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The effect on wear resistance of laser alloying with chromium and titanium of grey iron parts

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The aim of the presented study is to evaluate the influence of laser alloying with chromium and titanium on the surface layer microstructure and abrasive wear resistance of grey iron parts. A coulter flap was chosen as the object of this investigation. To produce the alloyed layer on the area of the flap that is the most exposed to wear, a diode laser was used as the heat source. The investigation demonstrated that laser alloying with chromium and titanium can increase the wear resistance of components working in abrasive conditions. A smaller mass loss after the wear tests in abrasive conditions of soil could be expected. The laser alloyed layer (with a depth of approx. 400 µm) was characterized by a martensite microstructure (mainly), homogenous morphology and fine grains. A fivefold increase in hardness (approximately 1050HV) in comparison to the hardness of the base material and twofold in comparison to the original ledeburitic surface layer of the coulter flap was noted. Some changes after laser alloying in the surface stereometry were observed (a decrease in the roughness parameters is possible). The roughness parameter values after the wear test decreased in the case of the original and alloyed coulter flaps..

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1. Introduction

Nowadays, development in the agricultural industry requires increasingly more modern materials as well as the surface treatment of agricultural machine parts. It especially concerns parts working in a soil medium [1-7]. Many of those parts are made of cast irons, like coulter flaps, which are exposed to intensive abrasive wear.

One of the methods that allows one to change the microstructure of the surface layer and improve the wear properties is laser alloying. Most of the information about laser alloying with different elements refers to steel than cast irons. This method has been already used for a few decades but is constantly being expanded, and new findings, especially for cast irons, are presented, like the difference in the dependence of the surface layer thermal effects on the laser treatment parameters in the case of cast irons than in the case of steels [8]. This treatment depends on laser heating causing melting of the thin layer of the surface of the treated part and allowing a particular element or elements to be introduced into the liquid zone. After laser alloying, a very fine martensite microstructure enriched with the alloying elements is formed. Such a microstructure is usually characterized by high hardness and good wear resistance, and sometimes also corrosion resistance.

For instance, in the case of cast iron parts, growth in the surface layer hardness (sixfold) could be

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obtained as a result of laser alloying with boron [9], which enabled an increase in the wear resistance (approx. a 3.5-fold reduction in mass loss after the wear tests) in comparison to parts after treatment involving only through-hardening [10].

Effective surface layer modification could be performed by laser alloying using various elements. To increase the corrosion resistance, besides boron, also chromium or copper could be applied [4, 9-14]. Those elements also efficiently increase the hardness of the surface layer in the case of grey irons. Especially chromium is an element commonly used to improve hardness and corrosion resistance. For example, this element is often employed to modify the surface layer of piston rings, which are especially exposed to friction wear and higher temperatures. Chromium is a widely used element in various types of surface modifications. For example some information about laser alloying with chromium of cast iron can be found in [11, 12, 15]. Works [10, 11] reported that the laser alloying of cast iron with chromium creates chromium carbides and significantly raises the hardness of the surface layer. A fourfold increase in hardness was noted after laser alloying with chromium of grey iron [11, 15]. Nevertheless, the wear tests in [10] revealed that the hard chromium carbides obtained in the remelted zone resulted in increased mass loss of the cast iron samples treated in this way. Thus, probably too much chromium or an incorrect selection of the laser parameters could cause the creation of an unsuitable microstructure that should raise the wear resistance. For example, a faster cooling rate during laser treatment (controlled by the laser beam power density and interaction time as was demonstrated in [9]) could consolidate the elements in the solid solution.

To intensify the strength effect in the surface layer, other elements could be also added. Such an element could be titanium. For example, titanium was added to nodular iron during laser alloying in the research presented in [16, 17]. A nearly threefold increment in the hardness of the surface layer was noted. Fourfold growth in hardness after titanium incorporation into nodular iron was noticed in the author's previous own research [18] although XRD did not indicate TiC in the surface layer. Near the surface, locally, only TiN or Ti(N,C) were visible in the microstructure as a result of interaction with nitrogen from the atmosfere. It seems that it is worth examining the influence of a Cr+Ti mixture during laser alloying on the surface layer of gray iron and its possibilities of increasing wear resistance.

