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Macrostructure of hardened chisel opener with silicon-manganese-chromium based cladding

D.Sh. Kossatbekova*[1], S.O. Nukeshev[2], N.N. Romanyuk[3]

[1,2]*S. Seifullin Kazakh agrotechnical research university, Astana, Kazakhstan*
[3]*Belarus State Agrarian Technical University, Minsk, Belarus*

(E-mail:[1]ms.kossatbekova@mail.ru, [2]snukeshev@mail.ru, [3]romanyuk-nik@tut.by)

Abstract. The relevance of this study lies in the fact that the wear of the working bodies of seeding machines leads to increased fuel consumption, deterioration of the quality of seed placement, and reduced yields. In this regard, this article is aimed at studying the condition of hardened working parts of the experimental grain-fertilizer-grass seeder. Based on the results of information search, the following hardening methods were adopted: electric arc cladding with hard-alloy electrodes and sormite; heating of the chisels by HFC quenching. Samples of experimental chisels of coulter chisels of a grain and grass seeder made of 65G steel were used for research. The state of worn surface layers of chisels was studied by ultrasonic flaw detector. Research has allowed to establish that among hardened samples the smallest equivalent area of wear has the sample, hardened full working surface by cladding with electrodes T590, and also according to the results of field experiments this sample had the greatest resistance to abrasive impact. On the basis of these results as the most rational method of chisel hardening for production conditions in agricultural enterprises it is recommended to replace the typical factory heat treatment with cladding of the full working part of chisel.

Key words: Macrostructural analysis, wear, hardened steel, heat treatment, ADC diagram, chisel opener, grain-fertilizer-grass seeder.

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* the corresponding author

Introduction

A comparison of macrostructural and microstructural analysis reveals that the former is unable to determine all the features of the structure. However, this study can be subjected to the surface of the unbroken product, fractures, unetched macro sections or with the structure revealed by special reagents, to detect fracture, violation of the continuity of metal, dendritic structure of cast metal, chemical heterogeneity of cast metal and the presence of coarse inclusions, fiber structure of deformed metal, structural and chemical inhomogeneity of metal,

To control the quality of metal to detect internal defects without destroying the integrity of the product, ultrasonic, radiation, X-ray methods of defectoscopy are used, which allow not only to detect the presence of defects, but also to determine their shape and size.

Ultrasonic method allows you to detect small defects of the part, located very deep in the product can be using ultrasounds, reflecting sound waves from the defect located inside the metal. This method not only enables the identification of internal defects, but also their precise location.

The research paper [1] shows the possibility of macrostructural study to identify defects of various origins in metal products of parts with stress concentrators. The influence of each criterion on the properties of steel products, distinctive features of the macrostructure of metal products and an example of the implementation of the results of macrostructural study to improve the durability of parts HFC (high frequency current), surface hardened from heating are considered.

The macrostructural and mechanical properties of rails clad by automatic gas-flame treatment were studied [2] and concluded that the treated rail had a higher hardness value (313.6 BHN) compared to the untreated rail (276.7 BHN). The same was confirmed by micro structural observations: there is a better arrangement of the crystal structure.

Nevertheless, the above mentioned works consider other spheres of mechanical engineering, and macrostructural analysis of agricultural machinery working bodies was not taken into account.

Having considered the processes of wear and repair of working bodies of agricultural machinery and equipment for forage production (plowshare, cultivator tine, disks of openers and markers of seeders, harrows, blades of silage combines, forage choppers, etc.), those parts that have a blade (cutting working surface) it is established that most of these parts are made of alloy steels (53C – casted steel, 60Mn, 65Mn, 70Mn, etc.). The cost of such steels is high and therefore metal losses should be minimized both in operation and during repair of worn parts.

It is possible to control the most important output parameters of the technological process by setting the properties of the surface layer of parts, thereby improving the quality of the surface layer of manufactured (restored) parts. Increasing the reliability of the technological process can be ensured to a certain extent by introducing special types of processing that increase wear resistance and fatigue resistance. For these purposes, technological processes that harden the surface layer and give it special properties are used.

