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ПОВЫШЕНИЕ ДОЛГОВЕЧНОСТИ ПЛУЖНЫХ ЛЕМЕХОВ С ИЗНОСОСТОЙКИМИ ПОКРЫТИЯМИ

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Проведен анализ различных материалов, используемых для высокопрочных износостойких покрытий режущих лезвий почвообрабатывающих рабочих органов. При выборе способа упрочнения деталей необходимо принимать во внимание максимально возможную толщину упрочненного слоя, проплавление и адгезию твердого сплава в основной металл, производительность и критерий «цена-качество». По критерию «цена-качество» наилучшие свойства из производимых отечественной металлургической промышленностью имеет сталь 30ХГСА. Упрочняющие материалы в виде твердосплавных порошков, электродов, проволоки российского производства в основном соответствуют по твердости и износостойкости зарубежным аналогам, но по прочности сцепления с основным металлом, адгезионным свойствам, отслоению и выкрашиванию фрагментов упрочняющего слоя при ударных нагрузках зачастую уступают в 1,5…2,5 раза. Разработана конструкция нового лемеха, состоящая из остова и накладного выдвижного долота. Материал остова лемеха и долота – сталь 30ХГСА, упрочняющий материал – твердосплавный порошок ФБХ-6-2 + 35%WC, метод упрочнения – плазменная наплавка толщиной от 0,5 до 4,5 мм. Результаты полевых испытаний показали преимущество опытных лемехов с накладным долотом по ресурсу в 2,5…4 раза, по прочности – в 3…5 раз.

Ключевые слова: плуг, лемех, износостойкое покрытие, ресурс.

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INCREASING THE DURABILITY OF PLOUGHSHARES WITH WEAR RESISTANT HARDFACING

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The authors have carried out an analysis of various materials used for obtaining high-strength wear-resistant coatings of the cutting edges of ploughshares. When choosing the method of hardening of agricultural working elements, it is necessary to take into account the maximum possible thickness of the hardened layer, the penetration and adhesion of the hard alloy to the base metal, process performance and the “price-quality” criterion. Steel grade 30ХГСА has shown the best “price-quality” properties as compared with those produced by the domestic metallurgical enterprises. Domestic reinforcing materials in the form of powders, electrodes, wires generally correspond in hardness and wear resistance to foreign analogues, however, it is necessary to take into account that in the strength of their adhesion to the base metal, adhesive properties, chipping and delamination of fragments of the reinforcing layer under shock loads they are 1.5 … 2.5 times lower in performance. The paper describes the design of the new ploughshare consisting of a blade and a face-mounted chisel. The material for the ploughshare is 30ХГСА steel grade. The reinforcing material is ФБХ-6-2 with 35% WC, the hardening method is plasma surfacing with a thickness of 0.5…4.5 mm. The results of field tests have shown the advantage of experimental ploughshares with a chisel overlap in resource by 2.5…4 times, in strength by 3…5 times compared with conventional ploughshares.

Key words: ploughshare, wear, hardfacing, durability.

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Introduction. The development of the working tools of tillage machines with a high service life is one of the most important tasks of domestic machine-building industry. The use of new materials, in particular, the obtaining of high-strength wear-resistant coatings in combination with the optimal hardening materials, largely determines the technical level of the new technology.

The development of import-substituting hard alloys and coatings from them will improve the operational and resource characteristics of the most loaded parts of agricultural machinery to the highly competitive level with leading foreign manufacturers, and by the “price – quality” criterion – even exceed this level [1].

Material and methods. Traditional materials used in the domestic tillage machine-building industry are steels ща 45, 65Г and Л53 grades. The analysis of the materials used to produce the working tool parts of tillage machines by famous foreign companies shows that the values of their tensile strengths are equal to 2800…3200 MPa, yield tensile strengh of 1500…2000 MPa, and hardness – 47…55 HRC

These materials for working tools have characteristics that are 1.5…1.7 times lower (1800…2500 MPa, 1100…1500 MPa, 38…42 HRC, respectively) as compared with their foreign counterparts. Therefore, wear resistance parameters of the materials and the durability of the working tools of domestic agricultural machinery are inferior to the best foreign analogues, which is due to both the materials used and with their design features [2].

