Increasing the wear resistance of steel parts using induction surfacing methods

Vladimir Malikov[1*], *Alexey* Ishkov[2], *Danil* Shmykov[1], *Pavel* Androsov[3], *Vladislav* Shleev[3], *Sergey* Voinash[4], and *Ramil* Zagidullin[4]

[1]Altai State University, Barnaul, Russia
[2]Altai State Agrarian University, Barnaul, Russia
[3]Ukhta State Technical University, Ukhta, Komi Republic, Russia
[4]Kazan Federal University, Kazan, Russia

Abstract. For the study, researchers selected reinforcing material, along with effective strengthening methods for the knives. These knives were intended to replace similar imported parts from MWS (Germany) on combines produced by Rostselmash plant LLC. During the study, the causes of the dispersion of blanks, wear in real operating conditions were determined, methods for optimizing charge materials for obtaining hardening coatings were described, material science studies of coatings containing wear resistance modifiers (B4C, WC). As an import-substituting material for strengthening coatings, completely similar in properties to the German one, a mechanical mixture of powders from nickel-based alloys of the PG-CP2, 3, 4 type with grinding powders of normal electrocorundum grades 14A, 13A with a grain size of 40-160 microns can be used. Induction surfacing of hard alloys (charges), at high frequencies (40-100, 150-220 kHz), using transistor inverter generators with a power of 100 kW and above, was used as a modern method of hardening knives, and laser surfacing (for blanks made of 65G steel) or laser thermal hardening (for blanks made of steel 6HV2S). The data demonstrating the effectiveness of induction surfacing to reduce knife wear are presented.

1 Introduction

The urgency of the problem of increasing the durability of agricultural machinery parts is increasing every year. This is due to the fact that the requirements for machines are increasing, the speed of movement, productivity and intensity of operation of machines are continuously increasing [1].

In practice, there are often cases when the insufficient durability of critical components limits the possibility of further improving the technical and economic performance of the machine. In agricultural machinery, such elements include ploughshares, cultivator paws, knives of milling and feed grinding machines, segments of cutting machines of mowers and other cutting components. To illustrate the need to combat abrasive wear of these elements, it is sufficient to note that their service life before scheduled repairs is calculated not in years

* Corresponding author: osys11@gmail.com

or months, but in hours. For example, before the introduction of modern hardening methods, the maximum blunting of mower segments occurred after 4-6 hours of operation, and the paws of cultivators after 6-8 hours, after which sharpening in the field was required.

When the knife cuts the straw, its sharp part gradually wears out, and the knife becomes blunt. The main damage to knives that cut straw can be as follows: breakage, bending, dents and chips on the cutting edge, as well as blunting. The first three damages occur when the knife encounters something hard, such as rocks or metal objects. But the bluntness of the knife occurs due to the fact that it constantly rubs against the straw and loses its sharpness, which reduces its ability to cut well.

A significant increase in the durability of restored IRS knives, 5-10 times, becomes achievable through the use of an innovative approach. This effect is achieved by creating a new design of the reinforcing coating, using modified hard alloys as the material for this coating, as well as improving the surfacing technology. As in any field of science, small changes in the initial conditions can lead to a dramatic improvement in the result if they are based on a deep understanding of the physics of processes.

Self–propagating high temperature synthesis (SHS) is a modern way to create durable coatings that saves energy and materials. This method works because many metals, such as those found in the periodic table, can react violently with elements like boron, carbon or silicon. The bottom line is that after the reaction has started at one point, it continues to spread throughout the sample like fire, due to the heat that is released during the reaction.

Metals, metal alloys and intermetallides are often used as binders, titanium, chromium, silicon carbides and their combinations, as well as aluminum, titanium, and chromium oxides, are usually used as refractory compounds.

Boration is one of the most effective methods for enhancing the wear resistance of machine components that operate under abrasive or high-wear conditions [1]. Indeed, the hardness of boride coatings formed on various metallic materials significantly surpasses that of coatings produced by conventional surface hardening techniques. It is comparable to the hardness of tungsten carbide and numerous PVD hard coatings [2-4].

