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Development and Investigation of the Technology of Electro-Induction Surfacing of Parts of Working Bodies of Agricultural Machines

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Abstract

This article examines ways to improve the wear resistance of agricultural machinery components operating under intense abrasive wear conditions. The study focused on cultivator shanks made of 50, 50KhGA, and 65G structural steels. The aim of the study is to develop and scientifically validate a technology for electro-induction surfacing of wear-resistant coatings based on Fe–Cr–C and Fe–Cr–C–B alloys, ensuring the formation of an optimal deposited layer structure and improving the performance of the components. A hardening process is proposed, including electro-induction surfacing of a hard-alloy material followed by pulsed high-energy heating, as well as the design of a special inductor that allows for simultaneous surfacing of the shanks' nose and hardening of their wings. The effect of chemical-thermal treatment (boriding) on the formation of a hardened surface layer is also studied. Field tests were conducted under cultivating conditions using pilot and control samples. Working tool wear was assessed based on changes in geometric parameters, overlap area, and mass loss. It was found that the relative wear of surface-hardened wingtip shanks ranged from 8–27%, while for standard parts hardened using traditional methods, it reached 25–40%. This indicates a 30–60% reduction in wear intensity. It was shown that the performance of wingtip shanks during operation is determined primarily by maintaining their overall arrowhead shape. For a more objective wear assessment, it was proposed to use integrated indicators including changes in the overlap area of the working tools and average mass loss. The developed technological solutions can increase the relative wear resistance of the working tools by 2.0–2.5 times, reduce traction resistance during soil operation by 6–8%, and improve the efficiency of agricultural processes.

Keywords: electro-induction surfacing, wear-resistant coatings, abrasive wear, arrow paw, working parts of agricultural machinery, boriding, alloys of the Fe–Cr–C system, alloys of the Fe–Cr–C–B system, surface hardening, wear resistance.

Introduction

Every year, as a result of abrasive wear, which occurs during soil cultivation and crop production processing, a significant loss of metal occurs. Even in parts subjected to hardening, the total volume of such losses reaches hundreds of thousands of tons. In order to increase the service life of parts and components operating under conditions of intense abrasive action, various hardening methods are used, one of which is surfacing of wear surfaces. Electro-induction surfacing using powder materials based on high-alloy chromium white cast irons and pseudoalloys of the Fe–Cr–C and Fe–Cr–C–B systems is considered a promising but still insufficiently studied direction. The study of the features of this process is devoted to the work of V.N. Tkacheva, M.M. Tenenbaum, A.I. Sydorov and other scientists. In the process of forming a hard alloy layer on the surface of structural and low-alloy steels, chemical and structural inhomogeneity of the coating occurs. As a result, the wear resistance of individual zones of the formed layer may differ and vary between 0.55 and 1.0 relative to each other. One of the ways to improve the reliability and durability of the working bodies of agricultural machines is the development of methods for controlling the structure and properties of wear-resistant coatings obtained by the method of electro-induction surfacing from white high-alloy chromium cast iron and pseudoalloys. The key stage of the electro-induction surfacing process is the formation of a durable wear-resistant layer on the surface of the parts, capable of working effectively under conditions of intense abrasive and shock-abrasive impact. To solve this problem, resource-saving technologies of electro-induction hardening of working bodies of agricultural machinery are widely used. Currently, about 73% of all welding operations are performed by the method of electro-induction surfacing in tractor and agricultural machine building.

An analysis of the operating conditions of working parts of agricultural machines strengthened by electro-induction surfacing shows that their premature failure is often associated with the formation of an inhomogeneous structure of the surfacing layer. Such inhomogeneity occurs when applying wear-resistant coatings made of high-alloy chromium white cast iron and pseudoalloys to carbon and low-alloy steels.

The increase in production efficiency and the quality of manufactured products is directly related to the fuller use of the potential of materials and technologies for applying wear-resistant coatings to structural steel. In this regard, the study of the influence of physical, chemical and technological factors, as well as their complex impact on the formation of the structure, chemical and phase composition of alloys of the Fe–Cr–C and Fe–Cr–C–B systems during electro-induction surfacing, becomes especially relevant.

