Aneta BARTKOWSKA[1], **Aleksandra PERTEK-OWSIANNA**[1], **Dariusz BARTKOWSKI**[1], **Mikołaj POPŁAWSKI**[1], **Damian PRZESTACKI**[2]
[1] Instytut Inżynierii Materiałowej
[2] Instytut Technologii Mechanicznej

Politechnika Poznańska
pl. M. Skłodowskiej-Curie 5, 60-965 Poznań, Poland
e-mail: aneta.bartkowska@put.poznan.pl

WEAR AND CORROSION RESISTANCE OF C45 STEEL LASER ALLOYED WITH BORON AND SILICON

Summary

The paper presents the results of studies on microstructure, microhardness, wear and corrosion resistance of C45 steel laser alloyed with boron end silicon. The aim of laser alloying was to cover the steel with the modifying element and then melting it with a laser beam. As a result of laser alloying a layer was obtained that was composed of remelted zone enriched in modifying elements and of heat affected zone. It was found that as a result of laser alloying with boron and silicon layer are formed that are characterized by good corrosion and wear resistance, high microhardness compared to laser boronized and laser siliconized layers.
Key words*: laser alloying, boronizing, siliconizing, borosiliconizing, microstructure, microhardness, wear resistance, corrosion resistance*

ODPORNOŚĆ NA ZUŻYCIE PRZEZ TARCIE I KOROZJĘ STALI C45 STOPOWANEJ LASEROWO BOREM I KRZEMEM

Streszczenie

W pracy przedstawiono wyniki mikrostruktury, mikrotwardości, odporności na zużycie przez tarcie i odporności korozyjnej stali C45 laserowo stopowanej borem i krzemem. Laserowe stopowanie polegało na nałożeniu pokrycia z pierwiastkiem modyfikującym, a następnie przetopieniu go wiązką laserową. W wyniku laserowego stopowania uzyskano warstwę złożoną z strefy przetopionej wzbogaconej w pierwiastek modyfikujący oraz strefy wpływu ciepła. Stwierdzono, że w wyniku laserowego stopowania borem i krzemem powstają warstwy, które charakteryzują się dobrą odpornością na korozję oraz na zużycie przez tarcie, dużą mikrotwardością w stosunku do warstw borowanych laserowo czy krzemowanych laserowo.
Słowa kluczowe*: laserowe stopowanie, borowanie, krzemowanie, borokrzemowanie, mikrostruktura, mikrotwardość, odporność na zużycie przez tarcie, odporność korozyjna*

1. Introduction

Surface technologies such as diffusion boronizing [15, 16], laser heat treatment by using elements (e.g. B, C, N, Si, Cr, Ni, Cu) [2, 3, 6, 7, 8, 9, 11, 12, 15, 17, 18, 21, 22, 23], intermetallic phases [10] or ceramic powder [5] enable shaping of materials, giving them new properties, like increased durability and reliability. Modification of boronized layers has been discussed in numerous publications [1 – 3, 7, 13 – 16]. The effect of various methods of boronized layer modification with elements such as Si [13, 14 ,16], Ni [2, 16], N [16, 21], C [7, 16], Cu [1, 16], Cr [3, 16] is analyzed.

Lasers are increasingly being used in surface engineering. As a result of laser heat treatment different metal alloys such as Fe, Ni, Nb, Cr, W can be modified [2-12, 15, 17, 18, 21, 22, 23]. Adequate selection of alloy additives and process parameters enables to obtain surface layers with properties comparable to high alloy steels [8, 18]. High temperature gradient at the border of the melted surface layer with a cold substrate leads to a rapid cooling of the material and its solidification. As a consequence, the fine crystalline microstructure, highly supersaturated with the selected element is obtained. Thermo-chemical treatment using a laser beam is advantageous because it results in good microhardness, high wear resistance and good corrosion resistance [2-12, 15, 17, 21, 22, 23].