The microstructure of the coating on stainless steel includes FeB (outer coating) and Fe2B (inner coating) in combination with CrB and Cr2B phases due to the substitution of FeCr. The existence of CrB and Cr2B phases significantly enhances the hardness of the outer layer of the borated surface [5]. Beneath the coating, the diffusion zone is divided into two distinct layers: a chromium-rich layer located directly below the boride coating, which promotes diffusion along grain boundaries, and a nickel-rich layer situated between the chromium-rich layer and the base material [6-7].

The process of electron beam surfacing of composite powders based on tungsten carbide is described in detail in [8]. Unlike powders containing titanium carbide, there is an active interaction of the carbide phase with the molten metal bond. As a result of this process, tungsten carbide partially dissolves in the melt, which leads to a two-fold decrease in the carbide content in the coating compared to the starting material [8].

The purpose of study is to increase the durability of IRS knives, as well as to maintain constant cutting quality throughout the entire service life. This is achieved by comprehensively improving the properties of the base material, the deposited coating.

2 Materials and methods

The study examined the blanks of knives for a straw chopper, which is installed on the drum of the device. Strict requirements are imposed on knives, not only in shape, but also in weight – the permissible weight difference should be only ± 2-3 grams. This is important because the knives are placed on a drum that rotates very fast (up to 3,800 revolutions per minute). If the knives installed opposite each other vary greatly in weight, this will cause an imbalance, which can lead to breakage and rapid failure of the equipment. Therefore, before installation or repair, knives are sorted into groups by weight (up to 8-10 groups), and only knives from one weight group are placed in opposite positions on the drum, where the difference in weight does not exceed ± 2-3 grams [9].

Materials such as steel 40 and steel 65G (for blanks), PG-C27 hard alloy powder, borate flux for surfacing, as well as special additives to increase wear resistance were used for the study. These additives were used to create more durable coatings in two different formulations.

To obtain reinforcing coatings, an converter (inverter) of the ELSIT brand, manufactured by LLC, was used [10].

The ELSIT inverter (figure 1) consists of two main parts. The first is the power unit of the frequency converter, which is made based on modern IGBT modules (from Germany) and is controlled using a microprocessor. The second part is a transformer unit with resonant capacitors. It is needed in order to separate the inverter from the network and adjust its operation to the desired load.

Fig. 1. ELSIT-100-40/70 inverter.

3 Experimental results

To create knives that will be no worse in wear resistance than their foreign counterparts, you need to choose the right material for the base and protective coating. In addition, it is important to understand exactly how the knife wears out – how its shape, weight changes, and which parts wear out faster. This will help to better design the protective coating.

To do this, experiments were conducted during the harvesting of wheat, corn and sunflower using a combine harvester. During the experiments, the wear of the shredder-spreader knives was measured, comparing new knives with already completely worn and damaged ones. Measurements were carried out on 47, 110, 162 and 225 hectares.

Results showed that the wear of the knives increased gradually and was predictable. In addition, the width of the knife remained almost the same at a distance of 80.3 and 99.5 mm, which indicates that the knife wears out weakly in this area. This is due to the fact that the cutting speed at the beginning of the knife is 1.5-1.6 times lower: from 97.9 m/s at the end to 60.9 m/s at the beginning. Therefore, the beginning of the knife wears out more slowly.

To keep the knife sharp for as long as possible, you need to change the design of the protective coating. First, it is necessary to abandon the application of hard strips on the back of the cutting edge in a section 64.9-69.8 mm long from the end of the knife. Secondly, the width of these strips should be different: it should increase closer to the end of the knife, 1.5-2 times the width of the blade itself. This will give the strips a triangular or curved shape, which will better protect the knife where it wears out more. Thirdly, such a triangular shape can be obtained by redistributing the material that will no longer be used on the part of the blade where protection is not needed.

