Marta PACZKOWSKA[*], **Jarosław SELECH**[*]

AN INVESTIGATION OF THE INFLUENCE OF LASER ALLOYING OF THE SURFACE LAYER ON ABRASIVE WEAR RESISTANCE OF CAST IRON ELEMENTS

BADANIE WPŁYWU STOPOWANIA LASEROWEGO WARSTWY WIERZCHNIEJ NA ODPORNOŚĆ NA ZUŻYCIE ŚCIERNE ELEMENTÓW Z ŻELIWA

Key words: laser heat treatment, cast iron with graphite flake, microstructure, wear.

Abstract The purpose of the study was to evaluate the influence of the laser alloying of the coulter flaps working in a sand medium on the intensity of their abrasive wear. The treatment was performed with a dual diode TRUDISK 1000 laser device. Two types of alloying were performed (with boron and the mixture of boron and chromium). The wear experiment was carried out with a "rotating bowl" device to testing wear in a sandy medium.

In comparison to the surface layer of the base coulter flaps (only chilled – with white cast iron microstructure) after laser alloying finer, more homogenous and additionally hardened microstructure of the surface layer was achieved. Such microstructure improved the hardness by approx. 2 times for laser alloying with boron and 3 times for the alloying with boron and chromium. Wear tests proved that this translated into over 2-fold improvement in durability of treated coulter flaps. Mass loss was similar in the case of both types of alloying despite of achieving the higher value of hardness by laser alloying with boron and chromium than by alloying only with boron. It may result from some discontinuities observed in the microstructure of the layer containing chromium that was created due to the technology. It was also observed that alloying with boron improved the surface roughness parameters.

Słowa kluczowe: laserowa obróbka cieplna, żeliwo z grafitem płatkowym, mikrostruktura, zużycie.

Streszczenie Celem badań była ocena wpływu stopowania laserowego stopek redlic pracujących w medium piaszczystym na intensywność ich zużycia ściernego. Obróbkę przeprowadzono za pomocą duo diodowego urządzenia laserowego TRUDISK 1000. Wykonano dwa rodzaje stopowania (borem oraz mieszaniną boru i chromu). Test zużyciowy przeprowadzono w urządzeniu „wirująca misa" do badania zużycia w podłożu piaszczystym.

Porównując do warstwy wierzchniej stopek redlic w stanie wyjściowym (tylko zabielanej) po stopowaniu laserowym otrzymano drobną, bardziej jednorodną i dodatkowo zahartowaną mikrostrukturę. Taka mikrostruktura poprawiła twardość ok. 2-krotnie dla laserowego stopowania borem i 3-krotnie dla stopowania borem i chromem. Test zużycia udowodnił, że przełożyło się to na ponad 2-krotne zwiększenie odporności na zużycie obrobionych stopek redlic. Ubytek masy był podobny w przypadku obu rodzajów stopowania pomimo osiągnięcia większej twardości w przypadku stopowania borem i chromem niż w przypadku stopowania tylko borem. Może to wynikać z nieciągłości zaobserwowanych w mikrostrukturze warstwy zawierającej chrom, która spowodowana była prawdopodobnie wadą technologii. Zaobserwowano również, że stopowanie borem poprawiło parametry chropowatości powierzchni.

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[*] Poznan University of Technology, Institute of Machines and Motor Vehicle, Piotrowo 3 St., 60-965 Poznan, Poland, e-mail: marta.paczkowska@put.poznan.pl, jaroslaw.selech@put.poznan.pl.

INTRODUCTION

The machine parts dedicated to operate in soil are required particular surface layer properties to increase their resistance to wear. Machine equipment is subject to substantial mechanical and tribological stress, as well as to corrosion processes. The problem of friction wear in the case of parts of agricultural machines is rising because of improving working speeds. For instance, seeder speeds have increased from 3 to 6 km/h to > 12 km/h, depending on the crop and seeder type [**L. 1**].

Suitable surface layer modification may decrease the wear of machine parts causing their better durability and longer intervals between their replacements.

Such modification could be a laser heat treatment (LHT). LHT is used in surface engineering in order to change the properties of the surface layer. Modification by heating using a laser beam is a developing procedure for improving the surface layer properties of machine part made of metal alloys. It is used especially for ferrous alloys, including cast irons. One of the types of LHT is laser alloying consisting in implementing the alloy element into the surface layer.

The alloyed zone of a cast iron is characterized by fine, hardened microstructure (often similar to ledeburite nature) enriched with new formed phases containing implemented elements. For example, carbide-rich microstructure was found in the surface layer of nodular iron with a hardness of 1200 HV0.05 obtained after laser alloying with a combination of elements: C-B-W-Cr [**L. 2**]. In turn, carbon implementation into to flake iron resulted in increased fatigue resistance of treated samples compared to samples only after laser remelting [**L. 3**]. In the article [**L. 4**], it was observed that hardness and corrosion resistance increased after laser alloying with copper of cast iron.

To show the effectiveness of another element (boron) as an alloying substance in the case of laser treatment of cast irons, it is worth mentioning research [**L. 5**], which proved that, after laser alloying with boron of nodular iron, it is possible to obtain a fine-grained microstructure of the remelted zone enriched with hard Fe_2B phases and thereby increase the hardness (even 6-fold) and wear resistance to friction of the surface layer of such treated samples than untreated ones. The mass loss of laser alloyed with boron samples (in pair with hardened steel) was 3.5-times lower than the value of only hardened samples [**L. 6**]. Mass loss after wear tests of nodular iron samples after laser alloying with boron was 0.0003 g, while the mass loss of hardened samples was 0.001 g.

