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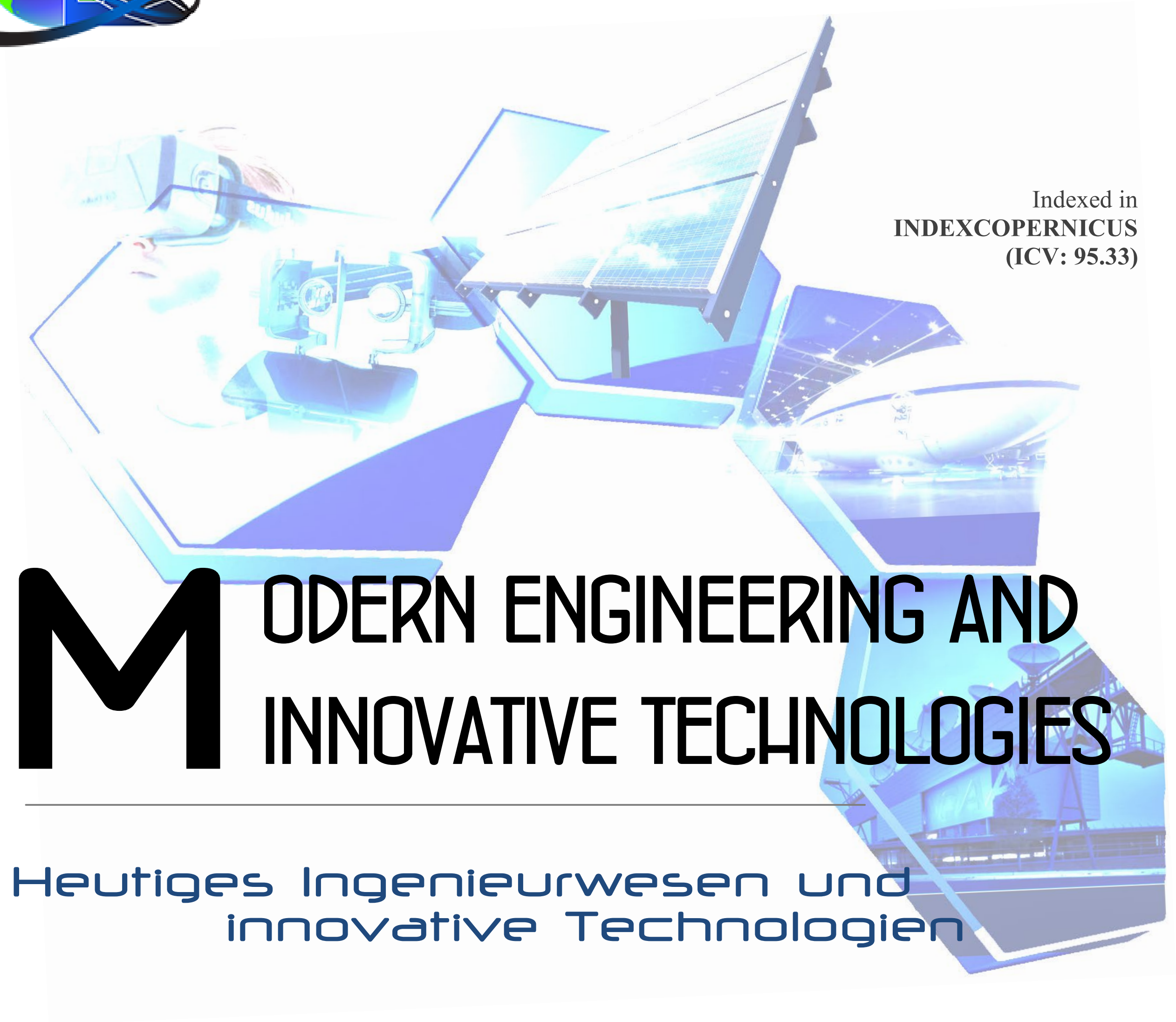

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The International Scientific Periodical Journal **"Modern Technology and Innovative Technologies"** has been published since 2017 and has gained considerable recognition among domestic and foreign researchers and scholars.

Periodicity of publication: Quarterly

The journal activity is driven by the following objectives:

- Broadcasting young researchers and scholars outcomes to wide scientific audience
- Fostering knowledge exchange in scientific community
- Promotion of the unification in scientific approach
- Creation of basis for innovation and new scientific approaches as well as discoveries in unknown domains

The journal purposefully acquaints the reader with the original research of authors in various fields of science, the best examples of scientific journalism.

Publications of the journal are intended for a wide readership - all those who love science. The materials published in the journal reflect current problems and affect the interests of the entire public.

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Subclass TA /TA165	Engineering instruments, meters, etc. Industrial instrumentation
Subclass TK /TK5101-6720	Telecommunication
Subclass TK / TK1-9971	Electrical engineering. Electronics. Nuclear engineering
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All tables and figures in the article should be numbered, have headings and links in the text. If the data is borrowed from another source, a bibliographic reference should be given to it in the form of a note.

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Articles should be accompanied by an annotation and key words in the language of the main text and must be in English. The abstract should be made in the form of a short text that reveals the purpose and objectives of the work, its structure and main findings. The abstract is an independent analytical text and should give an adequate idea of the research conducted without the need to refer to the article. Abstract in English (Abstract) should be written in a competent academic language.

The presence of UDC, BBK

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The editors are convinced that violations of copyrights and moral norms are not only ethically unacceptable, but also serve as a barrier to the development of scientific knowledge. Therefore, we believe that the fight against these phenomena should become the goal and the result of joint efforts of our authors, editors, reviewers, readers and the entire academic community. We encourage all stakeholders to cooperate and participate in the exchange of information in order to combat the violation of the ethics of publication of scientific research.

