

# Improving of the wear resistance of working parts agricultural machinery by the implementation of the effect of self-sharpening

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## Abstract

The failure of the cutting elements of farm machinery is due to the blunting of cutting edges (increase of their radius) till the limit values. The most effective method for increasing the wear resistance of farm machinery is the realization of self-sharpening effect of the cutting elements. The testings took place in laboratory and field at the State Technical University of Kirovograd (Ukraine) in 2015. The technical equipment consists of the consolidated farmer plowshares by different methods as well as their samples, devices for measuring the wear resistance and thumbprint plowshares. It was determined the resistance to wear, the radius of curvature and the changing coefficient of the blades shape. The self-sharpening process was examined throughout the experiment.

The results showed that the consolidated plowshares by the proposed technology (laser welding of the mixture (PS-14-60 + 6% B4C) compared to the traditional technology (volumetric heat treatment) have a blade radius 2.5 times lower, a wear 2.2 to 2.78 times lower and the self-sharpening process of the plowshares has been observed since the beginning of the wear until the time limit operation. The changing shape coefficient was respectively of 0.98 for the consolidated plowshares with alloy PS-14-60 + 6% B4C and 0.82 for those consolidated by volumetric heat treatment.

**Keywords:** Wear Resistance; Laser Welding; Plowshares; Self-Sharpener; Blades Profile.

## 1. Introduction

The cutting elements (CE) are the main working areas of farm machinery (MWAFFM) [1], [2]. When working in abrasive area, plowshares geometry of the growers changes. The size and nature of these changes are primarily dependent of the materials properties with which these plowshares are manufactured, the physical and technological soil properties and performance characteristics of farm machinery (FM).

Practice shows that, in most cases, the failure of the plowshares is due to the blunting of the cutting edge (increase in radius) to the limit values. In addition, there is uneven wear of the cutting plowshares of FM. The most active wear is observed at the plowshares point. It is therefore subjected to maximum loads, which corresponds to the maximum wear [3], [4], and [5].

The plowshares blunting influences on the stability of the work of FM in depth and the increase of the energy characteristics of the technological process of tillage. Increasing the thickness of the plowshares from 0.2 mm to 0.3 mm and 0.8 mm to 1.2 mm increases the tensile strength of the cultivator from 7 to 14%, and increasing this thickness of 2 mm causes an increase in the tensile strength of 34 % [2], [6].

The dynamics of change in the geometry of plowshares during the interaction of these latters with the ground is not sufficiently studied: no common view on the self-sharpening process and blunting and not clearly defined the conditions of their manifestation.

The consolidation of one of plowshares work surfaces slows the formation of the occipital chamfer and allows self-sharpening

effect [7]. The abrasive wear of MWAFFM management problem in the scientific literature is oriented mainly on the improvement of physico-mechanical properties of the friction surfaces by consolidation technology methods [8], [9]. Thus, the most effective method for increasing the wear resistance of MWAFFM is the achieving of the self-sharpening effect of CE, positively influencing on the quality and energy consumption of the soil working.

For the implementation of the effect of self-sharpening plowshares, consolidation can be carried out during the design, manufacture and operation [10], [11], [12].

For technological consolidation methods of MWAFFM, the welding is often used [10], [13], and [14].

During the manufacture of MWAFFM, nearly 90% of the coating works are done by high frequency induction welding [15]. The most widely consolidation methods used in recent years are those based on the use of concentrated energy flux (CEF) [16], [17], [18]. These methods are directly related to the use of flux directed to substance and energy of physical fields to modify the physical properties of the surface layer of the material MWAFFM [19], [20]. The analysis of the methods of improving wear resistance [4, 21] showed that the construction of MWAFFM is relatively unchanged and their improvement is mainly passed through the selection of materials, their methods of treatment and improving the geometric shape. However, the operational efficiency, especially of MWAFFM remains very low, which affects the productivity of tillage. The main way to solve this problem is the creation of self-sharpening plowshares [22], [23].

