Methods. Self-fluxing coatings of the Ni–Cr–B–Si–C system that consist of an Ni-based solid solution, eutectics of complex composition, and hardening phases are among the most complicated for metallographic study.

The physicomechanical properties of coatings of sprayed self-fluxing nickel-chromium alloys, fused by a laser beam, have been rather well investigated [1, 2]. However the problem of the effect of additionally introduced modifying substances on structure formation and microhardness of fused coatings has remained little studied.

Investigations of combined wear-resistant coatings that are produced by laser fusion show that the structure, properties, and serviceability of the coatings are governed primarily by the chemical nature of their components. However the technological parameters of laser treatment and the energy characteristics of the process of coating formation have a profound effect, too.

Coatings of the Ni–Cr–B–Si system are very sensitive to the conditions of heating, while the character of the structure produced governs the quality of the hardened layer. Therefore metallographic investigations serve as one of the basic quality criteria.

By changing the treatment regime one can produce both a rough dendritic structure and a structure that is a finely differentiated eutectic mixture of a hardening phase and a γ-nickel supersaturated solution [3, 4].

We investigated $10 \times 100 \times 5$ mm plane specimens and $\varnothing$ 50 mm circular specimens of steel 45. We used PN-KhN80S4R4 self-fluxing alloy as material for spraying.

The sublayer was applied to the prepared surface by the method of plasma spraying using a UPU-3D unit with an IPN-160/600 supply unit in the regime: $I = 250$ A, $U = 880$ V, and $p_{\text{gas}} = 6$ atm.

Once the coatings were plasma-sprayed, a modifying covering based on TiN, AlN, and NbC powders with additions of nickel powder and a small amount of binder (a 3% solution of AGO glue in acetone) was applied to the hardened surface with subsequent fusion of the coverving by a laser beam to obtain a unified phase composition and prescribed properties across the entire thickness of the coating.

Fusion was performed on an LGN-702 cw laser unit of power $N = 800$ W with a diameter of the laser beam $d = 1.0 \cdot 10^{-3}$–$3.0 \cdot 10^{-3}$ m and a displacement velocity $V = 1.33 \cdot 10^{-3}$–$5.0 \cdot 10^{-3}$ m/sec with a step $S = 2.0 \cdot 10^{-3}$ m.

After spraying and fusion, the specimens were cut across the laser tracks to exclude the effect of instability of the temperature conditions of heating and cooling at the specimen edges.

Microsections of the coated specimens were pressed into special plastic that ensured the absence of "heaping up of the edges" and then were prepared on Buehler-Met equipment (Switzerland) using a technology and materials

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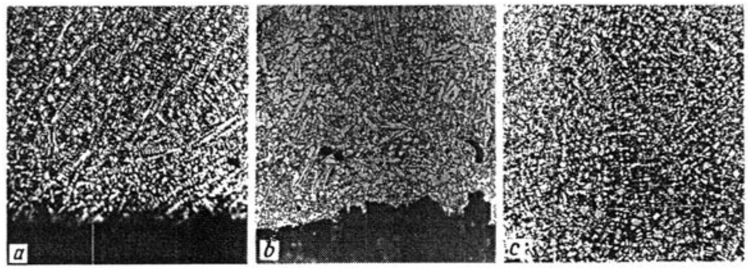

Fig. 1. Microstructure of coatings produced by fusion of modifying coverings at $N = 800$ W: a) covering with TiN (treatment regime: $V = 1.3 \cdot 10^{-3}$ m/sec, $d = 1.0 \cdot 10^{-3}$ m); b) the same with NbC ($V = 1.3 \cdot 10^{-3}$ m/sec, $d = 3.0 \cdot 10^{-3}$ m); c) the same with TiN ($V = 2.0 \cdot 10^{-3}$ m/sec, $d = 3.0 \cdot 10^{-3}$ m). ×500.

that practically ensure the production of microsections without cold working and preparation materials in the surface layer.

