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THE INFLUENCE OF SOIL ABRASIVE MASS PH ON STEEL WEAR PROCESSES

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Abstract: *The wear process of working elements in machines operating in abrasive masses is widely described in the literature. The relationships between the composition and structure of construction materials and their wear rates in physically diverse soil abrasive masses are presented. This study expands the existing knowledge by investigating the influence of chemical properties, defined by soil pH, on hydrogen content and the mass wear of samples.*

The experiment involved two types of steel: low-alloy martensitic steel 38GSA and high-strength boron martensitic steel HARDOX 500. The experiment was conducted under laboratory conditions. The samples were subjected to friction over a distance of 50,000 meters at a constant speed of 1.67 m/s in a soil abrasive mass composed of light sand with approximately 11% moisture content and a chemical pH ranging from 3,8 and 7,2. Every 10,000 meters, the sample mass was measured to determine the degree of wear.

Additionally, the effect of the friction process on hydrogen content in the samples was examined using the high-temperature extraction method. An increase in hydrogen content after the friction process was observed in both materials. For Hardox 500, the average hydrogen content increased by 28.77%, from 3.331 ppm before friction to 4.289 ppm after the process. In the case of 38GSA steel samples, a 61.68% increase in hydrogen content was recorded, from 2.093 ppm before friction to 3.383 ppm after the process. This indicates a greater potential for hydrogen absorption by steel during friction, which may affect its mechanical properties and, consequently, the wear process.

Keywords: *soil abrasive mass, pH, abrasive wear, Hardox 500 steel, 38GSA steel, hydrogen.*

1. INTRODUCTION

The abrasive wear processes of materials working in soil abrasive mass are the subject of intensive scientific research due to their significant impact on the durability and functionality of agricultural, construction, and mining machinery components [1,2]. Soil, as a complex biological environment, is characterized by specific properties that significantly influence the wear mechanisms of the materials that work within it [3,4]. Working elements of machines that operate in soil are subject to particularly intense frictional forces caused by contact with soil particles of varying granulometric composition, moisture content, and chemical reaction. Often, the wear intensity of these components exceeds several dozen grams per hour, which necessitates the search for new material solutions and production technologies [5,6].

A major challenge in this field is the appropriate selection of construction materials that demonstrate sufficient wear resistance in soil environments with a wide range of chemical and mechanical parameters. Steels, as the most commonly used construction materials in agricultural machines, are extensively analyzed to optimize their properties in the context of operational conditions. The wear resistance of steel in soil is determined by its chemical composition, microstructure, hardness, and response to environmental factors such as soil pH. These values, combined with machine operating parameters, determine the physicochemical mechanisms affecting the wear processes [7,8].

The degradation of working elements in soil abrasive mass is a multifaceted process, encompassing both mechanical and chemical interactions. One of the factors significantly affecting the wear process is the chemical reaction of the soil, i.e., the ratio of hydrogen ions (H^+) to hydroxide ions (OH^-) in the soil solution, measured in pH values [9,10]. Soil, as a biological medium, contains hydrogen ions that interact with the surface of the construction material, causing changes in the steel structure and decohesion processes. Phenomena related to the influence of hydrogen on the mechanical properties of materials have been the subject of numerous studies, which indicate significant differences in wear intensity depending on soil pH values [11,12].

The use of materials with high wear resistance, such as boron steels, wear-resistant steels, or sintered carbides, allows for improved durability and functionality of the working elements of soil-processing machines. At the same time, analyzing the influence of soil properties on wear processes is crucial for the proper selection of materials for specific environmental conditions. Optimizing construction parameters and mechanical properties of materials allows for the reduction of destructive phenomena intensity, which translates into increased durability of agricultural tools and reduced operating costs [13].

Wear processes in soil abrasive mass depend both on the properties of the soil itself and on machine operating parameters. The diversity of operating conditions for working elements results from the high variability of the bio-agrotechnical environment. Key soil characteristics such as granulometric composition, moisture content, compaction, and pH significantly influence the selection of appropriate construction materials. Modern research focuses on the mechanisms of soil-material interactions, supporting the development of durable and wear-resistant components of agricultural machines [14,15].

