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Comparison of 32CrMoV12-28 steel alloyed with WC, VC and TaC powder using HPDL laser

L.A. Dobrzański [a,*], K. Labisz [a], M. Bonek [a], A. Klimpel [b]
[a] Division of Materials Processing Technology, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
[b] The Chair of Welding, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

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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 hot work steel, 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 vanadium carbide VC, tungsten carbide WC and tantalum carbide TaC. 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, tantalum carbide and vanadium carbide powders were used. Three phases of carbides: TaC, 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; Ceramic powder; High power diode laser

1. Introduction

In this work the laser treatment with remelting of hot work tool steel 32CrMoV12-28 with ceramic powders: tantalum carbide, tungsten carbide and vanadium carbide is presented. The structure and improvement of mechanical properties is an aim of this work.

The reason of this work was to determine the optimal laser treatment parameters, particularly the laser power to achieve good layer hardness for protection of this hot work tool steel from losing their work stability and to make the tool surface more resistant to action in hard conditions. For alloying of the chosen hot work tool steel the tantalum carbide, tungsten carbide and vanadium carbide powders were used. For investigations hardness measurements of the different remelting areas were performed. The remelted layers which were formed in the surface of investigated hot work steel were examined metallographically and analyzed using light and electron microscope. Three phases of carbides, TaC, VC and WC, were observed. The laser treatment as a new technique applied in laser surface technology is presented in this paper.

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 ceramic particles to the material matrix. Rapid mixing leading to development of the surface layer from the remelted materials occurs during the alloying process with the sufficiently high laser power [1-6].

Therefore, 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 [7-16].

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 [8,16].

2. Material and experimental procedure

Materials used for investigation was the hot work tool steel 32CrMoV12-28, it has been supplied annealed. The chemical composition of the investigated steel is presented in Table 1. A standard heat treatment was applied. Austenisation was performed in an vacuum furnance at a temperature of 1040ºC for 0.5 hour. During the heating to the austenitic temperature two izotermic steps were applied, the first In the temperature of 585ºC and the second in 850ºC. After tempering two annealing operations were performed during 2 h each, the first in 550ºC and the second in 510ºC. On the prepared and fatless samples the carbide powders were carried on. The powder was before mixed with inorganic sodium glass. Every time a paste layer of 0.5 mm of thickness was carried on. The powders used are 5-10 µm in diameter, the chosen properties are presented in Table 2. The high power laser diode HPDL Rofin DL 020 with work parameters presented in Table 3 was used, the maximum speed for a good work process is v = 0.5 m/min. It was found out in the preliminary investigations made using the HPDL Rofin DL 020 high power diode laser, that the maximum feed rate at which the process is stable is v=0.5 m/min. Therefore all experiments were made at the constant remelting rate, varying the laser beam power in the range from 1.2 to 2.3 kW. It was established experimentally that the argon blow-in with the flow rate of 20 l/min through the 12 mm circular nozzle oppositely directed in respect to the remelting direction provides full remelting zone protection.

The surfaces of the samples were ground on diamond wheels and next polished using the diamond buffing compounds on Struers equipment. Etching of specimens was carried out in Nital with the following composition: 5 ml HNO_3 nitric acid, 100 ml C_2H_5OH ethyl alcohol, at room temperature. Etching time was selected experimentally for each investigated material's surface layer form.

Table 1.
Chemical composition of the investigated 32CrMoV12-28 hot work tool steel

	Concentration of the elements, mass in %							
	C	Si	Mn	P	S	Cr	Mo	V
32CrMoV12-28 steel	0.308	0.25	0.37	0.020	0.002	2.95	2.70	0.535

Table 2.
Properties of the used ceramic powder

Ceramic powder	Hardness, HV	Density, kg/m^3	Melting temperature, ^{o}C	Grain size, µm
WC	2600	15.6	2870	5
VC	2850	5.36	2830	5
TaC	1725	14.5	3880	10

Table 3.
HPDL Rofin DL 020 laser parameter

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

The observation were prepared perpendicularly to the cross section of the sample on 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.

Hardness measurements results were registered 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.