The study evaluated four knife hardening techniques: surfacing with alloy, surfacing using an alloy enhanced with two specialized additives, and surfacing applied to surfaces pre-treated using the EIL method. These methods differ in the materials used to make knives and protective coatings, as well as in the shape of the protective strips.

In both formulations, the main component that increases wear resistance was spherical tungsten carbide powder. Boron carbide was used as an additional modifier. In the second composition, nickel powder was also added, which replaced the hard alloy in order to improve the balance between the metal base and the ceramic part.

The outcomes of the chemical composition analysis for coatings produced through different methods are presented in Table 1.

Table 1. The results of the chemical composition analysis for coatings created using various techniques are detailed in Table 1.

C	Si	Cr	Mn	Ni	W	Mo	B	P	S
1st sample									
2.9-4.1	1.2-1.4	22.6-23.3	0.9-0.82	1.05-2.1	2.2-3.8	0.12-0.18	2.3-3.5	0.02-0.06	0.13-0.19
2nd sample									
3.6-4.2	0.9-1.0	22.8-26.1	0.7-1.1	2.8-3.5	5.2-6.0	0.09-0.19	5.2-6.9	0.02-0.04	0.11-0.20
3rd sample									
3.81-3.85	0.6-1.3	25.9-28.3	0.7-0.9	1.9-2.0	0.23-0.26	0.13-0.16	0.8-0.9	0.01-0.02	0.04-0.05
4th sample									
3.8-3.9	0.6-0.9	24.3-29.4	0.8-0.9	1.9-2.3	0.6-0.7	0.17-0.21	0.7-1.0	0.02-0.04	0.04-0.05

The degree of hardening of the samples was estimated by mass wear. The test results are presented in the table 2. When testing the blades of the straw grinder, hardened with surfacing mixtures Composition 1, Composition 2, base material, the greatest wear resistance was shown by knives hardened with material Composition 1 based on PG-US25 hard alloy powder with wear resistance modifiers, containing, wt.. %: PG-US25 - 70+75; spherorelite - 8+10; boron carbide – 0.9+1.44; flux P-0.66 - the rest.

Table 2. Values of mass wear of samples (containing carbide chromium 25% and 1-0%, tungsten carbide and boron carbide and without additives).

Wear time	Composition 1	Composition 2	Composition 3	Composition 4
	Sample weight, g			
1 min	6.5521	7.5207	6.8451	6.9503
5 min	6.5232	7.4664	6.8043	6.8901
10 min	6.5043	7.4318	6.749	6.849
15 min	6.4164	7.3899	6.6816	6.7399

20 min	6.3829	7.3472	6.6467	6.6933
25 min	6.3781	7.335	6.6403	6.6646
Wear, g	0.174	0.1857	0.2048	0.2857

As the results of X-ray decoding (figures 2-4) showed, the main phases found in all coatings were: α-Fe, FeC (austenite), iron carbides Fe_3C, Fe_7C_3, chromium carbides CrC, Cr_7C_3.

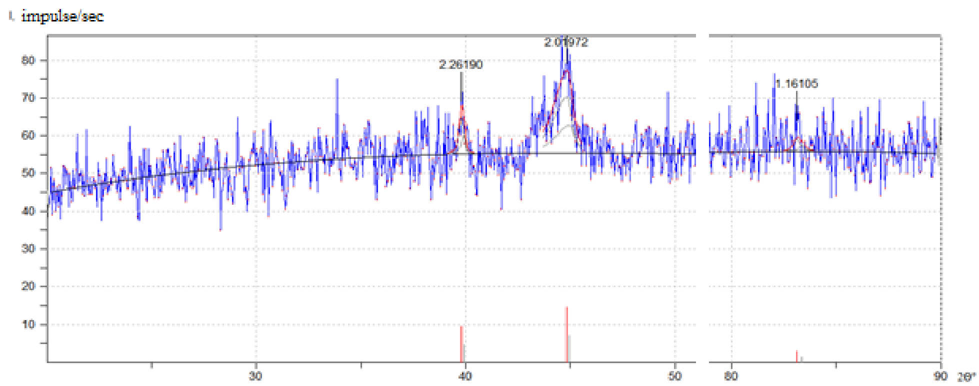

Fig. 2. X-ray of the first and second samples.

