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THE IMPACT OF PADDING WELD SHAPE OF AGRICULTURAL MACHINERY TOOLS ON THEIR ABRASIVE WEAR

WPŁYW KSZTAŁTU NAPOINY NARZĘDZI MASZYN ROLNICZYCH NA ICH ZUŻYCIE ŚCIERNE

Key words: wear, coulter, pad welding, laboratory tests, quartz sand.

Abstract: The paper presents laboratory tests results of wear in the abrasive mass of cultivator coulters subjected to coated electrode pad welding. In the first stage of the test, one type of electrode was used and a padding weld was applied to the coulter surface in three different shape variants (perpendicular, parallel to the abrasive mass stream and V-shaped). The lowest abrasive wear was obtained for samples with a padding weld deposited perpendicularly to the abrasive mass stream. Therefore, in the second stage of the research, this padding weld shape was selected and made using three different electrodes. Tests of abrasive wear both in the first and the second stage of the experiment were carried out at a distance of 100 km by the "rotating bowl unit" method. Both the direction of the application of the padding weld (shape) and the chemical composition of the electrode used in the pad welding process significantly increased the resistance to abrasive wear compared to coulters whose surface has not been welded.

Słowa kluczowe: zużycie, redlica, napawanie, badania laboratoryjne, piasek kwarcowy.

Streszczenie: W pracy zaprezentowano laboratoryjne wyniki badań zużycia w masie ściernej redlic kultywatora poddanych napawaniu elektrodą otuloną. W pierwszym etapie badań, używając jednego rodzaju elektrody, na powierzchnię redlic nałożono napoinę w trzech różnych wariantach kształtu (prostopadle lub równolegle do naporu strumienia masy ściernej oraz w kształcie litery „V"). Najmniejsze zużycie ścierne uzyskano dla próbek z napoiną nałożoną w kierunku prostopadłym do naporu strumienia masy ściernej. Dlatego w drugim etapie badań wybrano ten kształt napoiny i wykonano ją za pomocą trzech różnych elektrod. Badania zużycia ściernego zarówno w pierwszym, jak i drugim etapie prowadzono na dystansie 100 km metodą „wirującej misy". Kierunek (kształt) nałożenia napoiny i skład chemiczny elektrody wykorzystywanej w procesie napawania istotnie zwiększyły odporność na zużycie ścierne w stosunku do redlic, których powierzchnia nie została obrobiona nawet o 400%.

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INTRODUCTION

Along with the dynamic development of agriculture, there was a significant increase in agricultural acreages. Materials that were used in the 1980s or 1990s were replaced with new ones that perform their function better and have a higher resistance to abrasive wear. Popular 38GSA steel has been replaced by HARDOX, RAEX, or special-purpose steels such as TBL PLUS. Manufacturers of heavy machinery and agricultural machines, especially soil-working components, use various treatments during their production stage to increase the wear resistance.

Pad welding of the working surface with a coated electrode is used with an increasing frequency to reduce abrasive wear occurring during agrotechnical works **[L. 1]**. By means of pad welding, the surface layer is supplemented by alloying elements that affect its properties **[L. 2]**. The ease of pad welding with a coated electrode results in the frequent selection of this method of treatment to increase the resistance to abrasive wear. The pad welding is carried out by melting the material contained in the electrode, mostly a powder electrode, and the diffusion of its alloying elements into the native material **[L. 3]**.

Abrasive wear that occurs in the soil-material friction combination is the wear caused by soil particles that affect the surface layer causing the process of destruction by micro-cutting, micro-ridging, and micro-scratching **[L. 4]**. Degradation processes are divided into two types. The first type is single cycle wear when the abrasive particles have high hardness. In a situation where the particles have low hardness, multi-cycle wear occurs **[L. 5]**. The relation of these quantities is determined by the following relationship **[L. 5]**:

$$k_t = \frac{H_m}{H_s} \tag{1}$$

where
k_t – hardness ratio of materials,
H_m – material hardness,
H_s – abrasive hardness.