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APPLICATION OF WEAR-RESISTANT COATINGS TO INCREASE RESOURCE OF WORKING BODIES OF GRINDING MACHINES

НАНЕСЕННЯМ ЗНОСОСТІЙКИХ ПОКРИТЬ ДЛЯ ПІДВИЩЕННЯ РЕСУРСУ РОБОЧИХ ОРГАНІВ ҐРУНТООБРОБНИХ МАШИН

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Abstract. *Intensive compaction of the soil, which is caused by the use of modern powerful tractors with high weight and the presence of higher working speeds, and as a result reduces the service life of tillage equipment. Difficult weather conditions cause an increase in the load on the working bodies of tillage machines (plowshares, cultivator paws).*

The article considers the problem of restoring the resource of the working bodies of tillage machines by applying wear-resistant coatings. The types of wear and the impact of abrasive materials on the working bodies of tillage machines are analyzed. Determined optimal materials and methods to increase the wear resistance of the working bodies of tillage machines. Features of formation of a metallization covering which is reflected in its structure and character of defects which can differ in the sizes, density, morphology and orientation are considered. The dependence of the properties of coatings on the alloying system of the material is substantiated. Equipment and materials for coating are given.

Taking into account the received information, conclusions were made and the analysis of the technology of applying wear-resistant coatings for the restoration of the resource of the working bodies of tillage machines was carried out.

Key words: *tillage equipment, maintenance, tillage, metallization, surfacing, flux - cored wire, arc metallization, spraying.*

Formulation of the problem

The annual need of Ukraine's agriculture in working bodies for plows and other tillage machines is quite significant and cannot be estimated numerically. To maintain the efficiency of agricultural machinery, a significant number of spare parts are produced annually.

During tillage (plowing, cultivation) the energy intensity of the process increases sharply due to blunting of the working bodies due to abrasive wear [3].

The working bodies of tillage machines are exposed to shock-abrasive nature of wear, which occurs due to contact with soil particles and stones. Depreciation is influenced by concomitant factors such as: mechanical composition of the soil; humidity; hardness; material structure; pressure and speed of relative movement of soil on a surface of working bodies of tillage machines.

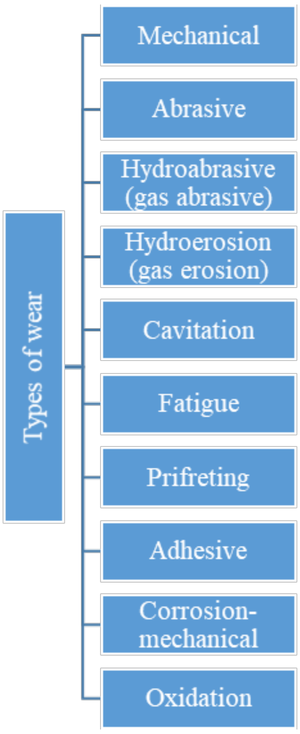
Table 1 shows an approximate classification of the characteristics of the variety of wear processes, which are the result of complex processes on the surface layer of the metal during wear, differences in conditions and modes of operation of friction pairs.

Abrasive wear is the main type of contact interaction during external friction.

Abrasive wear is present during the work of connections of working bodies of agricultural and other machines, which is the main factor that limits the technical characteristics and resource of machines, mechanisms and equipment [4].

This type of wear accounts for 50 to 80% of failures of the working bodies of machinery, including construction, road, transport, agricultural, livestock machinery and feed production [3].

Table 1. Classification of types of wear.



Abrasive particles such as quartz (HV 10.5-12.5 GPa) and feldspar (HV 6.5-7.2 GPa) are present in the soil. The presence of these minerals, based on sandy and loamy soils, explains the rapid wear of working bodies. Figure 1, 2 shows the characteristic wear profile of the working bodies of tillage machines.

Figure. 1. - Working bodies of tillage machines [4].

The manufacture of working bodies of tillage machines (plowshares, cultivator paws, harrow discs) should have increased requirements for the material, methods of improving wear resistance, manufacturing technology [4-5].

Abrasive wear is divided into four types:

1. destruction of material by cutting;
2. destruction of material by separation (brittle destruction);
3. destruction of the material by repeated deformation of the microvolumes of the surface layer (tiring destruction);
4. polydeformation process of destruction of materials (joint manifestation of the three above-mentioned destructions, including destruction as a result of re-riveting) [3].

Humidity, mechanical structure of the soil, the speed of relative movement and other factors affect the abrasive wear of the working bodies of tillage machines [3-6].

The abrasive content of the so-called quartz sand in the soil has the main effect on the abrasive wear of the working bodies of tillage machines. In addition to abrasive, which scratches or removes chips from the surface of the working bodies of tillage machines, the rate of wear is affected by the moisture present in the soil, which has a certain pH acidity. With increasing soil moisture and abrasive fraction (0.25 - 1.00 mm) the amount of wear increases by 25-50%.

Abrasive wear prevails over other types of wear, if the hardness of the abrasive exceeds the hardness of the material of the working body of tillage machines.

Figure. 2. The shape of the working body of the cultivator [4].

The purpose and objectives of the study

Restoration of the resource of working bodies of tillage machines due to the application of wear-resistant coatings.

To achieve this goal you need to solve the following tasks:

Analyze the types of wear and the impact of abrasive materials on the working bodies of tillage machines;

Determine the optimal materials and methods to increase wear resistance;

Taking into account the received information, draw conclusions and analyze the technology of applying wear-resistant coatings to increase the life of the working bodies of tillage machines.

Materials and methods to increase wear resistance

Increasing the wear resistance of the working bodies of tillage machines in agricultural engineering is due to:

- use of wear-resistant material and multilayer rolled metal;
- development of constituent working bodies;
- heat and thermochemical treatment;
- surfacing and spraying of wear-resistant materials.

When choosing a method of hardening depending on the type of soil should take into account not only technological and economic indicators, but also the need to implement the effect of self-sharpening of working bodies.

The essence of the effect of self-sharpening is the selective wear of the inhomogeneous cross-section of the blade, which retains the desired shape and cutting properties of the working body [4,5-7].