The application of hardening technologies contributes to the creation of a reliability margin of the technological process of restoration, as higher performance properties of the restored parts of agricultural machinery are ensured. In this regard, the developments related to hardening by vibration deformation method are of special interest.

In the works [3-22], on the basis of laboratory and field studies of working bodies of seeders and other tillage machines, the degree of wear of protective surface layers of chisel openers, hardened by different methods depending on metal properties, modes of operation, mechanical properties of soil, etc., was revealed. At the same time the state of worn surfaces was not studied for the presence of defects in them (presence of porosity and micro cracks of clad layers, their delamination, unsatisfactory roughness, corrosion sites, etc.), the rational method of surface hardening of seeder working bodies was not substantiated.

The aim of the research is to increase the wear resistance of anchor chisel openers of grain-fertilizer-grass seeders by substantiating the rational method of their surface hardening.

The investigations were carried out within the framework of the project AP05134800 "Development of automated grain-fertilizer-grass seeder for differentiated direct sowing of crops under cover crops and in turf with simultaneous application of mineral fertilizers".

Hardened samples, macrostructural studies were carried out on the basis of laboratories of the department of "Technological machines and equipment" at S.Seifullin KATRU.

Methodology

For the research samples of chisel openers of grain-fertilizer-grass seeders were used [23, 24], which was made of the most used for fast-wearing working organs structural spring steel 65Mn, which in comparison with other steels allows to get less rough surface at hot processing, less prone to decarburization. Steel 65Mn has increased strength, toughness and resistance to wear, high resistance to small plastic deformations and relaxation resistance, has a fairly high harden ability, relatively low cost [25].

Typical (factory) method of chisel heat treatment is realized by means of their volume hardening (temperature in the range of 800 - 830°C) in oil hardening medium and tempering (at temperature in the range of 300 - 350°C) in air.

Based on the results of information search and possibility of further realization of chisel opener hardening technologies at production in agricultural enterprises of Kazakhstan the following methods of wear resistance increase were adopted: electric arc surfacing with hard-alloying electrodes T590 (Mn 1,0-1,5%, Si 2,0-2,5%, C 2,9-3,5%, P ≤ 0,04, S ≤ 0,035, Cr22,0- 27,0, B 0,5-1,5) and CS-1 (Sormite №1) with diameter 5,0 mm; HFC-heating of chisels for hardening.

Heat treatment of commercially manufactured chisels was carried out in an electric furnace chamber laboratory model SNOL 12/12-V, cladding on the working surfaces of experimental chisel samples was carried out by inverter welding power source model Flextec 500P.

HFC-hardening of chisel opener samples was carried out at temperatures within 800 - 820°C (Figure 1) in hardening medium - in oil, surfacing process with electrodes T590 and CS-1 (Sormite №1) was carried out on optimal modes (23): surfacing current I = 250 - 300 A (constant reverse polarity), voltage U = 50 - 70 V.

