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Electrofriction treatment of plow shares

This paper presents the results of research aimed at developing the technology of plow share hardening by means of electrofriction hardening. It is shown that in electrofriction hardening of plow shares a structure with microhardness gradient is formed along the depth of the hardened zone. After electrofriction hardening the microhardness of plow share increases in 3–3.5 times in comparison with the initial state. The reason for the gradient character of microhardness distribution along the thickness of the modified layer is the ultra-high cooling rate, which causes a high temperature gradient near the surface. On the basis of the results of scanning electron microscopy it is established that at electrofriction hardening of steel 40Kh the hardened surface layer is formed, consisting of two zones: the surface hardened zone with the structure of fine–needle martensite and austenite; the zone of thermal influence (transition layer) with martensite-perlite structure, smoothly passing into the initial ferrite-perlite structure. It is established that the phase composition of steel 40Kh in the initial state consists of α-Fe phase with BCC lattice, and after electrofriction hardening the hardening phases of residual austenite (γ-Fe) and martensite (α'-Fe) are formed. The obtained data allow us to conclude that electrofriction treatment is an effective method of plow share hardening from structural steel 40Kh.

Keywords: electrofriction technology, hardening, plow share, microstructure, microhardness.

Introduction

Increasing the service life of soil tillage machinery working elements is one of the urgent problems of modern agricultural engineering. Analysis of the reliability level of tillage machinery shows that about 40% of the total number of failures is attributed to soil-cutting elements (plow shares, plow bits, bucket teeth of excavators, etc.) [1]. Operational and technological indicators of plows do not always meet the consumer properties declared by the manufacturer. According to [2] the average service life of P-702 chisel-shaped plow shares varies from 5 to 20 ha and the highest intensity of wear of plow shares by weight on sandy soils with stony inclusions is 260–450 g/ha, and on sandy and sandy loam soils without stony inclusions decreases to 100–260 g/ha. Thus, there is a serious scientific and technical problem associated with a low level of consumer properties of tillage tools operated under high impact-abrasive loads. The principal solution of the problem is the use of resource-saving hardening technologies, which will allow to increase the operational characteristics of critical parts of tillage machines. Therefore, the material science direction of new developments for parts of agricultural machines is the most important.

At present in Kazakhstan the following methods of increasing wear resistance of working parts of tillage machines are used: electric arc surfacing with hard-alloy electrodes or sormite and heating with high frequency currents under hardening [3]. One of the methods of hardening and restoration of plow shares, which has a wide application, is electric arc cladding (cladding reinforcement) [4, 5]. At the enterprises of the Karaganda region, the greatest use in repair production was made of cladding, which provides more than 70% of the restoration volume [6]. However, the disadvantages of cladding methods are: lack of hardness gradients, thermal influence, warping of products, reduction of resistance to cracking and destruction. Mikhalchenko A.M. and his co-authors analyzed the works reflecting the issues of heat treatment during hardening and hardening restoration with the use of cladding reinforcement. The analysis allowed to establish that the fact of hardness gain is insignificant, which does not provide a significant increase in the wear resistance of the plow share, so the authors recommend scientific searches to improve the technology [7].

In Kazakhstan, research is being conducted on the development of technology for hardening of soil tillage machine parts. A combined method of hardening of the blade of the working organ has been developed. This method includes electrospark alloying of the hardened surface with a carbide electrode and high-speed boriding of the hardened layer with subsequent re-treatment with electrospark alloying [8]. The method of restoration and hardening of worn parts using welding is known, mainly for hardening of lancet tines of cultivators. To restore the lancet tines, compensating plates (made of steel) of a certain repair size are used, which are welded to the restored part with a continuous seam using electric arc welding [9]. However, in our country there are no studies on strengthening of soil tillage machine working elements with the help of electrofriction technology.

