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THE ANALYSIS OF WEAR OF THE LAYERS CONTAINING WC/W$_2$C IN ABRASIVE SOIL

ANALIZA PROCESU ZUŻYWANIA WARSTW Z ZAWARTOŚCIĄ WC/W$_2$C W GLEBOWEJ MASIE ŚCIERNEJ

Key words:

WC/W$_2$C carbides, abrasive wear, “spinning bowl” method, abrasive soil mass.

Słowa kluczowe:

węgliki WC/W$_2$C, zużycie ścierne, metoda „wirującej misy”, glebowa masa ścierna

Abstract

The paper presents the results of research involving the resistance of hardfacing materials containing WC/W$_2$C carbides to abrasive wear. The tested hardfacing materials were made using PJ5D and El-Tung FeA rods. The WC/W$_2$C carbide contents of the examined materials amounted to 90% and 60%. These materials are meant to be used in mining tools subject to intense abrasive wear. In spite of its higher WC/W$_2$C carbide content, the intensity of wear of the hardfacing material made using the PJ5D rod was higher than that of the hardfacing material made using the El-Tung FeA rod. Wear resistance tests were conducted

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by means of the “spinning bowl” method, using real (natural) soil masses. Light and heavy soil masses were used.

INTRODUCTION

A method commonly used for improving the properties of the surface layers of materials prone to abrasive wear is the modification of the chemical composition and the surface structure using various techniques of hardfacing **[L. 1, 2, 3, 4, 5]**. Tungsten is among the materials whose application is becoming increasingly frequent. Tungsten is an element characterised by good mechanical and thermal properties. Combined with carbon, it forms tungsten carbide, with very high hardness and good resistance to various types of wear. Tungsten carbide can usually exist in two versions: WC and W_2C, with a hardness of 2000 – 2700 HV. Tungsten carbide powders take the form of WC mono-crystals, with a carbon content of ≈ 6.1%, or a eutectic mixture of WC/W_2C, with a carbon content of ≈ 4% **[L. 6]**.

The materials that are particularly significant contain crushed and cast tungsten carbides among their components, which, in the hardfacing process, are embedded in the surface layer of elements subject to abrasive wear. The wear process for those layers is affected by the distribution and sizes of the WC/W_2C carbides in the created layer **[L. 7, 8, 9, 10]**.

Papers **[L. 2, 10, 11**, and others**]** focused on the issue of the deposition of carbide insets.

The object of the paper is the analysis of the wear of surface layers containing cast WC/W_2C carbides in an abrasive soil mass.

MATERIALS FOR RESEARCH

Hardfacing materials were applied to through-hardened 38GSA steel. The substrate material was characterised by the structure of martensite with bainite and troostite. The hardness of the substrate material amounted to 414 HV10. The chemical composition of the steel was as follows: C – 0.38%, Mn – 1.07%, Si – 1.17%, P – 0.028%, Cr – 0.18%, Cu – 0.16%, and Al – 0.02%.

Cast WC and W_2C carbides were applied to the surface of steel using the following:

- A PJ5D rod – a steel tube filled with cast WC/W_2C tungsten carbides and a flux, with a WC/W_2C carbide content of approx. 90%; and,
- An El-Tung FeA rod – a nickel steel tube filled with cast tungsten carbides and a flux, with a WC/W_2C tungsten carbide content of approx. 60%.

In the examined materials cast tungsten carbides (a eutectic WC/W_2C mixture with a 3.5 to 4% C content) were present as hard grains with sharp edges (**Fig. 1**). The microhardness of carbide grains amounts to approx. 3000 HV, with a static load of 0.5 N.

The materials were applied by means of gas hardfacing technology, using a reducing flame (a surplus of acetylene). In order to avoid stress, the applied hardfacing materials were slowly cooled down in heated sand.

