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THE INFLUENCE OF THE LASER BEAM FLUENCE ON CHANGE IN MICROSTRUCTURE, MICROHARDNESS AND PHASE COMPOSITION OF FeB-Fe_2B SURFACE LAYERS PRODUCED ON VANADIS-6 STEEL

The paper presents the study results of laser modification of Vanadis-6 steel after diffusion boronized. The influence of laser beam fluence on selected properties was investigated. Diffusion boronizing lead to formation the FeB and Fe_2B iron borides. After laser modification the layers were consisted of: remelted zone, heat affected zone and substrate. It was found that increase of laser beam fluence have influence on increase in dimensions of laser tracks. In the thicker remelting zone, the primary dendrites and boron eutectics were detected. In the thinner remelting zone the primary carbo-borides and eutectics were observed. In obtained layers the FeB, Fe_2B, $Fe_3B_{0.7}C_{0.3}$ and Cr_2B phases were detected. Laser remelting process caused obtained the mild microhardness gradient from the surface to the substrate. In the remelted zone was in the range from 1800 HV0.1 to 1000 HV0.1. It was found that the laser beam fluence equal to 12.7 J/mm^2 was most favorable. Using this value, microhardness was relatively high and homogeneous.

Keywords: diode laser; boronizing; laser modification; microstructure; Vanadis steel.

1. Introduction

Boronizing is the thermo-chemical treatment involving diffusion saturation of surface layer by boron [1-3]. There are various boronizing methods involving the formation of layers in solid, liquid or gaseous media. This process can be successfully used for modification of different materials e.g. alloys of iron [4-16], nickel [17], chromium [18], or tungsten [18]. Depending on the substrate type, the needle-like boride microstructure with good adhesion and closely bonded to the substrate can be obtained. As a result of boronizing process of iron alloys, FeB iron borides near the surface, and Fe_2B iron boride near the substrate can be obtained. Diffusion boronizing process is usually carried out at approximately 1000°C for several hours. The diffusion boronized layers produced on iron alloys have a microhardness from 2325 HV 0.1 to 1700 HV 0.1 for FeB and Fe_2B phases respectively [1].

The boronized layers are characterized by numerous advantages, not only high microhardness, but also good wear resistance and resistance on high temperature up to 800°C [2]. Despite the many advantages there are some disadvantages such as brittleness on the surface, as well as a high microhardness gradient between layer and substrate. Currently, scientists conduct research on development of the manufacturing methods which will limits these negative properties. Modification methods of boronized layers include production of single-phase Fe_2B layers [3], or complex combinations of well-known processes such as nitriding and boronizing [10], nickelizing with boronizing [4], whether, for example chromizing with boronizing [5,13]. Laser modification of surface layers is becoming increasingly popular and widely used [3,4,7,8,19-33]. By using the high energy of laser beam can be modified the diffusion boronized layer, and this way the mild microhardness gradient can be obtained. After laser modification, the increase in thickness of layer enriched with boron can be observed [3]. In addition an important role plays appropriate selection of substrate material. Beside conventional steels, also steels obtained by powder metallurgy methods may be used [6]. An example of such material is Vanadis steel which characterized by fine microstructure and homogeneous distributed carbides phases [34]. These features are very desired because have positively influence on many properties such as e.g. microhardness and wear resistance [3-16,24,25].

In paper [19] the modification of Vanadis 6 steel using laser beam was investigated. Four typical regions were detected. The microstructure in remelted zone consisted of primary cells containing a low amount of martensite and high amount of retained austenite as well as continuous eutectic system based on M_7C_3 carbides. In some zones, undissolved eutectic of MC carbides were detected. Below the heat affected zone was present (material after austenitized and rapidly quenched). And finally, below the

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heat affected zone, the substrate (laser unaffected material) was located. In the substrate was found the microstructure consisting of tempered martensite and carbides which was obtained during the conventional heat treatment. It was also found that the laser remelted material had significantly lower microhardness than in the heat affected zone. According to the authors this is due to by the presence of high amount of retained austenite in remelted material.

In paper [20] the carburizing the low-alloy steel using laser beam was described. Authors give a detailed description of microstructure after laser modification of surface layer with graphite coating. They found that microstructure of the remelted zone consisted of the primary carbide dendrites in eutectic matrix ($\gamma + M_3C$). It was found that microhardness of specimens after laser carburized was 3.5 to 4.5 times higher than the microhardness of parent material (final microhardness ranged 700-900 HV). In paper [6] the influence of boronized layer on microstructure of K190MP powder tool steel was described. Boronizing was carried out at 1000°C for 8 h with a DURBORID powder mixture. X-ray diffraction (XRD) were carried out on different depths of boronized layers, as well as in the transition layers. It was found presence of FeB borides and the unidentified crystalline phases in produced surface layer, and their amount decreasing with increasing distance from the surface. With increasing distance from the surface, also gradual increase of Fe_2B (Me_2B) amount at the expense of MeB was observed. The zone of layer which was located close the substrate was consisted mainly of Me_2B and CrB. The transition zone between boride phases, and the substrate material contained the $Me_{23}(C,B)_6$ phases.

The paper [7] presents the study results of the diffusion boronized layer after CO2 laser modification. Boronized processes were carried out on Vanadis-6 steel at 900°C for 5h. Microstructure of described boronized layers after laser modification consisted of the boron-martensite eutectic in remelted zone and martensite in heat affected zone. As a result of laser modification, the new layers were obtained which were characterized by the mild gradient of microhardness from the surface to the substrate. Remelted zone consisted of boron-eutectic with martensite. In this case, the content of boron after laser modification was dependent on the laser parameters. Additionaly, in paper [7] chemical composition study using WDS X-ray microanalysis were conducted. It revealed that the boron is present only in the remelted zone. In the same zone, the FeB and Fe_2B equilibrium iron borides as well as Fe_3B nonequilibrium phase were detected. This study was conducted by XRD diffraction using Cu lamp. Microhardness of obtained layers ranged from 1500 to 1300 HV. It was found that in this case, the most advantageous parameters for modification process of boronized layer were: laser power beam $P = 1.04$ kW and laser scanning velocity $v = 2.88$ m/min.