Therefore, the aim of the presented study is to evaluate the influence of laser alloying with chromium and titanium on the surface layer microstructure and abrasive wear resistance of grey iron parts.

2. Methodology

The treatment was performed on agriculture parts made of grey iron with a flake graphite and ferrite-pearlite matrix with an average hardness of 205 HB. The chemical composition was as follows: 3.04 wt% C, 2.58 wt% Si, 0.42 wt% Mn, 0.07 wt% Cu, 0.07 wt% Cr, 0.02 wt% Ni, 0.005 wt% Mo, 0.11 wt% S, and 0.068 wt% P.

This agriculture part was a coulter flap, which works in a soil environment; thus, it is exposed to intense abrasive wear. It is commonly cooled to create a ledeburitic microstructure in the surface layer and improve the wear resistance. An example of such a part is presented in Fig. 1. It is 235 mm long, 60 mm high and 18 mm thick. The total mass is over 1 kg. In Figure 2 the place where the flap is the most exposed to wear is indicated.

Fig. 1. Coulter flap

Fig. 2. Coulter flap fixed in agriculture machine with place most exposed to wear marked.

Surface alloying was performed only on the coulter flap in a small area which is exposed to wear the most. The treatment consisted in covering the surface with a coat prepared of chromium and titanium in the composition of 50/50 and water glass. C The chromium as well as titanium was in the form of powder with a particle size of 325 mesh and 99.0% of purity. Those elements were chosen as the alloying elements for laser remelting also because of their ability to enrich the remelting zone during this treatment, which was confirmed during previous research [18, 19] by EDS and AES analysis. After covering the surface, heating using a laser beam was conducted with a diode laser. The laser beam was 900 W and the achieved spot on the treated surface was 1.2 mm. The laser beam velocity was 1100 mm/min.

The wear investigation was carried out in specially designed tester (called a "rotating bowl") dedicated to parts working in sandy medium and replicating their working conditions in the aspect of abrasive friction, moisture and others. By means of a holding arm, the flap is positioned in the bowl (with a diameter of 1.6 m). The bowl is filled with an appropriate abrasive material; in this test silica sand (grain fraction at 0.2–0.3 mm, hardness approx. 995HV) was used. The sand was selected in accordance with the PN-EN 933-1:2001 standard. The morphology of the grains (and the degree of reeling) accorded the requirements of features characteristic of the soil. The medium was flushed and also sieve analysis was performed (according to the PN-EN 933-4:2008 standard) to obtain the appropriate fraction, as well as to eliminate dust or organic pollutants. Less than 3% pollutantwas achieved. On the other hand, the moisture content was approx. 10% dry weight (it was determined by measuring the weight of the solid phase dried at 105 °C).

The conditions in this tester imitate operations during seeding. Of course, it is not a reflection of the real conditions of working but it is enough to perform comparison research. Nevertheless, the advantage of such laboratory research is the possibility of ensuring the same conditions throughout the entire test, which is not possible in the case of field research. This kind of tester was also used, for example, in studies [10,21]. Five coulter flaps were laser alloyed and 5 were untreated. This number of samples is typically used in wear evaluation. The flaps were placed on the special holding arm and put in to the rotating bowl with the friction medium. All the samples moved a distance reflecting seeding on a field of 35 hectares.

The samples were weighed before and after the friction test. Hence, the mass loss was evaluated. Furthermore, a Zeiss contact profilometer was utilized to estimate the condition of the surface before and after laser alloying and the friction test. To analyze the microstructure of the surface layer, a MIRA3 Tescan scanning electron microscope was employed. The Vickers method (with 100 g load) using a Zwick 3212 tester was applied for the hardness evaluation.

3. Results and discussion

After laser alloying, the modified surface layer was noted in all the coulter flaps. An example of a treated flap is presented in Fig. 3.