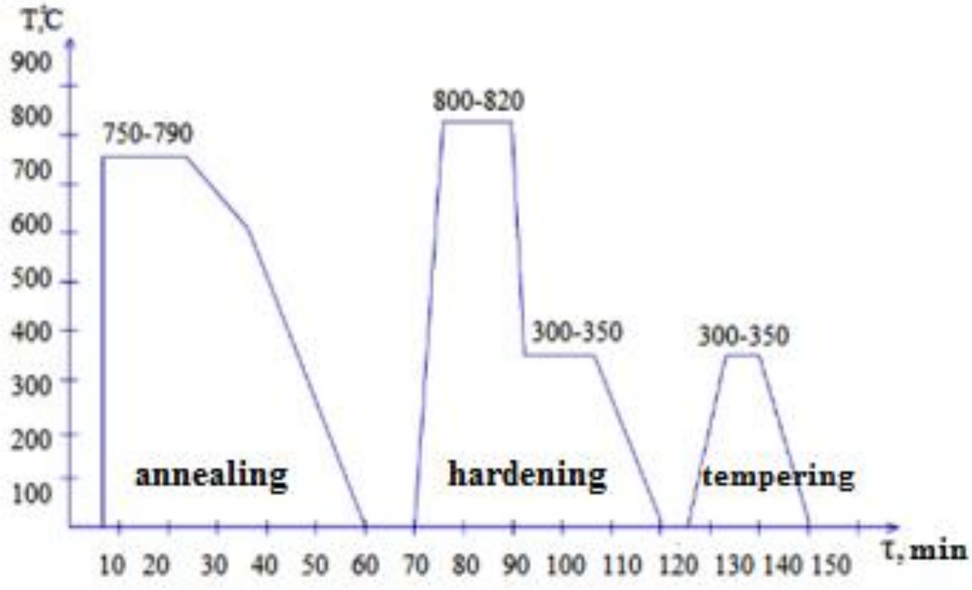


Figure 1. Proposed mode of heat treatment of spring steel 65Mn

Macrostructural analysis

During the macrostructural analysis by ultrasonic flaw detector ultrasonic pulse reflected from the defect and from the bottom is amplified and registered on the screen of the indicator. The indicator in the flaw detector is an electron-beam tube, on the screen of which, with the help of a special deployment device, there is a time diagram corresponding to the propagation of the ultrasonic pulse in the metal. Horizontal lines on the screen represent the time axis. Sending an ultrasonic pulse into the investigated metal is made periodically, the ultrasound propagates in this metal at a constant speed:

$$\vartheta = \frac{S}{T} \quad (1)$$

where ϑ – velocity sound,
S – distance,
T – time.

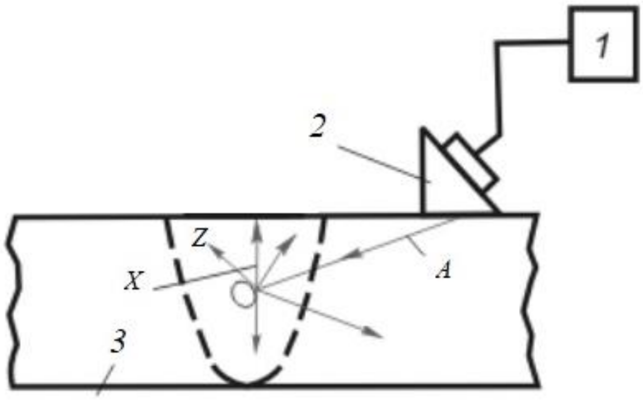
A defect located inside the metal can be detected by the pulse burst registered on the screen, where the distance between the initial pulse and the pulse reflected from the defect corresponds to the defect depth

a) Experimental opener-splitter b) Seeder before sowing

Figure 2. Experimental grain-fertilizer-grass seeder

Field tests of serially manufactured and hardened samples of anchor chisel openers (Figure 2) were conducted in the spring sowing campaign of 2019 in soil and climatic conditions of Akmola region of Kazakhstan on ordinary chernozemic soil (moisture 25 - 45 %, soil contamination with stones with an average diameter of 50 mm was 0.6 - 1.5 pcs/m2) at seeding of sown vetch (spring), creeping clover and alfalfa on a machine-tractor unit consisting of a wheeled tractor of traction class 2 + grain-fertilizer-grass seeder [26].

a) the process of measuring the working surface of the sample by the flaw detector sensor	b) Ultrasonic flaw detector model A1212 MASTER



c) working principle of the device: 1 – electronic unit of the flaw detector;
2 – piezoelectric transducer; 3 – controlled object

Figure 3. Ultrasonic flaw detector for examination of worn surfaces of chisel openers

The condition of worn surface layers of chisel openers for the presence of defects (microcracks in hardened surfaces, porosity, continuity and internal delamination of clad layers, corrosion centers) was studied by ultrasonic flaw detector model A1212 MASTER. The device allowed to implement standard and specialized methods of ultrasonic inspection, high productivity and accuracy of measurements.

The presence of elastic properties in a medium ensures the appearance of elastic waves in it. In a solid, displacements in a layer will cause stresses in neighboring layers. These stresses will cause displacements in neighboring layers, resulting in transverse waves [27, p.25].

