Research and modeling of the wear process of parts of the soil tillage working implements

N I Dzhabborov¹, A V Dobrinov¹,*, P N Jabbobov²

¹Federal State Budgetary Scientific Institution “Federal Scientific Agroengineering Center VIM”, 196625, Russia
²Green Economy Financing Facility/EBRD, 37a Bokhtar street, Dushanbe 734025, Republic of Tajikistan

*E-mail: a.v.dobrinov@yandex.ru

Abstract. Increasing the wear resistance of parts of tillage working implements and increasing their resource is an urgent problem. A decrease in the resource of tillage working implements occurs due to uneven wear of their parts and soil features. Accelerated wear of working surfaces reduces the quality of soil cultivation, increases the traction resistance of tillage machinery and thereby allows to an increase in the energy intensity of soil cultivation technology. The article presents the mathematical models developed by the authors that describe the process of interaction of the soil with the surface of parts of soil-cultivating working implements during their surfacing with hard alloys. The developed mathematical models make it possible to predict the values of traction resistance, the magnitude and rate of wear of the tillage working implements. The results of experimental studies confirm the adequacy of the developed mathematical models and indicate that the deposition of hard-facing from hard alloys of certain sizes and configurations on the working surfaces of the parts of soil-cultivating working implements ensures their wear resistance when working in an abrasive soil environment. The results of experimental studies of a plowing unit consisting of tractor MTZ-920 tractor and plow PLN-3-35 for sod-medium podzol, medium loamy (light loamy) soils on moraine loam showed that the wear resistance of the deposited share is 2.54 times higher than the wear resistance of the standard (serial) plowshares without surfacing.

1. Introduction
In solving the problem of improving the reliability of the functioning of tillage machines, an important role is played by the use of new effective methods of obtaining a wear-resistant working surface of the working implements of tillage equipment.

Analysis of studies on basic tillage with seam turnover gives a general idea of the traction resistance of the plow, which accounts for the resistance of the support wheels 9 – 11%, the resistance of the field board, depending on the plow body – 12 – 15%, the blade resistance 70 – 80%, and on the share itself 55 – 60%. During classical plowing as a process, energy costs for soil deformation are 17%, friction costs – 60%, for raising and turning the soil layer are at the level of – 13%, for its cutting – 10%.

Researchers have developed various methods of hardening parts of soil-cultivating working implements, applying wear-resistant coatings on the working surface of soil-cutting parts, substantiated and investigated modifications of hard alloys, studied methods of plasma, arc-surfacing
with hard alloys, revealed the effect of wear of working implements of machines on their technological performance. The assessment of methods and means of increasing the technical level of the working implements of machines for pre-sowing soil cultivation is given.

For example, article [1] is devoted to the analysis of the quality of surfacing, realized by arc-welding of shielded metal with covered electrodes. The wear resistance of the linings was determined from the weight loss due to abrasion.

In work [2], hard surfacing of structural steel was carried out by the method of thermal spraying using cobalt alloy powder and oxyacetylene gas. It was found that the increased heating temperature after spraying increased the hardness of the coating.

Researches of scientists [3] have found that medium-carbon steel used in tillage machines when coated with wear-resistant powders contributes to an increase in their service life. Experimental studies have shown that the use of tungsten carbide with cobalt (WC-Co) with a high addition of rare earths demonstrates lower wear rate losses and, therefore, negligible space velocity losses at a lower applied load.

The authors of [4] described the evolution of the wear of parts of tillage machines depending on the time or function of the volume of work performed. As a result of the research, a mathematical model was developed for assessing the duration of the operation of the arable unit.

The research results [5] showed that wear along the length and width of the bits of soil-cultivating equipment effectively reduces the hardening of the cutting edge (working edge) with tungsten carbide-based carbide inserts. At the same time, wear by weight and thickness effectively reduces the surfacing of the leading surface of the bits.

To increase the wear resistance of the plow share chisel, a method of covering it with three different hard surfacing electrodes was used. It has been established that the wear rate in laboratory and field studies is statistically significantly different, and the most effective are hard alloys EH-600 and EH-350 [6].

