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Comparison of the abrasion wear resistance of the X40CrMoV5-1 and 55NiCrMoV7 hot work tool steels with their surface layer enriched with the ceramic powders

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Properties

ABSTRACT

Purpose: In the paper there are presented the results of the influence of laser remelting parameters on the properties of the surface layer of the X40CrMoV5-1 and 55NiCrMoV7 hot work steel, using the high power diode laser (HPDL).
The aim of this work was to compare the abrasion wear resistance of the X40CrMoV5-1 and 55NiCrMoV7 hot work tool steel surface layers enriched with the TiC, WC and VC ceramic powders. The surface layers of hot work tool steel remelted with a diode laser beam have been metallographically examined and analyzed with the use of a hardness testing machine.
Design/methodology/approach: The high power diode laser (HPDL) and ceramic powders WC, VC and TiC were used. Remelting and alloying processes were carried out at the constant remelting rate and focus shape, varying the laser beam power for the alloyed test pieces in the range from 1,2 – 2,3 kW.
Findings: On the basis of the wear abrasion tests carried out on 55NiCrMoV7 and X40CrMoV5-1 steels it could be ascertained that each of those steels is characterized by different resistance for the same powders and the power of the laser beam. In the case of employing 1,2 kW laser, the surface layer formed using the majority of the investigated portions undergoes a total wear during the wear-rate test which also causes the wear of the initial material. When 2,3 kW is employed, the surface layers have crack and microcrack defections which decrease the resistance to the abrasion. The smallest mass loss for 55NiCrMoV7 steel among all the analyzed cases has been observed for the surface layers alloyed with TiC powder, at the of the laser beam power of 2,3 kW and for WC powder at 1,2 kW laser beam power. For the X40CrMoV5-1 steel the smallest mass decrement has been observed for the steel alloyed with WC powder at 1,2 kW laser beam power and VC powder at 1,6 kW laser beam power.
Practical implications: The investigations showed that as a result of the applied laser processing there is the increase in the hardness and resistance to abrasion of the surface layers in relation to the output material.
Originality/value: Wear resistance and hardness of two hot work tool steels were compared.
Keywords: Laser alloying; Hot work alloy tool steel; High power diode laser HPDL; Surface layer; Hardness

1. Introduction

The working surfaces of many technologically applied materials work in specific conditions and are exposed to different kinds of wear, namely abrasive, thermal and adhesive. The proper shaping of machine surface properties and devices, often working in the conditions of changing dynamic loads, is very important. This process, called the surface modification, aims at the reconstruction of the worn out surface of machine parts and the supplementation of decrements. It can consist in of the change of the structure of surface layer and/or change of its chemical composition [1].

A conventional heat treatment is the main way for increasing the abrasion resistance of tools made of tool steel; it consists in quenching and tempering causing a substantial growth of hardness of the material and connected with that the decrease of its plasticity [2].

Among modern, extremely intensively developing methods of machine elements and tool surface shaping, a particular position holds a laser heat treatment. It is the only way that allows the formation of surface layers with a thickness range of tenth parts of millimeters up to a few millimeters and is characterized by a high hardness and resistance to abrasion, at the same time having required plasticity of base material [2, 3].

The newest sources of thermal energy and only recently introduced on a large industrial scale are high power diode lasers (HPDL). Despite many evident advantages of those lasers and a huge interest in them of the producers only a few diode lasers work nowadays in the global industry [4].

The advantage of diode lasers is their very high factor of radiation absorption, which in the case of metals with ferrous matrix and length of laser beam of 0,940μm, is 20-40%. A durability of active elements of diode lasers (diodes) goes beyond 10000 hours and doesn't demand any other handling than cleaning of the optical system. The active element (Fig. 1) consists of many single diode emitters which are built from diode bars with dimensions in a range of a few millimeters. Those bars are put together in packs, which create a new source of laser radiation with the output power equal even to a few kW. [6, 7].