Studies of various steels produced by the Russian metallurgical industry have shown that Prometey 1200 and Prometey 1500 possess the best characteristics as compared to foreign analogues, and according to the “price-quality” criterion, 30 ХГСА steel grade is the best for manufacturing heavily loaded working tools of agricultural machines, in particular, ploughshares (Table 1) [3].

Table 1

The study results of plowshare steel grades

Таблица 1

Результаты исследования лемешных сталей

Steel name	Hardness after quenching, HRC	Tensile strength, $\sigma_в$, MPa	Wear resistance ratio
30ХГСА	44…48	1460…1620	1.05…1.07
Steel 45	42	700…750	1.00
Prometey 1200	51…54	1410…1480	1.21…1.25
65У	45	1000…1250	1.07…1.09
Prometey 1500	53…56	1720…1780	2.62
Л53	41	800…1100	0.98…1.02
40Х	43	900…1250	1.09…1.11
“Lemken*”	52…54	1850…2060	1.68…1,74
“Kverneland*”	52	1800…2040	1.61…1.71
“Kuhn*”	49	1450…1820	1.29…1.43

** foreign manufacturers of tillage machines [4, 5, 6]*

The following factors were taken into account when choosing a method of hardening ploughshare surfaces: the maximum possible thickness of the hardened layer; melting of solid alloy in the base metal; adhesion with the base metal; surfacing process performance; and the "price-quality" criterion.

The choice of surfacing materials was based on the using materials commercially produced by Russian industrial enterprises; minimizing the price of working tools; good sintering of surfacing material with the main metal satisfying the needs of agricultural machinery manufacturers.

The hardening materials produced in Russian enterprises in the form of powders, electrodes, and wire generally correspond in hardness and wear resistance to the best foreign analogues, but their properties of adhesion to the base metal, detachment and chipping of fragments of the hardening layer under impact loads often turn out to be lower in 1.5…2.5 times.

Table 2 presents the research results of the most common grades of hard alloys used in Russia to harden tillage parts operating in abrasive soils.

The data from Table 2 shows that ПГ-С-27 and ФБХ-6-2 alloys have better characteristics for hardening parts working in the most abrasive soil. The authors have chosen the ФБХ-6-2 alloy, which satisfies the requirements for wear resistance and adhesive properties. Prices for this alloy in the domestic market are also acceptable for agricultural machinery manufacturing.

Table 2

Study results of hard alloys

Таблица 2

Результаты исследования твердых сплавов

Hard alloy	Chemical elements content, %								Hardness, HRC
	Fe	C	Si	Cr	Ni	Mn	Mo	B	
ПГ-С –27	base	3.3…3.5	1…2	25…28	1.5…2	0.8…1.5	0.08…0.15	-	49…53
ПГ-УС-25		4.4…5.4	1.6…2.6	35…41	1…1.8	2.2…2.5	-	-	52…55
ПГ-УС4-30		3.3…4.5	2…4.7	46…50	2…4.7	2…4.7	1…2	-	56…58
ФБХ-6-2		3.5…5.5	1…2.5	32…37	-	2.5…5.5	-	1.3…2.2	52…55
ПС-14-60		4…5.7	2…3	35.7	0.7…1.8	0.7…0.8	-	0.1…0.3	47…49
ФБХ-6-2 +35% WC		3.5…5.5	1.2…2.5	32…37	-	2.5…5.5	-	1.3…2.2	53…59

Currently, the most common methods of applying hardening materials include surfacing with electrodes or wire, plasma spraying, gas-flame powder deposition, induction and a number of others related to electrochemical, laser, electromechanical and similar types of hardening.

The most versatile and high-performance method of hardening parts is plasma surfacing, which provides coatings with a thickness of 0.5…4.5 mm or more, allowing to harden a wide range of parts of various shapes and configurations.