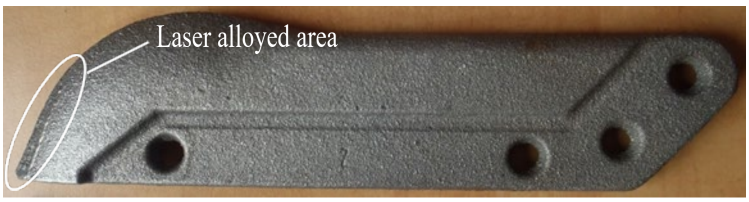

Fig. 3. Coulter flap after laser alloying with modified area marked

The alloyed area was formed only on the place of the coulter flap which is the most exposed to wear; therefore, it is relatively small in comparison to the dimensions of the whole part. The modified layer was detected during microscopic observations (Fig. 4).

The depth of the layer was approximately 400 μm. In Figure 4a the alloyed layer with the base material is visible. A very fine and homogenous microstructure of the alloyed layer can be seen (especially in comparison to the coarse-grained ledeburitic microstructure of the original surface layer of the coulter flaps (Fig. 5).

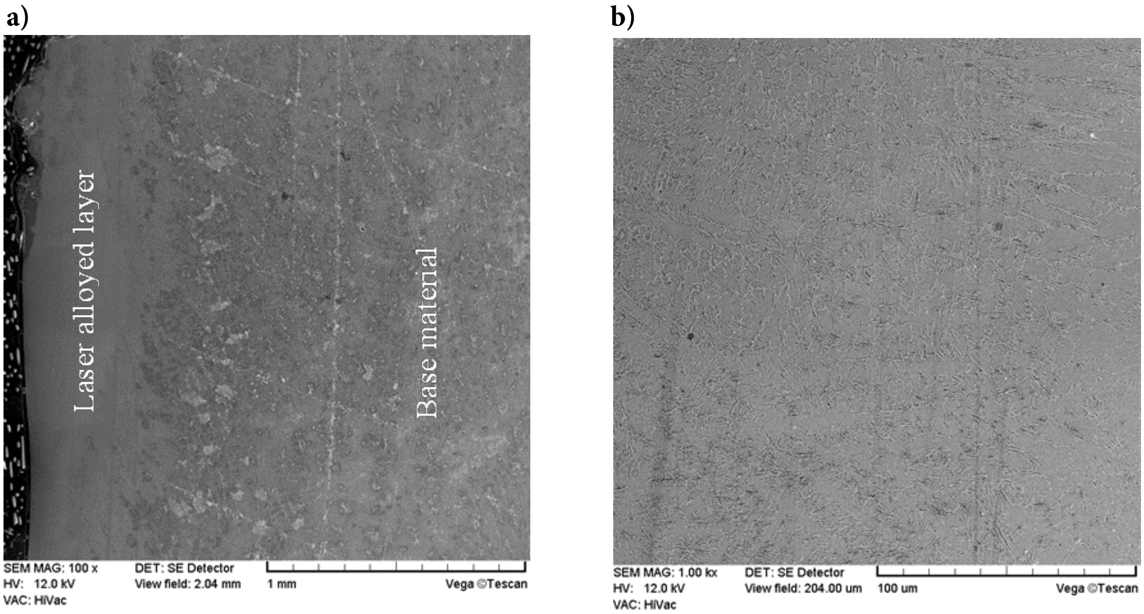

Fig. 4. Microstructure of laser alloyed layer of flake iron at various magnifications: a) 100 x, b)1000 x. SEM, etched with nitric acid

At higher magnifications – Fig. 6 a and b, a dendritic microstructure with martensite needles and retained austenite can be observed in the alloyed layer. The microscopic observation did not reveal chromium or titanium carbides. This suggests that the alloying elements saturated the solid solutions as a result of the high cooling rate during solidification.