In [7], the effect of local soil conditions on the abrasive wear of the plow share was studied. It has been found that soil moisture has a greater effect on wear than soil type. A strong correlation was found between soil type and wear at different values of hardness.

In studies [8], an assessment of the durability and geometry of wear of deep-ripper bits equipped with sintered carbide inserts was given.

The authors of this article also carried out theoretical and experimental studies on the issue of increasing the wear resistance of parts of the working implements of tillage machines [9, 10]. It was found that the hardening of the surfaces of soil-cultivating working implements increases their wear resistance by a factor of 2.0-2.5, depending on the method and scheme of applying hard alloys.

A brief analysis of the literature shows that a promising direction in solving the problem of increasing the reliability of tillage machines is the further improvement of the technology for hardening the surface of frequently worn working implements by arc surfacing with special high-hardness metal alloys.

In this regard, mathematical modeling of wear process of parts of the soil-cultivating working implements is an urgent task, it allows predicting the resource of soil-cultivating parts of working implements and planning production needs for them in various soil-natural conditions of the functioning of soil-cultivating units.

2. Material and methods
The purpose of the research is the development of mathematical expressions for the analysis and prediction of traction resistance, the magnitude and rate of wear of parts of tillage working bodies when applied to their surface of hardening coatings of hard alloys.

The object of research is the serial plowshares of the PLN-3-35 plow in a unit with a tractor of a traction class of 1.4 t (MTZ-920), as delivered, and a plowshare with a hard-faced working surface.

The indicators of the quality of soil cultivation, such as the depth of cultivation and the degree of loosening, the operating time of the MTZ-920 + PLN-3-35 plowing unit, the degree of wear of the
plowshares, were carried out according to the methods described in GOST R52778-2007 “Methods of operational and technological assessment.”

The subject of research is mathematical models of traction resistance, the magnitude and rate of wear of the deposited parts of the tillage working implements with hard alloy.

Experimental studies of the wear resistance of plow shares of the PLN-3-35 plow (Figure 1) were carried out on plowing for potatoes in the amount of 15 hectares using mathematical modeling methods, experimental studies on the energy assessment of tillage machines.

Materials under investigation: plow share of PLN-3-35 plow. Ploughshare hardness – 50HRC, weld metal – Endotec DO * 30 flux cored wire. This wire has a higher wear resistance compared to other wear-resistant materials, where the content of carbon C in the metal is 1%, that is, 4.5 times higher. Wire diameter -1.6 mm. Typical chemical composition of the deposited metal: C 4.5; Nb 5.0; W 1.0; Cr 17.5; Mo 1.0; V 1.0. Mechanical properties: hardness 58-62 HRC, machining – grinding only, current = (+), welding position 1, 2. Purpose – for surfacing of parts operating under intense abrasive and moderate impact wear at high temperatures, in CO2 or Ar mixture / CO2. Resistance to abrasive wear is high, impact wear is good. High temperature resistance – increased.

Scope of tests: 5-6 hectares per 1 deposited share.

Preparation of plowshares for testing included:

- numbering of parts of working implements (plowshares);
- measuring by weighing the mass of parts before surfacing, \(m_0\) g;
- measurement of the mass of parts after surfacing, \(m_1\) g;
- determination of the mass of the deposited material, \(m_n\) with an accuracy of 1 gram \(m_n = m_1 - m_0\) g;
- surfacing of plowshares on the bearing working surface by applying beads (lines) of wear-resistant material (wire) with a layer thickness of 1.0-1.2 mm, a width of 1.6-1.8 mm (Figure 2).
Figure 2. View of working surface of the welded share.

When applying a hardening coating on the surface of the investigated share (Figure 2) as the main working element of the plow body, 4 characteristic areas are formed, shown in Figure 3.

The first $F_1$ is formed in front of the deposited strip. In this area, some slowdown in soil movement occurs, while the specific pressure increases.

The second $F_2$ is formed at the top of the deposited strip. This area is subject to significant friction and wear during plowing.

The third $F_3$ is formed behind the deposited strip. This area is a zone of soil retention (stagnation). In this area, there is a significant decrease in the wear of the non-deposited metal, while also a significant decrease in the specific pressure on the working surface of the share, the friction rate of the soil against the soil and soil against the metal, respectively.

