Archives of Materials Science and Engineering

Volume 58
Issue 2
December 2012
Pages 182-192

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

Formation of gradient surface layers on high speed steel by laser surface alloying process

M. Bonek*
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
* Corresponding e-mail address: miroslaw.bonek@polsl.pl

Received 29.10.2012; published in revised form 01.12.2012

ABSTRACT

Purpose: The purpose of this research paper is focused on the high speed steel HS6-5-3-8 surface layers improvement properties using HPDL laser. The paper present laser surface technologies, investigation of structure and properties of the high speed steel alloying with the WC, VC, TiC, SiC, Si_3N_4 and Al_2O_3 particles using high power diode laser HPDL.

Design/methodology/approach: Investigation indicate the influence of the alloying elements on the structure and properties of the surface layer of investigated steel depending on the kind of alloying carbides, oxides, nitrides and power implemented laser (HPDL).

Findings: Laser alloying of surface layer of investigated steel without introducing alloying additions into liquid molten metal pool, in the whole range of used laser power, causes size reduction of dendritic microstructure with the direction of crystallization consistent with the direction of heat carrying away from the zone of impact of laser beam. In the effect of laser alloying with powder of the WC, VC, TiC, SiC, Si_3N_4 and Al_2O_3 particles occurs size reduction of microstructure as well as dispersion hardening through fused in but partially dissolved particles and consolidation through enrichment of surface layer in alloying additions coming from dissolving elements. Introduced particles of carbides, oxides, nitrides and in part remain undissolved, creating conglomerates being a result of fusion of undissolved powder grains into molten metal base. In effect of convection movements of material in the liquid state, conglomerates of carbides arrange themselves in the characteristic of swirl.

Practical implications: Laser surface modification has the important cognitive significance and gives grounds to the practical employment of these technologies for forming the surfaces of new tools and regeneration of the used ones.

Originality/value: The structural mechanism was determined of surface layers development, effect was studied of alloying parameters, gas protection method, and method of applied onto the steel surface on structure refinement and influence of these factors on the mechanical properties of surface layer, and especially on its hardness and microhardness.

Keywords: Heat Treatment, Laser, Tool Materials, Hardness

Reference to this paper should be given in the following way:

M. Bonek, Formation of gradient surface layers on high speed steel by laser surface alloying process, Archives of Materials Science and Engineering 58/2 (2012) 182-192.

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The basic and most often applied materials for manufacturing hot-work tools and also metal forms used in casting are alloyed hot-work steel. The properties of a surface layer of those steel must protect against the loss of exploitation durability and in particular must be characterised by wear resistance at the higher temperature, load and corrosion resistance of processed material. High speed steels belongs to the group of martensitic steel used in the production of forging tools. The microstructure of high speed steels changes several times during the complex thermo-plastic treatment. The aim of this processing is to obtain high wear and thermal fatigue resistance. Carbides release of two kinds is responsible for high mechanical properties. The primary release - produced in the process of crystallisation and the secondary release - a result of the thermoplastic treatment. The examination of the possibilities of the increase of application properties of tool steels having martensitic matrix by the change of chemical composition in the conventional way is very limited. It may be expected that the wear resistance as well as hardness and chemical stability will be increased in the materials in which additional, more stable and hard molecules were introduced to the native material. The future direction of research into the improvement of materials properties is a laser modification of the tool surface layer structure either by a laser relmelting or alloying by the use of materials such as tungsten carbides having huge hardness. The effect of the process in which the cooling speed is very high, is the minute-grained structured material with over-cooling phases [1-6].

The laser heat treatment includes operations which are conducted using the laser beam as the source of energy needed for heating the surface layer of the processed material, to change its structure for obtaining the relevant mechanical, physical, or chemical properties, improving service life of the processed element. Two methods of forming the surface layer have found applications so far within the framework of the laser heat treatment of the surface layer, namely:

- Forming by phase transformations in the solid state, consisting in heating of the surface layers to the austenitizing temperature and their sudden cooling - quenching, or slow cooling - annealing and tempering, or heating up, e.g., for improving the ductility before the succeeding surface treatment or shaping, like e.g., machining of the sintered carbides, welding, plastic working, laser treatment, e.g., before cladding or quenching (to avoid cracks or to assist the heating process).
- Forming by remelting the surface layer, consisting in heating the material above the solidus temperature, its rapid solidification, and in phase transformations in solid state. Surface layers with the very refined structure or amorphous, with the unchanged chemical composition in respect to material's core, but with significant chemical homogeneity, can be obtained with this laser forming method, depending on cooling rate. Variations of material forming by remelting its surface layer include: enrichment (alloying) of the surface layer with the selected alloying elements and cladding, consisting in applying a layer with another chemical composition onto the formed material, that ensures corrosion resistance, high-temperature resistance, or decorative properties [7-16].

Part of the absorbed heat energy penetrates inside the material during remelting, which results with a big temperature gradient between the liquid material layer and the matrix. Mixing of the molten metal occurs because of the convection motions during laser treatment with remelting. These motions originate because of the temperature difference between the remelted surface and the bottom of the remelted region, and moreover because of the protective gas blow-in and "pressure" of the laser beam. Quick solidification occurs after remelting and mixing the molten metal due to the big temperature gradient. The investigation results obtained may be used for the further research on optimisation of the surface layer properties of the high speed steels, targeted at obtaining tools with the possibly high mechanical and service properties. The goal of this work is studying the structural mechanisms and selected, for comparison, properties of the surface layers obtained by the high power diode laser (HPDL) treatment of the high speed steels.

The difficulty of that method results from two facts. First of all, it is hard to operate the concentrated source of heat and secondly, there is no theoretical data defining expected new structures created under those conditions. Empirical data, on which one usually is based, is not treated precisely as the only source of knowledge because the process is characterised by same deviation from the state of balance, resulting from high increase in temperature as well as great thermal gradients [4-8].