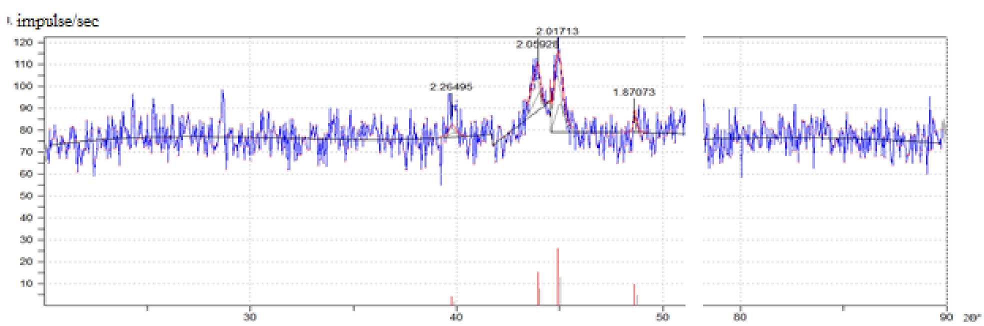

Fig. 3. X-ray of the third sample.

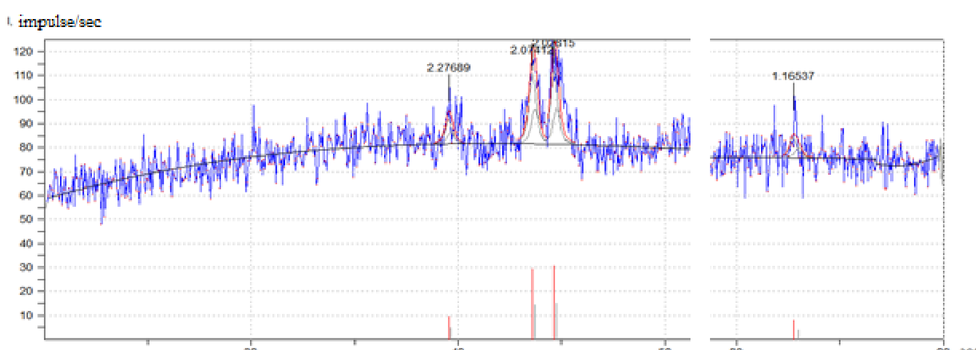

Fig. 4. X-ray of the fourth sample.

Therefore, incorporating tungsten carbide and boron carbide as modifiers to enhance the wear resistance of the hardening coating for straw grinder blades, based on the PG-C27 hard alloy, results in significant changes to its chemical composition, microstructure, and properties.

To achieve an optimal balance between cost, quality, hardness, and manufacturability, the recommended composition by weight percentage is as follows: tungsten carbide should be limited to 5-8%, and boron carbide should not exceed 1.5%. Additionally, to avoid the formation of pores and cracks, the metallic portion of the charge must constitute at least 77.8-79.9 wt.%, while the particle size of boron carbide should be minimized to a range of 0.04-0.95 mm.

4 Conclusion

Thus, it was possible to determine the causes of the dispersion of workpieces and hardened parts by weight. Methods for optimizing charge materials for obtaining reinforcing coatings are also presented, and studies of the coatings obtained are carried out. The coatings were made on the basis of such wear resistance modifiers as B4C, WC. A mechanical mixture of powders from nickel-based alloys was used. Induction surfacing of hard alloys (charge), at high frequencies (40-100, 150-220 kHz), using transistor inverter generators with a power of 100 kW and above, and laser surfacing or laser thermal hardening as a promising method is proposed. The results of the effect of induction surfacing on wear reduction are presented.

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