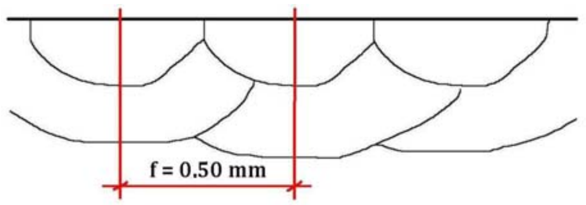
The microstructure of mild carbon steel after laser alloying with SiC is described in paper [22]. The macrostructure of the alloyed layer composed of three zones. The first zone consisted of crystals growing epitaxially on the partially remelted matrix grains, the second zone had only columnar crystals, and the third zone consisted of mixed (dendritic/acicular) crystals at the subsurface. The martensitic structure in the last zone varied in the needle size. They formed during the later stages of the martensitic transformation were much thinner.

2. Research methodology

The aim of the study was to evaluate the impact of laser alloying with boron and silicon on the basis of changes in microstructure, microhardness profiles, wear and corrosion resistance. The results of the study of laser alloying were compared with a typical diffusion boriding process.

C45 steel was used for investigations. The tests were carried out on C45 steel with the following chemical composition: 0.42% C, 0.72% Mn, 0.19% Si, 0.030% S, 0.008% P. The samples were ring-shaped of about 20 mm external diameter, 12 mm internal diameter and 12 mm high.

Laser alloying was carried out using TRUMPF TLF 2600 Turbo CO_2 laser of nominal power of 2.6 kW. Parameters used in the experiment were: laser beam power P = 1.04 kW, laser beam radiation density q = 33.12 kW/cm^2, scanning laser beam velocity v = 2.88 m/min, laser beam diameter d = 2 mm. Laser tracks were arranged as multiple tracks with distance f = 0.5 mm (Fig. 1), where f was distance between axes of adjacent tracks.



Source: Own work / Źródło: opracowanie własne

Fig. 1. Distribution scheme of the laser tracks
Rys. 1. Schemat rozłożenia ścieżek laserowych

Prior to laser heat treatment (LHT) the specimens were hardened in water from 850°C and tempered at 570°C for 1h. The scheme of layers production using laser alloying boron paste, silicon paste or boron and silicon paste method is presented in Fig. 2. The process of production of layers was composed of heat treatment (Step 1), paste application (Step 2) and laser modification (Step 3).

Microstructure tests were performed using an optical microscope Metaval Carl Zeiss Jena with a camera 2300 3.0 MP and Live Motic Images Plus 2.0 Resolution software.

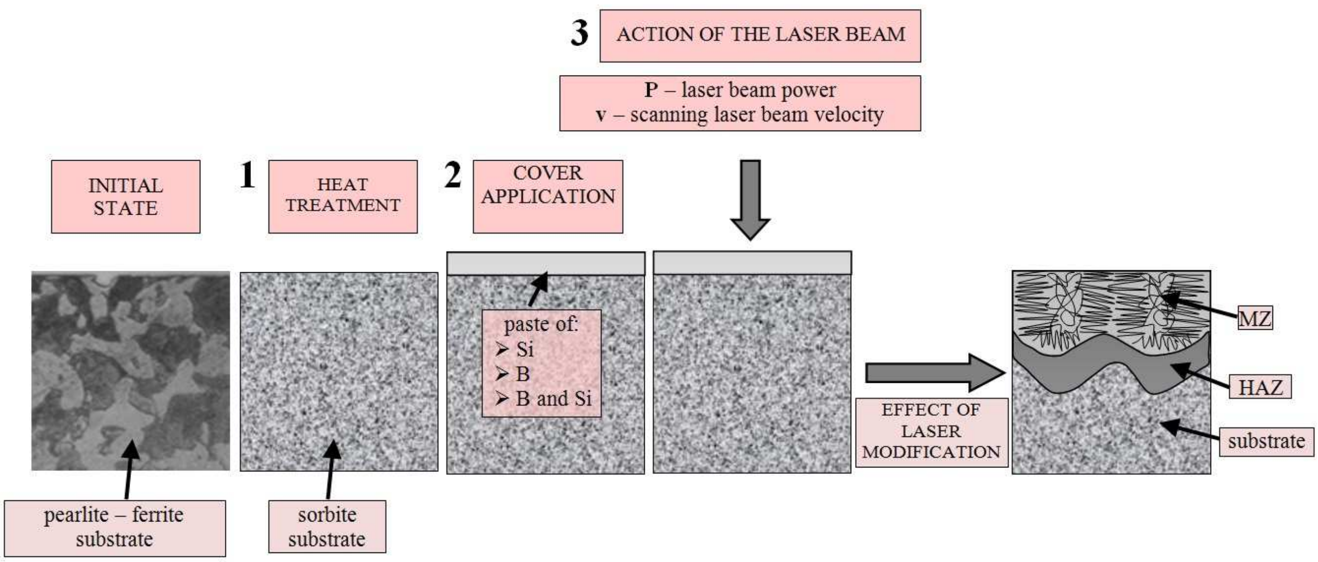
Metallographic observations of the microstructure were conducted on polished and etched cross-sections of the samples in a solution 2% HNO_3. To determine microhardness profiles a ZWICK 3212 B Vickers hardness tester was used with indentation load of 100 G (HV0,1). The studies were carried out according to standard PN-EN ISO 6507–1 [25].

