THE INFLUENCE OF LASER PROCESSING ON MICROSTRUCTURE AND SELECTED PROPERTIES OF THE DIFFUSION BORONIZED LAYERS PRODUCED ON TOOL STEEL FOR METAL FORMING

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Abstract

The paper presents the study results of microstructure, phase composition, microhardness and wear resistance of Vanadis-6 tool steel after diffusion boriding and laser processing. In this study the diode laser device was used. As a result of diffusion boriding the obtained surface layers were characterized by needle-like microstructure with good cohesion with the substrate but in the subsurface area delamination and porosity could be observed. Therefore the diffusion boronized layer was processed using laser heat treatment. As a result of influence of the laser beam, three zones were obtained. The remelted zone near the surface, next the heat affected zone and finally steel substrate were observed. The newly created microstructure in the remelted zone consisted of boron-martensite eutectic. Microhardness of boronized layer after laser processing in comparison to the one without laser processing was slightly lower and was approx. from 1300 HV0.1 to 1100 HV0.1. It was found that additional advantage of laser processing of boronized layers was the presence of heat affected zone. This led to obtaining a mild microhardness gradient between the surface and the substrate. The boronized layer after laser processing was characterized by higher wear resistance in comparison to one not subjected to this kind of processing.

Keywords: Boronized layer, laser remelting, microstructure, microhardness, wear resistance

1. INTRODUCTION

The diffusion boronizing is a method of thermo-chemical treatment, which improves the properties of surface layers [1]. As a result of this process, boronized layer composed of needle-like microstructure of FeB and Fe_2B iron borides can be obtained. The FeB iron boride is characterized by a high microhardness approx. 1800 HV0,1, but in area of its occurrence brittleness may appear. As a result, it leads to microcracks or peeling of layer. Despite this defect, boronized layer has many advantages such as high hardness, good corrosion resistance in a number acid solutions as well as good wear resistance [1-5]. The brittleness in subsurface zone in boronized layer is the reason for the search for new methods of its modification. One such method is preparing a layer composed of only Fe_2B phase characterized by lower microhardness of about 1600-1400HV. In recent times the boronized layers may be modified using diffusion [6], galvanic [7] and laser [8-10] processing. The last type of modification seems to be particularly interesting. Laser processing of surface layers produced on steel is rapid and precise. After laser modification the boronized layers obtain a new microstructure and properties. Undoubtedly, the laser processing has a positive influence on decreasing brittleness of layers. Additionally a reduction in microhardness gradient between surface and substrate can be obtained.

In this paper Vanadis-6 tool steel with boronized layer was laser processed using diode laser beam. The aim of this study was to determine the influence of laser processing parameters on the microstructure, microhardness and wear resistance of boronized layers.

2. METHODOLOGY OF RESEARCH

Experiments were carried out on Vanadis-6 powder metallurgical tool steel specimens and its chemical composition is shown in **Table 1**.

Table 1 Chemical composition of Vanadis-6 steel (%wt.)

C	Si	Mn	Cr	Mo	V	Fe
2.09	0.98	0.38	6.64	1.48	5.45	82.98

The production process of new surface layer is composed of several steps. In the first step, diffusion boronizing at temperature of 1030°C for 75 minutes was carried out using Durborid® mixture. Next austenitizing at 1025°C, followed by quenching using a nitrogen gas and double tempering at 530°C for 2 h were conducted. Experimental setup for diffusion boronizing process is presented in **Figure 1a**. In the final step the diffusion boronized layers were laser processed. For laser processing the TRUDIODE 3006 diode laser with a nominal power of 3 kW was used. The laser device was integrated with the KUKA robotic arm. The scheme of the test stand as well as the model of laser processed surface layer are shown in **Figure 1b**. The parameters of laser processing were as follows: laser beam power densities (*q*): 38 kW/cm^2, 64 kW/cm^2, 127 kW/cm^2, scanning rate of laser beam *v* = 3 m/min and laser tracks overlapping – 50 %.

