Increasing the service life of agricultural machinery parts and units by laser cladding

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Abstract. Ensuring the durability of the functioning of agricultural machinery is an urgent problem during the transition of the fields of activity to sustainable development. The article presents the results of metallographic and tribological studies of multicomponent environmentally friendly coatings of agricultural machinery with the addition of tantalum carbide to the charge composition. Using a full factorial experiment, the geometric parameters of the deposited coatings were determined depending on the power, processing speed and the diameter of the laser beam. Regularities of the change in the friction coefficients from pressure are obtained. The wear resistance of the coatings is higher than that of hardened 45 and 65Mn steels. A pilot batch of paws of a cultivator of agricultural machinery with laser cladding for field tests was made.

1. Introduction
Increasing the service life of parts and friction units of agricultural machinery is an urgent task. Traditional structural materials and heat treatment technologies in most cases are inferior in wear resistance to new hardening technologies and coatings using concentrated energy sources. Laser surfacing is an environmentally friendly technological process. The authors of the work [1] used nickel-based alloy powder (Ni-Cr-B-Si-Fe-C) as the surfacing material. Laser surfacing was performed on samples of 316L stainless steel with a fiber laser. The average microhardness of single-layer and three-layer coatings was 593 and 640 HV$_{0.2}$ respectively, which is almost 2.5 times higher than that of the 316L substrate (about 250 HV$_{0.2}$). In [2], Ni-Cr-B-Si coatings were applied by fiber laser to a substrate made of AISI 1020 steel. The best tribological characteristics were obtained for coatings with a high volume fraction of carbides. The influence of laser power 1500-1900W, spot diameter 3-5 mm and beam scanning speed 2-4 mm/s on the geometric parameters, microhardness and wear resistance of the deposited Ni-Cr-B-Si coating on 42CrMo steel samples was determined [3]. The wear mechanism of the coating is abrasive and adhesive. Laser surfacing of Ni-Cr and Ni-Cr-tic powders on AISI 420 steel was carried out with an Nd: YAG laser [4]. It was found that the mass loss of the Ni-Cr–tic composite coating is less than that of Ni-Cr and the steel substrate. Fe-WC coatings on low-carbon steel were obtained by laser surfacing using a disk laser [5]. The highest microhardness and corrosion resistance were observed for coatings obtained at a powder consumption of 12.5 g/min. To obtain coatings from Stellit-6/WC powder, a Yb: YAG disk laser with a nominal power of 1 kW was used [6]. The wear resistance of the nico30 layer is 3.6 times higher than that of the cobalt-free layer. Laser surfacing of iron-based powders Fe-Cr-Ni-Mo-Mn-C-Si was performed on AISI 4130 steel [8]. The deposited coatings had lower friction coefficients than the substrate, and the main wear
mechanism was moderate abrasive wear. A nickel-based coating with the addition of molybdenum was applied to the surface of 42CrMo steel using a 6 kW fiber laser [9]. The Ni45 + 10% Mo composite coating had a wear resistance 1.7 times higher than the Ni45 coating and 2.4 times higher than that of 42CrMo steel. The effect of processing parameters on the microhardness and wear resistance of an alloy based on Ni and TiC was studied [10]. The amount of wear decreased with an increase in the proportion of TiC powder.

The objectives of the work are to determine the parameters of laser surfacing zones and tribological characteristics of coatings when introducing nano-powder of tantalum carbide into the charge.

2. Materials and methods
The IMASH RAN laser system was used in experimental studies. The samples were made of 45(490-525HV), 65Mn (570-625HV) steels with dimensions of 15×20×70 mm. For the production of the charge, powders based on iron (Fe-Cr-Ni-Si) and nickel (Ni-Cr-B-Si) in a ratio of 3:1, respectively, with a particle size of 40-150 μm were selected. Nano Tantalum carbide powder TaC 5 and 10 vol.% was added to the charge with a particle size of 40-100 nm. Slip coatings were applied with a thickness of 0.67 - 0.8 mm. An aqueous solution of hydroxyethylcellulose was used as a binder. Metallographic studies of the deposited coatings were performed on a PMT-3 microhardness meter at a load of 0.98 N, an Altami MET 1C metallographic microscope, and an AM417 digital microscope. The structure and chemical composition of the deposited layers were studied using a TESCAN VEGA 3 SBH scanning electron microscope with an energy-dispersive analysis system using reflected and secondary electron modes. To determine the tribological characteristics of the deposited samples, a test was performed at normal temperature according to the scheme plane (deposited sample) - ring (steel SHCr15, 60-62). The sliding velocity and pressure on the sample varied discretely in the range of 0.25-3.5 m/s and 1-6 MPa, respectively. M10G2 oil was used as a lubricant. Tests for abrasive wear were carried out according to the disk-plane scheme. A flat sample was pressed against a rotating rubber disk, with a deposited coating with a load of 15 N. Quartz sand with a particle size of 200-600 microns was used as an abrasive. The duration of the tests was 10 minutes. The radiation power P=700-1000 W, the processing speed V=7-10 mm/s, and the beam diameter d=2.5-3.5 mm were chosen as the variable parameters. As an additional factor, the scanning of the beam with a fixed frequency f=217 Hz was considered. For the construction of mathematical models when performing a full factorial experiment (FFE), the height H and width B of the deposited rollers were considered as the responses of the system. Since FFE 2³ was performed, the number of experiments was 8 for each series.

