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FORECASTING THE WEARING OF PLOUGHSHARES PARTS UNDER OPERATING CONDITIONS

PROGNOZOWANIE ZUŻYWANIA ELEMENTÓW ROBOCZYCH W WARUNKACH EKSPLOATACYJNYCH

Key words: ploughshare, wear, sandy soil, padding layer.

Abstract: This study presents an analysis of the process of wear of ploughshares subjected to different types of technological processing. The experiment was conducted under real-life operational conditions. Tests were performed on operating parts made of three types of steel and of steel enhanced by pad welding. Changes in the geometrical dimensions of an operating part that were implemented into the Holm-Archard model to verify its suitability by determining the wear of materials used under abrasive conditions were adopted as a measure of wear.

Słowa kluczowe: lemiesz płużny, zużycie, gleba piaszczysta, warstwa napawana.

Streszczenie: W pracy przedstawiono analizę procesu zużywania lemieszy poddanych różnej obróbce technologicznej. Eksperyment prowadzono w rzeczywistych warunkach eksploatacji. Badaniom poddano elementy robocze wykonane z trzech rodzajów stali oraz stali ulepszonej poprzez napawanie. Jako miarę zużycia przyjęto zmiany wymiarów geometrycznych elementu roboczego, które zaimplementowano do modelu Holma-Archarda w celu weryfikacji jego przydatności, określając zużycie materiałów eksploatowanych w warunkach ściernych.

INTRODUCTION

The dominant process contributing to the destruction of operating parts used in soil is abrasive wear that takes place under the influence of loose abrasives moving along the material surface. Its basic forms include scratching, ridging, and micro-cutting **[L. 1–3]**. The occurrence of these processes results in changes in the weight, structure, and physical properties of the surface layer within the areas of contact with the abrasive **[L. 4, 5]**.

A soil mass is a complex natural object in which the processes of mineral and organic substance decomposition, translocation, and synthesis take place **[L. 6]**. The main components that affect the rate of wear of an operating part used in the soil include the physico-chemical properties of soil (grain-size distribution, moisture content, and acidity) and the features of the operating part (hardness, plasticity, micro-structure) as well as their mutual interactions **[L. 7–9]**.

In order to learn about wear processes, and thus to be able to contribute to their limitation, it is necessary

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to identify the phenomena occurring during the friction process and the physico-chemical properties of soil and the operating part.

The resistance of a material to wear within a soil mass is determined by the features and micro-structure of the material. The selection of a material's properties is possible thanks to the appropriate shaping of the structure through the selection of the chemical composition, including the size and shape of carbides.

Welding techniques are among the commonly applied methods for shaping the properties of the materials' surface layer. Pad welding results in surface layers with various chemical compositions and structures **[L. 9]**. Materials that proved to be the most resistant to the effects of an abrasive soil mass are those containing Fe and Cr with additions of transition metals, i.e. V, W, Mn, and Nb **[L. 10]**. Ploughshares are the most exposed to abrasive wear and mechanical loads among the tools for the processing of abrasive soil mass **[L. 12–14]**. As a result of efforts to increase the resistance of these parts to wear occurring during their operation, tests are carried out to properly shape these materials' structure to adapt them to the defined operational loads **[L. 15]**.

The difficulties associated with formulating models forecasting the rate of operating parts' wear result from the large number of factors affecting the level of wear and the complex relationships between them. An analysis of the state of the issue reveals that it is necessary to formulate mathematical models which enable the forecasting of wear values for operating parts processing abrasive soil masses. In order to define the phenomena occurring during wear, many mathematical models which allow the wear rate to be determined have been developed, in addition to experimental testing.

Among the existing models describing the wear processes of operating parts, two types can be distinguished. The first model involves the relationships describing the phenomena observed during the processing of soil, while the second model enables the forecasting of operating parts' durability depending on the bioagrotechnical system loads. One model proposed by Tenenbaum **[L. 16]** describes the abrasive wear of operating parts and belongs to the first group. This relationship takes into account the factors acting at the same time, i.e. the components of axial forces, friction force, and the slide velocity. On the other hand, the relationships occurring between each other include the processes of multi-deformation, micro-cutting, oxidation, hydriding, and wear-induced disturbance of the material structure. Another model that describes the wear of tools was presented by Wierzcholski **[L. 17]** in which the author assumed the plough's operating distance, the duration of work, spring stiffness, friction coefficient, the plough's velocity, and the type of soil.

