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# RESEARCH ON THE DEGRADATION PROCESS OF AGRICULTURAL TOOLS IN SOIL

**Key words**

Micro-alloyed steel, abrasive wear, hydrogen attack, agricultural tools.

## Summary

The wear of agricultural tools in previous publications was defined mostly as a simple process of abrasion. Any additional factors other than mechanical ones were not taken into account. Only a few explorers have taken into account the acidity of soil. The considerable content of salt, acids, and hydrocarbons at a significant degree, accelerates the processes of the wear on tools working in moist soil. The laboratory investigations were aimed at the assessment of electrochemical processes and hydrogen on the abrasive wear of agricultural tools. Carbon and micro-alloyed steel were studied.

## Introduction

The most popular materials for agricultural soil cutting tools in our country are medium carbon steels with the addition of manganese and silicon, usually 18G2, 40GS and 38GSA [6]. The alloyed steels with high abrasive and corrosion resistance are not applied due to high costs. In last few years interest has grown up about micro-alloyed steels, which having high wear resistance, are only 10% more expensive than medium carbon steel. The work conditions of agricultural tools are particularly difficult. The working elements of tools for the tillage of soil undergo wear mainly because of the abrasive influence on their surface of the hard mineral particles. Manufacturers deliver tools of a low hardness 200–250 HV or a hardness up to 400–550 HV. Heat treatments applied to this type of steel are usually full quenching and tempering or surface hardening [8]. Products with low hardness undergo abrasive wear while products with high hardness wear away more slowly, but they often crack. So far, studies on the wear of agricultural tools have usually omitted the influence of the chemically aggressive environment of soil.

## 1. The tribological proprieties of soil

Different research centres deal with the processes of abrasive wear accompanied by corrosion and the destructive influence of hydrogen [3, 4, 8, 11]. The complex forms of wear appear in pumps and pipelines of oil refineries, the mining industry, and the processing of plastics. Previously, there was an interest in the influence of organic compounds on the processes of the wear of tools during the processing of wood [4]. One of the most aggressive environments is seawater [15]. The author has spent many years on studies concerning the influence of a soil environment on the processes of the wear of agricultural tools. Agricultural tools such as shares, mouldboards or teeth of harrows, during contact with soil, undergo abrasion, mainly by friction. Soil is a mixture of mineral particles as well as organic and inorganic compounds of hydrogen with very varied composition and tribological proprieties [4]. With regard to variable composition, the moisture and temperature of soil, the investigation of wear processes is difficult. The process of wear, by simplification, can be treated as mechanical abrasion intensified by the chemical influence of the environment. The intensity of mechanical abrasion of the tool by sharp grains of sand depends on their geometry and the difference of hardness between the abrasive medium and the material of tool [1, 2, 14]. According to Rewut [7] the quartz sand grains present in soil have a hardness of 7 in the Mohs' scale. The hardness of steel tools applied in agriculture is 4–6 in the Mohs' scale. As we know, quartz sand is a basic component of the majority of national soils (Fig. 1), and it is an abrasive material even for hardened steel.

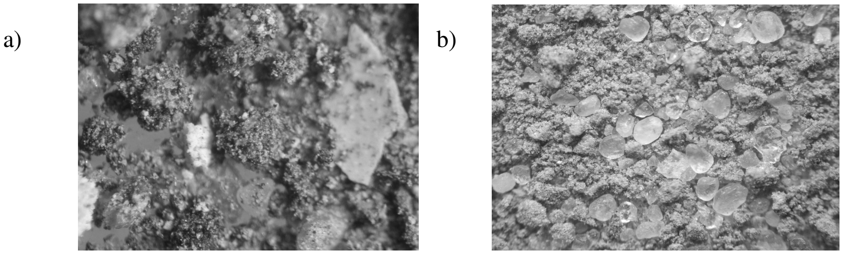

Fig. 1. Examples of soil a) clay – sandy, b) sandy. Grains of the sand and fine particles of clay. Stereoscopic microscope MBS-9. Mag. 25 x

The grains of corundum, calcium, siderite, fluorite, carbonates of calcium and magnesium are also present in soil. Mechanical interaction between the abrasive medium and tool is widely described in national and world literature [1, 2, 14].