The implementation of this direction is possible due to alloying wear-resistant coated with carbide-forming elements, saturating them with boron, applying heating with an electromagnetic field of increased frequency, optimizing the composition of charge materials, as well as additional impact on the deposited layer with an electric arc of a carbon electrode. The use of the specified methods allows you to purposefully control the process of forming the primary structure of the deposited layer. The cumulative application of physical, chemical and technological effects opens up opportunities for obtaining new scientific and technical solutions aimed at significantly increasing the operational characteristics of hardened parts.

Literature review

Working bodies of agricultural machines in the process of operation are exposed to intensive abrasive wear, which occurs when metal surfaces interact with soil, sand and hard mineral inclusions. As a result, there is a gradual destruction of the surface layer of parts, a change in their geometric parameters and a decrease in the efficiency of the equipment. Abrasive wear is one of the main reasons for failure of such elements as ploughshares, cultivator paws, knives of tillage units and other parts of agricultural machines. Therefore, increasing their wear resistance and durability is an important task of modern agricultural engineering.

One of the most common ways to increase the service life of parts operating under conditions of intense abrasive action is the application of wear-resistant coatings. For this, various methods of surfacing are widely used, which allow to form a layer of material with increased hardness and wear resistance on the surface of the part. Coating technologies allow not only to improve the performance characteristics of new parts, but also to effectively restore worn-out machine elements, which has a significant economic value.

In recent years, researchers have paid considerable attention to surfacing materials based on the Fe–Cr–C system, which are widely used to obtain wear-resistant coatings. Such alloys are characterized by the formation of a structure containing solid carbide phases that provide high hardness and resistance to abrasive wear. However, a number of studies show that the traditional materials of this system do not always provide sufficient durability of the coating at high specific loads and cyclic impacts. This is due to the formation of a coarse-grained structure and non-uniform distribution of carbide phases, which can accelerate the wear process.

To improve the operational properties of the coating, researchers suggest alloying surfacing alloys with various elements, such as boron, titanium, molybdenum, and others. The introduction of boron contributes to the formation of solid boride phases in the structure of the coating, which significantly increase the hardness and wear resistance of the material. Studies show that with an increase in the boron content in iron-containing alloys, the share of borides increases, which leads to an improvement in microhardness and an increase in resistance to abrasive wear.

Considerable attention is paid to the issues of increasing the wear resistance of the working bodies of agricultural machines in modern studies of Ukrainian scientists. For example, in the works of T. Skoblo, O. Nanka, O. Saichuk, I. Rybalko, A. Tikhonov, and A. Zakharov, the effect of modifying additives on the structure and properties of welded layers used in the restoration of plowshares and cultivator paws was studied. The obtained results show that the introduction of carbide and oxide modifiers makes it possible to improve the mechanical and tribological characteristics of welded coatings.

Foreign researchers also made a significant contribution to the development of surface hardening technologies and wear-resistant coatings. Thus, in the works of V. Malikov, A. Ishkov, D. Shmykov, P. Androsov and others, methods of increasing the wear resistance of parts using electro-induction surfacing were studied. The authors have shown that the use of electro-induction heating makes it possible to form durable wear-resistant coatings and significantly increase the service life of machine parts.

A number of foreign studies are devoted to the study of the structure and properties of iron-based composite coatings obtained by the method of electro-induction surfacing. Experimental results show that such coatings have high hardness and resistance to wear due to the formation of carbide and boride phases in the structure of the coating.

In the field of development of modern functional coatings and technologies of surface engineering, the research of the German scientist Robert Vaßen is also well-known, whose work is devoted to the creation of high-temperature and wear-resistant coatings for various branches of mechanical engineering. His research contributed to the development of technologies for obtaining functional coatings with increased operational properties.