The morphology of the microstructure is typical for this kind of laser modification with remelting. During solidification of the liquid zone, austenite dendrites form first as in the case of crystallization of hypoeutectic white cast iron. The next step of cooling is hardening. Consequently, the dendrites finally contain martensite needles and retained austenite.

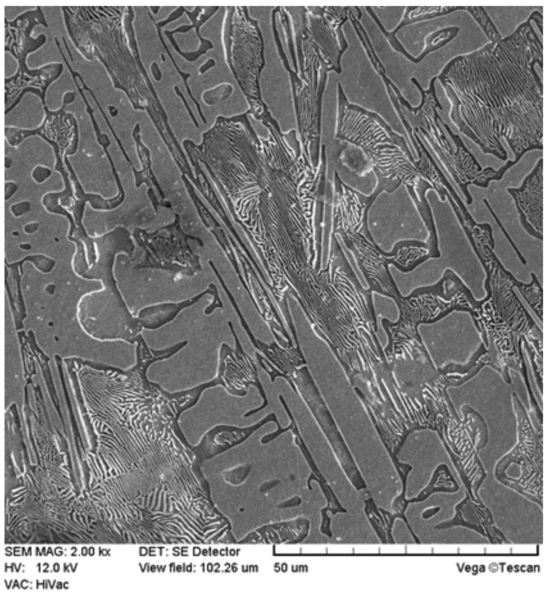

Fig. 5. Microstructure of surface layer of original coulter flap, SEM, etched with nitric acid

a) **b)**

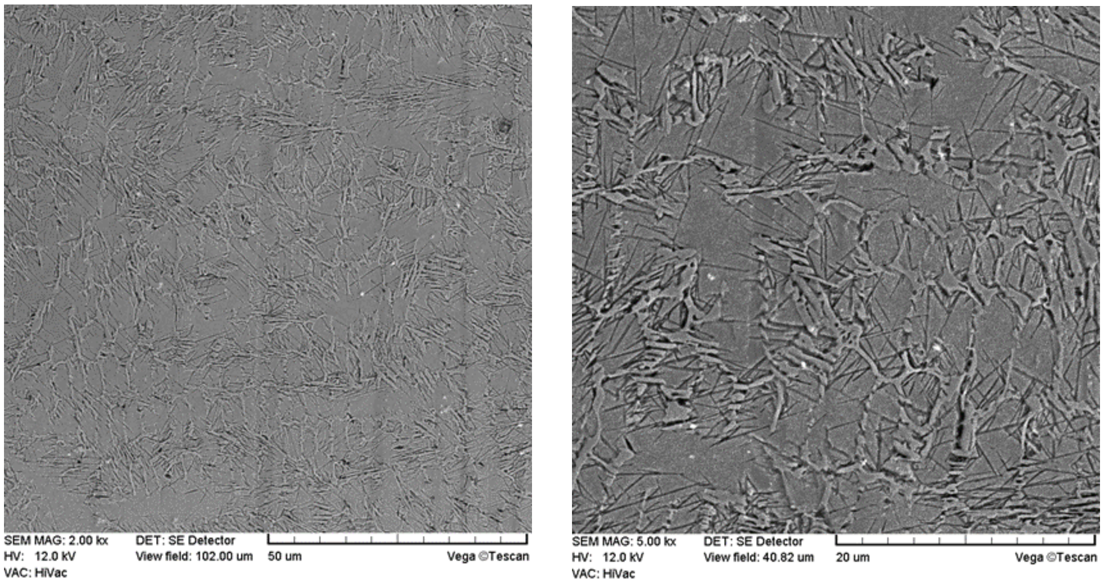

Fig. 6. Microstructure of laser alloyed layer of flake iron at various magnifications: a) 2000 x, b) 5000 x. SEM, etched with nitric acid

A 5.5-fold increase (approximately 1050 HV) in the surface layer hardness was noted as a result of laser alloying in comparison to the hardness of the base material and twofold in comparison to the original ledeburitic surface layer of the coulter flap (Fig. 7). No areas with a more increased hardness (with a value over the average hardness that was noted in the alloyed zone) that could suggest the formation of chromium or titanium carbides were observed in the alloyed zone. That corresponds to the lack of carbides observed during the microstructural tests. Furthermore, in work [18] the XRD analysis did not reveal carbides after laser alloying.