## 2. The synergic effect of hydrogen accompanying wear in soil

The second, previously defined, element of the wear process, the chemical interaction of soil, may intensify wear abrasion because of the corrosion process and hydrogen attack [5]. Ścieszka [10] confirms that, in aggressive environments, the synergic attack of wear and corrosion in metal takes place. The process includes a series of simultaneous, overlapping phenomena of forming and destroying absorbed or passivated layers, electrochemical dissolving intensified by stresses, corrosion and hydrogen destruction. Synergic effects signify that common attack causes a higher effect of wear than the summary of wear caused by each individual factor. In our country, predominate acidic soils have a acid-base-indicator pH 4-6. Components of soil containing aggressive hydrogen are usually inorganic acids (acid rain), organic acids (coming from plants), animal proteins and mineral fertilisers. Wranglen [12] claims that the speed of corrosion in soil is considerably higher than in the atmosphere, and it can be compared to the speed of corrosion in seawater. A good supply of oxygen and moisture, as well as soluble salts in the top layer of soil, are favourable for the intensity of the corrosive processes. An additional augmenting factor of wear in soil is microbiological corrosion. The direct influence of microbiological corrosion in the wear of agricultural tools is small, because it runs in deep clay layers of soil. However, bacteria from the family *Desulphovibrio* reduce sulphates and causes cathode depolarisation with the separation of hydrogen, and in an anode reaction, dissolve iron. In turn, *Ferrobacilius* bacteria cause oxidation of iron, and formed oxides are easily moved from the surface through sand grains. The author, studying the used surfaces of agricultural tools with the aid of stereoscopic microscope, noticed characteristic damages for corrosion (the pitting) and hydrogen action (microcracks) by the typical furrows and scratches resulting from mechanical friction of sand grains. On these bases, a thesis was stated that the process of the wear of steel tools in soil is a synergic process, with the essential part being corrosion and hydrogen degradation. The aggressive interaction of hydrogen on different metals, and particularly the steel, was examined and described by many authors of publications [3, 4, 11, 13]. As the result of friction and the catalytic activity of iron, the compounds of hydrogen contained in soil decompose [12]. The resulting atomic hydrogen, due to the small atomic radius (0,37 Å), can easily penetrate the structure of steel. The process of the formation of atomic hydrogen and penetration of the surface is stimulated by the high contact pressures, which values exceed the yield point of metal. The temperature raised by friction favours the diffusion of hydrogen in metal. The hydrogen becomes imprisoned in areas of dislocation, on grain borders and other areas, in the defects of steel structure. It may create "the Cotrell's atmosphere," blocking the movement of dislocations and generating the embrittlement of material. The concentrated in the defects of the structure atoms of hydrogen can join in particles of $H_2$ and even join with carbon contained in components of steel to form methane $CH_4$. The traces of the hydrogen degradation of the surface are indicated by microcracks and were observed by the author during the investigations of used agricultural tools. The appearance of a tool after exploitation is presented in Fig. 2.

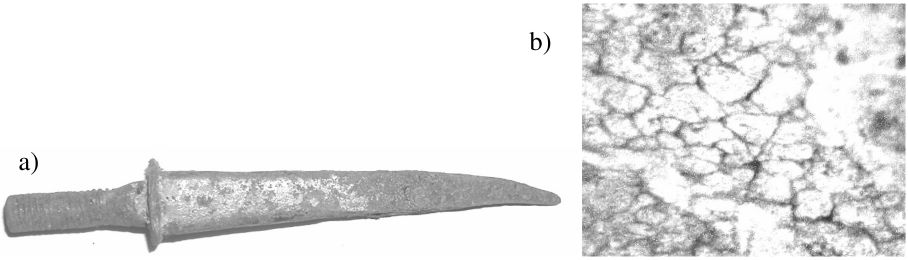

Fig. 2. The tooth of a harrow after exploitation (CANON digital photography): a) abrasive and corrosive wear; b) the hydrogen cracks on the surface of a tooth. Stereoscopic microscope MBS – 9. Mag. 90 x

To increase the agricultural tool's life, we need to search for some steels which are resistant to abrasion, mechanical loads, and hydrogen penetration.