Diode lasers have been known for many years and used mainly in electronic devices and metrology. The dynamical development of materials engineering (progress in production of semi-conductors) allowed for the introduction of industrial HPDL lasers. Diode lasers produced nowadays achieve power up to 6 kW on the surface of the laser beam focusing. Diode lasers of ROFIN DL type are characterised by a rectangular or linear shape of beam focus having multi-mode energy distribution. In that type of a laser power density delivered to a surface layer of processed materials is smaller in a comparison with mono-mode distribution, characteristic of other types of lasers and energy is spread evenly on the surface of the laser beam focus. Thanks to that phenomenon a HPDL laser is suitable for the modification of a material surface layer. It is confirmed by an empirically proved high energy absorption coefficient for steels (20-40%), high efficiency and the possibility of the precious control of the amount of energy delivered to a material surface layer. The condition of the surface layer of the processed material and especially its roughness and absorption coefficient are the most important factors in the process of laser treatment of materials. When laser radiation, as any light beam, is spread in different medium, it follows certain rules of absorption, reflection and refraction. The absorbance coefficient, characteristic of every material, is not constant in the laser processing and risen markedly when the material heated is covered with the oxides layer and when the temperature is its melting one [17-26]. The application of adequate protective gases as well as the correct choice of the nozzle and its position guarantee the high quality of the bead face and the recurrence of the results obtained. The phenomenon of wear of the working surface of tools, to which laser modification of the surface layer is applied, due to friction features an important aspect of the contemporary surface engineering. The friction process between two surface leads to their wear and is connected with energy losses. It is disadvantageous especially when it occurs along with other factors deteriorating properties of the surface layer, like corrosion, erosion, mechanical and thermal fatigue [27-33].

The goal of the work is to determine the technical and technological conditions for alloying the surface layer of the high speed steel HS6-5-3-8 with the high power diode laser (HPDL), and of the relationship between the parameters of laser treatment and the properties of the surface layer which increase the exploitation durability of high speed steels.

2. Material for investigation

The experiments were made on specimens made from the high speed steel HS6-5-3-8. The chemical composition of the steel is presented in Table 1. The investigated steel was molten in the electric vacuum furnace at the pressure of about 1 Pa, cast into ingots weighing about 250 kg, and were roughed at the temperature range 1100-900ºC into the O.D. 75 mm bars, which were soft annealed. After making by machining the specimens they were heat treated. The specimens were austenitized on the salt bath furnace and tempered in the chamber furnace in the protective atmosphere - argon. The specimens were gradually heated to the austenitizing temperature with the isothermic stops at 650 and 850°C for 15 min. Further they were austenized for 30 min at the temperature of 1180°C and cooled in hot oil. The specimens were tempered twice after quenching, each time for 2 hours, at the temperature of 560°C and next at 545 ºC. Surfaces of specimens were sand blasted and machined on magnetic grinder.

Particular attention was paid to prevent development of micro-cracks that might disqualify the specimen from further examination. On specimens surface two parallel grooves, deep for 0.5 of triangular shape (with angle of 45°) were machined. The grooves were located along sample axis and distance between them was ca. 1.0mm. Such prepared grooves were filled with the WC, VC, TiC, SiC, Si_3N_4 and Al_2O_3 particles. Properties of the particle powders are presented in Table 2.

Therefore all experiments were made at the constant remelting rate, varying the laser beam power in the range from 0.7 to 2.1 kW. At low laser power values, i.e., 0.4 to 0.6 kW, no remelting was observed for powders mentioned above.

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 microsections' surfaces were ground on diamond wheels and next polished using the diamond buffing compounds on Struers equipment. Metallographic examinations of the material structures after laser alloying its surface layer were made on Zeiss LEICA MEF4A light microscope with magnifications from 50 to 1000x. The Leica-Qwin computer image analysis system was used for thickness examination of the particular zones of the surface layer. Structure of the developed coatings were examined with SUPRA 25 scanning electron microscope (SEM) equipped with X-ray energy dispersive spectrometer (EDS). The observation were prepared perpendicularly to the cross section of the sample no the each remelted tray. The phase composition of the investigated coatings was determined on the Panalytical X'Pert PRO diffractometer, using the 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 30º - 110º. Hardness tests were made with Rockwell method in C scale on specimens subjected to the standard heat treatment and alloyed using the high power diode laser at various parameters, making 10 measurements for each condition and calculating their average value. Test results were analysed statistically. Hardness was measured on the ground and buffed front surfaces of specimens. Coating microhardness was tested on the FM-700 microhardness tester. The tests were carried out at 0.05 N load, making the necessary number of indents on the section of each examined specimen, correspondingly to the structural changes depth in the material surface layer. The microhardness tests were made along the lines perpendicular to specimens' surfaces, along the run face axis.

Table 1.
Chemical compositions of the investigated steel

Steel grade	Mass concentration of the elements, %							
	C	Cr	W	Mo	V	Co	P	S
HS6-5-3-8	1.28	4.2	6.3	5	3	8.4	0.002	0.022

Table 2.
Selected properties of powders

Powder	Average grain size, μm	Melting point, °C	Density g/cm^3	Hardness, HV
Tungsten carbide WC	5	2770	15.6	2600
Vanadium carbide VC	1.5	2830	5.36	2850
Titanium carbide TiC	3	3140	4.25	2800
Silicon carbide SiC	7	2700	3.21	2100
Silicon nitride Si_3N_4	5	1900	3,44	1600
Alumina oxide Al_2O_3	5	2047	3.90	2300

It was found out in the preliminary investigations made using the HPDL Rofin DL 020 high power diode laser, with parameters presented in Table 3, that the maximum feed rate at which the process is stable is v = 0.5 m/min. Rofin DL 020 high power diode laser (HPDL) was used for remelting and alloying. The laser used is a high power unit, a versatile one, and used in materials engineering among others for cladding, welding, remelting, and surface enrichment. The laser system consists, among others, of the following modules: laser head, rotating work table, movable in the X-Y plane, protective gas nozzle, power supply and coolingsystems, and the computer system controlling the laser operation and work table positioning. The rectangular or linear spot size is its significant advantage apart of its versatility, reliability, and small size. Dimensions of the laser beam focused on the material surface are 1.8 x 6.8 mm. The working focal length (measured from the protective glass in the head) is 92 mm. Remelting was carried out perpendicularly to the longer side of the focused beam with the multimode energy distribution, which makes it possible to obtain the wide run face. The test pieces were machined after remelting and alloying, to remove the non-remelted layer of the used carbides.