Abrasive mass associated with the wear of a machine component in soil consists of many independent factors **[L. 5]**. The basic factors of abrasive mass affecting wear and determining its value include the following **[L. 4]**:
- The hardness of abrasive grains,
- Granulometric composition,
- Chemical composition,
- Firmness,
- Moisture content, and
- Reaction.

Testing of structural materials that are subject to wear is a topic widely discussed by researchers in Poland **[L. 6–9]**. The studies are mostly devoted to measuring how the wear of components in the abrasive mass depends on the shape of the components and the parameters of soil. Relationships between steel wear and factors such as reaction, moisture content, and graining have been shown. Literature and research carried out around the world also point to other important directions of further development of reducing wear of soil-working components, i.e. strengthening the surface of working components, e.g., by using laser technology, which reduces abrasive wear expressed in mass or volume. The research results also show significant differences in the wear of components without any surface treatment and after such treatment have been applied **[L. 10–14]**. However, the problem of resistance to wear, including the abrasive wear of machine parts, has not been fully solved. Therefore, it is important to conduct research that will expand knowledge in this area and especially focus on improving the methods of surface layer treatment.

The purpose of the research described in the paper is to determine the abrasive wear value of a selected component of an agricultural tool (cultivator coulter) whose surfaces have been subjected to the process of pad welding with a coated electrode. The wear measurement of the cultivator's pad-welded coulters is divided into two stages (**Fig. 1**). The first stage contained an abrasive wear test of a coulter on which welds of various shapes were applied, and all of them were made with one type of electrode (Electrode 1). The criterion for choosing the electrodes was their typical area of application. These are electrodes used mainly for pad welding of components of agricultural machinery tools working in soil and to increase the components' resistance to abrasive wear. The electrodes used for pad welding differed in terms of the elements determining their hardness and abrasion resistance, i.e. chromium, manganese, molybdenum, silicon, or carbon. Electrodes with similar chromium content were selected for the research. Based on the results of the abrasive wear tests, one weld shape (characterised by the lowest wear) was selected to be used in the second stage of the research. Three different electrodes were used in the second stage for pad welding the surface of machine components subjected to abrasive wear.

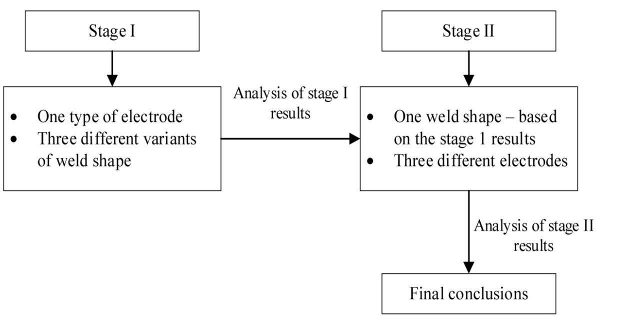


Fig. 1. Research implementation scheme
Rys. 1. Schemat realizacji badań

RESEARCH METHODOLOGY

Research object characterisation

Tests of abrasive wear were carried out on cultivator coulters made of 27MnCrB5 steel. It is a steel with increased resistance to abrasive wear, commonly used for agricultural machinery components by Polish manufacturers. The chemical composition (percentage content of individual elements) of this steel is shown in **Table 1**, while an example of the coulter subjected to the abrasive wear tests is presented in **Figure 2**. All coulters were produced by the same manufacturer and have the same shape. In the factory, the coulters are hardened and then cooled in the air. After this process, their final shape is formed.

Table 1. Chemical composition [%] in 27MnCrB5 steel [L. 17]
Tabela 1 Skład chemiczny [%] stali 27MnCrB5 **[L. 17]**

C	Mn	Si	Cr	Mo	P	S	B
0.24–0.3	1.1–1.4	0.4	0.3–0.6	–	0.025	0.035	0.005

Fig. 2. View of the cultivator coulter used during laboratory tests
Rys. 2. Widok redlicy kultywatora użytej podczas badań laboratoryjnych

