Arch. Mech. Tech. Mater. Vol. 37 (2017) 70-75

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Archives of Mechanical Technology and Materials
www.amtm.put.poznan.pl

Surface condition, microstructure and microhardness of boronized layers produced on Vanadis-6 steel after modification by diode laser

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ARTICLE INFO

Received 03 April 2017
Received in revised form 01 June 2017
Accepted 07 June 2017

KEY WORDS

Boronized layer
Laser remelting
Microstructure
Microhardness

ABSTRACT

The paper presents the study results of surface condition, microstructure and microhardness of Vanadis-6 tool steel after diffusion boriding and laser modification by diode laser. As a result of diffusion boriding the layers consisted of two phases: FeB and Fe_2B. A bright area under the continuous boronized layers was visible. This zone was probably rich in boron. As a result of laser surface modification of boronized layers, the microstructure composed of three zones: remelted zone, heat affected zone and the substrate was obtained. The microstructure of remelted zone consisted of boron-martensite eutectic. The depth of laser track (total thickness of remelted zone and heat affected zone) was dependent on laser parameters (laser beam power density and scanning laser beam velocity). The microhardness of laser remelting boronized layer in comparison with diffusion boronized layer was slightly lower. The presence of heat affected zone was advantageous, because it allowed to obtain a mild microhardness gradient between the layer and the substrate.

1. INTRODUCTION

One of the methods which improves the properties of surface layers is the diffusion boronized process. After diffusion boronizing, the machine parts and tools have decreased susceptibility on wear, especially in the case of total lack of lubrication or restricted of it [1-6]. Diffusion boronized layer has many advantages such as high hardness, good corrosion resistance with a number of acid and alkali and mentioned earlier good wear resistance. But these layers had one of fundamental drawbacks which is brittleness, which may cause their microcracks or peeling. Therefore, to improve this phenomenon various methods of modification are used. For the modification of boronized layers, the diffusion [7, 8], galvanic [9] and laser [10-12] processes are used. Recently the laser heat treatment has become more often used in industry.

After the laser modification, the boronized layer has a lower microhardness, but also reduces the microhardness gradient between the surface and substrate. This undoubtedly has a positive impact on the increase of the fracture toughness [1-3].

The laser heat treatment process is rapid and precise, for the reason that generally the laser beam is coordinated with the robot. This enables processing surface of different shapes, which is often quite complex. To the main advantages

DOI: 10.1515/amtm-2017-0011

of laser heat treatment processes one can include e.g.: the ability to select laser beam power density, laser beam scanning velocity and also precise distribution of laser tracks on the surface workpiece [13, 14].

The tool steels should be characterized by a high surface hardness and wear resistance. It is extremely important for their use on the forming tool [11, 15]. The aim of this study was to determine the influence of laser heat treatment parameters on the macrostructure, microstructure and microhardness of boronized layers produced on Vanadis-6 steel after laser modification.

2. METHODOLOGY OF RESEARCH

The studies were carried out on the specimens made of Vanadis-6 powder metallurgical tool steel. The chemical composition of this steel was shown in Table 1. The roller-shaped specimens (diameter 16 mm and height 5 mm) were used for the study.

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

In the first step, the specimens were diffusion boronized using Durborid® mixture at a temperature of 1030°C (1303 K) for 75 minutes. After the boronizing, the specimens subsequently austenitized at 1025°C, quenched using a nitrogen gas and double tempered at 530°C for 2 h.

In the next step, the boronized layers were modified using laser beam (laser modification). Laser heat treatment, using the TRUDIODE 3006 diode laser with a nominal power of 3 kW, was conducted. The diode laser was integrated with the robot arm from KUKA. The parameters of the laser heat treatment were as follows: laser beam power density q = 38 kW/cm^2, q = 64 kW/cm^2, q = 89 kW/cm^{2}scanning laser beam velocity v = 3 m/min and laser tracks overlap O = 50 %.

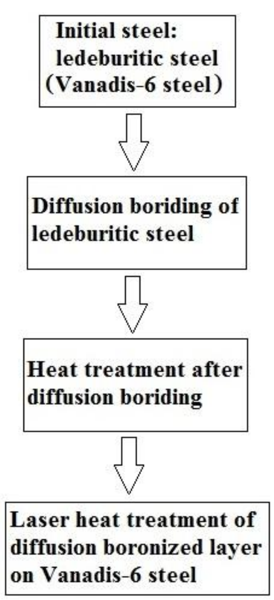

Fig. 1. Block diagram of surface layer formation on Vanadis-6 steel

A block diagram of the creation of new surface layer on Vanadis-6 steel was shown in Figure 1. Whereas the diagram of remelting of surface layer by using the laser beam is shown in Figure 2.