Table 3.
Specification of the HPDL Rofin DL 020 diode laser

Laser radiation wavelength, nm	808 ± 5
Laser beam output power (continuous wave), W	2300
Power range, W	100-2500
Laser beam focal length, mm	82 / 32
Laser beam spot dimensions, mm	1.8 × 6.8
Power density range in the laser beam plane, kW/cm^2	0.8-36.5

3. Discussion of the experimental results

Presented investigation results pertain to fabrication of the gradient surface layers of tools in service at elevated temperature and to supplementing the traditional heat treatment used to date for this type of tool materials. Laser alloying of the investigated steels with particles of hard phases makes behaviour prediction of this material in service complicated. Superposition of stress fields interaction, dislocation movements, presence of micro-cracks, results in development of a very complex system, much more complicated than in case of the high speed steels unalloyed with the hard phases powders. Improved abrasion wear resistance, mechanical-, and tribological properties, and also very high resistance to thermal fatigue displayed by these materials, can be obtained in particular by alloying with the WC, VC, TiC, SiC, Si_3N_4 and Al_2O_3 particles. Not only the right selection of the hard phases powder used for alloying but also its distribution and volume portion in the matrix, modelled later by various technological operations decides the further service properties of the completed product.

The main research goal is modelling the gradient structure leading to attaining properties of the surface layer impossible to obtain by the conventional heat treatment. Therefore, the practical goal of such treatment is obtaining the supersaturated fine-crystalline layers, characteristic of a significant chemical diversity and metallurgical purity, which leads to gradient change of hardness and service properties of the surface layer as a consequence of the fast crystalization due to solidification of metal.

It was revealed, basing on the metallographic examinations, that the structure of the material solidifying after laser alloying is characteristic of occurrences of areas with the gradient diversified morphology connected with crystallisation of the steel. Material surface is heated quickly to the temperature of 3420°C when the laser beam acts on it and the strong circulation of the molten material takes place, followed by rapid solidification when the laser beam has passed. This phenomenon is the reason for the super-fast phase transformations affecting the structural mechanism of forming the surface layers subjected to laser treatment. Occurrences of the remelted- and heat affected zones have been confirmed in the surface layers of the investigated steels, whose thickness depend on the employed laser treatment parameters and type of the hard phases particles (Figs. 1-3).

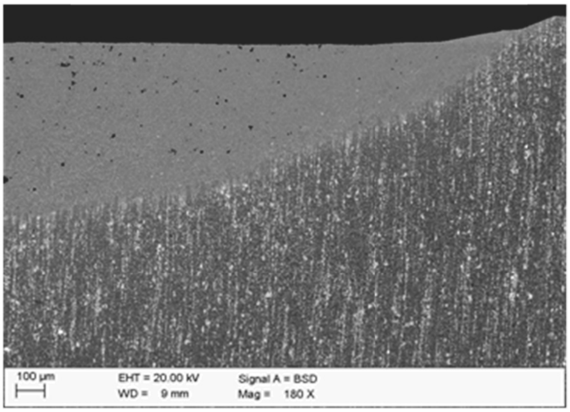

Fig. 1. Surface layer edge of the HS6-5-3-8 steel alloyed with TiC powder, laser power 1.7 kW

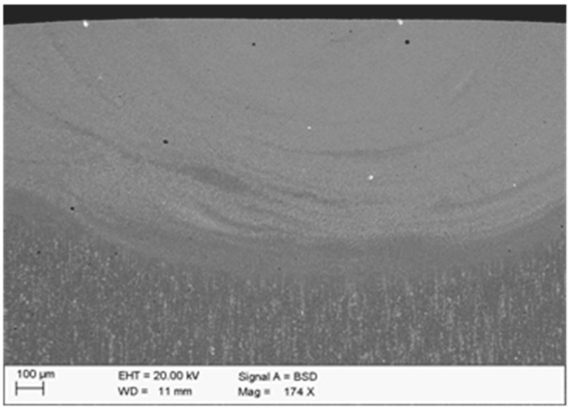

Fig. 2. Boundary of the remelted surface layer of the HS6-5-3-8 steel alloyed with WC powder, laser power 2.1 kW

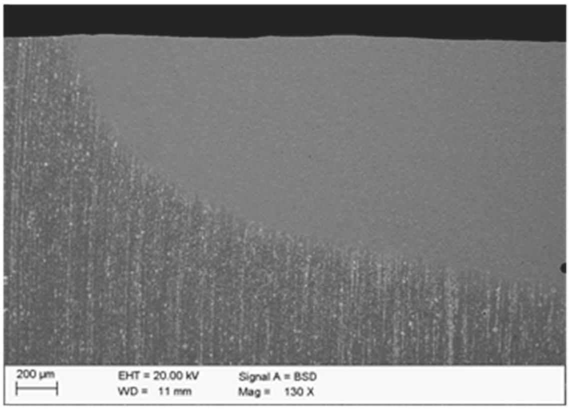

Fig. 3. Surface layer edge of the HS6-5-3-8 steel alloyed with Al_2O_3 powder, laser power 1.7 kW

The subsequent growth of the remelting zone and of the heat affected zone is also connected with the laser radiation absorption effect by the surface of test pieces covered with carbides and is proportional to the employed laser power. The biggest remelted zone thickness of 1.16 mm was revealed in case of the high speed steel HS6-5-3-8 alloyed with the Al_2O_3 carbide with the laser beam power of 2.1 kW (Fig. 4), and the smallest remelted zone thickness of 0.28 mm is characteristic of the steel alloyed with the vanadium carbide with the laser beam power of 0.7 kW.

During alloying with hard powders: WC, VC, TiC, SiC, Si_3N_4 and Al_2O_3, whose melting temperature is much higher than the melting points of the investigated steels, penetration occurs of the undissolved carbide powder grains into the molten steel substrate (Figs. 2, 5, 7). Carbides remain undissolved in certain cases, forming conglomerates (Fig. 8). Increasing the laser power results in decrease of the portion of the undissolved carbides dispersively hardening the remelted matrix of the steel surface layer. Fast crystallization leads to differentiation of structure in the cross section of the remelted zone for all investigated alloying particles (Figs. 6, 9). The characteristic repeated crystal growth direction change is observed for these areas. Small dendrites occur in the area at the boundary between the solid and liquid phases, whose main axes are oriented according to the heat transfer directions (Figs. 11-13). The significantly smaller sizes of crystals in this zone, compared to the central remelting area (Figs. 5, 7, 9), are connected with initiating the solidification process on the undissolved carbides and partly melted grains of the native material. Consecutive stages of crystals growth (cellular-dendritic and dendritic) are closely connected with retaining the privileged orientation - crystals growth direction corresponds with the direction of the biggest temperature gradient, assuming that the entire specimen's material volume receives remelting process originated heat. Structure of fine equiaxial crystals with the carbide lattice develops in the central zone of the fused area where heat abstraction takes place in all directions (Figs. 12). Mixing of materials proceeds according to various mechanisms, depending on the employed laser treatment parameters. Capillary lines are not connected and the remelting structure is relatively homogeneous at low energy values of the laser impact on the material (Figs. 7, 8, 12).