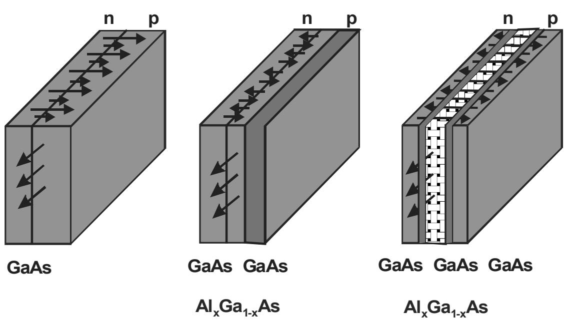

Fig. 1. Active element of high power diode laser HPDL (diode emitter) [6]

In HPDL the laser radiation is generated as an effect of the current flow, with the amperage in the range of 10-50 A, through p-n connections of a diode made of GaAs admixed with Al, In, or P. The radiation power of single diode is very small and doesn't usually exceed a few MW. Because in high power diode lasers there's no phenomenon of energy collecting, they are a source of a high stable and easy to control energy. High power diode lasers are also characterized by a high energetic efficiency which can achieve values of 30-50% [4, 5, 6].

The present application of diode lasers is alloying, fusion and surfacing by welding, soldering, covering with glaze and welding. However, those operations create only a small part of the entire market, of the laser processed materials. It's expected that in the next 5-10 years the application of high power diode lasers will increase. Fig. 2 presents actual participation of lasers in the market [8].

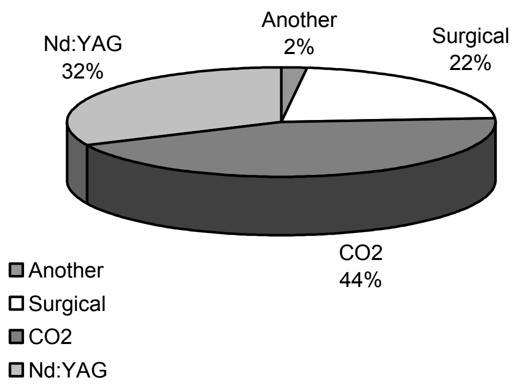

Fig. 2. Lasers participation on global market nowadays [8]

Among the most progressive thermo-chemical treatment is laser surface alloying (LSA) which consist in surface layer enriching with alloying elements and structure changes.

The alloying additions used in the laser alloying process are usually metal alloys, mainly Co, Cr, Mn, Nb, Ni, Mo, V, W, superalloys, stellits, carbides, nitrides and borides. The structure and chemical composition of the surface layer created in the laser alloying process, as well as its physical properties are highly different from the base and alloying material. Laser surface alloying allows forming surface layers with little thickness and special properties, with a high resistance to abrasion and activity of aggressive chemical agents, with high hardness, fatigue strength and heat resistance [9, 10, 12].

Alloying consists in a simultaneous melting and mixing the alloying material with the alloyed material (base material). As a result of the influence of a laser beam the materials are melting and the pool of remelted materials is created, in which, as a result of convection and gravitation movements and the pressure of the laser beam, the materials intensively mix and the fash can be observed on borders of the pool. After the laser beam is stopped, the created alloy solidifies and the base material in its neighborhood self quenches. The structure, chemical composition, physical and chemical properties of the alloy differ from the alloying material as well as from the base material. A rich in alloying elements surface of the alloy is characterized by a higher hardness than the surface and the base material, increased fatigue strength, tribological and anticorrosion to properties, decreased smoothness of the surface in comparison the one before alloying. All those properties depend mostly on the homogeneity of alloy in the liquid state, which depends, in turn, on the intensity of convective mass changes in this zone [11,12,13,14].