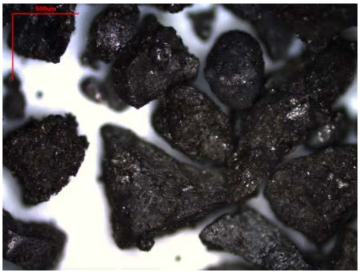

Fig. 1. Cast WC/W_2C carbide grains contained in hardfacing rods
Rys. 1. Ziarna lanego węglika WC/W_2C zawartego w pałkach do napawania

THE METHODOLOGY OF THE RESEARCH

The tests of the intensity of wear were conducted in laboratory conditions by means of the "spinning bowl" method **[L. 2]**. The examinations involved cuboidal samples with dimensions of 30 x 25 x 10 mm. The bowl of the device was filled with a natural abrasive soil mass, corresponding to dry soil with the following grain sizes according to the quality standard PN-EN ISO 14668-2(2004):

- Light soil – clay: 1.69%; silt: 20.83%; sand: 77.48%;
- Heavy soil – clay: 16.5%; silt: 49.92%; sand: 33.62%.

The following friction parameters were adopted during the research: speed 1.40 m/s, friction path 10000 m, and unit load 67 kPa. The measurements of wear were taken every 2000 m. The unit wear was calculated from the following formula:

$$Z_j = \frac{Z_w}{s*P} \; [g/km * cm^2], \tag{1}$$

where: Z_w – mass wear [g], s – friction path [km], and P – the surface area of the examined sample [cm^2].

The hardness of the materials was measured by means of a type HV-10D Vickers hardness tester, in accordance with the quality standard PN-EN ISO 6507-1:1999; an indenter load of 98 N was used, lasting 10 s.

Microscopic examinations by means of light microscopy were conducted using a Neophot 52 microscope coupled with a Visitron Systems digital camera.

Examinations by means of a scanning electron microscopy, and the microanalysis of the chemical composition were conducted using a JEOL JSM – 5800 LV scanning microscope, coupled with an Oxford LINK ISIS – 300 X-ray micro-analyser. This microscope was also used to observe the surfaces of materials after examinations in a wear testing machine.

TEST RESULTS

The microstructure of a surface subjected to hardfacing by means of a PJ5D rod is presented in **Figs. 2** and **3**.

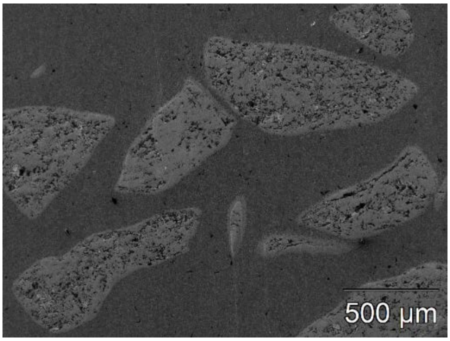

Fig. 2. PJ5D rod. WC/W_2C carbides embedded in the surface layer

Rys. 2. Pałka PJ5D. Węgliki WC/W_2C osadzone w warstwie wierzchniej

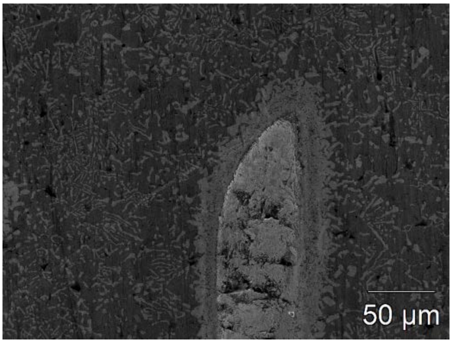

Fig. 3. PJ5D rod. Visible coating created between the edges of the WC/W_2C grains and the matrix

Rys. 3. Pałka PJ5D. Widoczna wytworzona otoczka pomiędzy granicą ziaren WC/W_2C a osnową

At the edges of most WC/W_2C carbides, the surrounding insets of WC were observed, which indicates the partial melting of carbides in the hardfacing process and the strengthening of the matrix by them. This phenomenon involves mainly small WC/W_2C grains. The average hardness of the matrix amounted to 600 HV10.

The microstructure of the surface subject to hardfacing by means of an El-Tung FeA rod is presented in **Figs. 4** and **5**.

In the case of a surface layer created by means of an El Tung FeA rod, insets of tungsten carbides in the matrix were also observed. However, no presence of carbide "coating" was recorded around the WC/W_2C grains. The measured hardness of the matrix amounted to 800 HV10.

The locations of the examinations of chemical compositions are presented in **Figures 6** and **7**, and sample X-ray spectra are shown in **Figures 8** and **9**.