Mathematically, the motion of a body under the action of a force is described by Newton's second law. When analyzing a continuous medium, all quantities are referred to the unit volume and the force F is defined by the tensor stress σ.

In field theory, Helmholtz's theorem, which states that any continuous vector field $\vec{u}$ can be represented as a sum of potential (linear) $\overrightarrow{u_l}$ and vortex (tangential) $\overrightarrow{u_l}$ fields.

$$\vec{u} = \overrightarrow{u_l} + \overrightarrow{u_t} \tag{2}$$

Acoustic emission appears at plastic deformation, at the emergence and at the formation of cracks. Acoustic emission signals propagating to the sample surface (28, p.111).

When examining defects after field experiments on the ultrasonic flaw detector, we consider the defect as a derivative of the area S_b and obtain a ratio for the coefficient determining the reflectivity of the defect

$$K = R \cdot S_b \tag{3}$$

where R≈1 – wave reflection coefficient at the steel-air interface;

S_b– defect area

Natural defects can have a wide variety of shape, size, orientation and acoustic properties.

The amplitudes of echo-signals from defects differ little if the size of defects is larger than the ultrasound wavelength [28, p.113-115].

Findings and Discussion

The values of physical characteristics for 65Mn steel (Table 1) were implemented in the ultrasonic flaw detector to obtain the results of ADC diagrams. From the given data, the velocity of 3250 m/s, gain of 40 dB, step gain of 1dB and chisel thickness of 11 mm were assumed.

Table 1.

Values of physical characteristics for steel 65Mn

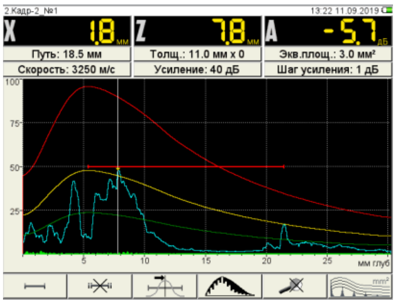
Modulus of elasticity E $(mN/m^2)\cdot10^3$	density p (kg/m^3) 10^{-3}	Poisson's ratio σ	Sound velocity (m/s)		Specific wave resistance $(kg(m^2\cdot s))\cdot10^{-6}$
			C_l	C_t	
12.8÷20.15	7.8÷7.9	0.28÷0.35	5320÷5850	2950÷3250	40÷45

ADC diagrams are usually constructed from a reference calibration of a known feature, such as a bottom reflector or flat-bottom hole at a given depth. Using this calibration point, the entire curve can be plotted, taking into account PET characteristics and material properties (Table 1). Instead of displaying the entire series of curves, the instrument typically displays a single curve based on the size of the selected reflector (detectable limit). In Figure 4, the upper curve (red) represents the ADC plot for a 2 mm disk reflector at a depth of 50 to 100 mm. The lower curve (yellow) is a reference curve plotted at amplitude (A) from 0.4 to 6.9 dB below. On the screen, the red strobe indicates the reflection from the flat-bottom hole at a depth of 11 mm. Based on the height and depth of the reflector in relation to the curve, the instrument calculated the equivalent area (lower blue and green curves) of the worn surface.

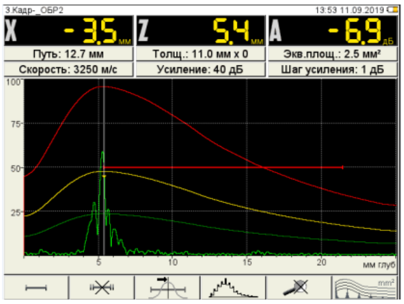
The ADC-diagram shows (Fig.4, a) that when probing the area at coordinates X=1.8 mm the signal is caught by the direct beam. This is evidenced by the "digit 0" after the multiplication sign in the box with the thickness of the object. The amplitude of the signal is 5.7 dB below the rejection level and the equivalent area is 3.0 mm2. The reflection is obtained at a depth of 7.8mm.