The X-ray qualitative micro-analysis and analysis of the surface distribution of the alloying elements in the test pieces of the investigated steel, subjected to the standard heat treatment and remelted and alloyed, were made on the Opton DSM-940 scanning electron microscope with the Oxford EDS LINK ISIS X-ray energy dispersive spectrometer at the accelerating voltage of 20 kV. The phase composition of the investigated coatings was determined on the Dron-2.0 X-ray diffractometer, using filtered radiation of the cobalt anode lamp, powered with 40 kV voltage, at 20 mA heater current. The measurements were made in the angle range 2ϴ: 35º - 105º.

3. Results and discussion

Preliminaries investigations of the remelted hot work tool steel 32CrMoV12-28 show a clear dependence of the ceramic carbide powder used to the shape and thickness of the remelted material (Figs. 1, 2 and 3). It can be seen that the thickest surface layer is in the case of vanadium and tantalum carbide powder. Also increasing of the roughness is depending of the powder used by adsorption through the machined material.

The investigated steel displays in the softened state the ferritic structure with carbides distributed uniformly in the matrix(Figs. 4-6). The lathe martensite structure is obtained after quenching, which is saturated with alloying elements, which is confirmed by the EDX chemical composition analysis (Figs. 7b, 8b and 9b), and also saturated with carbon. The anticipated hardenability of these steels was attained at the austenitizing time long enough, which ensures dissolving most alloying carbides in the austenite. Structural examinations consist in comparing the effect of parameters of heat treatment and remelting of the hot work tool steel with the diode laser on the run shape and remelting depth.

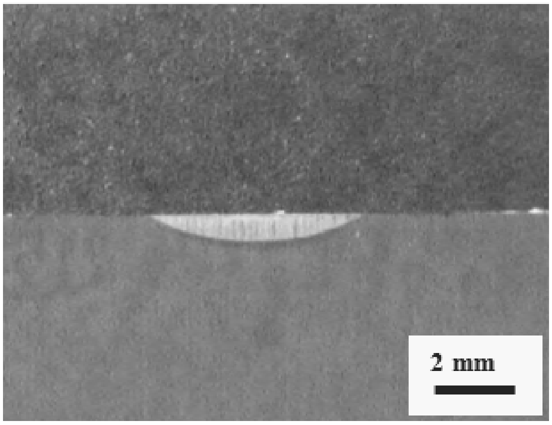


Fig. 1. Shape and thickness of cross-section of the laser remelted samples, alloyed with laser power of 1.2 kW, WC

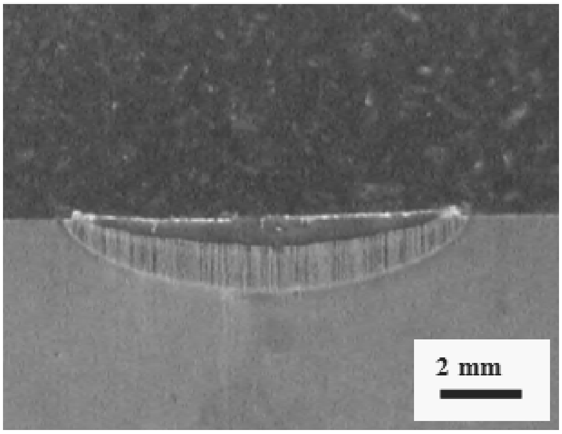


Fig. 2. Shape and thickness of cross-section of the laser remelted samples, alloyed with laser power of 1.2 kW, VC

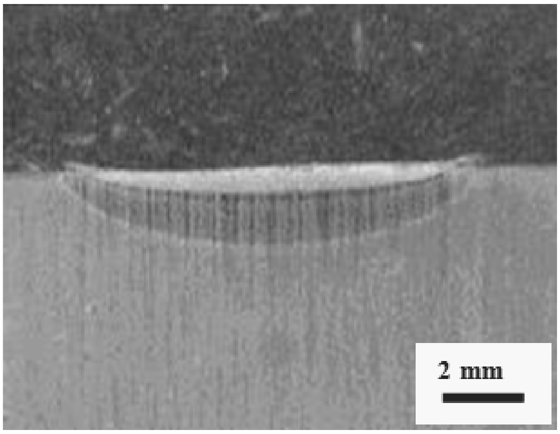


Fig. 3. Shape and thickness of cross-section of the laser remelted samples, alloyed with laser power of 1.2 kW, TaC

