

An analysis of the impact of soil mass pH on the wear process of steel

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Abstract. The chemical properties of soil mass are among the most important factors affecting the intensity of the wear of working elements. The paper analyses the wear process of 38GSA steel, used in working elements which cut soil, depending on the corrosiveness of the chemical environment. The tests were conducted in natural soil conditions. Changes in the mass of samples depending on soil pH were measured during the tests. Based on the obtained results, it has been concluded that along with an increase in soil acidity, the steel wear intensity also increases. The highest value of wear was observed in acidic soil, followed by neutral, with the lowest value corresponding to alkaline soil.

1 Introduction

Intense wear, being a process of qualitative and quantitative physicochemical changes occurring on the friction surface, is a phenomenon accompanying the operation of working elements in soil mass [1, 2].

The process of the rational selection of the construction and technological forms of working elements, and of planning the course of operation, is possible when their wear process is known. The identification and description of wear in soil comes down to a comprehensive description of the process of friction involving: the soil - the working element - the parameters of work [3]. The soil is a complex, animate creation of nature, in which continuous processes of decomposition and synthesis occur for both mineral and organic compounds, along with their displacement [4].

Due to the multiplicity of factors affecting the course of wear for working elements in soil mass, so far there has been no formalised theory of mutual interactions between the soil and the working element. Most papers indicate that the wearing properties of soil result from its grain sizes, cohesiveness and humidity [5, 6].

Hydrogen-bearing properties belong to the phenomena involving the destruction of metals as a result of environmental impact [7]. Hydrogen-related wear has been described,

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among other things, for the surfaces of rotors and timing gears of pumps, in braking systems and rolling bearings.

The aim of the paper is the analysis of the impact of soil pH on steel destruction processes in abrasive soil mass.

2 The characteristics of soil pH

One of the most important chemical features of soil mass is its pH. Soil pH is a condition of soil solution determined by the ratio of hydrogen (H^+) to hydroxide (OH^-) ions, affected by the presence of acids, alkalis and salts [8]. A solution may have one of three types of pH, namely: acidic, alkaline and neutral.

Based on electrical conductance, it has been concluded that at a temperature of $22^\circ C$ the product of the concentrations of hydrogen and hydroxide ions is constant and equals 10^{-14} . This means that in one litre of distilled water there are 10^{-7} gram equivalents of hydrogen ions and just as many hydroxide ions. Soil pH is therefore dependent on the concentration of $[H^+]$ and $[OH^-]$ ions.

Neutral solutions: $[H^+] = [OH^-] = 10^{-7} [H^+]$,

Acidic solutions: $[H^+] \gg [OH^-] = 100 \div 10^{-7} [H^+]$,

Alkaline solutions $[H^+] \ll [OH^-] = 10^{-7} \div 10^{-14} [H^+]$.

In order to simplify the mathematical calculations, Sorensen introduced the pH designation - a negative logarithm of the concentration of hydrogen ions in a solution, $pH = -\log[H^+]$.

The acidity of soil is caused by hydrogen ions $[H^+]$ contained in a soil solution. The acidity derived from the $[H^+]$ ions contained in a soil solution is called the active acidity. The acidity derived from adsorbed $[H^+]$ and $[Al^{3+}]$ ions is known as the potential acidity. Two types of negative charges have been observed in soil colloids:

- a. constant charges,
- b. charges dependent on the concentration of hydrogen ions.

The former are present mainly in clay minerals. They are generated by electrostatic forces originating from isomorphous replacements in the crystals of those minerals. The anions bound by those constant charges are replaceable at any values. The second type charges are not constant and depend directly on pH. They originate from several sources. The first of them are H_2SiO_3 and $Al(OH)_3$ on the free surfaces of crystals and the outer surfaces of silicate minerals. The second are the carboxylic ($-COOH$) and phenyl groups of topsoil colloids. Each of these groups contains covalently bound hydrogen which does not dissociate at low pH values. However, as pH increases, H^+ ions begin dissociating, leaving negative charges on the colloids. In this manner, hydrogen is replaced by other cations, which themselves are also replaceable [9].