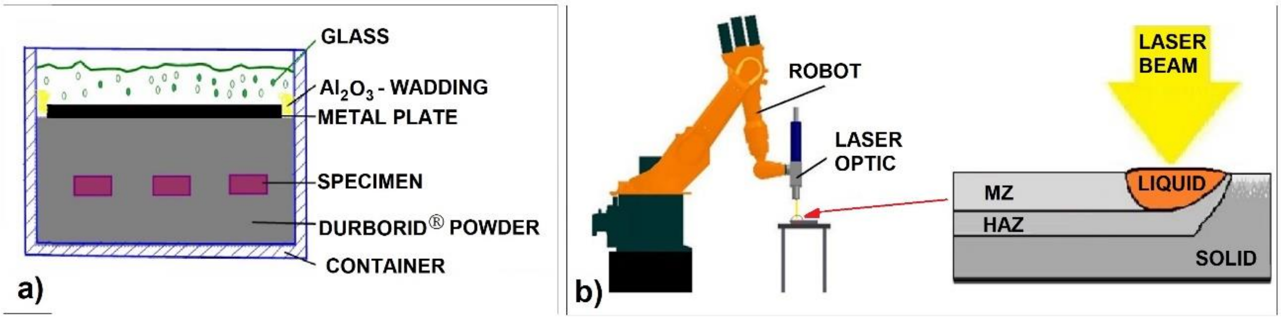

Figure 1 View of specimens preparation methodology for diffusion boronizing process (a) and scheme laser processing test stand with model of laser processed boronized surface layer (b)

Microstructure observations were carried out using Huvitz HRM-300 light microscope and JEOL JSM-7600F scanning electron microscope. The cross-sections of specimens were ground using abrasive papers, next were polished using Al_2O_3 and finally etched by COR reagent ($HCl + CH_3COOH + C_6H_3N_3O_7$ + ethanol). The phase analysis of all tested surface layers was performed using EMPYREAN PANalytical X-Ray diffractometer with CoKα radiation. To determine microhardness profiles, an FM-810 Vickers microhardness tester from Future-Tech equipped with FT-Zero automatic indentation measuring software was used. Indentation load of 100 G (HV0.1) and the loading time of 15 seconds were applied in these studies. Tribological properties of boronized layers before and after laser processing were measured using the CSM pin-on-disc tribometer at ambient temperature. Balls of 6 mm diameter, made from sintered alumina were used for these tests. During wear tests no external lubricant was applied, and the load was 5 N. The total sliding distance was 100 m. The wear rate was calculated from the width of the track by using the formula according to ASTM G 99-95a standard. In the wear volume calculations, the radius of pin point and depth of penetration were taken into account, whereas in the sliding distance calculation, the wear circle radius was included.

3. RESULTS AND DISCUSSION

Microstructure of boronized layer on Vandadis-6 steel after conventional heat treatment is shown in **Figure 2**. Diffusion boronized layer has a characteristic needle-like microstructure, which is continuous, uniform and oriented perpendicularly to the surface with good cohesion with the substrate. But in the subsurface zone of layer a little delamination and porosity could be observed. In microstructure of Vanadis-6 steel substrate, the chromium and vanadium carbides which are evenly distributed in martensite are visible. Smaller, vanadium carbides and larger chromium carbides are detected [8]. The thickness of needle-like microstructure of boronized layer was about 60 µm. It must be stated that that thickness of boronized layer produced on Vanadis-6 steel is less than the thickness of layer produced on low carbon steels. Also the shape of needles is different, without sharp ends of needles as on low carbon steel. This phenomenon is related to a decreased boron diffusion rate during boronizing process as a result of the high carbon content.

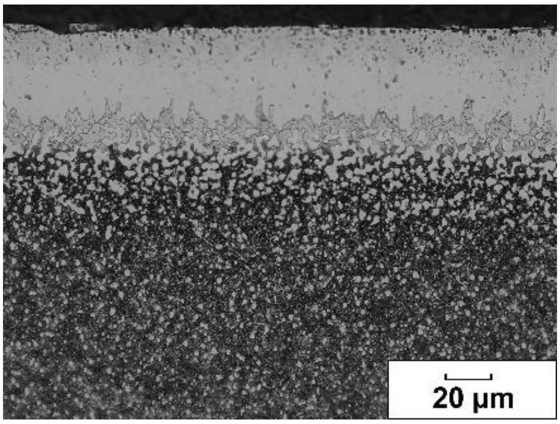

Figure 2 Microstructure of Vanadis-6 steel after diffusion boriding and conventional heat treatment

