

Wear Processes of Abrasion-Resistant Materials in Soil Environments of Varying pH

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ABSTRACT

The paper evaluates the effect of the value of the negative logarithm of the hydrogen ion concentration in solution, denoted as pH, on the wear of materials used for elements working in the soil mass. Three types of materials with different chemical composition and manufacturing technology were analyzed. The study was carried out under laboratory conditions using the “spinning bowl” method. Low-alloy martensitic steel, boron-containing wear-resistant steel, and Fe-Cr-Mn-containing surfacing applied to martensitic steel were tested. Soil pH was found to have a significant effect on the wear pattern of the materials tested. The greatest wear was found in acidic soils with a pH lower than 5, and it was 30–40% greater, depending on the type of material, with respect to soil with a pH above 6.8. The greatest destructive effect was found for low-alloy martensitic steel containing “promoters” of hydrogen penetration. The ways in which the surface is used depending on the pH of the treated soil are described. Hydrogen wear is revealed by decohesion due to weakening of the structural bond of the material. The stages of the process of destructive hydrogen action are defined.

Keywords: wear of steel, welded layers, wear testing, Martensitic steels, hydrogen wear, abrasive wear

INTRODUCTION

The issue of wear of working parts processing an abrasive soil mass is the subject of many studies [1, 2]. These elements are characterized by a very high wear intensity, up to several dozen grams per hour [3]. Even though the subject of wear in a medium with a discontinuous abrasion surface, such as soil, is the subject of many publications [4].

Research centers are primarily interested in the application of new material solutions and the technologies of their application [5, 6, 7]. It is forgotten that the aspect related to the operating part, i.e. its construction and manufacturing technology is only one of the components of the tribological system, as there are also the operation process parameters (loads, velocity, cutting depth). The authors' research to date indicates that most studies ignore the issue of abrasive mass properties as an important factor

affecting the course of wear processes. These properties can be divided into determined and random properties of the biological material of soil. The most common characteristic of the determined properties of a soil mass, adopted for analysis, is the grain-size distribution [8]. On the other hand, complementary characteristics are random properties such as moisture or specific density [9]. They primarily determine the shaping of the actual friction surface, which affects the size of the force interaction surface. In general, the chemical aspects of an abrasive mass are not taken into account in studies into wear within a soil mass. In the research wear and tear studies within land masses generally do not take into account aspects of the chemical impact on the environment. One of these is the reaction of the soil, which describes the activity of H⁺ ions. It is described quantitatively with the negative logarithm of the pH hydrogen ion concentration [10].

The acidity of the soil mass is caused by hydrogen ions $[H^+]$ contained in the soil and hydrogen $[H^+]$ and aluminium $[Al^+]$ ions adsorbed in the soil sorption complex comprising mineral and organic colloids. The acidity resulting from $[H^+]$ ions contained in the soil is referred to as active acidity. The acidity resulting from adsorbed $[H^+]$ and $[Al^+]$ is referred to as potential acidity. Two types of negative charges were observed on soil colloids:

- permanent charges,
- pH-dependent charges.

Permanent charges are mainly found in clayey materials. The pH-dependent charges are not permanent and are directly dependent on the pH. They originate primarily from the SiOH and AlOH groups on the free surfaces of crystals and outer surfaces of silicate minerals and the group of carboxyl and phenolic humic colloids. Each of these groups contains covalently bound hydrogen, which does not dissociate at low pH values. However, as the pH value increases, the H^+ ions begin to dissociate, thus leaving negative charges on the colloids.

In alkaline soils, hydroxyl ions $[OH^-]$ play the dominant role. In soils with this reaction, the permanent sorption-inducing charges primarily bind exchangeable bases that replaced the majority of H^+ and Al-OH ions. The place of the released hydrogen in the sorption complex is taken by Ca, Mg, and bases.

The effect of hydrogen on the mechanical properties of steel has been extensively reported in the literature [11, 12, 13, 14, 15]. Hydrogen-induced wear is a process most often caused by the following [16]:

- intensive hydrogen release during friction due to the tribodestruction of the environment containing significant amounts of hydrogen;
- a continuous flow of hydrogen in the surface layer of the construction material;
- hydrogen adsorption on friction surfaces,
- hydrogen diffusion into the deformed steel layer, whose velocity is determined by temperature and stress gradients;
- simultaneous development of multiple incipient cracks throughout the zone;
- reduction in plasticity and destruction of the metal structure under external loads.

Few works in area of wear concern, in principle, the motion friction of metal elements and associations with the static influence of the soil,

e.g. pipelines [7, 17, 18, 19]. The authors of the study noted that the hydrogen concentration in the surface layer of steel was related to the environmental pH value. A reduction in the pH value of the environment leads to an increase in hydrogen concentration in steel. Moreover, increasing the time of specimen exposure to the action of an acidic environment resulted in more subsurface cracks of steel. The dependence of the increase in the amount of hydrogen penetrating the steel structure on the duration of hydrogenation [18]. The authors observed that hydrogenation of the steel surface increases its susceptibility to hydrogen-induced cracking, and that hydrogen penetration occurs mainly on inclusions, such as aluminum oxides, titanium oxides and iron carbides in the steel.