The literature studies show that a material that can fulfil these expectations is steel with a micro-addition of boron. Boron in a quantity 0.002–0.005% in low carbon steels improves hardening ability and strengthens grain boundaries [5].

## 3. The research

The investigations of the destruction process of agricultural tools in aggressive soil require that the tests be conducted in natural conditions. It is possible only in a range limited by the agricultural season. To execute accelerated tests, we need to use soil bins or search laboratory stands. In the present article, the laboratory stand and method of investigation that had been described in the author's earlier publication [9] was used. The method of wear investigation in abrasive mass was chosen according to the work conditions of a harrow tooth. The range of investigations included the assessment of abrasion resistance in clean corundum with the addition of water (Fig. 3a) and in corundum with 10% addition of soil with a acid-base-indicator of pH 5.5 from the vicinity of Olsztyn

(Fig. 3b). The laboratory abrasion stand is presented in Fig. 4. Parameters of investigation are given in Table 2. The assessment of wear on the friction distance of 10 000 m was executed by the gravimetric method. The samples for investigations of wear were made of 38GSA steel and micro-alloyed 25G2B steel. The chemical compositions of the steels are given in Table 1. In these investigations, it was established that abrasive wear intensity is the function of steel hardness, its structure and the aggressiveness of environment. To obtain the optimum structure and hardness, samples were quenched and tempered in four temperatures. For each variant of heat treatment (Table 3) six samples from each steel grade were made. Measurement of the samples' hardness was executed by Vickers 's method on hardness tester – HPO 250. In the rotating disc, 3 sample of each steel grade were placed. During the abrasion test, water cooling was applied.

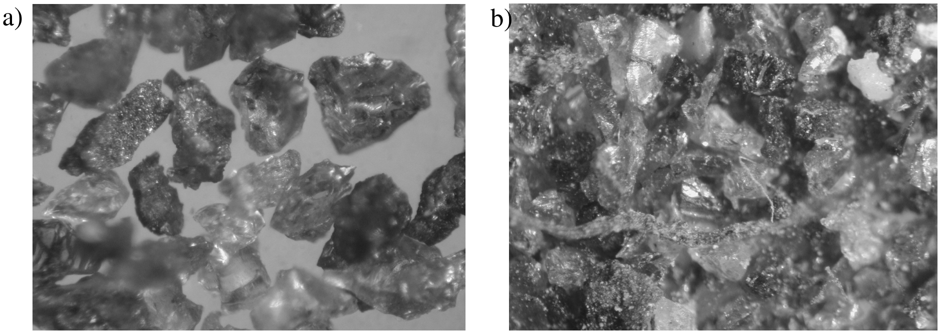

Fig. 3. Abrasive medium applied in investigations: a) corundum – visible the sharp – angled grains, b) the mixture of corundum with 10% soil addition – visible grain of corundum and particles of soil. Stereoscopic microscope MBS -9. Mag. 25 x