TEST CONDITIONS AND TEST STAND

Laboratory tests were carried out using the "rotating bowl unit" method, which consisted of measuring weight loss after the component moved along the friction path on a specially designed stand. The abrasive was quartz sand with d = 0.2–0.8 mm graining. The abrasion grain size curve, determined on the basis of laboratory tests, is shown in **Figure 3**. The tests were carried out under controlled humidity conditions at the level w = 12–15%. The speed at which the cultivator coulters moved at the test stand reflected the actual speed during agrotechnical works. A model and view of the test stand is presented in **Figure 4**. The samples during the tribological test moved at the speed of v = 6÷7 km/h and covered the distance of s = 100 km. The cutting depth from the bottom of the coulter was about 70–90 mm. Due to the different radii on which the cultivator coulters were mounted, periodically, every s = 33.3 km, they were exchanged at places on the test stand so that the distance covered by all samples was the same (**Fig. 4b**)

Both before mounting the samples on the test stand and after the tests, the cultivator coulters were washed and cleaned, and then the weight of each of them was checked using a laboratory balance with an accuracy of

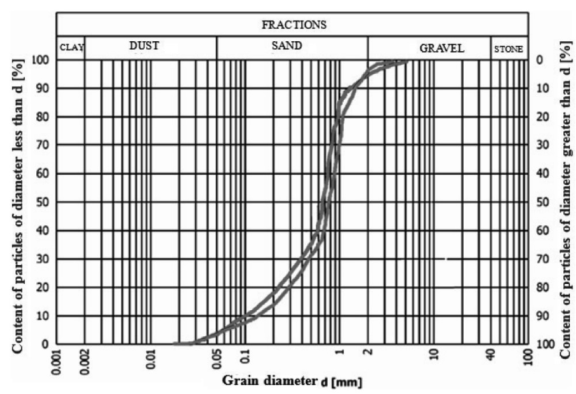


Fig. 3. Abrasion grain size curve [L. 5]
Rys. 3. Krzywa uziarnienia materiału ściernego **[L. 5]**

0.0001 g. The weight loss of the samples was determined on the basis of the following relationship (2):

$$Z_w = m_p - m_k \tag{2}$$

where
Z_w – weight wear,
m_p – initial mass of the sample,
m_k – final mass of the sample.