The fourth $F_4$ is the remaining area of the non-deposited part of the plow share, where friction of the soil against the metal occurs.

Based on the general theory of soil cultivation, it is known that the rate of pressure of the soil on the working implement depends on its hardness, the friction rate and the intensity of movement of the tillage working body.

Figure 3. Scheme of typical wear areas and a diagram of the pressure intensity on the working surface of the tillage part.
Experimental studies of the plowing unit, were carried out on the territory of the experimental production base of the Institute, “Krasnaya Slavyanka” under the following conditions:
- soil type – sod-medium podzolic. Soil – medium loamy (light loamy) on moraine loam;
- relief, degree – 2;
- ridge surface of the field, cm – 5-7;
- soil hardness before processing in a layer of 5-10 cm – 0.9 – 1.1 MPa, in a layer of 10 – 20 cm – 1.9 MPa.

3. Results and discussion.
To overcome the existing deformation of the soil, friction, tension, compression, shear, torsion and shear of the soil layer, some tractive effort of the energy device is required. The tractive effort developed by the energy device, that is, the tractor, must be higher than the tractive resistance of the tillage machine.

The numerical value of the traction resistance of the tillage working implement, including the machine, spent on the above processes, during plowing, in the general case, can be predicted by the formula:

\[ R^c_d = R^c_{d1} + R^c_{d2} + R^c_{d3} + R^c_{d4} = \frac{1}{2} \left( K_{1d} \cdot T_s \cdot V_i^2 \cdot F_1 \cdot f_{ss} \right) + \frac{1}{2} \left( K_{2d} \cdot T_s \cdot V_i^2 \cdot F_2 \cdot f_{sm} \right) + \frac{1}{2} \left( K_{3d} \cdot T_s \cdot V_i^2 \cdot F_3 \cdot f_{ss} \right) + \frac{1}{2} \left( K_{4d} \cdot T_s \cdot V_i^2 \cdot F_4 \cdot f_{sm} \right) \]

where \( T_s \) – soil hardness, Pa;
\( F_1 \) – frontal area to deposited strip with deceleration of soil movement
\( F_2 \) – frontal area at the top of the strip;
\( F_3 \) – frontal area behind the deposited strip;
\( F_4 \) – frontal area of non-deposited surface;
\( f_{sm} \) – soil friction rate against metal;
\( f_{ss} \) – soil internal friction rate, showing the resistance of soil movement over the soil;
\( K_{1d}, K_{2d}, K_{3d}, K_{4d} \) - terradynamic resistance rate, depending from soil hardness in friction areas \( F_1, F_2, F_3 \) and \( F_4 \).

\( V_i \) – intensity of soil movement against the surface of the part, which is directly proportional to the speed of movement of the tillage implement.

The magnitude of the traction resistance in the zone \( F_1 \) in front of the hard-faced strip of hard alloy can be determined from the formula:

\[ R^c_{d1} = \frac{1}{2} \left( K_{1d} \cdot T_s \cdot V_i^2 \cdot F_1 \cdot f_{ss} \right) \]  

(2)

The value of traction resistance in the zone \( F_2 \), on the surface of the strip, it is advisable to determine by the formula:

\[ R^c_{d2} = \frac{1}{2} \left( K_{2d} \cdot T_s \cdot V_i^2 \cdot F_2 \cdot f_{sm} \right). \]  

(3)
The value of the traction resistance in the zone $F_3$, the area behind the deposited strip, can be determined by the formula:

$$R_{d3}^c = \frac{1}{2} \left( K_{3d} \cdot T_s \cdot V_i^2 \cdot F_3 \cdot f_{ss} \right).$$ (4)

The value of the traction resistance in the zone $F_4$, on the non-welded part of the part of the tillage working body, can be determined from the following equality:

$$R_{d4}^c = \frac{1}{2} \left( K_{4d} \cdot T_s \cdot V_i^2 \cdot F_4 \cdot f_{sm} \right).$$ (5)

Based on the analysis of the described expressions (1–5), it can be concluded that the traction resistance, in the general case, is directly proportional to the rates of the soil internal friction $f_{ss}$ and the soil friction against the metal $f_{sm}$. In this case, the specific values of the $f_{ss}$ and $f_{sm}$ rates and are influenced by the physical and mechanical properties of the soils of the existing zones of application of the tillage unit.