At the low laser beam power the WC, VC, TiC, SiC, Si_3N_4 and Al_2O_3 particles introduced into the surface layer during alloying dissolve partially originating clusters of carbides (Figs. 14, 16); whereas, laser power increase causes their partial dissolution in the investigated steel matrix especially at grain boundaries. Similarly, after the laser alloying of steel with the TiC and WC these carbides dissolve partially originating conglomerates of carbides, and the laser power increase causes their partial melting, the local concentrations of titanium, and tungsten exceed the equilibrium concentrations in the alloyed surface layer. In case of alloying with the WC and TiC carbides presence of tungsten carbide was revealed in the surface layer developed by alloying (Figs. 14-17) and in the interdendritic spaces enriched in tungsten coming from the dissolved particles of the alloying material.

In all investigated hard particles grades grouping of the alloying elements was confirmed at dendrite boundaries in the area of the superfine eutectics occurring in the remelted zone due to fluctuation of the chemical composition, especially at the remelting bottom (Figs. 1-3). The capillary lines swirl occurs along with the laser power increase which begin to link and the occurring carbides' conglomerates form the characteristic swirls (Fig. 8). The remelting bottom is flat in this case, however slight waviness appears often on surface. Employment of the maximum laser power results in obtaining the maximum remelting thickness of the surface layer; however, the remelting bottom gets wavy because of the strong liquid motions (Fig. 8). Carbides introduced into the steel are present in the remelted zone only; however, their concentration grows at the dendrites boundaries (Figs. 14-17).

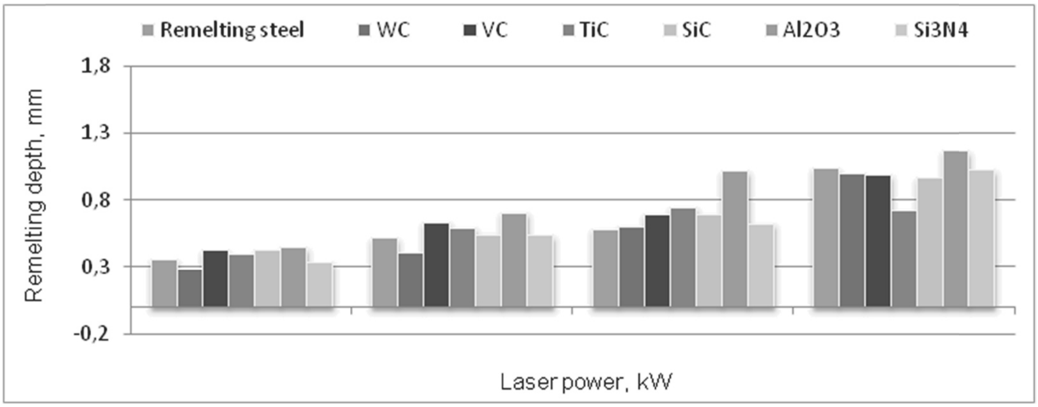

Fig. 4. Remelted zone thickness changes of the surface layer of the HS6-5-3-8 steel alloyed with hard particles with variable laser power

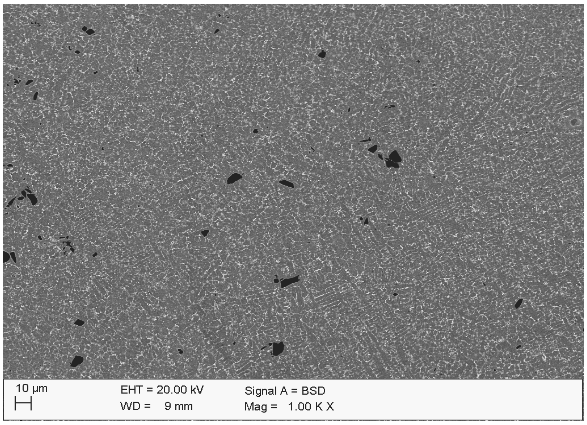

Fig. 5. Surface area of the surface layer of the HS6-5-3-8 steel after alloying with TiC powder, laser power - 1.7 kW

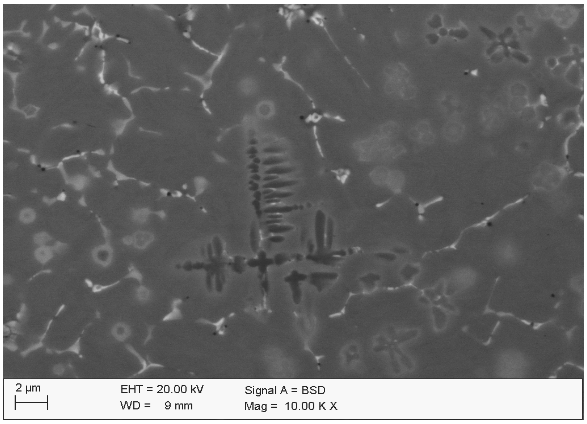

Fig. 6. Small eutectic in the surface layer of the HS6-5-3-8steel after laser alloying with TiC carbide, laser power 2.1 kW

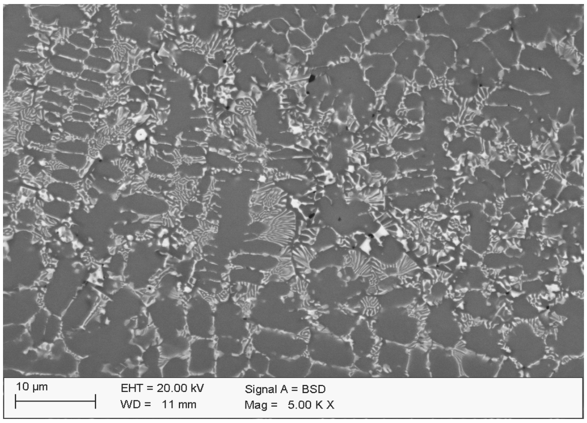

Fig. 7. Alloying material and small eutectic in the surface layer of the HS6-5-3-8 steel after laser alloying with WC carbide, laser power 2.1 kW

