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EVALUATION OF THE INFLUENCE OF THE LASER ALLOYING WITH CR, B AND NI OF GREY IRON PARTS ON THEIR WEAR RESISTANCE

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Abstract

The aim of this research was to evaluate the influence of the laser alloying with Cr, Cr+B+Ni and B+Ni on the wear resistance of grey iron. Agricultural component (coulter flap) exposed on friction wear (as well as corrosion) in the soil has been take into account as a tested machine part. Even 85% decrease of mass loss of the coulter flap with laser alloyed layer (with nickel and boron) after wear test in comparison to mass loss of flap without laser treatment was achieved. In case of alloying with chromium it was 44% and in case of nickel, boron and chromium this decrease was 58%. Laser alloying in each performed variant caused formation of the modified surface layer consisting of fine grains of mainly martensite enriched with alloy elements, increase of hardness of the surface layer and reduction of roughness parameters of the treated surface in comparison to the base surface.

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Introduction

Surface layer modification by laser alloying is very useful method of improving properties of selected parts of many machine components exposed to intensive friction wear and corrosion during their work. Such exploitation conditions can be found in many automobile and agriculture components, that are made of grey iron. The surface layer of grey iron can be effectively modified by laser treatment and especially alloying (CATALÁN et al. 2022, FELDSHTEIN et al. 2022, 2023, JANICKI 2020, JANICKI et al. 2024, KOTARSKA 2021, LONT et al. 2022).

Laser alloying consists on remelting of selected part of surface layer with covering paste containing alloying element or elements (as well as substances). As a result, alloyed layer is forming and it is characterized by hardened and fine microstructure (BURAKOWSKI, WIERZCHOŃ 1995, KUSIŃSKI 2000).

The microstructure and properties of surface layer strongly depend on kind of implemented element or elements used during laser alloying.

For example, in case of boron addition, it is possible to achieve a fine grained hardned microstructure with iron borides that can cause 6-fold increase hardness of the layer (PACZKOWSKA et al. 2010). Hardness can be control by element concentration in the layer. For example in case of boron increase from 7 to 17% at. of this element causes increase of hardness from about 1200 HV0.1 to 1600 HV0.1 (PACZKOWSKA 2013). As a result of laser alloying with boron, a 3.5-fold decrease of wear rate of parts made of nodular iron (when compared to the only hardened parts) was proved after laser implementing of boron (PACZKOWSKA, WOJCIECHOWSKI 2007).

Chromium, is the element of great attractiveness in applications when high hardness and corrosion resistance is need. It could be also useful during laser treatment. It was implemented to attain increase of hardness (WEI, DENG 1998) or thermal fatigue resistance by XIN et al. (2008). Nevertheless, sometimes by chromium implementation reduction of wear resistance can be achieved (DA COSTA, VILAR 1997).

To increase ductility in the surface layer, nickel could be added. This element is generally known for intensifying toughness. For example addition of nickel and chromium together can increase of corrosion wear resistance (MINLIN et al. 2006). Nickel addition during laser alloying with such elements as boron and chromium (that are responsible for increasing hardness and corrosion resistance) should eliminate the eventual possible negative effect of these elements consisting in increasing brittleness.

In presented research composition of those three elements has been take into account to check its influence on wear resistance of treated elements working in abrasive medium. Besides, it needs to be underline that, the final effect of laser modification depends also on laser processing parameters. Laser beam power density and its interaction time are crucial, and need to be accurately carefully chosen (PACZKOWSKA 2016a).

The goal of presented investigation was to assess the influence of the laser alloying with the Cr, Cr+B+Ni and B+Ni on the wear resistance of grey iron.

Agricultural component intensely exposed to friction wear (as well as corrosion) in the soli has been take into account. The increasing requirements for agricultural equipment need the improvement of modern engineering solutions also considering problems of the surface layer.

Material and methods

For evaluation of the influence of laser alloying of grey iron on its wear resistance, one of agricultural part of drill seeder has been chosen, that is exposed to intensive abrasive wear in the soil and corrosion. Hence, as the test object, a coulter flap has been selected (Fig. 1). This part is exposed to wear on its edge (as is marked on the Fig. 1), mostly. Therefore, the surface treatment just in relatively small area should be enough to increase its tribology properties.