It is also worth mentioning that a quite high increase in hardness (as a result of the high cooling rate and the formation of metastable solid solutions saturated with the alloying elements) was achieved in the presented research. For instance, as result of laser alloying with titanium only, the hardness only increased to approximately 700 HV in the case of ductile iron [16]. On the other hand, after laser alloying chromium-coated nodular iron, the hardness increased to 550-900 HV according to the results presented in [13].

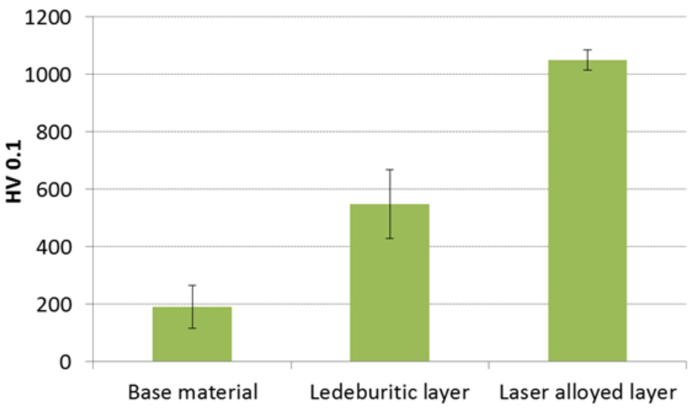

Fig. 7. Vickers hardness of layers after laser alloying with chromium and titanium in comparison to hardness of original coulter flap

The surface stereometry did not change much as a result of the laser alloying (Fig. 8). The arithmetic average roughness Ra roughness parameter was approximately 10 μm before and after laser alloying with chromium and titanium (Fig. 9). After laser alloying of the flap, the surface was quite rough with a wide scatter of the roughness parameters.

Fig. 8.1. Example of surface profile of original surface of flap

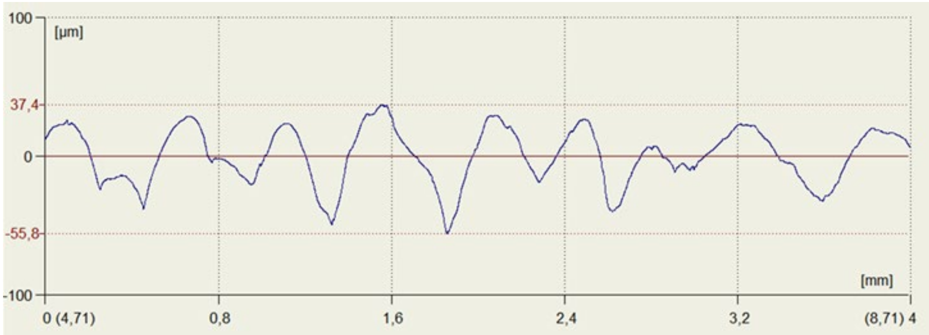

Fig. 8.2. Example of surface profile of original surface of laser alloyed flap

The wear test showed that a reduction in the coulter flap mass loss during work in abrasive conditions of soil could be expected when laser alloying with chromium and titanium is applied (Fig. 10). The influence of laser alloying with those elements on the decrease in mass loss is expected because of the lower average mass loss of about 35% that was noted in the flaps after the treatment than the average mass loss of the flaps without it. Confirmation of this conclusion in the next step of research should be achieved with more repetitions of the test to allow smaller values to be obtained of half-confidence intervals.

Examples of coulter flaps with and without laser treatment after the wear test are presented in Figure 11. Less surface roughness was visible in both cases in comparison to the surface before wear tests.