This paper presents the results of research on the influence of soil chemical reaction on the steel wear processes under laboratory conditions. The analysis of soil properties, such as chemical reaction, granulometric composition, and moisture content, allows for a better understanding of wear mechanisms and the optimization of construction materials for specific operating conditions. The results obtained provide a significant contribution to explaining the issue of abrasive wear of steel in soil abrasive mass, thus enabling more effective planning of operating processes and the design of modern construction solutions for agricultural machines.

The aim of this study is to analyze the influence of soil reaction, defined by pH value, on the wear and hydrogen content in 38GSA and Hardox 500 steels.

2. RESEARCH MATERIAL AND METODOLOGY

The subject of the research was:

- Low-alloy martensitic steel 38GSA,
- Wear-resistant steel Hardox 500.

From a steel sheet, four samples made of 38GSA steel and four samples made of Hardox 500 steel were cut using a high-energy abrasive water jet and then ground. The dimensions of the samples were 30 mm × 25 mm × 10 mm. The 38GSA steel was subjected by the manufacturer to bulk hardening and tempering. After tempering, cooling was carried out in still air. The heat treatment parameters were selected based on the industry standard BN-85/0642-48. In the hardened and tempered condition, it is characterized by a structure of fine-lath tempered martensite with bainite (Figure 1)

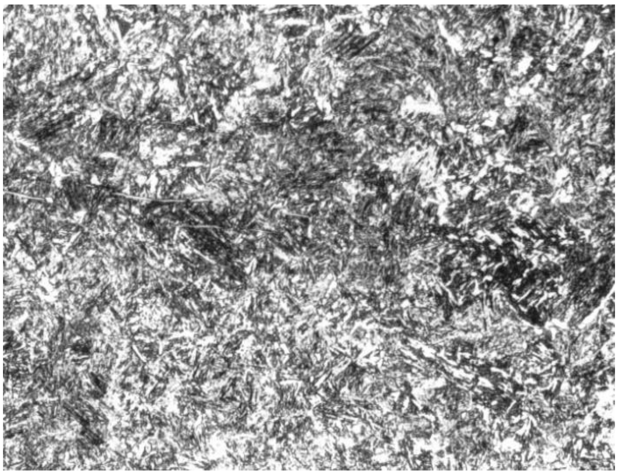

Figure 1. *Microstructure of 38GSA steel after heat treatment - tempered martensite with bainite. Magnification: 500x, etched with 3% HNO_3 (Mi1Fe), optical microscopy.*

According to the manufacturer's data, HARDOX steels are delivered in a water-quenched and tempered condition at temperatures ranging from 200 to 700 °C, which ensures a uniform hardness of 470–530 HBW. In the hardened and tempered state, they are characterized by a tempered martensitic structure (Fig. 2).

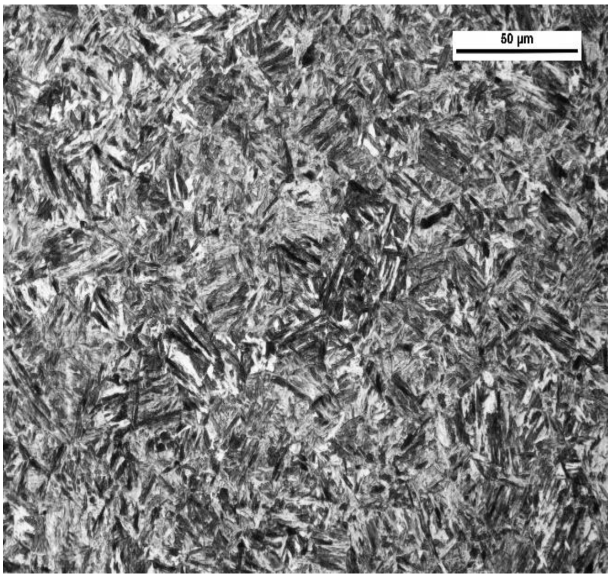

Figure. 2. *Microstructure of tempered martensite in HARDOX 500 steel. Magnification: 500x, etched with 3% HNO_3 (Mi1Fe), optical microscopy.*

Table 1 presents the chemical composition, structure, and hardness of the tested materials.