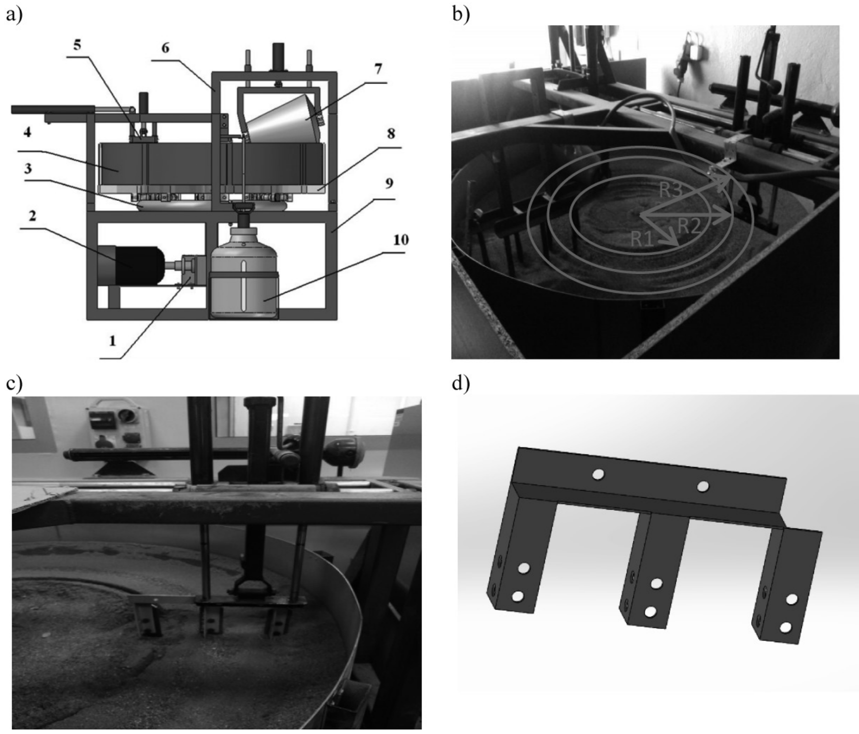


Fig. 4. Test stand: a) diagram of the "rotating bowl" unit: 1 – transmission shaft, 2 – engine, 3 – travel rail, 4 – bowl, 5 – sample holder, 6 – compacting roller frame, 7 – compacting roller, 8 – frame, 9 – main frame, 10 – water tank [L. 17]; b) view of the stand with circles with a marked radius along which the cultivator coulters under test travelled; c) place of attachment of the samples; d) sample mounting rack

Rys. 4. Stanowisko badawcze: a) schemat urządzenia „wirująca misa": 1 – wał transmisyjny, 2 – silnik, 3 – szyna jezdna, 4 – misa, 5 – uchwyt próbek, 6 – stelaż wału zagęszczającego, 7 – wał zagęszczający, 8 – rama, 9 – główna rama, 10 – zbiornik na wodę **[L. 17]**; b) widok urządzenia wraz z zaznaczonymi promieniami, po których przemieszczały się badane redliczki kultywatora; c) miejsce zamocowania próbek; d) stelaż mocujący próbki

IMPLEMENTATION AND RESULTS OF THE RESEARCH

Stage 1

In the first stage of the research, a padding weld was applied to the coulter surface in three different shape variants. The first variant was to apply pad welding strips to the base component perpendicular to the abrasive mass stream (**Fig. 5a**). The second variant was the application of a V-shaped padding weld (**Fig. 5b**). In the last variant, pad welding strips were applied in a direction parallel to the abrasive mass stream (**Fig. 5c**). The distance between the weld strips was about 15–20 mm, while the samples were covered with the weld on about 15% of the entire working surface. Three samples were prepared for each variant. The weld shapes were selected in accordance with the solutions most often used by farmers and companies that manufacture complete, pad-welded components. All samples used for the tests were pad welded under the same conditions. The electrodes were melted down according to the recommendations of their manufacturers, and the location of the weld on the coulter for a given variant was always the same. At this stage of the research, the electrode marked with number 1 was used. The chemical composition of the electrodes is given in **Table 2**. The weld thickness was 2–3 mm.

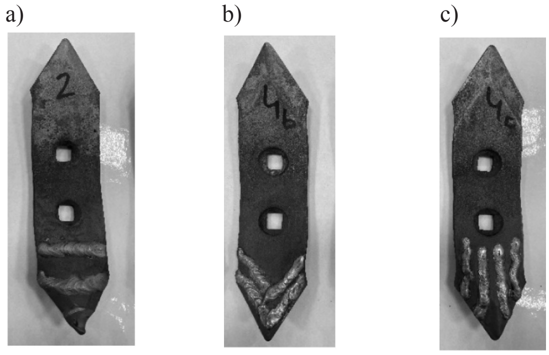


Fig. 5. Types of padding welds: a) strip arrangement perpendicular to the abrasive stream, b) V-shaped arrangement, c) strip arrangement in a direction parallel to the abrasive stream

Rys. 5. Warianty ułożenia napoiny: a) ułożenie pasmowe w kierunku prostopadłym do strumienia masy ściernej, b) ułożenie w kształcie litery „V", c) ułożenie pasmowe w kierunku równoległym do strumienia masy ściernej

Table 2. The chemical composition of the ecectrodes
Tabela 2. Skład chemiczny elektrod

Steel grade	C	Si	Mn	P	S	Cr	Ni	Mo	B
Raex 400	0.16	0.5	1.6	0.025	0.01	1.2	1	0.25	0.005
Hardox 500	0.27	0.5	1.6	0.025	0.01	1.2	0.25	0.25	0.005

The research carried out during the tribological laboratory test at the "rotating bowl" stand allowed the determination of the weight loss of the cultivator coulters, the surface of which was subjected to pad welding. The results of the tests in the form of average weight loss in grams for samples of different shapes of the applied weld are shown in **Figure 6**. The designations of individual samples included in **Figure 6** (in legend) should be interpreted as follows:

- "III" – pad welding with strips parallel to the direction of the abrasive mass stream,
- "–" – pad welding perpendicular to the direction of the abrasive mass stream,
- "V" – pad welding with V-shaped weld, and
- "Without welding" – sample without a surface layer.