2. Experimental procedure

The investigations have been carried out on test pieces from the X40CrMoV5-1 and 55NiCrMoV7 hot work tool steels. A chemical composition of the steel is given in Table 1. Test pieces for the examinations have been obtained from the vacuum melt and made as the O.D. 75 mm round bars. The material for specimens has been delivered in the annealed state, from which cubicoid 65x25x5 mm test pieces were cut out.

The heating to the austenitizing temperature has been done in two steps, with an isothermal stop in the temperature of 580-650˚C and around 850˚C for 15 minutes. The austenitizing has been led for 30 minutes in the temperature proper for each steel and then cooled down in hot oil. After quenching, the samples were double tempered, each time for one hour in the temperature dependent on the kind of steel.

The test pieces have been sand blasted and machined on a magnetic grinder after the heat treatment. Next, powder layer thick of VC, TiC and WC bounded with the sodium glass inorganic binding agent was put down onto the degreased specimens. Ceramic powders properties are presented in Table 2. Next, the test pieces were melted with the Rofin DL 0.20 high power diode laser (HPDL), whose technical specification is given in Table 3.

It has been found out, basing on the preliminary investigations, that the maximum feed rate at which the process is stable is 0.5 m/min. Remelting and alloying processes were carried out at the constant remelting rate and focus shape, varying the laser beam power for the alloyed test pieces in the range from 1,2 – 2,3 kW. The protective gas (argon) blow-in rate was established experimentally as 20 l/min providing full remelting zone protection.

After the remelting and alloying, the samples have been mechanically processed, which consisted in removing not remelted ceramic powders layers. Then the metal-ceramic material wear abrasion and hardness tests were carried out.

The wear rate tests have been done on a device prepared according to the ASTM standard. The measurement of a mass decrement after the wear abrasion test has been performed on a laboratory weight with the sensibility up to 0,0001g. According to the standard, the results of the tests can be considered reliable only in the case when the trace created after the experiment is uniform (Figures 3, 4).

The measurements of Rockwell hardness have been performed using Zwick ZHR hardness intender equipped with electronic sensor that allows the direct readout of the hardness values. The results of the investigation have been statistically elaborated. Figures 9-12 present the average values for the selected powders alloyed with the variable power of the laser and stable speed of scanning equal 0,5m/min.

Table 1.
Chemical composition of X40CrMoV5-1 and 55NiCrMoV7 steels

Type of steel	Mean concentration of elements (wt) [%]								
	C	Mn	Si	P	S	Cr	Mo	V	Ni
55NiCrMoV7	0,55	0,75	0,25	0,025	0,019	1,1	0,50	0,10	1,7
X40CrMoV5-1	0,41	0,44	1,09	0,015	0,010	5,40	1,41	0,95	–

Table 2.
Selected properties of VC, WC and TiC powders

Type of coating	Hardness [HV]	Melting point [°C]
VC	2800÷2900	2650÷2830
WC	1550	2730÷2870
TiC	2800÷3800	3070÷3180

Table 3.
Specification of the HPDL ROFIN DL 0.20 diode laser

Wavelength of the laser radiation, nm	808 ±5
Maximum output power of the laser beam (continuous-wave), W	2300
Laser power range, W	100÷2300
Focal length, mm	82/32
Laser spot size, mm	1.8×6.8
Range of the laser intensity, kW/cm^3	0.8÷36.5

a) b)

