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EFFECT OF LASER MODIFICATION ON STRUCTURE AND SELECTED PROPERTIES OF TOOL STEEL

Summary

The paper presents test results of boronized VANADIS 6 steel after laser surface modification. Influence of laser heat treatment on the microstructure, microhardness and cohesion of surface layer was investigated. Diffusion boronizing treatment was used in the powder method at the temperature of 900ºC for 5 h .The laser heat treatment was carried out with technological CO_2 laser. Laser modification of the boronized layer was carried out with laser power of P = 1.04 kW and at laser beam scanning velocity v: 2.88 m⋅min^{-1}, 4.48 m⋅min^{-1} and laser beam d = 2 mm. After boronizing the microstructure of surface layer had a needle-like iron boride structure. After laser heat treatment, which consisted of remelting a boronized layer, a new layer was obtained which included: remelted zone, heat affected zone and a substrate, with a mild microhardness gradient from the surface to the substrate. The microhardness measured along the axis of track after laser heat treatment of the boronized layer was about 1600 - 1400 HV0,1. As a result of the influence of laser beam, the newly created layer was characterized by better properties in comparison to boronized layers.
Key words: *tool steel, diffusion boronizing, laser remelting*

WPŁYW LASEROWEJ MODYFIKACJI NA STRUKTURĘ I WYBRANE WŁAŚCIWOŚCI STALI NARZĘDZIOWEJ

Streszczenie

W pracy przedstawiono wyniki badań borowanej stali VANADIS 6 po modyfikacji laserowej. Badano wpływ laserowej obróbki cieplnej na mikrostrukturę, mikrotwardość i kohezję wytworzonej warstwy. Borowanie dyfuzyjne prowadzono metodą proszkową w temperaturze 900ºC przez 5 h. Laserowa obróbka cieplna była wykonana przy użyciu lasera CO_2. Laserową modyfikację warstwy borowanej przeprowadzono przy użyciu mocy lasera P = 1,04 kW i prędkości skanowania wiązką laserową v: 2,88 m⋅min^{-1}, 4,48 m⋅min^{-1}, średnicy wiązki lasera d = 2 mm. Po borowaniu struktura warstwy wierzchniej miała iglastą strukturę borków żelaza. Po laserowej obróbce cieplnej z przetopieniem otrzymano nową warstwę składającą się z: strefy przetopionej, strefy wpływu ciepła i rdzenia o łagodnym gradiencie mikrotwardości od powierzchni do rdzenia. Mikrotwardość w osi ścieżki warstwy wierzchniej laserowo obrobionej cieplnie wynosiła 1600-1400 HV0,1. W wyniku oddziaływania wiązki lasera otrzymana warstwa charakteryzowała się dobrymi właściwościami w stosunku do warstw borowanej.
Słowa kluczowe: *stal narzędziowa, borowanie dyfuzyjne, laserowe przetapianie*

1. Introduction

Boronizing is a thermochemical process where a surface layer of material is saturated with boron [12]. The process is applicable to any ferrous material [3, 10-12] as well as to alloys of Ni [15], W [16] or Cr [16], where a boronized layer can be produced in three different media: solid, liquid or gaseous. In the case of steel it is carried out at temperatures between 700ºC and 1100ºC for up to 8 h creating iron borides (FeB and Fe_2B), which have a needle-like structure and hardness up to 2000 HV [12]. Boronizing process improves wear resistance, corrosion resistance and oxidation resistance. The main disadvantage of boronized layers consists in their brittleness, especially the surface layers where FeB phase is present. As a result of boronizing of tool steel the needle-like structure is smooth and compact.

Tool steels are a widely used group of tool materials because they have very good functional properties. A typical process of improving selected properties (wear resistance, hardness) of tools made of tool steel is conventional heat treatment.

After this treatment process (which consists of quenching and tempering) a significant growth of hardness of the material occurs in the material, but it is connected with a decrease in its plasticity [12].

Laser heat treatment [10] is one method to prevent this. This process in recent times has become very popular and it occupies a prominent place in a list of methods of shaping machine elements and tool surfaces. As a result of the influence of a laser beam the materials are melt and newly created tracks are formed as a result of intensive mixing in the melting pool, which is due to convection and gravitation movements. Laser heat treatment consists of: laser hardening [5, 6, 9, 14], laser remelting [4, 6, 10], laser alloying [1, 2, 6-8, 11, 13].

The paper presents the investigation results of the influence of laser remelting of boronized layer on powder tool steel surface, using a CO_2 laser.