Electrofriction technology is based on the joint fusion of the surfaces of the cast iron electrode and the blade of the tillage tool by introducing the energy of low-voltage electric arcs and cooling with water [10, 11]. The arcs are generated using safe welding voltage and friction of the electrode surfaces against the tool. EFT should provide the creation of a hardness gradient of the blade material, increasing resistance to abrasive wear and self-sharpening ability.

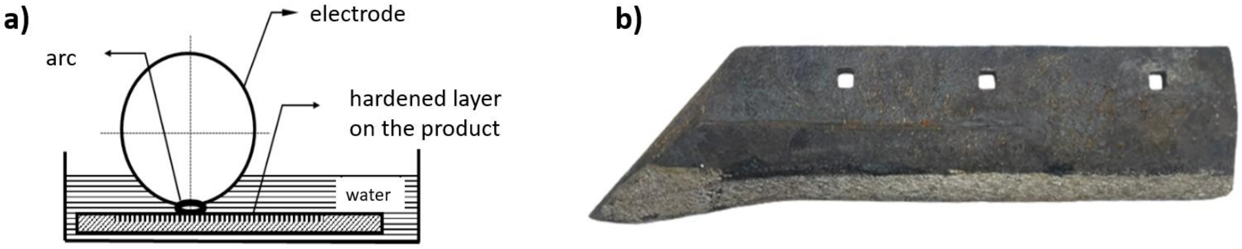
Bogdanovich P.N. and co-authors used the technology of electrofriction hardening as an experimental method for processing of cutting drum blades of forage harvesters. The effectiveness of using high-strength cast iron in the construction of cutting drum blades of forage harvesters is considered. The results of testing the wear resistance of hardened samples showed that the electrofriction method of hardening, depending on the regime of testing, increased the wear resistance of samples in 1.1–1.5 times, the thickness of the hardening zone was 400 μm [12]. It should be noted that for modern conditions of soil cultivation it is necessary to ensure the strength of the material of the product 1500–1800 MPa, and impact toughness should correspond to values not less than 0.8–1.0 MJ/m2 [13]. To reduce the intensity of abrasive wear it is necessary to provide the maximum possible surface hardness of 60–65 HRC. Such values of strength, impact toughness and hardness in the manufacture of parts from steels L53 and 65G (replaceable parts of plow bodies) are not provided by traditional technologies (hardening + tempering) [14].

The purpose of this work is to study the structural-phase state and microhardness of the surface layer of the plow share made of structural steel 40 Kh after electrofriction hardening.

Materials and experimental methodology

In the present work, plow shares made of structural alloy steel 40Kh are chosen as the material for electrofriction technology (EFT). The samples for the study were cut out from the plow shares with the size of 100×30×10 mm and were pre-treated with grinding paper with P100 grit.

Figure 1 shows a schematic diagram of the electrofriction technology setup. The friction of the electrode against the workpiece is accompanied by the formation and breaking of electrical contact between them. Contact between the product and the electrode is carried out by a sublayer of cooling liquid (water), which causes heating up to melting of the contacting surfaces. The treated surface of the product is melted, the melt is alloyed with elements included in the electrode or in the cooling liquid. Periodic breaking of the electrical contact, when the interelectrode gap increases, creates conditions for rapid cooling of the surface of the product doped in the melt. The cooling rate reaches 10^4–10^5 °C/s. A cast iron disk was used as an electrode for EFT. The electrode rotation speed is 165 rpm. The electrode is included in the electric circuit by the anode and isolated from the plant structure. Friction of the modified surface of the product was carried out against the periphery of the electrode with a force of 5 N. EFT treatment of steel 40 Kh was carried out at a current strength of 200 A and voltage of 70 V.



a) schematic representation of EFT; *b*) plow share after electrofriction treatment