The difficulty of obtaining self-sharpening plowshares is based on the need to maintain adequate sharpening during operation. The

profile shape of plowshares with two layers during the wear depends on the ground pressure ratio in different parts of the CE; the wear resistance of the materials and the thickness of their layers, and finally the ability to the soil wear [24]. The choice of the minimum thickness of the plowshare point must be associated with an economically reasonable life of MWAFFM, and the maximum thickness of the agro-technical requirements for the quality of their work.

The objective of this work is to improve the sustainability of CE FM by the implementation of the self-sharpening effect.

## 2. Material and method

### 2.1. Material

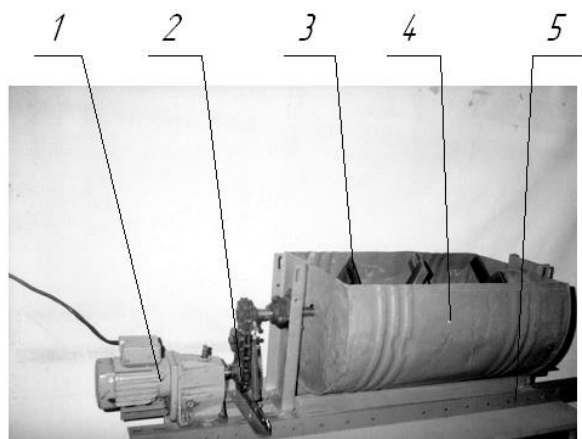
It is composed of:

- Plowshares made of steel 45, consolidated by volumetric heat treatment;
- Plowshares made of steel 45, consolidated by thermal laser treatment;
- Plowshares made of steel 45, consolidated by induction of alloy PS-14-60;
- Plowshares made of steel 45, consolidated by laser welding alloy PS-14-60 + 6% B<sub>4</sub>C;
- Samples in steel 45 of dimensions 50 x 20 mm and 4 mm thickness, consolidated by different technologies (volumetric heat treatment, laser heat treatment, induction welding of alloy PS-14-60, laser welding of alloy (PS-14-60 B<sub>4</sub>C + 6%);
- Device for carrying out testings on the resistance to abrasive wear;
- Device for taking thumbprints of MWAFFM plowshares;
- Brand tractor MTZ-80;
- Brand Cultivator CPS-4 with a working width of 4m;
- Brand electronic balance VDR - 200, 10<sup>-4</sup>g accuracy.

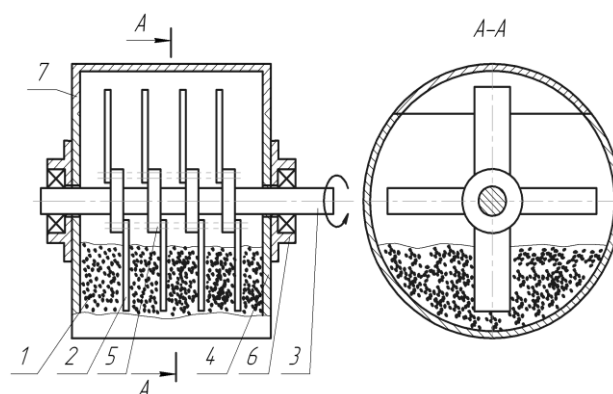
### 2.2. Method

The testings took place in 2015 in the laboratory and on the experimental field of the State Technical University of Kirovograd (Ukraine).

For laboratory testings, it was used samples in steel 45 of dimensions 50 x 20 mm and 4 mm thickness, consolidated by different technologies. The wear of the samples was determined using a laboratory device whose global aspect and diagram are shown in Figures 1 and 2. The samples were placed in the device and subjected to wear in the middle abrasive. The wear was controlled by the gravimetric method (weight) using a VDR-200 balance with a precision of 10<sup>-4</sup>g. The test duration is 100 hours and the testing was performed every 20 hours.