Another interesting element (due to its ability to substantial increase the hardness and corrosion resistance) for surface modification using various methods including laser implementation is chromium. Laser alloying of cast iron with this element creates chromium carbides and significantly increases the hardness of the surface layer [**L. 7, 8**]. In case the treatment performed during the research presented in [**L. 9**], laser alloying with chromium of nodular iron caused a fourfold increase in hardness. The layer consisted of ledeburite and chromium carbides Cr_7C_3 and $(CrFe)_7C_3$ as a result of the combination of chromium with carbon and iron found in cast iron. In work [**L. 10**], it was shown that the alloying with this element of cast iron allowed one to obtain an increase of resistance to heat in comparison with untreated cast iron. Unfortunately, alloying with chromium does not always increase the resistance to wear. In article [**L. 7**], it was noted that there was a negative impact of alloying with this element. The wear tests have shown that the created alloyed zone caused an increase in the mass loss of the cast iron samples. Nevertheless, according to results presented in article [**L. 11**], after alloying with two elements, chromium and nickel, resistance to wear (and corrosion) was achieved.

On the basis of the literature, it could be stated that boron should also increase the wear resistance in the case of the coulter flap. Due to ambiguous information about the chromium effect in the case of cast irons, it seems that it is valuable to study the addition of this element as well.

One of the significant components of operating costs of agricultural machines that can be significantly affected by the user (e.g., farmer) is the costs of renewal (repair or replacement for new ones) of damaged machines and devices or their subassemblies. Lowering these costs can be achieved by using modern (and organizational and economically justified) technologies that increase the operational periods of machinery and equipment. This effect can be obtained by increasing the durability of components and subassemblies that are most exposed to wear or damage. Moreover, it can be achieved by economically justified repair of damaged machines with a wide use in the renewal processes of both new and remanufactured spare parts. Thanks to this, it is possible to significantly reduce the material costs associated with both the operation and renewal of machines.

The problem of the abrasive wear of machine elements designed for work in a soil medium acquires new meaning in the context of increasing requirements for modern work and agricultural machines. In the case of agriculture, we are dealing with increasing the working speed, e.g., when sowing from 3 to 6 km/h to speeds above 12 km/h, depending on the type of crop and the type of seeder. All elements working in the soil at a depth of 2 to 5 cm, including coulter flaps, while the increase of the working speed, causes very intensive wear of materials from which these elements were made. It causes increased costs related to buying of new elements and losses related to the downtimes necessary for repairs.

Except for reducing the operating costs, it is also necessary to remember the ecological effects of the surface layer modification and pro-ecological management (scrapping) of worn out machinery and equipment. The modification of the surface layer should be understood as a series of technological processes, while the selected surface parts of the machines (the most exposed to wear), are given new quality features, mainly strength, to a much greater extent than parts not subjected to such modifications.

The purpose of presented investigation was to evaluate the influence of the laser alloying surface modification with boron and chromium of the coulter flaps working in a sand medium on the intensity of their abrasive wear.

METHODOLOGY

Coulter flaps from a Poznaniak mechanical drill seeder were used as test objects (**Fig. 1**). These coulters were designed as easy-to-replace parts. They are flat-shaped with average dimensions of 18×240×55 mm. One edge of the flap is taking the shape of a blade whose spherical surface becomes a rectangular prism. Its average mass is in the range of 1100–1250 g. The coulter flap is made of cast iron with fakes of graphite. The surface layer is chilled during production to obtain a white cast iron microstructure. The outer layer is characterized by hypoeutectic microstructure: transformed ledeburite (pearlite with cementite) and pearlite.

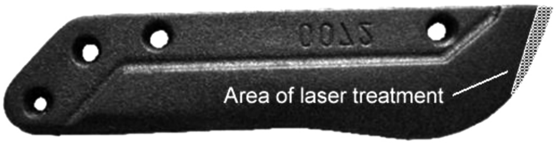

Fig. 1. The flap of a coulter
Rys. 1. Stopka redlicy

Laser heat treatment was performed as a surface modification. It consisted in remelting (and additionally alloying) a piece of the coulter flap tip (approximately 2 mm^2) by means of a dual diode TRUDISK 1000 laser device. Laser beam power (*P*) was 900W, its velocity (*v*) was 1100 mm/min, and the diameter (*d*) was 1.2 mm.

Two kinds of alloying of the coulter flap surface were performed. Before the laser treatment, the surface of this part was covered by a coating containing the alloying and bounding substances. In the first type of alloying, only boron was used; and, in the second type, a mixture containing boron and chromium was applied. Powders of chromium (< 45 μm) with a purity of ≥ 99.0% and boron (< 1 μm) with a purity of ≥ 99.0% were used as alloying substances. The first step of modification consist in applying the prepared coating on the surface, and the second step consist in remelting the surface layer of treated part of the coulter flap with the coating using laser heating.

The wear experiment was carried out with a "rotating bowl" device consisting in a transmission (1), motor (2), running rail (3), bowl (4), sample holder (5), supporting frame (6), compacting roller (7), bowl frame (8), and main frame (9) for performing wear tests in a sandy medium (**Fig. 2**). This device has been also used in the research presented in [**L. 12**]. This particular method was selected because the sample and the abrasive medium are similar to the movement of farming tools

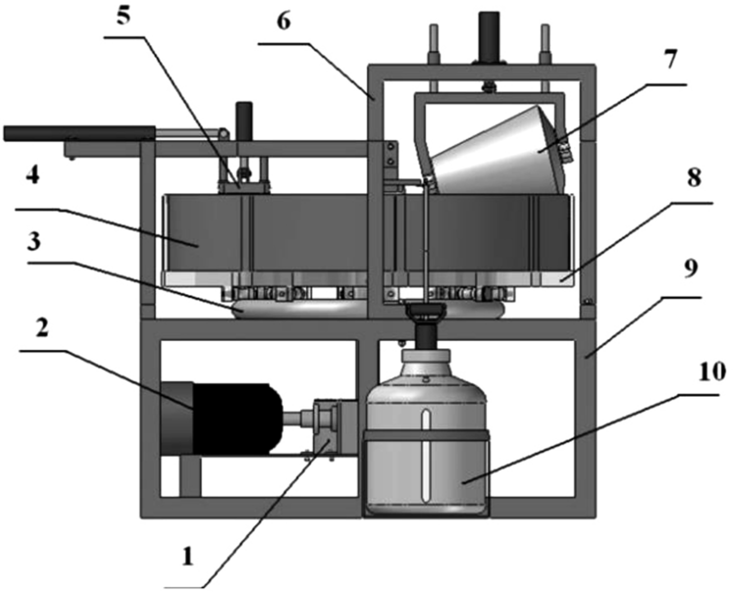

Fig. 2. The wear test device (description in the text)
Rys. 2. Urządzenie do badań tribologicznych (opis w tekście)

