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Technology of hardening surfaces of working bodies by electromechanical processing

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Abstract. The article presents the results of research on technology development and substantiation of the modes of strengthening the working surfaces of earth-moving machines by the electromechanical method. The types of wear and the appearance of defects on the working surfaces of the part are analyzed, taking into account the operating conditions. Based on the conducted studies on the study of surface wear, the arithmetic mean values were determined using the example of a plowshare of a bulldozer blade. A technology for restoring a part with subsequent electromechanical hardening has been developed. The influence of processing modes on the surface hardness was studied, and using a multifactorial experiment, a regression equation was identified, and optimal hardening modes were substantiated.

1 Introduction

In recent years, consistent reforms have been implemented on the efficient use of land and water resources, improvement of the water management system, modernization, and development of water facilities. Uzbekistan has the largest water management infrastructure in Central Asia, which provides water to about 4.3 million hectares of irrigated area and economic sectors with the help of more than 28,570.0 km of irrigation networks, 38,781 hydraulic structures, 19,752 gauging stations, 19 large hydroelectric facilities and other structures[1].

To improve the reclamation state of irrigated lands, a collector-drainage network with a total length of 142.9 thousand km is operated, of which 106.2 thousand km. - open, 36.7 thousand km - closed horizontal and 172 reclamation pumping stations and 3,897 vertical drainage wells.

To provide a stable water supply to the population and all sectors of the economy of the republic, improve the ameliorative condition of irrigated lands, widely introduce market principles, mechanisms, and digital technologies in the water sector, ensure the reliable operation of water facilities, as well as improve the efficiency of land and water use, a development concept was adopted water management of the Republic of Uzbekistan for 2020 - 2030. The Ministries of Water Resources, together with the Ministry of Agriculture, approved several measures to improve the existing infrastructure, including the construction and reconstruction of 1,758 km of a canal, 443 km of irrigation flumes, 329 hydraulic

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structures, 1,899 km of collector-drainage networks, 728 km of closed and vertical drainage, 1,896 viewing reclamation wells, as well as repair and restoration of 5026 km of main canals, 45595 km of reclamation networks[2].

In the above complex of works, the share of mechanized work has enormous values, which are mainly performed by universal earth-moving machines. Working in special environments, these machines are exposed to various soil and climatic influences that cause intense wear and corrosion of the surfaces of the working bodies. Analysis of the wear of these surfaces showed that the average wear rate is 5-400 microns/hour.

Machine failures are caused by wear and tear, which puts the problem of protecting machines from wear among the most urgent. The successful solution to this problem depends on the knowledge of the laws of friction and wear, which are determined not only by the properties of the material and the shape of the cutting body but also by the nature of the interaction of parts with the object being processed, due to the very working process performed by the earth-moving machine. The increase in wear resistance is inextricably linked with the study of the patterns and mechanism of wear of the cutting bodies of earth-moving machines at the design, manufacture, and operation stages, as well as the development of the basis for calculating their wear resistance and resource. It has been established that the complexity of the process of wear of the cutting bodies of earth-moving machines is due to continuously changing forces and pressure on the working friction surface, the heterogeneity of the abrasive medium, the complexity of the processes of contact and movement of abrasive particles[3, 4].

To improve the wear resistance of the working surfaces of earth-moving machines, various heat treatment and hardening methods have been developed, the hard alloys of which are applied to the working surfaces during manufacture or restoration. The object of study is the plowshare of the bulldozer blade "Shantui SD 22".

To develop a recovery technology with subsequent hardening, a number of technologies and articles by scientists were studied, who recommended one or another method for justifying regimes [5, 6]. Taking into account the operating conditions of the bulldozer in which friction occurs in the "metal-abrasive" system, it is advisable to apply surface hardening methods with the recommended processing depth and appropriate hardness.

Modern technologies for hardening surfaces with the use of a laser or ultrasound for parts made of carbon plowshare steels lead to an increase in the cost, while it is required in domestic mechanical engineering [7–9].

2 Methods

The bulldozer is a universal high-performance machine designed to perform various types of earth-moving, planning, and cultural works (construction of an embankment, development, and widening of an excavation, moving soil from excavation to an embankment, moving and stacking bulk materials and peat, backfilling temporary irrigation canals, excavation, the layout of areas, clearing roads from snow, cutting and clearing shrubs and undergrowth, uprooting small stumps, cleaning boulders, etc.).

When excavating with bulldozers, the following operations can be performed: cutting and collecting soil before the bulldozer blade, moving soil, unloading and laying soil, idling, and returning to the cutting site. The listed operations make up this type of machine's full cycle of operation. The development of soil with a bulldozer begins with the operations of cutting and collecting soil. For efficient operation of the bulldozer, the traction force of the tractor on which the bulldozer equipment is mounted must be variable, close to the maximum, which is first spent on cutting and removing chips, then on moving the soil dragging prism with a blade. Bulldozers are especially widely used in the construction of subgrade roads from side reserves, in the construction of all types of pits, and in leveling cavaliers during the construction of an open drainage network. Bulldozers can be used separately and with other earth-moving and reclamation machines.