In paper [8] the microstructure and selected properties of two kind of steels (C45 and CT90) were compared. These steels were subjected to diffusion boronizing process at 900°C during 5 h in EKabor powder mixture and then laser modification on a diode laser. It was found that the increase of carbon content caused reduced in thickness of boronized layer and decrease the boron diffusion rate deep into steel. Additionally, increasing of carbon content caused change in microstructure of boronized layer. Iron borides in the shape of sharp needles became rounding. As a results of laser modification of these layers, the microstructure composed of remelted zone, heat affected zone and substrate was obtained. Laser remelting of boronized layer reduces microhardness gradient on cross-section, due to the present heat affected zone. Laser remelting process of boronized layers causes reduced of microhardness from approx. 1700 HV to the approx. 1100 HV. The authors suggested that the using laser modification gives possibility to reduced the brittleness of boronized layer, which have negative influence on utility properties. The presence of heat affected zone was advantageous, because assured the mild microhardness gradient between layer and substrate. The authors were found that the specimens after laser modification were characterized by better corrosion resistance than specimens without modified layer.

The aim of presented work was to analized the influence of laser modification process on the diffusion boronized layers produced on Vanadis-6 steel. Authors focuses on microstructure, phase composition and microhardness of newly produced layer.

2. Experimental details

2.1. Material

The investigated material was Vanadis-6 steel produced using powder metallurgy method (rapidly solidified particles). Chemical composition of material used was given in Table 1. The rapid solidification technique enable to eliminate the problems of macro-segregation in steel, which have negatively influence on experimental results. Additionally, this type of steel is characterised by the high degree of purity what is related to small contains of oxides and sulfides. The specimens used for the study had the following dimensions: diameter 16 mm and height 4 mm.

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	balance

2.2. Diffusion boronizing and heat treatment

Diffusion boronizing was performed at 1030°C for 45 minutes using the powder method with Durborid® mixture. Prior the boronizing process, the specimens were cleaned and degreased. After that, the specimens together with the powder mixture were placed into a refractory container. The boronizing powder was placed on the container bottom. Afterwards, the steel specimens were placed to it, and on the end were put the remainder of powder. To the upper part of container, a metal plate was placed, and connection between plate and container was sealed with Al_2O_3 cotton wool. In the next step, on the top of container was put the shattered glass. The glass melts at the boronizing temperature and thereby makes an additional protection of the container from oxygen from external environment. After the boronizing process the specimens together with containers were cooled down to the room temperature.

After the boronizing process, the specimens were removed from the containers and next firstly austenitized at 1025°C, and secondly quenched by using a nitrogen gas. After this treatment, the specimens were double tempered at 530°C for 2 h. Specimens after boronizing and heat treatment were subjected to laser modification.

2.3. Laser modification

Laser modification processes were carried out using TruDiode 3006 diode laser with nominal power of 3000 W. The parameters used in the experiments were as follows: laser beam power (P) – 300 W, 500 W and 1000 W; scanning speed (v_l) – 16.7 mm/s and 50 mm/s. Laser tracks were arranged as the multiple tracks with the constant distance from each other equal to $f = 0.5$ mm, wherein f corresponded to distance between axes of adjacent tracks. Value of overlapping was equal to 50%.

During the process, the laser beam was moved from point A to point B. Next, laser beam was turned off, and laser head was moved from point B to point C. Afterwards, laser beam was turned on and moved from point C to point D. Cycles were performed on the entire surface of specimen (Fig. 1). The distance from the laser head to surface of specimen was equal to $l_h = 270$ mm. The laser head was mounted on KUKA KR16-2 robot arm. Due to the safety of laser fiber and possibility of beam reflection, the laser head was inclined in XY plane as was shown in Figure 1. The direction of scanning speed v_l was realized in XZ plane. Laser beam was characterized by TEM_{00} mode and constant diameter equal to $d_l = 1$ mm.

The list of production parameters used to the laser modification process was shown in Table 2. Absorbs of the laser energy causes melting of surface layer. A part of heat energy was absorbed by the substrate and contributes to its melting.

TABLE 2

Laser modification parameters of boronized layers and dimension of laser tracks

No.	Laser parameters				Thickness of the laser tracks		
	P [W]	**v_l** [mm/s]	**E_t** [s]	**F** [J/mm^2]	**MZ** [µm]	**HAZ** [µm]	**Total thickness** [µm]
1.	1000	16.7	0.06	76.4	860	230	1090
2.	1000	50	0.02	25.5	385	145	530
3.	500	50	0.02	12.7	210	115	325
4.	300	50	0.02	7.6	30	120	165

In this article authors highlights the problem of laser beam fluence. This parameter describes the value of optical energy delivered per unit of area. Fluence is often highest in the axis of laser beam, while lower in some distance from that axis. In this paper is assumed that energy is constant on the entire diameter of the laser beam. The values of the laser beam fluence (F) were calculated using the formula (1).

$$F = (P \cdot E_t)/(\pi \cdot r^2) \quad [\text{J/mm}^2] \tag{1}$$

where:

P – laser beam power [W];
r – radius of the laser beam [mm];
E_t – exposure time of laser beam on material [s].