The production of trapezoidal bimetallic ploughshare with a two-layer rolled part of the blade made of steel H6F1 (lower layer) and L-53 (upper layer), allows to increase the service life and provide a self-sharpening effect. These plowshares have a longer service life, but to restore them requires the manufacture of specialized equipment for processing metals by pressure [4].

One of the most common technological operations for hardening is heat treatment. Due to heat treatment, the hardness of the metal for steel 45 is HRC 40-46, and for steel 65G and alloy steels - HRC 55-61. Wear resistance of such working bodies is less in comparison with the details made of special materials, but at application of such working bodies on loamy soils self-sharpening is not observed [6].

Wear of cultivator paws with induction hardening (width of the hardening layer - 8-10 mm, HRC 48-52) for the season will be 30 mm, while not ensuring the quality of processing [6].

The use of laser heat treatment to strengthen the working bodies 1.5 times reduces wear compared to bulk hardening. Laser surfacing with PS-14-60 + 6% B4C alloy reduces wear by 1.7-1.8 times compared to induction hardening [4].

It is possible to increase wear resistance of details of cars at the expense of a surfacing.

Surfacing materials are self-protective flux-cored wires of the PP-AN170 type (PP-AN170M), provide the formation of a welded layer with a hardness of HRC 60-65.

Optimal wear resistance and self-sharpening is determined by adjusting the geometry of the deposited layer (height, depth, surfacing step), as well as the ratio of hardness of the deposited areas and the base metal in the range of 1.5: 1.0; 1.0: 1.0 [7].

Composite materials are mainly obtained by powder metallurgy. In addition, there are other methods, such as the method of direct introduction of the filler into the liquid metal or alloy before bottling. In the latter case, ultrasonic treatment of liquid melt is used to clean grease and other contaminants, improve wetting of parts with liquid metal and evenly place them in the matrix.

The use of composite materials (strong, plastic base - wear-resistant coating), meets the criterion of "price-quality" and is the best for strengthening the working bodies of tillage machines. In the manufacture of large batches of working bodies of tillage machines, strengthening technologies must be used at the stage of manufacture. Technologies to increase the resource must meet certain requirements: the type of production, be productive, economical and provide a given thickness and durability of coatings.

The method of gas-thermal spraying allows to provide long service life of working bodies, to reduce time of carrying out works on strengthening and to reduce their cost.

The process of gas-thermal spraying is as follows: the material is sprayed in the form of powder or wire is fed into the heating zone; the gas sprays the heated particles and gives them acceleration in the axial direction; in the heating zone when feeding the wire, the spray gas disperses the molten material, and it also performs the function of heating; the particles entering the surface have a high collision velocity, thus forming strong interatomic bonds and creating conditions for the adhesion of the unfolded material by activating the surface contact [4-7].

Classification of methods of gas-thermal spraying by type of energy used and heat source.

By type of energy are divided into:

- ✓ gas-electric, which use electricity:
- ✓ gas-flame methods, where thermal energy is generated by the combustion of combustible gases.

The following types of heat sources are used to heat the sprayed material:

- arc;
- plasma;
- gas flame.

Spraying methods are divided into types:

arc metallization;
plasma spraying;
gas-flame spraying;
detonation-gas spraying.

The first two methods belong to gas-electric, the last - to gas-flame [4,5-7].

The energy utilization factor of the supplied energy, the utilization factor of the sprayed metal, productivity, quality of coatings and the cost of their application determines the effectiveness of gas-thermal spraying methods. The predominant method of gas-thermal spraying in terms of thermal efficiency, productivity and cost of coatings is arc metallization.

When using arc metallization, the share of energy supplied goes directly to the heating and melting of the powder material, allows to increase the effective heating efficiency up to 60%. Low heat losses are due to the physical characteristics of the process.

The process of arc metallization occurs by spraying the wire into the arc burning between it and the powder, which is transported by gas, and the formed particles are accelerated and when they hit the surface form a coating. High thermal efficiency of arc metallization is due to the direct transfer of energy from the arc to the wire. The share of the introduced thermal energy from the arc going to the melting of the powder material is 60-70%, which is 7-10 times more than for other methods of gas-thermal spraying. Productivity of arc metallization is rather big - to 18 kg / h at steel sawing. The price of wire is 2-3 times cheaper than powders used for other methods of gas-thermal spraying.

The level of strength depends on the volume composition of the hardening phase, the uniformity of its placement, the degree of dispersion and location between the particles. According to Orovan's formula, the shear resistance increases with decreasing distance between the particles:

$$\sigma = Gb / l \qquad (1)$$

where G is the shear modulus; b is the interatomic distance; l is the distance between the particles.

Combustion of alloying elements in the applied material and saturation of powder metal with gases from the atmosphere in the combustion zone of the arc are physico-chemical features of the process of arc metallization, which makes it difficult to obtain quality coatings. Equipment for the process of arc metallization is characterized by a wide spray angle, up to 70 °, low 0.5-0.6, the utilization factor of the metal, reducing the concentration of alloying elements and excessive oxides in the coating.

Activated arc metallization equipment designed to eliminate these shortcomings, which differs from the typical in that it uses combustion products (propane-air mixture) as a gas conveyor [9].

Expensive nickel-based alloy powders are materials for the application of wear-resistant coatings in plasma spraying and arc metallization [4]. For arc metallization, economically alloyed Fe-Cr-B type iron-based flux-cored wires have become widespread, which, unlike solid wires, make it easier to obtain wear-resistant coatings of the required alloying system, which is necessary to vary the coating composition at different wear modes.

Coatings of these flux-cored wires increase the wear resistance of steels by 2-5 times and make the method of arc metallization predominant when sprayed on the working bodies of agricultural machinery [5].

The greatest danger is wear on the mechanism of internal friction, with high contact loads and the presence of shocks. For coatings, it is probably due to the occurrence and development of microcracks in oxide films. Oxide films and even larger pores can contribute to the exfoliation of metal by the mechanism of internal friction, increasing the rate of mechanical wear of the metal coating.