As you know, the share of failures caused by the wear of parts accounts for about 80% of the total breakdowns. The working bodies of earth-moving machines are subjected to especially intensive abrasive wear. Wear protection, the search for new materials, and the development of hardening methods for working bodies are becoming increasingly important every year.

When designing, the materials and structures of the elements of these machines are selected during operation following the physical and mechanical properties of the rocks and soils with which they have to work.

The main minerals that determine the properties of the soil are feldspar, mica, quartz, and others. Quartz (SiO_2), the main mineral in the composition of sands and loams, has a Brinell hardness of 800-1200 kg/mm^2, while the hardness of the metal from which earth-moving organs are made does not exceed 350-400 kg/mm^2 in many cases.

The plowshare of the bulldozer blade is made of carbon steel by cutting out from the plate and subsequent heat treatment. We studied the materials of the plowshare of the bulldozer blade, and the results of the comparison are shown in table 1.

Table 1. Mechanical properties and chemical composition of steels

The name of indicators	Steel 30Mnb	Steel 16Mnb
Share surface hardness after heat treatment	HB 420-480 HRC 45-50	HB 340 HRC 30-35
Strength (Rm MPa)	1450 Rm-N/m^2	≥1150 Rm-N/m^2
Deformation (stretching) (A%)	6%	≥12%
Tensile strength (Rp.02 MPa)	1150 Re-N/m^2	≥900 Re-N/m^2
Chemical composition	C:0.27-0.34; Mn:1.10-1.40; Si:0.17-0.37; S:≤0.035; B:0.0005-0.0035	C:0.12-0.20; Mn:1.20-1.40; Si:0.17-0.37; S:≤0.035; P:≤0.035 Cr Mo Ni

To determine the amount of wear, appropriate micrometric measurements were carried out according to existing methods, and a repair drawing of the plowshare of the bulldozer blade was developed (Fig. 1.). Studies have shown that under the influence of an abrasive and corrosive environment, various defects appear in the plowshare due to mechanical (defect 3 - abrasive wear of the blade), corrosion (defect 1 - oxidation of the blade and plowshare surface) and molecular mechanical (defect 2 - fretting corrosion and fatigue destruction) wear. After continuous micrometering of the sample volume, the wear results were processed by mathematical statistics, and the arithmetic mean of the wear in the cutting part was 1.16 mm, the standard deviation was 1.84, and the coefficient of variation was 0.454.

In the repair practice of restoring heavily worn parts, electric arc welding and surfacing or the installation of additional hard-alloy plates are used [10-14].

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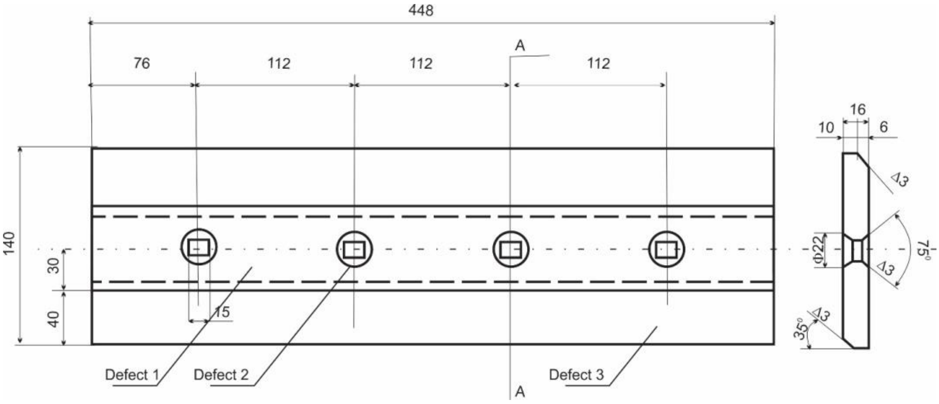

Fig. 1. Location of defects on surface of plowshare of bulldozer blade.

For surfacing, electrodes "Sormayt No. 1", "Sormayt No. 2", and "Wearshield-60" are used, after which the surface hardness is HRC 57–60. But when implementing this technology, the part is subjected to two-fold heating: blade pulling and electric arc surfacing. This worsens the quality of recovery and leads to a change in the structure and properties of the metal. Therefore, we have developed a recovery technology based on the deposition of metals by plasma technologies and recovery by electromechanical processing (Fig. 2) [5].

