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Laser treatment of the surface layer of 32CrMoV12-28 and X40CrMoV5-1 steels

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ABSTRACT

Purpose: This work presents the investigation results of laser remelting and alloying especially the laser parameters and its influence on the structure and properties of the surface of the 32CrMoV12-28 and X40CrMoV5-1 hot work steels, using the high power diode laser (HPDL). In this paper there are presented the investigation results of mechanical properties and microstructure with ceramic particle powders VC vanadium carbide and WC tungsten carbide. The purpose of this work was also to determine the laser treatment conditions for surface layer treatment of the investigated steels.

Design/methodology/approach: The purpose of this work was the determination of technological conditions for alloying and remelting of the surface layer particularly the laser power. There is studying the influence of treatment on the remelting depth of the surface layer to achieve high layer hardness for protection of the steel and also make the surface more resistant for work.

Findings: As a result structure changes in form of fragmentation were determined. For alloying the tungsten carbide and vanadium carbide powders were used. Two phases of carbides, VC and WC, were observed.

Research limitations/implications: The remelted layers which were formed on the surface of the investigated hot work steel were examined metallographically and analyzed using a hardness and micro hardness testing, X-ray diffraction, EDS microanalysis, electron scanning microscope.

Practical implications: This work helps to use the new developed laser treatment technique for alloying and remelting of hot work tool steel tools for hot working conditions.

Originality/value: The originality of this work is based on applying of High Power Diode Laser for improvement of steel mechanical properties as well the thermal fatigue and wear resistance.

Keywords: Surface treatment; Heat treatment; Hot work tool steel; High power diode laser

1. Introduction

The laser treatment as a new technique applied in laser surface technology is presented in this paper. There is presented laser treatment with remelting and cladding of hot work tool steels grade 32CrMoV12-28 and X40CrMoV5-1with chosen ceramic carbide powders: Tungsten Carbide WC and Vanadium Carbide VC. The structure and improvement of mechanical properties is the most important aim of this work; because the improvement of hardness of the surface layer is a critical factor for practical use.

Diode lasers have long been used as light emitters in fibre-optic telecommunications, as barcode readers, and for implementing the write–read functions of optical disks. Ideal material systems to fabricate high-power diode lasers are the III–V compound semiconductors. Power performance is so far restricted to wavelengths ranging from 630 nm to 1600 nm [1-5].

This type of surface treatment is used for improvement of hardness by changing the structure and improvement of the abrasion wear resistance, mostly by introduction of carbide or other ceramic particles to the material matrix. Rapid mixing is leading to development of the surface layer, with cross-section showed on Figure 1, from the remelted materials occurs during the alloying process with the sufficiently high laser power [6-9].

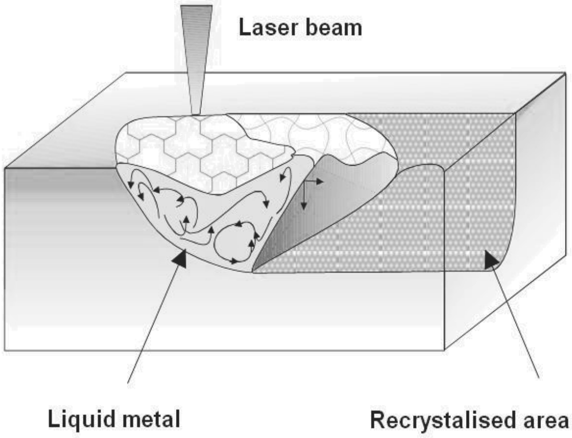


Fig. 1. Theoretical zone view of a cross-section of the laser remelted samples

For producing of a properly alloyed surface layer, the laser pool originates on the specimen surface, to which the carbide or ceramic powder is introduced. Intensive mixing in the remelted zone is due to the shear stresses developed in the remelted zone. This process is very important, as affects the type of convection motion, and therefore the final distribution of the alloying element in the remelted zone. The intensity of the convection motions, therefore velocity of liquid transition, is caused also by a big temperature gradient, which is the bigger the bigger is the energy portion delivered in the unit time of the laser beam operation. Entering of powder is done using the conveyor directly during remelting, or else the powder is being applied as paste which dries up on the specimen surface, and only next is subjected to alloying. This makes it possible developing the alloy with the bi- or multi-component structure, and also of the composite or gradient type with the intermetallic phases. Thanks to the rapid cooling because of heat removal to the cold substrate an advantageous, fine-grained structure develops, which may also display the gradient morphology. The surface layers obtained with laser alloying may have the heat-resisting and anti-corrosion properties, may also be characteristic of the high abrasion wear and erosion resistance [10-13].