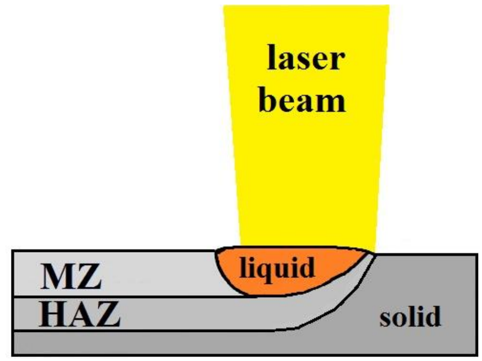

Fig. 2. Schematic of the laser heat treatment process by remelting of boronized surface layer

Macroscopic images were made using Nikon D3000 camera. Microstructure observations were carried out on polished cross-sections of specimens after etching in CORR solution which consisted of: HCl + CH_3COOH +$C_6H_3N_3O_7$ + ethanol. For this purpose the HUVITZ HRM-300 light microscope equipped with a camera was applied.

To determine microhardness profiles, the BUEHLER®IndentaMet™1100 SeriesVickers hardness tester was used. Indentation load of 100 G and loading time 15 seconds were applied in these studies.

3. RESULTS AND DISCUSSION

The microstructure of boronized layer on Vandadis-6 steel was shown in Figure 3. The boronized layer had a needle-like microstructure, wherein the needles have characteristic rounded edges and were oriented perpendicular to the surface. The substrate of Vanadis-6 steel was composed of ledeburite and evenly distributed of chromium and vanadium carbides. The thickness of boronized layers was about 60 μm.

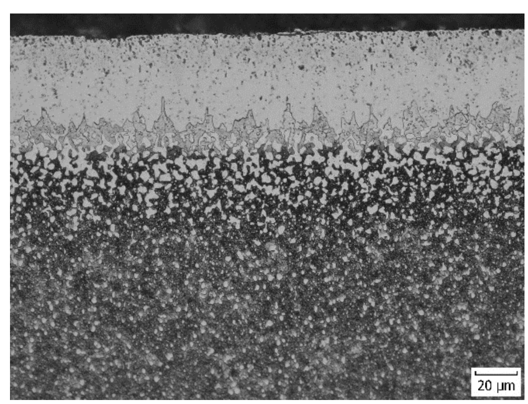

Fig. 3. Microstructure of Vanadis-6 steel after diffusion boriding

Thickness of boronized layer is less than the thickness of layer on low carbon steels. It may indicate a decreased boron diffusion rate during boronizing process as a result of the increase of carbon content.

In Figure 4 a macroscopic images of surfaces after laser modification boronized layer were shown. On the surface a clear parallel tracks resulting from a scanning of laser beam can be observed. The increased surface roughness after laser heat treatment was caused by the transition to a liquid state of thin surface layer during the laser modification.

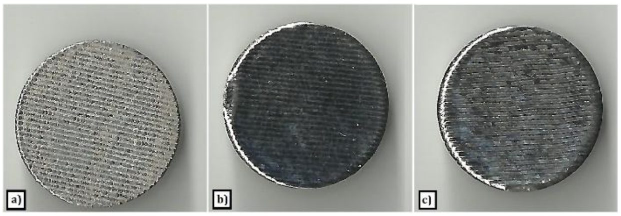

Fig. 4. Surface microstructure of specimens after the laser modification by using the following parameters:
v = constant = 3 m/min
a) q = 38 kW/cm², b) q = 64 kW/cm², c) q = 89 kW/cm²

As a result of laser modification of boronized layers, the needle-like microstructure of iron boride was changed which probably influenced the increase of ductility of newly formed layer.

As a result of the impact of the laser beam, in the microstructure two characteristic areas can be distinguished: remelted zone (MZ), heat affected zone (HAZ).

In all of the analyzed steel after laser heat treatment there was clearly visible a border of transition between individual areas. At the border of MZ and HAZ zones, the flat solidification front was clearly visible. The melted zone was the brightest and had a shade of light gray, below there was a gray area of the HAZ with white particles of carbides, and just below the HAZ there also was a steel substrate with fine particles of carbides.

In the remelted zone the brighter and darker areas changes were visible which were connected with chemical composition of microstructure. The changes of chemical composition were due to fluctuation of melted material in metal liquid pool.

The remelted zone composed of boron-martensite eutectic varying its contents. In the heat affected zone, fine carbides on the background of fine-needle martensite were visible.

Figure 5 presents the influence of laser beam power density on microstructure of laser tracks, when the scanning laser beam velocity was constant.