The electromechanical recovery method is based on a combination of thermal and force effects on the surface layer of the workpiece. From the point of view of metal science, electromechanical processing can be attributed to a special type of surface thermomechanical processing. A distinction is made between high-temperature thermomechanical processing, where deformation occurs at a temperature above the recrystallization threshold, and low-temperature thermomechanical processing, where deformation occurs at a temperature below the recrystallization threshold [15–17].

According to many researchers, the main reason for the increase in the strength of the metal after thermomechanical treatment is the refinement of the structure, associated with the crushing of austenite grains during deformation and the appearance of additional slip bands. Plastic deformation is accompanied by an increase in the number of linear imperfections of the atomic lattice or the so-called dislocations, which are characterized by the displacement of atoms. The dislocation density (the number of dislocation lines per 1 cm^2 of the surface) in the original metal is approximately 10^8, and slip during plastic deformation increases the dislocation density up to $10^{10}...10^{12}$. Such changes in the structure increase the endurance limit, impact strength, relaxation resistance, resistance to plastic deformation, and resistance to brittle fracture of the metal, which are the main requirements for plow steels [18].

Thus, metals' electromechanical processing is a combination of contact heating, plastic deformation, and cooling operations.

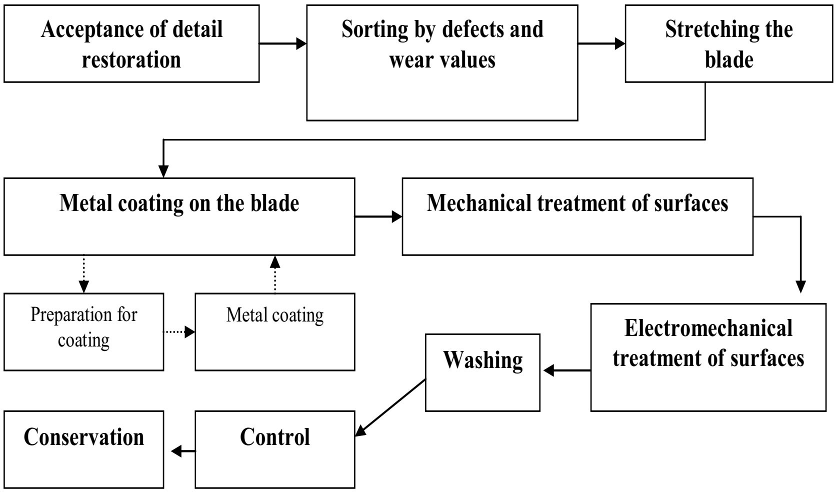

Fig. 2. Technological processes during recovery.

3 Results and Discussion

Increasing the wear resistance and durability of the working bodies of tillage machines is a major reserve for increasing the efficiency of machines. Therefore, to reduce the intensity of abrasive wear, it is necessary to provide the maximum possible surface hardness for medium-carbon steels at the level of maximum values, i.e., not less than 65-70 HRC. Such values of strength, impact strength, and hardness in the manufacture of replaceable parts from these steels by traditional technologies (HFC hardening, bulk heat treatment) are not provided. The set of required mechanical properties is provided by plasma hardening, which is optimal in terms of versatility, accessibility, and environmental friendliness [19], [20]. But during recovery, repeated thermal influence reduces the mechanical properties, and there is a risk of metal destruction.

With classical heat treatment methods, the process proceeds at temperatures in the range of 973-1473 K (transformation temperatures below Ac_1 to above Ac_3), followed by quenching in oil and tempering at 1033 K for 1 hour. After heat treatment, a predominantly tempered martensitic structure developed in the steel. But the process proceeds with a decrease in temperature, and the range of 973-1182 K is unstable from the point of view of metal science. In heating for quenching and quenching, cracks, deformation and warping, decarburization, soft spots, and low hardness may occur [21].

Therefore, local or contact heating technologies with combined machining are widely used in modern mechanical engineering.

The machine for electromechanical processing consists of a transformer for electromechanical processing manufactured by ELMA Ltd., a knurling device, and a universal milling machine.

During electromechanical processing, heating is provided due to the passage of current along the contact surface and friction of the roller on the part's surface. Thermal phenomena occurring during processing are associated with the release of heat due to the passage of electric current, the friction of the tool on the workpiece, and deformation of the metal in the surface layer, as well as heat transfer between the tool and the surface layer and heat transfer to the environment and inside the metal.