Tungsten and vanadium carbides are rarely used tool materials sometimes used in metal machining because of its high hardness and high resistance to softening at high cutting speed and at high cutting temperature. The second concern is to achieve a maximum hardness in the surface layer to ensure good working parameters [14-17].

Tool steels still feature the widely used group of tool materials, especially interesting because of their low price and very good functional properties. Big interest in these steels gives basis for carrying out investigations focused on improvement of the functional properties of these materials [18-21].

The purpose of this work is to study the effect of a HPDL laser melting on the hot work tool steel, especially on their structure and hardness. Special attention was devoted to monitoring of the layer morphology of the investigated material and on the particle occurred.

2. Experimental procedure

2.1. Description of the material used for investigation

The material used for investigation were the hot work tool steels 32CrMoV12-28 and X40CrMoV5-1, they were supplied in the annealed state.

This steels were supplied in form of rods 76 mm in diameter and in the length of 3 m. Samples of this material were of the plate form, of the rectangular shape, with dimensions 70 x 25 x 5 mm.

The chemical composition of the investigated steels is presented in Table 1. Before the laser treatment a standard heat treatment was applied presented on Figure 2. The heat treatment itself was performed in a horizontal flow-through furnace developed by Nitrex Metal Inc with an integral rapid cooling chamber which is especially suitable for large-scale nitriding of plain carbon steel or low alloy steel heat treatment, this furnace is presented on Figure 3.

Heat treatment of the 32crmov12-28 steel: Austenisation was performed in an vacuum furnance in a temperature of 1040 ºC for 0.5 hour. During the heating to the austenitic temperature two izotermic steps were applied, the first in the temperature of 585 ºC and the second in 850 ºC. After tempering two annealing operations were performed during 2 h each, the first in 550 ºC and the second in 510 ºC. After heat treatment the surface of specimens were grounded on magnetic grinder.

Heat treatment of the x40crmov5-1 steel: Specimens were twice subjected to heat treatment consisting in quenching and tempering austenizing was carried out in the vacuum furnace of 1020ºC with the soaking time 0.5 h. Two isothermal holds were used during heating up to the austenizing temperature, the first at the temperature of 640ºC and the second at 840ºC. The specimens were tempered twice after quenching, each time for 2 hours at the temperature 560ºC and next at 510ºC. After heat treatment the surface of specimens were grounded on magnetic grinder.

On the prepared and fatless samples the carbide powders (Fig. 4) were carried on. The powder was before mixed with inorganic sodium glass. Every time a paste layer of 0.5 mm in thickness was carried on.

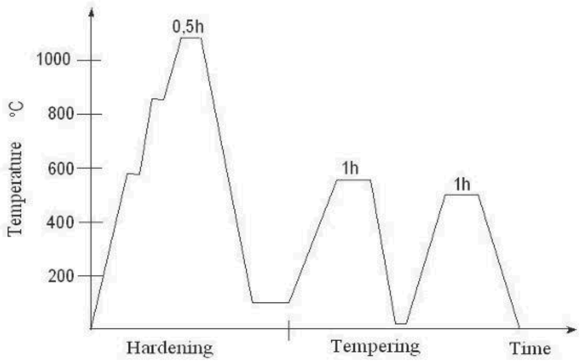


Fig. 2. Heat treatment process carried out for the investigated tool steel

2.2. Laser alloying

The WC and VC powders (Table 3) used are 5μm in diameter. The high power laser diode HPDL Rofin DL 020 with work parameters presented in Table 2 was used, the maximum speed for a good work process is v = 0.5 m/min. The laser power was set on 1.2 kW. For surface preparation the standard metallographic procedure was applied.