An important role in the formation of the structure and properties of wear-resistant coatings is also played by the technology of their application. Currently, various methods of obtaining such coatings are used, including arc surfacing, plasma spraying, laser surfacing and electro-induction surfacing. Among them, electro-induction surfacing is of considerable interest due to the possibility of local heating, high productivity of the process and relatively low energy consumption. In addition, this method makes it possible to obtain coatings with good adhesion to the base and a minimal zone of thermal influence.

Electro-induction surfacing is especially promising when using powder materials and high-alloy alloys. In the process of heating with a high-frequency electromagnetic field, the surfacing material is melted and a protective layer with specified properties is formed on the surface of the part. The structure of such a layer depends on the composition of the charge materials, heating modes and cooling rate. A number of studies have shown that the formation of a finely dispersed structure with a uniform distribution of carbides and borides contributes to a significant increase in the wear resistance of the coating.

Of special interest are wear-resistant coatings based on highly alloyed chromium white cast irons and pseudoalloys of the Fe–Cr–C and Fe–Cr–C–B systems. Such materials are characterized by high hardness due to the presence of chromium carbides and boride phases, which effectively prevent the development of abrasive wear. With an optimal ratio of components, it is possible to form a structure that provides a combination of high hardness and sufficient viscosity, which is especially important for parts that work under shock-abrasive conditions.

Despite a significant amount of research in the field of wear-resistant coatings, a number of issues related to the formation of the structure of the deposited layer and the management of its properties remain insufficiently studied. In particular, the tasks of optimizing the composition of surfacing materials, improving electro-induction heating modes, and developing combined surface treatment technologies are relevant.

Thus, the analysis of literary sources shows that the application of electro-induction surfacing using high-alloyed alloys and powder materials is a promising direction for increasing the durability of working bodies of agricultural machines. Further research should be directed to the study of the regularities of structure formation and phase composition of welded coatings, as well as to the development of technological solutions that provide an increase in their wear resistance and operational reliability.

Purpose

The purpose of the research is the development and scientific substantiation of the technology of electro-induction surfacing of wear-resistant coatings on parts of the working bodies of agricultural machines based on alloys of the Fe–Cr–C and Fe–Cr–C–B systems, which ensures the formation of the optimal structure of the deposited layer and increases the operational characteristics of parts operating under conditions of abrasive wear.

Research methodology

The subject of the study was the working parts of tillage machines – cultivator shanks made of 50, 50KhGA, and 65G structural steels. These materials were chosen due to their widespread use in the manufacture of working parts of agricultural machinery operating under conditions of intense abrasive wear.

The research aimed to increase the wear resistance of shanks by developing electro-induction surfacing and chemical-thermal hardening (boring) processes.

To strengthen the blade portion of shanks, a process was developed that included:

– applying a hard-alloy charge to the blade surface;
– electro-induction heating of the surfacing zone;
– forming a hardened layer;
– simultaneous hardening of the shanks' wings.

To implement this process, a special inductor was developed that simultaneously deposits the nose of the lance and hardens the working surface wings.

The inductor design includes:

– deposition coil;
– quenching coil;
– current conductor;
– connecting plate for connection to the generator;
– profiled tube for melting the charge.

Pulsed high-energy heating ensured localized melting of the carbide material and the formation of a hardened layer on the cutting edge.

Some of the experimental samples were additionally borided. Boriding was performed using special paste-like coatings of various compositions (coating codes I–VI). After coating application, the samples were heat-treated to form a boride layer of increased hardness.

The resulting hardened samples were used for further performance testing.

Field testing of the wingtip shares was conducted on a cultivator during soil cultivation. Experimental samples were installed in the first and second rows of working elements.

Control samples included production wingtip shares that had undergone bulk hardening, high-frequency hardening, and spark hardening.

The tests were conducted under identical agricultural conditions, with controlled tillage depth and operating modes.

Wear of the working parts was determined by changes in the geometric parameters of the wingtip sweep, which were measured before and after testing.