in actual operating conditions. Five coulter flaps treated with each alloying treatment and 5 untreated coulter flaps were tested. The coulter flaps travelled a distance of 100 km ±3 km. This corresponds to drilling of seeds on a field of 35 hectares, assuming that the mechanical seeder Poznaniak was used with a working width of 3.0 meters with 25 coulters and a 12 cm seed spacing. Due to the difference in linear velocities at various distances from the rotation axis of the bowl, the arm holding the test samples was inverted half way through the test, and the rotation direction was changed as well. As a result, the wear of each of the three samples tested simultaneously was more uniform. In order to reflect actual working conditions as closely as possible, the samples were placed at intervals of approx. 12 cm from one another to ensure that the abrasive medium flowing over the sample is not affected by the neighbouring sample. Linear velocities calculated for the three samples installed at different distances from the rotation axis of the bowl were as follows: 6.4 km/h, 5.4 km/h, and 4.3 km/h. The diameter of the bowl is 1600 mm, and its linear velocity at the circumference was 7.2 km/h. As a result of the aforementioned inversion of the arm holding the samples, it was possible to ensure that the distance travelled by all coulters was identical, irrespectively of their position on the holding arm [**L. 15**].

Based on the results from the sensors, the component of force values and resultant force acting on the coulter tip for different linear velocities, and the two depths of immersion of the coulter tips in the soil were calculated (**Figs. 3–5**). The values of the forces calculated on the basis of a simplified distribution of forces in the system are shown in **Fig. 6**. The single beam on the right side by the pivotal joint and on the left side by moving joint was supported. So the following formula can be written [**L. 13**]:

$$x: -R_a^x + F^x = 0 \Rightarrow F^x = R_a^x \tag{1}$$

$$y: R_a^y - R_b^y + F^y = 0 \Rightarrow F^y = R_b^y - R_a^y \tag{2}$$

$$M_b: -R_a^y * a + F^y * b + F^x * c = 0 \Rightarrow F^y = \frac{R_b^y * a - F^x * c}{a+b} \tag{3}$$

If R_a^x refers to the L6N-50 kg sensor and R_b^y refers to the L6N-30 kg sensor, and if the distance is known between the points of application of the force, we can determine the following relationships:

$$F^x = R_a^x \tag{4}$$

$$F^y = \frac{R_b^x * 275 - R_a^x * 105}{330} \tag{5}$$

Substituting the data for received dependences, the force values for all test cases were obtained. A resultant force *F* was calculated from the following formula:

$$F = \sqrt{F_x^2 + F_y^2} \tag{6}$$

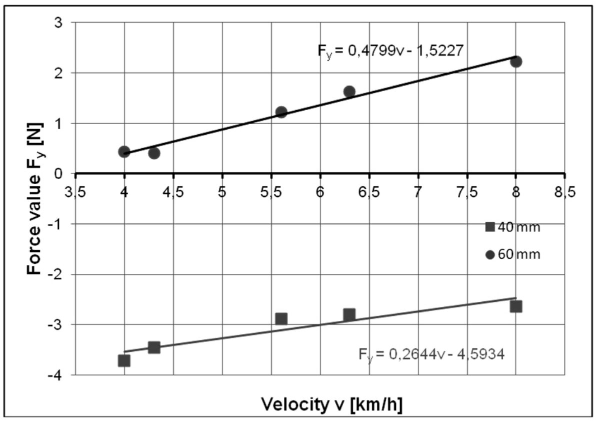

Fig. 3. ***F$_x$* force acting on the coulter tip [L. 13]**
Rys. 3. Wartość siły składowej *F$_x$* działająca na czubek redlicy [**L. 13**]

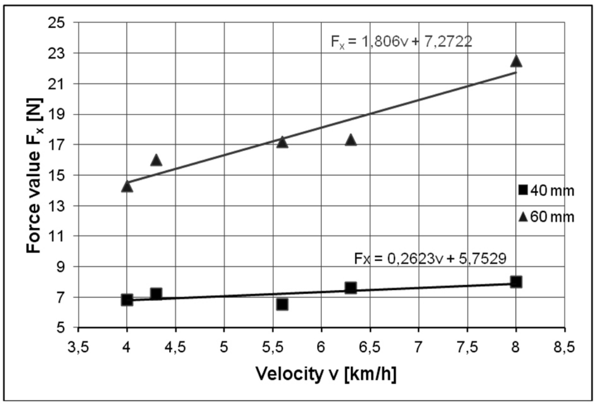

Fig. 4. ***F$_y$* force acting on the coulter tip [L. 13]**
Rys. 4. Wartość siły składowej *F$_y$* działająca na czubek redlicy [**L. 13**]

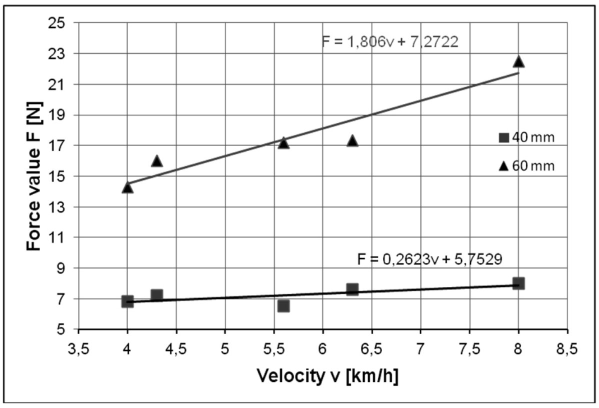

Fig. 5. The values of the resultant force *F* acting on the coulter tip [L. 13]
Rys. 5. Wartość siły wypadkowej *F* działająca na czubek redlicy [**L. 13**]