The same measurements were made with samples №2-9. The results of ultrasonic flaw detector examination of worn surfaces of experimental samples of coulter chisels are given in Table 2.

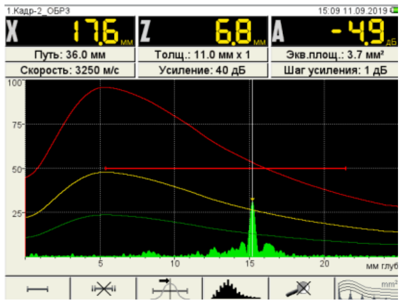
According to the data of frames from Figure 4 and Table 2, obtained as a result of ultrasonic flaw detector it can be noted that among the experimental samples the highest value of the equivalent area of defect (wear) were at the samples of commercially manufactured chisels (№4, №5, №7, №8 и №9) with the same parameters according to the factory technology. And the sample with hardened full working surface by surfacing with T590 electrode (Figure 4,b) has the smallest equivalent wear area.



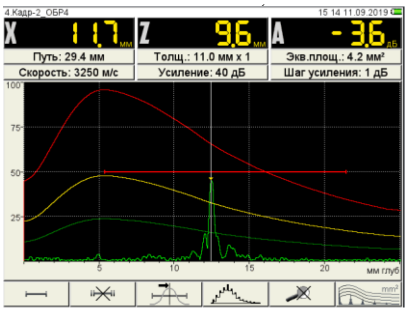
a) sample with hardened working surface by cladding with T590 electrode (front and back sides)



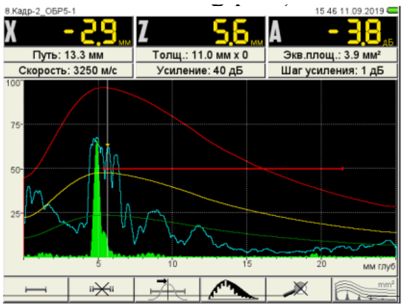
b) sample with hardened working surface by cladding with T590 electrode (full working part)



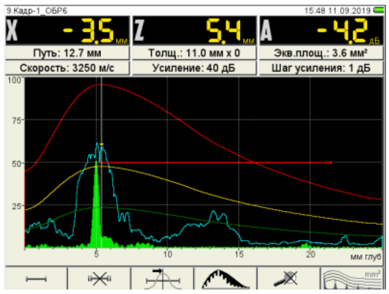
c) sample with hardened working surface by HFC hardening



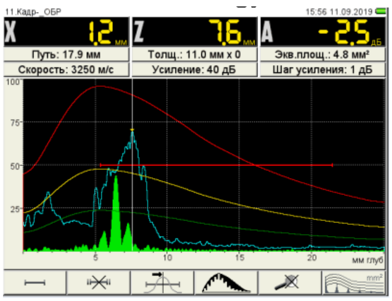
d) sample with thermally treated working surface according to factory technology



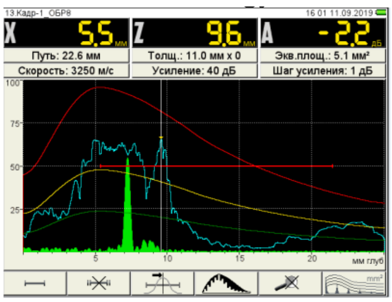
e) sample with thermally treated working surface according to factory technology



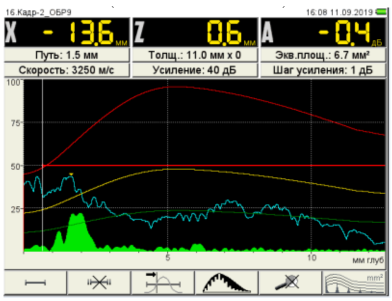
f) sample with hardened working surface by cladding with CS-1 electrode (sormite No.1)



g) sample with thermally treated working surface according to factory technology



h) sample with thermally treated working surface according to factory technology



i) sample with thermally treated working surface according to factory technology

Figure 4. Cadres from ADC diagrams of ultrasonic flaw detector of worn surfaces of grain-fertilizer-grass seeder chisel openers