2. Research methodology

VANADIS 6 [17] ledeburitic steel produced by powder metallurgy of rapidly solidified particles was the investigated material. Its chemical composition is given in Table 1.

VANADIS steel is a material which is chosen mainly because rapid solidification technique is used for its production, which enables us to eliminate problems with macro-segregation that can negatively influence experimental results; additionally, powder tool steel has a high degree of purity without inclusions like oxides or sulphides.

The specimens used for the study had the following dimensions: diameter 20 mm and height 4 mm.

Table 1. Chemical composition of VANADIS 6 steel [% wt]
Tab. 1. Skład chemiczny stali VANADIS 6 [% wg]

C	Si	Mn	Cr	Mo	V	Fe
2.09	0.98	0.38	6.64	1.48	5.45	balance

Source: Own work / Źródło: opracowanie własne

Diffusion boronizing was performed at 900ºC for 5 h using powder method in Ekabor mixture. Samples were boronized in cooperation with the Department of Heat and Surface Treatment of Silesian University of Technology. After boronizing the specimen was laser heat treated (LHT).

Laser heat treatment was carried out using TRUMPF TLF 2600 Turbo CO_2 laser of nominal power of 2.6 kW, which is located in the Laboratory of Laser Technology at the Department of Machining at Poznan University of Technology. The parameters used in the experiment were: laser beam power P = 1.04 kW, laser beam radiation density q = 33.12 $kW \cdot cm^{-2}$, scanning laser beam velocity v: 2.88 $m \cdot min^{-1}$, 4.48 $m \cdot min^{-1}$, laser beam diameter d = 2 mm.

Laser tracks were arranged as multiple tracks with distance f = 0.5 mm, where f was distance between axes of adjacent tracks. Laser heat treatment was carried out in multi-tracks, which facilitates application.

Cross-sectional samples were treated with abrasive papers, polished with Al_2O_3, and etched by 2% Nital reagent. Microstructure observations were carried out on polished and etched cross-sections of specimens using TESCAN VEGA 5135 scanning electron microscope.

To determine microhardness profiles a ZWICK 3212 B Vickers hardness tester was used, with the indentation load of 100 G (HV0,1). Adhesion tests of surface layers were conducted in accordance with the standard VDI 3198, which is a comparison of Rockwell indentations with scale standards. A standard Rockwell tester as a destructive quality test for examined layers was employed in this study, and damage to the layers was compared to the adhesion strength quality maps HF1-HF6 (Fig. 1) [18].

In general, the adhesion strength quality HF1-HF4 defined sufficient adhesion, whereas HF5 and HF6 represented insufficient adhesion.

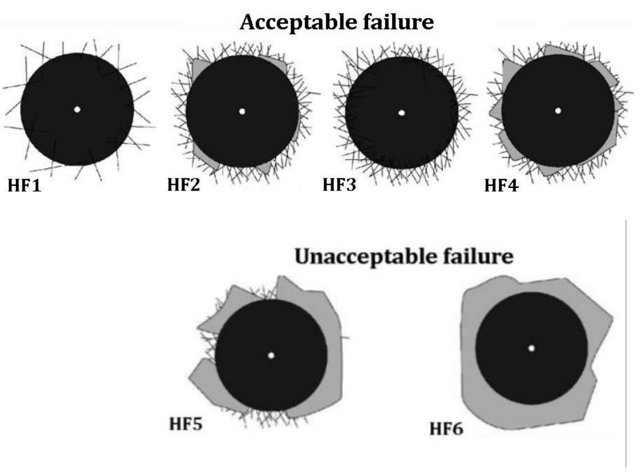

Fig. 1. Scale models to test cohesion [18]
Rys. 1. Skala wzorców do badania kohezji [18]

3. Results and discussion

The microstructure of the sample after boronizing obtained is shown in Figure 2. The boronized layer with a total thickness of about 50 µm had a needle-like structure and was closely bound to the substrate. It was composed of iron borides: FeB, which was situated closer to surface, and Fe_2B, situated below it. Under the typical boronized layer a diffusion zone enriched in boron was observed. The substrate material consisted of pearlite matrix and fine globular carbide particles. In the substrate of VANADIS steel two types of carbides are present: MC and M_7C_3 [4].