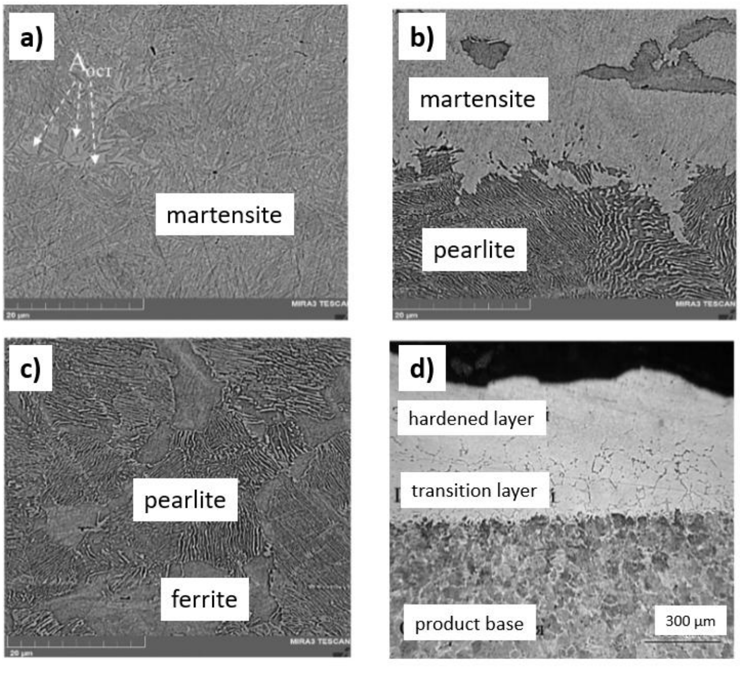
Figure 1. EFT hardening of steel products

The microstructure of the investigated samples was studied using Altami MET 5C optical microscope and TESCAN MIRA3 LMH scanning electron microscope. After electrofriction treatment, mechanical treatment (grinding and polishing) was carried out for further studies. Chemical treatment (etching) of the sample surface in 5 % ethyl alcohol based HNO_3 solution was carried out to study the microstructure of the sample on the cross section. X-ray phase analysis of the studied samples was performed on a SHIMADZU XRD–6000 diffractometer (monochromatic Cuα-radiation, wavelength 1.54056 Å) with the following imaging parameters: accelerating voltage 45 kV, beam current 30 mA, scanning step 0.02° in the range of angles 30–85°, signal acquisition time 0.5 s. The analysis of phase composition was carried out using PDF4+ databases and POWDER CELL 2.4 full-profile analysis program. The microhardness of the machined surface was determined on a METOLAB 502 microhardness tester at indenter load P=1N and dwell time at this load 10 s.

Experimental results

In the EFH process, steel and cast iron are subjected to high temperature and pressure generated by frictional forces and electric current. High temperatures can cause the transformation of austenite (the resistant crystalline structure of iron) into more stable phases such as martensite and cementite, but can also promote the formation of residual austenite. With the reverse polarity created by the arc in the EFH process, the electrode is heated more and the surface of the sample is alloyed with the elements that make up the cast iron (electrode). The process of heating and frictional forces leads to phase transformations in the surface layer of the material. These transformations may include recrystallization and martensitic transformation. A characteristic feature of the used EFH technology is the zonality of the formed structures along the thickness of the modified layer, which can be divided into the following zones: the zone of hardening, thermal influence and the base of the treated material.

The results of metallographic study of plow share microstructure after EFH showed that the thickness of the modified layer is ~500 μm (Fig. 2*d*). The structure of the surface layer consists of a hardened layer with austenite-martensite structure (Fig. 2*a*) and after the hardened layer there is a transition layer, which undergoes incomplete hardening, with the structure of martensite and ferrite (Fig. 2*b*). The base of the product (initial structure) is a ferrite-perlite structure (Fig. 2*c*). The hardened layer has the microstructure of needle martensite and has a smooth transition to the heat affected zone. The plates of greater thickness between the martensite needles are residual austenite (Fig. 2*a*). No microcracks are found at the transition boundary to the original structure. It was noted in [5] that the presence of a small amount of residual austenite in the structure of the surface and near-surface layers is a positive factor, since austenitic interlayers with increased ductility along the boundaries of martensitic plates are barriers to the propagation of cracks from the quenched layer into the base metal.