The second group among the models describing abrasive wear are the relationships proposed by Owsiak and Napiórkowski **[L. 18, 19]**. In order to determine the effect of a soil mass on wear processes, they took into account the material's properties and the relationships that characterise the soil.

The basis for formulating equations that describe wear is the Holm-Archard model which describes abrasive wear resulting from contact between two bodies. It is assumed that wear is directly proportional to the force and length of the experimental run and inversely proportional to the hardness of the part **[L. 20]**.

The model was applied in the study determining the wear occurring between two bodies **[L. 21–25]**. The study **[L. 26]** aimed at the theoretical determination of chisel wear conducted tests enabling the determination of the values of parameters required for the forecasting of wear. It was found that the rate of chisel wear during ploughing was mainly affected by the material's hardness and that the wear was proportionally lower with its increase.

The aim of the study was to verify the possibility for forecasting the wear of operating parts used under natural soil conditions using the Holm-Archard model.

TEST MATERIAL

Ploughshares with chisels designed for a four-furrow plough were subjected to testing. For the experiment, operating parts made of Hardox 500, B 27 and Raex 500 steels as well as a Hardox 500 steel pad welded using a Fidur 10/65 electrode were selected (**Table 1**). The thickness of the padded layer ranged from 2 to 3 mm.

Table 1. Chemical composition of the test materials (manufacturer's data)
Tabela 1. Skład chemiczny badanych materiałów (dane producenta)

Type of material	Content of chemical elements, %						
	C	Si	Mn	Cr	Ni	Mo	B
Hardox 500	0.29	0.70	1.60	1.00	0.50	0.60	0.004
B 27	0.27	0.25	1.20	0.30	0.03	–	0.002
Raex 500	0.23	0.80	1.70	1.50	1.0	0.5	0.005
Fidur 10/65	4.5	0.7	0.5	34	–	–	–

RESEARCH METHOD

A tribological experiment was conducted under natural operating conditions during ploughing at a depth of 0.20–0.25 m. During the testing, a daily change in the order of ploughshare installation was ensured.

Geometrical features of ploughshares and chisels were measured (**Fig. 1**) using a slide calliper with an accuracy of ± 0.1 mm, before the start of the experiment and during its course, on average, after every 6 ha of ploughed area. The total ploughed area amounted to 18.5 ha over the time of 23.5 hours.

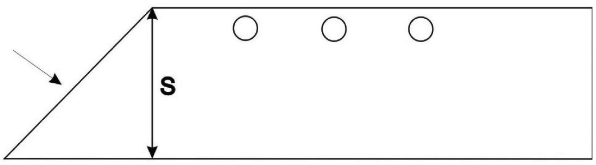

Fig. 1. Diagram of a ploughshare; S – ploughshare width
Fig. 1. Schemat lemiesza; S – szerokość lemiesza

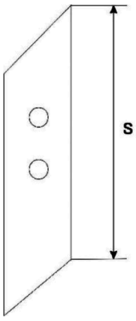

Fig. 2. Diagram of a chisel; S – chisel width
Rys. 2. Schemat dłuta; S – szerokość dłuta

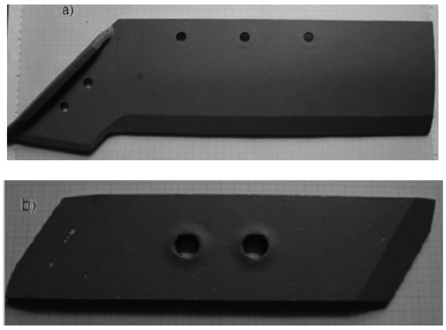

Fig. 3. Ploughshare (a) and chisel (b) made of Hardox 500 steel
Rys. 3. Lemiesz (a) i dłuto (b) wykonane ze stali Hardox 500

The tests were conducted in light soil with a moisture content ranging from 8 to 10%. Grain-size distribution of the soil (**Table 2**) was determined in compliance with standard PN- EN ISO 14668-2(2004).