Therefore, it is necessary to consider the peculiarities of the formation of metallic coatings and methods of improving the technology of their application, to ensure wear resistance of coatings during impact and abrasive wear, typical of operating conditions of working bodies of tillage machines [4, 8].

The main results of the study

The metallization coating is formed from layered elements formed by high-speed impact on a cold surface, which subsequently leads to solidification of the particles. The particles melt to a plastic state and are evenly distributed on the surface. The contact of the particles with each other occurs after their engagement on an uneven surface.

During spraying, the particles are oxidized, which leads to the formation of an oxide film, which enters the coating. Oxide film falling on the coating has a negative effect on it:

1. prevents the diffusion of particles;
2. reduces the strength of adhesion;
3. reduces the hardness of the coating.

On the last sprayed layer the fraction in the form of dust of the molten material or its oxides and adsorption of gases will be put.

High velocity during spraying leads to spreading and crystallization of particles in contact with the previously applied surface, which causes defects, cavities, microcavities filled with gas.

Overheating of particles leads to their evaporation and settling in the vapor phase [5, 9].

Formation of the resulting coatings, which are formed from unmelted particles, oxides, pores, thin plates connected to each other or welded areas, or by "setting" formed during crystallization and curing.

The coating has a lower strength and density than the base material, because the welded areas do not fill the entire contact area between the applied particles.

In the seed coating there are boundaries between layers and particles, which determine the strength of adhesion between the coating and the substrate:

1. cohesion;
2. layered boundaries;
3. the boundary between the layer and the particles. [4-9].

The adhesive strength of the coating can be determined by the following mechanisms:

- mechanical adhesion of the applied parts to the surface of the substrate or with pre-deposited particles;

- activation energy, when the heat from the applied particle will be enough to form the required amount of heat on the surface of the material or pre-applied particle for diffusion of mutual remelting. This will cause the presence of chemical reactions in the area of the particle and the substrate, ie the metallurgical bond;

- the presence of van der Waltz forces, when the physical interaction between the particles and the base is formed as a result of the convergence of atoms at a distance of the order of the size of atoms.

Summarizing the different estimates of the contribution of each type of connection, we can conclude that usually the share of metallurgical connection is small, otherwise the resistance to rupture of the coating is close to that of the source material [6-9].

Thus, the processes occurring in the two-phase flow affect the properties of the coatings and the features that determine the sprayed material will be:

- change in the composition of the particles of the sprayed material in interaction with the environment;
- high rate of crystallization and deformation upon impact of particles;
- the nature of the contacts between the particles in the coating.

The strength of the coating is ensured by adhesion and is characterized by the following mechanisms:

- the applied parts of the mine must be in mechanical adhesion to the surface of the substrate or with a pre-deposited layer;

- the presence of a metallurgical bond indicates the presence of chemical reactions in the area of the particle and the substrate, which leads to the diffusion of mutual remelting;

- physical interaction between particles and the base as a result of the convergence of atoms at a distance of the order of the size of atoms, indicates the presence of van der Waltz forces in this process.

The properties of the applied coating are influenced by the processes occurring in the two-phase flow. The features of the sprayed material include: the ability to change the composition of particles when interacting with the environment; at impact of particles there is a fast crystallization and deformation; the nature of the contacts between the particles in the coating.

The structure and nature of defects reflects the peculiarities of the formation of the metallization coating and differs in size, density, morphology and orientation.

In the study of metallization coating on the example of steel 30X13 descriptive composition of the sprayed layer. It has very thin alternately arranged wavy layers of white and gray-blue, which are hardened metal and oxides. The presence of metal and oxides indicates the presence of areas of mixed structure. Individual metal particles have a more rounded shape and globular, in turn, the pores have a globular and disc-shaped [10].

Insufficient layer-by-layer wetting of the droplets is the cause of the formation of disc-shaped pores that form between the layers. Globular pores occur as a result of insufficient filling of the hardening layer.

Etching of the samples made it possible to detect the rate of development, on thin layers of metal development occurred faster than in thicker layers and large particles. The high content of chromium in the structural components causes poor digestion compared to light areas.

Layer-by-layer chemical analysis of coatings sprayed with a DM apparatus showed that the content of elements is almost the same in the depth of the sprayed layer, but in the spraying process they burn out compared to the original content [10].

To determine the influence of the composition of the atmosphere of the transport gas on the peculiarities of the formation of the metallization coating, samples were taken using different metallization options. The serial device EM-14 became the basis for comparison. The ADM-10 apparatus uses the products of combustion of the propane-air mixture for spraying.

Assuming that the rounded metal particles got into the coating already in the cured state, with a particle size of less than 30 μm. Therefore, the coatings obtained by spraying in air have a rough inhomogeneous structure with elongated pores and large particles.

The use of propane-air medium made it possible to obtain a coating with a thinner structure, pores and voids are much smaller and they are smaller. The structure has a small amount of oxides, and oxide films are thinner. Therefore, when using an ADM device using propane-air environment, the resulting coatings are better.

Studies using a reducing atmosphere obtained with the use of propane-air environment have shown that the microhardness of coatings is much higher. There is a decrease in the porosity of the coatings and increase the microhardness in the various structural components is 6-12%. The increase in the porosity of the coatings, the increase in the number and size of the oxide layers, is due to the oxygen contained in the transport gas. Increasing the porosity reduces the cohesive strength, because the pores are voids with zero strength.

Physico-chemical features of the DM process are associated with the difficulty of obtaining quality coatings. This is due to the combustion of alloying elements in the applied material, and the saturation of the powder metal with gases from the atmosphere in the combustion zone of the arc. Typical DM equipment is characterized by a wide spray angle, up to 70 °, low, 0.5-0.6, the utilization factor of the metal, reducing the concentration of alloying elements and excessive oxides in the coating.

