Application of protective coatings on steel working bodies of soil-tilling implements

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Wear of working bodies of soil-tilling implements is one of the key problems having the effect on efficiency of soil treatment and quality of agricultural products. Gradually these working bodies are subjecting to essential mechanical, physical, abrasive and corrosion loads, what leads to deterioration of their operating parameters and decrease of service life, lowering of treatment depth and increase of draught resistance of an assembly. The fundamental analysis of applicability of protective coatings becomes necessary for optimization of assemblies operation and rise of economical efficiency in agricultural production. The results of this research can be applied in production of cutting blocks, with decrease of operating expenses and rise of economical efficiency in agricultural area. The research presents preparation to examination of operating efficiency of protective coatings, which were applied on working bodies of soil-tilling implements via three advanced methods of gas-thermal spraying. The aim of this research was comparative analysis of wear resistance and resource of the components after application of hard alloy coating, which was obtained via high-speed gas-thermal spraying, and the layer, which was formed via cold gas-dynamic spraying. The second experimental part of this work includes description of applied presented protective coatings, with comparative analysis of their efficiency. It is planned to provide analysis of wear resistance after mounting the working bodies in the assembly and their resting in real conditions. The novelty of this research is formulated as use and testing of new protective coatings and their combining, in order to increase operating resource of assemblies. These coatings were applied previously in production of metal-working equipment, but they were not used in manufacture of steel working bodies of soil-tilling implements.
Key words: high-speed gas-thermal spraying, cold gas-dynamic spraying, working body, abrasive wear, corrosion wear, extra hard protective coating.
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Introduction

Russian market of agricultural machine-building can be characterized as a high-competitive one, with essential degree of cooperation between manufacturers of agricultural machines , scientific and research companies and infrastructure supporting enterprises. This market in Russian Federation made 100.6 bln rubles in 2024.

Products of foreign manufacturers occupy significant part of this market (44 %). Visible trade of balance was negative in 2018 and was equal to 3 mln units of agricultural machines. China was the leader of import supplies at that time (more than 38 %), while Big Dutchman International GmbH was recognized as the leading supplier of agricultural machines (3.7 %).

Use of protective wear-resistant coatings for working blocks of agricultural machines is the key factor for increase of reliability and service life of the equipment. Due to up-to-date technologies (such as thermal spraying, laser welding deposition, PVD/CVD processes, chemical and thermal treatment etc.), manufacturing and maintenance enterprises can increase effectively resource of components, decrease expenses for their repair and technical maintenance, as well as reduce downtimes during the season of intensive use of agricultural machines.

PVD (Physical Vapour Deposition): most widely distributed magnetronic sputtering and arc evaporation for coatings of titanium nitride (TiN), titanium carbonitride (TiCN), chromium nitride (CrN), titanium-aluminium nitride systems (TiAlN) etc. They are characterized by high hardness (up to 2,000–3,000 HV), low friction coefficient and good adhesion with correct surface preparation. Thickness of this coating is usually restricted within the range 1–10 μm.

CVD (Chemical Vapour Deposition) takes place at increased temperature; the coating grows from a gas phase of the component surface. It allows depositing carbides, nitrides, borides of different metals and is mainly used in tool production, but also can be applied in the components operating in extremal wear conditions [1].

The main causes of wear of steel working bodies in agricultural machines are the following.

1) Abrasive wear. Permanent contact of working bodies of deep tillers with hard mineral soil inclusions and bio-silica-containing root parts of plants (agricultural crops and weed plants) leads forming of scratches and pitting of metal sections on the surfaces of working bodies.

2) Corrosion wear. When soil processing in the conditions of increased soil humidity, due to permanent contact between materials of disks and working bodies of a deep tiller (from one side) and salt fluid and root exudates of plants (from other side), metal is subjected to complex corrosion, which accelerates the total wearing process of working bodies.

3) Fatigue destruction, which caused by multiple cyclic loads, causes forming of microcracks in the surface metal layer of working disks. Integration of several functional layers, development of coatings with "clever" properties (self-restoration, wear indicator), as well as putting into practice additive methods for creating components with preset internal architecture and improved surface layers are considered as the most promising development directions [1–5].