Wear resistance tests were carried out with tribometer MBT-01 type Amsler [24]. A ring as specimen and sintered carbide plate S20S as counterspecimen were used to examine wear resistance. Wear resistance tests were carried out under the load F = 147 N and at specimen rotation speed of n = 250 rev/min, in dry friction conditions. Wear resistance was evaluated by specimen mass loss (Δm [mg]).

Corrosion resistance of laser modified layers was studied in a 5% solution of NaCl at temperature 22°C on the surface of 50 mm^2. The studies were performed on a potentiostat-galvanostat ATLAS 0531 EU & IA ATLAS SOLLICH. Auxiliary electrode was a platinum electrode, and the reference electrode was a calomel electrode. The test procedure and recording of the results were performed using AtlasCorr and AtlasLab computer programs. The polarization of the samples was carried out in the direction of the anode in the range of potentials from -1.5 to 1.5 V. The study was conducted at a rate of change in potential of 0.5 mV/min. Based on the analysis of current curves potentiodynamic corrosion and corrosion potential were determined. The corrosion resistance studies were carried out according to standard PN-EN ISO 17475 [26].

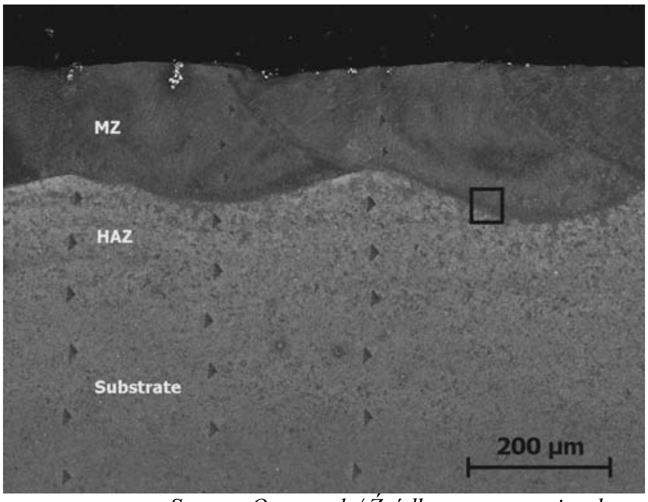
3. Results and discussion

Microstructure after laser alloying with silicon is shown in Figures 3, with boron in Figure 5 and with silicon and boron in Figure 7. Microstructure after laser modification consisted of three zones: remelted zone (MZ), heat affected zone (HAZ) and substrate (Fig. 3, 5, 7). Microstructure of the remelted zone was composed of solid solution or borides eutectic with martensite [4, 11]. Heat affected zone was composed of martensite needles. Figure 4 presents the microstructure of remelted zone which contained solid silicon solution with martensite. Figure 6 presents the microstructure of remelted zone of laser borided which contained eutectic borides with martensite. Microstructure of remelted zone after laser borosiliconized is presented in Figure 8 and which contained silicon borides eutectic with martensite. As a result of remelting of the layers laser track microstructure was composed of both surface layer material and substrate material. Fluctuations in the melting pool in boronickelized layers are clearly visible in Figure 5.