In the areas under consideration $F_1$ and $F_3$, the pressure intensity, the coefficient of thermodynamic resistance, the area of the friction area and the soil internal friction rate $f_{ss}$, which determines the angle $\varphi$ of friction of the soil, have a significant effect on the traction resistance (Figure 4).

Value of this rate expresses with formula:

$$f_{ss} = \tan \varphi.$$ (6)

where $\varphi$ – angle of internal friction. The angle of internal friction $\varphi$ varies within the range: for sandy soils 25 – 43°; for silty-clayey - 7 – 30° [10].

**Figure 4.** Scheme for determining the value of the angle $\varphi$: $\sigma$ – normal stress, $\tau$ – shear stress.

In the first area $F_1$ (Figure 3), the angle $\varphi$ is more, than areas $F_2$ and $F_3$, traction resistance $R_{d1}^c$ in the area $F_1$ is high.

The external friction rate $f_{sm}$ (or sliding friction) is mainly influenced by the mechanical composition of the soil, which ranges from 0.25 to 0.9. Clay soils have a high coefficient of external friction. The rate $f_{ss}$ is in the range of 0.7-1.1.
Based on the analysis of expressions (1) - (6), it becomes obvious that before the deposited strip in the stagnant zone at a high angle \( \varphi \), the specific pressure of the soil increases, and, accordingly, an increase in traction resistance is seen.

In areas \( F_2 \) and \( F_4 \) (Figure 4), the traction resistance is influenced by the rate \( f_{sm} \), in areas \( F_1 \) and \( F_3 \) by the rate \( f_{ss} \). In this case, in the area \( F_1 \) the largest value of the angle \( \varphi \) is observed on the area \( F_3 \), and the smallest angle \( \varphi \) falls on the area.

Theoretically, the traction resistances of the areas \( F_2 \) and \( F_4 \) among themselves are equal. In accordance with this circumstance, we assume that the traction resistance on the area \( F_3 \) is the same as in the areas \( F_2 \) and \( F_4 \), due to the fact that the angle \( \varphi \) on the area \( F_3 \) is less than in other areas of friction, which leads to a decrease in resistance, despite the friction of the soil about soil.

Despite this statement, the application of a high-hardness coating to the working surface of the part to reduce its wear and increase the resource leads to a slight but increase in traction resistance. The value and intensity of wear of the working surface of machine parts for basic soil cultivation are more influenced by the friction rate, the speed of its movement and the hardness of the deposited material.

The amount of wear of the tillage working implement is functionally dependent on the resistance of the soil, the path and area of friction, the hardness and bulk density of the metal:

\[
\Delta G = f(p, S, L, H, g),
\]

where \( p \) – soil pressure \( L \) – friction path; \( S \) – friction square; \( H \) – hardness of metal; \( g \) – volumetric weight of metal.

In expanded form, the dependence of the amount of wear \( W_{ti} \) looks like this:

\[
W_{ti} = f(p, L, H_h, H_{hm}, f_{sm}, f_{ss}, F_1, F_2, F_3, g_{hm}, g_{mm}),
\]

where \( p \) – soil pressure to working surface;
\( H_h \) - hardness of deposited coating, HRC;
\( L \) – friction path, mm;
\( H_{hm} \) - hardness of main metal, HRC;
\( g_{hm} \) - volumetric weight of hard weld alloy;
\( g_{mm} \) - volumetric weight of main material, which the material of tillage working implement is made.