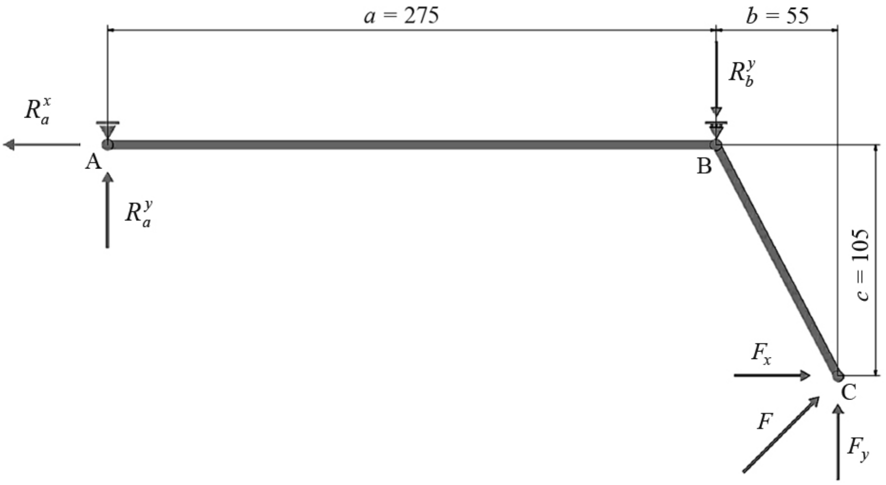

Fig. 6. Simplified distribution of forces in the measuring system [L. 13]
Rys. 6. Uproszczony rozkład sił w układzie pomiarowym [**L. 13**]

With the increase of the coulter velocity in the soil on the rotating bowl unit, there was an increase of forces acting on the tip. A negative value of the force in the vertical direction that occurs at a depth of immersion of 40 mm for component F_y is also important. This means that the component “y” of the force F is less than the weight of the test system. The resultant force F acting on the coulter tip in both cases of coulter depth of immersion in the soil is increasing. This increase is significant in the case of the immersion of 60 mm. For a speed of 4 km/h, the value is 14.29 N, and for the 8 km/h, the value is more than 22.5 N.

This gives an increase of less than 60% in the velocity growth about 100%. From the graphs can also be noted that in the case of horizontal forces to 8 km/h is a significant force increase compared to the previous presented velocity. So a significant increase in resultant force is not re ported for work at a depth of 40 mm. The resultant value, in this case, fluctuates at a similar level of 8 N with a slightly increasing trend with the increased velocity of the coulter in the soil. This is due to the direction of the vertical force at a lower immersion in the soil.

River sand was selected as the abrasive medium. Following a grain size analysis, the grain size distribution curve was determined. The choice of river sand was based on a high proportion of quartz particles as compared to other types of soil, thus making this medium particularly abrasive [**L. 14**]. The mechanical composition of the soil was analysed as part of the experiment, which was based on the conclusions from the study of the effect of the medium on wear intensity. In monophase media, consisting, e.g., exclusively of fine sand, a phenomenon obstructing the experiment and potentially interfering with the results was observed. Namely, as the soil was coming in contact with the test subjects, the grains of the abrasive medium became rounded. A similar phenomenon was also observed in multiphase media consisting of at least two fractions, but the relative proportions of abrasive grain fractions stabilized after some time and were no longer affected by the tested tools [**L. 15**]. The medium selected for this study underwent sieve analysis. After sieving 1000g of soil, the grain size distribution curve was determined (**Fig. 7**) for the sand fraction. The remaining dust fraction (less than 5 g) was considered insignificant. The gravel fraction constituted approximately 2.5% of the tested medium. An analysis of the grain size distribution curve indicates that one deals here with medium sand with a very low share of gravel and dust fractions (less than 3%) [**L. 14**].

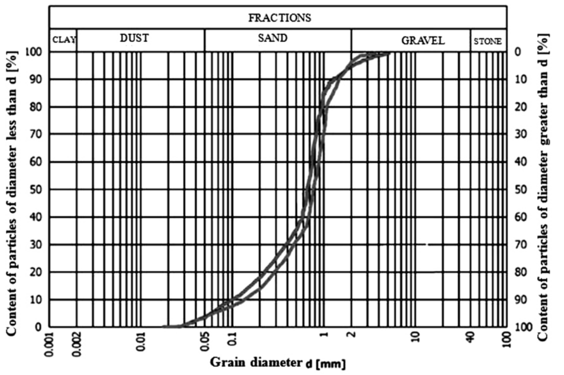

Fig. 7. Abrasive medium grain size distribution curve [L. 14]
Rys. 7. Krzywa rozkładu wielkości ziarn środowiska ściernego [**L. 14**]

The wear test effects were determined by measuring coulter flap masses before and after the test using a Radwag PS 1000/Y precision balance with an accuracy of 0.001 g.

The investigation involved surface and surface layer microscopic analysis. The analysis was performed by means of a Zeiss Epiquant light microscope and Tescan Vega 5135 scanning electron microscope.

Surface roughness measurements were carried out with a ZAISS contact profilometer equipped with induction transducers and SUFORM with SAJD METROLOGIA software.

Microhardness tests were carried out by means of a ZWICK 3212 microhardness tester via the Vickers method with a load of 100 G.

THE ANALYSIS OF THE RESULTS

As a result of laser treatment, both types of alloying remelted areas were created. The remelted area was visible in all treated coulter flaps on their tip on the one side of the part (**Fig. 8**). This tip was characterized by a modified surface in comparison to the rest of surface of the coulter flap.