Table 2. Granulometric composition of the soil
Tabela 2. Skład granulometryczny gleby

Granulometric composition of the soil				
Traction	Clay	Dust		Sand
Fraction size [mm]	<0.002	0.002-0.020	0.020–0.050	0.050–2.000
Content [%]	1.66	10.73	10.27	77.33

Measurements of hardness of the test materials were carried out by the Vickers method in accordance with standard PN-EN ISO 6507-1;1999, using a semi-automatic Vickers HV-10D hardness tester. The average hardness values for the test materials were as follows: B27 steel: 518 HV10; Hardox steel 500:550 HV10; Raex 500 steel: 490 HV10; padding weld made using a Fidur 10/65 electrode: 760 HV10. Tests on the micro-structure were carried out using a Zeiss Neophot 52 microscope coupled with a Visitron Systems digital camera. For the tests using scanning electron microscopy (SEM) methods, and to carry out micro-analyses of the chemical composition, a JEOL JSM – 5800 LV scanning microscope coupled with an Oxford LINK ISIS – 300 X-ray analyser was used.

Based on the empirical data obtained from the conducted tribological testing, the accuracy was verified by forecasting of the wear rate described by the Holm-Archard model which is as follows:

$$Z = \frac{k \cdot P \cdot L}{3H} \qquad (1)$$

where:
Z – linear wear,
k – soil abrasive properties coefficient,
P – pressure force of the operating part on the soil,
H – hardness of operating part material,
L – ploughed area.

The value of the “k” coefficient was determined based on separate data obtained from the conducted experiment using reverse modelling in Matlab Simulink software. Based on an analysis of the results of calculations of the “k” coefficient, which was carried out for each tested operating part, a mean value was adopted for the group of tested materials under the same soil conditions.

The pressure force of an operating part on the soil was adopted based on studies by Owsiak and Bernacki **[L. 27, 28]**. Although the adopted value refers to the same soil conditions, hardness H of the operating part was adopted based on the manufacturer’s data. For the analysis of the model, the data presented in **Table 3** were adopted.

Table 3. Data adopted for the model
Tabela 3. Dane przyjęte do modelu

Test material	H [N/mm²]	"k" coefficient value	P [N]	L [ha]
B 27	1700	0.0000002632	550	0–18.5
Hardox 500	1810			
Hardox 500 + padding weld	2490			
Reax500	1600			

STUDY RESULTS AND ANALYSIS

The test materials are characterised by a similar structure, and thus high resistance to abrasive wear. Both Hardox 500 (**Fig. 4**) and Raex 500 steel have a martensitic structure. B27 steel (**Fig. 5**) is characterised by a fine-dispersed structure of temper sorbite (high-temperature tempered martensite). Consequently, it has a structure of post-martensitic orientation (tempered martensite) with precipitates of fine carbides distributed consistently within martensite grains.

In the structure of the materials, a difference between the number and the size of carbide phase precipitates can be noted. These disproportions are due to the different contents of carbon and alloying elements. Such properties of steel have a significant effect on resistance to wear as well as to dynamic loads.

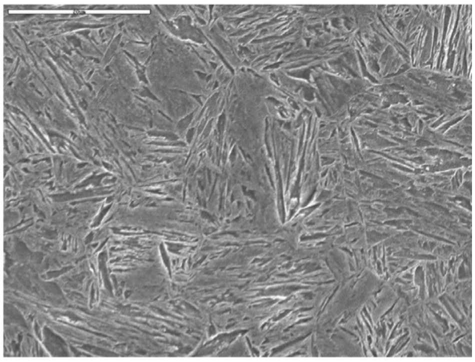

Fig. 4. Micro-structure of Hardox 500 steel
Rys. 4. Mikrostruktura stali Hardox 500

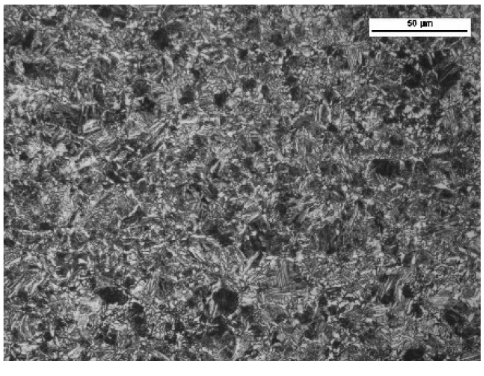

Fig. 5. Micro-structure of B 27 steel
Rys. 5. Mikrostruktura stali B27

Based on the results of the conducted tribological experiment, it was found that the ploughshare which was subject to the greatest wear was made of Raex 500 steel, while the smallest geometrical wear was noted for the Hardox 500 steel pad welded using a Fidur 10/65 electrode.