In **Figures 3a-3f** the microstructures of Vanadis-6 steel with boronized layer after laser processsing are presented. In the microstructure two characteristic zones can be distinguished: remelted zone (MZ) and heat affected zone (HAZ). The remelted zone is composed of boron-martensite eutectic, while in the heat affected zone, fine carbides in the background of fine-grained martensite were visible. Below these two zones the microstructure of substrate, which does not exhibit changes compared with specimens before laser processing is visible. As a result of laser processing, the microstructure of boronized layer is changed which may affect the increase of ductility of newly formed layer. **Figures 3b, 3d, 3f** show the magnification of the central area of the remelted zone from **Figures 3a, 3c and 3e** respectively. The influence of laser beam power density at constant scanning laser beam rate on laser track dimensions and microstructure in remelted zone was analyzed. It could be concluded that when laser beam scanning rate was constant but laser beam power density was variable, then increasing laser beam power induces creation of larger laser tracks (**Figures 3a, 3c, 3e**). Laser processing contributes to intensive mixing of the preformed boronized layer with the substrate material. But, using too low power laser beam results in complete remelting of boronized layer on the border of laser tracks. This is because the remelted zone has a depth of approx. 30 µm whereas the boronized layer has approx. 50 µm (**Figure 3e**). **Figure 3b** presents the microstructure of the central part the remelted zone from **Figure 3a** at high magnification. Boron eutectic along with alloy martensite are visible. **Figure 3d** presents the microstructure of the remelted zone from **Figure 3c**, where boron eutectic with martensite can be seen, but with a higher proportion of eutectic. The highest content of boron eutectic with martensite can be seen in **Figure 3f**. Therefore, depending on the parameters used, the remelted zone with hypoeutectic structure (αphase + eutectic) in **Figure 3b**, hypereutectic microstructure (eutectic + iron boride and carbides) in **Figure 3f** and purely eutectic microstructure in **Figure 3d** may be identified. Boron-martensite eutectic in remelted zone can take different shapes i.e. branched, round, prismatic, or angular which was also confirmed by Safonov [10]. In microstructure of remelted zone various shades can be seen after etching. It is related to the changes of chemical composition in microstructure, due to fluctuation of melted material. Clear transition area between remelted zone, a heat affected zone and the substrate is also visible. The boronized layers before and after laser processing were analyzed using XRD method, and the results showed that the remelted region or layer was composed of iron borides and martensite. In the diffusion boronized layer, FeB and Fe_2B phases are present which was also confirmed in papers [5, 8]. Phase composition results are shown in **Figure 4**. After laser processing of boronized layers, equilibrium iron boride phases FeB and Fe_2B, non-equilibrium and probably meta-stable iron-carbon-boride phase ($B_{0.7}Fe_3C_{0.3}$) as well as Feα iron phase were identified. Similar phases were presented by Safonov in paper [10] where the steel substrate was covered with a paste of amorphous boron, and next laser processing was conducted.