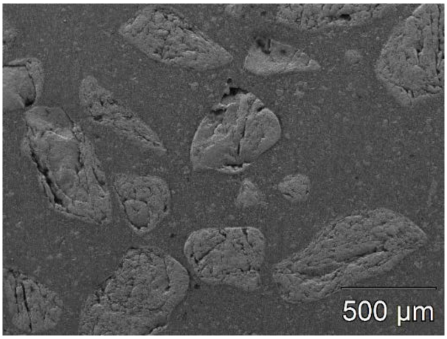

Fig. 4. El-Tung FeA rod. WC/W2C carbides embedded in the surface layer

Rys. 4. Pałka El-Tung FeA. Węgliki WC/W_2C osadzone w warstwie wierzchniej

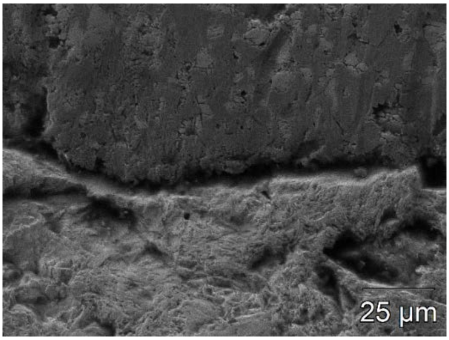

Fig. 5. El-Tung FeA rod. Boundary between WC/W_2C and the matrix

Rys. 5. Pałka El TungFeA. Granica pomiędzy WC/W_2C a osnową

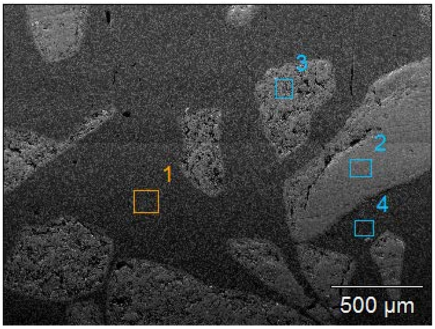

Fig. 6. PJ5D rod. The places of the examination of chemical composition: 1, 4 – matrix, 2, 3 – WC/W_2C carbides

Rys. 6. Pałka PJ5D. Miejsca badania składu chemicznego: 1, 4 – osnowa, 2, 3 – węgliki WC/W_2C

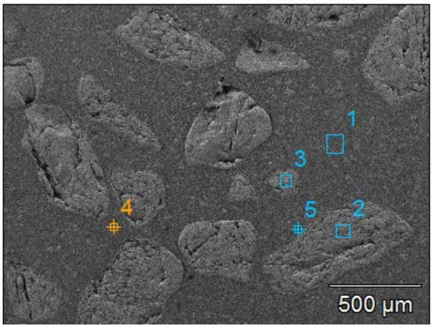

Fig. 7. El-Tung FeA rod. The places of the examination of chemical composition: 1, 4, 5 – matrix, 2, 3 – WC/W_2C carbides

Rys. 7. Pałka El-Tung FeA. Miejsca badania składu chemicznego 1, 4, 5 – osnowa, 2, 3 – węgliki WC/W_2C

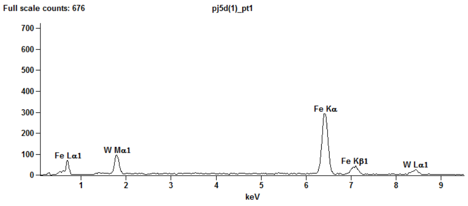

Fig. 8. PJ5D rod. The X-ray spectrum of the matrix

Rys. 8. Pałka PJ5D. Widmo promieniowania rentgenowskiego osnowy

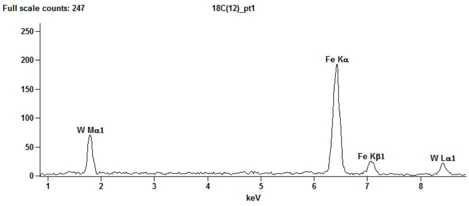

Fig. 9. El-Tung FeA rod. The X-ray spectrum of the matrix

Rys. 9. Pałka El-Tung FeA. Widmo promieniowania rentgenowskiego osnowy

The chemical composition of the tested materials is presented in **Table 1**.

For the PJ5D rod, the chemical composition was examined in an area directly surrounding the WC/W_2C carbide (**Fig. 10**). The results are presented in **Table 2**.