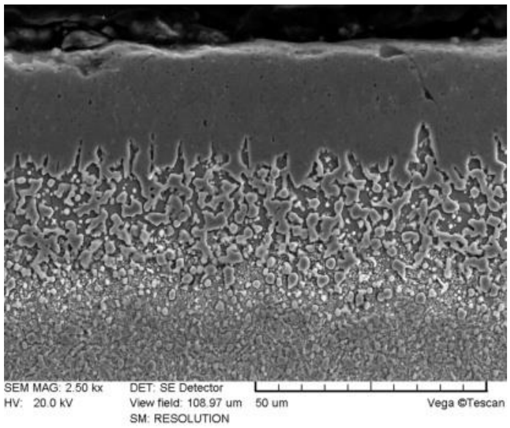

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Fig. 2. Microstructure of diffusion boronized layer on VANADIS 6 steel
Rys. 2. Mikrostruktura warstwy borowanej dyfuzyjnie na stali VANADIS 6

Figures 3-6 present the laser tracks of boronized layer after laser remelting. A new formed layer consisted of remelted zone (MZ), heat affected zone (HAZ) and substrate (Fig. 3 and 5).

The microstructure in Figure 2 presents the laser tracks with the following parameters: P = 1.04 kW and v = 4.48 $m \cdot min^{-1}$. The remelted zone of the laser tracks of boronized layer had a thickness of approximately 100 µm along the axis of tracks (Fig. 3). In remelted zone the microstructure was composed of boron-martensite eutectic with high carbon martensite, where the boron-martensite eutectic had numerous branches (Fig. 4).

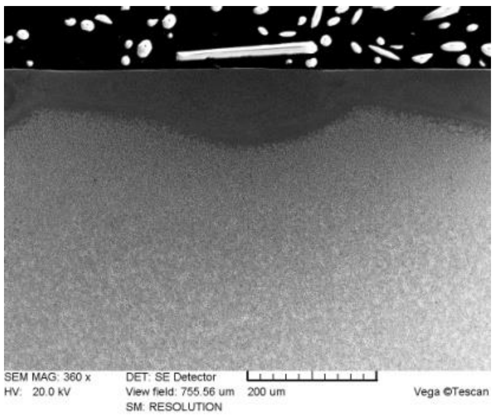

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Fig. 3. Microstructure of diffusion boronized layer after laser heat treatment on VANADIS 6 steel; LHT: P: 1.04 kW; v: 4.48 $m \cdot min^{-1}$; laser tracks
Rys. 3. Mikrostruktura warstwy borowanej dyfuzyjnie po laserowej obróbce cieplnej na stali VANADIS 6 LOC: P: 1,04 kW; v: 4,48 $m \cdot min^{-1}$; ścieżki laserowe

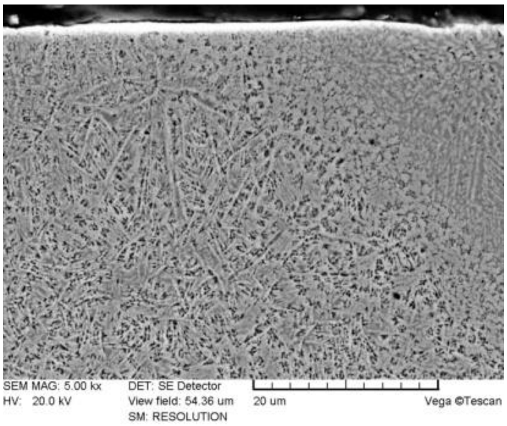

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Fig. 4. Microstructure of diffusion boronized layer after laser heat treatment on VANADIS 6 steel; LHT: P: 1.04 kW; v: 4.48 $m\odot min^{-1}$; remelted zone

Rys. 4. Mikrostruktura warstwy borowanej dyfuzyjnie po laserowej obróbce cieplnej na stali VANADIS 6 LOC: P: 1,04 kW; v: 4,48 $m\odot min^{-1}$; strefa przetopiona

Microstructure in Figures 5 and 6 presents the laser track with the following parameters: P = 1.04 kW and v = 2.88 $m\odot min^{-1}$.

For those parameters, the laser tracks are deeper and they have a thickness of approximately 200 µm along the axis of tracks (Fig. 5). In remelted zone the microstructure is composed also of boron-martensite eutectic with high carbon martensite, but the boron-martensite eutectic has a flowers-like shape (Fig. 6).

In both cases heat affected zone had martensite structure with carbide particels. The substrate was not treated and was composed of pearlite and primary carbides.