Table 1.
Chemical composition of the investigated hot work tool steels

Alloying additives wt. %	Steel grade 32CrMoV12-28	Steel grade X40CrMoV5-1
C	0.308	0.41
Si	0.25	1.09
Mn	0.37	0.44
P	0.020	0.15
S	0.002	0.10
Cr	2.95	5.40
W	-	0.01
Mo	2.70	1.41
V	0.535	0.95

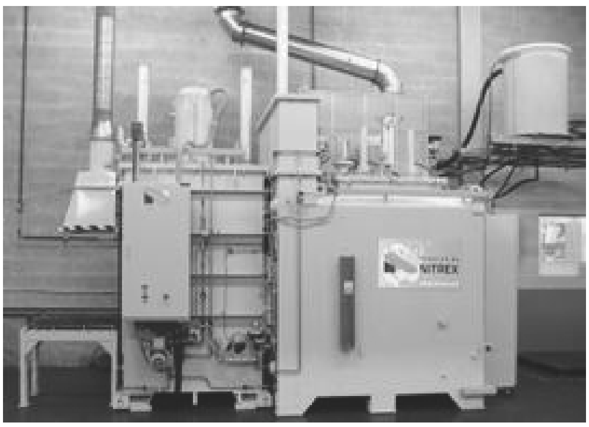


Fig. 3. Nitrex Metal Inc horizontal chamber furnace

Table 2.
HPDL laser parameters.

HPDL laser parameter used for alloying	
Parameters	Value
Laser wave length, nm	940 ± 5
Peak power, W	100 - 2300
Dimensions of the laser beam focus, mm	1.8 x 6.8

Table 3.
Properties of the used ceramic powders.

Properties Powder	Hardness, HV	Density, kg/m3
WC	2600	15.6
VC	2850	5.36
Properties Powder	Melting temperature, ºC	Grain size, µm
WC	2870	5
VC	2830	1.5

Structure investigation was performed using the light microscope Leica MEF4A supplied by Zeiss in a magnification range of 50 - 500x. The micrographs of the microstructures were made by mind of the KS 300 program using the digital camera. The observation were prepared perpendicularly to the cross section of the sample no the each remelted tray. Metallographic investigation were performed also using the scanning electron microscope DSM 940 supplied by OPTON in a magnification range of 500 - 2000x. Phase composition and crystallographic structure was determined by the X-ray diffraction method using the DRON 2.0 device with an Cobalt lamp, voltage 40 kV. The measurement was performed by an 2Θ angel range of 35º - 105º. Hardness measurements results were performed for each of the remelted areas according to the power used. For this reason the Rockwell hardness tester supplied by Zwick was used according to the norm PN-EN ISO 6507-1, by a load of 147.2 N for 15 s.

a)
b)

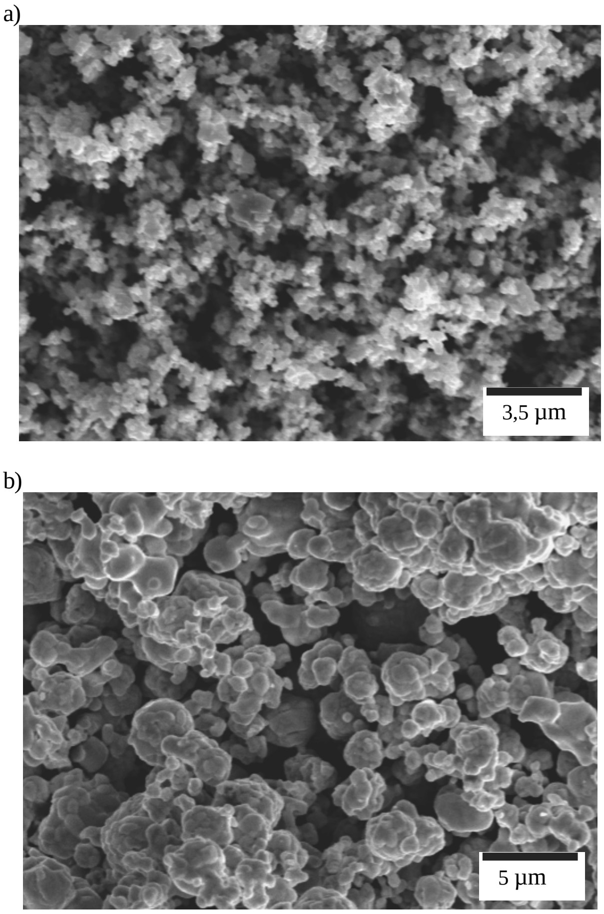


Fig. 4. Ceramic carbide powders used for alloying, a) Vanadium carbide VC, b) Tungsten carbide WC (SEM)