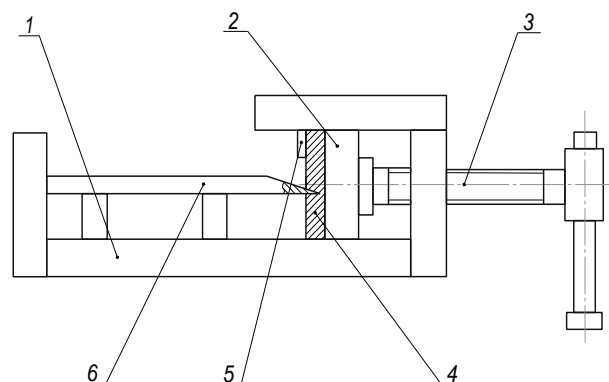
**Fig. 1:** General View of the Sample Testing Device on The Resistance to Abrasive Wear: 1 - Gear Motor; 2 - Chain Drive; 3 - Sample; 4 - Body Cylindrical Drum; 5 - Frame.



**Fig. 2:** Diagram of the Device for the Samples Testing on the Resistance to Abrasive Wear: 1 - Abrasive; 2 - Sample; 3 - Shaft; 4 - Body; 5 - Washer; 6 - Support; 7 - Cover.

For the testing in field, plowshares in steel 45 consolidated by different technologies have been connected to a farmer hitched to a tractor. The wear of local areas was controlled by the linear method. The measurements were taken every 5 ha. Data processing was done on the computer.

The study of the formation of character of plowshares profiles was conducted by taking thumbprint method of the plowshares studied areas. To this end, it has been used the device [1], [3], [4] whose diagram is shown in Figure 3. The blades of the footprint taken was performed every 30 ha operating until 120 ha. The thumbprint obtained from blades profiles were photographed using an electronic camera and analyzed with the computer by setting the radius of curvature of the blades and wear values.



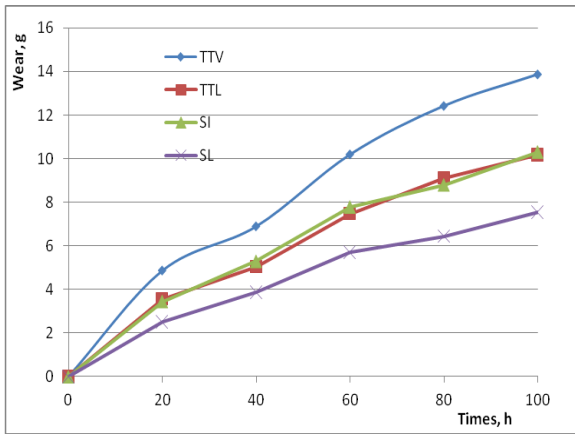
**Fig. 3:** Diagram Device of the Plowshares Taking Thumbprint: 1 - Body; 2 - Slide; 3 - Screws; 4 - Lead Plate; 5 - Support; 6 - Cutting Element.

## 3. Results and discussion

### 3.1. Results

The results from laboratory (Fig. 4) showed that after 100 hours of testing, the consolidated samples by laser welding showed the smallest wear (7.55g) while those consolidated by the volumetric heat treatment were subjected to the greatest wear (13.88g). At all samples level, the intensity of wear at the beginning of the experiment (until 50 h) is slightly higher compared to that of the remaining experiment.

Tables 1 and 2 show the results of the linear wear to the characteristic points of the farmer plowshares.



**Fig. 4:** Dependence of the Gravimetric wear of the Samples in Steel 45 Depending on the Duration of the Testing at Different Methods of Consolidation VHT- Volumetric Heat Treatment, LHT -Laser Heat Treatment, IW- Induction Welding, LW – Laser Welding.

**Table 1:** Linear wear to the Characteristic Points of the Farmer Plowshares Consolidated by the Volumetric Heat Treatment (VHT) and the Laser Heat Treatment (LHT).