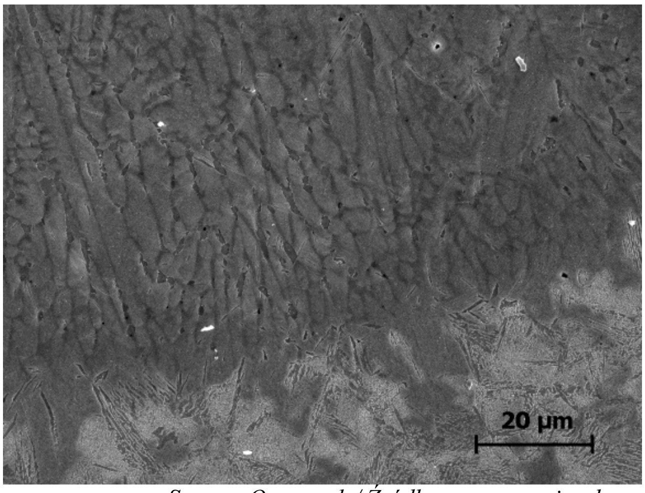
Source: Own work / Źródło: opracowanie własne

Fig. 2. Scheme of laser alloying with silicon, boron or boron and silicon
Rys. 2. Schemat laserowego stopowania borem, krzemem lub borem i krzemem



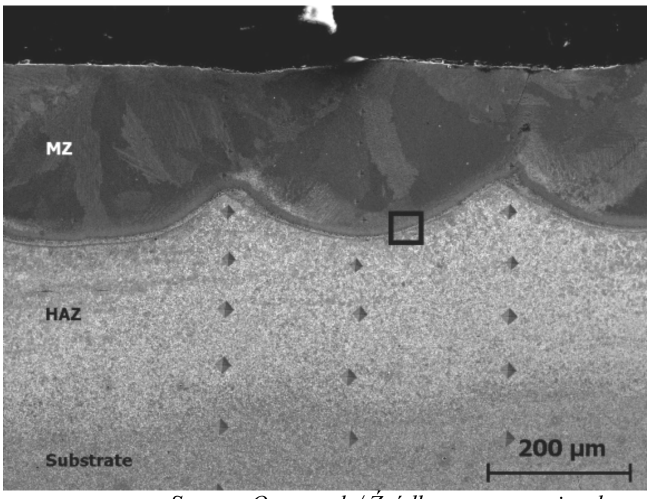
Source: Own work / Źródło: opracowanie własne

Fig. 3. Microstructure of laser siliconized layer
Rys. 3. Mikrostruktura warstwy laserowo krzemowanej



Source: Own work / Źródło: opracowanie własne

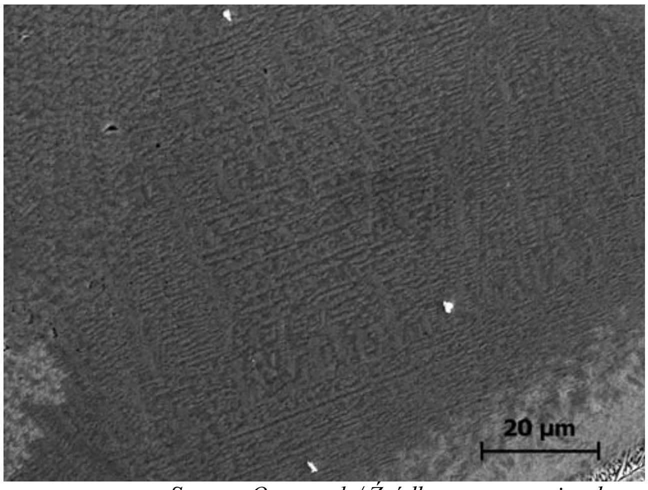
Fig. 4. Microstructure of laser siliconized layer
Rys. 4. Mikrostruktura warstwy laserowo krzemowanej