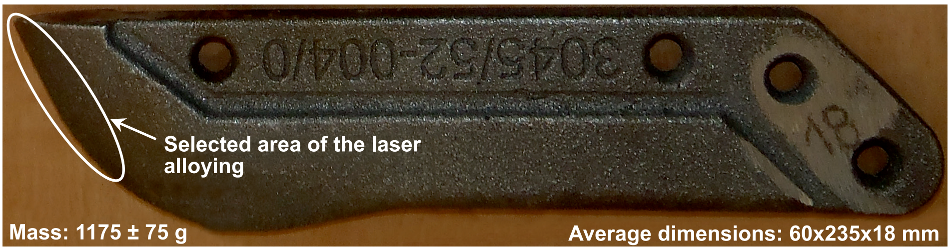

Fig. 1. The coulter flap with its base parameters and marked the area of the laser alloying

The coulter flap was made of grey iron (EN-GJL-250) with flake morphology of graphite and the matrix made of pearlite with small amount of ferrite (which results in hardness of about 200 HB) but in its surface layer transformed ledeburite is present as an effect of chilling (Fig. 2).

The tested material contains: C (3.0 wt.%), Si (2.6 wt.%), Mn (0.4 wt.%) and S (0.1 wt.%), P (0.1 wt.%), Cu (0.1 wt.%), Cr (0.1 wt.%).

The modification of the surface layer was performed on only small area of the most exposed to wear part of the coultre flap (marked in the Fig. 1).

The coating was prepared as following. The powder of element or elements powder was mixed with binding substance. Such binding substance was water glass. Three variants of alloying have been carried out: with chromium, with combination of nickel, boron and chromium (in composition of 1:1:1) and combination of nickel and boron (in composition of 1:1) has been applied. The size of the particles and the purity was: <45 μm and ≥99.8% for nickel; <1 μm and purity of ≥99,0% for boron; <1 μm and ≥99.0% for chromium, respectively.

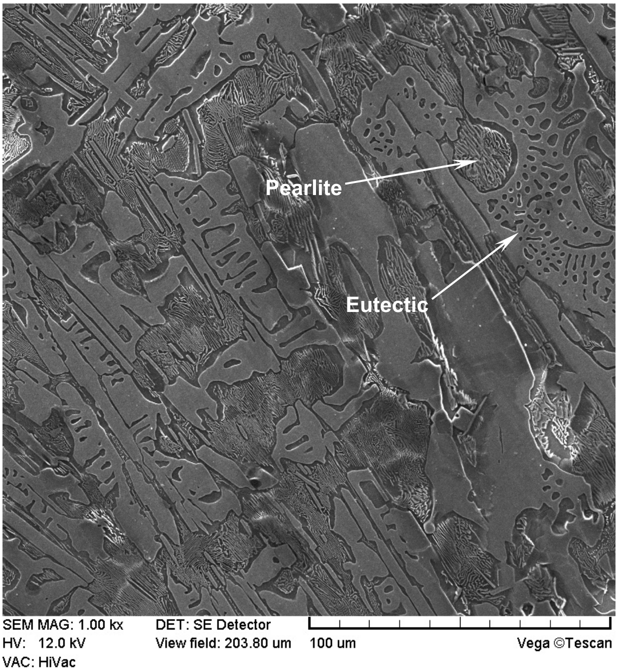

Fig. 2. The chilled surface layer of the coultre flap

The next step was covering the paste on the selected area of the surface and than heating using a laser beam with a TRUDISK 1000 laser device. The laser beam power density in was 85 kW/cm^2 and its radius spot was approximately 0.6 mm. The laser beam interaction time was 0.06 s. For all variants of alloying the same laser beam parameters were applied. Five coultre flap have been treated in case of each variant.

A special tribological tester called ‘rotating bowl’ (Fig. 3), dedicated for assessment of wear resistance such parts in a sandy medium, was applied. Such device is used in case of abrasive wear invesigation in sandy medium (for example: in the research: NAPIÓRKOWSKI et al. 2019).

The character of movement and friction is similar to conditions of culture flaps during seeding. The distance for each coulter flap was planned to reflect the seeding on a field of 35 hectares. The shape of grains and the degree of reeling of the sand corresponding the requirements of similarity to soil sands, in accordance with the PN-EN 933-1:2001 standard. Except laser treated flaps, also 5 untreated have been verified. The distance of the traveling for each coulter flap was planned in the way to reflect the seeding of seeds on 35 hectares field. The abrasive material was silica sand with its grain fraction of 0.2–0.3 mm. The hardness was 995 ±10% HV. The shape of grains and the degree of reeling