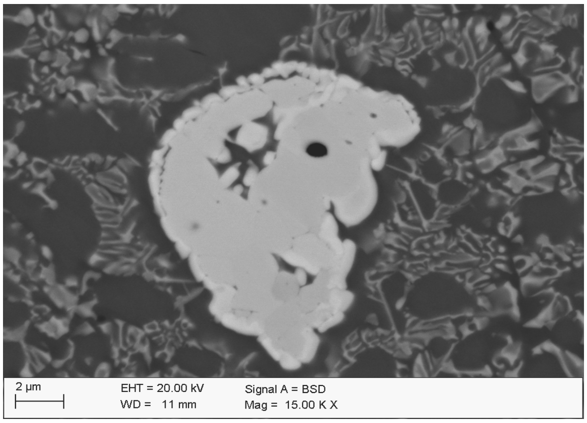

Fig. 8. Alloying material in the surface layer of the HS6-5-3-8 steel after laser alloying with WC powder, laser power 2.1 kW

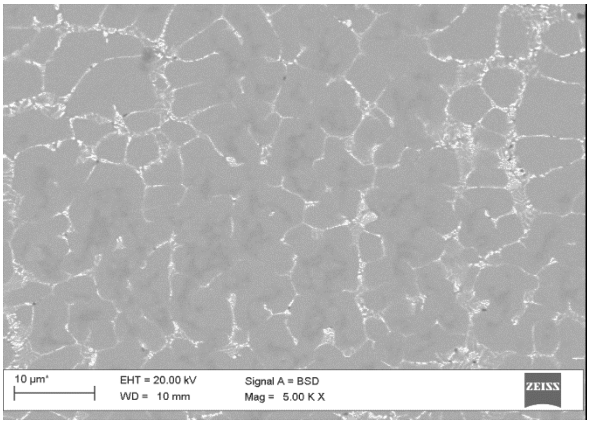

Fig. 9. Surface area of the surface layer of the HS6-5-3-8 steel after alloying with Al_2O_3 powder, laser power - 0.7 kW

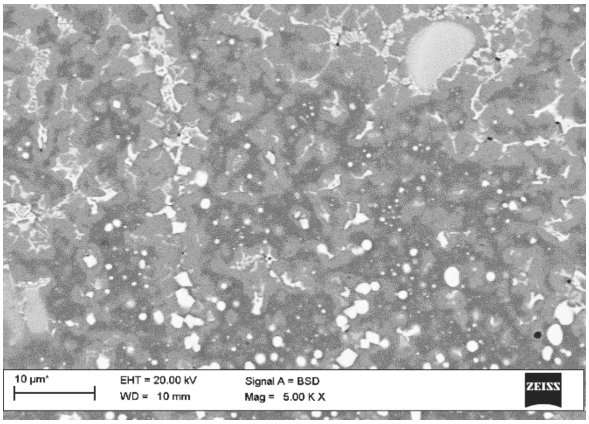

Fig. 10. Boundary of the remelted zone in the surface layer of the HS6-5-3-8 steel after laser alloying with Al_2O_3 powder, laser power 0.7 kW

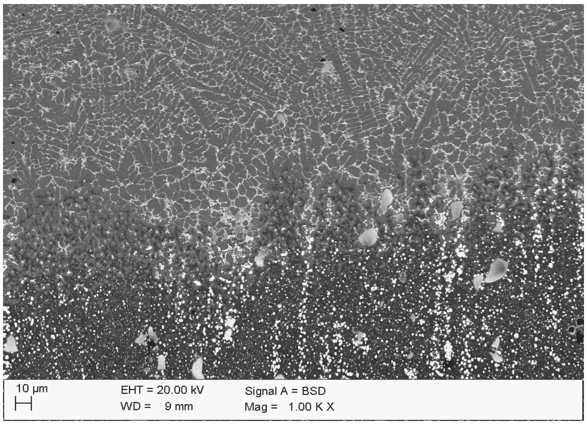

Fig. 11. Edge of the alloyed surface layer of the HS6-5-3-8 steel after laser alloying with TiC powder, laser power 1.7 kW

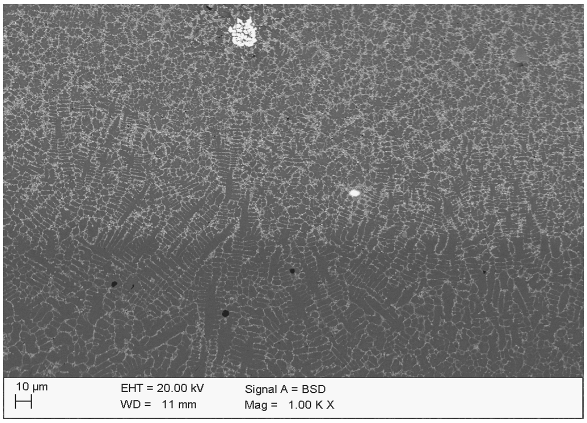

Fig. 12. Boundary of the remelted zone in the surface layer of the HS6-5-3-8 steel after laser alloying with WC powder, laser power 1.7 kW

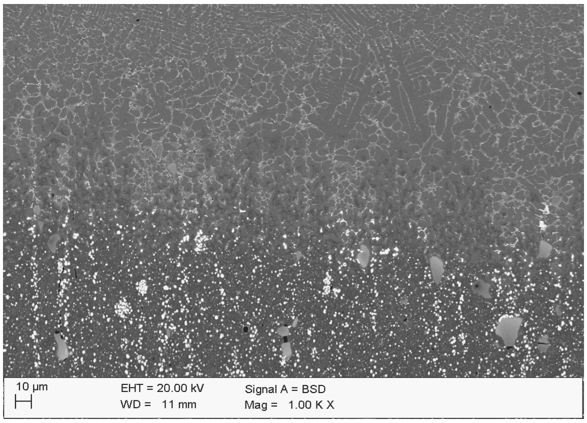

Fig. 13. Boundary of the remelted zone in the surface layer of the HS6-5-3-8 steel after laser alloying with Al_2O_3 powder, laser power 1.7 kW

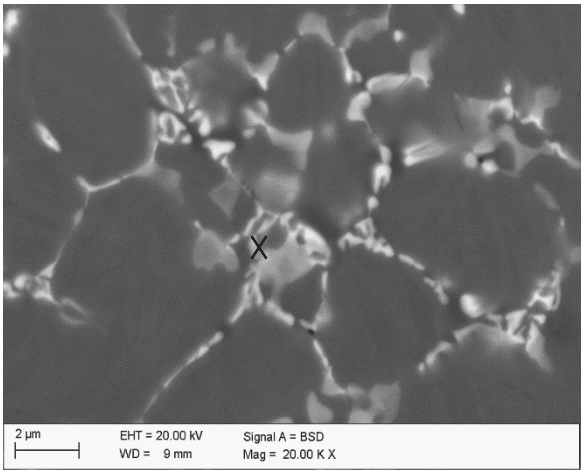

Fig. 14. Small eutectic in the surface layer of the HS6-5-3-8 steel after laser alloying with WC carbide, laser power 0.7 kW