To eliminate these shortcomings, activated arc metallization (ADM) equipment has been developed, which differs from the typical one in that combustion products (propane-air mixture) are used as a gas conveyor. In ADM devices, the spray angle is 10 degrees, the utilization factor of the material reaches 85%, particle velocity - 140-200 m / s, the degree of oxidation of the steel coating - 2.1-2.9%, porosity - 2%. On average, the level of parameters is 40% higher in comparison with both domestic and foreign DM installations [7, 25-26].

Expensive nickel-based alloy powders are used as materials for the application of wear-resistant coatings in PN and DP [6]. Economically doped Fe-Cr-B iron-based flux-cored flux-cored wires (DM) have become widespread for DM, which, unlike solid wires (SP), makes it easier to obtain wear-resistant coatings of the required alloying system, which is necessary to vary the coating composition in different modes. wear. Coatings from the specified PP [7, 25-26] provide increase in wear resistance of steels in 2-5 times and advantages of DM at spraying on working bodies of agricultural machines.

It should be noted that at high contact loads and the presence of shocks the greatest danger is wear on the mechanism of internal friction. For coatings, it is probably due to the occurrence and development of microcracks in oxide films. Oxide films and even larger pores can contribute to the exfoliation of metal by the mechanism of internal friction, increasing the rate of mechanical wear of the metal coating. Oxide films formed during spraying play a dual role. On the one hand, it is one of the hardest components of the coating structure, its microhardness is 5-6 GPa. On the other hand, oxides are a fragile part of the structure, characterized by low adhesion to other components. Therefore, for each type of coating there is an area of optimal oxide content. Taking into account the above, it is necessary to consider the peculiarities of the formation of metallic coatings and methods of improving the technology of their application, to ensure wear resistance of coatings during impact and abrasive wear, typical of operating conditions of tillage machines [6-9].

Comparing the coating sprayed with EM-14 without the use of a restorative atmosphere with the coating applied by ADM-10, it was found that the resistance of coatings and impact abrasion increases several times with decreasing oxidation of droplets, and as a result - oxidation of the coating.

Tests of materials 10HGSA, 45G, 50HFA, 30X13 showed that the coating of steel 30X13 has the best results: wear resistance is 2-5 times higher than coatings of other materials; there is a released martensite and structural transformations in it will be accompanied by compressive stresses favorable for operating loads.

Subsequently, a sample of active arc metallization coatings made of 30X13 solid wire was adopted as a reference for testing the wear resistance of coatings.

Therefore, to improve the properties of coatings, it is necessary to create a protective atmosphere, especially in the combustion zone of the arc, as well as alloying of powder metal elements - deoxidizers, this will reduce the amount of oxide film on the particle surface [4,8-9].

Dependence of coating properties on the material alloying system

The choice of the doping system of the sprayed material, through the simulation of the process of oxygen supply to the sprayed particles makes it possible to obtain the required amount of oxides in the metallization coating and the required indicators of its properties. Technological parameters of arc metallization should be optimized according to an independent criterion that determines the performance of coatings during operation. The adhesive strength of coatings is a criterion in the conditions of impact and abrasive wear, which shows their ability to resist peeling from the base.

When estimating the dependence of the properties of coatings on the composition of the sprayed material, the model of particle oxidation in arc metallization, presented in [4, 9-10].

The works describe the process of arc metallization, consisting of three zones, which differ in the interaction of the sprayed metal with oxygen in each zone. The first stage describes the behavior of the metal at the end of the electrode. The second stage characterizes the metal in the combustion zone of the arc. The third stage describes the flight of drops over the spraying distance.

Equipment and materials for coating

Installation of active arc metallization ADM-10, designed for wear-resistant and anti-corrosion coatings of wire materials by thermal spraying. The installation is operated in the conditions for which the products are designed in category 3, in accordance with GOST 15150-69.

The installation works from a three-phase alternating current network with a voltage of 380/220 V, frequency 50 Hz. The operation requires the presence of compressed air, propane, and welding power supply with a rigid characteristic of VDU-506.

The process of melting wires with an electric arc and spraying molten metal with a high-speed jet of transport gas is the basis of the installation.

The installation works as follows:

1. voltage is applied to two wires that act as electrodes;
2. wires at a constant speed enter the spray head of the metallizer, where as a result of the convergence between them there is an electric arc and melting;
3. transport gas (compressed air and propane) blows the particles of molten metal from the ends of the wires, picks them up, accelerates to high speed and provides delivery to the surface of the workpiece.

When spraying PP in typical modes, the alloying elements burn out and saturate the metal sprayed with oxygen from the atmosphere. The diversity and complex nature of the relationship of parameters that determine the possibility of obtaining high-quality coatings, make it appropriate to use the method of experiment planning [9,10]. Using the method of experiment planning, it is possible to investigate the influence of technological parameters of ADM on the properties of metallic coatings with PP and perform their optimization.

To perform the installation work requires a summary:

• compressed air;
• propane;
• voltage from the welding power supply.

In the study of coatings were used: solid wire brand 30X13 FeC-Cr doping system and flux cored wire of the base Fe-Cr-B doping system of different brands: 45X13P10CI Fe-Cr-B-C-Y doping system; 40X18P10C5I alloying system Fe-Cr-B-Si-Y; 40X18P5Ю5CI alloying system Fe-CrB-Al-Y with a diameter of 2.0 mm (table 2).