Another feature of soil humidity, defined as the amount of water in the medium. During the cultivation of soils with low humidity, which are characterized by a high compactness, it consumes flank plowshares. This reduces the width of the trapezoidal and the length of the bow section of working elements. In the studied conditions, soil moisture was $8.5\% \pm 2.3\%$. With the saturation of the soil with water followed by reducing the amount of wear, but the degree of these changes it depends on the type of soil. All soils change their properties with the change of water content.

Another condition affecting the process of abrasive wear in abrasive soil bulk density is, which is the ratio of the weight of the soil to the volume they occupy. During the research the density was $1.54 \text{ g} \cdot \text{cm}^3$.

Compactness of soil, which was $2.53 \pm 0.87 \text{ MPa}$ is defined as the degree of binding of the particles.

Shear stress in the layer of soil within a range of 10-20 cm were 45kPa.

3 The methodology of the research

The tests involved samples 30 x 20 x 10 mm in size, made of 38GSA steel. This is martensitic steel which contains bainite and troostite. The chemical composition was as follows: C - 0.38%, Mn - 1.07%, Si - 1.17%, P - 0.028%, S - 0.02%, Cr - 0.18%, Cu - 0.16%, Al - 0.022%. The hardness of the steel ranged between 409 and 442 HV10. Some of the samples had their wear evaluated by placing them in a soil of diversified pH, while another part was subjected to the examinations of wear in a laboratory device (Figure 1). The soil was collected from a pine forest from a depth of approximately 20 cm. Its pH amounted to 4.2. It was measured by means of a FieldScout pH meter from Spectrum Technologies, Inc. In accordance with the quality standard PN-EN ISO 14668-2(2004), the soil was defined as loamy sand, and it consisted of: sand: 85.8%, silt: 11.2% and clay: 3%. Soil humidity was evaluated by means of the measurement of the mass of the solid phase dried at a temperature of 105°C, and it ranged between 10 and 12%. Prior to the test, the samples were subjected to washing in an ultrasonic cleaner with a washing agent based on potassium hydroxide. The value of the mass wear of the samples was determined by means of a laboratory weighing scale with an accuracy of +/- 10⁻⁴ g. The samples were placed in vessels containing 2 kg of soil and stored for 21 days. The soil was deacidified by means of burnt lime (CaO) in various quantities in order to obtain the varying values of pH. The tests of wear were conducted in a wear testing machine utilising the “spinning bowl” method. Friction tests were conducted at a load of 53 kPa, a cutting speed of 2 ms⁻¹, and a friction path of 20 000 m. The assessment of the surface after wear was performed upon completing the whole friction path under a JSM 5310LV type JEOL scanning electron microscope in a digital system. The microscope was equipped with a detector of reflected electrons, a detector of secondary electrons, and an EDS type Ultra DR7 ThermoScientific X-ray spectrometer.

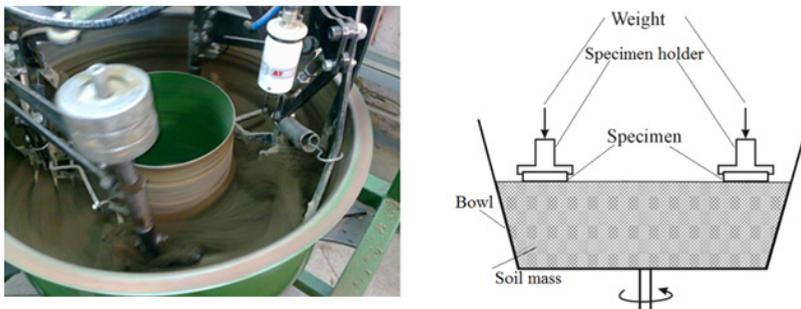


Fig. 1. A view of the wear testing machine.