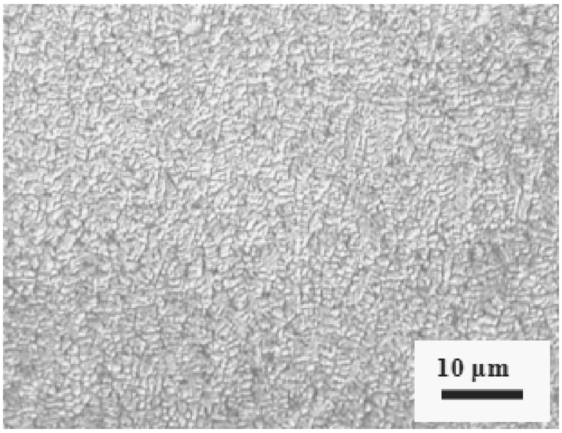


Fig. 4. Microstructure of the steel remelted with TaC powder, alloyed with laser power of 1.2 kW

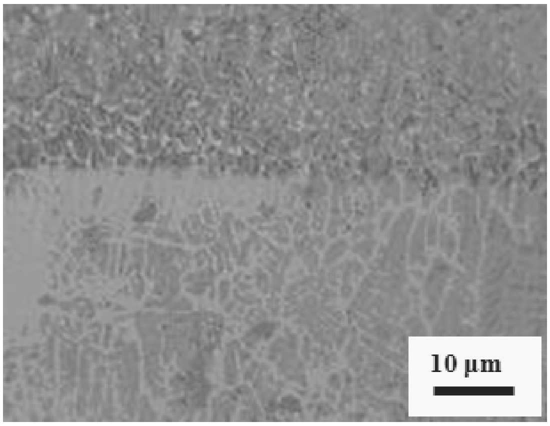


Fig. 5. Microstructure of the steel remelted with WC powder, alloyed with laser power of 1.2 kW

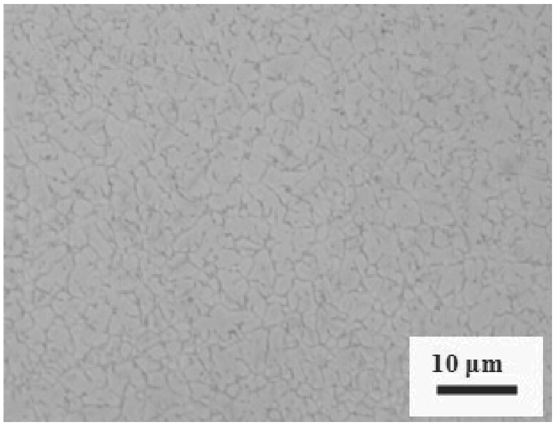
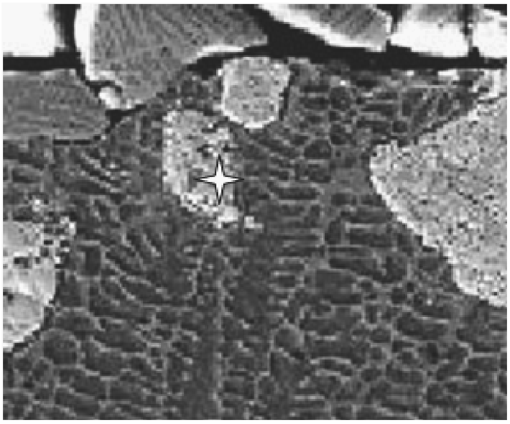


Fig. 6. Microstructure of the steel remelted with VC powder, alloyed with laser power of 1.2 kW

a)



b)

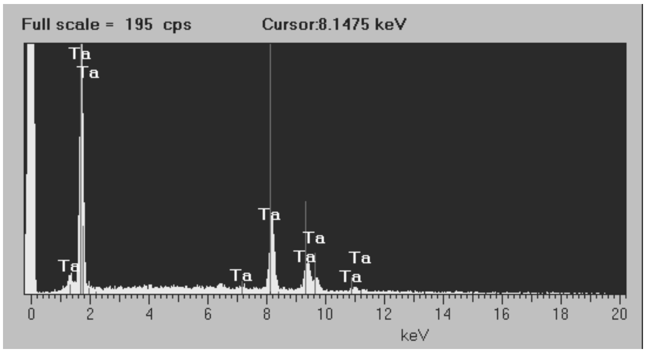
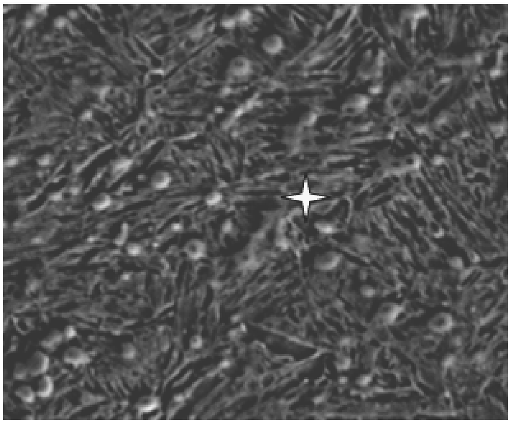