Field tests of conventional ploughshares made of Л53 and 30ХГСА steel grades featuring plasma blade surfacing with the ФБХ-6-2 alloy have shown the advantage in service life in 1.4…1.7 times of the ФБХ-6-2 alloy on different soils [3].

For domestic ploughs of the ПЛН type, new composite ploughshare with face-mounted chisel have been designed and manufactured. The share is an oblique trapezoid with an angle between the back and the blade, with the distance from the back to the blade decreasing linearly from the field to the furrow trim (Fig. 1).

a)

b)

Fig. 1. Experimental composite ploughshare:
a) plowshare with chisel; b) ploughshare assembly

Рис. 1. Экспериментальный лемех:
а) остов лемеха и долото; б) составной лемех в сборе

As a result of the carried out laboratory tests, a generalized empirical relationship has been proposed for calculating the thickness of a ploughshare

$$B = \frac{A + c\sigma_B}{\mu\sigma_B} R_{x\ \max}, \text{ mm}, \quad (1)$$

where σ_B – is the ultimate strength of steel, MPa; $R_{x\ max}$ – maximum traction resistance acting under normal conditions on the working tool (a plough body, a cultivator paw, or a harrow disc), N; A, mm·MPa/N; c, mm/N и μ – empirical coefficients (Tab. 3). There are four holes for the chisel in the share, which has two mounting holes. When the chisel blade is worn out during operation, it can be mounted on the lower holes, which allows increasing the ploughshare service life.

The most important parameter determining the strength and performance characteristics of the working tool blades of tillage machines is the thickness of these parts. A method has been developed to select the ploughshare thickness taking into account the loads acting on the part, and the mechanical properties of the material [7].

Table 3

Empirical coefficients for the relationship (1), which determines the blade material thickness of tillage working tools

Таблица 3

Эмпирические коэффициенты для зависимости, определяющей толщину материала лезвий рабочих органов почвообрабатывающих машин

Type of working body	A, mm·MPa/N	c, mm/N	μ
One-piece ploughshare	2.5	0.002	6
Ploughshare with face-mounted chisel:			
plowshare	2.5	0.002	7
chisel	2.5	0.002	4.5
Plough moldboard (chest and wing)	2.5	0.002	10
Cultivator paw	2.5	0.002	1
Spherical disc of a heavy harrow	2.5	0.002	1.3
Spherical disc of a stubble harrow	2.5	0.004	1

The average thickness B of the cutting blade can be calculated using the simplified formula

$$B \geq (0{,}01\ldots0{,}013)\, p, \quad (2)$$

where p, MPa – specific contact pressure acting on the most loaded cutting part.

The angle i of the blade sharpening and its thickness b_0 can be calculated taking into account the material strength σ_B, MPa, using the formulas

$$i = \frac{1000}{\sigma_B}\left(20...25°\right), °; \quad b_0 = \frac{1000}{\sigma_B}\left(0{,}26...0{,}29\right), \text{ mm}. \quad (3)$$

The method of selecting the blade width (its cutting part) taking into account the wear margin is based on the dependencies of the linear wear values obtained in operational tests.

Thus, the blade width with a linear wear margin, taking into account certain operating time in specific soil conditions, can be calculated using the relationship

$$H = H_{0\ \min} + U_{lin}, \text{ mm}, \quad (4)$$

where H – blade width, mm; $H_{0\ \min}$ – minimum blade width based on agrotechnical conditions [8], mm; U_{lin} – calculated linear wear, with the planned operating time, mm.

The results of the laboratory and field studies have shown that, basing on the technological conditions and the requirements for obtaining maximum wear resistance, the thickness of the deposited blade layer can be ρ calculated using the formula

$$\rho \geq (0.18\ldots0.25)\ \text{B, mm}, \quad (5)$$

where B – the base material thickness of a tillage working tool, mm.

The thickness of the hardened layer should be specified according the agrotechical requirements for the tillage working tool [8].