Table 1. Chemical composition, structure, and hardness of the examined materials.

		Material	
		38 GSA	Hardox 500
Chemical composition [%]	C	0,35	0,29
	Mn	1,07	1,60
	Si	1,17	0,7
	Cr	0,18	1,0
	Mo	-	0,6
	Ni	-	0,5
	Al	0,022	1,18
	Cu	0,16	-
	P	0,028	0,025
	S	0,02	0,01
	B	-	0,005
Structure		Microstructure of tempered martensite with bainite and a small amount of troostite.	Microstructure of tempered martensite.
Hardness		481 HV	512 HB

The friction process was carried out using a wear testing machine of the "rotating bowl" type (Fig. 3). During the tests, the linear speed of the samples was 1.67 m/s. The sample load was 50 kN (67 kPa).

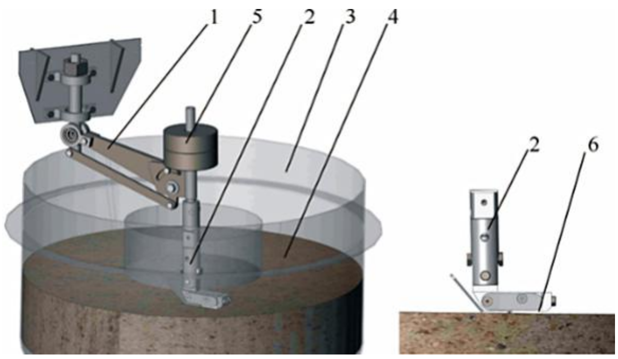

Figure 3. Diagram of the testing for wear by the rotating bowl method: 1 – rocker arm, 2 –specimen holder, 3 – rotating bowl, 4 – abrasive mass, 5 – specimen weights, 6 – specimen, [15]

The soil abrasive mass consisted of loose sand with a moisture content of approximately 10.5% and two pH values: 3.8 (acidic reaction) and 7.2 (neutral reaction). To achieve a neutral pH, chalky calcium carbonate ($CaCO_3$) was added to the soil abrasive mass, while an acidic reaction was obtained by adding citric acid monohydrate

($C_6H_8O_7 \times 1H_2O$). The pH value was monitored using a SoilStik pH Meter Flat Sensor FieldScout pH-meter with a measurement accuracy of ±0.01 pH. The soil grain size distribution is presented in the table below.

Table 2. The grain size of the soil abrasive mass.

Type of soil	Grain size - % fraction content [mm]		
	<0,002	0,002-0,050	0,050-2,000
Loose sand (according to PTG)	0,00	5,95	94,05

The total friction distance to which the tested samples were subjected was 50 000 m. However, during the tests, the mass of the samples was measured every 10 000 m after placing them in an ultrasonic cleaner for 15 minutes and then drying them. A laboratory scale with a measurement accuracy of ±10^{-4} g was used to weigh the samples.

Weight loss was determined using the following equation:

$$Z_w = m_w - m_i \qquad (1)$$

m_w - mass of the sample before the friction test [g],
m_i - mass of the sample after traveling the friction distance [g].

The analysis of the friction surface of the tested materials was carried out using a Keyence VHX digital microscope.

The determination of the total hydrogen content in the tested materials was performed using the high-temperature extraction method, which involved heating a 7 g sample in an inert gas atmosphere to a temperature of approximately 800 °C, followed by analysis of the released gases using the RHEN602 analyzer. The measurement accuracy was up to 0.001 ppm.

3. RESEARCH RESULTS

The results of the total hydrogen content tests in the samples subjected to friction in acidic soil with a pH of 3.8 (Table 3) indicate an increase in the average total hydrogen content in both materials after the friction process. In the case of Hardox 500 steel, the average hydrogen concentration increased by over 28% — from 3.331 ppm to 4.742 ppm. For 38GSA steel, the average hydrogen concentration rose by more than 61% — from 2.093 ppm to 3.383 ppm.

Table 3. Total hydrogen content of the samples.