The microstructure was investigated prior to and after etching at macro- and microlevels in a Reichert MeF-3 light microscope (Switzerland).

The compound for nitride-phase etching was prepared in the following manner: copper sulfate – 2.5 g, magnesium chloride – 1.0 g, hydrochloric acid – 2.0 g, water – 100 ml, and ethyl alcohol – 1000 ml.

The formulation for NbC-phase ething included: hydrofluoric acid – 1 part, nitric acid – 3 parts, and water – 5 parts.

The etched specimens were photographed using a NEOFOT electron microscope.

Microhardness was measured on a Buehler-Met Micromet-2 microhardness meter (Switzerland) with a diamond-tipped pyramid on nonetched transverse microsections in the coating, transition zone, and substrate material to the level of the values in the substrate core, which were determined previously; the microhardness was determined on a statistical-average basis over the levels of measurements performed parallel to the coating surface.

Results and Their Discussion. Modifying additives affected the structural change to various degrees. However the presence of the nickel matrix in all the coatings caused the same regularities of the effect of the laser-treatment regime on the character of structure formation for all types of compositions.

For $d = 1.0 \cdot 10^{-3}$ m and $V = 1.33 \cdot 10^{-3}$ m/sec, a dendritic structure formed. The principal axes of the dendrites were directed from the boundary with the substrate to the coating surface, forming oriented columnar crystals (Fig. 1a). As the center was approached the axes of the dendrites lost their directivity and, at the center, they became more disoriented and disperse than in the substrate.

At high fusion rates ($V = 5.0 \cdot 10^{-3}$ m/sec), the hardening dendrite phase threaded, as it were, the entire coating. A low cooling rate led to the formation of short and broad dendrites of the solid solution. As the cooling rate decreased, coarse carboboride plates acquired the form of "rods" (Fig. 1b).

The investigation of the microstructure of coatings laser-fused in different regimes showed that by varying the parameters of the process one can form the structure of the surface and the main layer depending on the operating conditions.

Thus, under the conditions of accelerated cooling in fusion at moderate rate and power, the crystallization temperature range became shorter, which led to equalization of the crystallization rate for the carbide and boride phases and the γ-solid solution with formation of small grains and a fine eutectic mixture (Fig. 1c).

In a number of works, it is established that the change in the friction coefficient in the run-in period is governed by the microhardness of the hardening zones and the area of the hardened surface [5]. Thus, the smallest friction coefficient was obtained when the hardness of the hardened zones was greatest. However, for a large relative area of the hardened surface, we should use a laser-treatment regime that leads to the creation of hardening zones with lower hardness but improved plasticity.

In fusing coatings with coverings of all three types, pronounced alloyed zones with a nonuniform distribution of the modifying substance over both the treatment area and the depth formed. A high temperature