It was noticed that the roughness of the surface tip after laser alloying with boron decreased in comparison to the base surface of the coulter flap (nearly 12 µm of *Ra*); however, for laser alloying with the mixture containing boron and chromium was similar to the base surface, roughness was similar (**Fig. 9**) (also nearly 12 µm of *Ra*). Therefore, it could be stated that laser treatment consisting in alloying with boron improved the base surface of the coulter flap in the aspect of the surface roughness parameters.

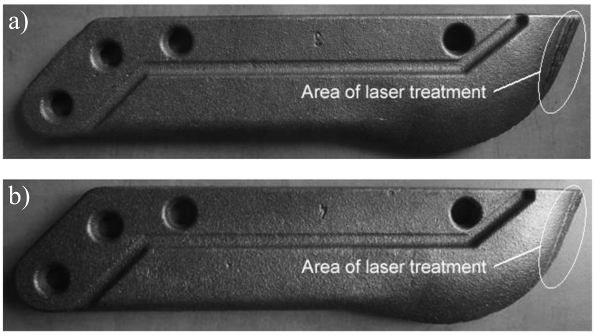

Fig. 8. The coulter flap after laser alloying: with boron (a) and with mixture of boron and chromium (b)

Rys. 8. Stopka redlicy po stopowaniu laserowym: borem (a) oraz mieszaniną boru i chromu (b)

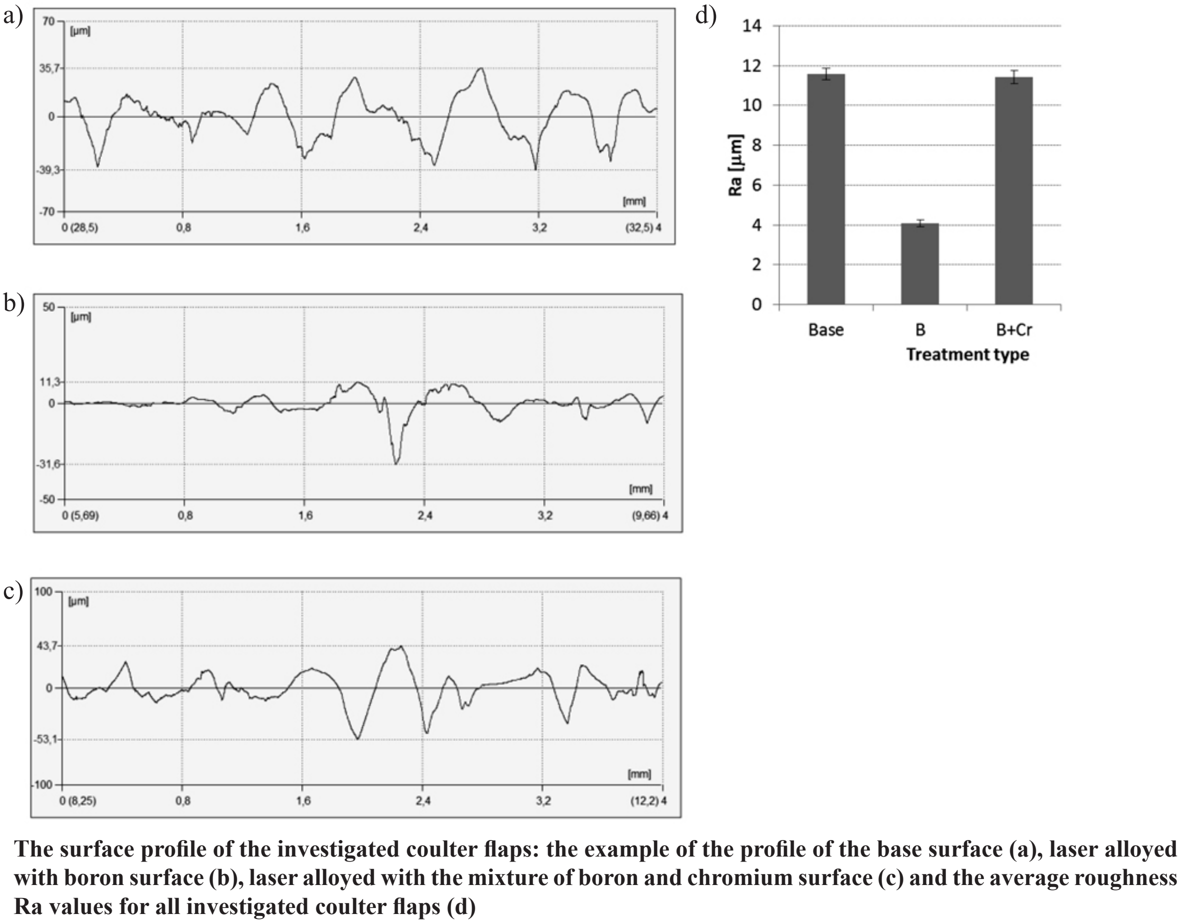

Fig. 9. The surface profile of the investigated coulter flaps: the example of the profile of the base surface (a), laser alloyed with boron surface (b), laser alloyed with the mixture of boron and chromium surface (c) and the average roughness Ra values for all investigated coulter flaps (d)

Rys. 9. Profil powierzchni badanych stopek redlicy: przykład profilu powierzchni bazowej (a), powierzchni po stopowaniu borem (b), powierzchni po stopowaniu borem i chromem (c) oraz średnia wartość chropowatości Ra dla wszystkich badanych stopek redlicy (d)

Examination with the application of a microscope showed that, after laser treatment, a fine and quite homogeneous microstructure surface layer appeared in both cases of alloying (**Figs. 10** and **11**), especially compared to the base surface layer of the coulter flap that is usually treated to achieve white cast iron (**Fig. 12**). Fine and hardened microstructure with characteristic dendrites is typical for laser heat treatment with remelting [**L. 15**]. The microstructure of the laser treated surface was more finely grained than the microstructure of the chilled part of the coulter flap. Sometimes, new formed phases were noticed, as in the case of the coulter flaps alloyed with boron where boride irons with their characteristic shape after this kind of treatment appear