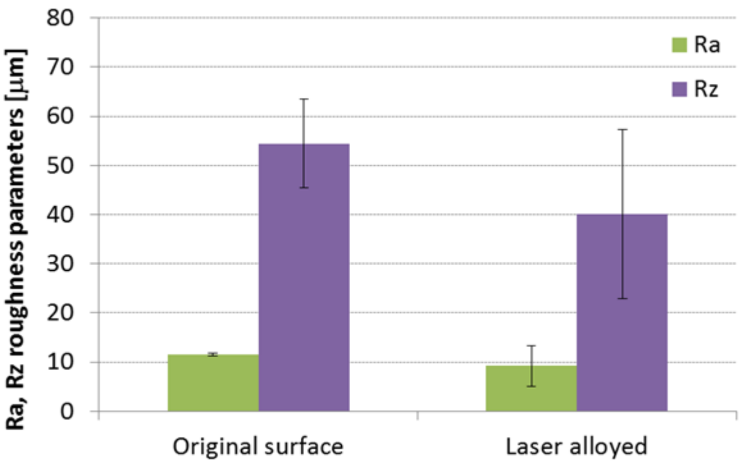

Fig. 9. Roughness parameter values (arithmetic average roughness Ra and mean roughness depth Rz) before and after laser alloying of coulter flaps

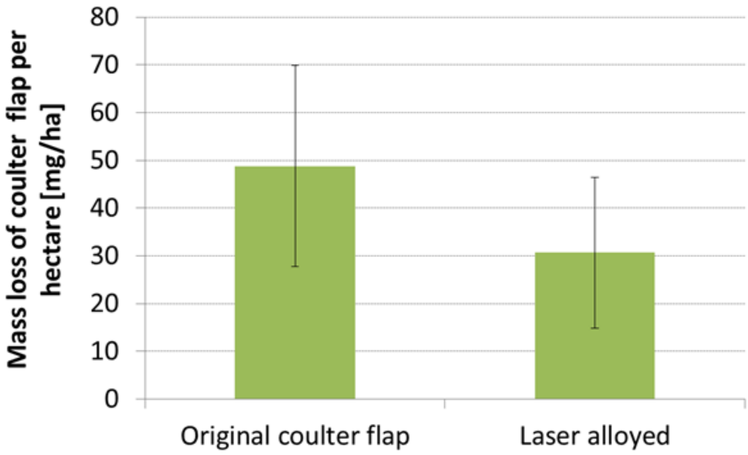

Fig. 10. Mean mass loss counted per hectare of original coulter flaps and alloyed after wear test

a)

Fig. 11.1. Original coulter flap after wear test

b)

Fig. 11.2. Laser alloyed coulter flap after wear test

The profiles of the surface confirmed less roughness (Fig. 12). The roughness parameters after the wear test decreased for the original and the alloyed coulter flaps as well (Fig. 13). The arithmetic average roughness Ra and the mean roughness depth Rz of the original coulter flaps were reduced by about 50%, and of the alloyed coulter flaps they were reduced by over 20% (Figs. 9 and 13). Those changes were less in the case of the treated coulter flaps, probably owing to the much higher hardness than in the case of the original flaps.

a)

Fig. 12.1 Example of surface profile after wear tests of original surface of flap

b)

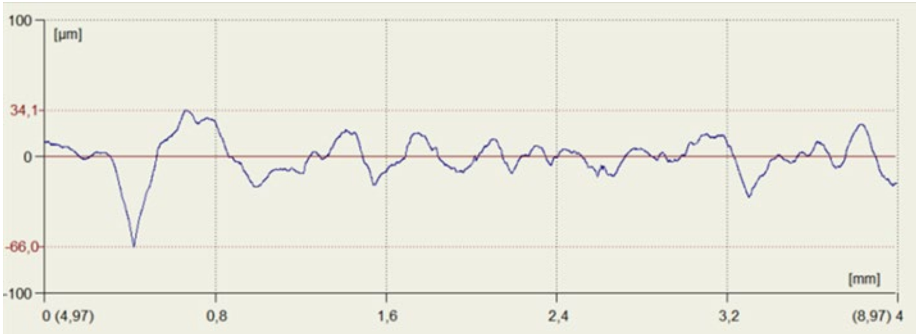

Fig. 12.2. Example of surface profile after wear tests of laser alloyed surface of flap