In the direct surroundings of the carbide, the tungsten content amounts to 74.45%, with 25.55% iron. In the places in the matrix where: carbide insets are not visible (pt. 3 and 8) the iron content of the matrix amounts to approx. 90%, and in the areas of insets in the matrix (pt. 5, 6), the tungsten content amounts to approx. 63-67%, with approx. 33-37% iron. This can be related to the diffusion of tungsten from carbides into the matrix in the hardfacing process.

Table 1. The chemical composition of the tested materials
Tabela 1. Skład chemiczny badanych materiałów

El-Tung FeA rod				PJ5D rod		
Elements in%						
Place of measurement **(Fig. 7)**	Mn	Fe	W	Place of measurement **(Fig. 6)**	Fe	W
Pt 1		69.93	30.07	Pt 1	71.53	28.47
Pt 2			100.00	Pt 2		100.00
Pt 3			100.00	Pt 3		100.00
Pt 4		81.05	18.95	Pt 4	70.98	29.02
Pt 5	3.11	88.79	8.10			

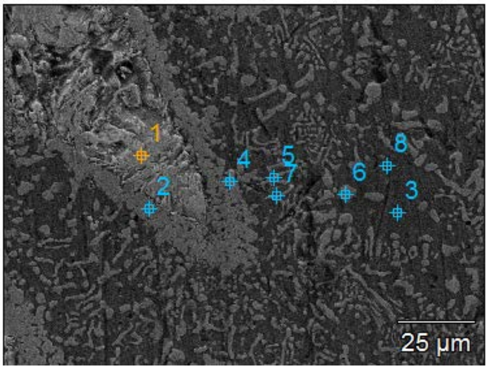

Fig. 10. The place of the examination of the chemical composition of a PJ5D rod in the direct surroundings of WC/W_2C carbide
Rys. 10. Miejsce badania składu chemicznego pałki PJ5D w bezpośrednim otoczeniu węglika WC/W_2C

Table 2. The chemical composition of the surroundings of WC/W_2C carbide on the surface of the PJ5D rod
Tabela 2. Skład chemiczny otoczenia węglika WC/W_2C na powierzchni pałki PJ5D

Place of measurement	Elements in%	
	Fe	W
Pt 1		100.00
Pt 2	25.55	74.45
Pt 3	91.05	8.95
Pt 4	25.87	74.13
Pt 5	36.83	63.17
Pt 6	32.62	67.38
Pt 7	70.79	26.64
Pt 8	88.48	11.52

Test results for the value of the mass wear of the examined materials as a function of the friction path for the individual types of soil masses are presented in **Figs. 11** and **12**.

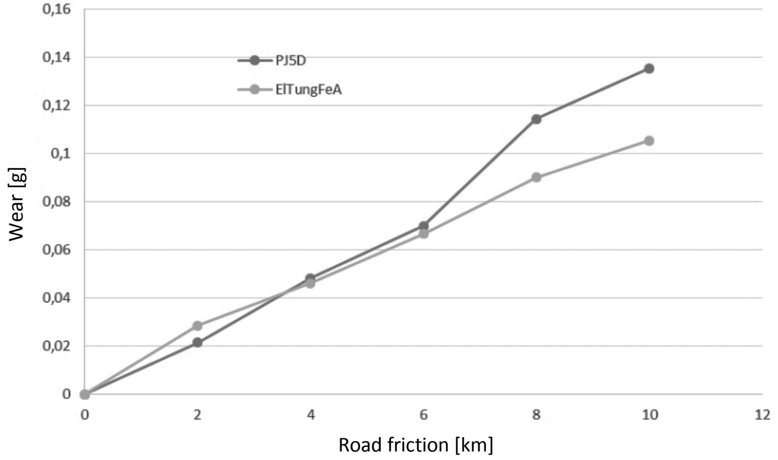

Fig. 11. The course of the mass wear of the examined materials in heavy soil mass
Rys. 11. Przebieg zużycia masowego badanych materiałów w masie glebowej ciężkiej