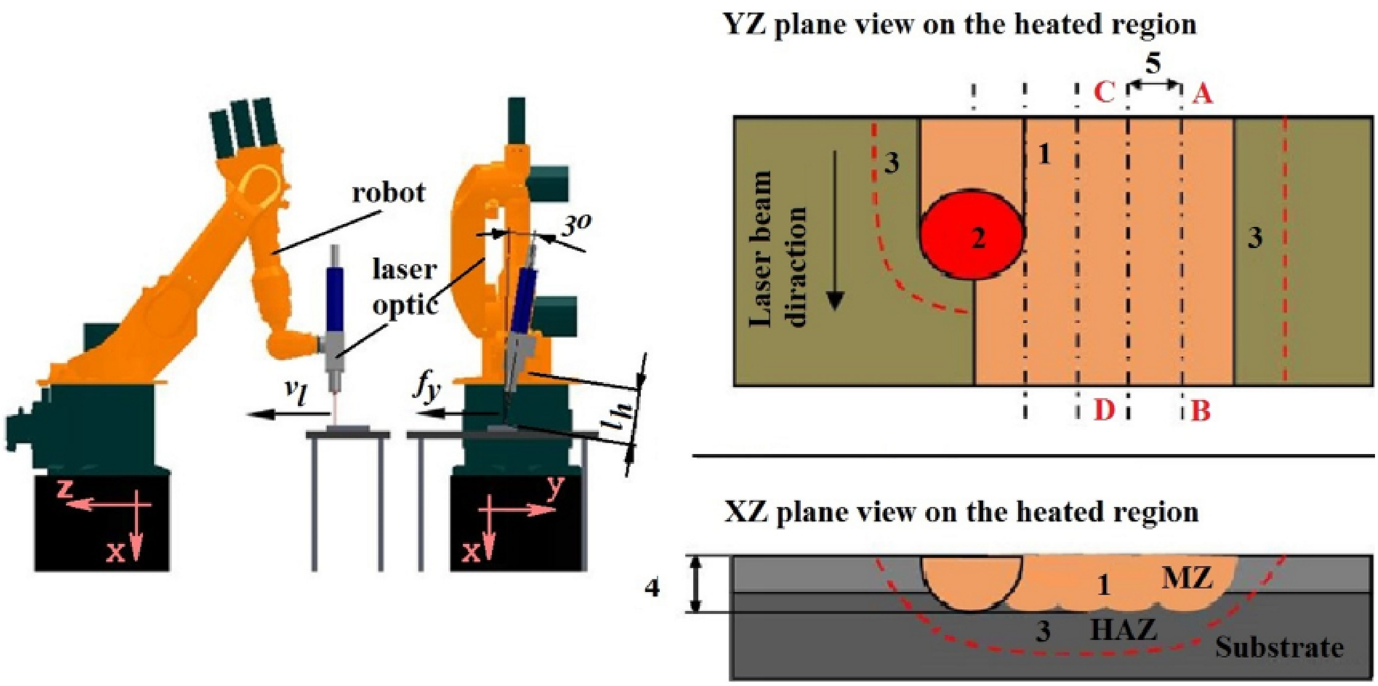

Fig. 1. Scheme of laser modification process; 1 – coating produced, 2 – area heated by laser beam, 3 – heat affected zone, 4 – remelted zone, 5 – overlapping zone

Exposure time of laser beam on material (E_t) was calculated using the formula (2).

$$E_t = d / v_l \quad [s] \tag{2}$$

where:

d – laser beam diameter (mm);

v_l – scanning speed (mm/s).

2.4. Microstructure, X-ray phase analysis and microhardness profiles

Cross-section of specimens were grinded using abrasive papers, polished using Al_2O_3, and etched in COR reagent (HCl + CH_3COOH + $C_6H_3N_3O_7$ + ethanol). Microstructural observations were carried out using Huvitz HRM-300 light microscope and JEOL JSM-7600F scanning electron microscope. The phase analysis of boronized layer before and after laser modification were performed by EMPYREAN PANalytical X-Ray diffractometer using CoK_α radiation. Data were recorded in the range from 30° to 140° (2θ) using a constant steps equal to 0.5°, exposure time equal to 40 seconds and rotating of specimens.

To determine microhardness profiles, the Indente Met 1100 series Vickers microhardness tester was used, with the indentation load of 100 g (HV 0.1).

3. Results and discussion

3.1. Microstructure and X-ray diffraction analysis

In Figure 2 was presented the microstructure of diffusion boronized layers on Vanadis-6 steel. The boronized layers are two-phased and consist of FeB and Fe_2B phases. The diffusion zone (Fe-based solid solution enriched with boron) is situated below the needle-like iron borides. The microstructure of substrate consists of fine carbides uniformly distributed in the martensitic matrix. The total thickness of the boronized layers was approximately 50 μm. Below the needle-like zone, the typical diffusion zone with microstructure consisting of grains enriched with boron was observed. Additionaly it should be noted that the external FeB zone is characterized non-uniform thickness, hence it is practically impossible to determine the thickness of each individual layers (FeB, Fe_2B).

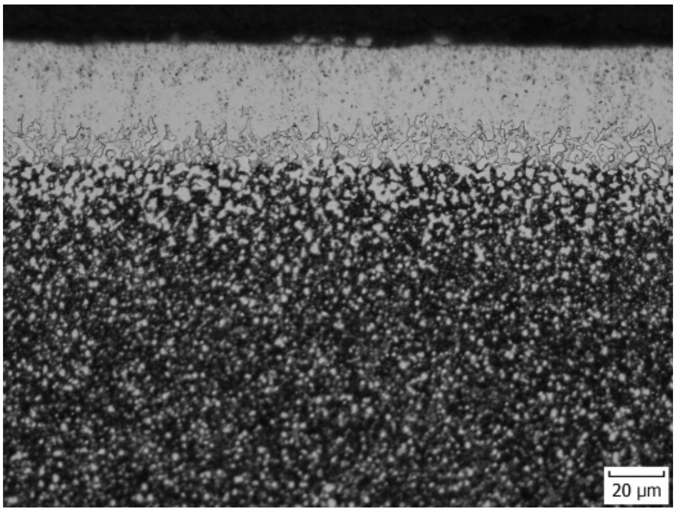

Fig. 2. Microstructure of boronized layers (light microscope)

In Figures 3-6 were presented the microstructure of boronized layer after laser modification. Macroscopic observations did not reveal any surface defects like external porosity or cracks. As a result of laser modification, the boronized layers in the form of tracks were created. It was found that newly created layers consisted of remelted zone (MZ), heat affected zone (HAZ) and substrate. The remelted zone was enriched in boron, whereas heat affected zone had a martensitic microstructure. The influence of laser parameters on laser track dimensions was analyzed. Each parameters had affect on laser beam fluence. The typical image of microstructure of the laser boronized layer was shown in Figure 3a. The total depth of remelted zone was around 860 μm. Below this zone, there is a transitional zone in which occurred the processes of austenitizing and rapidly quenching during the laser heating cycle (Heat Affected Zone). The thickness of HAZ was around 230 μm. The overlapping of laser tracks was equal to 50%.