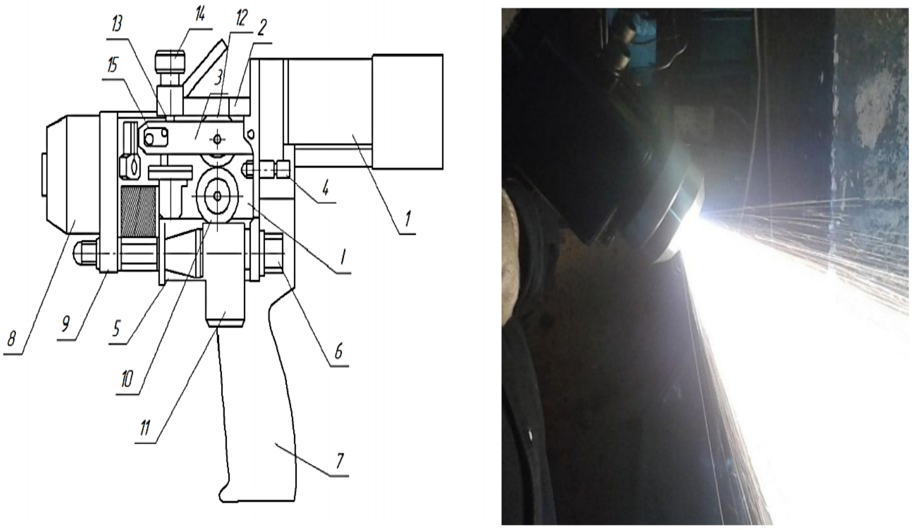


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Figure. 3. - General view of the metallizer: a - *metallizer device*; **b -** *installation in operation*; *worm reducer* **- I;** *electric motor* **- 1;** *bracket of the mechanism of pressing of rollers* **- 2;** *levers* **- 3;** *front and rear guides* **- 4;** *crankcase tray* **- 5;** *power lines* **- 6;** *handle* **- 7;** *spray head* **- 8;** *plate* **- 9;** *feed rollers* **- 10;** *crane* **- 11;** *clamping rollers* **- 12;** *springs* **- 13;** *nuts* **- 14;** *levers* **- 15 [10].**

Table 2.

Estimated chemical composition of the wires used.

Brand of wires	Mass fraction of elements, %						
	C	Cr	B	Al	Si	Y	Fe
СП 30Х13	0,16-0,25	12-14	-	-	До 0,6	-	Basic
ПД 45Х13Р5СІ	0,6	13	5	0,2	1	1	Basic
ПД 20Х11Р5С5І	0,2	11	5	0,2	4,5	1	Basic
ПД 20Х11Р5Ю3СІ	0,2	11	5	3	1	1	Basic

During the process of arc metallization using the ADM-10 installation, auxiliary equipment was used:

- cassettes with electrode wire;
- device for installing cassettes, which eliminates the possibility of touching the wires when unwinding to avoid short circuits:
- compressed air network;
- propane network (cylinder).

The coating was sprayed on the surface of plates made of steel 40 according to GOST 1050-88, the thickness of the coating is 2.5 mm. Surface preparation of samples for coating was carried out in accordance with GOST 9.304.

Before spraying the surface of the plates was degreased with acetone according to GOST 2768-84. The surface was blown with compressed air and jet-abrasive treatment. The air temperature during the preparation of the surface for spraying was carried out was not lower than plus 5 ° C in order to exclude moisture condensation on the samples.

The coating was applied no later than 2 hours after jet-abrasive treatment using the installation of activated arc metallization ADM-10.

The samples for research were cut on an EDM CHARMILLES CUT 20 EDM machine from plates with sprayed activated arc metallization coating.

Preparation of micro- and macro-sections of samples for research of structure, physical-mechanical and operational properties of samples of coverings was carried out with use of nitric acid (HNO3) - GOST 4461-77, ethyl technical alcohol (C2H5OH) - GOST 18300-87, distilled water (H2O). GOST 6709, paste GOI № 2 (TU 6-18-36) and diamond paste NOM 60/40 (GOST 25593).

Results of optimization of arc metallization modes

Tables 3 and 4 show the results of determining the modes of arc metallization by planning an experiment on the criterion of maximum adhesive strength of flux coated wire coatings 20H11R5Yu3SI, which determines their ability to resist peeling under operating conditions of the working bodies of tillage machines.

Table 3.

Estimation of statistical significance of coefficients *.

Factors	Beta	t (3)	$p - level$
I, A	0,55	8,78	0,005
U, B	0,07	1,38	0,287
T, мм	0,73	12,59	0,002
S, мм	-0,4	-5,05	0,018

** Beta - regression coefficient; p - level of significance; t - Student's criterion.*

The linear regression equation is adequate to the experimental data according to Fisher's test. All coefficients of the regression equation, except for the determining influence of the arc voltage, are statistically significant according to the Student's t-test for a given p-level of significance.

Table 4.

Assessment of the adequacy of the linear model *

Factor	SS	cc	MS	*F*	*p*
I, A	90,64	1	89,06	78,06	0,004
U, B	2,18	1	2,14	1,84	0,267
T, мм	184,16	1	184,16	159,45	0,001
S, мм	28,95	1	29,95	25,20	0,015
Error	3,46	3	1,16		
Total SS	308,33				

** SS - the sum of squares; cc - degree of freedom; MS - root mean square; F - Fisher's test; p - level of significance.*

The dependence of the adhesive strength of the coating on the parameters of DM can be estimated by the results of regression analysis:

$$y = 0{,}52x_1 + 0{,}74x_3 - 0{,}34x_4 \quad (2)$$

where x_1 is the arc current, A; x_3 - coating thickness, mm; x_4 - spray distance, mm

The obtained results were performed using surface graphs (Fig. 4 and 5).

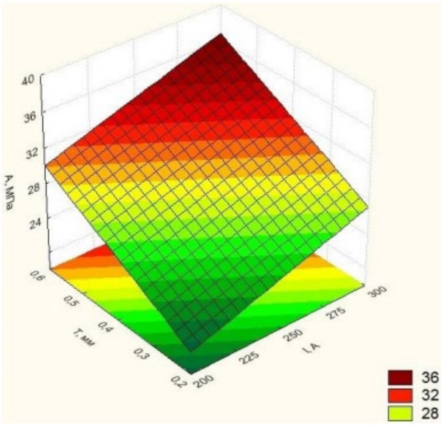


Figure 4. - Graph of the surface for the factors of arc current and coating thickness.