3. Investigation results

Performed investigations of the alloyed hot work tool steels 32CrMoV12-28 and X40CrMoV5-1 grades show a influence of the laser working parameters and ceramic carbide powders used for cladding to the shape and thickness of the remelted material (Figures 5 - 8). On Figures 5, 8 - 10 the surface roughness and shape is presented, it can be state that the higher laser power of 2.3 kW causes a higher surface roughness compared to the 1.2 kW power used, in general the roughness increases with increased laser power respectively 1.2; 1.6; 2.0 and 2.3 kW. Considering the ceramic powder used for cladding it can be state that the thickest surface layer is present in the case of VC powder for both 32CrMoV12-28 and X40CrMoV5-1 steel grades. Structures presented on figures 11 and 12 show the structure of VC alloyed samples, were only grains are visible without any dendrites for both steel grades. Pictograms presented on Figures 13 to 14 show a dendritic structure in the remelted area for the case of WC remelted steels. There are also WC particles present distributed in the matrix specially for cladding with WC powder (Figure 14.) There is also a clear relationship between the employed laser power and the dendrite size, namely with increasing laser power the dendrites are larger. Moreover the hot work tool steel has a ferritic structure with homogeny distributed carbides in the metal matrix in the annealed state.

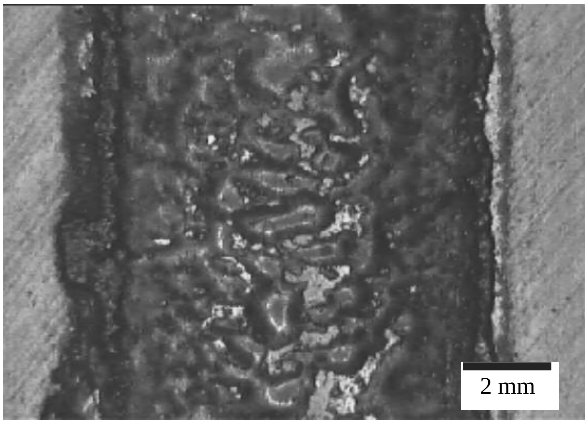


Fig. 5. Structure of the surface layer of the laser remelted samples, 32CrMoV12-28 steel, VC, laser power 2.3 kW

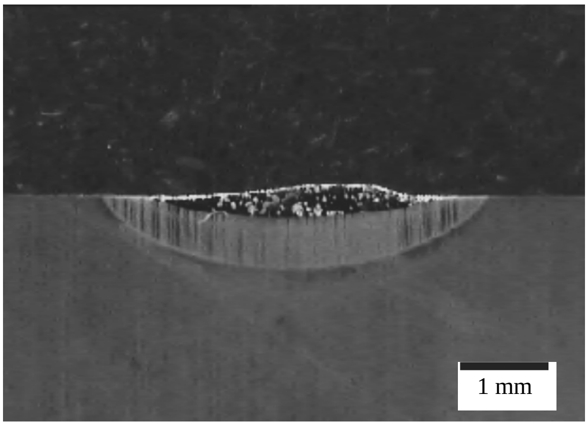


Fig. 6. Shape and thickness of the cross-section of the laser remelted samples, 32CrMoV12-28 steel, WC, laser power 2.0 kW

There is also a clearly relationship between the ceramic carbide powder used and the dendrite size, namely the structure with WC show a dendritic structure and the material with VC powder alloyed has a grain structure for both steel grade investigated.

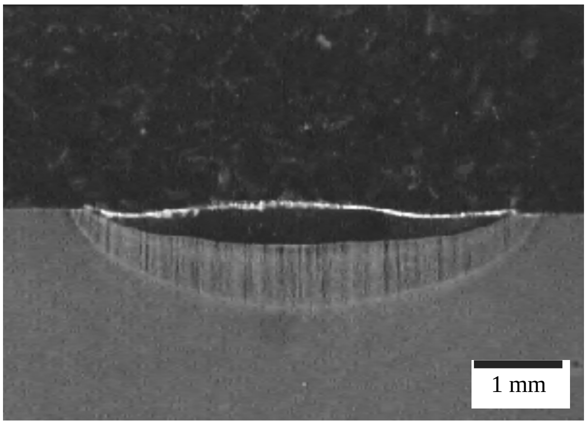


Fig. 7. Shape and thickness of the cross-section of the laser remelted samples, 32CrMoV12-28 steel, VC, laser power 2.0 kW