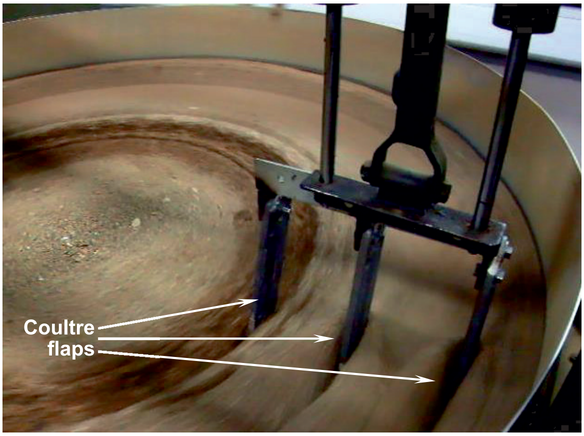

Fig. 3. The view on rotating bowl during the experiment

of the material were selected in such way to matched the requirements of similarity to sands of the soil (in accordance with the PN-EN 933-1:2001 standard). The sand was flushed and a sieve analysis was performed (according to the PN-EN 933-4:2008 standard) to get the right fraction and dispose of dust and organic pollutants. The pollutions share was <3% and the moisture content was about 10% dry weight (determined by evaluating the weight solid phase dried at 105°C). Above tests conditions have been already applied in the author's previous research (PACZKOWSKA, SELECH 2022).

The coulter flaps before and after the test were measured using a precision mass scale. After the treatment microstructure and hardness was studied. For microscopic observation MIRA3 Tescan SEM was used. For strengthening evaluation Zwick 3212 hardness device using the Vickers method. according the standard ISO 6507 was applied. The load was 100 g (it is given in grams because in most results presented in the literature, the Vickers hardness mark is presented as HV0.1, HV0.2, which directly refers to this unit). For detection of elements Princeton Gamma-Tech EDS microanalyzer was used. Zeiss contact profilometer was applied for the surface profile assessment. The profiles has been done perpendicular to the trace of laser beam. The parameters: roughness average R_a and the mean roughness deph R_z obtained from the roughness profile concern the samplingh lenght (l). The samplingh lenght (l) is a reference for the calculation of roughness parameters. The surface roughness parameters were determined for a given samplingh lenght, but ultimately they are averaged (in accordance with the standard) from five samplingh lenght (l) within the so-called assessment lenght (L) (L=5×l). Five repetition were made on one traveling distance. The general puropose of the roughness measument was to assess the changes of the surface conditions of coultre flaps caused by (firstly) laser treatment and (secondly) by abrasive friction.

Results and disscusion

As a result of the all laser alloying variants – with implementig of: chromuim; chromium, boron and nickel; as well as boron and nickel, the modified surface appeared (characterstic of this kind of treatment) (Fig. 4).

Fig. 4. The example of the coulter flap after laser alloying

More smooth surface after laser alloying that was revealed during macroscopic observation has been confirmed by stereometric measurement of the treated surface. Examples of the surface profiles of a modified area by laser treatment are presented in the Figure 5 and the comparison of choosen roughness values in the Figure 6.

The arithmetic average roughness R_a, as well as, the mean roughness depth R_z of the surface after laser alloying decreased in comparison to the untreated surface (Fig. 6). It could be even 3-fold decrease in case of alloying with chormium – taking in to account R_a parameter and over 2-fold decresee in case of laser alloying with boron and nickel – taking into account R_z parameter.

Hence, the improvement of the stereometric structure of the surface quality after the laser alloying was noticed.

The carried out wear tests shown that laser alloying can significantly decrease the mass loss of treated parts (Fig. 7). In case of alloying with boron and nickel it could be even almost 7-fold decrease in comparison to untreated parts. It need be emphasize that the laser alloyed area of coulter flap was quite small (Fig. 3). As could be noticed, alloying with chromium (alone or in combination with boron and nickle) did not cause so much decrease. It could be related with the influence of chromium on the microstructure of alloyed layer (DA COSTA, VILAR 1997). Too much hard phases made on the base of chromium could cause higher stresses in the microstructure and may not affect as successfully in decreasing wear as other implemented elements (like nickel especially). Nevertheless, all performed variants of laser alloying resulted in decreasing of the mass loss of the treated parts.