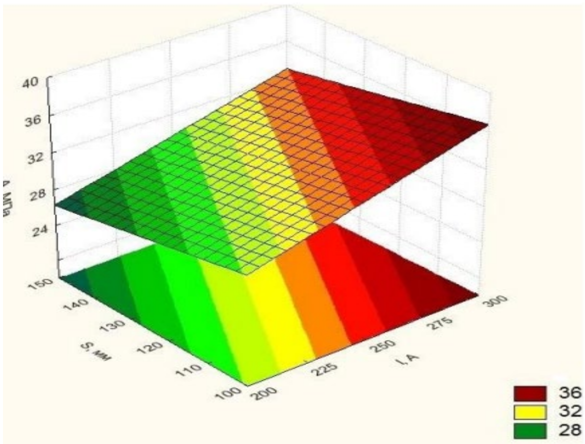


Figure 5. - Graph of the surface for the factors of arc current and spray distance.

Analysis of these data allows us to conclude that the adhesion of metallic coatings increases with increasing thickness, arc current, as well as reducing the spraying distance (in order to reduce the effect of factors), the effect of arc voltage is statistically significant.

In DM, an increase in the arc current leads to an increase in particle temperature, the development of interaction in the contact "particle-substrate" and increase the adhesive strength of the coating. Increasing the arc voltage, despite the increase in particle temperature, leads to a decrease in the utilization rate of the metal particles and its burnout by increasing the arc length [4], which probably causes little effect of this factor on the adhesion of the metal coating. The regularities obtained in this work coincide with the data of other authors [3, 4]. In DM, the specific energy expended on melting, overheating and evaporation of the metal, with increasing arc power increases, and therefore increases the temperature of the sprayed particles. Increasing the temperature of the sprayed particles in turn leads to increased adhesion strength, density and surface development of the resulting coatings.

When choosing the mode, you should strive for the minimum values of arc voltage without violating the stability of the process, and the power required to overheat the sprayed particles to set by changing the current [7].

To optimize the technological parameters of arc metallization by the criterion of maximum strength of sprayed coatings used the method of steep ascent, table 4 [7].

As a result, the optimal parameters of arc metallization of powder wire coatings 20Х11Р5Ю3СІ were determined: I = 320 ± 15 A; U = 34 ± 1.5 B; S = 0.7 ± 0.05 mm; L = 95 ± 5 mm, this metallization coating was the most durable, so it can be stated that it has the highest adhesive strength.

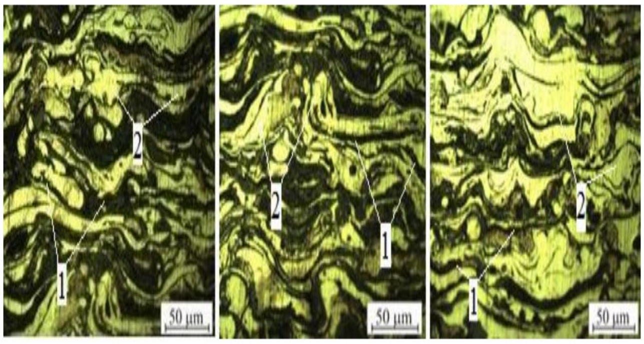
Table 5.

Optimization of arc metallization modes by steep ascent.

Characteristic	Factor		
	x_1, A	x_3, мм	x_4, мм
Zero level x_{i0}	300	0,8	100
Variation interval Δx_i	50	0,2	25
Coefficient b_i	0,54	0,75	-0,30
The product $b_i \Delta x_i$	27	0,15	7,5
Step h_a when changing the base factorx_i на 10	10	0,054	2,778
Rounding the variation step	10	0,05	2,8
State variable	Steep growth		
$\bar{y}$	310	0,65	97,2
36,97	310	0,65	97,2
42,76	320	0,7	94,4
31,18	330	0,75	91,6

The results of experimental studies

The obtained metallization coatings (Figure 7) have a lamellar-porous structure characteristic of gas-thermal spraying methods, where light areas are a metal base formed from droplets of molten metal, and dark ones are a layer of oxides formed by oxidation of droplets at the spraying distance. The coatings are characterized by a significant uneven alloy of individual sprayed particles with each other. Probably, the microheterogeneity of the coating structure is due to the presence of refractory boron-containing components in the PP.



a) b) c)

Figure. 6. - Structure on cross sections of coatings:
a - *flux-cored wire 45X13P5CI*; **b -** *flux-cored wire 20X11P5C5I*; **in -** *flux-cored wire 20X11P5IO3CI* **1 -** *oxide films*; **2 -** *metal*.

Coatings made of flux-cored wire 20X11P5IO3CI (Figure 6, c) have less microheterogeneity, their structure is thinner, less oxide films, and they are smaller, which is probably due to the lower degree of oxidation of the coatings.

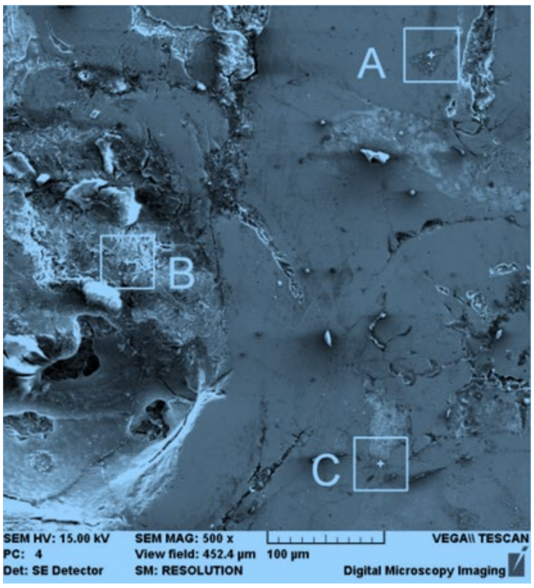


Figure 7. - Microstructure of the coating with flux-cored wire 20X11P5IO3CI: A, B, C - areas of the microstructure with different composition.