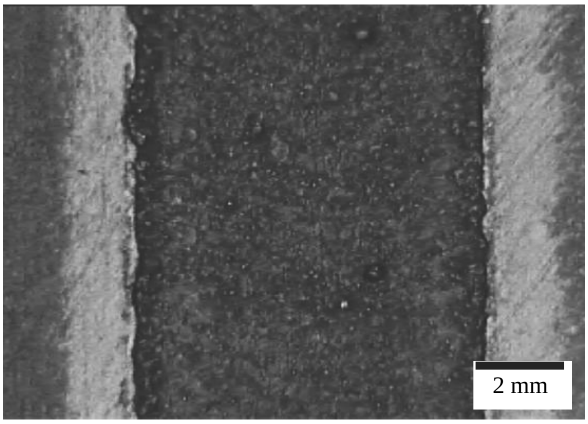


Fig. 8. Structure of the surface layer of the laser remelted samples, 32CrMoV12-28 steel, VC, laser power 1.2 kW

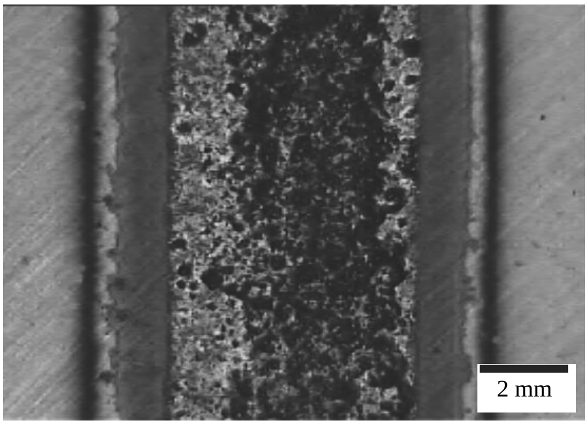


Fig. 9. Structure of the surface layer of the laser remelted samples, WC, laser power 1.2 kW

Increasing of the roughness value is depending, as shown before, of the laser power and ceramic powder used and is caused also by adsorption grade of the laser beam energy through the machined material.

The metallographic investigations on light microscope and in the electron scanning microscope show, that the structure of the crystallized material after laser remelting can be characterized by a differentiation of the structure, which dependent on the speed of crystallization and of the powder used. In general the microstructures presented on Figures 6 and 7 show the different zones in the surface area, namely the remelted zone, the heat affected zone over the steel matrix. In areas, which are between the solid and molten state dendritic structure with large dendrites can be found .

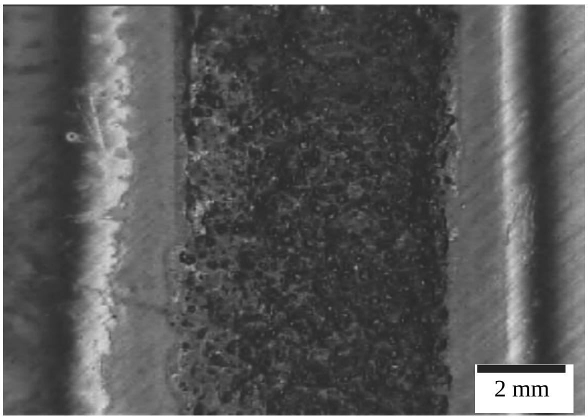


Fig. 10. Structure of the surface layer of the laser remelted samples WC, laser power 2.3 kW

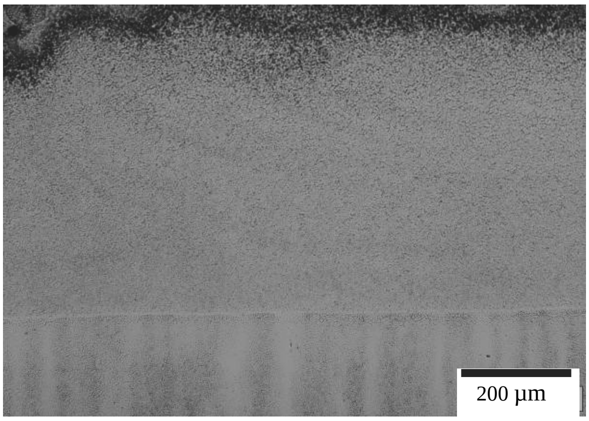


Fig. 11. Microstructure of the VC alloyed sample, X40CrMoV5-1 steel grade, laser power 2.3 kW

The required hardenability for this tool steel was achieving after a suitable tempering time, which assures melting of the alloying carbides in the austenite. The structural investigations carried out using the high power diode laser allows to compare the surface layer as well as the shape and depth of the remelting area. It was noticed that the depth of remelting area grows together with the increasing laser power, which was confirmed by the results presented on Figures 6 and 7.