The wear effects could be observed on the surface of the edge of flaps after the tribological test. In all cases it appeared as matte, but more smooth that

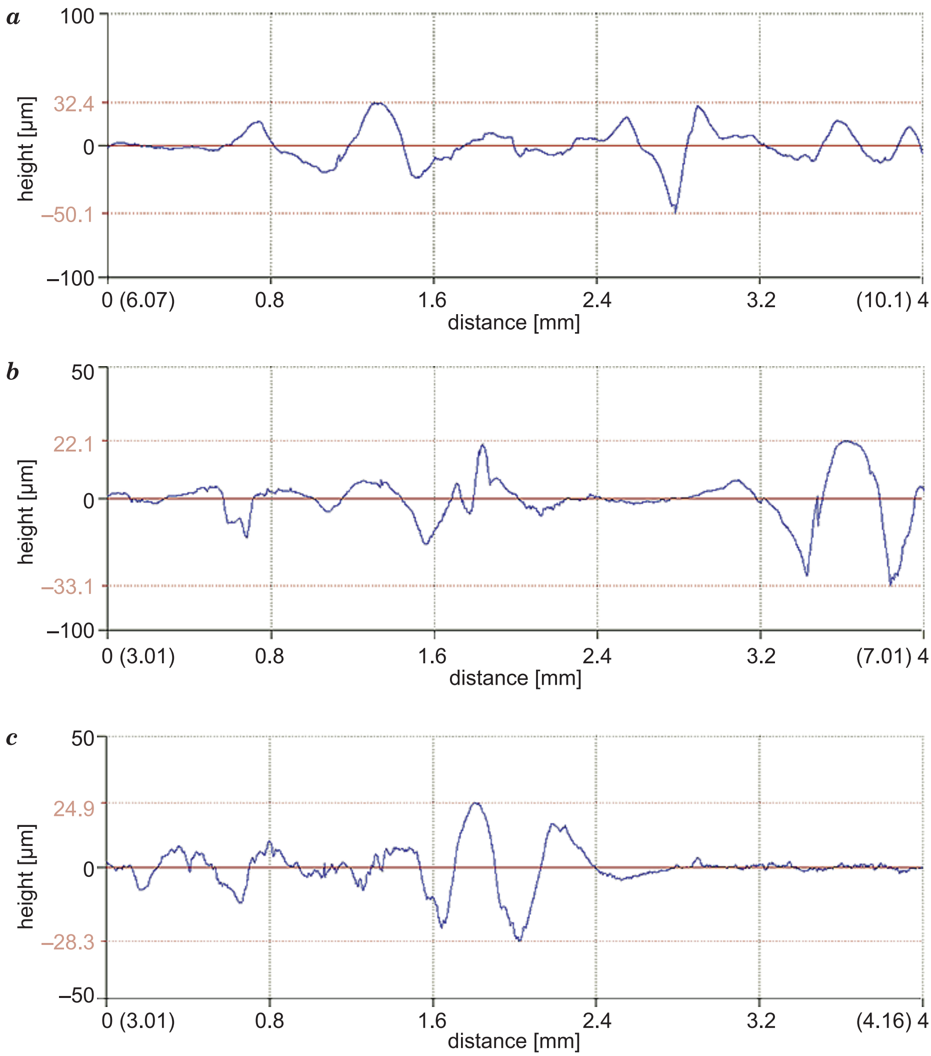

Fig. 5. The surface profile of the coulter flap after laser alloying with Cr (*a*), a combination Cr+Ni+B (*b*) and Ni+B (*c*)

before the test (Fig. 3). Less rough surface of the edge of flaps was confirmed by surface profile examination.

The investigation of the surface profiles of the flaps after wear test showed that generally (Fig. 8), such values of parametares like arithmetic average roughness R_a as well as mean roughness depth R_z decreased (only in case of laser alloying with chromium R_a parameter rised a little to 4.4 µm). R_a of flap after alloying of boron and nickel decreased to 3 µm, and after alloying with nickel,

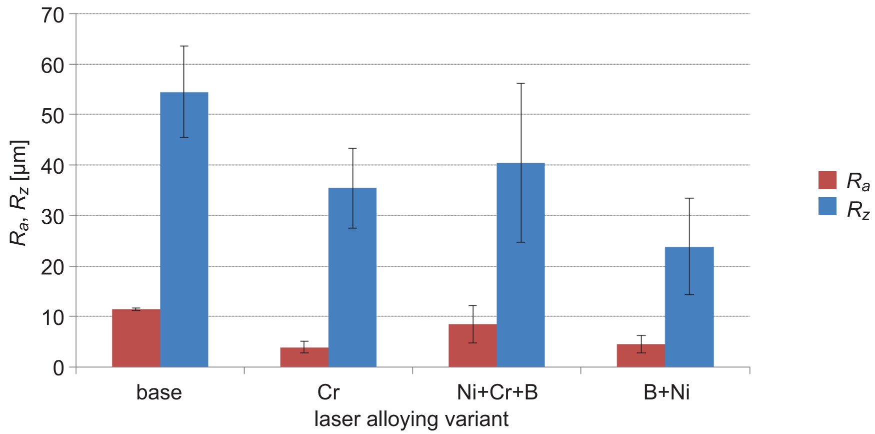

Fig. 6. The average roughness R_a values and the mean roughness depth R_z of the surface after laser alloying and the untreated surface