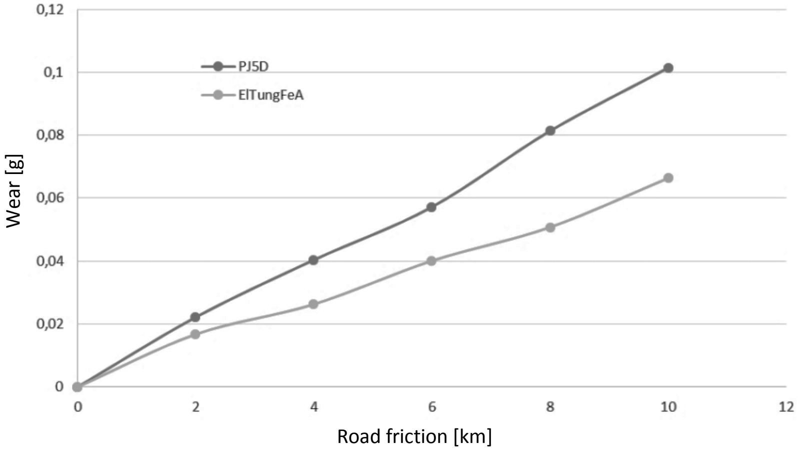

Fig. 12. The course of the mass wear of the examined materials in light soil mass
Rys. 12. Przebieg zużycia masowego badanych materiałów w masie glebowej lekkiej

The comparison of the values of unit wear is presented in **Fig. 13**.

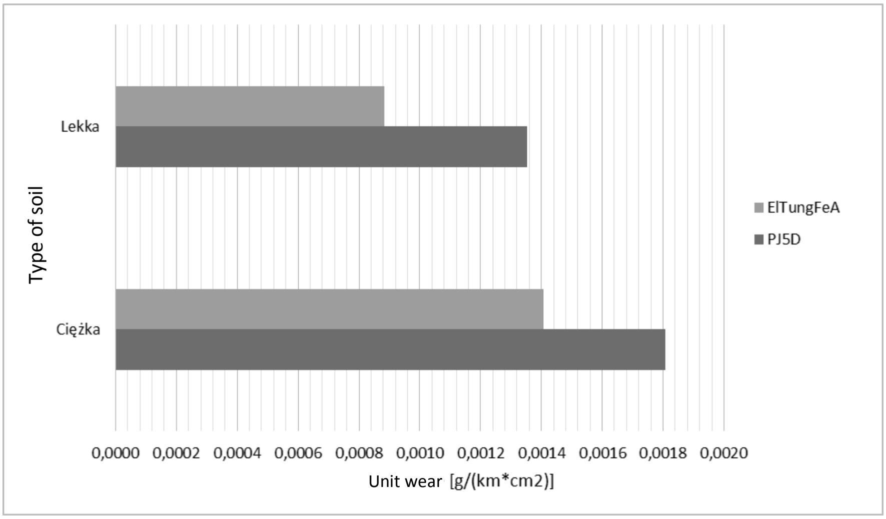

Fig. 13. A comparison of the unit wear of the examined materials
Rys. 13. Zestawienie zużycia jednostkowego badanych materiałów

Based on the analysis of mass and unit wear of the examined materials under various soil conditions, it has been concluded that the wearing impact of a heavy soil mass is higher compared to a light mass. In both types of abrasive masses used in the studies, the ElTung FeA hardfacing material was characterised by its higher resistance to wear. In spite of its higher cast WC/W_2C carbide content, the PJ5D hardfacing material exhibited a higher intensity of wear, which indicates the great significance of the carbide-embedding matrix. For the light abrasive soil mass, the difference in the unit wear reached 53%, with 29% for the heavy soil mass.

The surface of the samples viewed after testing the wear in a heavy soil mass is presented in **Figs. 14** and **15**.

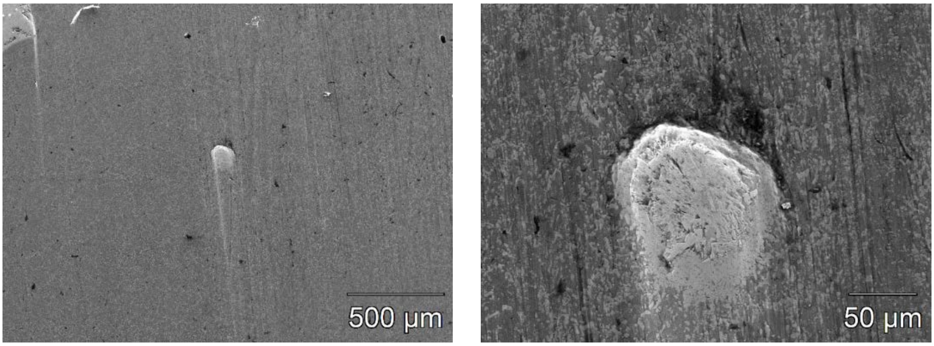

Fig. 14. The surface of PJ5D worn in a heavy soil mass
Rys. 14. Powierzchnia PJ5D zużywana w ciężkiej masie glebowej