When designing the configuration of a new ploughshare, the following provisions should be taken into account. The new ploughshare must comply with the conventional counterpart in the size of fastening holes for its mounting on the plough rack shoe, as well as in the operating width and the geometrical parameters of conventional moldboards. The design of the proposed ploughshares should provide the necessary deepening ability of a plough, but should not exceed the traction resistance of conventional ploughshares.

The optimum geometry of the blade part of a ploughshare is achieved with a curved surface of the front side of a frame, which runs in the direction from the first mounting hole to the furrow cut. The operating angle of the ploughshare to the furrow bottom (the cutting angle) in a section perpendicular to the back and passing through the first mounting hole should equal 43°, and in a section perpendicular to the back and located at the point of intersection of the furrow trim and back – 23°. Thus, the chisel blade inclination in the toe area should amount to 43°, and 23° at the heel, which contributes to the optimal operating depth of the ploughshare. This provides for reduced traction on the ploughshare frame. For comparison, the conventional П702 ploughshare has a constant cutting angle along its entire length, which is equal to 36…39°.

Results and discussion. Field operational and service life tests were performed in the periods of autumn arable works in 2015-2017. The soil type was heavy loamy (Tula region, Shchekino district), medium and light loamy, sometimes turning into sandy (Moscow region, Sergiev Posad district), and medium loamy with stony inclusions (Vladimir region, Pokrov district). The test results of chisel ploughshares are presented in Fig. 2 and in Tab. 4.

The test results have shown a significant superiority of experimental ploughshares with a face-mounted chisel as compared with the conventional ones both in terms of their service life (2.5…4 times) and in performance. Operational tests have shown that the experimental ploughshares exceed the conventional ones in the strength parameter in 3…5 times or more.

As the operating area increased, the plough stability with experimental ploughshares practically did not change with the depth, whereas, the conventional counterparts began to lose depth after operating an area of 3…5 hectares, and from time to time it was necessary to restore it by adjusting the support wheel – even at a critical state when the plough deepening process became irreversible (the ploughshares completely lost their performance).

a)

b)

Fig. 2. Type of worn-out shares at the end of tests:
a) experimental composite ploughshare;
b) conventional П702 ploughshare

Рис. 2. Вид изношенных лемехов по окончании испытаний:
а) опытный составной лемех; б) серийный лемех П702

Table 4

Results of ploughshare field tests

Таблица 4

Результаты полевых испытаний лемехов

Indicators	Soil type: I – heavy loam, II – light loam with stony inclusions	Soil hardness, MPa	Ploughshares option	
			composite ploughshare with a chisel	conventional P702
Average operating time of a plowshare, ha	I II	2.8…4.6 2.4…4.1	59…76 8.9…11.6	14…28 2.4…3.6
Rejection for wear limit, %	I II	2.8…4.6 2.4…4.1	92 58	61 5
Rejection by breakdown, %	I II	2.8…4.6 2.4…4.1	8 42	39 95
Average operating time to the maximum wear of the chisel, ha	I II	2.8…4.6 2.4…4.1	46…69 8.2…10.6	- -
Average operating time to the maximum wear of the base, ha	I II	2.8…4.6 2.4…4.1	54…69 8.9…11.6	- -

It is important to note that the difference in the values of wear parameters occurs with an increase in the abrasive capacity of the soil, in particular, with an increase in the soil hardness and the presence of stony inclusions.

The field test results have shown the advantage of experimental chisels ploughshares by their service life in 2.5…4 times and reduced breakdown occurrence in 3…5 times as compared to the П702 standard ploughshares.

Conclusion

The new design of the developed composite ploughshare includes a base and a face-mounted retractable chisel from the 30ХГСА steel grade with reinforcing material based on ФБХ-6-2 powder with 35% WC applied by plasma surfacing.

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Contribution

Liskin I.V., Mironov D.A., Panov A.I. carried out the experimental work, on the basis of the results summarized the material and wrote the manuscript. Liskin I.V., Mironov D.A., Panov A.I. have equal author's rights and bear equal responsibility for plagiarism.

Conflict of interests

The authors declare no conflict of interests regarding the publication of this paper.

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