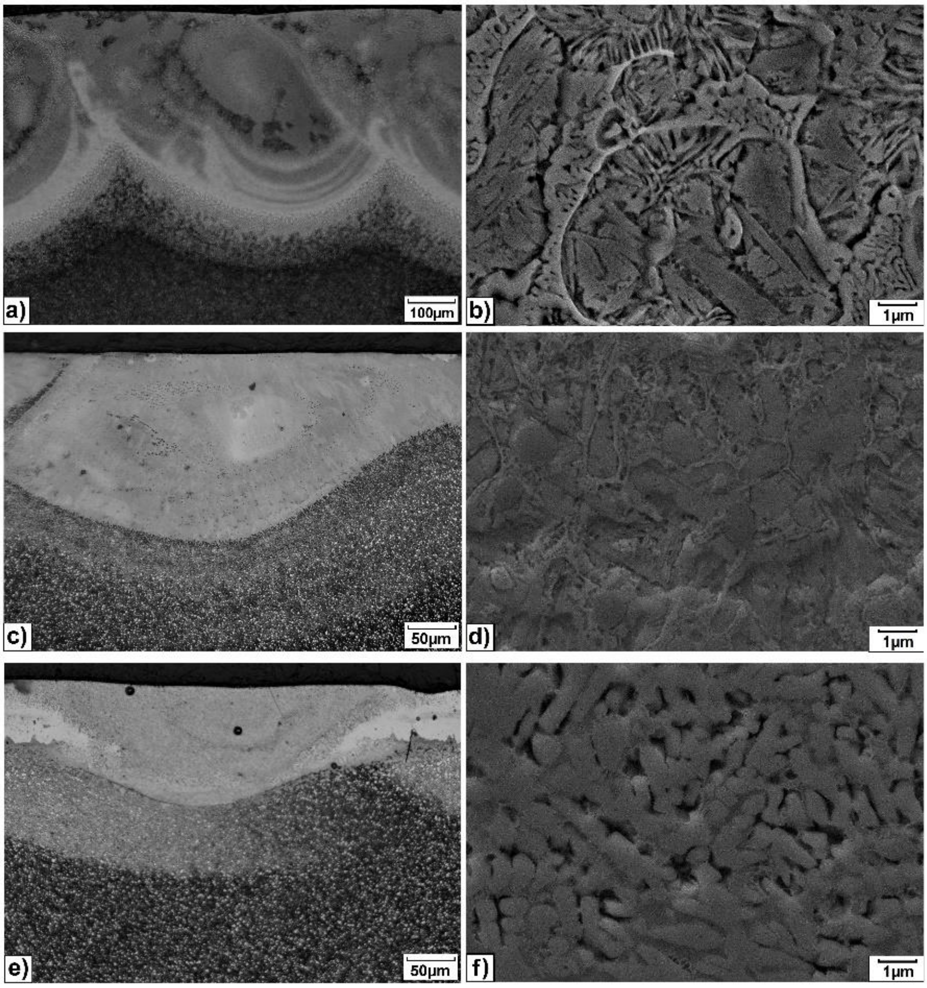

Figure 3 Microstructure of boronized layers after laser processing; laser tracks left column, magnified area of laser track – right column; q = 127 kW/cm^2 (a, b), q = 64 kW/cm^2 (c, d), q =38 kW/cm^2 (e, f)

Microhardness of boronized layer produced on VANADIS 6 steel was between 1800 and 1400 HV and is presented in **Figure 5a**. **Figures 5b-5d** show the microhardness of borided layers after laser processing, and the depths of remelted zone and HAZ are marked on the graphs. It may be noted that the laser processing parameters have an influence on microstructure and consequently on the microhardness of laser tracks. **Figure 5b** shows the microhardness of boronized layer after laser processing using the highest laser beam power density (its microstructure is presented in **Figure 3a**). The microhardness was approx. 1100 HV. However, decreased laser beam power density affects the increase in microhardness in the remelted zone to about 1300 HV. In all the analyzed specimens, microhardness profiles gradually decrease from remelted zone through heat affected zone to the substrate. Microhardness in HAZ oscillates within the range of 900-800 HV, and then decreases to the value of approx. 700HV in the substrate. It can be seen that the microstructure of the formed eutectic has an influence on microhardness. Therefore a specimen with hypereutectic microstructure had higher microhardness (**Figure 3f** and **Figure 5d**). It can be found that due to laser processing the microhardness of new layers was lower than in diffusion boronized layers but much thicker (even 2 to 6 times). This depends on laser processing parameters.

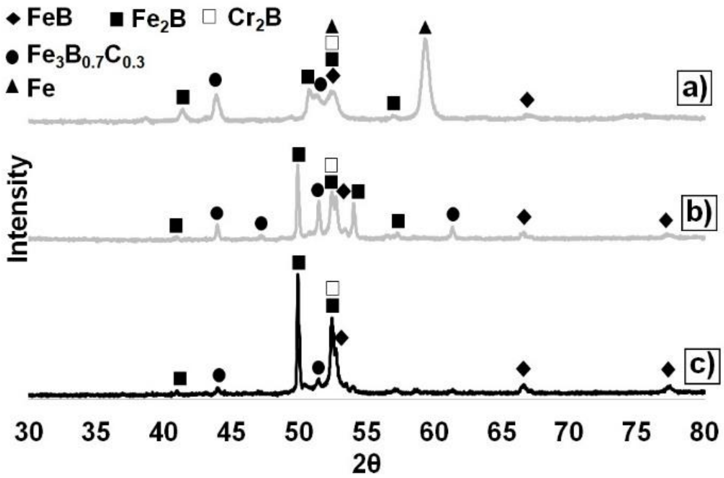

Figure 4 XRD spectrum of boronized layers after laser processing; q = 127 kW/cm^2 (a), q = 64 kW/cm^2 (b), q = 38 kW/cm^2 (c)