Source: Own work / Źródło: opracowanie własne

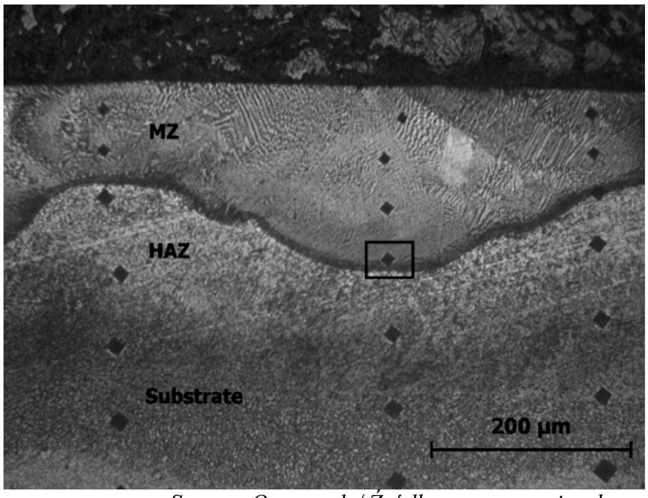
Fig. 5. Microstructure of laser borosiliconized layer
Rys. 5. Mikrostruktura warstwy laserowo borokrzemowanej

Results of microhardness tests of layers after laser alloying are shown in Figures 9, 10 and 11. Microhardness was tested along the axis and along the interface of laser tracks. The microhardness in the remelted zone of the laser siliconized layer was about 850 HV 0.1 (Fig. 9).



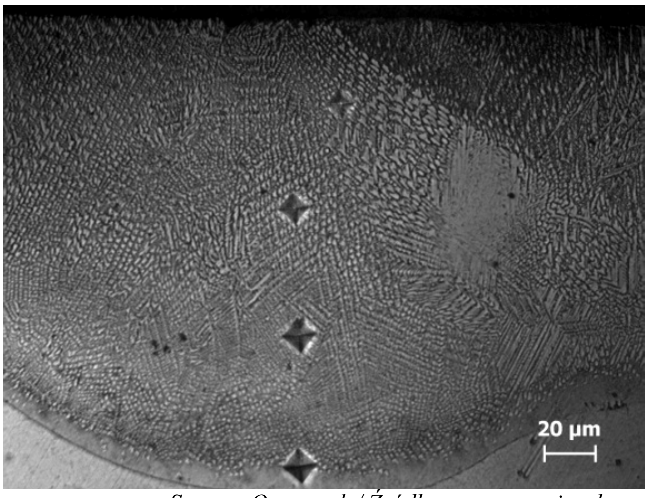
Source: Own work / Źródło: opracowanie własne

Fig. 6. Microstructure of laser borosiliconized layer
Rys. 6. Mikrostruktura warstwy laserowo borokrzemowanej



Source: Own work / Źródło: opracowanie własne

Fig. 7. Microstructure of laser boronized layer
Rys. 7. Mikrostruktura warstwy laserowo borowanej

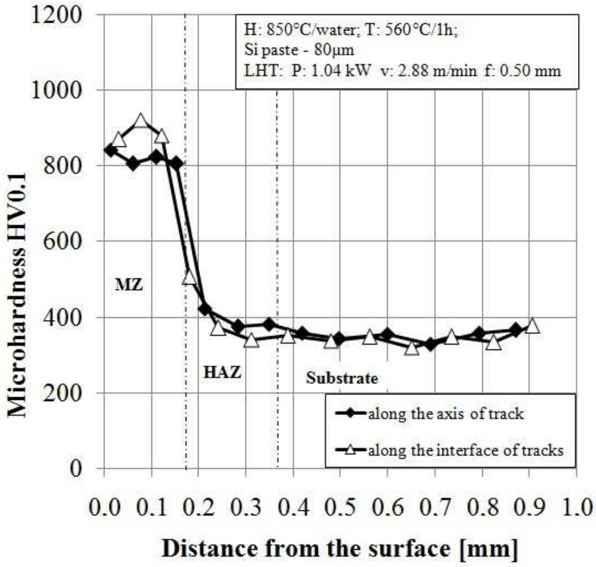


Source: Own work / Źródło: opracowanie własne

Fig. 8. Microstructure of laser boronized layer
Rys. 8. Mikrostruktura warstwy laserowo borowanej