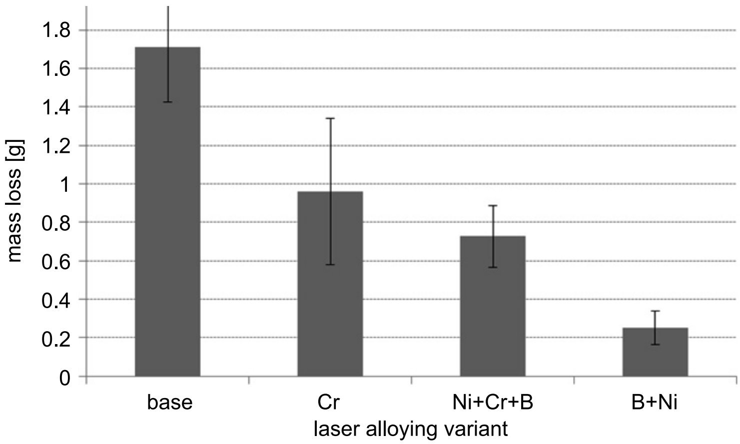

Fig. 7. Mean weight loss of coultre flaps after the wear test

boron and chromium decreased to 5.7 µm. R_z in case of flaps after alloying with chromium decreased to 22.7 µm, alloyed with nickel and boron to 15.5 µm and with nickel, boron and chromium to 28 µm. Nevertheless, it could be noticed that the softest surface layer of culture flaps without laser alloying were characterized by the largest decrease of roughness after the wear tests (Fig. 9).

Even 85% decrease of mass loss (Fig. 7) of coulter flaps after wear test in comporison to mass loss of flap without laser treatment is result of characteristic microsructure of the surface layer (Fig. 10) that is forming after laser alloying with much more uniform morphology (especially in opposition to the base material) (Fig. 11).