Figure 7 presents the X-ray diffraction pattern of boronized layer before and after laser heat treatment of VANADIS 6 steel. In diffusion boronized layers phases of FeB, Fe_2B iron borides were detected. After diffusion boronizing and laser heat treatment phases of Fe_2B, Fe_3B iron borides and $Cr_{23}C_6$, Cr_7C_3 carbides were detected in the remelted zone.

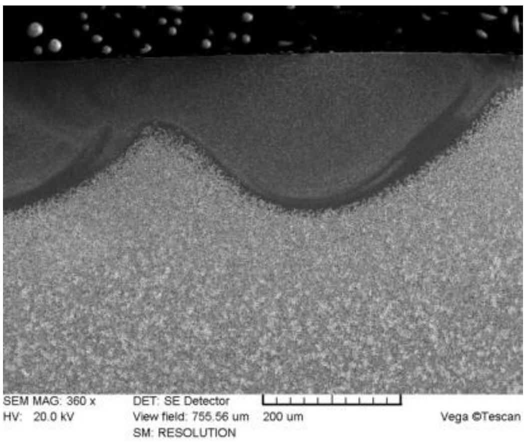

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Fig. 5. Microstructure of diffusion boronized layer after laser heat treatment on VANADIS 6 steel; LHT: P: 1.04 kW; v: 2.88 $m\odot min^{-1}$; laser tracks

Rys. 5. Mikrostruktura warstwy borowanej dyfuzyjnie po laserowej obróbce cieplnej na stali VANADIS 6 LOC: P: 1,04 kW; v: 2,88 $m\odot min^{-1}$; ścieżki laserowe

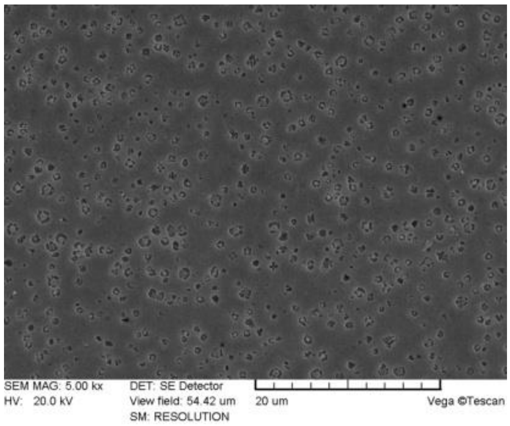

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Fig. 6. Microstructure of diffusion boronized layer after laser heat treatment on VANADIS 6 steel; LHT: P: 1.04 kW; v: 2.88 $m\odot min^{-1}$; remelted zone

Rys. 6. Mikrostruktura warstwy borowanej dyfuzyjnie po laserowej obróbce cieplnej na stali VANADIS 6 LOC: P: 1,04 kW; v: 2,88 $m\odot min^{-1}$; strefa przetopiona

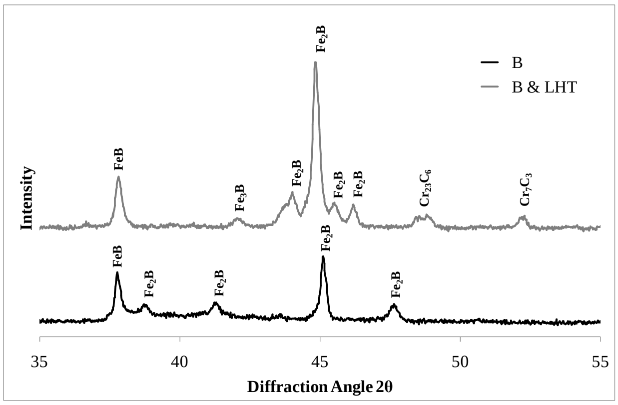

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Fig. 7. X-ray diffraction pattern of boronized layer before and after laser heat treatment on VANADIS 6 steel

Rys. 7. Dyfrakcja rentgenowska warstwy borowanej przed i po laserowej obróbce cieplnej na stali VANADIS 6

Microhardness of diffusion boronized layers was about 1800-1400 HV0.1. With increasing distance from the surface, microhardness of boronized layer gradually decreased towards 600 HV0.1 in the steel substrate (Fig. 8).