The problem was solved by the heat balance method to the EMT conditions; the

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dependences for determining the value of the current strength during EMT were obtained, taking into account the contact area and the pressure force of the roller, which were determined based on the process of plastic compression of metals, applying to the electromechanical processing of parts:
Contact area in the interface "surface-roller":

$$S = 2\pi(\Delta p + \Delta)\sqrt{bR}, \text{ mm}^2 \quad (1)$$

The force of pressing the roller to the surface:

$$P = \omega k_p \delta_v^1 e^{-2t} S(3.3)^m, \text{ H} \quad (2)$$

Current strength:

$$I = \frac{\text{ShjcT} - Pv/102}{\text{Utk}\mu\eta}, \text{ A} \quad (3)$$

where b is roller contact width on the surface, m; R is roller radius, m; Δρ is plastic strain value, m; Δ is elastic strain value, m; ω is speed coefficient; $k_п$ is transition coefficient; $\delta_в^1$ is temporary resistance of metal at temperature 1000^0C, $\delta_в^1$=0,1$\delta_в$; $\delta_в$ is tensile strength of metal, MPa; e^{2t} is coefficient taking into account the resistance of the metal to plastic deformation at temperature 900^0C; m is the compression polytropic exponent; h is depth of the high-temperature layer, m; j is metal density, kg/m^3; c is specific heat capacity of metal, J/g K; v is processing speed, m/s; U is voltage in the secondary winding of the transformer, V; *t* is heating time, s; k is coefficient taking into account the absorption of heat from the coolant; μ is heat distribution coefficient; η is coefficient taking into account current losses in the secondary winding of the transformer.

Having the values of the current strength and the pressure of the roller on the surface of the plowshare, which is provided by the process of electromechanical processing, research has studied the influence of each technological factor on the quality of recovery for a multifactorial experiment.

The surface hardness was chosen as the optimization function from the factors selected:

X_1 is current, A is heating of the contact area.

X_2 is the roller pressing force, N is the plastic deformation of the surface.

A multivariate experiment was carried out according to plan B_2, by varying the values of factors affecting the quality of restoration and developing a mathematical model that explains the surface hardness and strength.

Construction of the mathematical dependence of the surface hardness Y on the current strength during electromechanical processing X_1 and the pressing force of the roller X_2 during processing.

The plan and results of the multi-factor experiments are presented in Table 2 below.

Table 2. Plan B_2 and the results of the experiment.

Name	Factors		Criteria for Optimization				Mean squared deviation
	I, A	P, N	Coating adhesion strength, MPa				
	X_1	X_2	Y_1	Y_2	Y_3	Y_{cp}	
High (+)	2400	2000					
Basically (0)	1800	1500					
Low (-)	1200	1000					
Plan of experiments							
1	-1	-1	46.0000	46.0000	47.0000	46.3333	0.333333
2	1	-1	60.0000	62.0000	61.0000	61.0000	1.000000
3	-1	1	46.0000	46.0000	45.0000	45.6667	0.333333
4	1	1	65.0000	64.0000	64.0000	64.3333	0.333333
5	-1	0	45.0000	46.0000	46.0000	45.6667	0.333333
6	1	0	63.0000	62.0000	61.0000	62.0000	1.000000
7	0	-1	55.0000	54.0000	54.0000	54.3333	0.333333
8	0	1	58.0000	59.0000	59.0000	58.6667	0.333333
						438.0000	4.000000

All the coefficients of the regression equation describing the processing process were confirmed, and the resulting regression equation was:

$$Y = 56 + 8.28X_1 + 1.17X_2 + X_1X_2 - 2.17X_1^2 + 0.5X_2^2\ , \qquad (3)$$

The following dependencies were used to convert the regression equation factor from the coded view to the natural one $x_1 = \dfrac{X_1 - 1800}{600}$ ва $x_2 = \dfrac{X_2 - 1500}{500}$.

The view of the regression equation in the form of natural variables is as follows:

$$R_{HRc} = 21.62 + 3.05 \cdot 10^{-3} I - 9.66 \cdot 10^{-3} P + 3.33 \cdot 10^{-6} IP - 6.03 \cdot 10^{-6} I^2 + 2 \cdot 10^{-6} P^2 \quad (4)$$

After analyzing this model, the optimal processing modes for the electromechanical method are current strength - 2000A with a force of pressing the roller to the surface of 1800 N.

4 Conclusion

In world practice, in machine-building and repair enterprises, the classical methods of heat treatment for processing parts are replaced by more modern ones, such as laser and ultrasonic ones. Based on theoretical studies, we have analyzed various methods of hardening the surfaces of carbon steels and substantiated the use of an electromechanical method, which is based on a combination of thermal and force effects on the contact surface. In terms of its manufacturability, versatility, and technical and economic feasibility, it is not inferior to the above technologies. Based on the arithmetic average wear of the bulldozer blade plowshare, a resource recovery technology has been developed with hardness in the range of 55-62HRC. Based on the heat balance and plastic deformation, equations are derived that determine the initial processing modes in which electromechanical hardening is carried out. Using a multifactorial experiment, regression equations were identified, and the optimal values of processing modes were determined. The conducted studies and developed technology and models show that the recommended processing modes provide the necessary hardness and, with this, increase the wear resistance of the surface.

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