Table 2

Results of investigation of worn surfaces of 11mm thick chisel openers

Sample number	Repetition of experiment	Material	Coordinates of defect parameters			Path, mm	Eq. area, mm²	Average arithm. eq. area, mm²
			X, mm	Z, mm	A, dB			
1	1	Steel 65Mn+T590 (front and back side)	1.8	7.8	-5.7	18.5	3	3.25
	2		-3.3	5.5	-4.4	12.9	3.5	
2	1	Steel 65Mn +T590 (full working part)	-3.5	5.4	-6.9	12.7	2.5	2.85
	2		-2.1	6	-5.1	14.2	3.2	
3	1	Steel 65Mn (HFC-quenching)	17.6	6.8	-4.9	36	3.7	3.3
	2		-3.5	5.4	-8.8	12.7	2.9	
4	1	Steel 65Mn (factory technology)	10.9	9.9	-6.6	28.6	3.8	4.0
	2		11.7	9.6	-3.6	29.4	4.2	
5	1	Steel 65Mn (factory technology)	0.2	7.1	-5.6	16.8	3.8	3.85
	2		-2.9	5.6	-3.8	13.3	3.9	
6	1	Steel 65Mn +CS-1 (sormite №1)	-3.5	5.4	-4.2	12.7	3.6	3.55
	2		-3.5	5.4	-4.5	12.7	3.5	
7	1	Steel 65Mn (factory technology)	1.2	7.6	-2.5	17.9	4.8	4.8
	2		3.1	8.4	-0.8	17.9	4.8	
8	1	Steel 65Mn (factory technology)	5.5	9.6	-2.2	22.6	5.1	4.6
	2		-1.3	6.4	-3.5	15.1	4.1	
9	1	Steel 65Mn (factory technology)	-1.7	6.2	-11.1	14.7	3.5	4.1
	2		-13.6	0.6	-0.4	1.5	6.7	

In addition, at sample 1, hardened only by the front and back side of the surfacing electrode of T590 brand (Figure 4, a) and the sample with the working surface hardened by the surfacing electrode of CS-1 brand (Sormite №1) the equivalent area of wear were smaller in comparison with the samples with the working surface hardened by HFC hardening and mass-produced according to the factory technology.

In Figure 5, on the front surface of the chisels, samples d, e, and i are left with small dents and chips in the form of grooves and holes when exposed to hard particles, and cutting marks and rounded chamfer from mineral substances with sharp edges in samples c, f, g, h. Samples a and b are less susceptible to abrasive wear.

As a result, it can be noted from Table 2 and Figures 4 and 5 that the data of sample №2 is abrasion resistant due to hardening of the full working surface by surfacing with T590 grade electrode.

a) sample with hardened working surface by cladding with T590 electrode (front and back sides)

b) sample with hardened working surface by cladding with T590 electrode (full working part)

c) sample with hardened working surface by HFC hardening

d) sample with thermally treated working surface according to factory technology

e) sample with thermally treated working surface according to factory technology

f) sample with hardened working surface by cladding with CS-1 electrode (sormite No.1)

g) sample with thermally treated working surface according to factory technology

h) sample with thermally treated working surface according to factory technology

i) sample with thermally treated working surface according to factory technology

Figure 5. Photos of worn surfaces of grain-fertilizer-grass seeder chisel opener hardened by different methods

Conclusion

Analyzing the photos of worn surfaces of chisel opener, data from Tables 1-2, Figures 1 and 2, and information on the method of hardening and materials used, the following conclusions can be drawn:

1. The condition of worn surface layers of chisel opener for defects in them can be studied using an ultrasonic flaw detector.

2. According to the results of ADC-diagrams obtained by ultrasonic flaw detector it is established that the equivalent wear area of hardened samples is less in comparison with serially manufactured (factory technology) samples.

3 Among the hardened samples, the sample hardened with the full working surface with T590 electrode cladding has the smallest equivalent wear area, and also according to the results of field experiments, this sample had the highest resistance to abrasive impact.