a — hardened layer; *b* — transition layer; *c* — base of the product (untreated layer);
d — general view of the hardened layer (metallographic microscope)

Figure 2. Cross-sectional microstructure of steel 40Kh after EPH

Figure 3 shows diffractograms of steel 40Kh before and after EPH. The phase composition of steel 40 Kh in the initial state consists of α-Fe phase with BCC lattice (Fig. 3b). After EPH of steel 40Kh, residual austenite (γ-Fe) and martensite (α'-Fe) phases appear. Martensite is formed on the steel surface as a result of rapid cooling during the EPH process. The results of X-ray phase analysis are consistent with the results of the study of the microstructure of steel 40Kh after EPH.

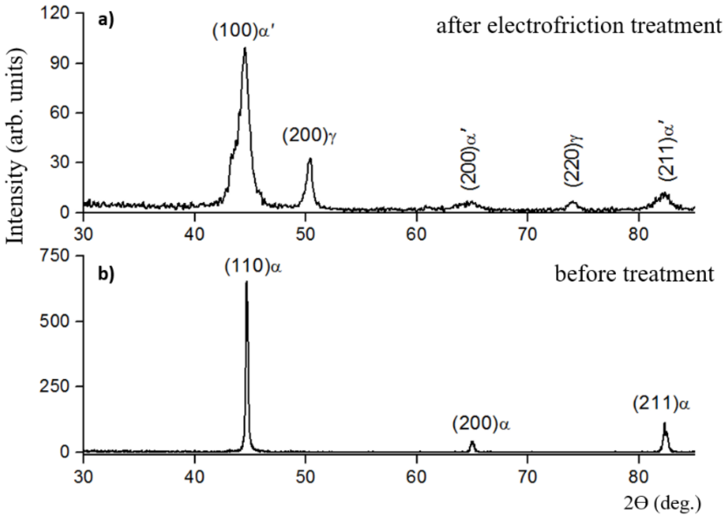
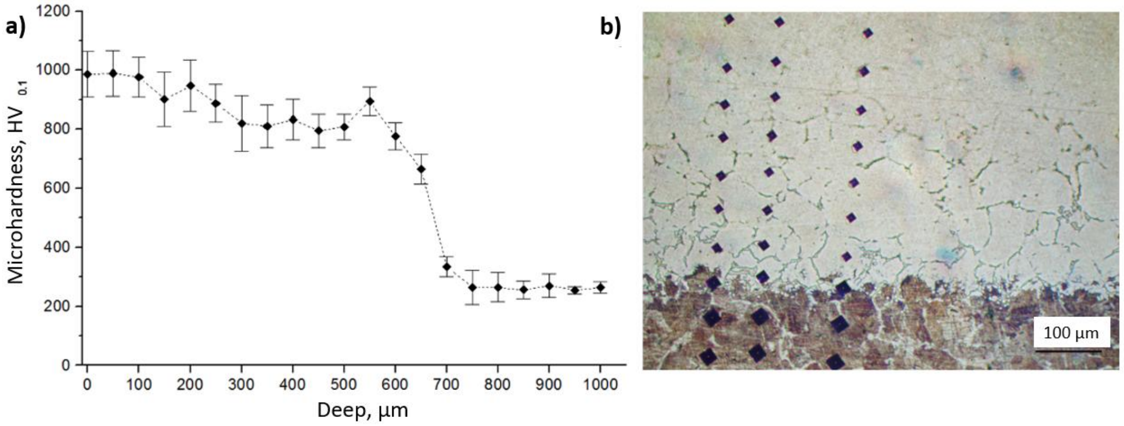