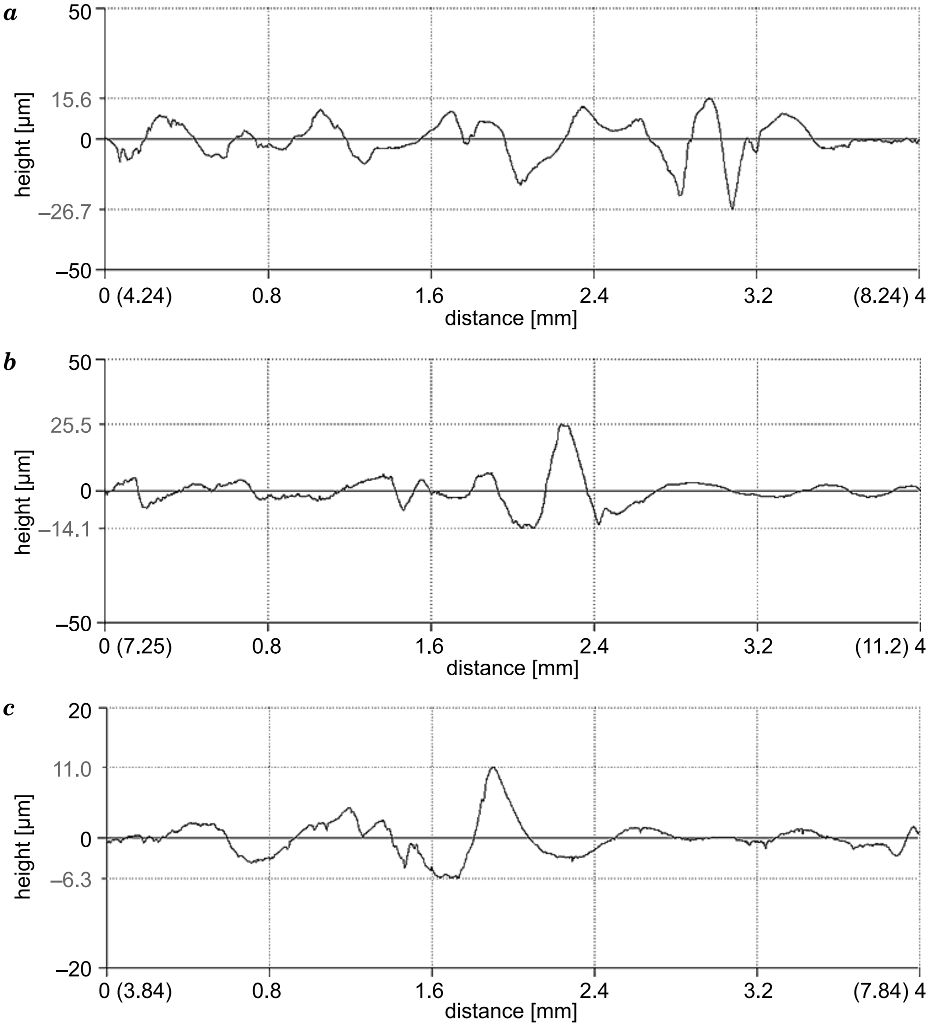

Fig. 8. The surface profile of the coulter flap after wear tests: alloyed with Cr (*a*), a combination Cr+Ni+B (*b*) and Ni+B (*c*)

A rapid melting and solidification of the surface layer causing fine, dendritic microstructure in the whole modified layer (Fig. 9). During solidification, austenite dendrites are crystallizing directly from the liquid state, similarly to the hypoeutectic white cast iron case.

As an effect, dendrites (made of martensite needle – Fig. 12 – with retained austenite) in hardened eutectic matrix are formed (PACZKOWSKA 2016b). The depth of alloyed layers did not exceed 0.5mm in all perfomed variants (Fig. 10).

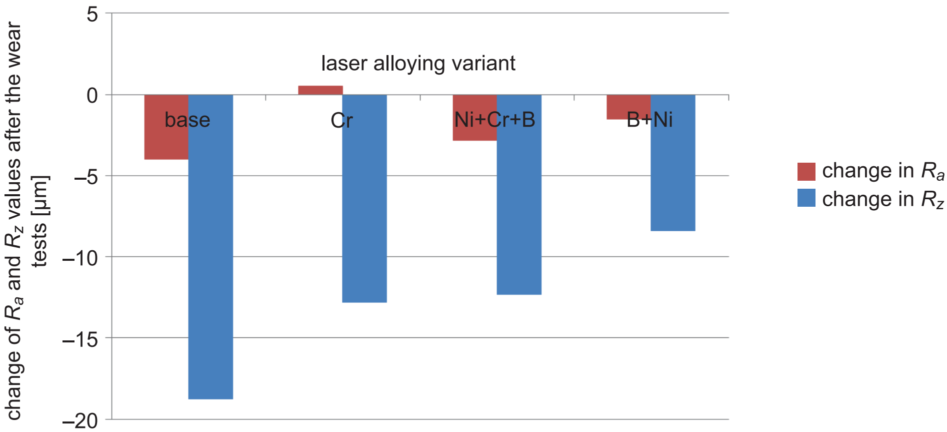

Fig. 9. The change of the average roughness R_a and the mean roughness depth R_z values of the surfaces after wear tests

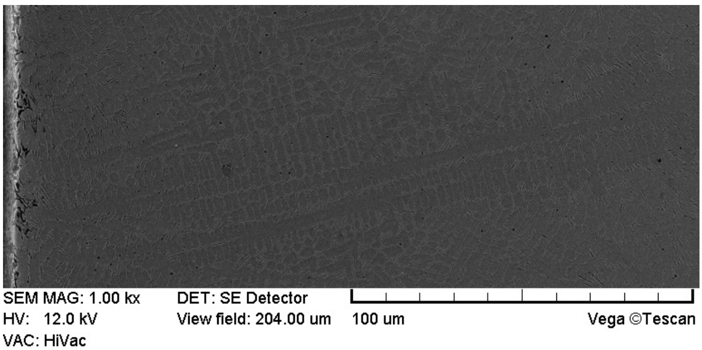

Fig. 10. The example the microstructure of laser alloyed layer of the coulter flap (scanning electron microscope, etched with nitric acid) in magnification of 1k

The existence of chromium and nickel in the alloying layer was confirmed using EDS method (Fig. 13). Implemented elements usually enriched solid solutions (PACZKOWSKA 2016b). But in case of laser alloying with Cr, $(Fe,Cr)_3C$ phase was observed in the research (JANICKI 2020). Detection of light elements is not easy by EDS. So results of boron concentration are not presented. Nevertheless, as was observed, in case of boron alloying, iron borides (Fig. 14) are was formed. Such morphology of iron borides is typical in case of laser alloying and has been already noticed (PACZKOWSKA et al. 2010, PACZKOWSKA 2008). It is different than in case of diffusive treatment. Such borides has been identified in the previous research by X-ray diffraction and boron was detected by Auger Electron Specstroscopy.