In Figure 3b was presented surface layer, in which the fluctuations in chemical composition in the liquid metal pool were quite clearly visible. As a result of laser remelting and solidification process, the chemical homogeneity of material was observed. As a result of the intensive convection movements which were present in the liquid melting pool, the new microstructure was obtained. In addition, the fragmentation phenomenon of microstructure and crystallization of highly supersaturated phase (metastable) were occured. In Figure 3b the convection movements of the melting pool in the cross section perpendicular to the direction of the laser beam was observed. It was found that the change in the laser beam fluence value, resulted in change of the laser tracks dimensions (Table 2). In Figures from 3a to 3d were shown that decrease of the laser beam fluence resulted in decreased of the remelted zone depth. In Table 2 were presented study results of thickness, as the average value with 10 measurements.

Laser modification caused intensive mixing the diffusion boronized layer with steel substrate (Fig. 3c). This concerned the areas, which were deeper than the boronized zones. Application of too low laser beam energy resulted in formation of an additional area between remelted zone and heat affected zone, e.g. no-remelted iron borides. In this case, remelted zone was thinner than the diffusion boronized layer. In this case the laser modification process was incompletely (Fig. 3d), because remelted zone had depth of 30 μm whereas the previously formed diffusion boronized layer had depth approx. 50 μm.

In Figures from 4a to 4c were shown SEM images of microstructures obtained using laser modification. These are the magnified areas of MZ, and HAZ marked by squares in Figure 3a. In the bottom of the melted pool, there is the heat transfer mainly oriented into the no-remelted (parent) material. On the contrary,

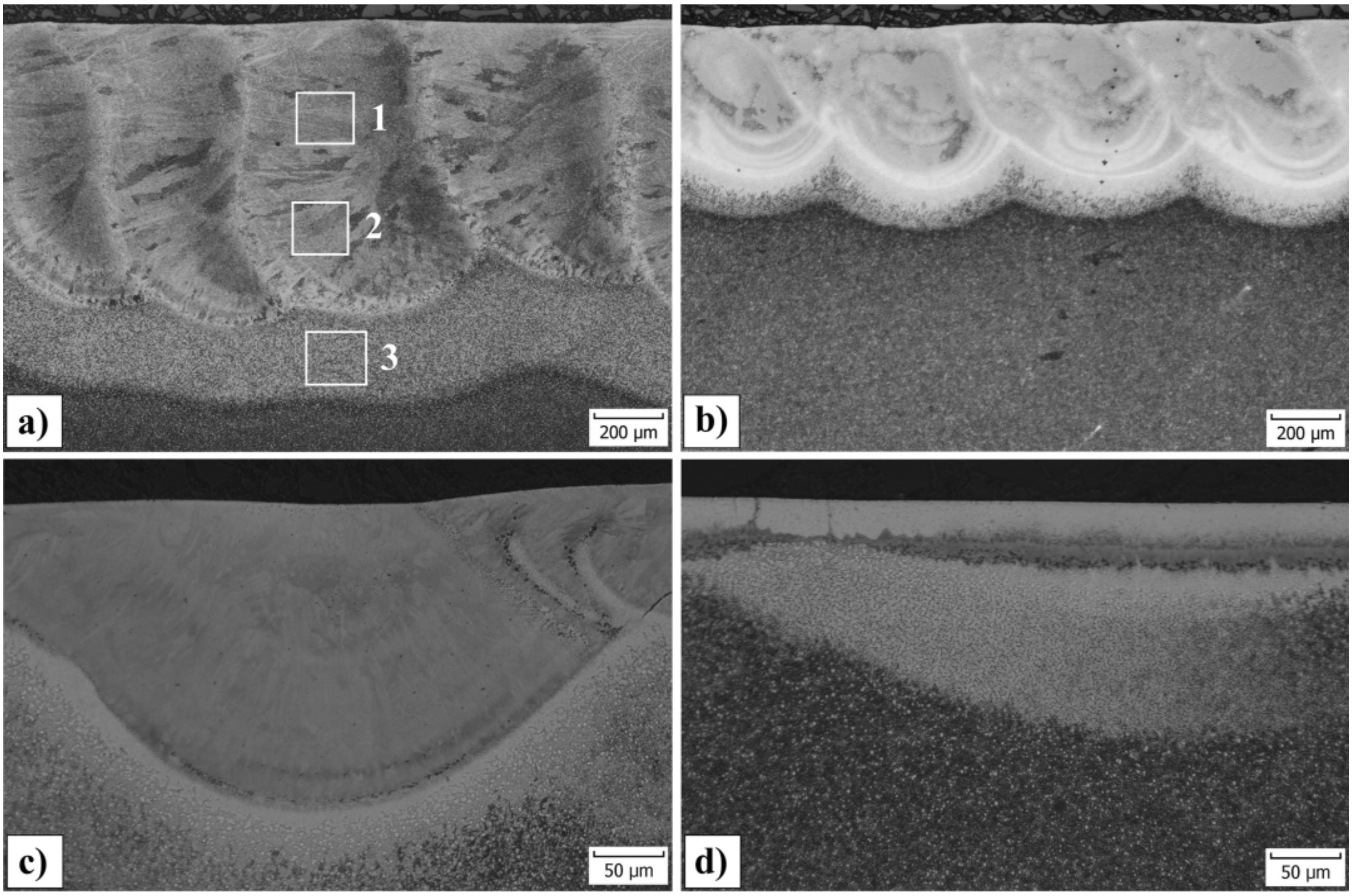

Fig. 3. Microstructure of boronized layer after laser modification with using different value of the laser beam fluence: a) 76.4 J/mm^2; b) 25.5 J/mm^2; c) 12.7 J/mm^2; d) 7.6 J/mm^2

at the top of melted pool, an additional heat flux was found. It was the flux from the molten metal to ambient atmosphere. It can thus assume that there is higher solidification rate in the vicinity of the free surface. It can result in refined microstructure compared to the material at the bottom of melted pool.