Figure 3. Diffractogram of steel 40Kh before and after electrofriction treatment

It is known that the characteristic properties of steel with martensitic structure are high hardness [15]. Of particular interest is the consideration of hardness distribution curves along the thickness of the modified steel layer after hardening. The study of microhardness distribution along the depth showed the presence in them of a harder surface layer and a less hard layer underlying it, the extent of which is ~550 µm. Figure 4*a* shows that the microhardness in the modification zone decreases smoothly from the surface to the depth of the sample. In the near-surface layers, the microhardness of steel 40 Kh reaches an average value of 960 $HV_{0.1}$ with a smooth transition to the heat affected zone, which has an average microhardness of 813 $HV_{0.1}$. The microhardness of steel 40Kh in the initial state is 252±16 $HV_{0.1}$.



a — distribution of microhardness by thickness of hardened layers; *b* — microstructure of the modified layer

Figure 4. Microhardness of steel 40Kh after EFH

Thus, the obtained data allow us to conclude that electrofriction treatment is an effective method of hardening of plow shares made of steel 40Kh. The hardness of the rapidly hardened layer smoothly decreases from the surface of the modified layer to the boundary with the base. It should be noted that the basis of known hardening methods is the creation of surface layers with a hardness gradient along the cross-section of the treated product.

Conclusion

The influence of electrofriction treatment of structural steel 40Kh on the structure and microhardness of a plow share made of structural steel 40Kh was investigated. It was found that the structure of the cross–section of steel 40 Kh after electrofriction hardening was conditionally divided into 3 zones: hardened layer, heat affected zone and the base of the treated material. The microstructure of the hardened layer of steel 40Kh consisted of needle-like martensitic structure and residual austenite. The heat affected zone of steels contains martensite and highly dispersed pearlite (trostite). The microstructure of the initial state of steel 40Kh consists of ferrite-perlite structure. It is shown that a gradient structure with a regular changing micro-hardness of structural components is formed at the depth of the zone. High hardness of steels after electrofriction treatment is explained by the formation of martensitic structure as a result of ultra-high heating and cooling rates, which are unattainable by traditional heat treatment methods.

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References

1 Панов И.М. Технический уровень почвообрабатывающих и посевных машин / И.М. Панов, А.Н. Черепахин // Тракторы и сельскохозяйственные машины. — 2000. — № 9. — С. 10–12.

2 Шило И.Н. Повышение работоспособности деталей рабочих органов сельскохозяйственных машин: моногр. / И.Н. Шило, Г.Ф. Бетеня, Г.И. Анискович. — Минск: БГАТУ, 2010. — № 320.

3 Косатбекова Д.Ш. Разработка и обоснование параметров сошниказернотукотравяной сеялки и повышение ресурса работы его рабочей поверхности / Д.Ш. Косатбекова, С.О. Нукешев // Материалы Междунар. науч.-теор. конф. «Сейфуллинские чтения–17: Современная аграрная наука: цифровая трансформация», посвящ. 30-летию Независимости Республики Казахстан. — 2021. — Т. 1. Ч. 2. — С. 225–228.

4 Singh P. Reduction of abrasive wear via hardfacing of mouldboard ploughshare / P. Singh, S. Singh Chatha // Materials Today: Proceedings. — 2020. — Vol. 33 (3). — P. 1505–1512.

5 Kostencki P. Wear of cultivator coulters reinforced with cemented–carbide plates and hardfacing / P. Kostencki, T. Stawicki, A. Krolicka, P. Sędłak // Wear. — 2019. — Vol. 438–439. — P. 203063.

6 Жаркевич О.М. Анализ методов восстановления деталей наплавкой / О.М. Жаркевич, А.В. Жукова, О.А. Нуржанова // Материалы X Междунар. науч.-техн. конф. «Техника и технологии машиностроения». — Омск, 2021. — С. 122–125.