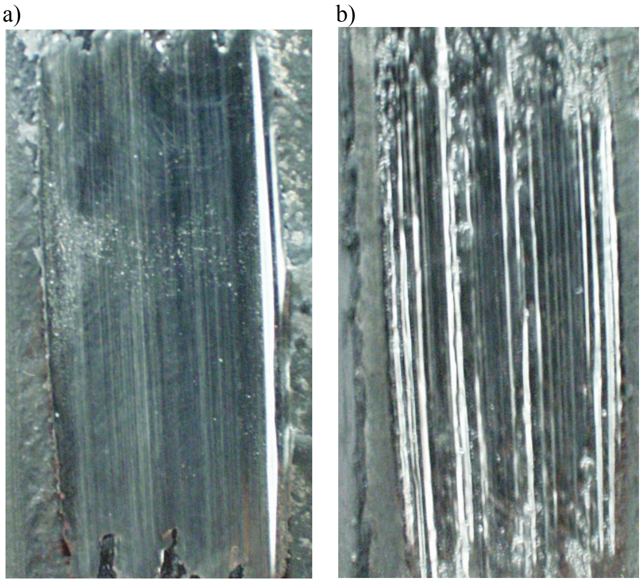

Fig. 3. Surface layer of the test piece from the X40CrMoV5-1 tool steel after wear test alloyed with parameters: feed rate-0,5 m/min a) TiC powder, the range power- 2 kW, b) WC powder, the range power- 1,6 kW, magnification 10x

a) b)

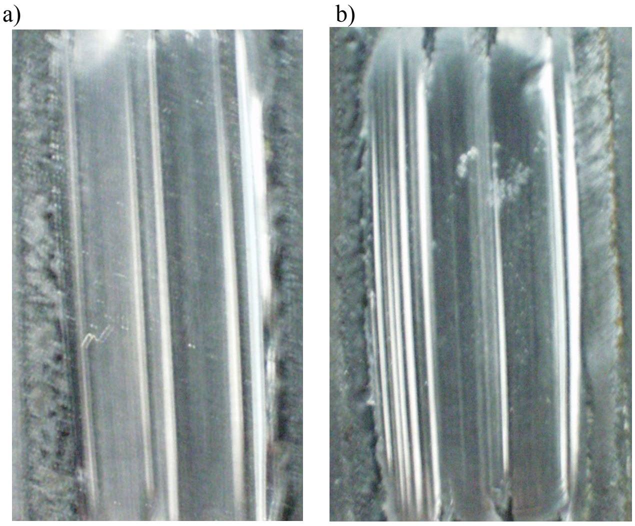

Fig. 4. Surface layer of the test piece from the 55NiCrMoV7 tool steel after wear test alloyed with parameters: feed rate- 0,5 m/min a) TiC powder, the range power- 2 kW, b) WC powder, the range power- 1,6 kW, magnification 10x

3. Results and discusion

As chosen materials referring to the achieved results of experiments have been steels after a conventional heat treatment – 55NiCrMoV7 and X40CrMoV5-1, for which the average mass decrements have been 1,0777 g and 0,7138 g, respectively. Table 4 presents the achieved results of the wear abrasion test.

Figures (5-8) show mass decrement of samples in the function of laser beam power and phases used to alloying.

4. Conclusions

On the basis of the wear abrasion tests carried out on 55NiCrMoV7 and X40CrMoV5-1 steels it could be ascertained that each of those steels is characterized by different resistance for the same powders and the power of the laser beam.

In the case of employing 1,2 kW laser, the surface layer formed using the majority of the investigated portions undergoes a total wear during the wear-rate test which also causes the wear of the initial material. When 2,3 kW is employed, the surface layers have crack and microcrack defections which decrease the resistance to the abrasion.

The smallest mass loss for 55NiCrMoV7 steel among all the analyzed cases has been observed for the surface layers alloyed with TiC powder, at the of the laser beam power of 2,3 kW and for WC powder at 1,2 kW laser beam power. For the X40CrMoV5-1 steel the smallest mass decrement has been observed for the steel alloyed with WC powder at 1,2 kW laser beam power and VC powder at 1,6 kW laser beam power.

The investigations showed that as a result of the applied laser processing there is the increase in the hardness and resistance to abrasion of the surface layers in relation to the output material.
A modification of tool steels surface using a laser beam radiation, as well as coating them with special pastes containing ceramic particles such as wolfram, molybdenum, titanium and others, allows the essential improvement of the surface layer properties – their quality and abrasion resistance, decreasing at the same time the surface quality, what is dependent on the processing parameters such as energy of impulse and the time of its work. The changes of the surface layers hardness formed as a result of remelting and alloying with ceramic powders containing carbides are accompanied with the increased tribological properties in comparison to the conventionally heat treated steels.