Taking into account the above, the amount of wear \( W_{ti} \) can be determined from the formula:

\[
W_{ti} = C_f \cdot t_w \cdot V_s \cdot T_s \cdot \rho_m \left( \frac{K_{ld} \cdot f_{ss} \cdot F_1}{H_{hm}} + \frac{K_{ld} \cdot f_{sm} \cdot F_2}{H_h} + \frac{K_{ld} \cdot f_{ss} \cdot F_3}{H_{hm}} + \frac{K_{ld} \cdot f_{sm} \cdot F_4}{H_{hm}} \right),
\]

where \( C_f \) - correction factor;
\( t_w \) – duration of working of the part in the soil, hour;
\( V_s \) – moving speed of part in the soil, km/hour;
\( T_s \) – soil hardness, kg/cm²;
\( \rho_m \) – specific weight of main material, which material of observed part is made, g/cm³.
The mathematical model (9) gives a fairly complete picture of the process of wear of the surface of hard-faced parts of tillage machines, during the period of their use. With an increase in the corresponding operating time and, accordingly, a certain period of operation of the working element, the hard alloy applied in the form of a strip or a dot is gradually erased due to wear. With complete wear of the hard alloy, the areas \( F_1 \), \( F_2 \) and \( F_3 \) gradually disappear, and the area \( F_4 \) increases and eventually becomes equal to the entire working area of the working implement part, in our case the plow share.

Next, consider the degree of reduction of the characteristic areas of wear of the working implement. The area of the non-welded zone of the working implement can be determined from the formula:

\[
F_i = F_{ia} - (F_1 + F_2 + F_3), \tag{10}
\]

where \( F_{ia} \) - total area of working surface of the working implement.

The wear of the deposited hard alloy during operation \( t \) leads to a decrease in the characteristic zones \( F_1 \), \( F_1 \) and \( F_3 \). The size of the characteristic zones \( F_1 \), \( F_2 \) and \( F_3 \) from the time of operation, it is advisable to determine from the expressions:

\[
\begin{align*}
F_1(t) &= F_1(1 - K_{F_1}) ; \\
F_2(t) &= F_2(1 - K_{F_2}) ; \\
F_3(t) &= F_3(1 - K_{F_3}),
\end{align*} \tag{11}
\]

where \( K_{F_1} \) - coefficient taking into account the degree of zone \( F_1 \) reduction; \( K_{F_2} \) - coefficient taking into changes of character zone \( F_2 \); \( K_{F_3} \) - coefficient taking into degree of zone \( F_3 \) reduction.

Value of \( K_{F_1} \), \( K_{F_2} \) and \( K_{F_3} \) coefficients may be defined from 0 to 1 through this equation:

\[
\begin{align*}
K_{F_1} &= \frac{\Delta F_1}{F_1^0} ; \\
K_{F_2} &= \frac{\Delta F_2}{F_2^0} ; \\
K_{F_3} &= \frac{\Delta F_3}{F_3^0},
\end{align*} \tag{12}
\]

where \( \Delta F_1, \Delta F_2, \Delta F_3 \) - actual value \( F_1 \), \( F_2 \) and \( F_3 \) after some work \( t \); \( F_1^0, F_2^0 \) и \( F_3^0 \) - original value \( F_1 \), \( F_2 \) and \( F_3 \) during work \( t = 0 \) hour.

Typical areas \( \Delta F_1, \Delta F_2, \Delta F_3 \) defines with following formulas:

\[
\begin{align*}
\Delta F_1 &= \lambda_{ha}^{ha} \cdot F_1 ; \\
\Delta F_2 &= \lambda_{ha}^{ha} \cdot F_2 ; \\
\Delta F_3 &= \lambda_{ha}^{ha} \cdot F_3,
\end{align*} \tag{13}
\]

where \( \lambda_{ha}^{ha} \) - the wear degree of hard alloy from the time \( t \) of working implement depending its density and hardness.
In order to verify the reliability of the given theoretical position on the fields of the experimental-production base of the Institute, laboratory-field studies were carried out to determine the wear resistance of hardfaced and non-hardfaced plowshares of the PLN-3-35 plow in a unit with a tractor of 1.4 t class.

The obtained experimental data made it possible to reveal the regularity of the change in the degree of wear $\lambda_w$ of the hard-faced plowshares from the time $t$ of their operation, which is described by the empirical dependence:

$$\lambda_w = 0.00005137 \ t^2 + 0.00240200 \ t + 1.0006047$$  (14)

Research has established that when using various hard alloys (formula 14), the values of the slope and constant value change.