7 Михальченко А.М. Способы упрочнения и упрочняющего восстановления лемехов плугов с сопутствующей термообработкой / А.М. Михальченко, И.В. Козарез, А.А. Тюрева // Вестн. Брян. гос. с.-х. акад. — 2017. — № 2 (60). — С. 24–27.

8 Шугаев Б.К. Патент на изобретение № 32142. Комбинированный способ упрочнения лезвия рабочего органа / Б.К. Шугаев, С.А. Кадочников. — Опубл. от 08.12.2015 г.

9 Шугубаев Ж.Б. Патент на изобретение № 27615. Способ восстановления рабочих органов почвообрабатывающих машин / Ж.Б. Шугубаев // Бюл. — № 11. — Опубл. 15.11.2013 г.

10 Sagdoldina Zh. Electrofrictional Hardening of the 40Kh and 65G Steels / Zh. Sagdoldina, Yr. Tyurin, N. Berdimuratov, O. Stepanova, N. Magazov, D. Baizhan // Coatings. — 2023. — 13(11). — 1820.

11 Tyurin Y.N. Investigation of the hardness of 65G steel after electrofriction treatment / Y.N. Tyurin, Zh. Sagdoldina, Y.Y. Kambarov, M.N. Magazov // Bulletin D. Serikbayev of EKTU. — 2023. — No. 3. — P. 99–106.

12 Богданович П.Н. Исследование влияния электрофрикционного упрочнения ножей режущего барабана кормоуборочного комбайна на их износостойкость / П.Н. Богданович, М.И. Михайлов, К.М. Михайлов // Вестн. Баранович. гос. ун-та. Сер. Технические науки. — 2016. — Т. 4. — С. 77–84.

13 Машиностроение: энцикл.: [В 40-а т.]. — Машиностроение. —2002. — Т. IV. — Вып. 16.

14 Канаев А.Т. Плазменная закалка лемеха плуга из конструкционной стали 65Г / А.Т. Канаев, А.А. Гуляренко, П.А. Тополянский, Т.Е. Сарсембаева // Горение и плазмохимия. — 2020. — Вып. 18. — С. 87–93.

15 Rakhadilov B.K. Impact of Volume and Surface Heat Treatment on the Structure and Properties of Steel 30HGSA / B.K. Rakhadilov, R.S. Kozhanova, P. Kowalewski, D.R. Baizhan, Zh.B. Sagdoldina, L.G. Zhurerova, G.U. Yerbolatova // Bulletin of the University of Karaganda – Physics. — 2021. — Vol. 4(104). — P. 16–24.

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Соқа түренін электрфрикциялық өңдеу

Мақалада электрфрикциялық қатайту тәсілімен соқа түренін қатайту технологиясын әзірлеуге бағытталған зерттеу нәтижелері баяндалған. Соқа түренін электрфрикциялық өңдеуде қатайтылған аймақтың тереңдігі бойынша микроқаттылық градиентті құрылымда қалыптасатыны көрсетілген. Электрфрикциялық қатайтудан кейін соқаның микроқаттылығы бастапқы күймен салыстырғанда 3-3,5 есе артады. Модификацияланған қабаттың қалыңдығы бойынша микроқаттылықтың таралуының градиенттік сипатының себебі аса жоғары салқындату жылдамдығы болып табылады, бұл бетке жақын температураның жоғары градиентін тудырады. Сканерлеуші электрондық микроскопияның нәтижелері негізінде 40Х болатын электрфрикциялық қатайту кезінде екі аймақтан тұратын қатайтылған беткі қабат түзілетіні анықталды: ұсақ ине тәрізді мартенсит пен аустенит құрылымы бар беткі қатайтылған аймақ; бастапқы феррито-перлит құрылымына тегіс ауысатын мартенсит-перлит құрылымы бар термиялық әсер ету аймақтары (өтпелі қабат). Бастапқы күйдегі 40Х болаттың фазалық құрамы BCC торымен α-Fe фазасынан тұратыны анықталды, ал электрфрикциялық қатайтудан кейін қатайтатын қалдық аустенит (γ-Fe) және мартенсит (α'-Fe) деген фазалар пайда болады. Алынған мәліметтер бойынша электрфрикциялық өңдеу 40Х құрылымдық болаттан жасалған соқаны қатайтудың тиімді әдісі болып табылады деген қорытынды жасауға мүмкіндік береді.