The problem of hydrogen-induced wear also affects other parts operating in a soil environment, including operating parts processing the soil, e.g. agricultural equipment [20]. The soil environment contains many hydrogen-bearing substances, e.g. water, acids, hydrogen sulfide, hydrocarbons, and inorganic compounds. During the friction of steel tools against the mineral components of the soil, a portion of hydrogen-bearing compounds are degraded due to the physico-chemical phenomena accompanying this process.

Hydrogen-induced wear is a physicochemical process in which a metal surface layer deformed by friction is subjected to the action of hydrogen released from the materials of the soil-structure tribological pair under the influence of friction. It results in decohesion processes and changes in the plastic properties of the surface layer of a metal part.

The purpose of this study is to analyze the effect of soil reaction characterized by pH value on the wear of steel and welded layer in soil abrasive mass.

MATERIAL AND METHODS

Test material

The subject of the research were:

- low-alloy 38GSA martensitic steel,
- steel resistant to abrasion Hardox 600,
- EStelMn60 welded layer on 38GSA steel.

Welded layers applied to the surfaces of machine parts, combined with macro- and micro-structure, are one of the primary methods of increasing abrasive wear resistance in the ground

mass. The starting point of the paper is the analysis of composition diagrams and the study of the phase structure and microstructure of layer welded. A welded layer with a thickness of 0.003 m was obtained by applying a Fe-Cr-C alloy-based coated electrode on 38GSA low-alloy martensitic steel (Fig. 1) at a given welding current of 100 A. In the first layer, the backing weld contained primary eutectic carbides [$\alpha + (\text{Fe}, \text{Cr})_7 \text{C}_3$] with a predominantly lamellar structure + residual austenite (Fig. 2) (hardness of the surface layer: 360-525 HV10; shim strip hardness: 240 HV10)

Steel samples were taken in the form of 30×25×10 mm cuboids using methods ensuring that their structure remained unchanged. The method of water jet cutting with water and an abrasive substance was used for cutting the samples. The finishing of samples to the required surface roughness was carried out using a surface grinder.

Chemical composition was assessed with a Thermo ARL Quantis iSpark™ Series Optical Emission Spectrometer using the CCD technique. The obtained results were the arithmetic mean from five measurements (Table 1). The hardness of the test steels was measured by the Brinell method in accordance with the standard PN-EN ISO 6506-1:2008P, using a hardness tester with a 0.0025 m sintered carbide ball, under a load of 1875 kg, 9 N applied for 15 s. Measurements of the hardness of the padding layer were carried out by the Vickers method in accordance with standard PN-EN ISO 6507-1:1999. The measurements were conducted using a hardness tester, under a load of 1 kg (9.807 N) applied for 15 s.

Observations of the microstructure were carried out using a Neophot 32 light microscope

using a digital camera with NIS Elements software. Analysis of the surface of the samples after wear was carried out using a light microscope and a scanning electron microscope.

The steels were obtained directly from the manufacturers. The 38GSA steel was subjected to volumetric hardening and tempering in open air. In the hardened and tempered state, it is characterized by a fine-grained structure of hardening martensite and bainite. The average hardness of the steel was 415 HBW (Fig. 1).

The padding layers applied onto the surfaces of machinery parts, in combination with the macro- and micro-structure are one of the basic methods for increasing their abrasive resistance in a soil mass. The starting point for the study is an analysis of composition diagrams and research into the phase structure and micro-structures of padding welds. The padding layer of a 0.003 m thickness was obtained by applying a Fe-Cr-C alloy-based coated electrode onto 38GSA low-alloy martensitic steel (Fig. 1) at a set welding current of 100 A. In the first layer, the padding weld contained primary eutectic carbides [$\alpha + (\text{Fe}, \text{Cr})_7 \text{C}_3$] of a mainly lamellar structure + residual austenite (Fig. 2) (surface layer hardness: 360-525 HV10; backing strip hardness: 240 HV10).

The commonly used Hardox 600 steel resistant to abrasive wear (Fig. 3) was sampled from 12 mm thick sheet metal plates. The steel was supplied as water-hardened and tempered at a temperature of 200–700°C, which ensures obtaining a homogeneous hardness over 90% of the sheet section of the sheet. The micro-structure of Hardox 600 steel comprises tempered martensite with a fine-stripped structure. Moreover, the



Fig. 1. Microstructure of 38 GSA steel. Tempered martensite with bainite. Magn. 500×; etched with 3% HNO_3 (MnFe), light microscopy



Fig. 2. External surface of the EstelMn60 padding weld. Dendritic precipitates of alloy ferrite (light areas) and dark areas of the eutectic system. Magn. 200×; electrolytically etched with chromic acid



Fig. 3. Hardox 600 steel tempered martensite micro-structure. Magn. 500×; etched with 3% HNO₃ (Mi1Fe)

presence of numerous structure banding characteristics was noted (average hardness of the surface layer: 585 HBW).

Prior to the testing, the materials were processed by grinding, after which the roughness for the steel was equal to $R_a = 0.26 \times 10^{-6}$ m, while for the padding weld, $R_a = 0.36 \times 10^{-6}$ m. The chemical composition of test materials is provided in Table 1.

The study used soil with a very acidic reaction, taken from a pine forest. Grain-size distribution of the soil was measured using a Mastersizer 2000 PB 33 particle size analyser. Based on the results of tests for grain-size distribution, the soil was classified as loose sand containing the following grain fractions:

- 0.002–0.020 – 0.69%,
- 0.020–0.050 – 3.01%,
- 0.050–2.000 – 96.30%.