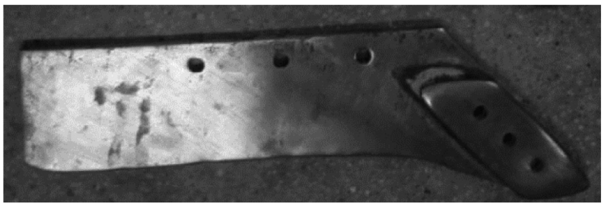

Fig. 6. Ploughshare and chisel made of B 27 steel after testing
Rys. 6. Lemiesz i dłuto wykonane ze stali B27 po badaniach

An analysis of data concerning the wear of chisels presented in **Fig. 7** shows that the chisel made of B 27 steel was characterised by the greatest loss of material, while the chisel made of pad-welded steel was characterised (similar to the ploughshare) by the smallest loss. Both for a ploughshare and a chisel, the wear rate on their width increases with the processed surface. The causes of these changes should be traced to the change in the shape of the chisel blade due to wear. The blade gets rounded, which leads to an increase in resistance during soil processing. An increase in the forces acting on both the chisel and the ploughshare at the point of width measurement results in an increase in the wear rate.

Based on the analysis results obtained from the implemented Holm-Archard model and those obtained from the conducted experiment, a high determination coefficient was found for the tested parts (**Table 4**, **Figs. 7** and **8**). The highest fitting value was obtained for a ploughshare made of Hardox 500 steel with padding weld, while it was B 27 steel for the chisel. The lowest determination coefficient was noted for a ploughshare made of Raex 500 steel and a chisel made of Hardox 500 steel.

Based on the results obtained, it was found that the Holm-Archard model correctly described wear for the presented materials under particular soil conditions. However, in order to determine the possibility for forecasting wear using this model of materials operated

Table 4. The coefficient of determination between data from in-use tests and the results from the model for particular parts and materials.

Tabela 4. Współczynnik determinacji pomiędzy danymi z badań eksploatacyjnych a wynikami z modelu dla poszczególnych elementów i materiałów

Part	Material	Determination coefficient
Ploughshare	B 27	0.82
	Hardox 500	0.80
	Hardox 500 + Fidur 10/65	0.94
	Raex 500	0.76
Chisel	B 27	0.85
	Hardox 500	0.77
	Hardox 500 + Fidur 10/65	0.84
	Raex 500	0.82

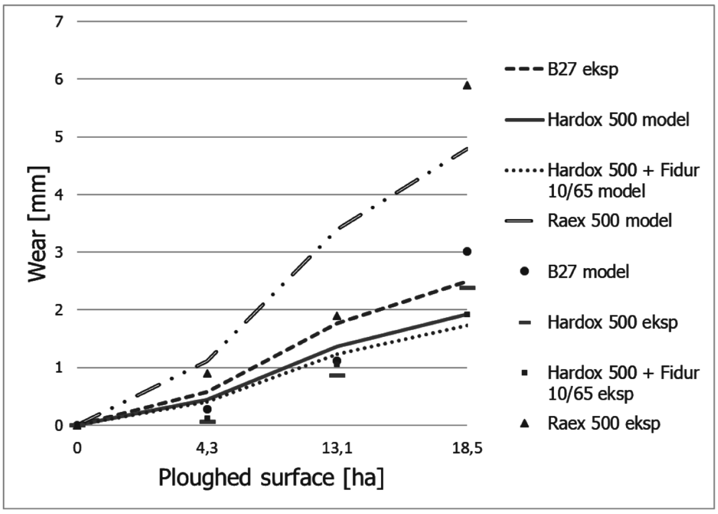

Fig. 7. The relationship between the wear of ploughshares (Z) and the surface of ploughed soil (L), determined under real-life conditions and the fitting of the model