Кілт сөздер: электрфрикциялық технология, беріктендіру, соқа түрені, микроқұрылым, микроқаттылық.

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Электрофрикционная обработка лемеха плуга

В статье изложены результаты исследований, направленные на разработку технологии упрочнения лемеха плуга способом электрофрикционного упрочнения. Показано, что в электрофрикционной обработке лемеха плуга по глубине упрочненной зоны формируется структура с градиентом микротвердости. После электрофрикционного упрочнения микротвердость лемеха плуга увеличивается в 3–3,5 раза по сравнению с исходным состоянием. Причиной градиентного характера распределения микротвердости по толщине модифицированного слоя является сверхвысокая скорость охлаждения, вызывающая высокий градиент температуры вблизи поверхности. На основе результатов сканирующей электронной микроскопии установлено, что при электрофрикционном упрочнении стали 40Х формируется упрочненный поверхностный слой, состоящий из двух зон: поверхностной закаленной зоны со структурой мелкоигольчатого мартенсита и аустенита; зоны термического влияния (переходный слой) с мартенситно-перлитной структурой, плавно переходящей в исходную феррито-перлитную структуру. Установлено, что фазовый состав стали 40Х в исходном состоянии состоит из фазы α–Fe с ОЦК решеткой, а после электрофрикционного упрочнения образуются упрочняющие фазы: остаточный аустенит (γ–Fe) и мартенсит (α’–Fe). Полученные данные позволяют сделать вывод, что электрофрикционная обработка является эффективным способом упрочнения лемеха плуга из конструкционной стали 40Х.

Ключевые слова: электрофрикционная технология, упрочнение, лемех плуга, микроструктура, микротвердость.

References

1 Panov, I.M., & Cherepakhin, A.N. (2000). Tekhnicheskii uroven pochvoobrabatyvaiushchikh i posevnykh mashin [Technical level of tillage and seeding machines]. *Traktory i selskokhoziaistvennye mashiny — Tractors and Agricultural Machines*, 9, 10–12 [in Russian].

2 Shilo, I.N., Betenya, G.F., & Aniskovich, G.I. (2010). Povyshenie rabotosposobnosti detalei rabochikh organov selskokhoziaistvennykh mashin [Improving the serviceability of parts of working bodies of agricultural machines]. Minsk: Belorusskii gosudarstvennyi agrarnyi tekhnicheskii universitet [in Russian].

3 Kosatbekova, D.Sh. & Nukeshev, S.O. (2021). Razrabotka i obosnovanie parametrov soshnikazernotukotravianoi seialki i povyshenie resursa raboty ego rabochei poverkhnosti [Development and justification of the coulter parameters of grain and grass seeders and increase of its working surface resource]. *Materialy Mezhdunarodnoi nauchno-teoreticheskoi konferentsii «Seifullinskie chteniia–17: Sovremennaia agrarnaia nauka: tsifrovaia transformatsiia», posviashchennoi 30-letiiu Nezavisimosti Respubliki Kazakhstan — Proceedings of the international scientific and theoretical conference “Seifullin readings – 17: Modern Agrarian Sci-*

ence: digital transformation", dedicated to the 30th anniversary of Independence of the Republic of Kazakhstan, 1, 2, 225–228 [in Russian].

4 Singh, P. & Singh, Chatha S. (2020). Reduction of abrasive wear via hardfacing of mouldboard ploughshare. *Materials Today: Proceedings, 33*(3), 1505–1512.