Material	Friction distance [m]	Hydrogen content [ppm]	Average hydrogen content [ppm]
Hardox 500	0	4,978	3,331
		2,281	
		2,733	
	50 000	4,786	4,289
		3,339	
		4,742	
38 GSA	0	2,210	2,093
		2,200	
		1,868	
	50 000	3,733	3,613
		2,804	
		3,613	

The comparison of mass wear results for 38GSA steel in acidic and neutral soil (Fig. 4) indicates more intensive wear in the soil abrasive mass with an acidic pH. The difference in wear amounted to 34% over a friction distance of 50 000 m.

The mass wear results of Hardox 500 steel in acidic and neutral soil (Fig. 5) highlight the phenomenon of more intensive steel wear in an acidic soil environment, where wear was recorded to be 30% higher over a friction distance of 50 000 m.

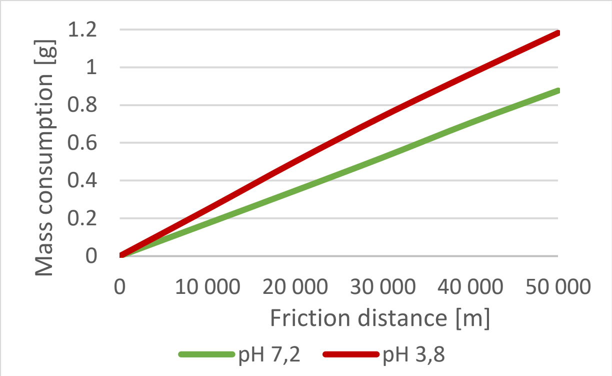

Figure 4. Mass consumption of steel 38 GSA in acid and neutral soil

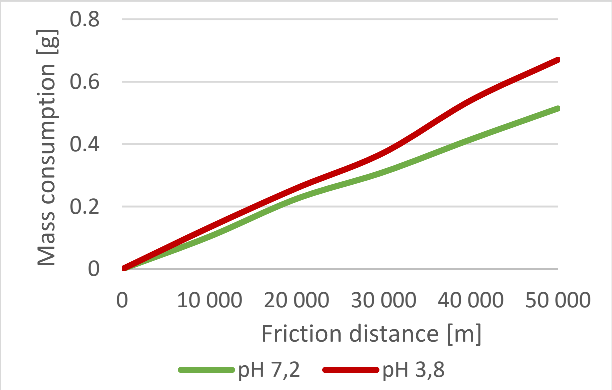

Figure 5. Mass consumption of Hardox 500 in acidic and neutral soil

Figure 6 shows the mass wear progression of 38GSA and Hardox 500 steel in acidic soil. Despite the abrasive soil mass having the same pH value, it can be observed that 38GSA steel wore more intensively, with a wear difference of 0.5 g at the final stage of the friction process.

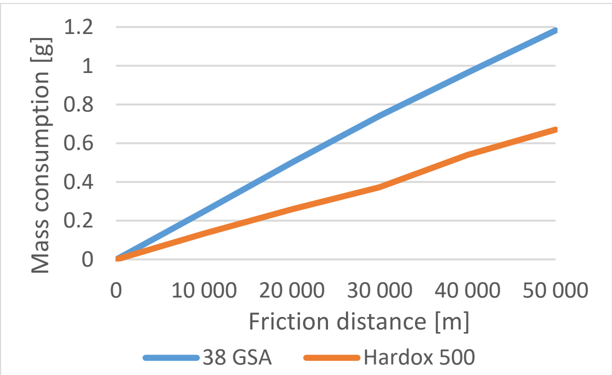

Figure 6. Mass consumption of 38 GSA and Hardox 500 steel in acid soil.

The comparison of wear between 38GSA and Hardox 500 steel in neutral soil is presented in Figure 7. From the beginning of the friction process, more intensive wear of the 38GSA samples was observed. The difference in mass wear amounted to 0.36 g over a friction distance of 50 000 m.