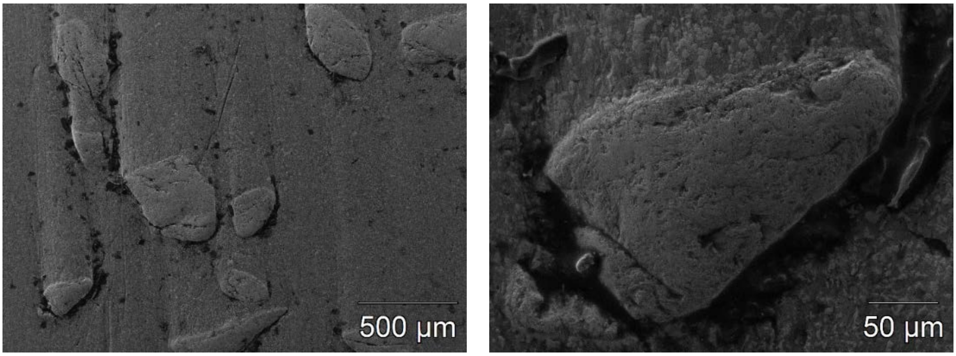

Fig. 15. The surface of ElTung FeA after testing the wear in a heavy soil mass
Rys. 15. Powierzchnia ElTung FeA po badaniu zużycia w ciężkiej masie glebowej

On the surface of the materials worn in an abrasive soil mass with a high share of fine abrasive particles, defects in the matrix around carbides were noticed from the side of the inflowing abrasive grains. As a result of this action, the weakening of the embedment of carbides took place, along with their removal under the impact of larger abrasive grains. The strengthening of the matrix by the diffusion of tungsten in the close surroundings of the carbide observed in the case of the PJ5D rod did not considerably affect the manner of wear. The carbide is scoured by abrasive particles together with the generated coating **(Fig. 15)** and subsequently removed along with it. This process occurs not only in relation to large WC/W_2C carbides, but also in relation to small carbide insets in the matrix – **Fig. 16**.

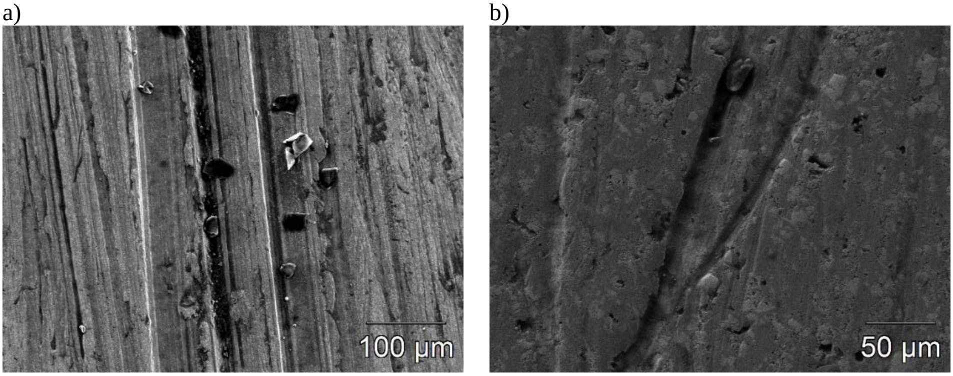

Fig. 16. The surface of the matrix of samples worn in a heavy soil mass: a) PJ5D, b) ElTung FeA
Rys. 16. Powierzchnia osnowy próbek zużywanych w ciężkiej masie glebowej: a) PJ5D, b) ElTungFeA

On the surface of samples worn in a light soil mass with a low share of fine abrasive particles, no such intense removal of the matrix around the carbides was observed (**Figs. 17** and **18**).