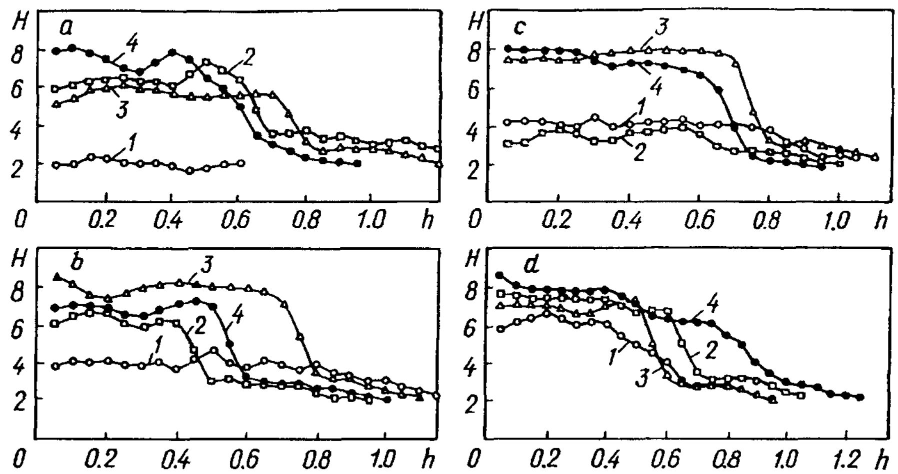

Fig. 2. Microhardness of coatings fused at $N = 800$ W in the regimes: a) $k = 1.5$, $d = 1.0\cdot10^{-3}$ m: 1 (TiN) and 3 (AlN) for $V = 1.33\cdot10^{-3}$ m/sec, 2 (TiN) and 4 (AlN) for $V = 5.0\cdot10^{-3}$ m/sec; b) $k = 0.5$, $d = 3.0\cdot10^{-3}$ m: 1 (TiN) and 3 (AlN) for $V = 1.33\cdot10^{-3}$ m/sec, 2 (TiN) and 4 (AlN) for $V = 5.0\cdot10^{-3}$ m/sec; c) $k = 1.5$, $V = 1.33\cdot10^{-3}$ m/sec: 1 (TiN) and 3 (AlN) for $d = 1.0\cdot10^{-3}$ m, 2 (TiN) and 4 (AlN) for $d = 3.0\cdot10^{-3}$ m; d) $k = 0.5$, $V = 5.0\cdot10^{-3}$ m/sec: 1 (TiN) and 3 (AlN) for $d = 1.0\cdot10^{-3}$ m, 2 (TiN) and 4 (AlN) for $d = 3.0\cdot10^{-3}$ m. H, GPa; $h\cdot10^{-3}$, m.

gradient and high-power convective flows led to formation of different alloyed zones with microhardness fluctuation in the melt bath (Fig. 2).

In certain regimes the nitrides and carbides were not melted down under the laser action and were present in the melt bath as large monolithic inclusions.

Under the action of hydrodynamic forces and the temperature gradient, the main portion of the modifying components was distributed in the melting zone by directed flows.

Because of the inhomogeneity of the laser-radiation energy flux the temperature in the surface layer decreased from the center of the bath toward its edges. The motion of the molten metal on the surface occurred in the same direction, since the coefficient of surface tension is maximum at the edges of the bath.

Gravity forces brought into motion the internal liquid layers, which produced vortex motion in the melt. In the central part of the vortex flow, we observed a somewhat lower concentration of the modifying components than on the bath surface or at the melt-solid phase boundary. This can explain the nonuniformity of the distribution of the nitride particles over the coating volume revealed by means of nitride-phase etching.

Therefore the nonuniformity of the microhardness was governed to a large degree by the character of the modifying-substance distribution over the coating volume.

The investigations performed showed that in the range of laser-fusion regimes studied, for the coatings with nitride and carbide additives, the spread in microhardness values is rather large, which made it impossible to obtain the equation of microhardness as a function of the laser-fusion regime.

However in analyzing the plots of the microhardness distribution over the fused-layer thickness for different regimes of fusion presented in Fig. 2, we revealed some regularities. Thus, in fusing a covering with TiN and AlN, the coating microhardness increased with the laser-beam velocity, which can be explained by the higher degree of supercooling in fusion at high rates. This contributed to formation of a small-dendrite coating structure in which a strong dendrite framework formed. Furthermore, as the velocity increased, there was no intense burn-out of the modifying components.

Conclusions. It is established by durometric investigations that laser fusion of modifying coverings leads to the production of a layer that is somewhat inhomogeneous in properties, which is due to the introduction of additives and their distribution over the coating volume under the action of hydrodynamic forces and the temperature gradient.

In studying the effect of the technological parameters of laser treatment on the microhardness of coatings with TiN and AlN it is established that, to improve the microhardness, one must increase the velocity and diameter of the laser beam ($V = 5.0 \cdot 10^{-3}$ m/sec and $d = 3.0 \cdot 10^{-3}$ m for $N = 800$ W).

NOTATION

I, current strength; U, voltage; p_{gas}, gas pressure; N, power of the laser unit; d, laser-beam diameter; V, laser-beam velocity; S, step of laser-beam motion; k, coefficient of laser-track overlapping.

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