Depending on the technology of hard alloy deposition on the working surface of the part, the values $F_1$, $F_2$, $F_3$, and $F_4$ vary significantly.

The previously obtained formulas (9) - (14) of the process of changing the amount $W_{ni}$ of wear from the operating time $t$ can be described by the equation:

$$W_{ni} = C_f \cdot t \cdot V_i \cdot T_s \cdot \rho_m \left\{ \frac{K_{1d} \cdot f_{ss} \cdot F_1 \cdot (1 - K_{F1})}{H_{hm}} \right\} + K_{2d} \cdot f_{sm} \cdot F_2 \cdot (1 - K_{F2}) \ \frac{H}{H} +$$  
$$+ \frac{K_{3d} \cdot f_{ss} \cdot F_3 \cdot (1 - K_{F3})}{H_{hm}} \right\} + K_{4d} \cdot f_{sm} \cdot \left[ F_4 + (F_1 - \Delta F_1) + (F_2 - \Delta F_2) + (F_3 - \Delta F_3) \right] \right\} \ \frac{H_{hm}}{H} \ \cdots \ (15)$$

Wear intensity $V_w$ of part surface defined by following formula:

$$V_w = \frac{W_{ni}}{T_w}$$  (16)

where $W_{ni}$ - amount of wear of the deposited part of the tillage working implement, g;

$T_w$ - work of deposited part of the working implement, hour.

The wear process of working surface also depends on the angle of soil crumbling (Figure 5.) When surfacing the working surface of the tillage working implement in characteristic zones $F_1$, $F_2$ and $F_3$, the angle of soil crumbling changes.

![Figure 5](image_url)  
*Figure 5.* Scheme for determining the degree of change in the angle $\alpha$ of crumbling of the soil of a part deposited with hard alloy: $\alpha_1$ - the angle of crushing of soil in the characteristic area $F_1$. 
The analysis shows that with an increase in the production of hard alloy-hardened tillage working implements of machines, the areas $F_1$, $F_2$, $F_3$ decrease, and $F_4$ increase.

After abrasion of the hard alloy, the process of wear of the working surface occurs according to a general pattern, which is characteristic of serial parts as supplied from the manufacturer. Experimental studies have shown that the main factors affecting wear are operating time, travel speed, hardness of the soil and the weld material.

The wear rate of the plowshares can be estimated by the wear rate factor:

$$V_{wp} = \frac{M^{nn}}{M_0},$$

where $M^{nn}$ – weight loss of serial plowshares without hardfacing of the working surface, g; $M_0$ – weight loss of serial plowshares with hardfacing of the working surface, g.

Table 1 shows the data obtained in the course of experimental studies of the MTZ-920 + PLN-3-35 plowing unit.

| № plowshare in plow body | Plowshare weight until hardfacing, g | Plowshare weight after hardfacing, g | Plowshare weight after working, g | Plowshare wear, g |
|--------------------------|-------------------------------------|-------------------------------------|----------------------------------|------------------|
| 1 | 4190 | 4307 | 4200 | 107 |
| 2 Without hardfacing | 4204 | - | 4017 | 187 |
| 3 | 4145 | 4238 | 4198 | 40 |

The data in Table 1 show that the amount of wear per 1 deposited share is 73.5 g, while the total wear of the share without surfacing was 187, taking into account the data obtained, the wear intensity factor was determined:

$$V_{wp} = \frac{M^{nn}}{M_0} = \frac{187.0}{73.5} = 2.54.$$  

The value of the coefficient $V_{wp}$ indicates that the wear resistance of conventional plowshares deposited with hard alloy is 2.54 times higher than the wear resistance of the same plowshares, but without surfacing.

Figure 6 shows a general view of a plowshare with stagnant soil zones and a picture of wear of the deposited surface.
Figure 6. General view of the hardfaced plowshare with the formation of stagnant zones of the contact layer of the soil.

Figure 7 shows the working surface of the share after hard-facing with identical strips with a thickness of 2.0-2.5 mm, located at a distance of 40-45 mm parallel to each other.