The microstructure of the material in the top of remelted zone consisted of boride eutectic with martensite (Fig. 4a). Microstructure details in the bottom of remelted zone was shown in Figure 4b. The material in this zone consists of primary dendrites that are embedded in eutectic mixture. The details of the microstructure of the dendrites were not visible at the given magnification, however, based on thermal history of the material one can assume that they contain mainly the martensite with certain amount of retained austenite. The eutectic mixture around the dendrites shows lamellar morphology with the thickness of individual lamellae of around 0.1 μm. The heat affected zone consists of martensitic matrix with regularly shaped carbides with a general size ranging between 0.5 and 3 μm (Fig. 4c). There are two main types of these carbides. The first is the M_7C_3 and the second is MC. This is consistent with previously published results concerning laser remelting of the same material (but without the pre-boronizing) where the same phases were detected in heat affected zone [19,34].

In Figures 5 and 6 were shown the microstructures of surface layer remelted with using the lowest value of the laser beam fluence. As a consequence of used the mentioned parameters of laser remelting, the depth of remelted zone was very small corresponds to the depth of pre-boronized layer. Firstly, it was found that smaller volume of remelted material resulted in correspondingly finer microstructure of this zone as shown in Figures 5 and 6, in comparison with SEM image in Figure 4. In Figure 6b was shown magnification of area marked by square from Figure 6a, while in Figure 6d was shown magnification of area marked by square from Figure 6c. Figures 6a and 6b show that the material is composed of primary flower-shape intermediary phases and very fine eutectic formations. The nature of primary phases can not be determined by SEM because their size was too small (less than 1 μm). Based on the nature of the parent material and based on the fact that boron was input into the surface, it can only assume, that the particle is complex carbo-boride. Eutectic mixture is also refined in comparison to that formed in the specimen modified using higher laser output power (Fig. 4) – estimated inter-lamellar distance was about 20 nm. The microstructures shows in Figures 6c and 6d were different from that shown in Figures 6a and 6b. However, the determination of the nature of the primary phase (light grey) is a controversial issue. It seems to be that these features correspond to solid solution (note that the Vanadis-6 steel crystallizes in a hypoeutectic manner at slow solidification rate [35]), however, the formations do not manifest typical dendritic morphology.

Hence, a primary crystallization of some intermediary phase might be expected, also.

However, it can conclude that the laser remelting of pre-boronized Vanadis-6 steel was accompanied to the rapid solidification effect, which was expressed by considerable refinement of main microstructural features and changes in the basic solidification mechanism from hypo- to hypereutectic.

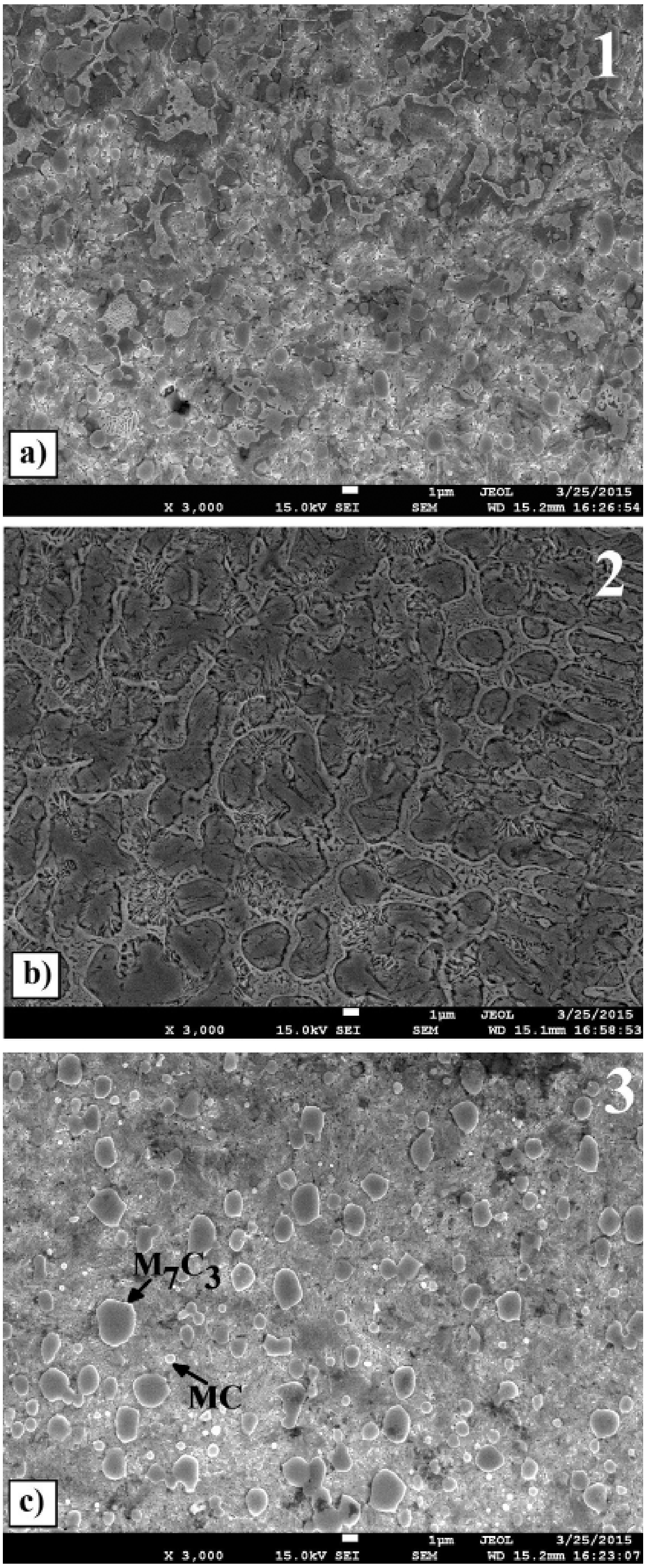

Fig. 4. Microstructurs of boronized layer after laser modification with using fluence equal to 76.4 J/mm^2: a) top of remelted zone, b) bottom of remelted zone, c) heat affected zone