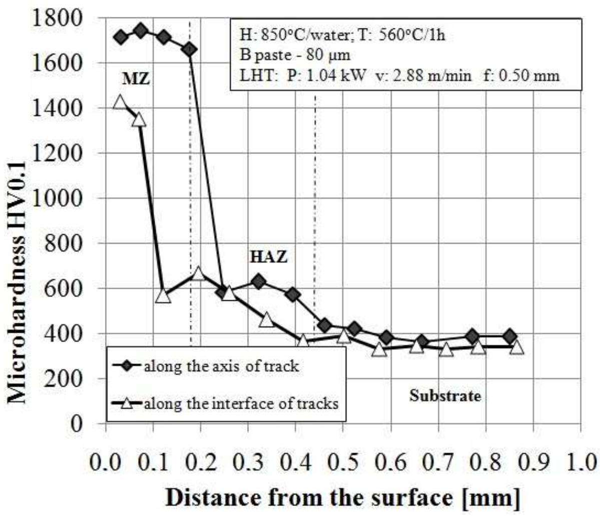
For laser boronized layer the microhardness in the remelted zone of approximately 1700-1400 HV0.1 was obtained (Fig. 10). Microhardness is different in the axis and at the interface of the laser tracks, in the remelted zone, which may be dependent on aggregated impacts of the laser beam and laser tracks distribution. The microhardness in remelted zone of laser borosiliconized layer was about 1800 HV 0.1 (Fig. 11). In all layers the microhardness in heat affected zone reached 600 - 400 HV0.1 and decreased towards the substrate - 350 HV0.1. The microhardness of the remelted zone had a milder gradient towards the substrate. Varying microhardness of the heat affected zone is probably due to the different thermal conductivity of applied element coatings.

Wear resistance of boronized and borosiliconized laser layer was compared. It was found that concomitant alloying of boron and silicon has a lower weight loss; thus higher resistance to frictional wear.



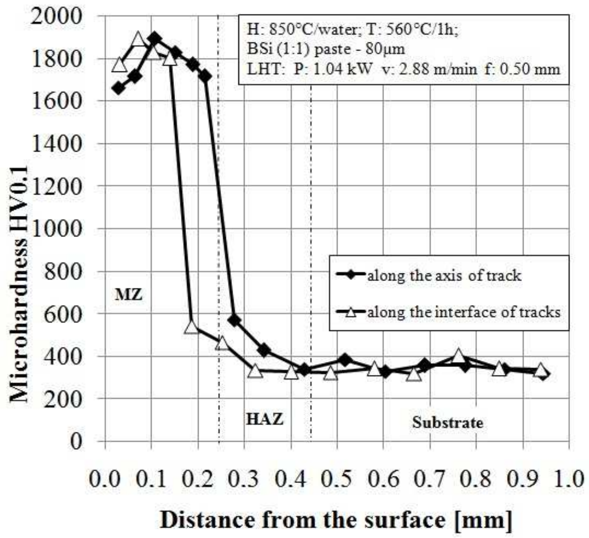
Source: Own work / Źródło: opracowanie własne

Fig. 9. Microhardness profiles of laser siliconized layer
Rys. 9. Profile mikrotwardości warstwy laserowo krzemowanej



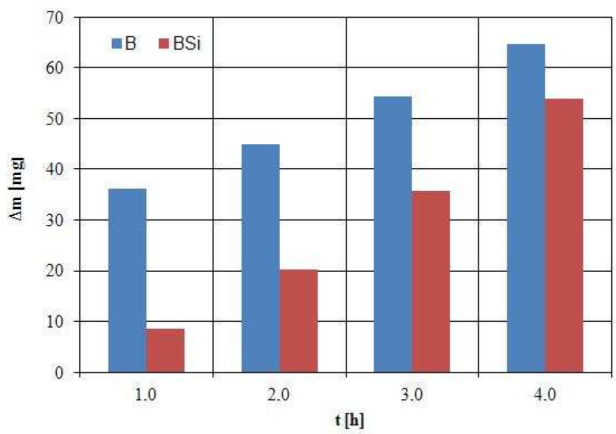
Source: Own work / Źródło: opracowanie własne