The following parameters were monitored:

l_B – wear along the nose width;

l_b – wear along the wing width;

l_l – wear along the blade length;

l_S – change in overlap area;

l_m – change in working part weight.

Relative wear was determined using the formula:

$$I = ((X_0 - X) / X_0) \times 100\%$$

where:

X_0 – initial parameter value;

X – parameter value after testing.

For a comprehensive characterization of wingtip sweep wear, it is proposed to use the following integrated indicators:

– change in working part overlap area (Js);

– change in average sweep weight.

This approach allows for a more objective assessment of the performance of wingtip sweeps, since maintaining their arrow-shaped shape is the main factor in meeting agricultural requirements.

The test results were processed using a comparative analysis of the experimental and control samples. Relative wear was determined for each hardening variant and compared with the control samples.

Research results

Modern constructions of the working bodies of agricultural machines and the applied methods of strengthening them must ensure a minimum level of wear and a reduction in traction resistance with mandatory observance of agrotechnical requirements. Fig. 1 shows the scheme of applying a hardening coating, which helps to reduce the intensity of wear.

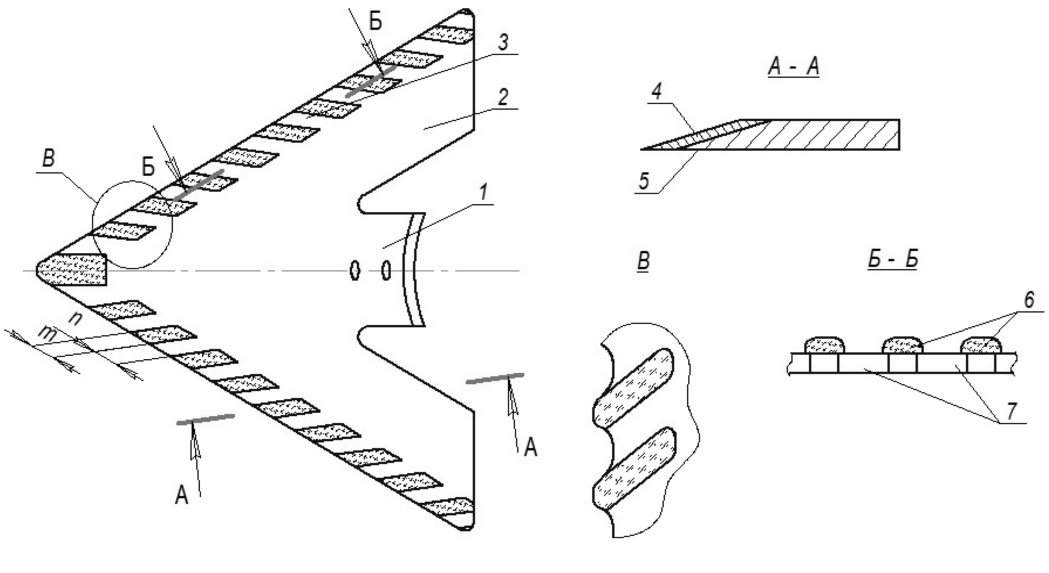

Fig. 1. Scheme of application of a hard alloy with subsequent high-energy heating (pulse heating): 1, 2 – shank and wing of the arrow paw; 3 – hardened layer on the cutting surface; 4 – cross section of the hardened layer; 5 – base metal

In this regard, the working body of the agricultural machine was developed, the design of which allows, with the gradual dulling and change of the geometry of the blade, arising as a result of abrasive wear during operation, to prevent a situation in which soil particles stop in front of the cutting edge and are pressed into the soil layer.

In addition, a technological process was proposed, which allows simultaneous surfacing of a hard alloy and hardening of individual parts of the working bodies of agricultural machines in a special inductor (Fig. 2).