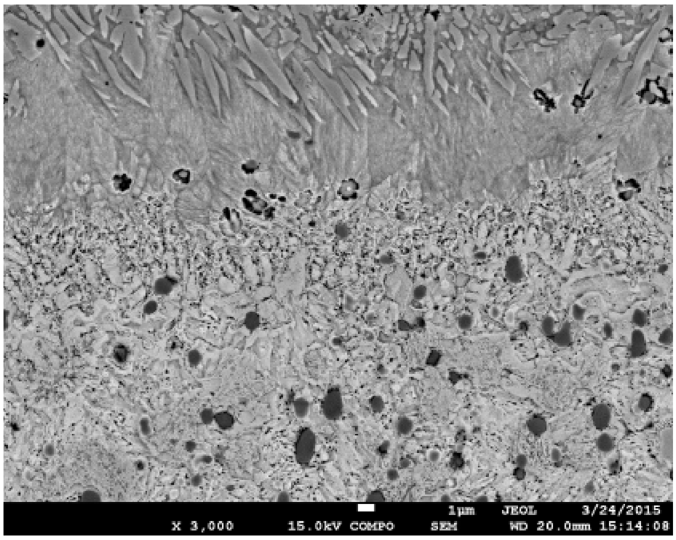

Fig. 5. SEM image of microstructures of boronized layer after laser modification with using the lowest laser beam fluence (7.6 J/mm^2)

The boronized layers before and after laser modification were analyzed with an X-ray diffractometer and the results showed that the remelted region was composed of iron borides and martensite. After laser modification of boronized layers equilibrium iron boride phase FeB and Fe_2B and non-equilibrium iron-carbon-boride phase $B_{0.7}Fe_3C_{0.3}$ were detected.

In Figure 7a was presented X-ray pattern of boronized layers after laser modification with using the highest value of laser beam fluence. It can be observed that the peak intensity of iron phases increases together with the laser modification parameters. The peak intensity of iron boride phases (FeB and Fe_2B) decreases with increasing depth of laser tracks. On X-ray spectrum which was shown in Figure 7a, the chromium boride Cr_2B phases were detected. Presence of this phases was connected with a high participation of steel substrate. Its intensity increases at the expense of iron boride intensity. Furthermore, the peaks intensity of the iron boride phase decreases along with the increase of value of laser beam fluence.

In Figure 7b was shown X-ray spectrum of boronized layers after laser modification using the lowest value of laser beam fluence. It was found that such value of fluence caused increase the peaks intensity of iron boride phase. The highest peaks intensity was detected for Fe_2B and FeB phases. Additionally the $B_{0.7}Fe_3C_{0.3}$ complex phase was detected. The results of this study were in an excellent agreement with the results obtained by Author of paper [21]. The cited paper focused on produced a boronized layer on the specimens, with precoat of amorphous boron paste underwent laser modification. As a result of laser modification, α-Fe, FeB, Fe_2B, and Fe_3B (metastable) phases in the remelted zone were detected. The Author concluded that insertion the low amount of boron into the melt, which occurs at a small thickness of the coat or in deep melting, leads to the formation of a microstructure that consists of primary dendrites

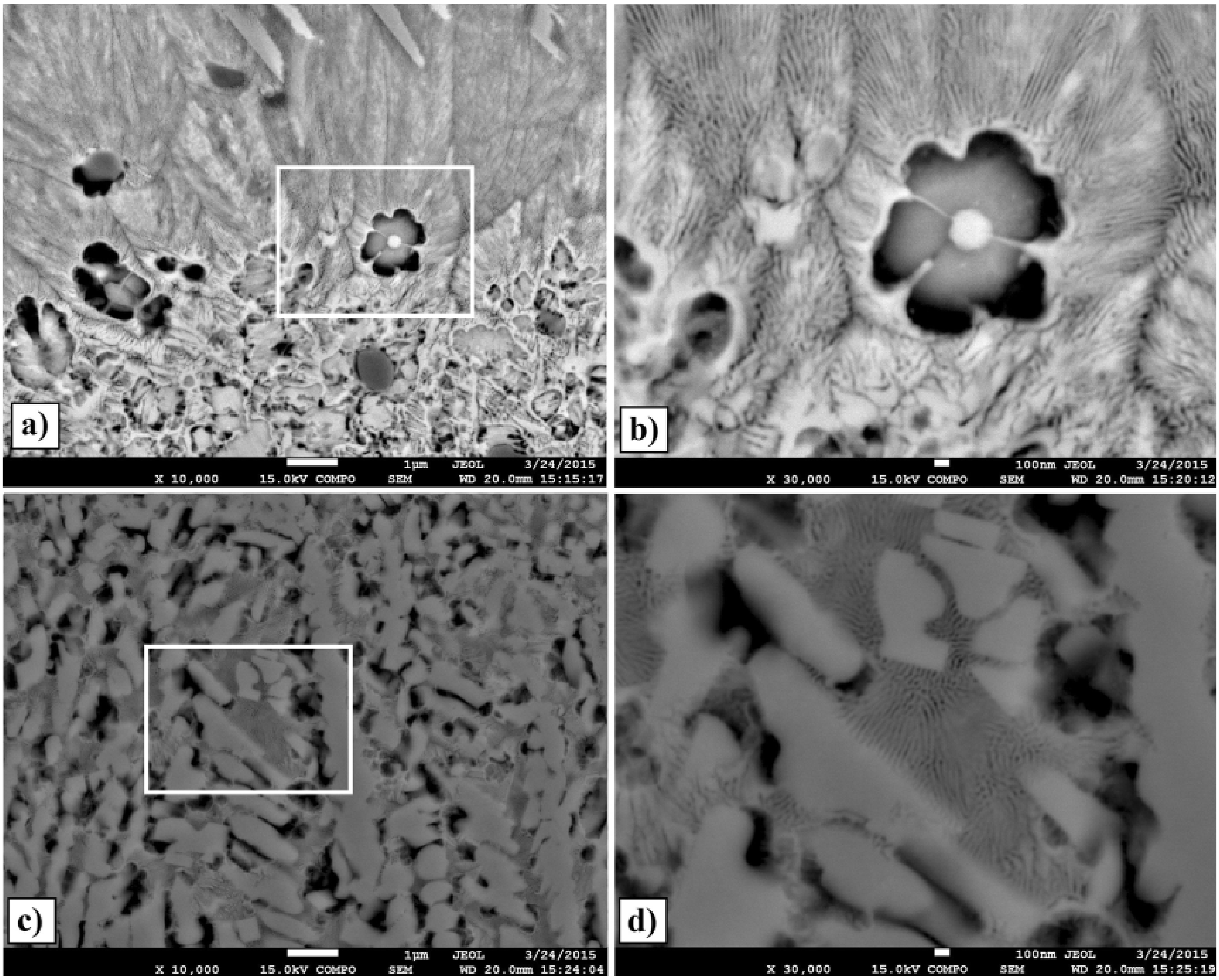

Fig. 6. Details of microstructures of boronized layer after laser modification with using the lowest laser beam fluence equal to 7.6 J/mm^2 (areas selected from Figure 5)