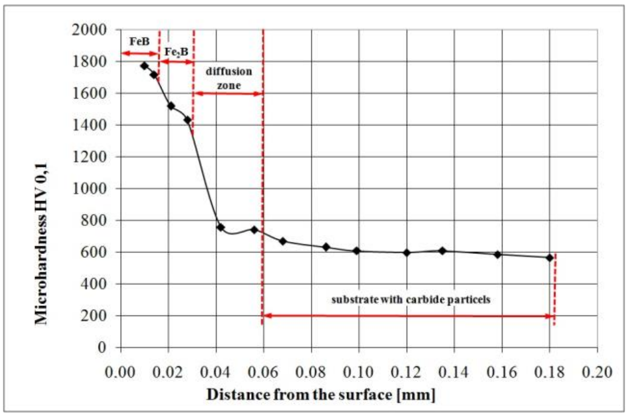

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Fig. 8. Microhardness profile of diffusion boronized layer on VANADIS 6 steel

Rys. 8. Profil mikrotwardości warstwy borowanej dyfuzyjnie na stali VANADIS 6

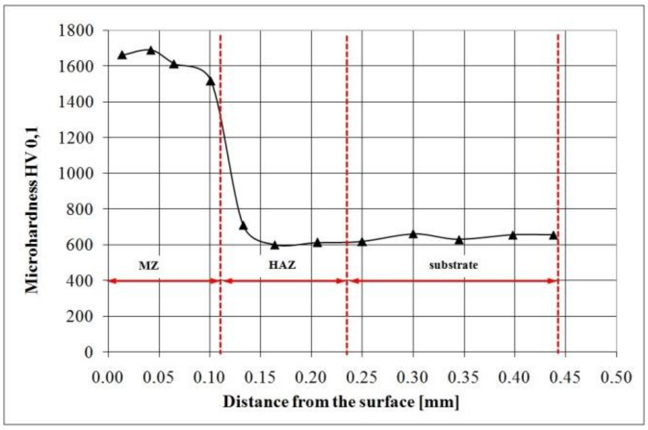

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Fig. 9. Microhardness profile of diffusion boronized layer after laser heat treatment on VANADIS 6 steel; LHT: P: 1.04 kW; v: 4.48 $m\cdot min^{-1}$; measurement in the axis of track
Rys. 9. Profil mikrotwardości warstwy borowanej dyfuzyjnie po laserowej obróbce cieplnej na stali VANADIS 6 LOC: P: 1,04 kW; v: 4,48 $m\cdot min^{-1}$*; pomiar w osi ścieżki*

Results of microhardness tests of layers after laser heat treatment are shown in Figures 9 and 10. Microhardness was tested along the axis of laser tracks. The microhardness in the remelted zone of the laser remelting of boronized layers was about 1600 - 1400 HV 0.1 (Figs. 9 and 10). For laser remelting of boronized layer (P = 1.04 kW and v = 4.48 $m\cdot min^{-1}$) the microhardness in the remelted zone of approximately 1600-1500 HV0.1 was obtained (Fig. 9). The microhardness in remelted zone of laser remelted boronized layer for parameters P = 1.04 kW and v = 2.88 m/min was about 1450-1250 HV 0.1 (Fig. 10). In all the layers after laser heat treatment the microhardness in heat affected zone reached 800 - 600 HV0.1 and decreased towards the substrate - 600 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 thickness, which is dependent on the laser parameters.

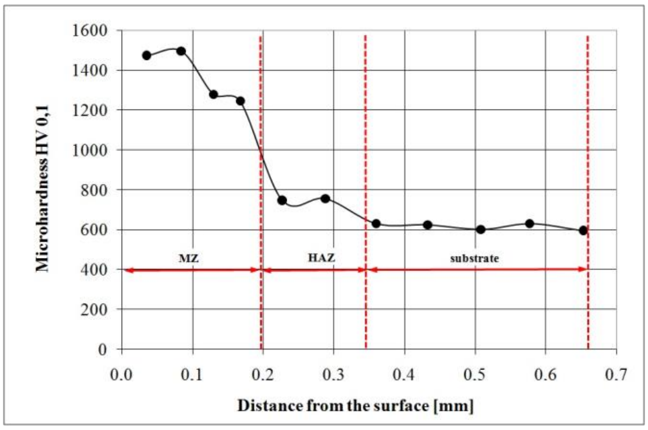

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Fig. 10. Microhardness profile of diffusion boronized layer after laser heat treatment on VANADIS 6 steel; LHT: P: 1.04 kW; v: 2.88 $m\cdot min^{-1}$; measurement in the axis of track
Rys. 10. Profil mikrotwardości warstwy borowanej dyfuzyjnie po laserowej obróbce cieplnej na stali VANADIS 6 LOC: P: 1,04 kW; v: 2,88 $m\cdot min^{-1}$*; pomiar w osi ścieżki*