5 Kostencki, P., Stawicki, T., Krolicka, A., & Sędłak, P. (2019). Wear of cultivator coulters reinforced with cemented-carbide plates and hardfacing. *Wear,* 438–439, 203063.

6 Zharkevich, O.M., Zhukova, A.V., & Nurzhanova, O.A. (2021). Analiz metodov vosstanovleniia detalei naplavkoi [Analysis of methods of restoration of parts by cladding]. *Materialy X Mezhdunarodnoi nauchno-tekhnicheskoi konferentsii «Tekhnika i tekhnologii mashinostroeniia» — Proceedings of the X International Scientific and Technical Conference "Engineering and Technology of Mechanical Engineering". Omsk,* 122–125 [in Russian].

7 Mikhalchenko, A.M., Kozarez, I.V., & Tyureva, A.A. (2017). Sposoby uprochneniia i uprochniaiushchego vosstanovleniia lemekhov plugov s soputstvuiushchei termoobrabotkoi [Ways of strengthening and reinforcing recovery of ploughshares with concomitant heat treatment]. *Vestnik Brianskoi gosudarstvennoi selskokhoziaistvennoi akademii — Bulletin of Bryansk State Agricultural Academy,* 2(60), 24–27 [in Russian].

8 Shugaev, B.K. & Kadochnikov, S.A. Patent na izobretenie № 32142. Kombinirovannyi sposob uprochneniia lezviia rabochego organa [Patent for invention No. 32142, Combined method of workpiece blade hardening]. Published on 08.12.2015 [in Russian].

9 Shugubaev, J.B. Patent na izobretenie № 27615. Sposob vosstanovleniia rabochikh organov pochvoobrabatyvaiushchikh mashin [Patent for invention No. 27615, Method of restoration of working bodies of soil tillage machines] [in Russian].

10 Sagdoldina, Zh., Tyurin, Yu., Berdimuratov, N., Stepanova, O., Magazov, N., & Baizhan, D. (2023). Electrofrictional Hardening of the 40Kh and 65G Steels. *Coatings, 13*(11), 1820.

11 Tyurin, Y.N., Sagdoldina, Zh., Kambarov, Y.Y, & Magazov, M.N. (2023). Investigation of the hardness of 65G steel after electrofriction treatment. *Bulletin D. Serikbayev of EKTU,* 3, 99–106.

12 Bogdanovich, P.N., Mikhailov, M.I., & Mikhailov, K.M. (2016). Issledovanie vliianiia elektrofriktsionnogo uprochneniia nozhei rezhushchego barabana kormouborochnogo kombaina na ikh iznosostoikost [Investigation of the influence of electrofriction hardening of cutting drum knives of forage harvester on their wear resistance]. *Vestnik Baranovichskogo gosudarstvennogo universiteta. Seriia Tekhnicheskie nauki — Bulletin of Baranovichi State University. Series Technical Sciences, 4,* 77–84 [in Russian].

13 (2002). Mashinostroenie: entsiklopediia: [V 40 tomakh] [Mechanical engineering: encyclopedia: in 40 vol.]. Moscow: Mashinostroenie, IV, 16 [in Russian].

14 Kanaev, A.T., Gulyarenko, A.A., Topolyanskiy, P.A., & Sarsembayeva, T.Ye. (2020). Plazmennaia zakalka lemekha pluga iz konstruktsionnoi stali 65G [Plasma quenching of plow plowshare made of 65G structural steel]. *Gorenie i plazmokhimiia — Combustion and Plasma Chemistry, 18,* 87–93 [in Russian].

15 Rakhadilov, B.K., Kozhanova, R.S., Kowalewski, P., Baizhan, D.R., Sagdoldina, Zh.B., Zhurerova, L.G., & Yerbolatova, G.U. (2021). Impact of Volume and Surface Heat Treatment on the Structure and Properties of Steel 30HGSA. *Bulletin of the University of Karaganda – Physics, 4*(104), 16–24.

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