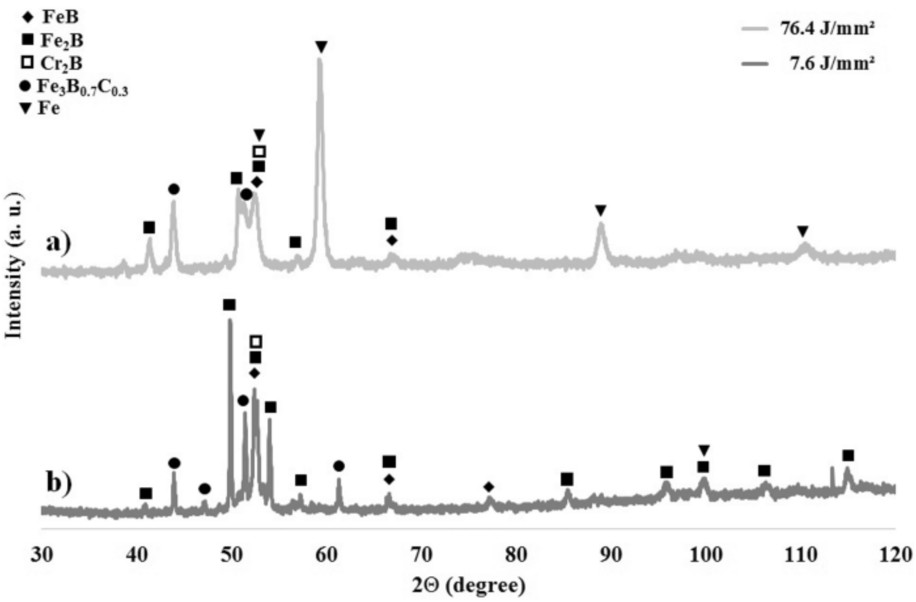

Fig. 7. X-ray spectrum of boronized layers after laser modification with using: a) the highest laser beam fluence equal to 76.4 J/mm^2, b) the lowest laser beam fluence equal to 7.6 J/mm^2

(very likely α-phase) and lamellar boride eutectic. The microstructure of the boronized zone in cited case was hypoeutectic and had the form of α + eutectic. When the laser modification allows to adding the high amount of boron, the remelted zones have a microstructure that consists of primary boride crystals and an eutectic. As a results the microstructure of the boride zone is hypereutectic (eutectic + borides). Author of paper [21] also showed, that the primary borides can take various shapes like branched, round, prismatic or angular. These various shapes were mainly represented by primary borides Fe_2B or complex carbo-borides $Fe_2(B,C)$.

In this paper was found that with using highest laser beam fluence, it can be produce the layer containing all these phases. The layer produced using the lower laser beam fluence contained mostly Fe_2B, together with unusual $Fe_3B_{0.7}C_{0.3}$ complex phase. The hypereutectic microstructure consisting of primary borides/complex carbo-borides $Fe_2(B,C)$ and eutectics has been reported in the cases of insertion the high amounts of boron into the melt, e.g. when the melting depth corresponded to the thickness of pre-boronized regions. Therefore one can claim that laser remelting of pre-boronized layers on the Vanadis-6 steel produces considerably refined as-solidified microstructures and additionally contributes to the formation of unusual metastable phases in selected cases being represented by the highest cooling rates (the smallest remelted areas). Additionaly, in hese case, a change of solidification mechanisms from hypo- to hypereutectic takes place.

3.2. Microhardness profiles

Microhardness of boronized layer on Vanadis-6 steel was between 1600 and 1800 HV 0.1. In figures from 8a to 8d were shown the microhardness results of the studied laser tracks. The depth of MZ and HAZ zones were marked on the graphs. It may be noted that the laser modification parameters significantly affected on microstructure and consequently on microhardness of laser tracks. In Figure 8a was shown the microhardness of boronized layer produced using the highest laser beam fluence. This microstructure was presented in Figure 3a. The microhardness of remelted zone was approximately 1000 HV 0.1. However, lowered value of the laser beam fluence caused formation smaller laser tracks and thereby caused elevated microhardness in corresponding remelted zones (1700 HV 0.1 in selected cases). In the all of studied specimens, microhardness profiles gradually decreased from remelted zone through heat affected zone to the substrate. Microhardness oscillated within the range of 800-1000 HV 0.1 in HAZ and droped to a value ranging between 700 and 800 HV 0.1 in the substrate. The microhardness oscillations in MZ and in HAZ can be related to the rate of heat