After tempering a martensite structure is achieving, where the alloyed additive elements are solute, which confirms the chemical EDX microanalysis. The EDS point wise analysis diagram shown in Figures 15 to 21 confirms the occurrence of WC and VC particles in the matrix in form of small particles homogeny distributed in the steel matrix specially for the VC powder. The distribution is clearly shown on Figures 15a and 18 as a result of scanning microscope structural investigations.

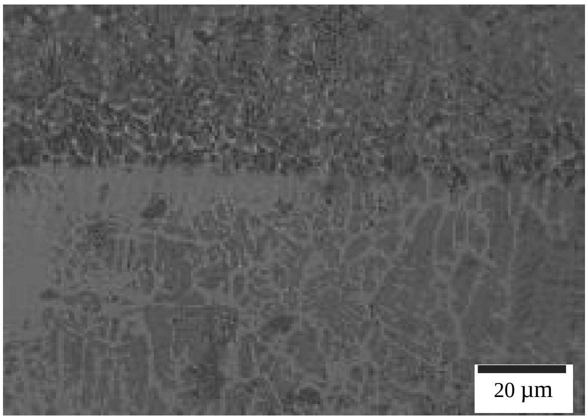


Fig. 12. Microstructures of the WC alloyed sample, 32CrMoV12-28 steel grade, WC powder, laser power 2.0 kW

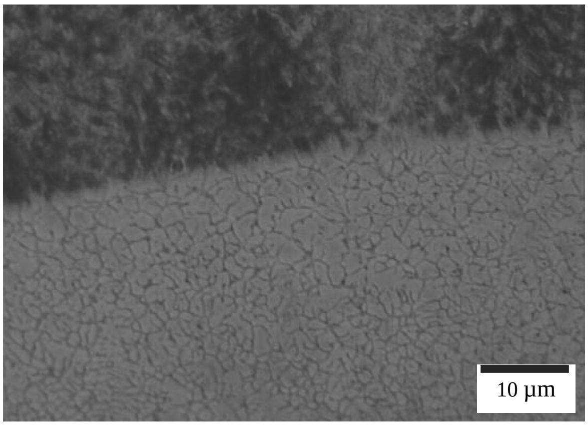


Fig. 13. Microstructures of the VC alloyed sample, 32CrMoV12-28 steel grade, VC powder, laser power2.0 kW

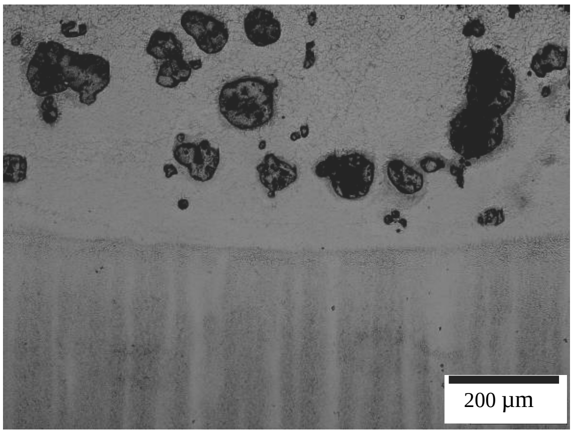


Fig. 14. Microstructure of the WC alloyed sample, X40CrMoV5-1 steel grade, laser power 1.6 kW

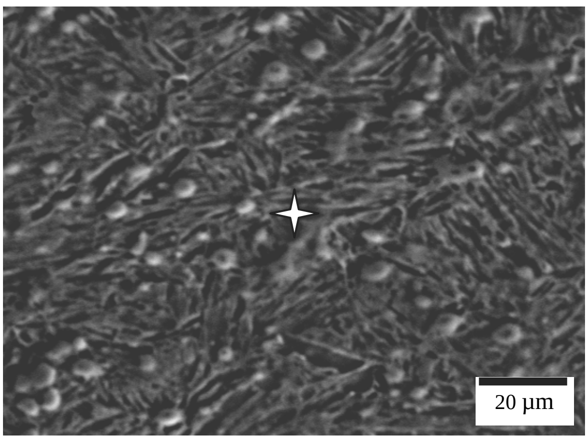
Table 4.
Hardness measurements results X40CrMoV5-1 steel