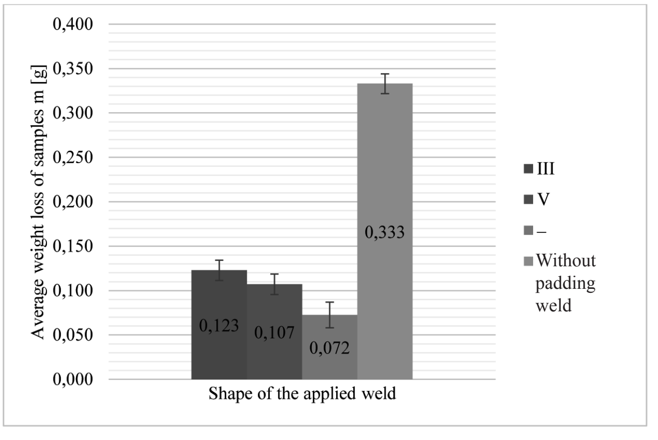


Fig. 6. Average weight loss [g] for different shapes of padding welds
Rys. 6. Średni ubytek masy m [g] dla różnych kształtów napoin

The weight loss for the padding weld placed perpendicularly to the direction of the abrasive mass stream was approximately 4 times smaller than for the sample with an untreated surface. The uncertainty of measuring the average weight loss of individual samples was determined using the Student-Fisher method and plotted the results on a graph. The samples with the remaining shapes of the padding welds (parallel to the direction of the abrasive mass stream and V-shaped) were also characterised by higher abrasive wear in relation to the padding weld placed perpendicularly. Therefore, it should be stated that this shape of the padding weld is the best from the analysed variants in terms of resistance to abrasive wear and should be used in the second stage of the research.

Stage 2

In the second stage of the research, three types of electrodes were used for pad welding of components subjected to intensive abrasive wear. For three different electrodes, a weld in the shape selected during the first stage was applied – a banded arrangement perpendicular to the abrasive mass stream (**Fig. 5a**). **Table 3** presents the chemical composition of the electrodes used for pad welding of the cultivator coulters.

Table 3. Chemical composition [%] of the electrodes used to shape the surface layer (pad welding) of the cultivator coulters [L. 16]
Table 3. Skład chemiczny [%] elektrod wykorzystanych do kształtowania warstwy wierzchniej (napawania) redlic kultywatora **[L. 16]**

Electrode No. \ Chemical composition	C	Mn	Si	Cr	Mo
Electrode 1	2.1	1.1	0.75	6.5	0.4
Electrode 2	0.5	0.4	1.8	9	-
Electrode 3	0.55	0.5	1.5	4.5	0.5

Electrode 1 is used for pad welding components particularly exposed to abrasive wear, and it can also be used for metal-to-metal friction associations. According to the catalogue data, it has a hardness of 450 to 590 $HV_{0.1}$. Electrode 2 is designed for shaping the surface of machine components operating in harsh agricultural conditions and it has a nominal hardness of 500 to 650 HV_1. Electrode 3 is designed for pad welding components that do not need to have wear resistance in a tribological pair of (pad-welded) metal-abrasive, and its hardness is from 280 to 590 HV_1 depending on the place of the measurement. The selected cultivator coulters after the pad welding process were subjected to laboratory tests of hardness and microstructure. Hardness tests were carried out using the $HV_{0.1}$ method, while the microstructures were verified by a microscope. The device used during the research is a Zeiss multifunctional metallographic machine. The results of the hardness tests (in core-native material, padding weld, transition zones SP1 and SP2 – **Fig. 7**) are shown in **Figure 8**. **Table 3** illustrates the place that the metallographic specimen was taken from and a view of the specimen and obtained microstructures.