The needle-like microstructure of iron boride layers has been incompletely remelted on the border of laser tracks (Fig. 5a). In the middle part of this laser track the thickness of the remelted zone was twice as thick as the diffusion boronized layer.

With the increase of the laser beam power density the dimensions of the laser tracks increases.

The measurements of dimension of laser tracks were presented in Table 2.

The increase of the laser beam power density causes remelting also of the border of laser tracks (Fig. 5b and Fig. 5c).

For low laser beam power density in the microstructure of laser tracks a slight porosity can be observed (Fig. 5a).The microstructure in Figure 5c shows solidified turbulence of chemical composition due to interaction of the laser beam on the material. Also you can observe the overlap of laser tracks to each other. (Fig. 5b and Fig. 5c).

Figure 6 presents the microstructure of Vanadis-6 steel after laser remelting of boronized layer. In this case the laser parameters were as following: the laser beam power density q = 38 kW/cm² and scanning laser beam velocity v = 3m/min. Cross-section of laser track for those parameters is visible in Figure 5a.

Table 2. Dimension of laser tracks

Laser parameters	Depth of MZ [μm]	Depth of laser track (MZ + HAZ) [μm]
q = 38 kW/cm², v = 3 m/min	121	193
q = 64 kW/cm², v = 3 m/min	193	329
q = 89 kW/cm², v = 3 m/min	257	364

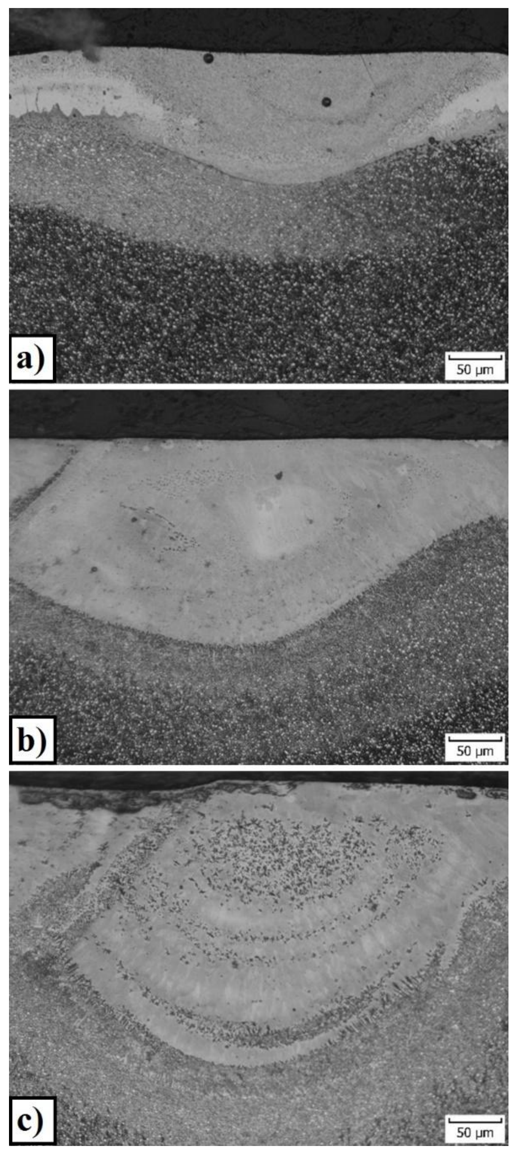

Fig. 5. Microstructure of boronized layers after laser modification: v = constant = 3 m/min
a) q = 38 kW/cm², b) q = 64 kW/cm², c) q = 89 kW/cm²