Duration of the exploitation, ha	Consolidation method	Linear wear to the characteristic points, mm					
		1	2	3	4	5	6
5	VHT	8.7	7.8	6.9	5.8	5.8	6.7
	LHT	6.3	5.4	4.2	3.9	4.0	4.4
10	VHT	13.	12.	11.	9.9	9.7	10.
	LHT	4	1	5	9.9	9.7	1
15	VHT	9.1	8.2	7.3	6.7	6.5	6.9
	LHT	16.	14.	13.	12.	12.	12.
20	VHT	0	9	8	7	5	9
	LHT	12.	11.	10.	9.3	8.9	9.2
25	VHT	18.	16.	15.	14.	14.	15.
	LHT	6	2	6	9	8	3
30	VHT	13.	12.	11.	10.	9.9	10.
	LHT	2	0	1	3	9.9	2
35	VHT	22.	19.	18.	17.	17.	16.
	LHT	0	5	7	9	4	9
40	VHT	14.	12.	12.	11.	10.	10.
	LHT	1	8	0	4	2	9

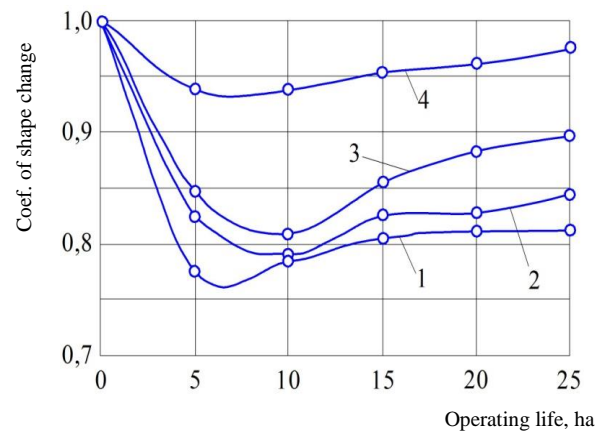
**Table 2:** Linear wear to the Characteristic Points of Consolidated Plowshares by Induction Welding (IW) of Alloy PS-14-60 and Laser Welding (LW) of Alloy PS-14-60 + 6% B<sub>4</sub>C

Duration of the exploitation, ha	Consolidation method	Linear wear to the characteristic points, mm					
		1	2	3	4	5	6
5	IW	4.5	3.9	3.0	3.3	3.1	3.5
	LW	2.6	2.5	2.4	2.4	2.5	2.4
10	IW	6.4	5.2	5.0	4.9	4.9	5.1
	LW	4.1	4.0	4.0	3.8	3.9	4.0
15	IW	8.5	7.6	7.2	6.7	6.8	7.0
	LW	5.2	5.0	5.1	4.9	4.8	5.0
20	IW	10.	9.9	9.5	9.3	9.4	9.6
	LW	8	6.7	6.5	6.4	6.2	6.5
25	IW	13.	12.	11.	11.	11.	11.
	LW	0	5	9	2	0	7
30	IW	7.9	7.7	7.8	7.5	7.8	7.7
	LW	7.9	7.7	7.8	7.5	7.8	7.7

Tables 1 and 2 show that after 25 ha of operation, the wear at different characteristics points of the consolidated plowshares by the volumetric heat treatment and those consolidated by laser welding of alloy PS-14-60 + 6% B<sub>4</sub>C respectively varied from 22.0 to 16.9 mm and 7.9 to 7.7 mm. This implies that the wear of plowshares

consolidated by the volumetric heat treatment is from 2.2 to 2.78 higher than that of the plowshares consolidated by laser welding. In addition, at points 1, 2 and 3, the wear is more intense for these methods of consolidation and it was observed a local character of the wear throughout the blade of the plowshares. Besides, during the laser consolidation, the radius optimal values of the cutting edge will keep up the operating time of 25 ha, which proves the realization of the self-sharpening process, whereas during the volumetric heat treatment the radius maximum values of the cutting edge can already be seen in an operating time of 15 ha and self-sharpening is not performed.