4 Analysis of the test results

Figure 2 presents the relation between the loss in weight of the samples and soil pH. The elements stored in a soil having a considerable concentration of hydrogen ions (pH) are characterised by an increased loss in weight compared to the steel placed in more neutral and alkaline environments.

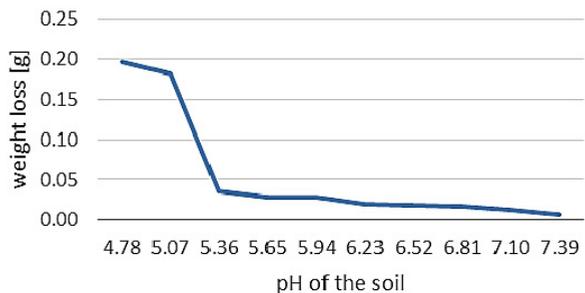


Fig. 2. The dependence of the samples' loss in weight on soil pH.

The obtained dependence is confirmed by the test results involving wear during friction in soil, presented in Figure 3.

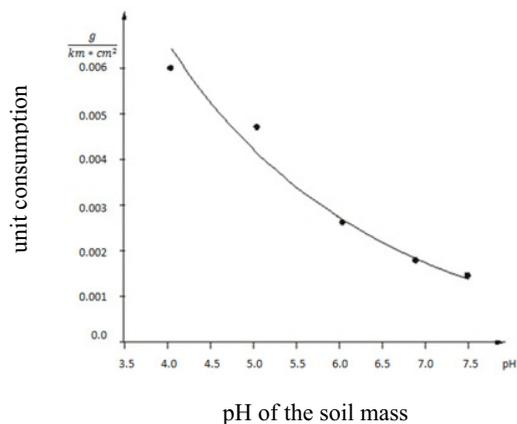


Fig. 3. The course of the intensity of wear depending on soil pH.

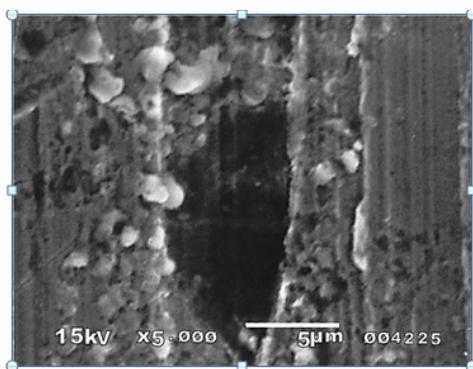


Fig. 4. A view of the surface after friction tests in the very acidic soil.

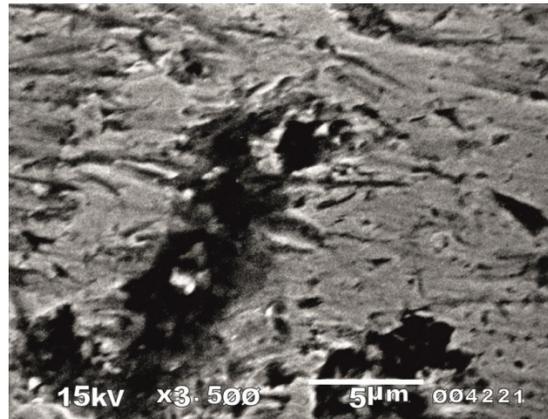


Fig. 5. A view of the surface after friction tests in the neutral soil.

An important impact of soil acidity on the course of wear was observed based on the obtained results. No statistical differences between the intensity of wear in neutral and alkaline soils were observed. The wear of 38GSA steel in the very acidic soil was over 3 times, and in the acidic soil over 2 times more intense than in the neutral soil.

The surface of wear in the very acidic soil (Figure 4, Figure 5) is characterised by the mutual interactions of chemical (the creation of oxides, deep pitting) and mechanical wear (micro-cutting and furrowing). Mechanical wear is predominant in the case of soils with neutral pH. Locally present pitting can indicate the presence, to some slight extent, of accompanying chemical wear.