Laser Power kW \ carbide powder	Steel grade X40CrMoV5-1 hardness HRC	
	WC	VC
1.2	56	55
1.6	58	56
2.00	58	63
2.3	59	60

Table 5.
Hardness measurements results of the 32CrMoV12-28 steel

Laser Power kW \ carbide powder	Steel grade 32CrMoV12-28 hardness HRC	
	WC	VC
1.2	57	57
1.6	58	57
2.00	60	58
2.3	60	59

a)



b)

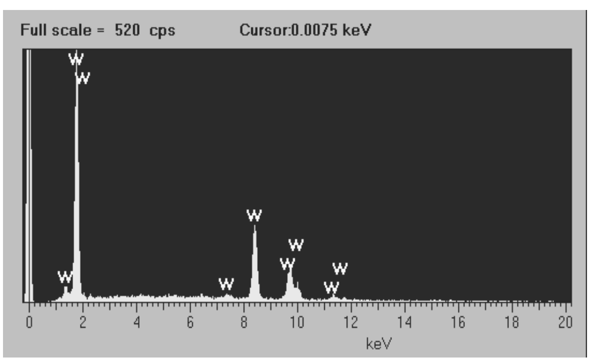


Fig. 15. a) SEM Microstructure of the of the 32CrMoV12-28 steel remelted with WC powder, b) EDX point analysis made on the marked point in a)

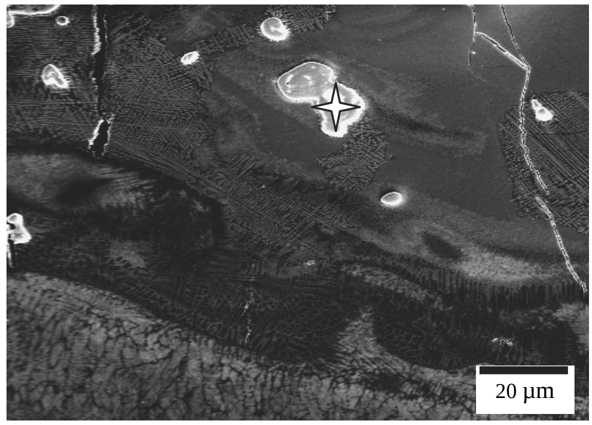


Fig. 16. SEM Microstructure of the 32CrMoV12-28 steel remelted with VC powder, laser power

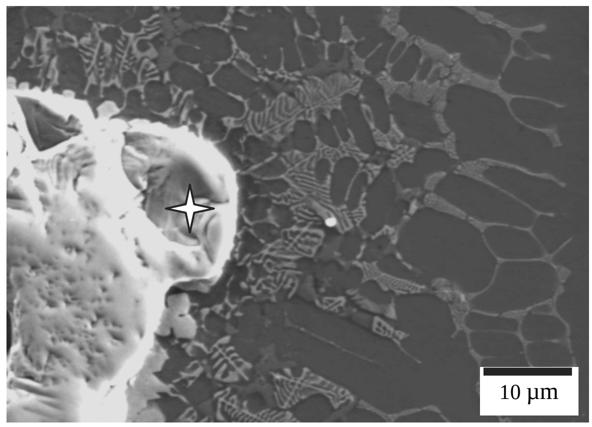


Fig. 17. SEM Microstructure with small eutectics of the X40CrMoV5-1 remelted with WC powder, laser power 1.2 kW

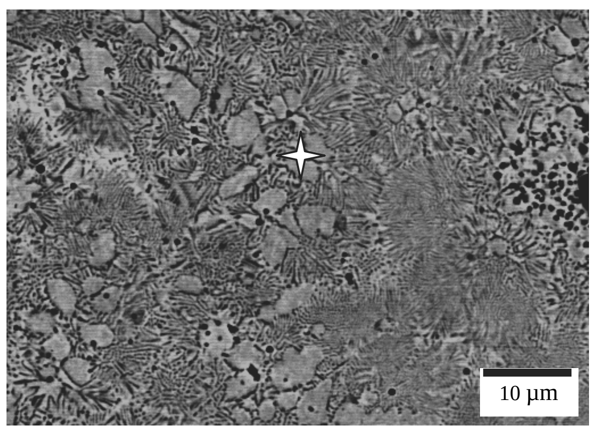


Fig. 18. SEM Microstructure of the X40CrMoV5-1 remelted with VC powder, laser power 1.6 kW

As a result of WC laser alloying powder the difference of the remelted area thickness among the power of 1.2 kW and 2.3 kW is about 25 % larger for the 2.3 kW power. For VC powder the difference is smaller and achieves only ca. 18%. These values are similar for both grades of steels. The highest value is achieved for alloyed top surface and id decreased with the remelting depth until the hardness value of the steel matrix is achieved.