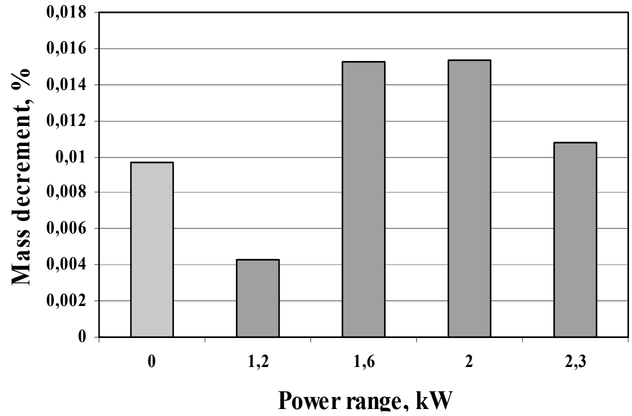

Fig. 5. Mass decrement of X40CrMoV5-1 hot work tool steel WC surface layer alloyed with HPDL

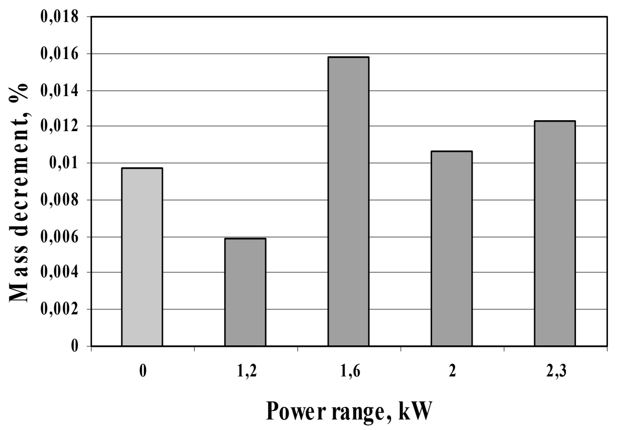

Fig. 6. Mass decrement of 55NiCrMoV7 hot work tool steel WC surface layer alloyed with HPDL

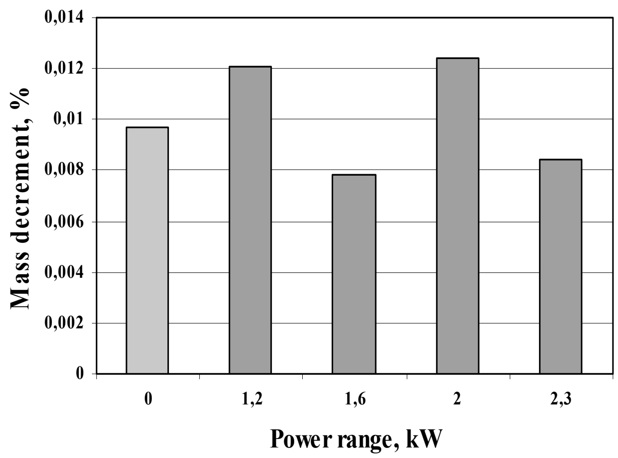

Fig. 7. Mass decrement of X40CrMoV5-1 hot work tool steel TiC surface layer alloyed with HPDL