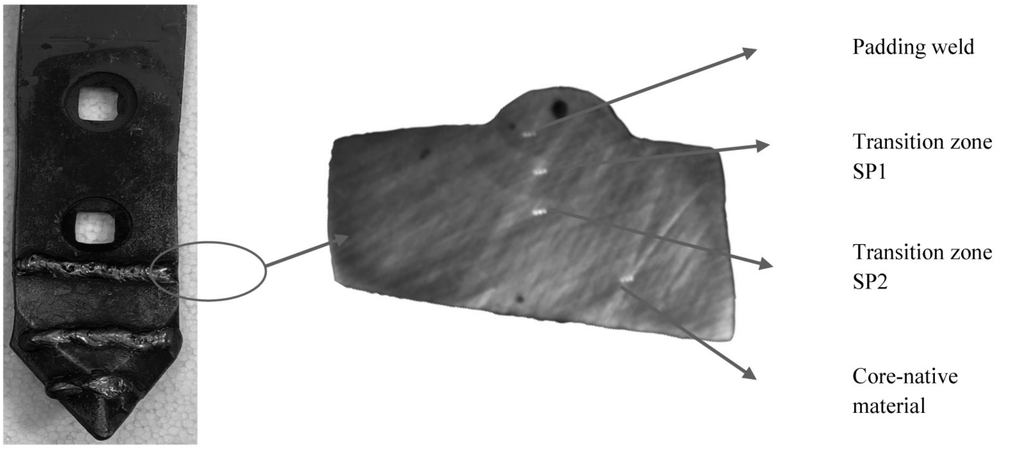


Fig. 7. Place of hardness tests
Rys. 7. Miejsce badań twardości

During the microstructure tests, two heat affected zones were identified, which were characterised by variable hardness parameters. Zone 1 for all three electrodes has a similar hardness of about 460–500 HV_1. Transition zone SP1 has a coarse-grained structure, and transition zone SP2 has smaller grains than the SP1 zone. The core (native material) in each of the tested cultivator coulters has the same structure and the hardness results are at the same level. A large amount of chromium was noted in the padding welds, and it was found that its grains get smaller with the depth of the measurement place from the surface. The padding weld made with Electrode 1 was almost twice less hard than the welds made with Electrodes 2 and 3.

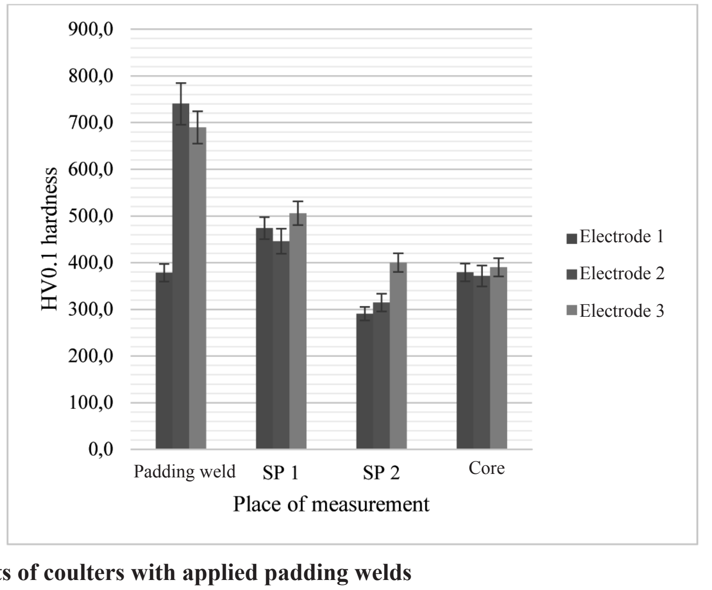


Fig. 8. Hardness test results of coulters with applied padding welds
Rys. 8. Wyniki badań twardości redlic kultywatora z naniesionymi napoinami

Table 4. View of microstructures and places of their execution for three electrodes
Tabela 4. Widok mikrostruktur oraz miejsc ich wykonania dla trzech elektrod