Fig. 7. Steel alloyed with TaC powder, a) SEM Microstructure of the steel alloyed with 1.2 kW laser power, b) EDX point analysis of place marked on Fig. 7a

a)



b)

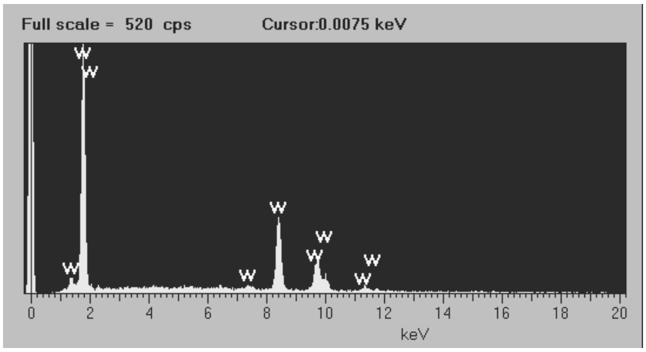


Fig. 8. Steel alloyed with WC powder, a) SEM Microstructure of the steel alloyed with 1.2 kW laser power, b) EDX point analysis of place marked on Fig. 8a

a) b)

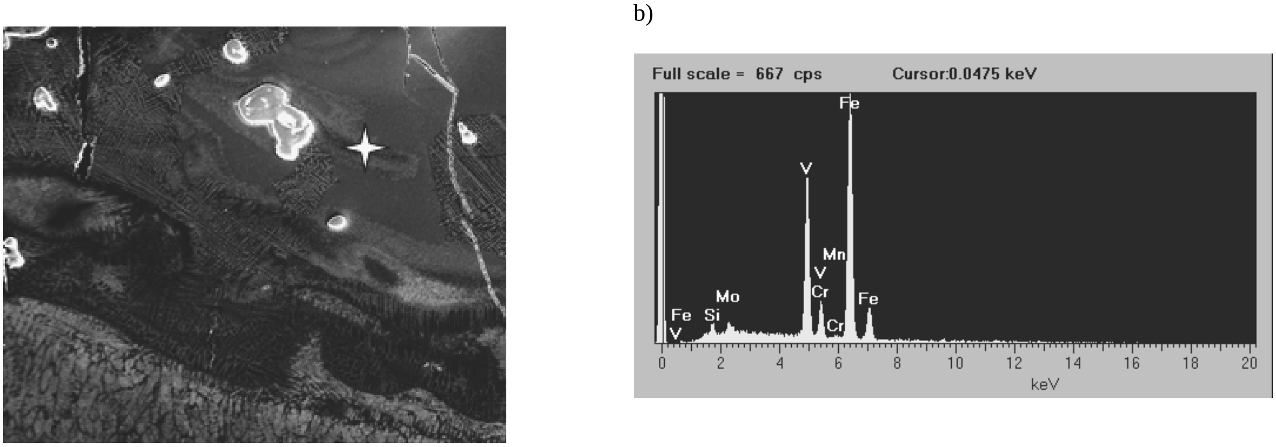


Fig. 9. Steel alloyed with VC powder, a) SEM Microstructure of the steel alloyed with 1.2 kW laser power, b) EDX point analysis of place marked on Fig. 9a

The metallographic investigations on light microscope and in the electron scanning microscope show, that the structure of the crystallized material after laser remelting is characterized by a dendritic structure for all used ceramic powders, the dendrite size is dependent on the speed of crystallization and of the powder used. In areas, which are between the solid and molted state dendritic also a structure with large dendrites can be found. The EDX point analysis confirms the presence of VC, WC and TaC phase in the matrix.