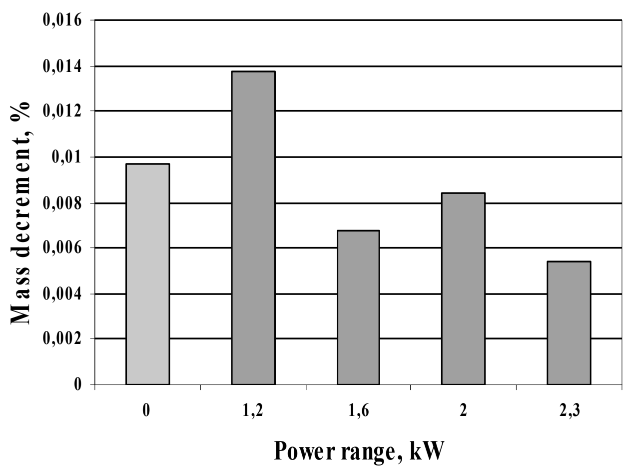

Fig. 8. Mass decrement of 55NiCrMoV7 hot work tool steel TiC surface layer alloyed with HPDL

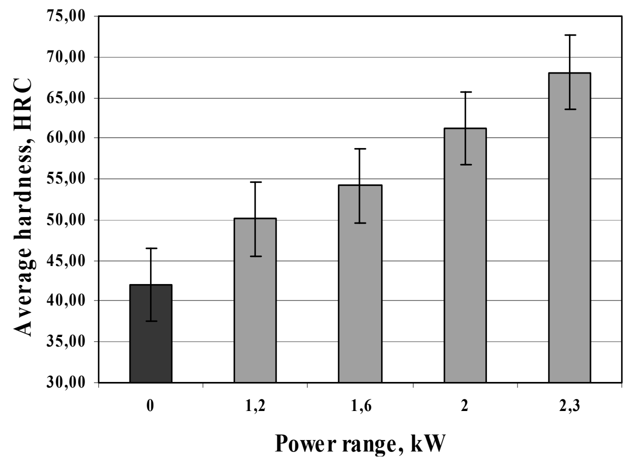

Fig. 9. Average value changes of surface layer hardness of 55NiCrMoV7 alloyed with WC, laser with change range power

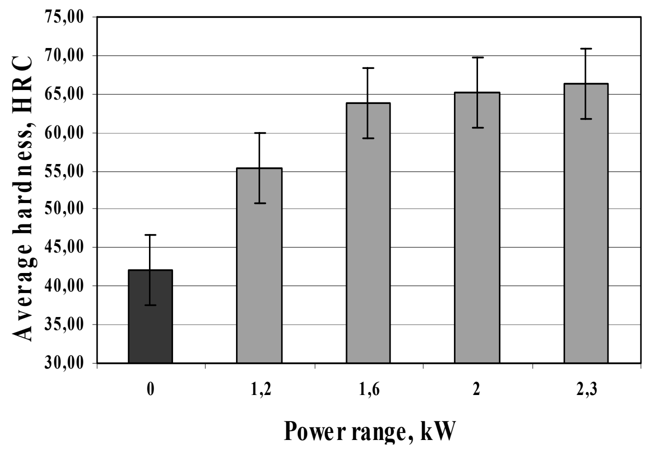

Fig. 10. Average value changes of surface layer hardness of 55NiCrMoV7 alloyed with VC, laser with change range power

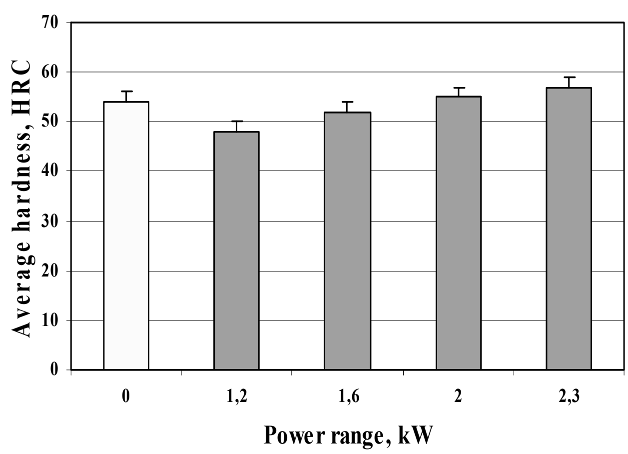

Fig. 11. Average value changes of surface layer hardness of X40CrMoV5-1 alloyed with WC, laser with change range power