Moisture content of the soil was determined by measuring the weight of the solid phase dried at a temperature of 105°C. Prior to the testing, the specimens were washed in an ultrasound cleaner with a potassium hydroxide-based detergent. The value of specimen mass loss was determined using laboratory scales with an accuracy up to $\pm 10^{-4}$ g.

Description of tests

The pH value of the soil was measured by the electrometric method using a SoilStik PH Meter Flat Sensor FieldScout pH-meter with an accuracy of ± 0.01 pH. The specimens in the soil were left to stand for 21 days. The soil moisture content was 12–14%. The testing for wear in an abrasive soil mass under laboratory conditions was conducted by the rotating bowl method (Fig. 4).

During the testing, the soil moisture content was maintained at a level of approx. 12–13%. The specimen, fixed in the holder, was placed in a rotating bowl filled with loose sand with an acidic pH. Soil pH was measured by electrometric method using a SoilStik PH Meter Flat Sensor FieldScout pH meter with an accuracy of ± 0.01 pH. The soil pH was changed by adding calcium oxide (CaO 70%) at 46 g per 0.22 m³ soil. During the testing, the following friction parameters were adopted: velocity of 1.66 m/s, total friction distance of 10 000 m, and total load on the specimen of 58.9 N. Mass loss was measured every 2000 m. The testing for wear was conducted in six replications in each variant. Two specimens of one of each of the test materials were fixed in the wear-testing machine.

Mass loss of the specimens was referred to as a loss in specimen weight.

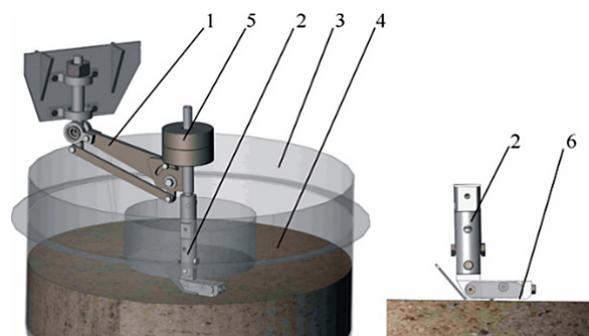


Fig. 4. Diagram of the testing for wear by the rotating bowl method: 1 – rocker arm, 2 – specimen holder, 3 – rotating bowl, 4 – abrasive mass, 5 – specimen weights, 6 – specimen.

Table 1. Chemical composition of test materials

Type of material	Element content, %							
	C	Si	Mn	Cr	Ni	Mo	B	Ti
38GSA	0.29	0.86	1.07	0.18	–	–	–	0.09
Hardox 600	0.45	0.71	1.00	1.2	0.50	0.80	0.004	–
EStelMn60	4.90	0.98	2.99	31.60	0.30	–	–	–

$$M_l = m_0 - m_1 \tag{1}$$

where: M_l – mass loss; m_0 – initial specimen weight; m_1 – specimen weight at the end of the experimental run.

Wear rate was defined as a ratio of the weight loss to the product of the load force and the sliding distance.

$$W_r = \frac{M_l}{F \cdot D} \tag{2}$$

where: W_r – wear rate; M_l – mass loss; F – load force; D – sliding distance.

RESULTS AND DISCUSSION

The obtained test results of wear are provided in Tables 2 and 3 and are shown in Figure 5. An analysis of variance was conducted

using Duncan’s test with Statistica 13.3 software (StatSoft) to determine the significance of differences between the wear values of test materials for different soil reactions (significance level $\alpha = 0.05$). It was found that for 38GSA steel, there are significant differences in wear in soils with different reactions. The relationship is different for the EstelMn60 rootstock weld. Statistically significant differences in wear intensity were found between very acidic and acidic soils and neutral and basic soils. For both 38GSA steel and the EstelMn60 shim weld, no differences in wear intensity were noted between neutral and alkaline soils. Wear of 38GSA steel in very acidic soil was more than three times (and more than twice in acidic soil) more intense than in neutral soil (Table 4). Images of the surface after friction tests of 38GSA steel are shown in Figure 6.

Table 2. A comparison of the wear of the 38GSA steel in different soil reactions

Soil reaction	pH	Mass loss [g]	Standard deviation [g]	Variance [g]	Confidence interval
<i>Very acidic</i>	3.9	0.4490	0.0204	0.00053	0.4311<m<0.4669
<i>Acidic</i>	4.9	0.3524	0.0409	0.00209	0.3166<m<0.3882
<i>Slightly acidic</i>	5.8	0.1950	0.0238	0.00071	0.1742<m<0.2185
<i>Neutral</i>	6.8	0.1320	0.0152	0.00028	0.1187<m<0.1453
<i>Alkaline</i>	7.5	0.1084	0.0136	0.00023	0.0965<m<0.1203

Table 3. A comparison of the EstelMn60 padding weld wear in soils with different pH values

Soil reaction	pH	Mass loss [g]	Standard deviation [g]	Variance [g]	Confidence interval
<i>Very acidic</i>	3.9	0.1154	0.0297	0.00110	0.0894<m<0.1414
<i>Acidic</i>	4.9	0.0760	0.0140	0.00024	0.0638<m<0.0882
<i>Slightly acidic</i>	5.8	0.0674	0.0202	0.000051	0.0497<m<0.0851
<i>Neutral</i>	6.8	0.0344	0.0235	0.000058	0.0139<m<0.0549
<i>Alkaline</i>	7.5	0.0414	0.0192	0.00046	0.0244<m<0.0584