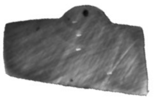
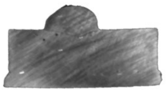
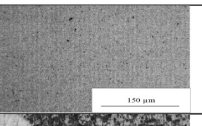
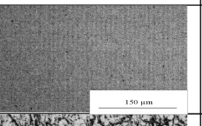
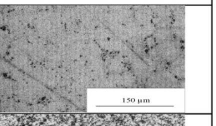
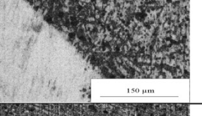
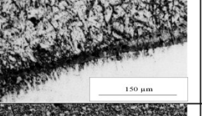
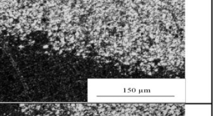
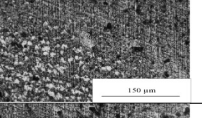
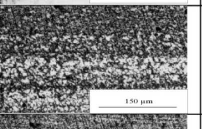
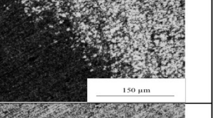
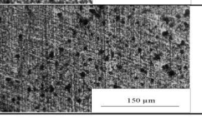
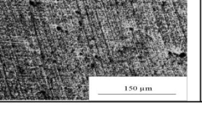
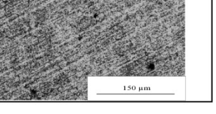
Electrode	1	2	3
Place where the specimen was taken from			
View of the specimen			
Padding weld			
SP1			
SP2			
Core			

Figure 9 summarises the results of the average wear of samples pad welded with different electrodes. Additionally, the results of tests of the average weight loss of the cultivator coulter without pad welded surface were included. The results of the second stage (testing of the cultivator coulters whose surfaces were pad welded with different electrodes) are close to each other and oscillate at m = 0.05–0.07 g. This is a weight loss many times smaller than that of the sample without a weld. However, no significant change in the shape of the native component was found. This means that the welded area is the one most exposed to wear and is mainly affected by the abrasive mass stream during the work of the component in soil. It is possible to create an abrasive layer in the "pockets" between the padding welds that act on the abrasive, which results in friction between abrasive and abrasive.

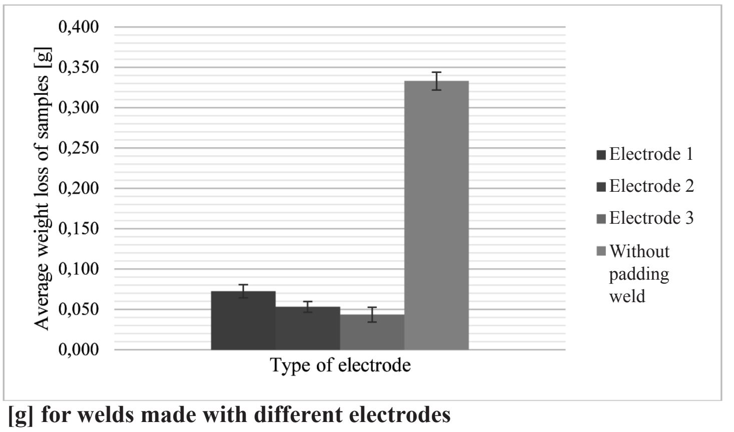


Fig. 9. Average weight loss [g] for welds made with different electrodes
Rys. 9. Średni ubytek masy m[g] dla napoin wykonanych różnymi elektrodami

CONCLUSIONS

The analysis of the tribological test results allows us to state that there is a significant relationship between the value of wear and the padding weld shape on the tested coulters. The coulter which had a weld applied perpendicular to the direction of abrasive mass stream was characterised by a lower weight loss than the coulters with weld strips arranged in parallel or V-shaped. Components welded with different electrodes were characterised by a different weight loss depending on the chemical composition of the electrode used. The weld made with Electrode 3 proved to be the most resistant to abrasive wear. Based on the results obtained from the tests carried out in the first and second research stages, it can be unequivocally stated that the pad welding of the cultivator coulter surface significantly improves the wear resistance of this component in relation to samples whose surface has not been treated (native material).

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