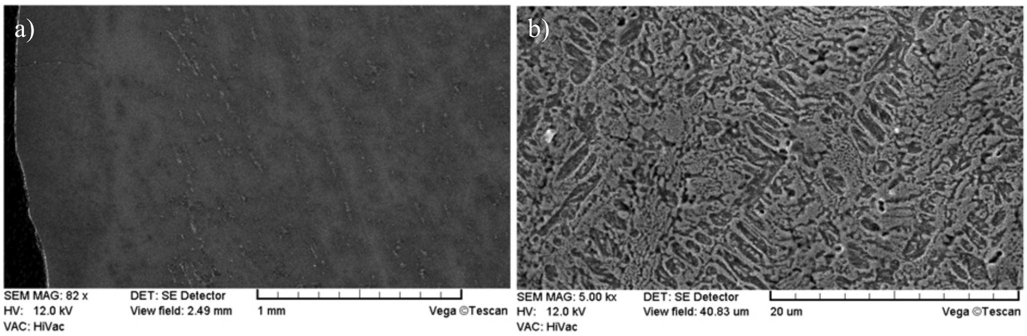

Fig. 10. The surface layer after laser alloying with boron (scanning electron microscope, etched with nitric acid)
Rys. 10. Warstwa wierzchnia po stopowaniu laserowym borem (elektronowy mikroskop skaningowy, trawione nitalem)

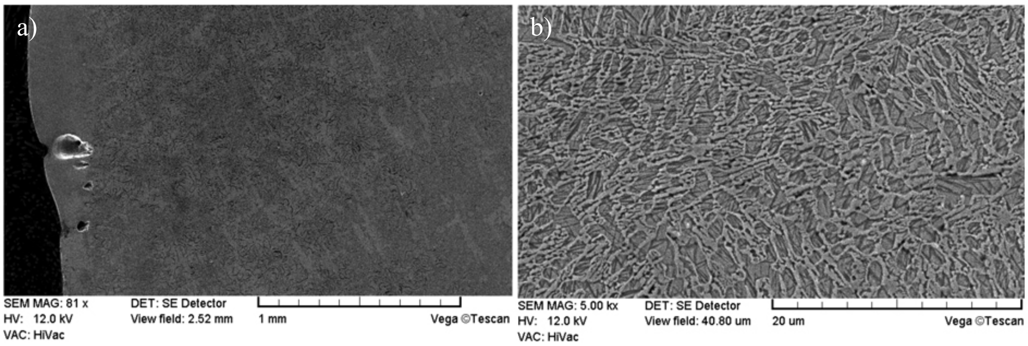

Fig. 11. The surface layer after laser alloying with the mixture of boron and chromium (scanning electron microscope, etched with nitric acid)
Rys. 11. Warstwa wierzchnia po stopowaniu laserowym mieszaniną boru i chromu (elektronowy mikroskop skaningowy, trawione nitalem)

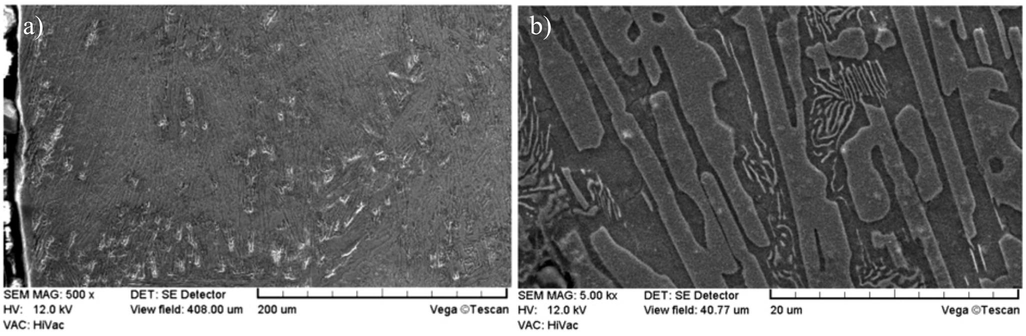

Fig. 12. The surface layer of the untreated coulter flap (ledeburide microstructure of the white cast iron) (scanning electron microscope, etched with nitric acid)
Rys. 12. Warstwa wierzchnia nieobrobionej stopki redlicy (elektronowy mikroskop skaningowy, trawione nitalem)

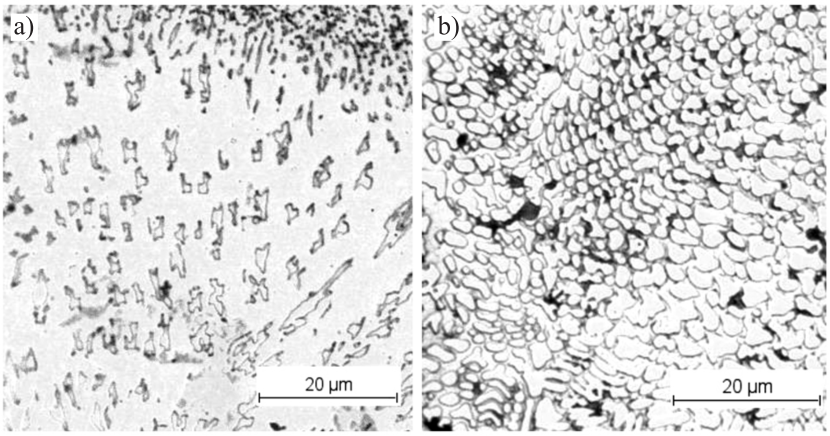

Fig. 13. Boride irons in the surface layer of the coulter flap after its laser alloying (optical microscope, etched with nitric acid)

Rys. 13. Borki żelaza w warstwie wierzchniej stopki relicy po jej stopowaniu (mikroskop optyczny, trawione nitalem)

(**Fig. 13**). Such boride irons have been previously noticed [**L. 5**].