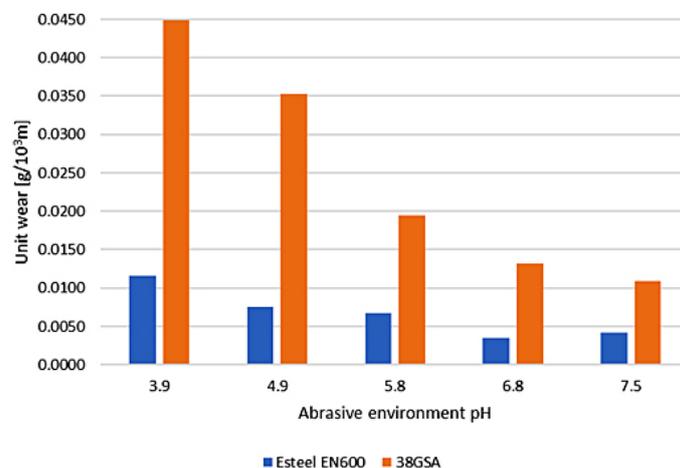


Fig. 5. A comparison of unit wear of materials depending on the soil reaction

Table 4. Results of the analysis of variance of mass loss, depending on the abrasive environment pH value

Subclass No.	Duncan's test; approximate probabilities for post hoc tests			
	Soil	1.618875	1.3062	1.1773
1	very acidic		0.000210	0.000092
2	acidic	0.000210		0.000210
3	neutral	0.000092	0.000210	

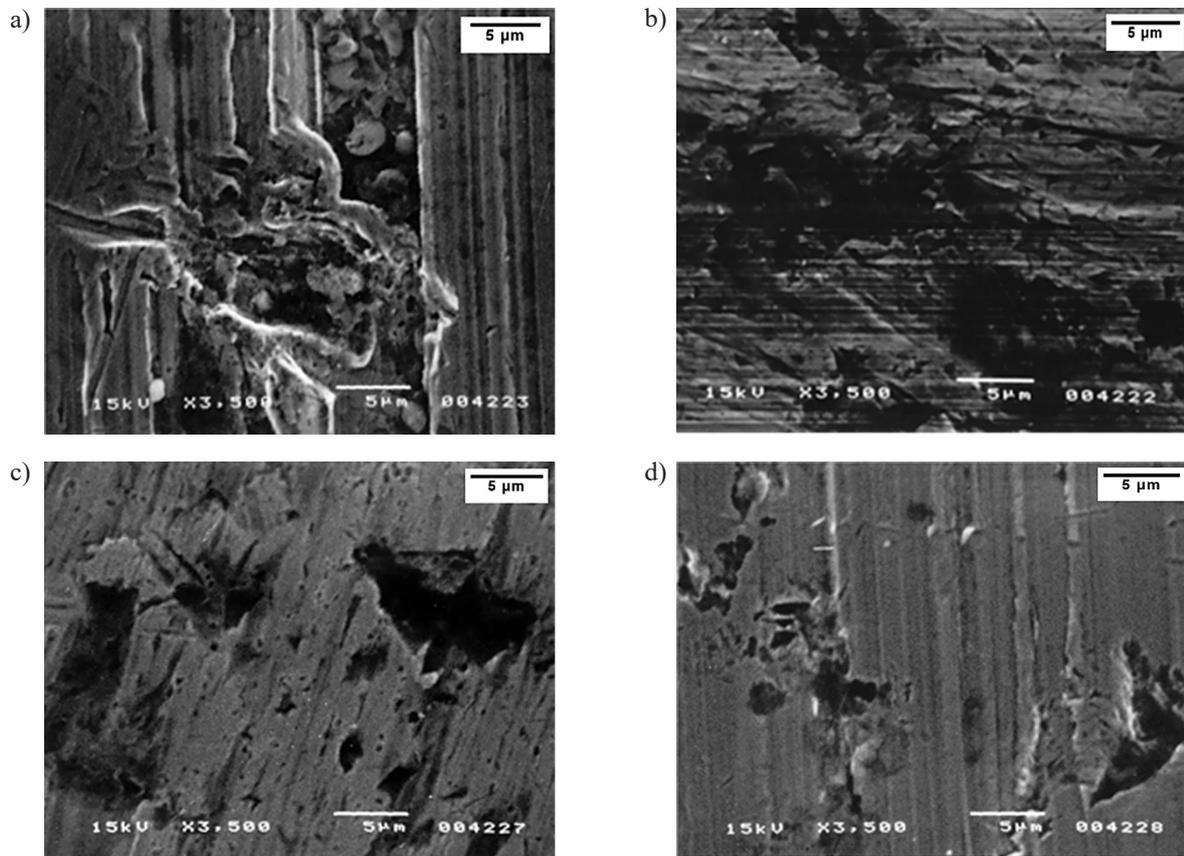


Fig. 6. A view of 38GSA steel surface following wear in soils with different pH values: (a) Very acidic – 38GSA steel, magn. 3500×, (b) Acidic - magn. 3500×, (c) Slightly acidic – magn. 3500×, (d) Alkaline – 38GSA steel, magn. 3500×

The view (Fig. 6) of the surfaces being worn in acidic soils indicates the dominant proportion of chemical wear. In these soils, there are also mechanic wear processes (micro-cutting and ploughing) whose intensive action in the weakened surface layers of materials results in increased wear. For soils with a neutral and alkaline pH, mechanical wear is predominant. The locally occurring pinholes may indicate the occurrence of chemical wear as well.