Theoretical part

Deposition

The method includes application of a powder composition on the component surface by plasma jet, then the coating is subjected to additional melting (e.g. using high-energy heat source, such as electron beam, laser unit of plasma arc). It provides dense adhesion and minimal number of pores and microcracks in the structure. Chemical-thermal treatment [6], carbonitriding (joint diffusion of nitrogen and carbon in the surface steel layer) provide more hard surface layer, improving its wear resistance and fatigue properties. Boriding (surface saturation by boron) leads to forming of very hard layer (up to 2,000 HV), which ensure well resistance against abrasive wear. Gas or ion nitriding allows obtaining the layer of Fe nitrides or nitrides of alloys. This method promotes increase of microhardness and fatigue strength.

If we consider PVD- and CVD-processes (physical and chemical deposition from a vapour phase), we can confirm that PVD is most widely used as magnetronic sputtering and arc evaporation and CVD takes place at increased temperature [7–9].

Electric arc deposition by an electrode of "Sormait" type is a classic method for renovation and hardening or working bodies of soil-tilling implements, which is widely used in agricultural machine-building and is based on application of the layer of special wear-resistant alloy on worn or new component surface via manual arc welding [10]. The alloy "Sarmait" itself, which was named after Sormovo plant (where it was developed for the first time), is a cast hard Fe-based material with high content of carbon and chromium, as well as mandatory presence of nickel, manganese and silicon in its composition. Totally it provides high hardness and abrasive wear resistance to a deposited layer in the conditions of friction with soil and sand. Depending on relationship between alloying elements, two main modifications of such electrodes are industrially produced: TsS-1 (made of "Sormait No. 1" alloy, providing hardness after heat treatment within the range 48–54 HRC) and TsS-2 (based on more tough and strong "Sormait No. 2" alloy, which can provide hardness up to 62 HRC after quenching and tempering). Thus, TsS-2 electrodes are more preferable for components operating in the conditions of not only abrasive wear, but also moderate impact loads [2].

Technological process of welding deposition by "Sormait" electrodes is characterized by a row of features, stipulated by sensitivity of high-alloy chromium cast iron to crack forming and brittle destruction in the welding zone with basic steel. So, this operation is carried out mainly by a short arc with direct current 180–240 A of reversed polarity, depending on a rod diameter, while welding deposition itself is usually conducted with two layers maximally (to avoid pitting of coating under the effect of operating stresses). In order to release residual stresses and to prevent delamination of a hardened layer of a component before welding deposition, it is recommended to subject the components to preliminary heating up to the temperature ~ 500 °C, and sometimes also to consequent slow cooling or heat treatment. This appearance takes place despite such requirement can be hardly executed in field conditions of repair shops, what arises a well-known problem of forming microcracks and graphitization in a transition zone, decreasing adhesion strength between deposited and base metals. Metallographic studies of the samples, hardened by "Sormait" [11], reveal a typical microstructure of white cast iron; however, the transition diffusion zone here is either expressed very weakly, or is absent at all, unlike more updated methods of powder metallurgy. It creates distinct separation boundary of mechanical properties and is a cause of potential coating pitting when meeting hard stone inclusions in soil.

Despite appearance of more advanced technological and wear-resistant alternatives, such as SHS materials or plasma coatings, electric arc welding deposition by "Sormait" still keeps its positions as a basic method for hardening of arrow-type arms of a rippers and plough shares owing to its economical acceptability and possibility of operations using standard welding equipment directly in the field conditions or technical workshop. Comparative tests display that use of "Sormait" in combination with induction quenching or in composite charges with Fe borides allows increasing service life of working bodies by 1.2–1.5 times in comparison with non-hardened steel, though "Sormait" wear resistance is smaller than expensive hard alloys of VK type of tungsten carbide by 2.5–3.5 times. It is acceptable compromise between restoration cost and service life of a component for many customers.

High-speed gas-flame spraying

High-speed gas-flame spraying, that is well-known in technical literature as HVOF, is one or the most effective thermal methods for applying wear-resistant coatings; it is based on the principle of high-speed acceleration and heating of a powder material in a jet of burning products of hydrocarbon fuel in oxygen or compressed air [12–14]. The key feature of this process concludes in construction of a special nozzle and combustion chamber, where supersonic gas flow with the temperature sufficient for partial or complete melting of sprayed particles is created due to continuous burning of fuel mixture (**Fig. 1**). In this case, motion speed of these particles can exceed 700 m/s. Unlike conventional gas flame spraying, where speed of the particles is low and coating structure is characterized by essential porosity and low