Tables 4 and 5 show the hardness measurements results of the remelted surface for 1.2, 1.6, 2.0 and 2.3 kW laser power. The highest hardness value is achieved for the 2.3 kW laser power. For both ceramic particle used for both steel grades. Compared to the steel remelted only - without any ceramic powder used - can be also clearly state an improvement of the wear resistance. The HRC hardness for the steel after a standard heat treatment is about 52 HRC, so a 15% increase can be achieved.

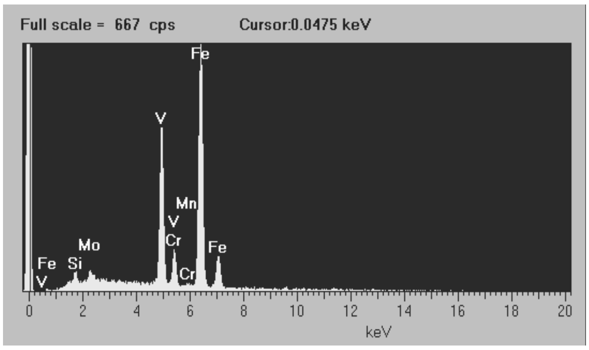


Fig. 19. EDX point analysis made on the marked point in Fig. 16

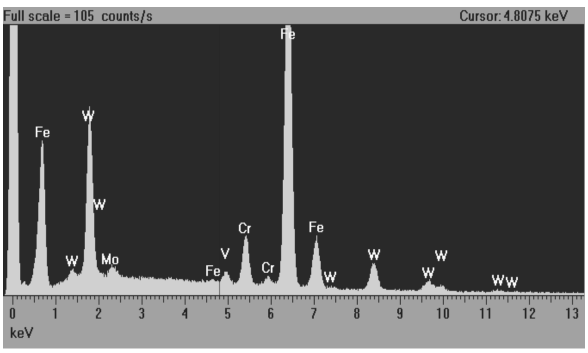


Fig. 20. EDX point analysis made on the marked point in Fig. 17

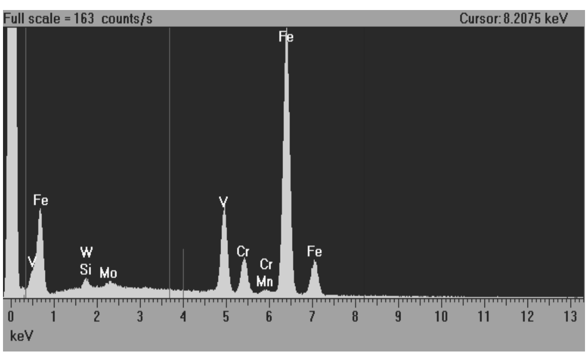


Fig. 21. EDX point analysis made on the marked point in Fig. 18

Next investigation of these steels alloyed with ceramic carbide powders will be performed on the basis of a wear test, using the metal- ceramic material or metal – metal method, where as a measurement standard was chosen the depth of wear trace measured on the cross-section of the steel ball. This investigation gives a result about wear resistance of the surface layer there will be investigated if the wear resistance increases with increasing laser power, as it can be assumed on the hardness measurements results.

4. Conclusions

The performed investigations aloud to conclude, that as a result of heat-treatment as well as cladding of the hot work steels 32CrMoV12-28 and X40CrMoV5-1 with WC and VC powder can be possible to obtain high-quality top layer without cracks and defects as well as considerably higher hardness value compared to material after a standard heat treatment. The hardness value increases according to the laser power used so that the highest power applied gives to highest hardness value in the remelted layer. Together with the increasing laser power, also the depth of remelting material grows up. The metallographic investigations performed on the scanning microscope using the EDX analysis confirm the occurrence of vanadium and tungsten carbide distributed in the steel matrix, the distribution is more uniform in the case of VC for both steel grades.

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