Figures 6 and 7 show that in the friction process of the contact layer of the soil on the opposite side of the fused arcuate stripes, areas are formed on which the soil is retained. The appearance of such areas reduces friction with the base metal in the zone of its greatest wear.

Figure 7. Working surface of the hardfaced plowshare after a certain operating time.

Figure 7 shows that on the back side of the weld beads in the area of formation of stagnant soil zones, the base metal retains its original state and does not lend itself to the action of abrasive particles, since friction of the contact layer of the soil in these zones occurs over the stagnant soil layer.

Figure 8. Wear pattern of the ploughshare weld surface.
The pattern of wear of the deposited surface in Figure 8 confirms the results of theoretical studies on the reduction of abrasive wear of parts of tillage machines by the method of active deformation of the contact layer of the soil by the formation of a wavy relief of the friction surface.

Figure 9 shows the graphical dependences of the wear value of a hard-faced share and a share without surfacing on their production.

![Graphical dependences of the amount of wear of the deposited plowshare $M_s^n$ and plowshare without surfacing $M_{sn}$ on their production: a - approximate area $F_s$ of the plowshare running-in, before the wear of the base metal begins.](image)

On the surface of the base metal without hardfacing, characteristic wear lines are formed in the form of scratches in the direction of movement (Figure 8). This is due to a slight increase in surface plastic deformation under the action of abrasive particles of the contact layer of the soil.

The obtained experimental data made it possible to establish the empirical mathematical dependences of determining the amount of wear of the deposited and not deposited plowshares on their operating time.

For soddy-medium podzolic, medium loamy soils on moraine loam, the amount of wear of the plowshares not deposited $M_{sn}^{**}$ and hardfaced $M_s^{**}$ with hard alloy can be determined from the empirical dependences:

$$M_{sn}^{**} = 1.26189 F^2 + 34.74479 F + 5.50057 .$$  \hspace{1cm} (19)

$$M_s^{**} = 0.31898 F^2 + 14.40500 F + 2.02624 .$$  \hspace{1cm} (20)

Empirical dependences (19) and (20) are valid in the range of operating time $F$ of a share from 0.20 to 19.0 ha.

The average statistical data indicate that the operating time of a factory-supplied share, that is, without hard-facing, is approximately 8 hectares. Judging by the weight of the share, the allowable wear should be no more than 9-10% of its total weight. The permissible share width is less than 108 cm.
With an increase in the wear resistance of the share by our proposed method and scheme (Fig. 2), the production of the welded share until the permissible wear by weight is reached is 18.74 ha. The experiments carried out showed that the total production of the deposited share by hard alloy is 10.72 hectares more, compared to the share without surfacing, that is, 2.5 times.

To determine the wear rate of new and welded plowshares, it is proposed to use the rate of their wear intensity based on the weight loss of the tested parts.

For specific test conditions, the wear rate remains constant regardless of the operating time of the plow.

For sod-medium podzolic, medium loamy (light loamy) soils on moraine loam, where the studies were carried out, the wear rate factor is $K_i = 2.54$. The value of this coefficient shows that the wear resistance of the deposited share is 2.54 times higher than the wear resistance of a serial share without surfacing.

4. Conclusion

Mathematical models have been developed for predicting the values of traction resistance, the magnitude and intensity of wear of the working surfaces of the organs of soil-cultivating equipment, deposited with hard alloys.

The experimental data obtained as a result of the research carried out confirm the adequacy and high significance of the developed mathematical models.

In addition, the research results obtained confirm that the application of hard alloy coatings of certain sizes and configurations to the working surfaces of agricultural machinery parts increases their wear resistance by an average of 2.3-2.5 times, compared with non-welded parts.

Reducing the wear rate of the working surfaces of parts is ensured by reducing the mechanical effect of the contact layer of the soil on the base metal. In the area of formation of characteristic stagnant soil zones, the base metal retains its original state, does not lend itself to the action of abrasive particles. In this case, the friction of the contact layer of the soil in these zones occurs along the layer of stagnant soil.

Empirical mathematical models are established to determine the amount of wear of deposited and non-deposited plowshares from their operating time for specific soil conditions of the plowing unit.

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