The different characters of wear in the selected points of plowshares reflect the change of their shape during the operation. The dynamics of change in the shape of the plowshares during operation was evaluated according to the coefficient of change in shape (Fig. 5).



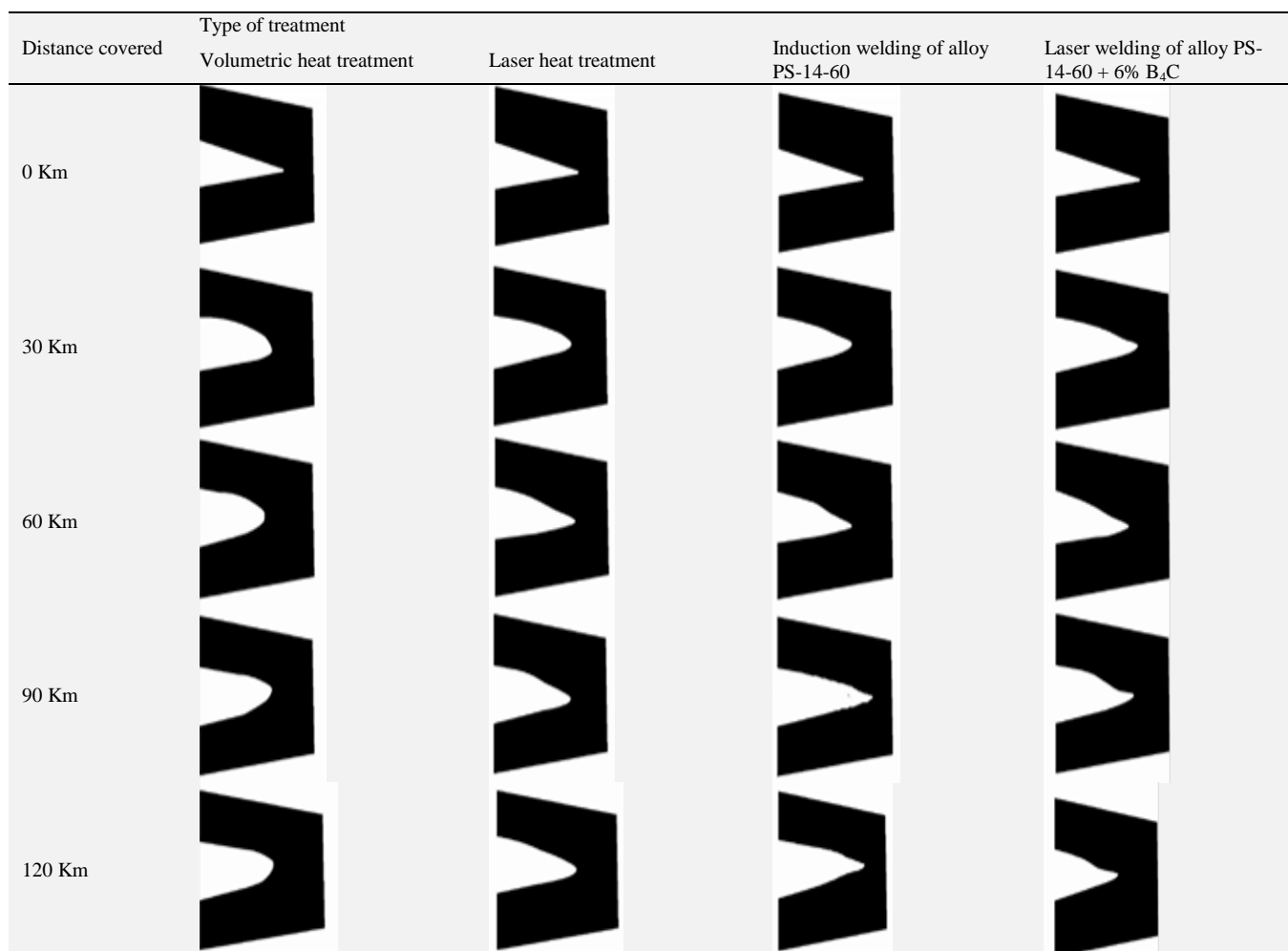
**Fig. 5:** Dependence of the Coefficient of Change in Shape According to the Operating Life of the Plowshares at Different Consolidation Methods: 1 - Volumetric Heat Treatment (Basic Technology), 2 - Laser Heat Treatment, 3 - Induction Welding of Alloy PS-14-60 (Basic Technology), 4 - Laser Welding of the Alloy PS-14 -60 + 6% B<sub>4</sub>C.