Some discontinuities of the microstructure of the surface layer of the coulter flap after laser alloying with boron and chromium were noticed (**Fig. 11a**). It could be the reason for the lack of the roughness reduction of the surface after laser alloying with boron and chromium, which was observed in the case of laser alloying only with boron.

The average hardness of the areas formed by laser alloying with boron was approximately 2-times higher than the area of white cast iron microstructure in the surface layer of untreated coulter flap (the base) (**Fig. 14**). The hardness of approx. 1100HV0.1 after laser alloying with boron has been already achieved on parts made of cast irons [**L. 5**]. However, the addition of chromium allowed achieving 3-times higher hardness of the alloyed layer than layer of the base.

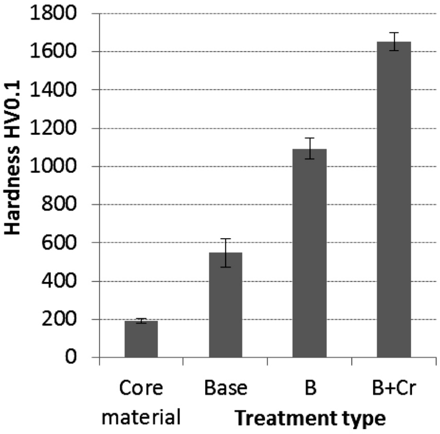

Fig. 14. Average hardness of the surface layers of investigated coulter flaps

Rys. 14. Średnia twardość warstw wierzchnich badanych stopek redlicy

After wear tests, the edges of the blade became rounded. The surfaces of all coulters seem to be smoother than their state before the wear tests (**Fig. 15**).

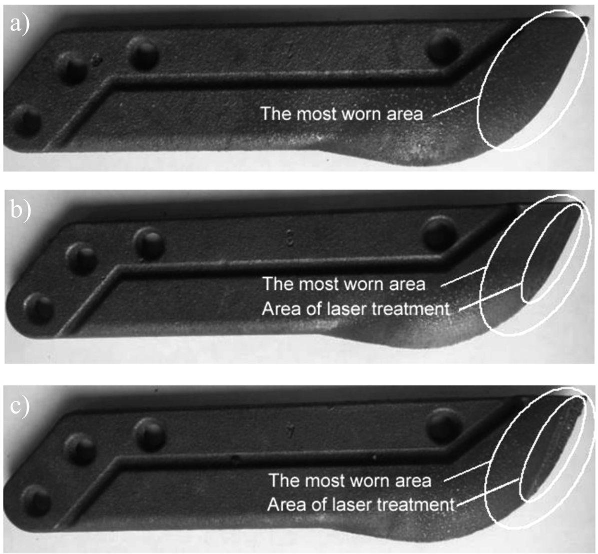

Fig. 15. The coulter flap (after wear test): without laser treatment (a), after laser alloying with boron (b) and after laser alloying with mixture of boron and chromium (b)

Rys. 15. Stopka redlicy (po badaniach zużycia): bez obróbki laserowej (a), po stopowaniu borem (b) po stopowaniu borem i chromem (b)

Wear tests showed that laser treatment of a relatively small part of the coulter flap reduce their mass loss (**Fig. 16**). In both cases, a 50% reduction of mass loss was noticed. It seems that, in the case of alloying only with boron, this reduction could be even bigger (nearly 2.5 times).

Consequently, it could be stated that, by improving the hardness of the surface layer by laser alloying, the

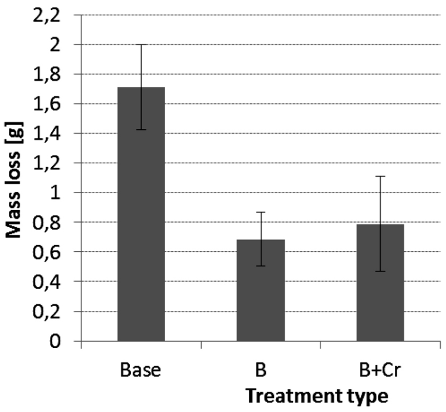

Fig. 16. Average coulter flap mass loss after 100 km in abrasive medium in the rotating bowl tester, depending on surface treatment (Base – untreated flaps, B – flaps after laser alloying with boron, B+Cr – flaps after laser alloying with boron and chromium)

Rys. 16. Średni ubytek masy stopek redlic po przebytych 100 km w ośrodku ściernym w urządzeniu „wirująca misa" w zależności od zastosowanej obróbki powierzchni (Base – redlice nieobrobione, B – redlice po stopowaniu laserowym borem, B+Cr – redlice po stopowaniu laserowym borem i chromem)

coulter flap should be characterized by lower wear. It is worthy noticing that increasing the hardness by laser alloying with both boron and chromium (to over 1600HV0.1) did not result with lower mass loss of the coulter flaps after the wear tests than the mass loss of the coulter flaps alloyed only with boron which had a lower surface hardness (1100HV0.1). It may result from some discontinuities in the microstructure in the layer containing chromium. Very hard chromium carbides could generate internal stresses. As noticed by the authors of article [**L. 7**], laser alloying with chromium of cast irons can increase wear.

Figure 17 shows the surface profile of the investigated coulter flaps (after the wear test). It was noticed that, after the wear tests, the roughness of the surface tip of the untreated coulter flap and the surface tip after laser alloying with boron was comparable (Ra of untreated surface was >6µm and Ra of alloyed with boron < 6 µm). While for surface alloyed with boron and chromium, the roughness was higher (*Ra* was approx. 9 µm). That could be related with the discontinuities in the microstructure in the layer containing chromium.