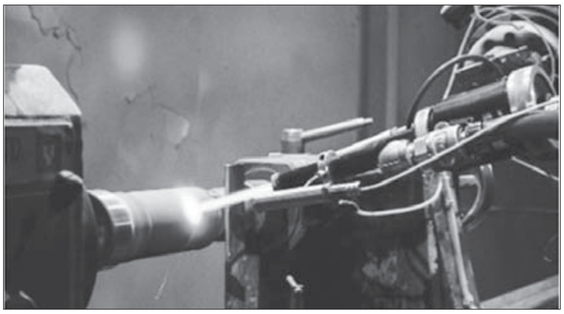

Fig. 1. Gas-flame spraying

cohesion strength, the HVOF technology provides forming only of dense layers with minimal content of oxide inclusions, owing to short time of material processing in a heating zone. When a particle of hard alloy on the base of tungsten of chromium carbide, which is heated to plastic state, meets a substrate with enormous kinetic energy, immediate deformation and mechanical bonding with surface occurs. This process accompanies by forming of laminated structure with residual compression stresses, what has a positive effect on fatigue strength of a component. Meaning hardening of working bodies of soil-tilling implements, just high-speed gas-flame spraying allows obtaining of coatings, which can be compared with solid hard alloy plates, but having better crack resistance and ability to withstand impact contacts with stones and dense soil monoliths [13–15]. This technology makes possible to apply layers with thickness from several tens to several hundred micrometers, while high adhesion parameters exclude coating delamination during abrasive wear in contact with soil. HVOF use is considered as a “golden standard” in the cases when combination of high microhardness, corrosion resistance and maximal wear resistance at reversal loads is required; however, this process needs serious expenses for equipment and strict observation of technological procedures of powder feed and component cooling.

Cold gas-dynamic spraying

Cold gas-dynamic spraying is the advanced technological process of forming of metallic and composite coatings, which are principally different from conventional high-temperature methods; this difference concludes in material application on a substrate in solid state, without melting of particles. Physical nature of this method is presented by speed-up of powder microscopic particles in a supersonic flow of compressed and preliminarily heated gas to the speed, which exceeds essentially the critical adhesion threshold for the examined pair of materials (**Fig. 2**). When striking with a substrate surface, kinetic energy of a particle transforms in heat energy in the contact area as a result of adiabatic compression and intensive plastic deformation; it causes local temperature rise and metal solidification at atomic level, missing the liquid phase stage [16].

Absence of phase transfers and high-temperature oxidation is a key advantage of this technology, because it allows to save the initial chemical composition and microstructure of sprayed powder, excluding burning of alloying elements, grain growth and forming of undesirable intermetallics, which are typical for plasma and gas-flame analogues. In addition, minimal thermal effect on substrate prevents buckling of thin-walled components and origination of residual extension stresses in the melting zone [17], what is extremely important for hardening of precise working bodies of soil-tilling implements. Forming of a coating occurs only in the case when speed of particles exceeds the critical value; if this value is not achieved, either elastic reflection, or erosion surface destruction takes place.

This technology allows applying aluminium, copper, zinc, nickel layers as well as hard alloy compositions with metal binder, this providing high adhesion at the level of tens MPa and porosity less that 1 %. Strict requirements to powder purity and dispersity, as well as necessity of using expensive equipment with the systems for heating and forming of supersonic nozzle are considered as the main factors restricting use of cold gas-dynamic spraying [18]. However, in the context of restoration and hardening of soil-tilling implements, it is compensated by significant increase of service life of components with saving their initial geometrica accuracy.

Practical realization

This part of the research presents the data on practical realization of the formulated task – application of hard alloy coatings, which prevent increased wear of working bodies of soil-tilling implements. The following plan was accepted for this aim.

At first, it was necessary to find and use the components made of the most simple and acceptable steel grade for testing, in order to form their low final cost and profitable appli-

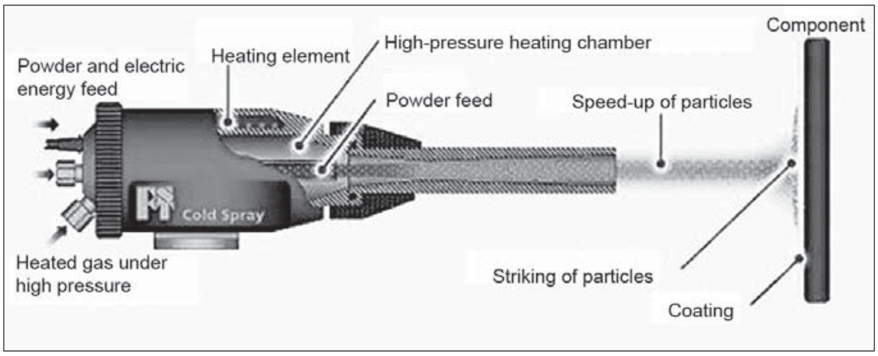

Fig. 2. The scheme of gas-dynamic spraying

cation in agriculture. Then, it was required to prepare them for applying two kinds of coatings.