It appears from the experiment that the change in shape of the plowshares depends on the consolidation method. The proposed technology in laser reloading of alloy PS-14-60 + 6% B<sub>4</sub>C allows for a long operating time to maintain the original shape of the parts of MWAFM, as evidenced by the biggest differences of the coefficient values change in shape. The other methods of consolidation are characterized by a sudden decrease of the coefficient of change in shape at the beginning of the operating period of the plowshares (0-10 ha), after which it was observed some stability until the operating time of 25 ha.

Thus, after 25ha of operation, the coefficient of change in shape is respectively 0.98 for the laser consolidated plowshares of alloy PS-14-60 + 6% B<sub>4</sub>C and 0.82 for the consolidated plowshares by volumetric heat treatment.

The results of the study of blade profiles of the plowshares are presented in Figure 6.

Figure 6 shows that the consolidated plowshares by volumetric heat treatment have already intensely worn out after the 30 km course. The gradual increase of the covered distance leads to the increase of the curvature radius of the sharpen angle and under certain conditions to the formation of the occipital chamfer. During the experiments, after a covered distance of 50 to 60 km, these plowshares are subjected to reparation as the blunting radius blades exceeded their 1.2 mm that is the limit value.



**Fig. 6:** Dynamics of Changing Profiles of the Plowshares Blades According to the Type of Treatment and the Covered Distance.

The induction welding of the alloy PS-14-60 provides the effect of self-sharpening plowshares slows the formation of the occipital chamfer and offers a minimum radius of the blade after 100. 120 km distance covered. The next increase of the distance leads to a rapid increase in the blade curvature radius with the formation of the occipital chamfer.

The adoption of the laser heat treatment of the underside of the plowshares to a depth of 1.0 mm favors self-sharpening of the plowshares. After a covered distance of 90 to 100 km, the radius of curvature of the plowshares blade is between 0.6 and 0.8 mm, which corresponds to admissible values. With the increase of distance up to 120 km and the wear of the consolidated layer, it was observed a similar board for the consolidated plowshares by volumetric heat treatment at a distance equal to 60 km.

Consolidated plowshares by laser welding with the alloy PS-14-60 + 6% B<sub>4</sub>C have more presented the best results. The self-sharpening process is observed since the beginning of the plowshares wear until the operating period (120 km of course). Besides, during the testing the coating detachment brought was not observed.

The observations of the dynamics of the plowshares blade have shown that during the increase of the friction distance covered, the radius of the blade has changed. The processing data treatment by the computer allowed to determine the radius of the blade and its dependence according to the frictional distance and the consolidation method (Table 3).

**Table 3:** Dependence of the Blade Radius of Curvature Depending on the Frictional Distance and the Consolidation Method

Consolidation method	Blade radius of curvature, mm				
	30 Km	60 Km	90 Km	120 Km	150 Km
Volumetric heat treatment	0.51	0.76	0.95	1.23	1.34
Laser heat treatment in function with' thickness, mm	0.50	0.41	0.57	0.68	0.72
Induction welding of PS-14-60	0.75	0.37	0.52	0.60	0.63
Laser welding of PS-14-60	1.00	0.34	0.51	0.58	0.59
Laser welding of alloy PS-14-60 + 6% B <sub>4</sub> C	0.32	0.39	0.46	0.50	0.52
	0.29	0.34	0.41	0.45	0.48
	0.29	0.35	0.41	0.44	0.46