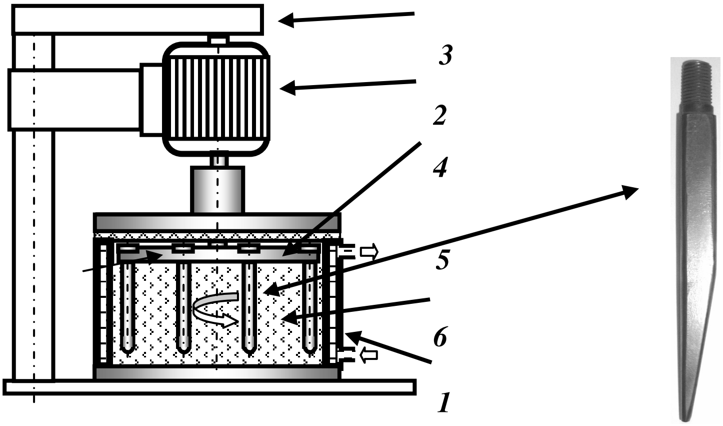

Fig. 4. Laboratory stand – scheme: 1 – water cooled chamber, 2 – electric motor, 3 – steering and registration, 4 – disc, 5 – sample, 6 – abrasive medium

Table 1. Chemical composition of tested steels

| Steel grade | Elements content % | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | P | S | Cr | Ni | Al | V | B |
| 38GSA | 0.36 | 0.90 | 0.82 | 0.032 | 0.041 | 0.15 | - | - | - | - |
| 25G2B | 0.26 | 1.13 | 0.32 | 0.022 | 0.035 | 0.45 | 0.08 | 0.02 | 0.08 | 0.003 |

Table 2. Details of the laboratory test procedure

| Parameter | Unit | Value |
|---|---|---|
| Sample dimension | mm | 12 x12 x 130 |
| Sample quantity | piece | 6 |
| Chamber dimension | mm | $\phi$250 x 150 |
| Disc diameter | mm | $\phi$200 |
| Disc velocity | rpm | 700 |
| Friction distance per cycle | m | 10 000 |
| Quantity of abrasive medium | $dm^3$ | 6 |

The abrasive medium was exchanged after every cycle. The samples before abrasion and after abrasion were weighed with exactitude of 0.001 g. The hardness and mass loss of each sample were recorded. The results of investigations were presented as the dependencies of wear from the hardness of samples and the kind of abrasion medium used in tests – Fig. 5. The steel wear resistance was estimated measuring the sample mass loss in relation to load of friction. In Institute of Physical Chemistry of the Polish Academy of Sciences with the method of vacuum extraction, the sensibility of tested steels on hydrogen penetration in structure was estimated. The extraction of hydrogen was carried out at a temperature 400$^o$C for 90 minutes. The samples were tested before and after abrasion in corundum and with the addition of soil. During abrasion, the concentration of hydrogen in the sample had increased almost 4 times for 38GSA steel and 2.5 times for the micro-alloyed 25G2B steel. The samples wear off in corundum without the addition of soil, which indicated the insignificant growth of hydrogen content.

Table 3. Parameters of heat treatment of 38GSA and 25G2B steels

| Steel grade | Sample symbol | Sort of treatment | Temperature $^o$C | Time of heating [min] | Way of Cooling |
|---|---|---|---|---|---|
| 38GSA | G | Quenching | 900 | 20 | water |
| | G1 | Tempering | 220 | 30 | air |
| | G2 | Tempering | 350 | 30 | air |
| | G3 | Tempering | 400 | 30 | air |
| | G4 | Tempering | 500 | 30 | air |
| 25G2B | B | Quenching | 900 | 20 | water |
| | B1 | Tempering | 220 | 30 | air |
| | B2 | Tempering | 350 | 30 | air |
| | B3 | Tempering | 400 | 30 | air |
| | B4 | Tempering | 500 | 30 | air |