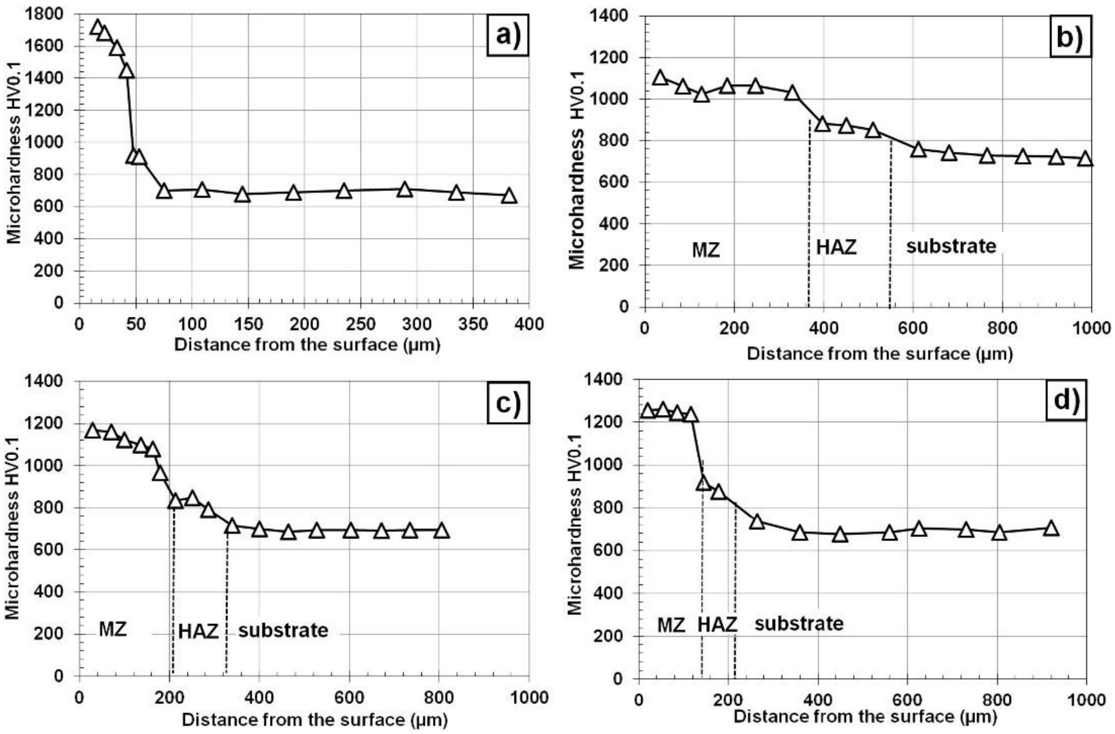

Figure 5 Microhardness profiles of Vanadis-6 steel with boronized layers: after diffusion process (a) and after laser processing using: q = 127 kW/cm^2 (b), q = 64 kW/cm^2 (c), q = 38 kW/cm^2 (d)

The results of wear resistance tests of boronized layer before and after laser processing conducted using pin-on-disc method are presented in **Table 2**. Boronized layer with the highest microhardness and characterized by hypereutectic microstructure was selected for testing. The received friction coefficient measured for diffusion boronized layer was slightly lower than what was achieved in the case of laser remelted boronized layer.

Table 2 Wear resistance results obtained using pin-on-disc method

Specimens	**Values of friction coefficient**	**Widths of wear tracks (mm)**	**Wear rate (m^2/N)**
boronized layer	0.562	0.176	$5.90 \cdot 10^{-10}$
boronized layer after laser processing	0.626	0.202	$5.58 \cdot 10^{-10}$

From the measurements of the width of wear tracks it is shown that the wear rate of laser processed specimen is slightly better than for diffusion boronized layer. Slightly lower wear rate is related to thicker layer after laser processing which generally had a lower microhardness than that diffusion boronized layer.

4. CONCLUSION

The conclusions are as follows:

- Laser processing of boronized layer reduces microhardness gradient on cross-section from the surface to the substrate in comparison to diffusion boronized layer. It is associated with the presence of heat affected zone.
- Laser processing contributes to reducing the microhardness from approx. from 1700 HV0,1 to 1400 HV0,1 (for diffusion boronized layer) to approx. from 1300 HV0,1 to 1100 HV0,1 (for laser processed boronized layer).
- After laser processing, in microstructure of boronized layer, Fe_2B, $Fe_3B_{0.7}C_{0.3}$ and Feα phases were detected.
- Wear resistance tests using pin-on-disc method did not show significant improvement of the wear resistance of laser processed boronized layer in comparison to the diffusion boronized layer.

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