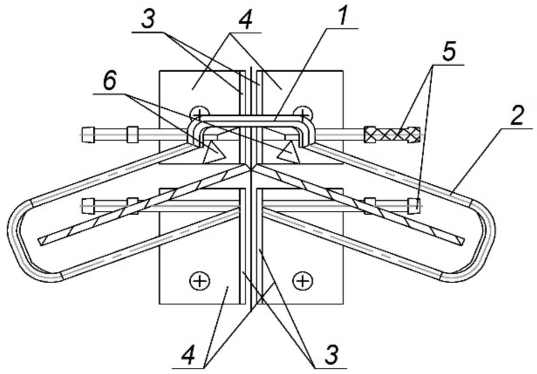

Fig. 2. Inductor for simultaneous surfacing of the nose part of the arrow paw and hardening of its wings: 1, 2 – naplavochny and zakalochny turns; 3 – current conduit; 4 – plate for connection to the generator; 5 – fitting; 6 – profiled tube for melting the charge material

The developed and manufactured inductor provides the necessary modes of hardening of both welded and stamped arrow legs when performing electro-induction surfacing of the nose part with simultaneous hardening of the wings. The working bodies, made of steel 50, 50KhGA and 65G, were subjected to the process of boronization, after which tests of the formed hardened layer were carried out in real field conditions of operation.

Table 1

Relative wear of surface-hardened arrow feet

Plastering code	Wear by parameter l_x, %					Installation diagram for a field (row-crop) cultivator
	B	b	l	S	m	
1-2-WP, O	12.1	17.2	20.7	33.8	28.6	first row
II-1-AP, O	12.7	27.9	21.5	33.4	34.5	second row
III-1-WP, O	12.3	16.8	20.9	34.9	28.6	first row
III-2-AP, O	19.1	22.4	29.6	41.2	33.3	second row
V-2-WP, C	9.9	8.8	13.7	23.5	19.1	first row
V-2-WP, C	9.3	16.3	13.2	25.2	25.0	second row
IV-1-WP, O	27.4	33.8	30.0	49.4	44.1	first row
IV-2-AP, O	28.2	52.3	33.3	51.8	55.9	second row
I-1-WP, O	8.4	11.1	13.6	23.5	20.2	first row
I-1-WP, C	13.4	13.1	18.9	31.1	22.6	second row
VI-2-AP, C	25.9	36.4	31.3	50.5	35.7	first row
Control	19.9	43.6	32.5	50.4	40.5	second row

The analysis of the data presented in Table 1 shows that the influence of the investigated technological factors on the intensity of wear of the hardened working body in real operating conditions is ambiguous. Regardless of the method of applying the coating to the surface of the arrow paws, in all samples with surface hardening, wear is recorded in the range of 8–27% according to individual dimensional parameters. At the same time, control arrow legs tested under similar conditions (both volume hardening and three-stage hardening) show significantly greater wear, which is 25–40%. The appearance of industrially manufactured arrow paws after operation is shown in Fig. 3. The obtained experimental results show that there is a definite relationship between the amount of wear and the parameters of the deposited layer of surface-hardened working bodies. At the same time, despite a significant change in some geometrical parameters (l_B, l_b, l_l), the arrow legs remained operational throughout the entire period of testing. This allows us to conclude that the performance of a worn arrow paw is largely determined not by a change in individual geometric dimensions, but by the ability of the working body to maintain a general arrow-shaped shape.

a b c

Fig. 3. Photos of worn arrow paws: a – initial paw; b – paw strengthened according to scheme IV-1-WP after testing; c – serial pawl subjected to volume hardening, surface high frequency currents hardening and electrospark hardening (HRCe ≈ 50) after testing

In this regard, it is proposed to estimate the wear of surface-reinforced arrow feet using integral indicators, such as the change in the overlapping area (J_S) and the average mass loss.

Conclusions

A technological process for hardening the shovel blades of tillage machines has been developed. This process involves electro-induction surfacing of a carbide material followed by pulsed high-energy heating, ensuring the formation of a localized wear-resistant layer on the most heavily loaded areas of the working element.