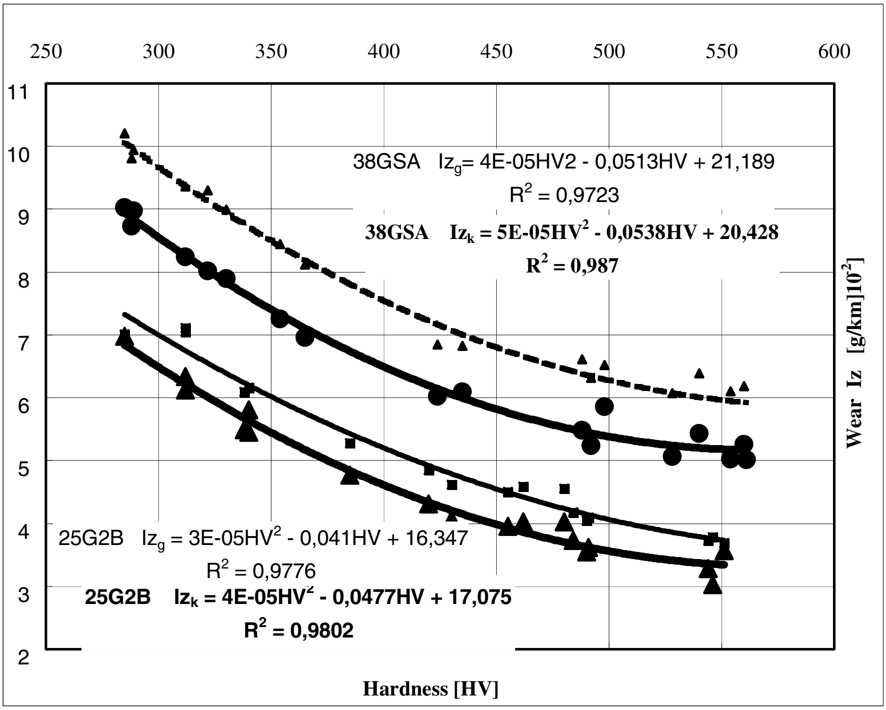

Fig. 5. Wear dependence related to hardness and kind of abrasive medium for 38GSA and 25G2B steels. $I_{zk}$ – wear in corundum, $I_{zg}$ – wear in corundum with soil addition

## Conclusions

Analysing the obtained dependencies, it could be confirmed that the aim of the investigations was reached. The addition of soil to corundum permitted the production of an aggressive environment indicating the synergic effect of abrasive-hydrogen degradation. By modifying the temperature of tempering after quenching, the hardness of samples in the range 280–560 HV was achieved. The highest hardness was achieved after low and middle tempering temperature (G1, G2, B1, B2), which found a reflection in the results of wear investigation. The shape of curves in the graph (Fig. 5) testifies the existence of an exact dependence between wear and the hardness of steel. Together with an increase in hardness, the coefficient of wear intensity ”$I_z$” diminishes. It was confirmed that the influence is smaller in the high hardness range. Raising the hardness above 450 HV did not extend the already considerable increase of abrasion resistance. It was caused by the effect of brittleness formation in material caused by the loss of elasticity. Taking under consideration the conditions of work, it was possible to confirm that agricultural tools working in soil should not be too hard, because, while hitting stone, they will crack. It was recognised that, in wear testing conditions, a hardness of 400–450 HV, which was achieved after water quenching and tempering of the steel at temperature 350°C, is optimal. The selection of hardness should take into account the type of soil. On soils including stones, tools with a lower hardness should be applied. On sandy and clay soils, tools with a hardness of 500 HV should be used. The results of the investigations of wear show that the 25G2B steel, despite comparable hardness, shows 1.5 times higher wear resistance than 38GSA steel. Both materials have shown different wear in relation to the type of abrasive medium environment. The addition of acid soil to the abrasive environment caused $I_{zg}$ to increase by 4% for steel including boron and 10% for steel without boron. The significance of these differences was confirmed by the Student's test at the significance level $\alpha = 0.05$. The results of the hydrogen content investigation in samples confirmed the stated hypothesis that steel surface activated with friction was attacked by hydrogen which penetrated the top layer and was trapped inside the steel. The measurable result of influence, both of hydrogen and it's compounds, resulting in the dynamic corrosive processes, is the higher wear of samples in a medium including the organic and inorganic chemical compounds as part of soil components. These dependencies confirm the higher growth of wear caused by the aggressive environment of soil for 38GSA steel usually applied for agricultural tools. This indicates that heat-treated steel with boron is considerably more resistant to hydrogen penetration than similarly treated steel without boron.