It was previously noted that oxide films promote the exfoliation of metal by the mechanism of internal friction, increasing the rate of mechanical wear of the coating. Favorable microstructure of the coating of flux-cored wire 20H11R5Yu3SI with a minimum amount of oxide films in the end may cause high performance of its physical and mechanical and operational properties.

According to the results of determining the porosity of the coating of flux-cored wire 45H13R5SI maximum pore size is 24.2 μm, minimum - 1.2 μm, while the number of pores up to 10 μm is estimated at 92.8%, the area of these pores is 69.7%, volume - 46.7% (table 6).

Table 6.

Distribution of coating time with flux-cored wire 45X13P5CI by size, area and volume.

D, мкм	0,-2	2-4	4-6	6-8	8-10	Σ
n,%	30,0	43,5	12,0	4,4	1,8	91,7
A,%	5,4	22,6	19,8	13,12	9,8	70,72
V,%	1,12	8,3	12,92	12,4	11,56	46,3

Table 7.

Distribution of coating time with flux-cored wire 20H11R5S5I by size, area and volume.

D, мкм	0,-2	2-4	4-6	6-8	8-10	Σ
n,%	30,2	42,5	12,8	5,5	2,3	93,3
A,%	5	20,8	17,9	14,8	11,8	70,3
V,%	1,01	8,5	11,75	13,8	14,1	49,16

The coating with PP 20X11P5Ю3CI differs in the greatest uniformity of distribution of microhardness on thickness that is explained by uniform distribution of strengthening phases in firm solution and smaller degree of oxidation that leads to decrease in thickness of an oxide layer. Boron components in the coating cause high hardness, which is one of the main factors affecting wear resistance. As a result of determining the wear resistance of the fixed abrasive it was found that the greatest weight loss are coatings with PP 45H13R5SI, and the smallest - coatings with PP 20H11R5Yu3SI, while the wear resistance of coatings with PP 20H11R5Yu3SI is 3.58 times higher than the wear resistance of coatings with SP 20X13 and times higher than 28MnB5 steel samples.

Table 8.

The number of pores up to 10 μm.

D, мкм	0,-2	2-4	4-6	6-8	8-10	Σ
n,%	31,8	43,9	13,5	5,7	2,8	97,7
A,%	5,3	21,7	18,9	15,9	12,7	74,5
V,%	1,15	8,8	12,7	14	13,9	50,55

For the coating of flux-cored wire 20H11R5S5I the maximum pore size is 27.7 μm, the minimum - 1.2 μm, while the number of pores up to 10 μm is estimated at 92.5%, the area of these pores is 69.4%, the volume - 47 .9% (table 7). For the coating of flux-cored wire 20X11P5Ю3CI the maximum pore size is 28.3 μm, the minimum - 0.5 μm, while the number of pores up to 10 μm is estimated at 96.2%, the area of these pores is 72.2%, the volume - 49 , 8% (table 8).

The number of large pores with sizes larger than 10 μm for coatings of flux-cored wire 45X13P5CI, 20X11P5C5I, 20X11P5Ю3CI is estimated at 2.2; 2.5 and 2.6%, which suggests their insignificant role in reducing the resistance of coatings to impact and abrasion. fine-porous structure of coatings indicates the stability of the process of spraying flux-cored wire. The lowest porosity is in the coating with flux-cored wire 20X11P5Ю3CI (2.8%), and the highest - in the coating with flux-cored wire 45X13P5CI (3.5%).

Conclusions

Thus, the introduction of gas-thermal spraying technology to strengthen the working bodies of tillage machines, allows to reveal the influence of the composition of sprayed materials and modes of their application on the process of spraying oxidation coatings, which determines their physicomechanical and operational properties, in particular work of working bodies of tillage machines.

During the study, it was found that the dependence of physical and mechanical and operational properties of metallic coatings of flux-cored wires from their alloying system. The microhardness of 20X11R5Yu3CI flux coated coatings is 1.35 times higher on average, the porosity is 1.45 times lower, and the wear resistance is 1.15 times higher than for 60X13P5CI flux coated coatings. Metallographic studies have shown that the structures of metallization coatings of flux-cored wires 60X13P5CI, 20X11P5C5I, 20X11P5Ю3CI differ.

Operational studies of loosening paws coated with flux-cored wire 20X11P5Ю3CI showed that the relative wear resistance of reinforced plowshares was 2.18-2.66 times, for double-sided bit - 1.97-2.45 times relative to the serial, due to high physical performance -mechanical and operational properties of metallic coatings. The technological process of arc metallization of wear-resistant coatings of flux-cored wire 20X11P5Ю3CI has been developed, which allows to increase the wear resistance of working surfaces by loosening cultivator legs and their resource by 1.8 times.

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Анотація. *Інтенсивне ущільнення ґрунту, що спричинене застосуванням сучасних потужних тракторів із великою вагою та наявністю у них більших робочих швидкостей, і як наслідок зменшується термін експлуатації ґрунтообробної техніки. Складні погодні умови викликають збільшення навантаження на робочі органи ґрунтообробних машин (леміші плуга, культиваторні лапи).*

У статті розглядається проблема відновлення ресурсу робочих органів ґрунтообробних машин за рахунок нанесенням зносостійких покрить. Проаналізовано види зношування та вплив абразивних матеріалів на робочі органи ґрунтообробних машин. Визначинні оптимальні матеріали та методи підвищення зносостійкості робочих органів ґрунтообробних машин. Розглянуто особливості формування металізаційного покриття, що відображається в його структурі та характер дефектів, які можуть відрізнятися за розмірами, щільності, морфології і орієнтації. Обґрунтованно залежність властивостей покриттів від системи легування матеріалу. Наведенно устаткування і матеріали для нанесення покриттів.

З врахуванням отриманої інформації, зробленні висновки та проведений аналіз технології нанесення зносостійких покрить для відновлення ресурсу робочих органів ґрунтообробних машин.

Ключові слова: *ґрунтообробна техніка, технічне обслуговування, обробіток ґрунту, металізація, наплавка, порошковий дріт, дугова металізація, напилення.*

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