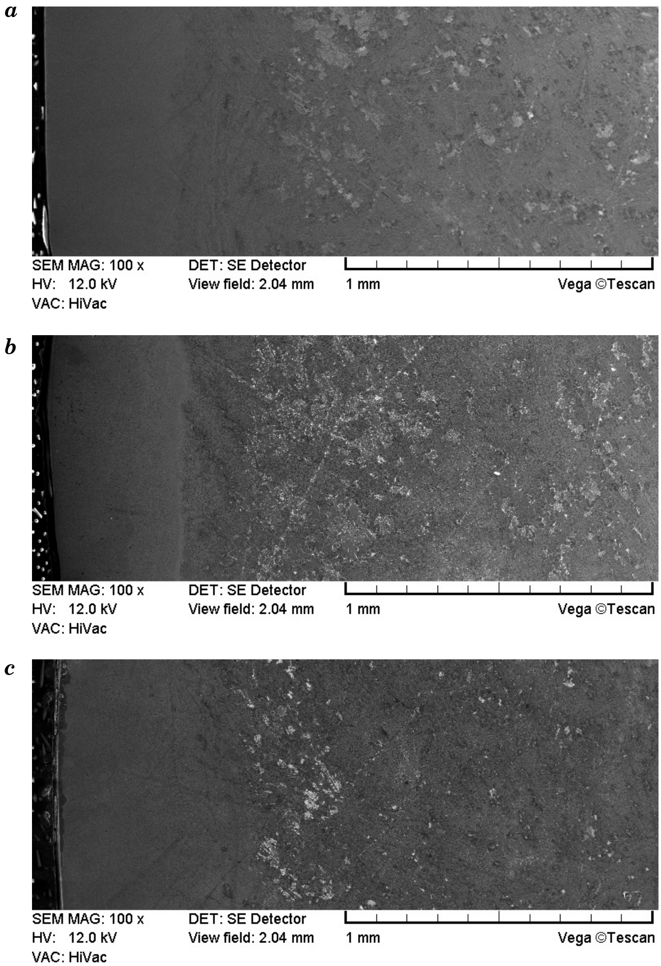

Fig. 11. The example of microstructure of the surface layer after laser alloying with: Cr (*a*), Cr+Ni+B (*b*) and Ni+B (*c*) (scanning electron microscope, etched with nitric acid)

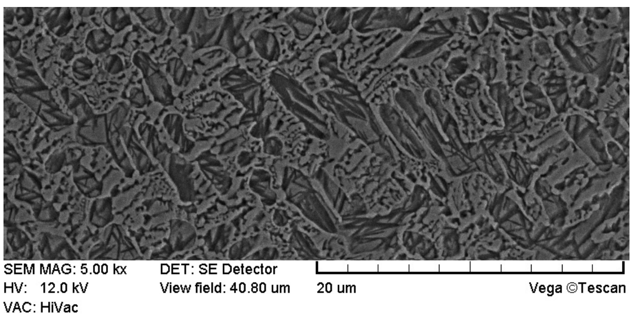

Fig. 12. The example the microstructure of laser alloyed layer of the coulter flap (scanning electron microscope, etched with nitric acid) in magnification of 5k

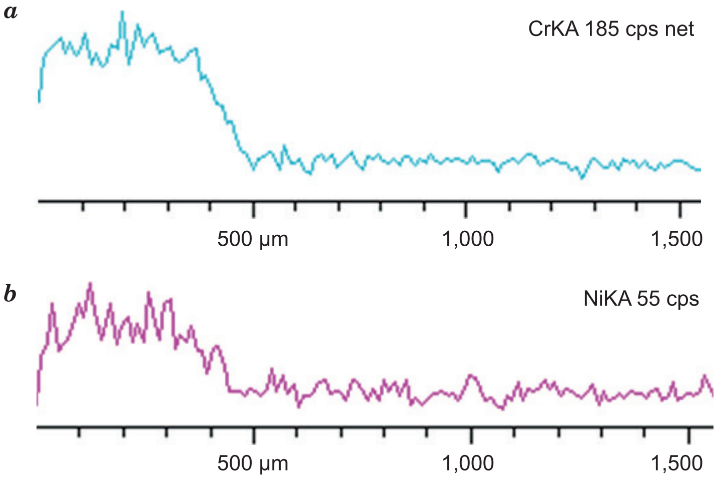

Fig. 13. The examples of distributions of chromium (*a*) and nickel (*b*) on the section from the surface to the core material achieved with an EDS microanalyzer