Moreover, it was found out, that the alloying of the surface layer alloyed with tungsten carbide causes dissolving the carbides in the 32CrMoV12-28 steel matrix and grows along with the laser power increase, which confirm the EDS microanalysis performed on the steel matrix, which is shown on Figure 8b.

Figure 10 shows the achieved hardness measurements results of the remelted steel surface for each carbide powder. The highest hardness value is achieved for the TaC alloyed sample for 2.3 kW laser power, ca 65 HRC, for all ceramic particles used the highest hardness value is achieved for the 2.3 kW laser power. The HRC hardness for the steel after a standard heat treatment is about 52 HRC, so an significant increase can be state.

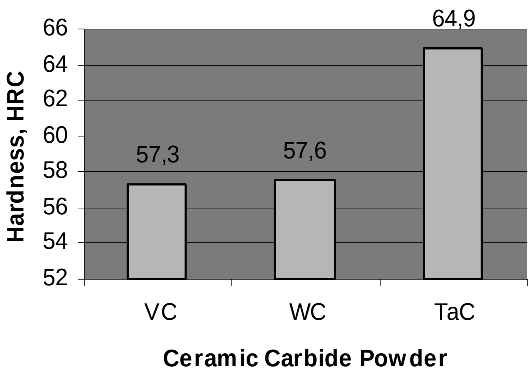


Fig. 10. Hardness measurement results of the laser alloyed steel

a) b)

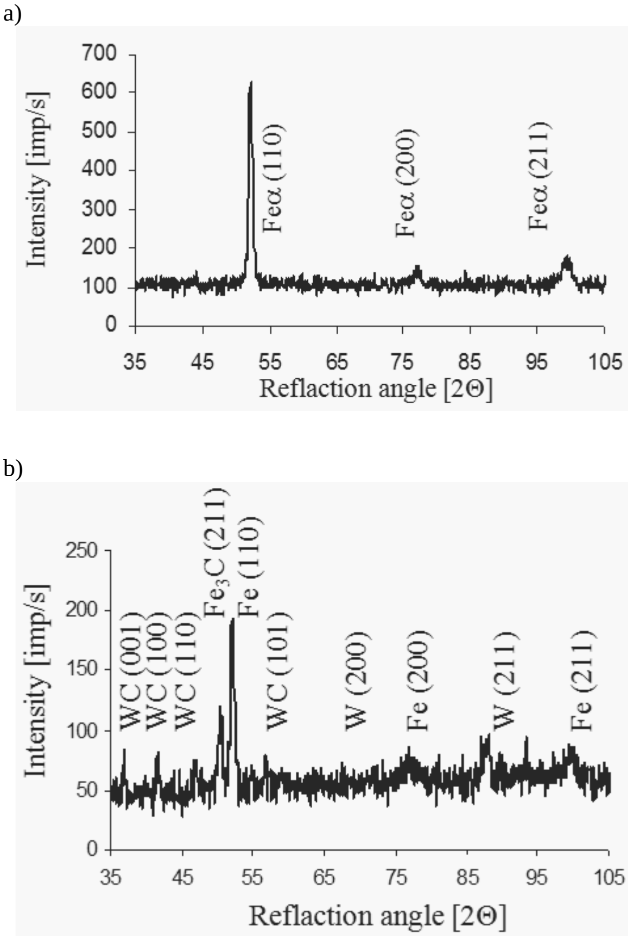


Fig. 11. X-ray diffraction pattern: a) of the 32CrMoV12-28 hot work steel alloyed with the HPDL high power diode laser, b) steel alloyed with the WC ceramic powder

X-ray photographs were also made of the steel remelted (Fig. 11a) and alloyed with the ceramic carbide powders. According to the assumptions, on surface of the investigated test pieces alloyed with the WC powders, occurrences of the WC carbides and also tungsten were observed in the surface layer of the investigated steel (Fig. 11b) using the X-ray qualitative phase analysis methods.

4. Conclusions

The experiments carried out to obtain the highly resistant surface layers by using laser treatment of the 32CrMoV12-28 hot work tool steel indicate to the clear effect of the process parameters, especially of the laser beam power and the ceramic powder used, on shape and structure of the surface layer. Employing the hard particles, especially WC powder, and the adequate laser power used makes it possible to obtain the surface layers with no cracks and defects and with hardness significantly higher than the substrate metal.