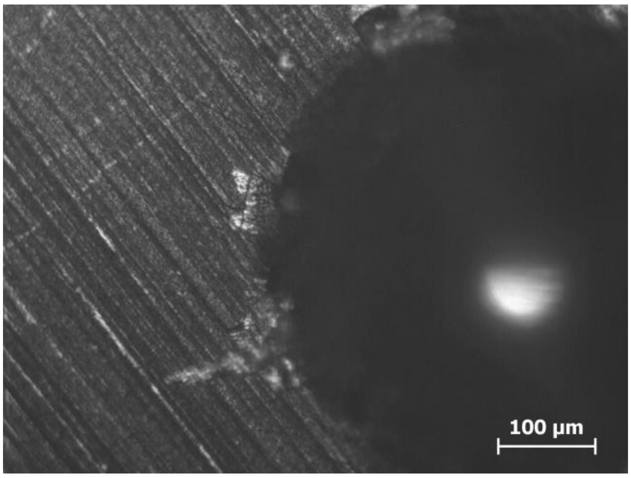

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Fig. 11. Rockwell indentation image made on VANADIS 6 steel
Rys. 11. Odcisk Rockwella na stali VANADIS 6

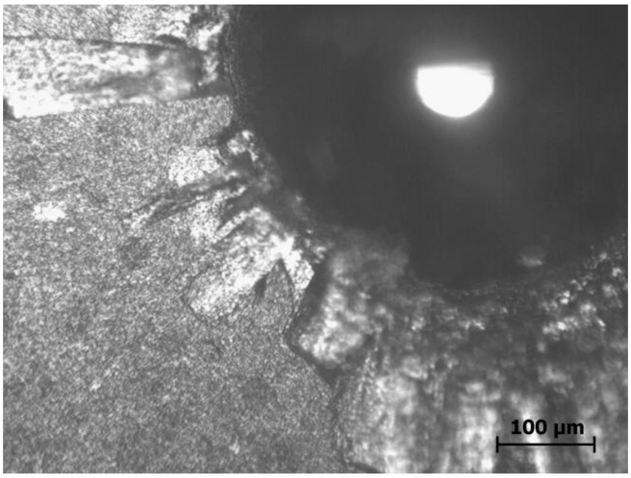

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Fig. 12. Rockwell indentation image made on VANADIS 6 steel after boronizing
Rys. 12. Odcisk Rockwella na stali VANADIS 6 po borowaniu

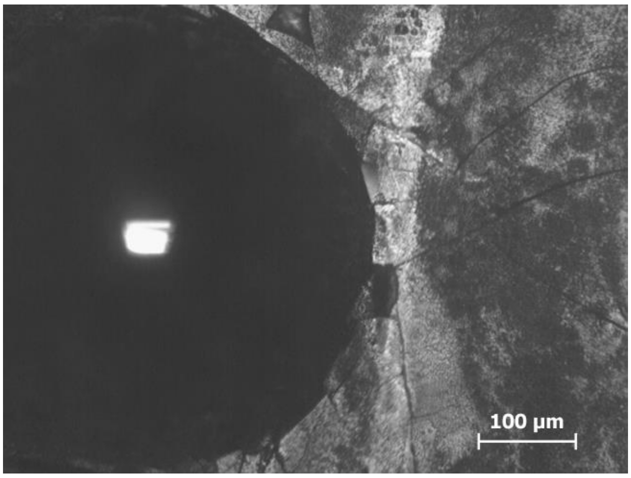

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Fig. 13. Rockwell indentation image made on VANADIS 6 steel after boronizing and laser heat treatment
Rys. 13. Odcisk Rockwella na stali VANADIS 6 po borowaniu i laserowej obróbce cieplnej

Figure 11 shows an image of the as-delivered surface without boronized layer with Rockwell indentation, whose hardness was 50 HRC. Figure 12 shows an image of the surface of diffusion boronized layer with Rockwell indentation, from which micro-cracks radiate, and layer adhesion conforms to the standard in terms of HF1 and HF2 (Fig. 1). Figure 13 shows the resulting indentation on steel after diffusion boronizing and laser heat treatment, which can be classified as standard HF2, and this failure is also acceptable.

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.
- After laser heat treatment the properties of VANADIS 6 steel are advantageous, because the microhardness profiles are mild from the surface to the substrate.
- By means of laser heat treatment the thickness of the layers can be adjusted so they can successfully used on machine parts and tools.

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