As a result of the friction process, there is a local increase in the concentration in the hydrogen crystal lattice, which results in reduced plasticity and decohesion of the surface layer fragments, thus intensifying the wear. This is directly related to the penetration “promoters”.

In order to confirm the wear results in acidic soils obtained in previous studies, the effect of soil reaction on the wear of Hardox 600 steel commonly used to produce soil-processing operating parts was investigated. The mass loss values for individual pH values are presented in Figure 7, and the wear rate values in Figure 8.

The greatest loss in steel weight was noted for abrasion in a very acidic environment (pH of 3.9). With the neutralisation of the abrasive mass reaction, the mass loss value decreased by 24%. The lowest wear value was noted for the specimens being abrasively worn in an environment with a neutral pH value.

Based on the course of mass loss (Fig. 9), it can be observed that over a friction distance of

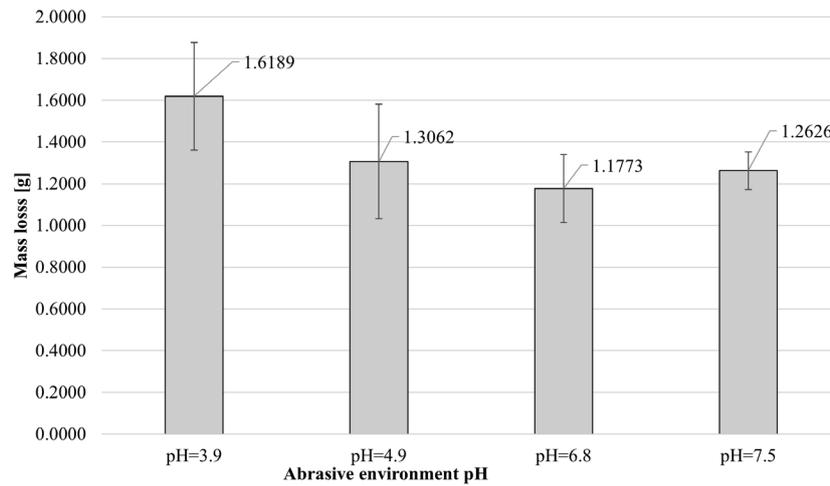


Fig. 7. Total loss in weight of Hardox 600 steel depending on the pH of soil

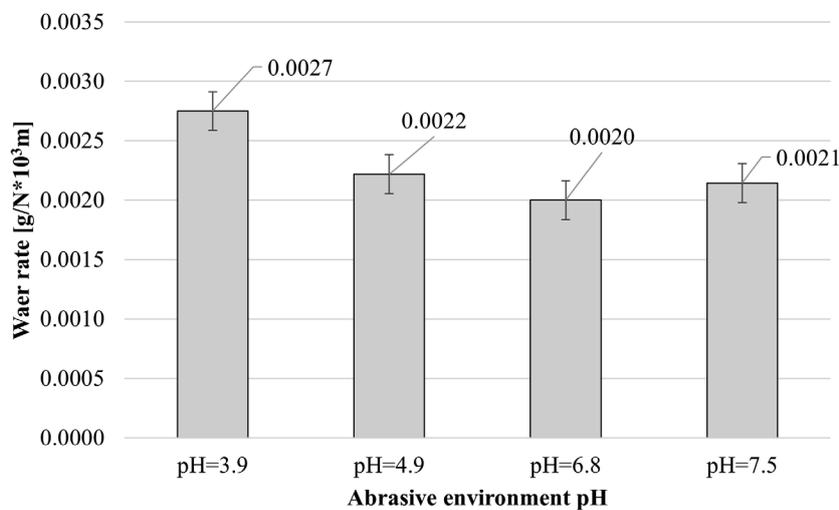


Fig. 8. 38GSA steel wear rate values, depending on the pH of soil

up to 4 km, the course of wear was similar irrespective of the environmental pH value. Over a friction distance of 4 to 6 km, the wear of steel in an environment with a pH of 3.9 increased in relation to other abrasive masses, and then the wear dynamics remained at a level similar to that of the wear in other abrasive media (Fig. 10). The increase in steel wear dynamics in a very acidic environment can be linked to the processes associated with the increased chemical impact of this environment. The effect of this impact was an increase in wear intensity between the 4th and 8th kilometre of the friction distance.

Such a course of material wear can be explained by means of results from hydrogen adsorption. It involves the actual penetration of hydrogen ions into the micro-cracks of the surface and the formation of so-called adsorption centers on the surface of the adsorbent. As a result of adsorption, the adsorbed substance, or adsorbate,

becomes concentrated on the surface of the adsorbent. It should be noted that soil consists of a solid, liquid and gas phase containing many hydrogen-bearing compounds (water, acids, hydrocarbons, inorganic compounds). Hydrogen diffusion can occur from both the gas and liquid phases. Adsorption is the first stage of hydrogen entering the metal simultaneously from both phases. The second stage is physical adsorption (E_p) and chemical adsorption, or chemisorption (E_c). The presence of an oxide layer on the metal surface increases the activation energy of hydrogen from the gas. The intensity of hydrogen entry is determined by the kinetics of hydrogen molecular dissociation. Hydrogen absorption proceeds differently in the thin (on the order of several atomic layers) “near-surface zone”. Hydrogen absorption from the liquid phase is related to the hydrogenation mechanism, particularly cathodic hydrogenation.