4 According to the results of field experiments, the samples serially manufactured by the factory technology, hardened with Sormite and HFC quenching on the front surface of the chisel had small indentations and chips in the form of grooves and holes when exposed to hard particles, as well as cutting marks and rounded chamfer from minerals with sharp edges.

5. As the most rational method of chisel hardening for the conditions of production and agricultural enterprises it is possible to recommend replacement of typical factory heat treatment by surfacing of the full working part of working bodies of seeder opener with T590 electrodes.

Acknowledgements, conflict of interest

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No potential conflict of interest was reported by the author(s).

Authors' contribution:

Dinara Kossatbekova has collected of literature data and then done analysis and synthesis of them. She carried out macrostructural study, conducted an analysis and systematization of experimental data, and tracked the reproducibility of the results. Dinara conducted comparative analysis, summarizing the results of the study, formulation of conclusions, and interpreting the results of the study. She wrote and organized the text of the manuscript.

Sayakhat Nukeshev has justified the research concept with formulation of the idea, research goals and objectives and created the research model. He has revised critically and edited the manuscript text, including stages before or after publication of the manuscript. Professor Sayakhat did analysis, systematization and accumulation of experimental data, both for initial **and subsequent use.**

Nikolay Romanyuk has justified of the research concept by formulation of the idea, research goals and objectives and developed of research methodology. He did analysis, systematization and accumulation of experimental data, both for initial and subsequent use.

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Д.Ш. Косатбекова*[1], С.О.Нукешев[2], Н.Н.Романюк[3]
[1,2]Казахский агротехнический исследовательский университет имени С.Сейфуллина, Астана, Казахстан
[3]Белорусский государственный аграрный технический университет, Минск, Беларусь

Макроструктурный анализ упрочненного долота с помощью наплавки на основе кремний-марганец-хрома

Аннотация. Актуальность исследования обусловлена тем, что износ рабочих органов посевных машин приводит к увеличению расхода топлива, ухудшению качества заделки семян и, как следствие, снижению урожайности. В связи с этим, данная статья направлена на исследование состояния упрочненных рабочих органов экспериментальной зернотукотравяной сеялки. На основании результатов информационного поиска принимались следующие методы упрочнения: электродуговая наплавка твердосплавными электродами и сормайтом; нагрев ТВЧ долот под закалку. Для проведения исследований использовались образцы экспериментальных долот сошников зернотукотравяной сеялки, изготовленные из стали 65Г. Состояние изношенных поверхностных слоев долот сошников изучалось ультразвуковым дефектоскопом. Исследования позволили установить, что среди упрочненных образцов наименьшую эквивалентную площадь износа имеет образец, упрочненный полной рабочей поверхности с наплавкой электродами марки Т590, а также по результатам полевых экспериментов у данного образца была наибольшая стойкость к абразивному воздействию. На основании этих результатов в качестве наиболее рационального метода упрочнения долот для условий производства в сельскохозяйственных предприятиях рекомендуется замена типовой заводской термообработки на упрочненную полной рабочей части.

Ключевые слова: макроструктурный анализ, износ, упрочненная сталь, термическая обработка, АРД диаграмма, долото сошника, зернотукотравяная сеялка.

Д.Ш. Косатбекова*[1], С.О. Нукешев[2], Н.Н. Романюк[3]
[1,2]С.Сейфуллин атындағы Қазақ агротехникалық зерттеу университеті, Астана, Қазақстан
[3]Белорусь мемлекеттік аграрлық техникалық университет, Минск, Беларусь

Кремний-марганец-хром негізіндегі балқытумен нығайтылған қашауға макроқұрылымдық талдау