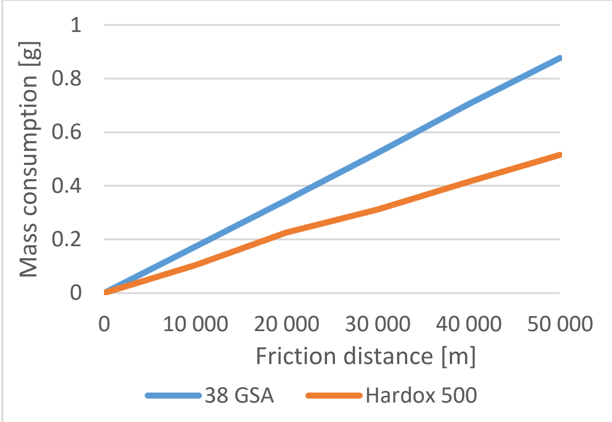

Figure 7. Mass consumption of 38 GSA and Hardox 500 steel in neutral soil

The surface view of the tested materials (Fig. 8–10), captured using an optical microscope, presents the friction surfaces. In each image, fundamental wear features can be identified, such as surface scratches and grooves in the top layer running parallel to the direction of friction, which are the result of hard soil particles interacting with the metal surface.

In the images showing the surfaces of the tested materials subjected to abrasive action in acidic soil (Fig. 8 and Fig. 10), numerous pits can also be observed, appearing as material loss on the friction surface. The origin of these pits may be related to the accumulation of a significant amount of hydrogen just beneath the surface of the material, which subsequently led to the intensification of intergranular cracking. This resulted first in the formation of cracks and then in the detachment of large structural fragments from the material's surface. In the images showing the surfaces of the tested materials subjected to abrasive action in acidic soil (Fig. 8 and Fig. 10), numerous pits can also be observed, appearing as material loss on the friction surface. The origin of these pits may be related to the accumulation of a significant amount of hydrogen just beneath the surface of the material, which subsequently led to the intensification of intergranular cracking. This resulted first in the formation of cracks and then in the detachment of large structural fragments from the material's surface.

Figure 8. Surface of specimen made of 38GSA steel after friction in soil abrasive compound with a pH of 3.8, magnification: 500x.

Figure 9. Surface of specimen made of 38GSA steel after friction in soil abrasive compound with a pH of 7.2, magnification: 500x.

Figure 10. Surface area of the Hardox 500 steel specimen after friction in a soil abrasive compound with an abrasion factor of 3.8, magnification: 500x.

Figure 11. Surface area of the Hardox 500 steel specimen after friction in soil abrasive compound with a pH of 7.2, magnification: 500x.

4. CONCLUSION

The conducted research confirms that the chemical reaction (pH) of soil has a significant impact on the wear processes of steel components operating in soil environments. Both 38GSA and HARDOX 500 steel exhibited clearly higher wear rates under acidic pH conditions (approximately 3.8) compared to a neutral environment. Particularly notable was the susceptibility of 38GSA steel, which showed 34% higher mass wear in acidic soil.

An important outcome of the study was the comparison of total hydrogen content in the samples before and after the friction process, which suggests active hydrogen absorption by the materials during operation in the soil abrasive mass. This phenomenon may lead to the weakening of the steel's mechanical properties and intensify decohesion processes, especially in acidic conditions. The increase in hydrogen content was especially pronounced in the case of 38GSA steel, where an increase of over 61% was recorded.

It is also worth noting the boron content in Hardox 500 steel, amounting to 0.005% by weight. In addition to improving hardenability, this element inhibits grain growth. As a result, it may limit hydrogen diffusion into the steel structure, thereby reducing susceptibility to hydrogen-induced corrosion. This is supported, among other things, by the significant differences in wear observed in the two environments (acidic and neutral) in favor of Hardox 500 steel.

These results point to the need for careful selection of construction materials based on environmental conditions, with particular attention to soil pH. Wear-resistant steels, such as HARDOX 500, exhibit better resistance to abrasion and lower susceptibility to hydrogen absorption, making them more suitable for operation in aggressive soil environments.

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5. REFFERENCE

[1] F. Cucinotta *et al.*, "On the morphology of the abrasive wear on ploughshares by means of 3D scanning," *Biosystems Engineering*, vol. 179, pp. 117–125, Jan. 2019, doi: 10.1016/j.biosystemseng.2019.01.006.