Fig. 10. Microhardness profiles of laser boronized layer
Rys. 10. Profile mikrotwardości warstwy laserowo borowanej



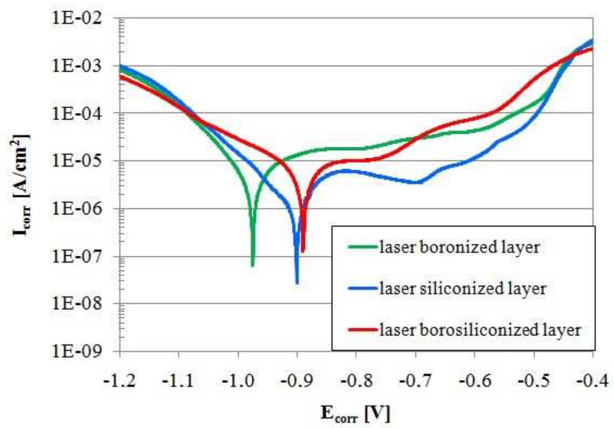
Source: Own work / Źródło: opracowanie własne

Fig. 11. Microhardness profiles of laser borosiliconized layer
Rys. 11. Profile mikrotwardości warstwy laserowo borokrzemowanej



Source: Own work / Źródło: opracowanie własne

Fig. 12. Wear resistance of laser alloyed layer
Rys. 12. Odporność na zużycie przez tarcie warstw laserowo stopowanych



Source: Own work / Źródło: opracowanie własne

Fig. 13. Corrosion resistance of laser alloyed layer compared to diffusion boronized layer
Rys. 13. Odporność korozyjna warstw laserowo stopowanych w porównaniu z warstwą borowaną dyfuzyjnie

As a result of laser alloying with boron and silicon corrosion resistance increases. The worst corrosion resistance was observed on boronized layers. Based on these studies it can be concluded that silicon improves corrosion resistance.

4. Conclusions

- The microstructure of layers after laser alloying with elements is composed of three areas: remelted zone, heat affected zone and the substrate.
- Microhardness measurements are characterized by a mild microhardness gradient from the surface into the material.
- Wear resistance and cohesion increase after laser alloying with boron and silicon.
- Corrosion resistance increases after laser alloying with boron and silicon.
- The surface layers formed as a result of laser alloying are characterized by lower energy consumption in the manufacturing process.
- After laser alloying the properties of C45 steel i.e. microhardness, wear and corrosion resistance increase.

5. References

[1] Bartkowska A., Pertek A.: Borocopperizing of C45 steel. Materiały konferencyjne - III International Interdisciplinary Technical Conference of Young Scientists, INTERTECH 2010, Poznań, Poland, 19-21 May 2010, s. 33-35.

[2] Bartkowska A., Pertek A.: Laser production of B-Ni complex layers. Surface & Coatings Technology vol. 248, 2014, s. 23-29.

[3] Bartkowska A., Pertek A., Jankowiak M., Jóźwiak K.: Laser surface modification of borochromizing C45 steel. Archives of Meatlurgy and Materials, 2012, vol 57, s. 211-214.

[4] Burakowski T., Wierzchoń T: Inżynieria powierzchni metali. Warszawa, 1995.

[5] Dobrzański L. A., Polok A., Jonda E., Bonek M.: Wpływ obróbki laserowej na zmiany właściwości warstw wierzchnich stali 55NiCrMoV7 stopowanych proszkami ceramicznymi. Inżynieria Materiałowa, 2006, nr 5, s. 924-927.

[6] Katsamas A. I., Haidemenopoulos G. N.: Laser-beam carburizing of low-alloy steels. Surface and Coatings Technology, 2001, 139, s. 183-191.

[7] Kulka M.: The gradient Boride Layers Formed by Borocarborizing and Laser Surface Modification. Rozprawy nr 428. Poznań: Wydawnictwo Politechniki Poznańskiej, 2009.