The first of them is a hard alloy coating on a cutting (working) edge. This procedure is practically implemented via electric arc welding deposition by "Sormait" electrode. The achieved surface hardness will be about 50 units. The examined composition of metals concludes nickel, nichrome of Kh20N80 grade and titanium alloy Ti-6Al-4V.

Electric arc welding deposition by "Sormait" electrode (most often by C-1, type E-300Kh28N4S4, see the **Table**) is realized for rise of wear resistance of the components. This electrode is often used of welding deposition on the components of agricultural machines, which operate in the conditions of abrasive wear. This is a high-carbon, high-chromium alloy, and its deposition requires observation of special procedures for cracking prevention due to high hardness (49–56.5 HRCe).

The main technological conditions and recommendations are presented below.

1. Preparation before welding deposition: calcination of "Sormait" electrodes before use at the temperature 190–210 °C during 1 hour; preparing of a component via its cleaning with removal of dirtiness, corrosion and oils; preliminary heating of massive components to the temperature 300–400 °C (if required).

2. Welding deposition conditions: this process is usually realized via arc method, using direct current with straight polarity (electrode is fixed on "minus") or alternative current.

Diameter of electrode bars is usually 3–7 mm. Welding current is 160–200 A for the electrodes with diameter 4–5 mm (for arc welding deposition). Deposition coefficient is high, about 13.0 g/A·h. Consumption of electrodes makes approximately 1.4 kg per 1 kg of deposited metal.

3. Deposition technique is based on maximally short arc to minimize alloy oxidation. This arc should be preferably in bottom position. Deposition by separate rollers is used most often. To obtain smooth surface and form the required geometrical shape, graphite or copper forms are used (especially for deposition of TsI-1M).

The cooling process should be slow (in sand, or in furnace, or under heat insulation), in order to avoid cracking in a deposited layer.

Chemical composition of "Sormait" alloy (on the example of C-1 grade)

Chromium	25–31 %
Carbon	2.5–3.5 %
Silicon	2.8–4.2 %
Nickel	3–5 %
Manganese	up to 1.5 %
Sulfur	up to 0.08 %
Phosphorus	up to 0.08 %

The second coating was aluminium oxide Al_2O_3, which was applied on other component sides, in order to prevent wearing during operation and contact with soil. It was suggested during the research to replace galvanized coating by high-speed gas-flame spraying or cold gas-dynamic spraying.

Preparation

New stands of a deep tiller were used, the stands themselves and chisel were made of 09G2S steel with thickness 16 mm. This steel is considered as one of the most widely used and relatively cheap in Russia. The depth of soil processing reached 300 mm. The stand in disassembled state is presented in the **Fig. 3** (3 pieces).

The chisel is manufactured vial metal plasma cutting, thereby its working edge is uneven (**Fig. 4**). To provide coating via electric spark method, it is expedient to equalize its surface using a turning machine and one of the milling methods, when a workpiece is placed in a cutter holder and a cutter fixed in a chuck will be used as a milling cutter (**Fig. 5**). It is important, that workpiece fixing was implemented using a modular workholder, what creates large out-in from a cutter holder, providing thus low processing rigidity. However,