Experiments have shown that after 150 km of distance, the greater the blade curvature radius was observed during the volumetric heat treatment of the CE (1.34 mm), while the consolidated plowshares by laser welding of the mixture PS- 14-60 + 6% B<sub>4</sub>C presented the smaller diameter (0.46 mm). Therefore, the blades curvature radius consolidated by laser welding with mixture PS-14-60 + 6% B<sub>4</sub>C is 2.5 times lower than that of the blade consolidated by volumetric heat treatment. During laser heat treatment, the value of the blade curvature radius depends on technological regimes of treatment and plowshares material. Experiments have shown that for the self-sharpening effect to be achieved it is necessary that the coating thickness should be between 0.75 and 1.00 mm.

### 3.2. Discussion

The wear of plowshares consolidated by volumetric heat treatment is of 2.2 to 2.78 times higher than that of the consolidated plowshares by laser welding. This is due to the low hardness relative to the hardness of the abrasive particles in quartz of the soil and the wear capacity of the latter. These figures are higher than those

Semenov (2002) where they are from 1.8 to 2.5. It was revealed that the speed (intensity) of the samples gravimetric wear at the beginning of the experiment (until 50 h) is slightly higher than that the remaining experiment. After some time of operation it is observed stabilization in the mass wear intensity. The appearance of this time depends mainly on the consolidation method or the type of coating. Laboratory testings confirm a tendency towards the results from the fields because they show that the wear of the plowshares consolidated by volumetric heat treatment is of 1.84 times higher than that of consolidated plowshares by laser welding after 100 h of experiment.

The process of self-sharpening plowshares consolidated by laser welding of alloy PS-14-60 + 6% B<sub>4</sub>C is observed since the beginning of the plowshares wear until a period of operating limit of 120 km of course. These results are better than those of Aduov (2009) where self-sharpening was observed during the 100 km of course. The implementation of the self-sharpening effect can be explained by the characteristics of its own and the properties of the consolidated layer: porosity, hardness, linear wear dependency of the samples depending on fractions of the abrasive soil, the formation of the surface relief of work and the distribution of material in the surface layer. The addition of the boron carbide to the alloy PS-14-60 increases the wear resistance due to the formation of borides of iron and chromium which present a big hardness of 15-19 GPa.

Besides, during the testing, the detachment of brought coating was not observed. This can be explained by the strong adhesion of the coating with the base metal plowshares. The radius of curvature of the blades consolidated by laser welding of mixture PS-14-60 6% B<sub>4</sub>C is 2.5 times lower than that of the consolidated plowshares by volumetric heat treatment.

These numbers are similar to the results of Grigor'yants (2010) where the curvature radius of the experimental plowshares blade is of 2.7 times lower than that of the plowshares blade from existing technology

#### 4. Conclusion

The consolidated plowshares by laser welding of alloy PS-14-60 + 6% B<sub>4</sub>C showed the best results. Compared with traditional technology, they have a wear resistance of 2.2 to 2.78 times lower, a blade radius of curvature of 2.5 times lower and the self-sharpening process is observed since the beginning of the plowshares wear until the operating time of 120 km the distance covered. Besides, during the testing, the coating detachment provided has not been observed. During the heat treatment with laser, the experiments have shown that for the effect of self-sharpening to be realized it requires that the thickness of the coating should be between 0.75 and 1.00 mm. After 25ha operating in the fields, the coefficient of the change in shape was respectively of 0.98 for the laser consolidated plowshares of alloy PS-14-60 + 6% B<sub>4</sub>C and 0.82 for the consolidated plowshares by volumetric heat treatment. Therefore, laser welding of the mixture PS-14-60 + 6% B<sub>4</sub>C is the best solution for achieving the self-sharpening effect. That's why this technology can be recommended in the process of the manufacturing and rectification of the famer plowshares.

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