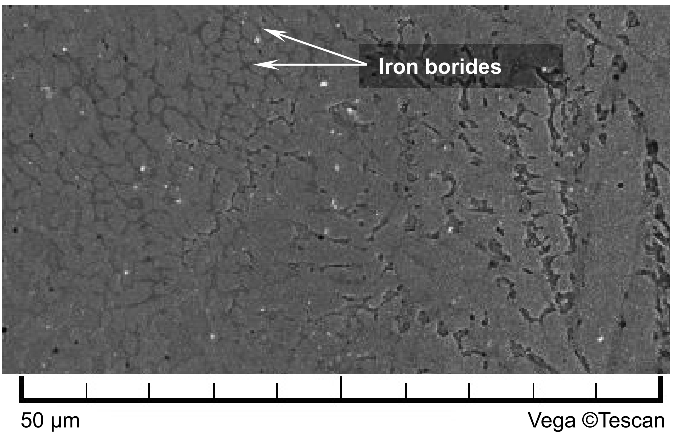

Fig. 14. Iron borides in the surface layer after laser alloying with Cr+Ni+B

A fine, mainly martensitic microstructure of the created layer, additionally enriched with alloyed elements increased the hardness in comparison to the hardness of untreated flaps with a white cast iron microstructure in the surface layer (the base). The comparison of hardnesses of surface layer is presented in the Figure 15.

The addition of chromium allowed to achieve hardness of nearly 800 HV0.1, in case of addition of nickel, chromium and boron of approx. 1200 HV0.1 and boron with nikiel of approx. 1100 HV0.1. After laser alloying with chromium and molibdenium in the research presented (JANICKI 2020) the hardness was approx. 600 HV0.2. The maximum hardness of 1200 HV_{100} was achieved in the surface layer of grey cast iron after laser alloying but with WC in the research (FELDSHTEIN at al. 2023), maximum hardness of 1300 HV_{100} was obtained but with SiC. Approx. 700 HV0.2 of hardness was achieved in the surface layer after laser alloying with titanium (LONT et al. 2022).

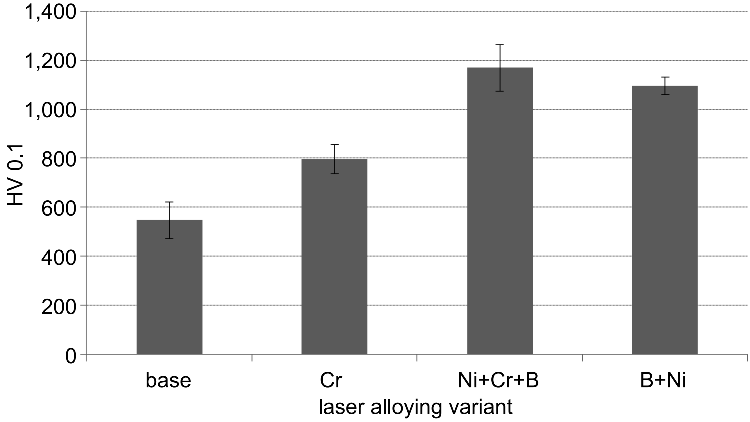

Fig. 15. The average values of surface layers hardness of the coultre flaps without and with laser alloying

Conclusion

The carried out investigation allows to state, that it is possible to increase the wear resistance of grey iron machine parts for example exposed to intensive abrasion by applying of laser alloying of surface layer with implementation of elements such as Cr, Cr+Ni+B and Ni+B.

As a result of perfomed laser treatment the modified surface layer (consisting of fine grains of mainly martensite enriched with alloy elements) appeared. The depth of this layer did not exceed 0.5 mm. It was characterized by high hardness. A hardness of the layer only with chromium was nearly 800HV0.1, in case of addition of nickel, chromium and boron of approx. 1200 HV0.1 and boron with nikiel of approx. 1100 HV0.1.

Laser alloying caused reduction of roughness parameters of the treated surface in comparison to the base surface.

Even 85% decrease of mass loss of coulter flap with alloyed layer (with nickel and boron) after wear test in comparison to mass loss of flap without laser treatment was achieved. In case of alloying with chromium it was 44% and in case of nickel, boron and chromium this decrease was 58%.

The reduction of mass loss after laser alloying has been achieved in under laboratory testing conditions. It could be stated, that such treatment (even concerning a very small area) can reduce wear of machine parts exposed to intensive friction like agriculture parts in soil. Further verification of the results should consist in field tests of coulters treated in this way.

By laser alloying is possible to reduce the costs related with replacing of worn machine parts (like costs of new parts or regeneration process, men-hours costs and downtime costs).

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