Fig. 3. The samples for coating application

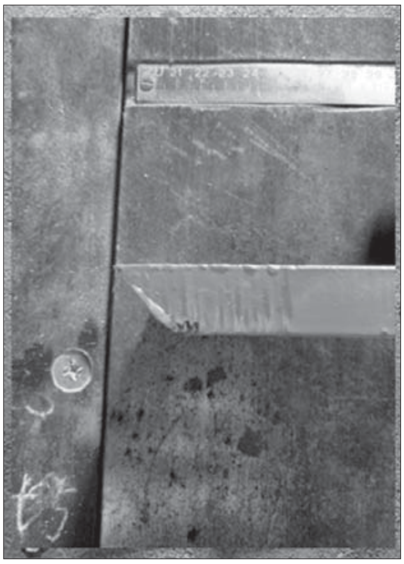

Fig. 4. The chisel with uneven working edge

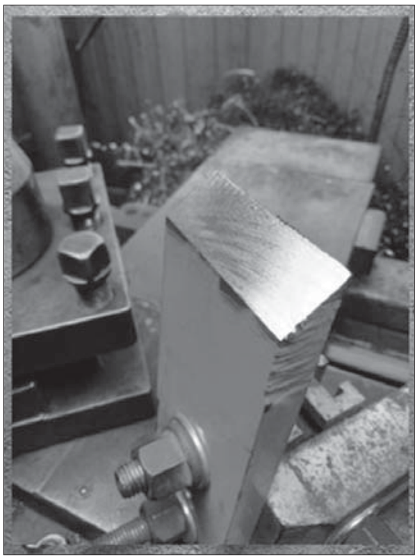

Fig. 5. Chisel processing

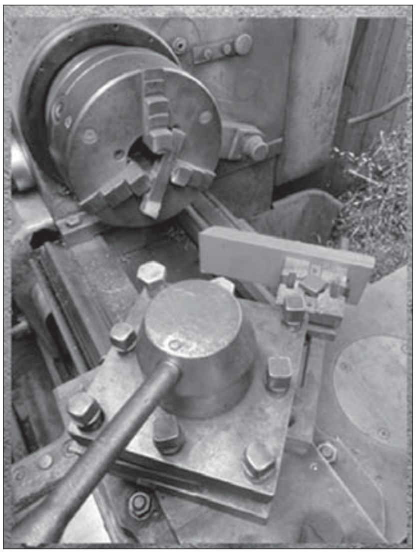

Fig. 6. The processed surface

Fig. 7. The cleaned chisel before coating application

a workpiece displayed good processability in this case, thus ensuring low steel hardness (**Fig. 6**). Then a component was cleaned from dye before aluminium oxide Al_2O_3 coating application (**Fig. 7**); the sample microstructure is also presented (**Fig. 8**).

Expanded laboratorial and experimental researches for testing of the suggested coatings in the real operating conditions of used agricultural equipment are planned in the future during the further works within the framework of the project No. N-25.1/36. The consequent obtained results will be published in the forthcoming articles as continuation of this paper.

Conclusion

Use of protective wear-resistant coatings for working blocks of agricultural machines is the key factor for increase of reliability and service life of the equipment. Due to up-to-date technologies (such as thermal spraying, laser welding deposition, PVD/CVD processes, chemical and thermal treatment etc.), manufacturing and maintenance enterprises can increase effectively resource of components up to 15 %, decrease expenses for their repair and technical maintenance, reduce frequency of replacement of steel working bodies to 1,500–2,000 hectares as well as cut downtimes during the season of intensive use of agricultural machines. Marketing analysis for soil-tilling implements in Russian Federation is conducted. The tested samples were examined and the required protective coatings to be applied are determined. The studied methods of applying protective coatings on steel working bodies of soil-tilling implements were presented and described in this work; preparation of the samples for experimental coating application is also carried out.

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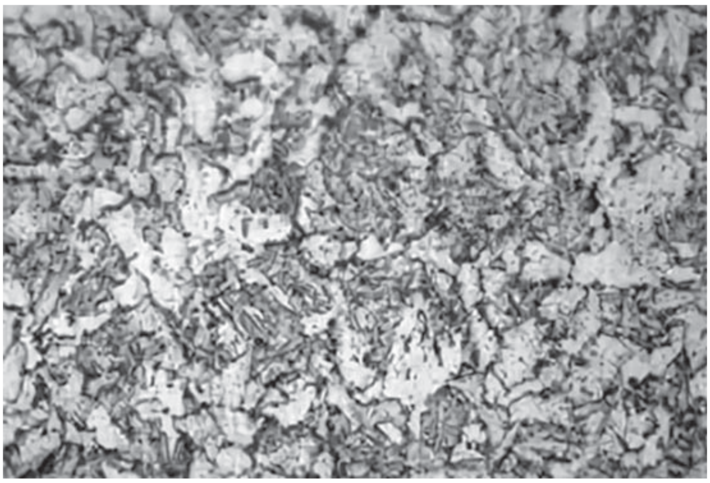

Fig. 8. Chisel microstructure

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