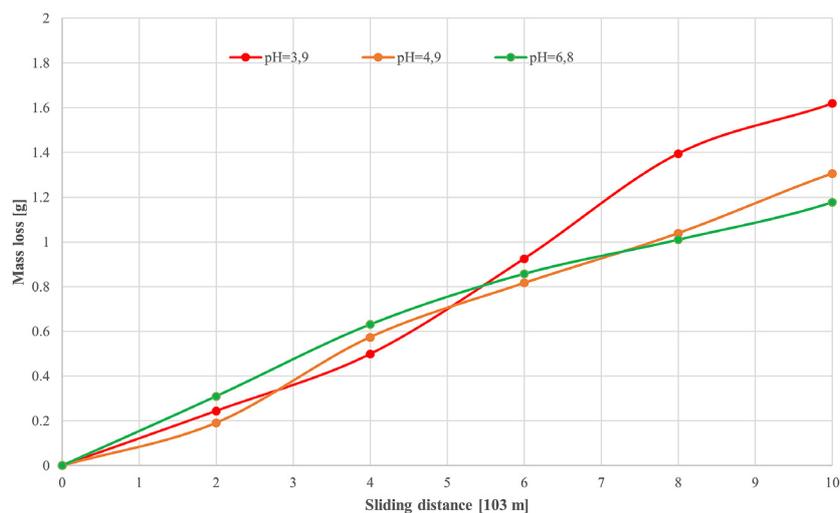


Fig. 9. The course of Hardox 600 steel wear in an abrasive environment with different pH values

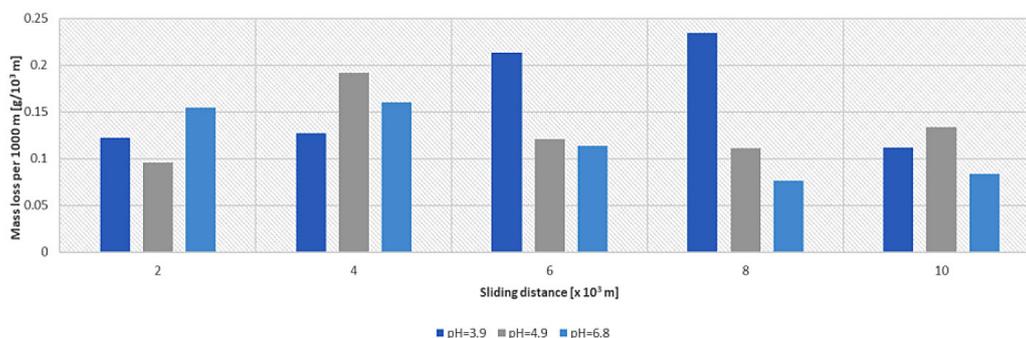


Fig. 10. Unit mass loss of Hardox 600 steel in an abrasive environment with different pH values

The literature notes that most of the cracks resulting from the hydrogen impact are located under the material surface [1]. Under this assumption, the exposure of the areas containing hydrogen-induced cracks resulting from mechanical processes can result in spalling of the weakened (brittle) material and the acceleration of the wear process.

Surfaces analysis

Analysis of the view of surfaces of the specimens being worn in an abrasive environment with different pH values, deep scratches and ridges as well as few micro-cutting traces can be noticed (Fig. 11). In addition, on the surface of the steel being worn in a very acidic and acidic environment, small cracks can be seen.

The cracks revealed on the surface of the specimens being worn in a very acidic and acidic environment are characterised by sharp edges and a depth greater than the depth of the largest ridges (Fig. 12). Their view shows that they are not a result of the action of abrasive grains. Figure 12 shows that the nature of the cracks is

distinctly different from the micro-cutting traces that are accompanied by the strain of the material near the trace edge, which was not observed for cracks. Figure 13 shows the surface of steel being worn in a very acidic environment (pH = 3.9) and a neutral environment (pH = 6.8).

On the surface of steel being worn in an acidic environment, the number of surface cracks is considerably greater than that on the surface of steel being worn in a neutral environment. On both surfaces, the dominant wear type is ridging.

Based on the results obtained, a significant relationship between the effect of soil acidity and the course of wear was noted. Mass loss of Hardox 600 steel in a very acidic soil was greater by 37% than that in neutral soil, while in acidic soil, it was greater than that in neutral soil by over 10%.