Аңдатпа. Зерттеудің өзектілігі егіс машиналарының жұмыс органдарының тозуы отын шығынының артуына, тұқым себу сапасының нашарлауына және нәтижесінде өнімділіктің төмендеуіне әкелетіндігіне байланысты. Осыған байланысты, бұл мақала тәжірибелік астық-тыңайтқыш-шөп сепкіштің қатайтылған жұмыс органдарының жағдайын зерттеуге бағытталған. Ақпараттық іздеу нәтижелерінің негізінде қатайтудың мынадай әдістері қабылданды: қатты қорытпалы электродтармен және сормайтпен электр доғалық балқыту; шынықтыру үшін ЖЖТ қашауды шынықтыру. Зерттеу жүргізу үшін 65Г болаттан жасалған астық-тыңайтқыш-шөп сепкiштiң эксперименттiк қашауларының үлгiлерi пайдаланылды. Зерттеулер қатайтылған үлгiлердiң iшiнде тозудың ең аз эквиваленттi ауданында Т590 маркалы электродтармен балқытылған толық жұмыс бетiмен қатайтылған үлгi бар екенiн, сондай-ақ далалық эксперименттердiң нәтижелерi бойынша бұл үлгiнiң абразивтi әсерге төзiмдiлiгi жоғары екенiн анықтауға мүмкiндiк бердi. Осы нәтижелерге сүйене отырып, ауылшаруашылық кәсiпорындарындағы өндiрiс жағдайлары үшiн қашауды қатайтудың ең ұтымды әдiсi ретiнде типтiк зауыттық термиялық өңдеудi толық жұмыс бөлiгiнiң бетi қатайтылғанға ауыстыру ұсынылады.

Түйiн сөздер: макроқұрылымдық талдау, тозу, қатайтылған болат, термиялық өңдеу, ААД диаграммасы, сiңiрушiнiң қашауы, астық-тыңайтқыш-шөп сепкiшi.

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Сведения об авторах:

Косатбекова Динара Шадиярбековна – магистр технических наук, докторант, старший преподаватель, Казахский агротехнический исследовательский университет имени С.Сейфуллина, пр. Победы 62, 010000, Астана, Казахстан, 8707 106 5219, ms.kossatbekova@mail.ru

Нукешев Саяхат Оразович – доктор технических наук, профессор, Казахский агротехнический исследовательский университет имени С.Сейфуллина, пр. Победы 62, 010000, Астана, Казахстан, 8701 512 9791, snukeshev@mail.ru

Романюк Николай Николаевич – кандидат технических наук, доцент, ректор, Белорусский государственный аграрный технический университет, пр. Независимости, 99, 220023, Минск, Беларусь, +375 (29) 557 06 09, romanyuk-nik@tut.by

Косатбекова Динара Шадиярбековна – техника ғылымдарының магистрі, докторант, аға оқытушы, С. Сейфуллин атындағы Қазақ агротехникалық зерттеу университеті, Жеңіс даңғылы 62, 010000, Астана, Қазақстан, 8707 106 5219, ms.kossatbekova@mail.ru

Нукешев Саяхат Оразович – техника ғылымдарының докторы, профессор, С. Сейфуллин атындағы Қазақ агротехникалық зерттеу университеті, Жеңіс даңғылы 62, 010000, Астана, Қазақстан, 8701 512 9791, snukeshev@mail.ru

Романюк Николай Николаевич – техника ғылымдарының кандидаты, доцент, ректор, Беларусь мемлекеттік аграрлық техникалық университеті, Тәуелсіздік даңғылы, 99, 220023, Минск, Беларусь, +375 (29) 557 06 09, romanyuk-nik@tut.by

Kossatbekova Dinara Shadiyarbekovna – master of technical Sciences, doctoral student, senior lecturer, Kazakh Agrotechnical Research University named after S.Seifullin, 62 Pobedy Ave., 010000, Astana, Kazakhstan, 8707 106 5219, ms.kossatbekova@mail.ru

Nukeshev Sayakhat Orazovich – doctor of technical sciences, professor, Kazakh Agrotechnical Research University named after S.Seifullin, 62 Pobedy Ave., 010000, Astana, Kazakhstan, 8701 512 9791, snukeshev@mail.ru

Nikolay Nikolaevich Romanyuk – candidate of Technical Sciences, docent, rector, Belarusian State Agrarian Technical University, 99 Nezavisimosti Ave., 220023, Minsk, Belarus, +375 (29) 557 06 09, romanyuk-nik@tut.by.