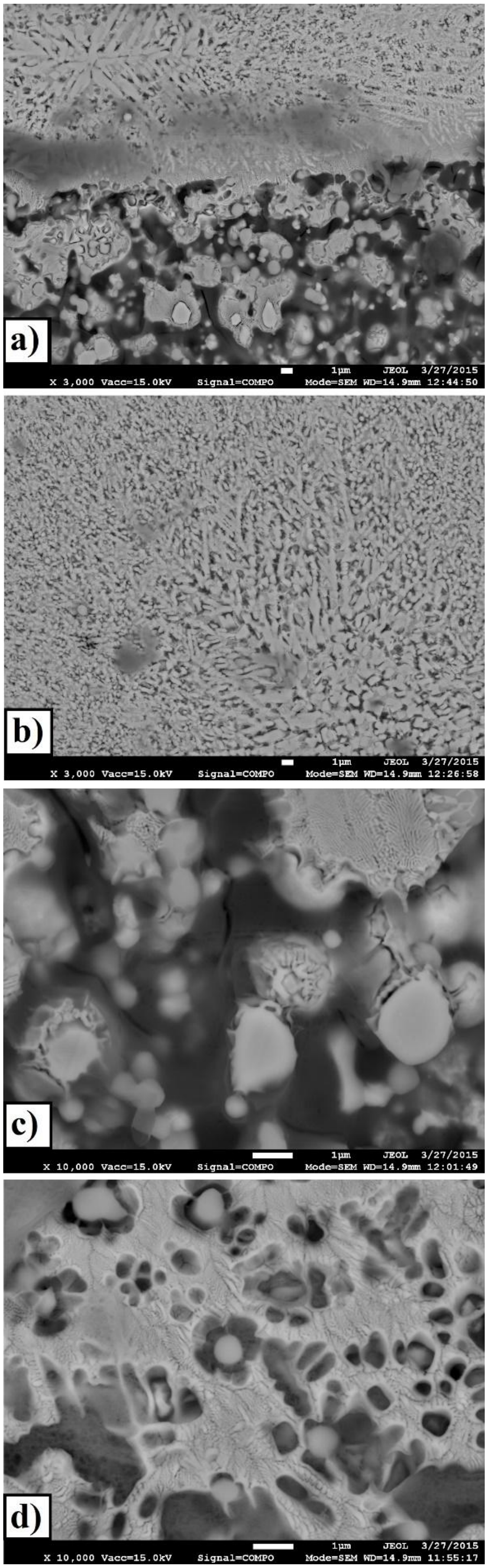

Fig. 6. Microstructure of Vanadis-6 steel after laser remelting of boronized layer; LHT: q = 38 kW/cm², v = 3 m/min; a) boundary between of MZ and HAZ; b) MZ; c)magnified area 1 from figure 6a; d) magnified area 2 from figure 6a

In Figure 6a the boundary between the remelted zone (MZ) and heat affected zone (HAZ) was presented. In Figure 6b it can be visible, that the dendrite axes were oriented parallel to the direction of heat removal.

On Figure 6a a square areas were marked, which magnification was presented in Figure 6c and 6d.

In Figure 6c the transition area between a remelted zone and a heat affected zone was presented. One can observe partially molten carbides, and in the upper part of the microstructure the boron-martensite eutectic is visible.

Figure 6d presents the microstructure from lower area of the remelted zone. Here, carbide particles can be seen which are surrounded by the boron-martensite eutectic.

Increasing the laser beam power density in steel causes the increase of the reach of melted area. This undoubtedly has an impact on melting of the entire boronized layer (see Fig 5a and Fig. 5c). Also, as an effect followed by the increase of the dimensions of the laser tracks. Higher laser beam power density used in laser processing ensures slower solidification and it influences the reducing of the occurrence of cracks or pores.

In Figure 7 the microhardness profile on cross-section of Vanadis-6 steel specimen after diffusion boriding was shown. On the cross-section a high microhardness gradient between the layer and the substrate occurs. The microhardness of the boronized layer was approx. 1700 HV - 1600 HV0,1. At the place where this layer ends, the microhardness decreases in to the metal substrate, and is approx. 700 HV0,1.

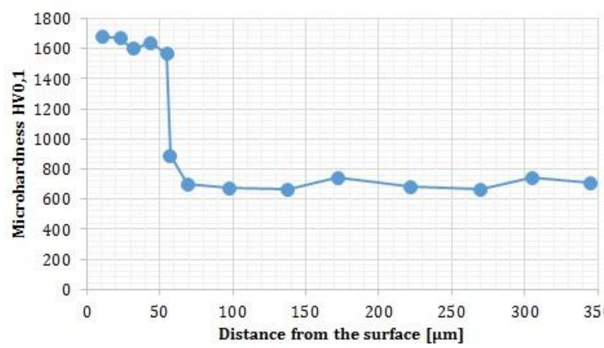

Fig. 7. Microhardness profiles of Vanadis-6 steel after diffusion boriding

In Figures 8a–8c microhardness profiles of Vanadis-6 steel after diffusion boriding and laser modification were shown. In any case, the layers have microhardness less than boronized layer but they have a mild microhardness gradient between the layer and the substrate. The measurements of microhardness of laser tracks were conducted in axis of the laser tracks.

In Figure 8a the microhardness profile of boronized layers was shown after laser modification for the following parameters: q = 38 kW/cm^{2}and v = 3 m/min.

In the remelted zone the microhardness had approx. 1200 HV0,1. The microhardness in the heat affected zone decreases with increasing distance from the surface from approx. 1000 HV0,1 to approx. 850HV0,1. At a distance of approx. 380 µm from the surface the substrate is located and its microhardness had approx. 700HV0,1.