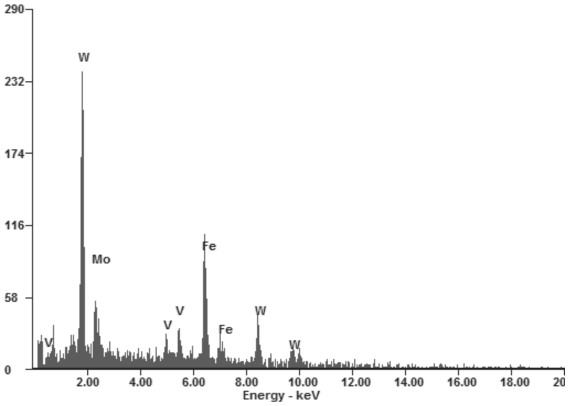

Fig. 15. EDS point-wise analysis of the HS6-5-3-8 steel sample after laser alloying with WC powder, laser power 0.7 kW

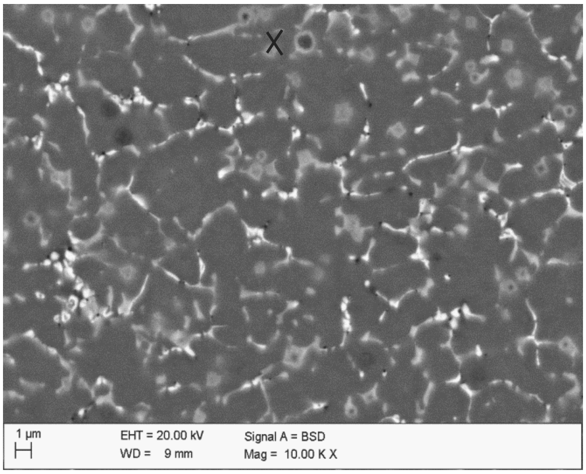

Fig. 16. Small eutectic in the surface layer of the HS6-5-3-8 steel after laser alloying with TiC carbide, laser power 1.7 kW

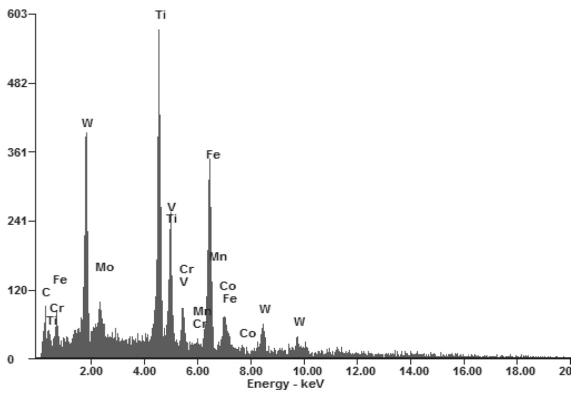

Fig. 17. EDS point-wise analysis of the HS6-5-3-8 steel sample after laser alloying with TiC powder, laser power 1.7 kW

Laser alloying with all of the above mentioned particles results in structure refinement in the entire investigated laser power range, which is presented with the HS6-5-3-8 steel example (Fig. 18). Grains of varying sizes occur in the particular zones of the surface layer after laser alloying. The average grain sizes in the remelted zone of the investigated steels are for the particular particles in the ranges: WC from 8 to 31 μm^2, VC from 9 to 32 μm^2, TiC from 6 to 12 μm^2, SiC from 15 to 26 μm^2, Al_2O_3 from 17 to 27 μm^2 and Si_3N_4 from 21 to 44 μm^2. However, in the conventionally heat treated stel the average grain size is 240 to 266 μm^2; therefore, it is 5-10 times bigger. Only at the crystallization front, between the fused and heat affected zones, the elongated and smaller grains occur, which are subjected to partial melting and re-crystallization during laser treatment.

Laser treatment of surface layers results in the steel surface hardness increase of all investigated steels and this effect is achieved thanks to occurrences of phase transformations connected closely with the heat removal rate from the remelted zone. The factor controlling in great measure the cooling rate is thickness of the remelted layer, dependant on the absorbed radiation energy and the time period of the laser beam impact on the material. Only the laser power affects the energy delivered to the surface layer with the constant remelting rate. At the low power of the laser beam the remelting depth is small; therefore heat removal rate is the highest. High cooling rate causes occurrences of the super-fast phase transformations; therefore, the fine-grained martensite structure occurs in the material, responsible for hardness growth. The highest hardness of the steel surface layer reveals the HS6-5-3-8 steel alloyed with the Ti carbides, its maximum hardness growth to 73.6 HRC occurs at the laser beam power equal to 2.1 kW (Fig. 19). One can state based on the hardness tests of the steel subjected to laser alloying with the hard phases powders that for most of the powders the steel hardness was improved, compared to the steel subjected to the standard heat treatment only. In case of the other carbides used for alloying of this steel, i.e.: WC, VC, TiC, SiC, Si_3N_4 and Al_2O_3 particles hardness of the surface layer grows moderately compared to the steel after the standard heat treatment.

Figures 20-23 presents the flow of the gradient micro-hardness changes depending on the distance from the surface layer of the investigated steels. In case of all investigated steels alloyed with carbides the visible gradient micro-hardness growth occurs at the surface layer. The highest micro-hardness from all test pieces of steels subjected to laser treatment of 1331 $HV_{0.01}$ is obtained at the laser power of 1.4 kW for the alloyed steel with the Ti carbide; whereas, the gradient layers obtained by alloying of the steel are characteristic of the similar micro-hardness in the remelted area in the laser power range from 0.7 to 2.1 kW after alloying with the variable particles (Figs. 21, 22). The hardness drop attests to development of the tempered material zone during laser treatment, heated to the temperature higher than the tempering temperature. Occurrences in the structure of the graded fused carbides and lattice of carbides at dendrites' boundaries, demonstrating hardness different from the substrate, feature the reason of the microhardness measurement results discrepancy for the remelted zone and the alloyed one on the transverse section of the laser paths versus distance from the surface. Investigations demonstrated that as a result of remelting the surface layer of the hot work alloy tool steels using the HPDL high power diode laser or its dispersive hardening by the innudated, or partially dissolved carbides, with the simultaneous enrichment of the surface layer with the alloying additives coming from the disolving carbides hardness increase occurs and improvement of the tribological properties of the surface layer of the laser remelted or alloyed steel takes place, compared to the analogous properties of this steel after the conventional heat treatment.