As shown in **Fig. 18**, the roughness (*Ra*) after the wear tests only increased a little bit for the surface alloyed with boron (it could be due to the reduction

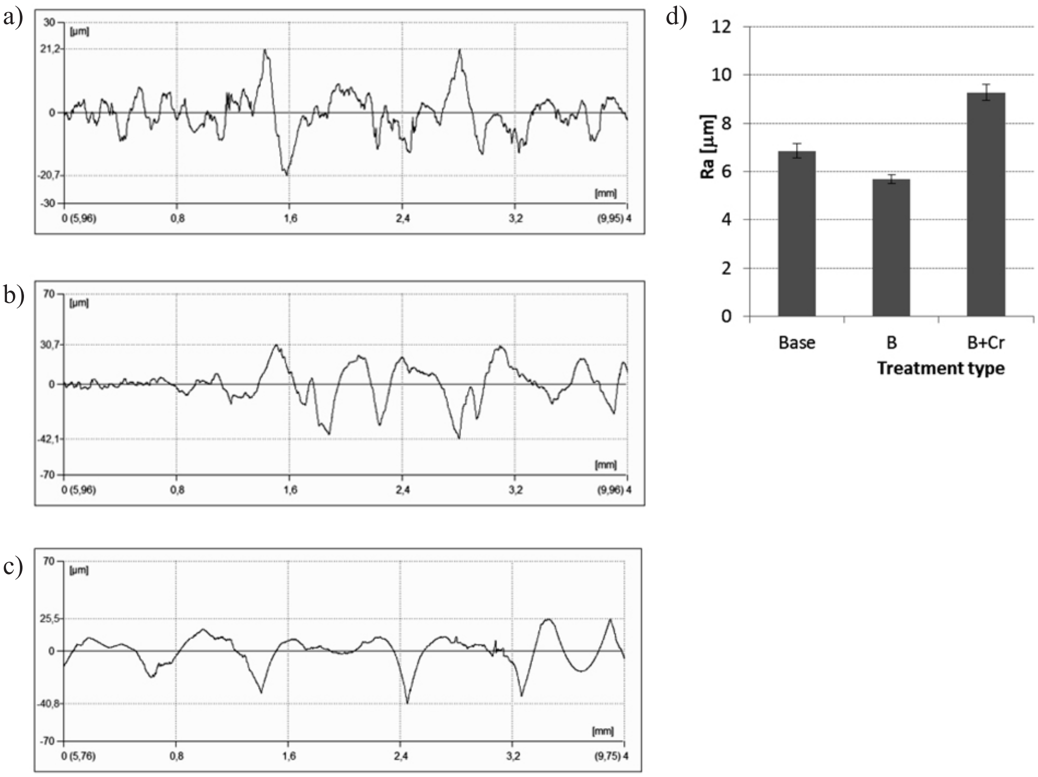

Fig. 17. The surface profile of the investigated coulter flaps (after the wear test): the example of the profile of the base surface (a), laser alloyed with boron surface (b), laser alloyed with the mixture of boron and chromium surface (c) and the average roughness Ra values for all investigated flaps (d)

Rys. 17. Profil powierzchni badanych stopek redlicy (po badaniach zużycia): przykład profilu powierzchni bazowej (a), powierzchni po stopowaniu borem (b), powierzchni po stopowaniu borem i chromem (c) oraz średnia wartość chropowatości Ra dla wszystkich badanych stopek (d) in the roughness by the performed laser treatment). In the case of the surface tip of the untreated coulter flap and the surface tip after laser alloying with boron and chromium, the roughness decreased.

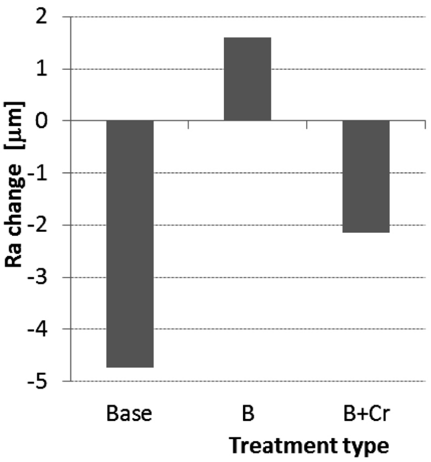

Fig. 18. The roughness (*Ra*) change as a result the wear test of investigated coulter flaps

Rys. 18. Zmiana chropowatości (*Ra*) w wyniku badań zużycia dla badanych stopek redlic

CONCLUSIONS

The following conclusions can be drawn from the performed investigations:

The surface layer microstructure of the coulter flap could be change by laser alloying with boron or with a mixture of boron and chromium. In comparison to the surface layer of untreated coulter flaps (only chilled – with white cast iron microstructure), after laser treatment, a fine, quite homogeneous, and hardened microstructure of the surface layer was achieved. Such microstructure improved its hardness by approximately 2-fold for laser alloying with boron and 3-fold for laser alloying a mixture of with boron and chromium.

The roughness of the surface tip after laser alloying with boron decreased in comparison to the untreated surface of the coulter flap characterized by quite large coarseness. Whereas, for laser alloying with the mixture containing boron and chromium, the surface tip of the coulter flap stayed similar the sample with the untreated surface.

Laser alloying caused over 2-fold improvement in the durability of treated coulter flaps in comparison to untreated ones. Mass loss was similar in the case of coulter flaps after both types of alloying. Despite of increasing the hardness by laser alloying with boron and chromium to over 1600HV0.1, lower mass loss of the coulter flaps has not been achieved than for those that have been alloyed only with boron (reaching the hardness only 1100HV0.1). It may result from some discontinuities in the microstructure in the layer containing chromium (more detailed investigation of this microstructure are planned) that have not been observed in the layer containing only boron. Perhaps, application of shield gas during the treatment would help to avoid or decreased such defects of microstructure.

Laser alloying with boron seems to be a better solution for improving the wear resistance of coulter flaps than alloying with the mixture of boron and chromium. The microstructure is more homogenous, and its hardness is enough to effectively decrease the mass loss. Additionally, this treatment improved the surface roughness parameters of coulter flaps.

This investigation showed that there exist ready-to-use methods for enhancing operational efficiency and delaying terminal wear. Therefore, it seems reasonable to continue research on the influence of laser alloying on the wear process in an abrasive medium. Field tests would be especially valuable.

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