The wear surface in very acidic soil (Fig. 13a) is characterised by interpenetration of chemical wear (the formation of oxides and deep pits) and mechanical wear (micro-cutting and ridging). For soils with a neutral pH value (Fig. 13b), mechanical wear is predominant. The locally occurring pinholes may indicate that chemical wear is also

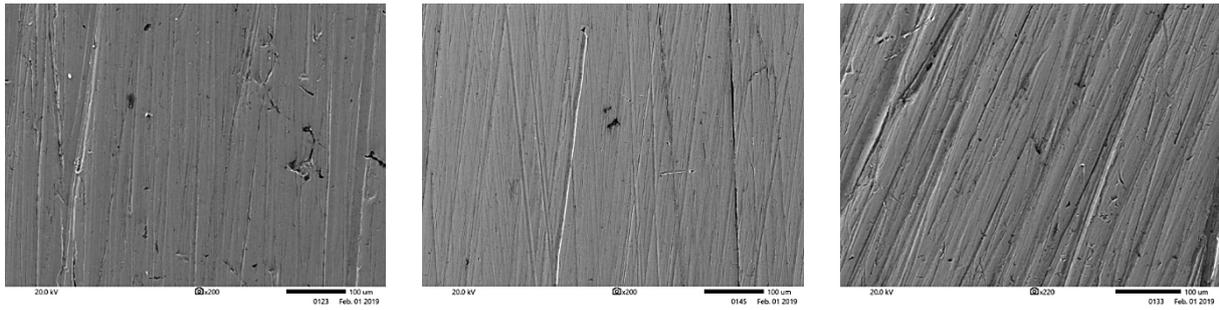


Fig. 11. A view of the surface of the specimens being worn in an abrasive environment with different pH values

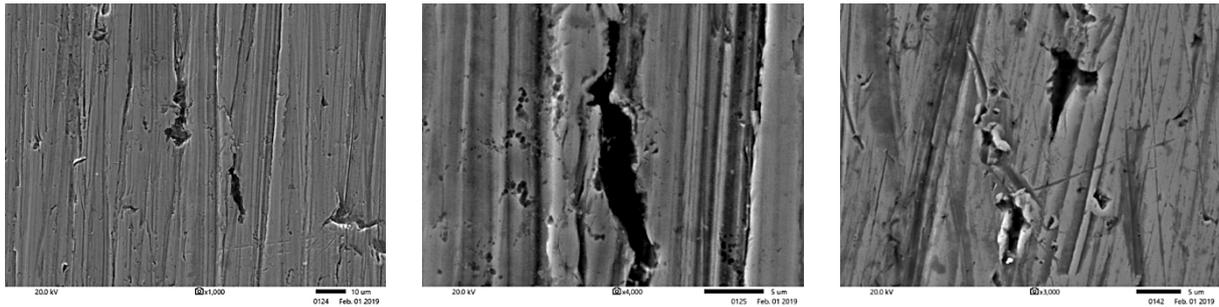


Fig. 12. A comparison of marks of micro-cutting and surface cracking of steel being worn in an acidic environment (pH=4.9)

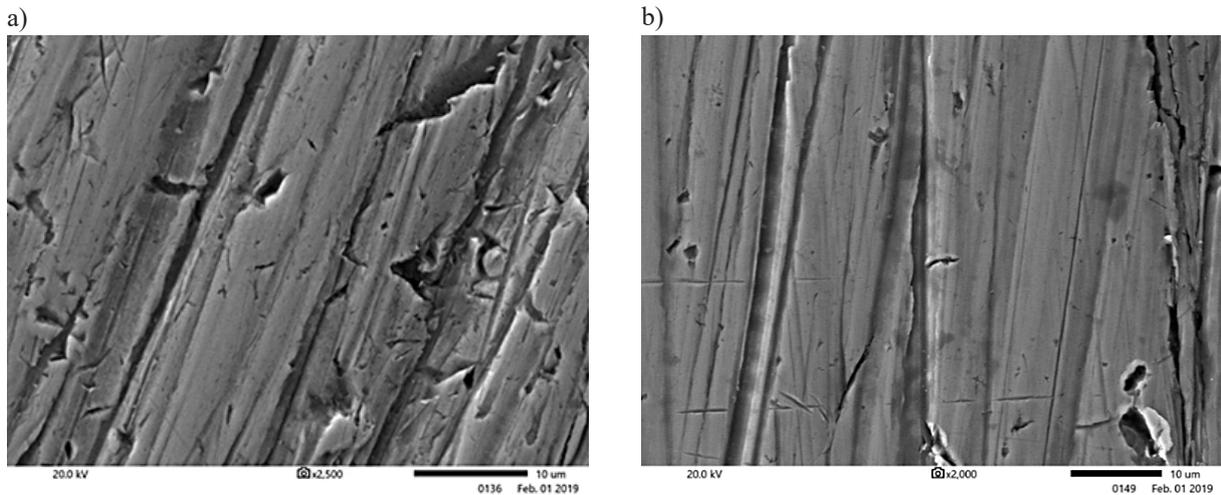


Fig. 13. The surface of steel being worn in an environment with pH values of 3.8 (a) and 6.8 (b)

occurring to a small extent. The phenomena noted during wear in very acidic and acidic soils can be classified as hydrogen-induced wear. The hydrogenation source is the surrounding environment, including increased soil acidity and technological hydrogen contained in the metal. The increased hydrogen saturation of this type of soil results in its intensive adsorption on the surface of an operating part, followed by hydrogen diffusion into the surface layer. Hydrogen molecules, when approaching the metal surface at a small distance (less than 0.5 nm) are sufficiently affected by this surface for the adsorption phenomenon to occur. Dispersion

forces cause physical adsorption, which leads to the formation, on the solid body surface, of a layer of non-localised mobile particles that form a type of two-dimensional liquid. The particle that will overcome the activation energy barrier can be bound to it by forces of a specific character, magnitude and nature characteristic of covalent or ionic chemical bonds. In the friction process, significant hydrogen concentrations in the crystal lattice and processes related to decreased plasticity and decohesion of surface layer fragments occur locally, causing permanent mechanical damage and, ultimately, intensifying the wear.