3. Results
Laser surfacing of the samples was performed under optimal conditions with a defocused beam and with transverse oscillations of the beam normal to the laser processing speed vector. The microhardness of the deposited coatings (Fe-Cr-Ni-Si, Ni-Cr-B-Si), (Fe-Cr-Ni-Si, Ni-Cr-B-Si + 5 vol. % TaC), (Fe-Cr-Ni-Si, Ni-Cr-B-Si + 10 vol. % TaC) was 670-750, 870-980, 960-1280 HV, respectively. The penetration zone of the substrate during processing with a defocused beam and a scanning beam was 174 and 56 μm, respectively, which indicates a high adhesion strength of the coating. The cross-sectional area of a single deposited layer when scanning the beam is 2.16 times larger than when surfacing with an unfocused beam. The regression equations are used for calculations, which are compared with the results of the experiment. The calculated values differ from the actual values of the depth and width of the quenching zones by no more than 2.98%. The radiation power has the greatest influence on the geometric parameters of the deposited rollers. With increasing power, the width and height of the surfaced tracks grow. As the speed of movement increases, the depth and width of the rollers decreases. As the diameter of the laser radiation increases, the height and width of the rollers increases.

The dependence of the friction coefficients of steel 45 in the quenched state and deposited coatings is shown in figure 1. With an increase in the load from 1.2 to 4.0 MPa on hardened steel samples 45,
the coefficient of friction decreases from 0.11 and 0.09. With a further increase in the load of the sample, the coefficient of friction increases. The coefficient of friction for a multicomponent coating varies in the range of 0.04-0.05. The minimum coefficient of friction of 0.018-0.025 was obtained on a coating with additives of 10 vol. % nano powder in TaC.

Figure 1. Dependence of friction coefficients on pressure: 1 – Steel 45, 2 - (Fe-Cr-Ni-Si, Ni-Cr-B-Si) 3 - (Fe-Cr-Ni-Si, Ni-Cr-B-Si) + 5 TaC vol.%, 4- (Fe-Cr-Ni-Si, Ni-Cr-B-Si) + 10 TaC vol.%

Figure 2 shows the patterns of changes in the jamming load from the sliding speed. Hardened steel samples 45 are inferior to deposited multicomponent coatings and with the addition of nano-tantalum carbide powder. At a pressure of 5.5 MPa, jamming occurs at a speed 1.5-3 times lower for a hardened steel sample 45, compared to surfacing with a multicomponent coating and with additives of 10 TaC vol. % respectively.

Figure 2. Dependence of the jamming load on the sliding speed: 1-Steel 45, 2- (Fe-Cr-Ni-Si, Ni-Cr-B-Si) 3 - (Fe-Cr-Ni-Si, Ni-Cr-B-Si) + 5 TaC vol.%, 4- (Fe-Cr-Ni-Si, Ni-Cr-B-Si) + 10 TaC vol.%

Wear resistance, the inverse of the wear intensity, increases for many component coatings by 30% with hardened steel 45 and by 57 and 67% compared to the addition of 5 and 10 vols to the charge.% of nano powder of TAC, respectively.

Tests for abrasive wear during friction with loose abrasive grain of samples of hardened steel 65Mn and with coatings deposited on it (Fe-Cr-Ni-Si, Ni-Cr-B-Si), (Fe-Cr-Ni-Si, Ni-Cr-B-Si) + 5 TaC vol.%,(Fe-Cr-Ni-Si, Ni-Cr-B-Si) + 10 TaC vol.% showed that the mass loss samples were made up of $0.064 \times 10^{-3}$, $0.046 \times 10^{-3}$, $0.032 \times 10^{-4}$ and $0.028 \times 10^{-4}$ kg, respectively.

Figure 3 shows a fragment of a pilot batch of cultivator legs made of 65 Mn steel with laser surfacing of the working surface, made for field testing.
4. Discussion
Laser surfacing of multicomponent coatings, with the addition of nano powder of tantalum carbide, it can be used in the restoration of worn camshafts and crankshafts, piston pins, shaft seats for rolling bearings and other parts of agricultural machinery. In addition, this technology can be used to increase the wear resistance of tillage tools, ploughshares, disc harrows, cultivator legs, which are made of 45 and 65Mn steels. Losses on idle time of agricultural machines during the period of seasonal field work related to harvesting and cultivation of agricultural crops lead to significant economic costs. The effect of self-sharpening of the cutting edge is of great importance for the effective operation of the paws of cultivators and disc harrows. The use of laser surfacing technology with multicomponent materials with the addition of nano-powder of tantalum carbide with a layer thickness of 0.5-0.8 mm practically does not change the geometry of the cutting edges and at the same time provides self-sharpening tools.

5. Conclusion
The technology of laser surfacing of multicomponent coatings with additives of nano-tantalum carbide 5 and 10 vol.% has been developed. The wear resistance of these coatings is significantly higher than hardened steels 45 and 65Mn. At a sliding speed of 2.5 m/s, the jamming pressure of deposited coatings with nano carbides was 1.8-2.5 times higher than that of hardened steel 45. Coatings with nano-tantalum carbides had low friction coefficients of 0.02-0.034.

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