The phenomena observed during wear in very acidic and acidic soils can be categorised as hydrogen-related wear. Hydrogen originates from the surrounding environment, including the increased acidity of soils, and from technological hydrogen contained in metal.

The increased saturation with hydrogen for these types of soils causes its intense adsorption on the surface of a working element, followed by the diffusion of hydrogen into the surface layer. When approaching the surface of metal, the particles of hydrogen in close proximity to it (less than 0.5 nm away) are subject to sufficient interaction with this surface, so that the phenomenon of adsorption can take place. The dispersion forces cause physical adsorption, resulting in the creation of a layer of non-localised moving particles on the surface of a solid, creating a kind of a two-dimensional liquid. The particle which will break the barrier of the activation energy may be bound to it by the forces of a specific character, size and nature, typical for covalent or ionic chemical bonds. It is a chemical reaction known as chemical adsorption or chemisorption. In the process of friction there are considerable concentrations of hydrogen present locally in the crystalline grid, along with the processes related to lowering the plasticity and decohesion of the fragments of surface layers, causing lasting mechanical damage, and as a final result intensifying the wear. This is directly related to the "promoters" of penetration.

The process of wear observed in acidic soils corresponds to classic hydrogen-related cracking wear. During the wear, hydrogen is accumulated in the places of the discontinuous structure of the surface layers, such as the boundaries of grains and phases, as well as dislocations. It remains there in a lasting manner due to the high bond energy of the "hydrogen atom – trap" complex. Cyclically repeating mechanical impulses move the subsequent portions of hydrogen atoms to the places of their storage, until reaching local concentrations which trigger nucleation and the creation of 1 – 2 μm deep local cracks in the surface layer.

5 Conclusion

The elevated hydrogen content precipitates in a reaction of the components of steel in an acidic environment. Hydrogen-related wear considerably affects the wear of soil handling elements, although this phenomenon is not predominant. It should only be considered as wear which intensifies the abrasive wear, which is the primary type of wear present in soil handling elements.

The mechanisms of hydrogen-related wear are described by the theories of the pressure of molecular and adsorptive hydrogen and the maximum triaxial stresses. In the case of wear in soil mass, the observed phenomena are explained by the theory of absorption. This states that the diffusing hydrogen is adsorbed on the tips of a fissure, reducing the surface energy of metal atoms, and being subject to tensile stresses it causes the creation and propagation of a fissure, resulting in the local displacements of material. The intensity of the diffusion of hydrogen into the material causes brittle cracking in the micro-volumes of the surface layer and its destruction by the forces of friction.

References

1. Napiórkowski J. (ed.), *Research and modeling of abrasive wear and fatigue*, (University of Warmia and Mazury in Olsztyn, 2014)
2. Bayhan, Y., *Tribology International* **39**, 570–574 (2006)
3. Napiórkowski, J., Drożyner, P., Kołakowski, K.; Mikołajczak, P., *International Virtual Journal for Science, Technics and Innovations for the Industry* **6 (11)**, 27–29 (2012)
4. Bhakat A. K., Mishra A. K., Mishra N. S., *Wear* **263**, 228-233 (2007)
5. Stachowiak, G. W.; Batchelor, A. W. *Engineering tribology* (3rd ed. Amsterdam, Boston: Elsevier Butterworth-Heinemann, 2005)
6. Gościański, M., Łabęcki, M., Kapcińska, D., Pirowski, Z., *Journal of research and applications in agricultural engineering* **52(2)**, 43–51 (2007)
7. Stabryła J., Starczewski L., The impact of water-bearing soil components wear agricultural tools, *Maintenance Problems* 1-2006, 199-206
8. Uggla H., *Agricultural soil science* (PWN Warsaw, 1981)
9. Fred A., *Soil Science Society of America Journal* **35** No. 3, 420-426 (1971)