Rys. 7. Zależność zużycia lemieszy (Z) od powierzchni zaoranej gleby (L) wyznaczona w warunkach rzeczywistych i dopasowanie modelu

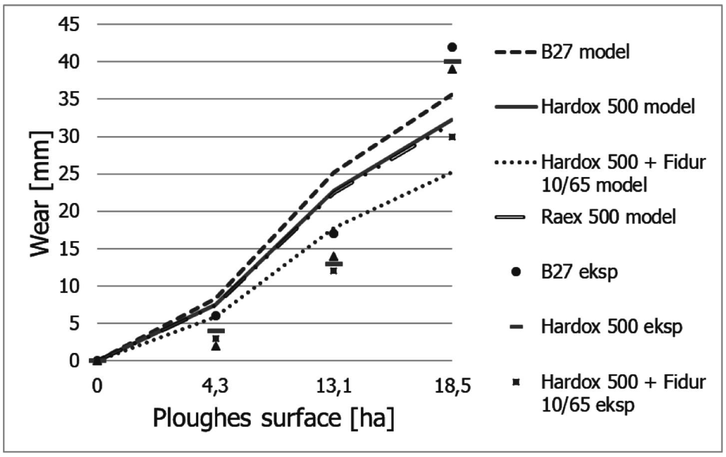

Fig. 8. The relationship between the wear of chisel (Z) and the surface of ploughed soil (L), determined under real-life conditions and the fitting of the model

Rys. 8. Zależność zużycia dłut (Z) od powierzchni zaoranej gleby (L) wyznaczona w warunkach rzeczywistych i dopasowanie modelu

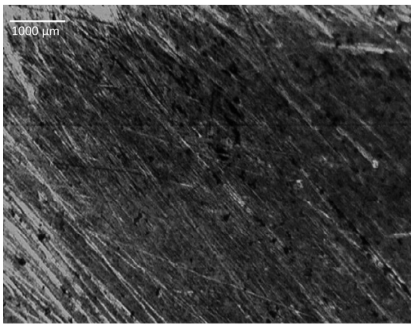

Fig. 9. The surface of B 27 steel after 18.5 ha
Rys. 9. Powierzchnia stali B27 po 18.5 ha

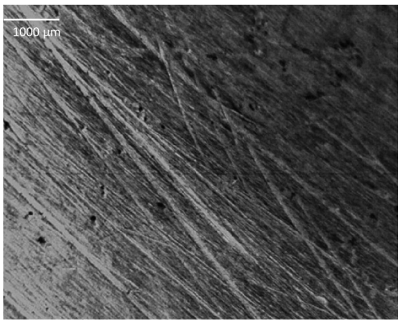

Fig. 10. Surface of pad welded Hardox 500 steel after 18.5 ha
Rys. 10. Powierzchnia stali Hardox 500 po 18.5 ha

in the soil, an analysis needs to be carried out for another group of materials characterised by different properties and, thus, by other wear rates.

Examples of microphotographs from the surface after testing are presented in **Figs. 9** and **10**.

After an analysis of the wear processes occurring in soils containing a significant percentage of sand fractions, it can be noted that the dominant type of wear for parts made of non-pad welded steel is scratching. Ploughshares and chisels made of Hardox 500 steel pad welded using a Fidur 10/65 electrode were characterised by the greatest carbide (Cr-C) content, which contributed to an increase in the material's hardness and, thus, to a reduction in the wear rate.

SUMMARY

Based on the obtained study results, it can be concluded that ploughshares made of martensitic steel subjected to testing under natural operating conditions were characterised by wear of similar values, except for Raex 500 steel.

Regarding chisels, the greatest geometrical wear was noted for parts made of B 27 steel. The use of padding weld enabled a three-fold reduction in wear for ploughshares and 1.5-fold reduction for chisels.

The obtained values of the determination coefficient allow the authors to conclude that the proposed model can be applied for forecasting the wear of operating parts used under particular natural conditions. In order to determine the correctness and universality of the application of the model, the performance of tests on a greater group of materials under different operational conditions is required.

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