On the basis of the conducted investigations, it is possible to confirm the following:

- Measurements with the vacuum extraction method showed that, during abrasion of steel in a soil environment, hydrogen penetration into the steel structure took place.
- The aggressive environment of soil is a factor in increasing the abrasive wear of agricultural tools.
- 25G2B steel shows an abrasive wear resistance in soil higher than 38GSA steel.
- It is recommended to use micro-alloyed steel with boron (25G2B) for agriculture tools quenched at temperature 900°C in water and tempered at a temperature of 300–350°C in in relation to of the kind of soil.
- The obtained dependencies require confirmation in field tests on different kinds of soil.

## Bibliography

1. Bethelor A.W., Stachowiak G.W.: Tribology in materials processing. Journal of Processing Technology. No 48, 1995, p. 503–515.
2. Bhakat A. and other: Metallurgical life cycle assessment trough prediction of wear for agricultural grade steel. Wear No. 257, 2004.

3. Flis J. i in.: Wodorowe i korozyjne niszczenie metali. PAN Instytut Chemii Fizycznej. Wyd. PWN, Warszawa 1979.
4. Kula P.: The comparison of resistance to "hydrogen wear" of hardened surface layers. Wear. No 178, 1994.
5. Łunarska E., Nikiforov K., Stabryła J., Starczewski L.: Effect of the boron alloying and laser treatment on corrosion and hydrogen charging of low alloy steel. Surface Engineering. 2A, 2005, p. 187–194.
6. Owsiak Z.: Narzędzia skrawające glebę. Wyd. AR, Wrocław 1998.
7. Rewut I.B.: Fizyka gleby. PWRiL, Warszawa 1980.
8. Stabryła J.: Improwing the mechanical properties of steels for agriculture machine elements subject to strong load. Annual Reviev of Agicultural Engineering. 3(1) 2004, p. 171–180.
9 Stabryła J.: Stanowisko do badań zużycia ściernego materiałów na narzędzia pracujące w glebie. VI Sympozjum im. Cz. Kanafojskiego, Płock 1994.
10. Ścieszka S.: Synergizm w procesach tribologicznych. Tribologia nr 3/2002, s. 1031–1038.
11. Starczewski L.: Wodorowe zużywanie ciernych elementów maszyn. WITPiS, Sulejówek – Radom 2002.
12. Wranglen G.: Podstawy korozji i ochrony metali. WNT, Warszawa 1985.
13. Zakroczymski T.: Wnikanie i transport wodoru w żelazie i jego stopach. ICHF PAN Warszawa 1990.
14. Zwierzycki W., Grądkowski M.: Fizyczne podstawy doboru materiałów na elementy maszyn współpracujących tarciowo. Radom 2000.
15. Zieliński A., Domzalicki P.: Hydrogen degradation of high-strength low-alloyed steels. Journal of Materials Processing. Technology 133, 2003, p. 230–235.

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## Badanie procesu niszczenia narzędzi rolniczych w glebie

### Słowa kluczowe

Stal mikrostopowa, zużycie ścierne, atak wodoru, narzędzia rolnicze.

### Streszczenie

W dotychczasowych publikacjach zużycie uprawowych narzędzi rolniczych określano najczęściej jako prosty proces ścierania, nie uwzględniano dodatkowych czynników – innych niż mechaniczne. Tylko nieliczni badacze brali pod

uwagę kwasowość gleby. Znaczna zawartość soli, kwasów i węglowodorów w dużym stopniu przyśpiesza procesy zużycia narzędzi pracujących w wilgotnej glebie. Przeprowadzono badania laboratoryjne, które miały na celu ocenę wpływu procesów elektrochemicznych i wodoru na zużycie ścierne narzędzi rolniczych. Badano stal węglową i mikrostopową.