The performed investigations allows to conclude, that as a result of heat-treatment as well as remelting of the hot work steel 32CrMoV12-28 with VC powder can be possible to obtain high-quality top layer without cracks and defects as well as considerably higher hardness value compared to the non remelted material. The hardness value increases according to the laser power used so that the highest power applied gives to highest hardness value in the surface layer. The highest hardness value is achieved for TaC powder with the laser power of 2.3 kW. Together with the increasing laser power, also the depth of remelting material grows up. The biggest depth is achieved in the case of VC powder with the laser power of 2.3 kW. Also the surface of the remelted area is more regular, less rough and more flat with increasing laser power. The metallographic investigations on the scanning microscope using the EDX analysis confirm the occurrence of tantalum carbide TaC, as well as of the carbides WC and VC. The TaC particles are present in the matrix mostly in form of conglomerates, only a minor part of tantalum is solved in the steel.

References

[1] L. Achab, E.H. Amara, N. Mebani, N. Allalou, F. Hamadi, Numerical thermodynamic field modelling of a metallic substance during laser welding, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 94-99.

[2] A. Klimpel, A. Lisiecki, Laser welding of butt joints of austenitic stainless steel AISI 321, Journal of Achievements in Materials and Manufacturing Engineering 25/1 (2007) 63-66.

[3] J. Okrajni, A. Marek G. Junak, Description of the deformation process under thermomechanical fatigue, Journal of Achievements in Materials and Manufacturing Engineering 21/2 (2007) 15-24.

[4] L.A. Dobrzański, K. Labisz, M. Piec, A. Klimpel, Modelling of surface layer of the 32CrMoV12-28 tool steel using HPDL laser for alloying with TiC powder, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 27-34.

[5] E. Ohmura, F. Fukuyo, K. Fukumutsu, H. Morita, Internal modified-layer formation mechanism into silicon with nanosecond laser, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 381-384.

[6] B. Kosec, M. Brezigar, G. Kosec, J. Bernetic, M. Bizjak, Heat treatment of cold formed steel forgings for the automotive industry, Journal of Achievements in Materials and Manufacturing Engineering 22/2 (2007) 87-90.

[7] M. Hamedi, Optimizing tensile strength of low-alloy steel joints in upset welding, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 341-344.

[8] L.A. Dobrzański, K. Labisz, M. Piec, A. Klimpel, A. Lisiecki, Influence of vanadium carbide ceramic powder on structure and properties of hot work tool steel alloyed with HPDL laser, Proceedings of the 2nd International Conference "Manufacturing Engineering" ICMEN 2005, Kassandra-Chalkidiki, 2005, 185-191.

[9] E. Hajduczek, L.A. Dobrzański, J. Adamczyk, Effect of heat treatment on structure and properties of experimental hot-work tool steel 47CrMoWVTiCeZr16-26-8, Proceedings of the 5th International Congress "Heat Treatment of Materials", Budapest, 1986, 976 -982.

[10] J. Kusiński, J. Przybyłowicz, S. Kąc, A. Woldan, Structure and properties change in case of laser remelting of surface layers and coatings, Metallurgist (1999) 14-20 (in Polish).

[11] X. Changqing, J. Yucheng, Y. Guangli, Effect of a single peak overload on physically short fatigue crack retardation in an axle-steel, International Journal of Fatigue 19 (1996) 201-206.

[12] A. Klimpel, A. Lisiecki, The mechanism of diode laser butt joint welding, Proceedings of the 2nd International Conference "Advances in Production Engineering", Warszawa, 2001, 44-50.

[13] S. Rusz, L. Cizek, P. Filipec, Evaluation of fatigue of micro-alloyed 23MnB4 steel, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 223-226.

[14] S. Yahong, H. Satoshi, Y. Masato, U. Hitoshi, T. Hironobu, Fatigue behaviour and fractography of laser-processed hot work tool steel, Vacuum 73 (2004) 655-660.

[15] F.F.P. Medeiros, A.G.P. Da Silva, C.P. De Souza, Synthesis of niobium carbide at low temperature and its use in hardmetal, Powder Technology 126 (2002) 155-160.

[16] L.A. Dobrzański, K. Labisz, M. Piec, A. Klimpel, Mechanical properties of the surface layer of the laser alloyed 32CrMoV12-28 steel, Archives of Materials Science and Engineering 29/1 (2008) 57-60.