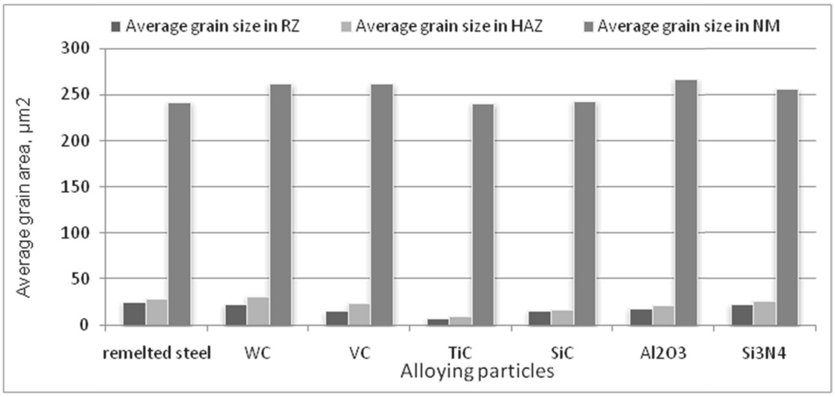

Fig. 18. Average grain size in the remelting area of the HS6-5-3-8 steel alloyed with hard particles, laser power 2.1 kW

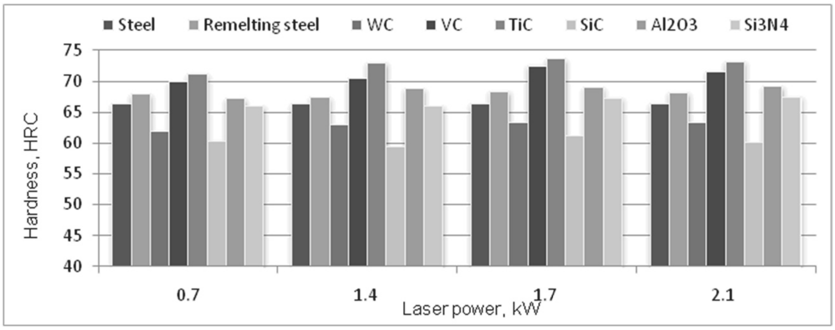

Fig. 19. Average hardness changes of the surface layer of the HS6-5-3-8 steel alloyed with hard particles with variable laser power

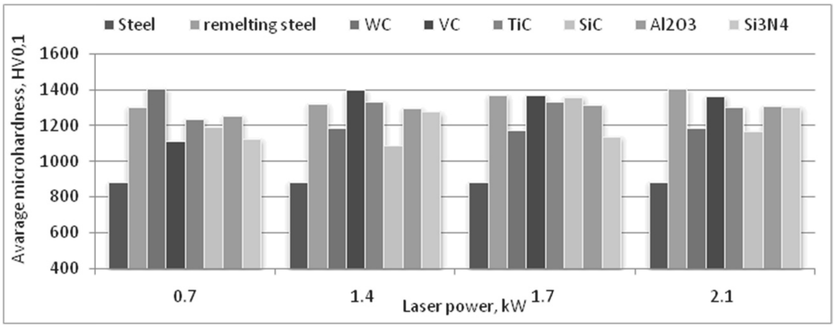

Fig. 20. Average microhardness changes of the surface layer of the HS6-5-3-8 steel alloyed with hard particles with variable laser power

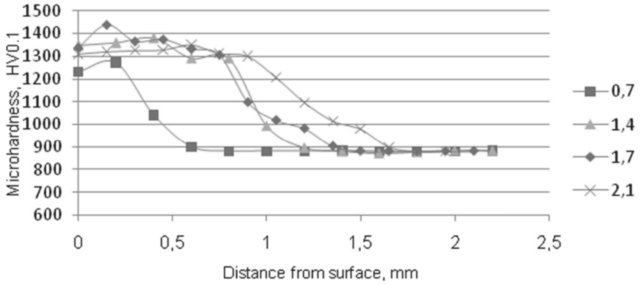

Fig. 21. Microhardness changes of the surface layer of HS6-5-3-8 steel after alloying with TiC powder, laser power 0.7 kW, 1.4 kW, 1.7 kW, 2.1 kW

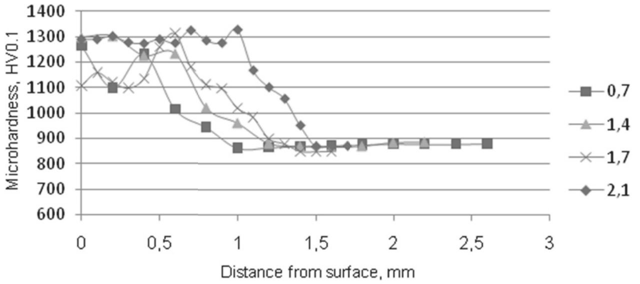

Fig. 22. Microhardness changes of the surface layer of HS6-5-3-8 steel after alloying with Si_3N_4 powder, laser power 0.7 kW, 1.4 kW, 1.7 kW, 2.1 kW

4. Summary

Examinations carried out indicate to occurrences of several mechanisms of the alloying carbides’ effect on structure and properties of the surface layer of the investigated steels, depending on the dissolution extent of the alloying additives in this layer’s matrix, depending both on the type of the alloying carbides used, as well as on the laser power. The presented research results give grounds to the statement that the fabricated gradient surface layers, especially those made using the WC, VC, TiC, SiC, Si_3N_4 and Al_2O_3 particles may be used for manufacturing new tools used for hot working. The results obtained make continuation possible of the research carried out and extend the area of interest in this problem, and especially in the laser treated steels investigations, according to criteria corresponding to the high speed steel service conditions, especially employing the thermal fatigue resistance-, hardness-, and abrasion wear resistance tests.

Acknowledgements

This scientific work was financially supported by the Polish Ministry of Science and Higher Education as a research project no. N N507 471738 on the years 2010-2012.

References

[1] Y. Miyamoto, W.A. Kaysser, B.H. Rabin, A. Kawasaki, R.G. Ford, Functionally Graded Materials, Kluwer Academic Publishers, Boston, 1999.

[2] T. Hirai, in R.J. Brook (Ed.), Materials Science and Technology, Vol. 17B, Processing of Ceramics, Part 2, VCH Verlagsgesellschaft, Weinheim, Germany, 1996, 292-341.