Soil is a medium that promotes electrochemical corrosion. In this type of corrosion, the anode, or metal, is dissolved and metal ions are formed, which later form metal oxides and hydroxides (corrosion products). The further process of material destruction can be explained by adsorption theory. Adsorption of hydrogen involves the actual penetration of hydrogen ions into surface microcracks and the formation of so-called adsorption centers on the surface of the adsorbent. As a result of adsorption, the adsorbed substance, or adsorbate, becomes concentrated on the surface of the adsorbent. It should be noted that soil consists of a solid, liquid and gas phase containing many hydrogen-bearing compounds (water, acids, hydrocarbons, inorganic compounds). Hydrogen diffusion can occur from both the gas and liquid phases. Adsorption is the first stage of hydrogen entering the metal simultaneously from both phases. The second stage is physical adsorption (E_p) and chemical adsorption, or chemisorption (E_c). The presence of an oxide layer on the metal surface increases the activation energy of hydrogen from the gas. The intensity of hydrogen entry is determined by the kinetics of hydrogen molecular dissociation. Hydrogen absorption proceeds differently in the thin (on the order of several atomic layers) “near-surface zone”. Absorption of hydrogen from the liquid phase is associated with the hydrogenation mechanism at corrosion potential or with cathodic hydrogenation. In the first case, the hydrogen concentration is low. Corrosion destruction is actually hydrogen-induced stress corrosion cracking. Thus, such hydrogenation occurs when crack development can be initiated by hydrogen as a result of electrochemical reactions occurring in holes and cracks. Hydrogen enters the metal in the crack tip area.

An important factor influencing the rate of hydrogen sorption by wear materials is their chemical composition. This is directly related to the elements that are penetration “promoters”, even a small amount of which can significantly accelerate the penetration of cathodic hydrogen into the metal. The most effective “promoters” are compounds of some groups V-A (phosphorus, arsenic, antimony) and VI-A (sulfur, selenium). In the case of group V-A elements, the influence of pH on the rate of hydrogen penetration is revealed, while in the case of group VI-A elements, there is also a reduction in the activity of the hydride as a catalyst, caused by dissociation in aqueous solution. Hydrides of this group are stable only in acidic solutions. The

reason for the increase in wear intensity in acidic soils is the increase in hydrogen adsorption by the friction surface as a result of the activation of its penetration promoters, e.g. sulfur.

In the case of 38GSA steel and EStelMn60 padding weld, the increase in wear between very acidic and neutral soil was similar and amounted to 3.4. It should be noted that these values for the padding weld were obtained despite the much higher content of elements such as C, Cr and Mn compared to steel, considered to slow down the hydrogen absorption process. The content of these elements decreased the wear value as a result of obtaining a higher hardness of the surface layer and a microstructure more resistant to abrasive wear. However, this did not reduce the destructive effect of hydrogen. However, in the case of Hardox 600 steel, which contains boron in the amount of 0.004%, the value was 1.38×. The task of boron in this type of steel is to improve the hardenability and strengthen the grain boundary. This hinders the diffusion of hydrogen to the surface layer as a result of occupying the space where the hydrogen moves.

The wearing course observed in acidic soils corresponds to the classical hydrogen-induced wear by spalling. During the wearing, hydrogen is accumulated in the areas of discontinuity in the surface layer structure, such as grain and phase boundaries and dislocations. It is retained there permanently due to the high binding energy of the “hydrogen atom – trap” complex. Cyclically repeating mechanical pulses, related to the effects of abrasive grains, move successive portions of hydrogen atoms to their capture sites until local concentrations are reached that induce nucleation and the formation of local cracks in the surface layer.

CONCLUSIONS

Based on the results, it was shown that the intensity of consumption of construction materials is significantly influenced by soil acidity. In acidic soils with a low pH value, hydrogen is released by the reaction of water-bearing substances, such as water, acids, hydrogen sulfide, hydrocarbons and inorganic compounds.

This is especially true in highly acidic soils, where, regardless of the type of construction material, the mass loss was significantly greater than that of other materials. The intensity of mass consumption in very acidic soil was 30 to 40%, depending on the material tested, higher than in neutral soil.

The condition of the surface after friction tests indicates that, in addition to the classic wear modes for abrasive wear (furling, scratching), there are local surface tears. They reflect intensive hydrogen wear through decohesion due to weakening of the structural bond of the material.

In the process of destructive hydrogen action, the following process steps occur:

- tribochemical reactions with the soil resulting in the release of hydrogen;
- adsorption and the process of penetration of hydrogen into the surface layer of the material through dislocations, fissures;
- diffusion of hydrogen in the surface layer;
- accumulation of hydrogen and destruction of the surface layer.

However, it should be emphasized that the process of hydrogen consumption in the soil is not dominant and, in principle, intensifies wear through mechanical modes of wear. In addition to the cognitive aspect of friction processes in soil, the results obtained have a utilitarian significance. The study of wear in natural soil environments should be carried out in inert soils, and materials containing hydrogen penetration promoters should not be used on working elements for soil use.

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