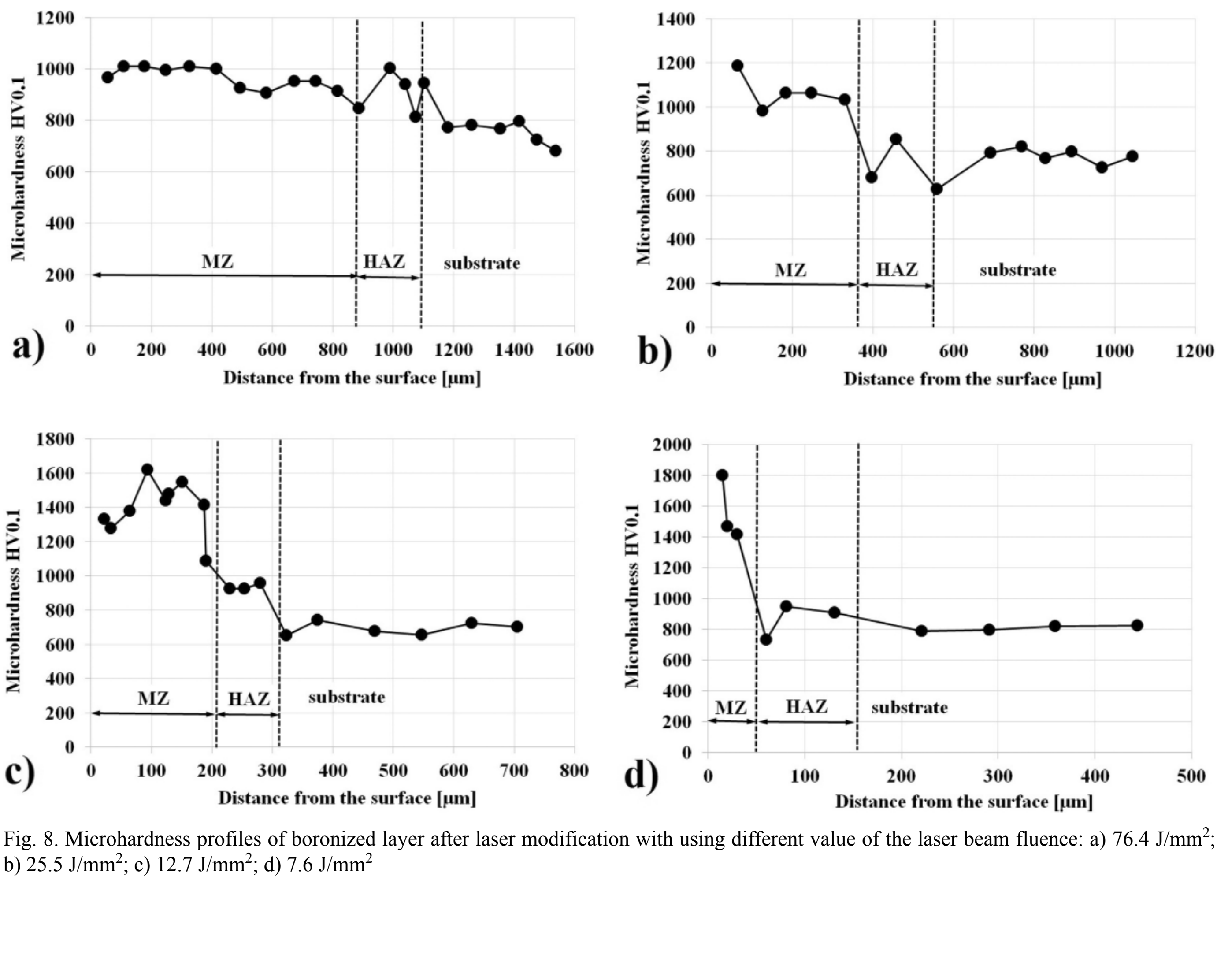

Fig. 8. Microhardness profiles of boronized layer after laser modification with using different value of the laser beam fluence: a) 76.4 J/mm^2; b) 25.5 J/mm^2; c) 12.7 J/mm^2; d) 7.6 J/mm^2

dissipation. The lowest value of the laser beam fluence caused the higher rate of heat dissipation.

Based on obtained results, it was also shown that the thinner remelted zone causes obtaining the higher microhardness. In previous text it has been demonstrated that the thinner remelted solidify in a hypereutectic manner, while those thicker manifest rather hypoeutectic microstructure. Therefore it is clear that the final microhardness of boronized and laser remelted zones may result from the parameters of laser beam and also from the thickness of boronized region. It can be seen that the microstructure of formed eutectic with iron borides and carbides (hypereutectic) had a higher microhardness (Fig. 8d), whereas the eutectic with martensite microstructure had lower microhardness (Fig. 8a). Laser modification was characterized by the fact that solubility of boron in the liquid pool of laser tracks may be vary. Laser modification parameters affect on microstructure in remelted zone, in which the amount of eutectic, iron borides and carbides can change. It also affects on the microhardness value.

4. Conclusions

1. The diffusion boronizing process at 1030°C for 45 minutes in Durborid® powder mixture, carried out on Vanadis-6 steel leads to formation the double-phased (FeB/Fe_2B) layers with a thickness of 50 μm.
2. As a result of laser modification the new layers consisting of three zones: remelted (MZ), heat affected (HAZ) and the substrate were obtained.
3. In the remelted zone, two areas were situated: first - enriched in boron and carbide (hypereutectic area) and second – containing lesser amount of boride and carbide (hypoeutectic area). Depending on the laser beam parameters, in the remelted zone iron boride FeB, Fe_2B, $B_{0.7}Fe_3C_{0.3}$ or Cr_2B and iron phases were detected.
4. Laser modification causes formation very fine microstructures consisting of primary dendrites and eutectics (in the case of thicker melted zones), as well as primary carboborides surrounded by eutectics (in the cases of thinner melted zones).
5. The important parameters which have influence on the obtained properties are laser beam power, scanning speed and the resulting from these: exposure time of laser beam on material and laser beam fluence. The increase of laser beam fluence causes increase the dimensions of the laser tracks. The most advantageous parameters are those that allow to obtain the laser beam fluence equal to 12.7 J/mm^2. For this value of fluence, the thickness of layer is four times greater than for boronized layers. In this case, the microhardness in remelted zone was relatively high and constant.
6. The remelted zones has lowered microhardness in comparison to the pre-boronized material. The degree of microhardness decrease is directly proportional to the thickness of remelted zones. Boronized layers modified by laser beam were characterized by a milder microhardness gradient from the surface to the substrate in comparison to diffusion boronized layers. A mild microhardness gradient was dependent on the microstructure consisting of three zones. Microhardness in the remelted zone was approximately from 1800 HV0.1 to 1000 HV0.1 and its value was dependend on laser modification parameters. The lower value of laser beam fluence, the microhardness value in remelted zone was higher.

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