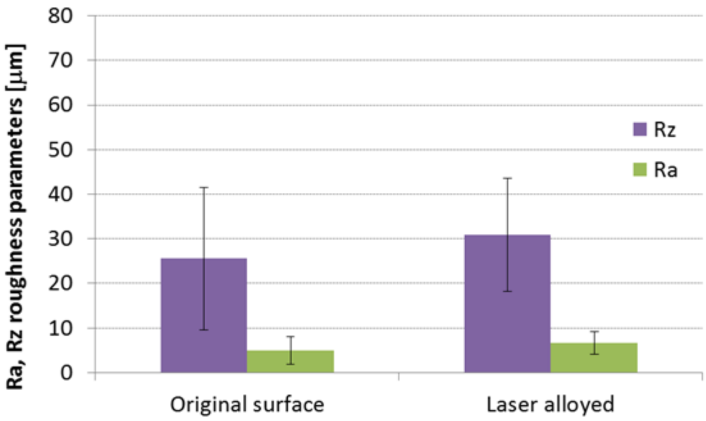

Fig. 13. Roughness parameters (arithmetic average roughness Ra and mean roughness depth Rz) after wear test for original and alloyed coulter flaps

5. Conclusions

Taking in to account the fact that the aim of the presented study was to evaluate the influence of laser alloying with chromium and titanium on the surface layer microstructure and abrasive wear resistance of grey iron parts, it could be stated that the presented investigation allows us to conclude that laser alloying with those elements entirely changes the microstructure and may contribute to an increase in the wear resistance of components working in abrasive conditions.

The following main conclusions can be drawn:

– It is possible to achieve a modified surface layer in a coulter flap made of grey iron as a result of laser alloying layer with chromium and titanium.
– The laser alloyed layer (with a depth of approx. 400 μm) is characterized by homogenous morphology and fine grains in comparison to the coarse grained microstructure of the base material. Analysis of the alloyed layer using a higher magnification revealed a dendritic microstructure with martensite needles and retained austenite.
– As a result of laser alloying with chromium and titanium, a fivefold increase in hardness (approx. 1050 HV) in comparison to the hardness of the base material and twofold in comparison to the original ledeburitic surface layer of the coulter flap was noted.
– The mean mass loss of the laser alloyed flaps was lower by about 35% after the wear tests than the flaps without this treatment. Thus, higher abrasive wear resistance of the flaps after laser alloying with chromium and titanium could be expected in comparison to the untreated flaps.
– After laser alloying the mean values of the surface roughness parameters decreased.
– The roughness parameter values after the wear test decreased in the case of the original and alloyed surfaces of the coulter flaps.

The presented research demonstrated that it is possible to perform laser alloying with such a mixture as chromium and titanium of grey iron. It was proved that it is possible to achieve an appropriate microstructure and hardness of the surface layer in this way. It was also shown that higher wear resistance could be expected when such treatment is applied.

It is significant that even a relatively small area of such modification could result in increasing the wear resistance of such parts as a coulter flap made of grey iron. It is due to the specific microstructure that appears in the case of laser alloying – it is especially related to homogenization and the formation of fine grains.

Such treatment should contribute to cost reductions related to the purchase of new parts and downtimes that are necessary for replacement.

Nevertheless, it needs to be underlined that performing five repetitions did not allow small enough values of half-confidence intervals to be obtained in the case of the wear tests results. It also should be taken into account that laboratory wear tests do not reflect the real exploitation conditions of machine parts, where many other factors can influence their wear and even damage the parts.

In the next step of the research, performing a greater number of wear tests should confirm the expected positive influence of laser alloying with chromium and titanium of grey iron parts on their wear resistance.

Further research that is necessary to perform is field research and verification of the treatment effects in real conditions of usage.

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