[3] A. Kawasaki, R. Watanabe, Concept and P/M fabrication of Functionally Gradient Materials, Ceramics International 23 (1997) 73-83.

[4] A. Kieback, A. Neubrand, H. Riedel, Processing techniques for functionally graded materials, Materials Science and Engineering A 362 (2003) 81-106.

[5] M. Yuki, T. Murayama, T. Irisawa, A. Kawasaki, R. Watanabe, in M. Yamanouchi, M. Koizumi, T. Hirai, I. Shiota (Eds.), FGM'90, Proceedings of the 1st International Symposium on Functionally Gradient Materials, Sendai, FGM Forum, Tokyo, 1990, 203-208.

[6] W. Lengauer, K. Dreyer, Functionally graded hardmetals, Journal of Alloys and Compounds 338 (2002) 194-212.

[7] E.M. Ruiz-Navas, R. Garc´ýa, E. Gordo, F.J. Velasco, Development and characterisation of high-speed steel matrix composites gradient materials, Journal of Materials Processing Technology 143-144 (2003) 769-775.

[8] Z. Changchi, Study of protection from cracks in laser cladding of metal- ceramic composite coating, The International Society for Optical Engineering 2888 (1996) 259-264.

[9] J.H. Abboud, Functionally gradient titanium-aluminide composites produced by laser cladding, Journal of Materials Science 29/13 (1994) 3393-3398.

[10] Z. Tao, Microstructures and tribological behavior of Cr/WC laser modified gradient layer on cast Al.-Si alloy, Journal of Shanghai Jiaotong University 36/5 (2002) 612-615.

[11] P. Yutao, Laser clad TiC_p/Ni alloy functionally gradient coating and its in-situ formation mechanism, Acta Metallurgica Sinica 34/9 (1998) 987-991

[12] W. Xiaolei, In situ formation by laser cladding of TiC composite coating with a gradient distribution, Surface and Coatings Technology 115/2 (1999) 111-115.

[13] J.T.M. De Hosson, V. Ocelik, Functionally graded materials produced with high power laser, Materials Science Forum (2003) 163-176.

[14] L. Qibin, Microstructure and character of friction and wear of WC_p/Ni based alloy gradient composite coating by wide-band laser cladding, Acta Materiae Compositae Sinica 19/6 (2002) 98-103.

[15] Z. Tao, Microstructure of Ni/WC laser gradient coating on cast AL-Si alloy, Journal of Shanghai Jiaotong University 36/1 (2002) 203-208.

[16] T. Nailing, Laser cladding high temperature alloy and WC ceramic, The International Society for Optical Engineering 3862 (1999) 47-55.

[17] M. Bonek, L.A. Dobrzański, M. Piec, E. Hajduczek, A. Klimpel, Crystallisation mechanism of laser alloyed gradient layer on tool steel, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 411-414.

[18] L.A. Dobrzański, M. Piec, A. Klimpel, Z. Trojanowa, Surface modification of hot work tool steel by high-power diode laser, International Journal of Machine Tools and Manufacture 47/5 (2007) 773-778.

[19] L.A. Dobrzański, M. Piec, M. Bonek, E. Jonda, A. Klimpel, Mechanical and tribological properties of the laser alloyed surface coatings, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 235-238.

[20] L.A. Dobrzański, M. Piec, A. Klimpel, Improvement of the hot work tool steel surface layers properties using a high power diode laser, Journal of Achievements in Materials and Manufacturing Engineering 21/1 (2007) 13-22.

[21] L.A. Dobrzański, M. Bonek, M. Piec, E. Jonda: Diode laser modification of surface gradient layer properties of a hot-work tool steel, Materials Science Forumm 532-533 (2006) 657-660.

[22] M. Bonek, L.A. Dobrzański, A. Klimpel, Structure and properties of hot-work tool steel alloyed by WC carbides by a use of high power diode laser, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 175-178.

[23] L.A. Dobrzański, M. Piec, K. Labisz, M. Bonek, A. Klimpel, Functional properties of surface layers of X38CrMoV5-3 hot work tool steel alloyed with HPDL laser, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 191-194.

[24] 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.

[25] M. Piec, L.A. Dobrzański, K. Labisz, E. Jonda, A. Klimpel, Laser Alloying with WC ceramic powder in hot work tool steel using a High Power Diode Laser (HPDL), Advanced Materials Research 15-17 (2007) 193-198.

[26] L.A. Dobrzański, K. Labisz, A. Klimpel, Structure and properties of the laser alloyed 32CrMoV12-28 with ceramic powder, International Journal of Surface Science and Engineering (2007) 237-245.

[27] L.A. Dobrzański, E. Jonda, A. Polok, A. Klimpel, Comparison of the thermal fatigue surface layers of the X40CrMoV5-1 hot work tool steels laser alloyed, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 135-138.

[28] L.A. Dobrzański, E. Jonda, A. Kriz, K. Lukaszkowicz, Mechanical and tribological properties surface layer of the hot work tool steel obtained by laser alloying, Archives of Materials Science and Engineering 28/7 (2007) 389-396.

[29] L.A. Dobrzański, A. Polok, P. Zarychta, E. Jonda, M. Piec, K. Labisz, Modelling of properties of the alloy tool steels after laser surface treatment, International Journal of Computational Materials Science and Surface Engineering 5 (2008) 135-147.

[30] M. Bonek, M. Piec, L.A. Dobrzański, The study of properties of laser modified hot-work tool steel surface layer, Journal of Achievements in Materials and Manufacturing Engineering 28/1 (2008) 75-78.

[31] M. Bonek, L.A. Dobrzański, Microstructural and tribological characterization of hot-work tool steel modified by laser alloying, Proceedings of the 24th International

Manufacturing Conference IMC24, Manufacturing - Focus on the Future, Waterford Institute of Technology, Ireland, 2007, 805-812.

[32] L.A. Dobrzański, K. Labisz, M. Bonek, A. Klimpel, Structure and properties of the 32CrMoV12-28 hot work tool steels alloyed with BN and Si_3N_4 powder using HPDL laser, The International Conference Advances in Materials and Processing Technologies AMPT'2008, Manama, Kingdom of Bahrain, 2008 (CD-ROM).

[33] L.A. Dobrzański, K. Labisz, M. Bonek, A. Klimpel, Comparison of WC, VC and TaC powder HPDL alloyed 32CrMoV12-28 steel with using HPDL laser, Journal of Achievements in Materials and Manufacturing Engineering 30/2 (2008) 187-192.