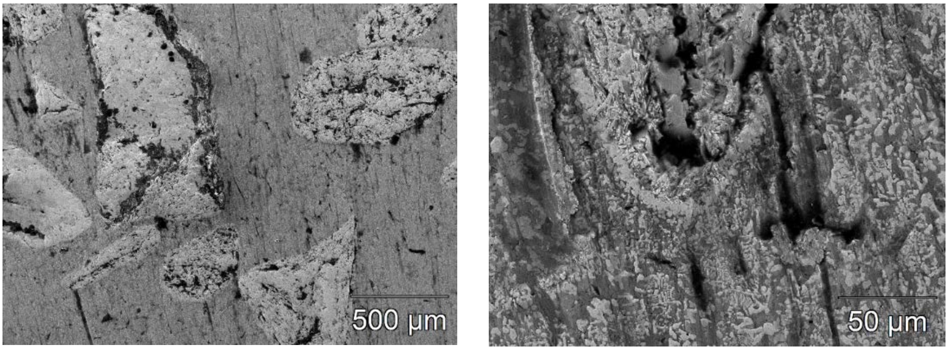

Fig. 17. The surface of a PJ5D sample worn in a light soil mass
Rys. 17. Powierzchnia próbki PJ5D zużywanej w lekkiej masie glebowej

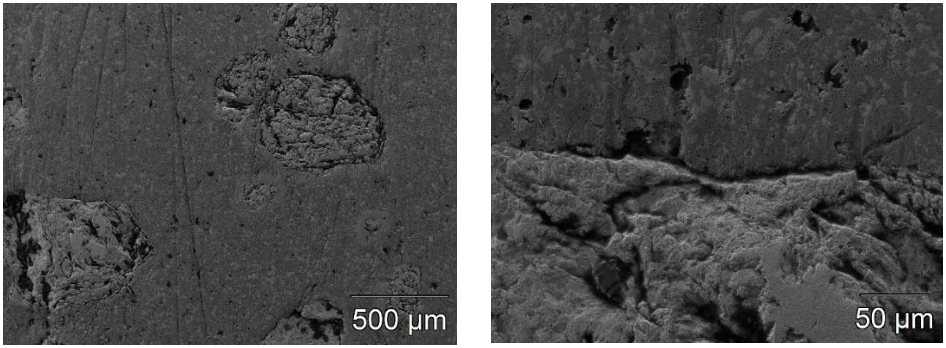

Fig. 18. The surface of an ElTungFeA sample worn in a light soil mass
Rys. 18. Powierzchnia próbki ElTungFeA zużywanej w lekkiej masie glebowej

For this type of abrasive soil mass, the course of wear is dominated by processes associated with the scratching and furrowing of the surface by abrasive grains. These processes are particularly visible in the material of the matrix. It has been observed that the marks of scratching and furrowing end when an abrasive particle encounters the hard grains of WC/W_2C carbides (**Fig. 18**).

SUMMARY

Adding cast tungsten carbides to materials improving the surface layers of soil cutting elements increases their resistance to abrasive wear. This is particularly important in the case of handling soils with loosely interconnected grains of gravel and sand, containing low amounts of silts.

In the case of cohesive soils containing fine abrasive particles, the hardness of the matrix greatly affects the resistance to abrasive wear. The soft matrix is subjected to the impact of silt grains and removed, which results in the carbides lacking proper fixing. Weakening the embedment of carbides results in their removal under the impact of larger abrasive grains.

Depending on the used abrasive masses, the average difference in the unit wear of the tested materials amounts to approx. 40%.

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Streszczenie

W pracy przedstawiono wyniki badań odporności na zużywanie ścierne napoin z zawartością węglików WC/W$_2$C. Badano napoiny wykonane pałeczkami PJ5D i El-Tung FeA. Zawartość węglików WC/W$_2$C w badanych materiałach wynosiła 90% i 60%. Materiały te są przeznaczone do stosowania w narzędziach górniczych narażonych na intensywne zużycie ścierne. Pomimo większej zawartości węglików WC/W$_2$C intensywność zużywania napoiny wykonanej pałeczką PJ5D była większa od napoiny wykonanej pałeczką El-Tung FeA. Badania odporności na zużycie przeprowadzono metodą „wirującej misy" z wykorzystaniem rzeczywistych (naturalnych) mas glebowych. Zastosowano masy glebowe lekkie i ciężkie.