[2] E. A. Gharahbagh, J. Rostami, and A. M. Palomino, "New soil abrasion testing method for soft ground tunneling applications," *Tunnelling and Underground Space Technology*, vol. 26, no. 5, pp. 604–613, May 2011, doi: 10.1016/j.tust.2011.04.003.

[3] R. Chotěborský and M. Linda, "Determination of chemical content of soil particle for abrasive wear test.," *Agronomy Research*, vol. 14, pp. 975–983, Jan. 2016, [Online]. Available: https://www.cabdirect.org/cabdirect/abstract/20163195307

[4] K. Ligier, M. Zemlik, M. Lemecha, Ł. Konat, and J. Napiórkowski, "Analysis of wear properties of hardox steels in different soil conditions," *Materials*, vol. 15, no. 21, p. 7622, Oct. 2022, doi: 10.3390/ma15217622.

[5] J. Napiórkowski, „Zużyciowe oddziaływanie gleby na elementy robocze narzędzi rolniczych," habilitation thesis, Inżynieria Rolnicza, vol. 9, no. 12, pp 3-171, 2005.

[6] Á. Kalácska, P. De Baets, D. Fauconnier, F. Schramm, L. Frerichs, and J. Sukumaran, "Abrasive wear behaviour of 27MnB5 steel used in agricultural tines," *Wear*, vol. 442–443, p. 203107, Nov. 2019, doi: 10.1016/j.wear.2019.203107.

[7] K. Ligier, J. Napiórkowski, and M. Lemecha, "Effect of abrasive soil mass grain size on the steel wear process," *Tribology in Industry*, vol. 42, no. 2, pp. 165–176, Jun. 2020, doi: 10.24874/ti.784.10.19.04.

[8] M. Petrica, E. Badisch, and T. Peinsitt, "Abrasive wear mechanisms and their relation to rock properties," *Wear*, vol. 308, no. 1–2, pp. 86–94, Oct. 2013, doi: 10.1016/j.wear.2013.10.005.

[9] J. Napiórkowski, M. Lemecha, M. Rosiak, " An analysis of the impact of soil mass pH on the wear process of steel," The 4th International Conference on Computing and Solutions in Manufacturing Engineering - CoSME'16, Brasov, November 3-4, 2016.

[10] C. F. Dong, Z. Y. Liu, X. G. Li, and Y. F. Cheng, "Effects of hydrogen-charging on the susceptibility of X100 pipeline steel to hydrogen-induced cracking," *International Journal of Hydrogen Energy*, vol. 34, no. 24, pp. 9879–9884, Oct. 2009, doi: 10.1016/j.ijhydene.2009.09.090.

[11] R. A. Oriani, "Hydrogen embrittlement of steels," *Annual Review of Materials Science*, vol. 8, no. 1, pp. 327–357, Aug. 1978, doi: 10.1146/annurev.ms.08.080178.001551.

[12] A. R. Troiano., "The Role of Hydrogen and Other Interstitials in the Mechanical Behavior of Metals," *Metallography, Microstructure, and Analysis*, *5*(6), 557–569, 2016, https://doi.org/10.1007/s13632-016-0319-4

[13] M. Lemecha, J. Napiórkowski, K. Ligier, W. Tarasiuk, and K. Sztukowski, "Analysis of wear properties of powder metallurgy steel in abrasive soil mass," *Materials*, vol. 15, no. 19, p. 6888, Oct. 2022, doi: 10.3390/ma15196888.

[14] F. Bosio, E. Bassini, C. G. O. Salazar, D. Ugues, and D. Peila, "The influence of microstructure on abrasive wear resistance of selected cemented carbide grades operating as cutting tools in dry and foam conditioned soil," *Wear*, vol. 394–395, pp. 203–216, Nov. 2017, doi: 10.1016/j.wear.2017.11.002.

[15] M. Lemecha, J. Napiórkowski, and K. Ligier, "Wear processes of Abrasion-Resistant materials in soil environments of varying pH," *Advances in Science and Technology – Research Journal*, vol. 17, no. 3, pp. 269–279, Jun. 2023, doi: 10.12913/22998624/166508.