[8] Kusiński J.: Lasery w inżynierii materiałowej. Kraków: Wydawnictwo „Akapit", 2000.

[9] Lysenko A. B., Kozina N. N., Lysenko A. A.: On the Distribution of a Saturating Element in the Zone of Laser Siliconizing of Steels. The Physics of Metals and Metallography, 2006, Vol. 102, No. 6, pp. 619-625.

[10] Major B: Laserowa modyfikacja stali poprzez wprowadzenie węglików i borków. III Ogólnopolska Konferencja Obróbka powierzchniowa, Częstochowa-Kule, 1996, materiały konferencyjne, s. 263-269.

[11] Morimoto J., Ozaki T., Kubohori T., Morimoto S., Abe N., Tsukamoto M.: Some properties of boronized layers on steels with direct diode laser. Vacuum, 2009, 83, s. 185-189.

[12] Paczkowska M., Ratuszek W., Waligóra W.: Microstructure of laser boronized nodular iron. Surface & Coatings Technology, 2010, 205, s. 2542-2545.

[13] Pertek A., Niemczura Z.: Borosilizieren als eine Methode der Erhöhung von Reibverschleißfestigkeit der Werkstoffe. Internationaler Kongress über 5.Wärmebehandlung der Werkstoffe, Budapest, 20-24 October, 1986, t.3, s.1462-1469.

[14] Pertek A. Thermodynamic and experimental conditions of obtaining the coatings consisted of iron borides and silicons in a silicoboronizing process. International Conference "Carbides-Nitrides-Borides", Poznań, Kołobrzeg, 1987, p. 16-17.

[15] Pertek A.: Kształtowanie struktury i właściwości warstw borków żelaza otrzymanych w procesie borowania gazowego. Poznań: Wyd. Politechniki Poznańskiej, 2001.

[16] Przybyłowicz K.: Teoria i praktyka borowania stali. Kielce: Wyd. Politechniki Świętokrzyskiej, 2000.

[17] Safonov A. N.: Special features of boronizing iron and steel using a continuous-wave CO_2 laser. Metal Science and Heat Treatment, 1998, 40, 1-2, s. 6-10.

[18] Steen W.M.: Laser material processing-an overview. J. Opt. A: Pure Appl. Opt. 5, 2003, S3-S7.

[19] Ueda N., Mizukoshi T., Demizu K., Sone T., Ikenaga A., Kawamoto M.: Boriding of Nikel by the powder-pack method. Surface and Coatings Technology, 2000, vol. 126, s. 25-30.

[20] Usta M., Ozbek I., Bindal C., Ucisik A. H., Ingole S., Liang H.: A comparative study of borided pure niobium, tungsten and chromium. Vacuum 2006, 80, s. 1321-1325.

[21] Wiśniewski K., Bartkowska A., Pertek A.: Laserowe stopowanie borem azotowanej stali 42CrMo4, Zeszyty Naukowe Politechniki Poznańskiej, Budowa Maszyn i Zarządzanie Produkcją, 2008, nr 9, s. 117-123.

[22] Woldan A., Kusiński J., Tasak E.: The microstructure of plain carbon steel laser-alloyed with silicon carbide. Materials Chemistry and Physics, 2003, Vol. 81, Issues 2–3, s. 507–509.

[23] Woldan A., Kusiński J., Kąc S.: Laser surface alloying of plain carbon steel with chromium powder. Inżynieria Materiałowa, 2004, nr 3 (140), XXV, s. 689-692.

[24] Instrukcja obsługi - opis techniczny. Maszyna Badawcza MBT-01. Politechnika Poznańska, Poznań 1974.

[25] PN-EN ISO 6507–1, Metale, Pomiar twardości sposobem Vickersa. Część 1: Metoda badań. Warszawa, czerwiec 2007.

[26] PN-EN ISO 17475, Korozja metali i stopów. Elektrochemiczne metody badań. Wytyczne wykonania potencjo statycznych i potencjo dynamicznych pomiarów polaryzacyjnych. Warszawa, marzec 2010.