The microhardness of laser modified boronized layer for the q = 64 kW/cm^2 and v = 3 m/ min was presented in Figure 8b.

The highest microhardness occurred in the remelted zone and was approx. 1200 - 1050 HV. The microhardness on the cross-section of sample decreases smoothly from the remelted zone to the heat affected zone (approx. 800 HV0,1), and next to the substrate (approx. 700 HV0,1).

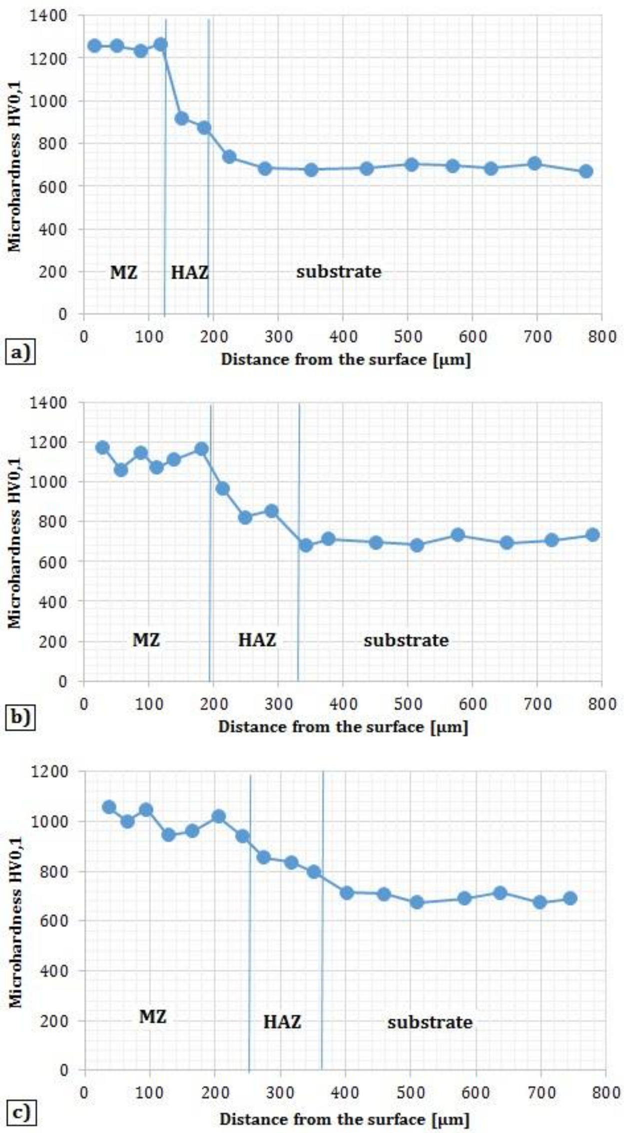

Fig. 8. Microhardness of boronized layers after laser modification: v = constant = 3 m/min
a) q = 38 kW/cm², b) q = 64 kW/cm², c) q = 89 kW/cm²

In Figure 8c the microhardness profile of after diffusion boronizing and impact of laser beam was shown, when the laser parameters were as following: q = 89 kW/cm^2 and v = 3 m/min.

The highest microhardness for those parameters occurs within the remelted zone and it ranges from 1100 HV0,1 to 900 HV0,1. The microhardness of the heat affected zone was approx. from 800 HV0,1 to 900 HV0,1. After crossing the HAZ followed a decrease microhardness in substrate to approx. from 700 HV0,1 to 600 HV 0,1.

In comparison to the diffusion boronized layers, it can be seen that the decrease microhardness on the cross-section of sample is not as rapid, but the maximum microhardness is lower.

CONCLUSIONS

The conclusions are following:

1. As a result of diffusion boronized process, the surface layer with needle-like microstructure iron borides was obtained, which is characterized by microhardness on cross-section from 1700HV to 1600 HV0,1.
2. Laser remelting of boronized layer reduces the microhardness. It is dependent on laser parameters. Additionaly, the presence of the heat affected zone positively affects on the obtained the mild microhardness gradient on cross-section of specimens.
3. Using laser modification of boronized layer can reduce the brittleness in the region of FeB phase which has a negative influence on properties of boronized layers.
4. Laser remelting of boronized layers causes reduction of microhardness of these layers from approx. 1200 HV0,1 to 1000 HV0,1.

ACKNOWLEDGEMENT

This article was financially supported within the project "Engineer of the Future. Improving the didactic potential of the Poznan University of Technology" - POKL.04.03.00-00-259/12, implemented within the Human Capital Operational Programme, co-financed by the European Union within the European Social Fund.

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