A special inductor design has been proposed that allows for the combined hardening of the shovel nose and the hardening of its wings, ensuring differentiated hardening of the working surfaces and increasing the technological efficiency of the hardening process.

Experimental studies have shown that the use of the developed coating compositions during boriding of working elements made of grades 50, 50KhGA, and 65G steels promotes the formation of a hardened surface layer with increased resistance to abrasive wear under operating conditions.

Field tests showed that the relative wear of surface-hardened wingtip tines, based on controlled geometric parameters, ranges from 8% to 27%, while the wear of standard wingtip tines hardened using traditional methods (bulk hardening, high-frequency hardening, and spark hardening) reaches 25% to 40%, indicating a 30% to 60% reduction in wear intensity.

It was established that the continued performance of wingtip tines during operation is determined primarily by the maintenance of the overall wingtip shape of the working element, rather than by individual geometric wear parameters. This is crucial for ensuring consistent tillage performance.

It is proposed to use integrated wear indicators, including changes in the overlap area of the working elements and average mass loss, which allow for a more objective assessment of the service life of surface-hardened working elements.

The research resulted in the proposal of new design solutions and technologies for hardening working parts, based on the use of electro-induction surfacing of high-chromium white cast irons and pseudoalloys on 65G and 50KhGA steel for components such as feed mill hammers, as well as welded and solid-stamped wing tines. Implementation of the developed technologies increases the relative wear resistance of the components by 2.0–2.5 times compared to traditional hardening methods, reduces traction resistance during movement in the working environment by 6–8%, and improves the efficiency of agricultural processes.

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Марченко Д.Д., Матвєєва К.С. Розробка та дослідження технології електроіндукційного наплавлення деталей робочих органів сільськогосподарських машин

У статті розглянуто питання щодо підвищення зносостійкості робочих органів сільськогосподарських машин, що експлуатуються в умовах інтенсивного абразивного зношування. Об'єктом дослідження були стрілчасті лапи культиваторів, виготовлені з конструкційних сталей 50, 50ХГА та 65Г. Метою роботи є розробка та наукове обґрунтування технології електроіндукційного наплавлення зносостійких покриттів на основі сплавів систем Fe–Cr–C та Fe–Cr–C–B, що забезпечує формування оптимальної структури наплавленого шару та підвищення експлуатаційних характеристик робочих органів. Запропоновано технологічний процес зміцнення, що включає електроіндукційне наплавлення твердосплавного матеріалу з наступним імпульсним високоенергетичним нагріванням, а також конструкція спеціального індуктора, що дозволяє одночасно виконувати наплавлення носової частини стрілчастої лапи та загартування її крил. Додатково досліджено вплив хіміко-термічної обробки (борування) на формування зміцненого поверхневого шару. Польові випробування проводилися в умовах обробки ґрунту на культиваторі з використанням дослідних та контрольних зразків. Знос робочих органів оцінювався щодо зміни геометричних параметрів, площі перекриття та втрати маси. Встановлено, що відносне зношування поверхнево-зміцнених стрілчастих лап становить 8–27%, тоді як у серійних деталей, зміцнених традиційними методами, він досягає 25–40%. Це свідчить про зниження інтенсивності зношування на 30–60%. Показано, що працездатність стрілчастих лап у процесі експлуатації визначається переважно збереженням їхньої загальної стрілоподібної форми. Для більш об'єктивної оцінки зношування запропоновано використовувати інтегральні показники, що включають зміну площі перекриття робочих органів та середню втрату маси. Розроблені технологічні рішення дозволяють підвищити відносну зносостійкість робочих органів у 2,0–2,5 рази, знизити тяговий опір при їх роботі у ґрунті на 6–8 % та підвищити ефективність агротехнічних процесів.

Ключові слова: електроіндукційна наплавка, зносостійкі покриття, абразивний знос, стрілчаста лапа, робочі органи сільськогосподарських машин, борування, сплави системи Fe–Cr–C, сплави системи Fe–Cr–C–B, зміцнення поверхні, зносостійкість.