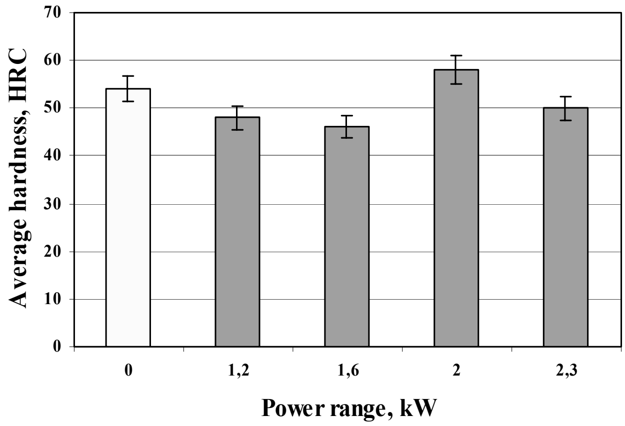

Fig. 12. Average value changes of surface layer hardness of X40CrMoV5-1 alloyed with VC, laser with change range power

Table 4.
Results of wear resistance test of 55NiCrMoV7 and X40CrMoV5-1 hot work alloy tool steels after alloying with high power diode laser HPDL

Type of coating	Laser power range used for alloying, kW	Mass of the specimen before abrasive wear, g	Mass of the specimen after abrasive wear, g	Mass decrement after abrasion wear, g
TiC	1,2	74,0149	72,9974	1,075
	1,6	73,9592	73,4614	0,4978
	2,0	73,3654	72,75	0,6154
	2,3	73,6762	73,276	0,4002
WC	1,2	74,8901	74,451	0,4391
	1,6	75,0345	73,8514	1,4936
	2,0	74,6295	73,8344	0,7951
	2,3	74,8056	73,888	0,9176
VC	1,2	74,1052	73,0162	1,089
	1,6	73,8273	73,255	0,5723
	2,0	73,8397	72,9533	0,8864
	2,3	73,2763	72,809	0,4673
Specimen *55NiCrMoV7*	-	73,9336	72,8559	1,0777
Type of coating	Laser power range used for alloying, kW	Mass of the specimen before abrasive wear, g	Mass of the specimen after abrasive wear, g	Mass decrement after abrasion wear, g
TiC	1,2	74,0216	73,1255	0,9489
	1,6	73,7222	73,1455	0,5767
	2,0	74,1393	73,2215	0,9178
	2,3	74,3073	73,6800	0,6273
WC	1,2	75,0985	74,7790	0,3195
	1,6	74,5973	73,457	1,1403
	2,0	74,5904	73,4455	1,1449
	2,3	75,2006	74,3880	0,8126
VC	1,2	74,1052	73,4570	0,6482
	1,6	74,387	73,8432	0,5438
	2,0	73,266	72,5582	0,7078
	2,3	73,8876	73,2771	0,6105
	2,0	73,459	72,4384	1,0206
	2,3	73,6758	73,0172	0,6586
Specimen *X40CrMoV5-1*	-	73,5663	72,8525	0,7138

Table 5.
Hardness results of specimens alloyed with ceramic powders using high power diode laser

The type of processing	Average value, HRC			
	Power range of laser, kW			
	1,2	1,6	2,0	2,3
55NiCrMoV7				
heat treatment	42			
alloyedg with VC	55	63	64	66
alloyed with WC	50	54	60	68
a alloyied with TiC	64	64	62	62
X40CrMoV5-1				
heat treatment	54			
alloyed with VC	48	46	57	50
alloyed with WC	48	52	55	57
alloyed with TiC	54	56	57	62

References

[1] J. Senkara: Modification of surface with energetic beams, Welding review, nr.8-9, 2001, pp. 23-26.

[2] A. Klimpel, A. Lisiecki, D. Janicki, P. Wochnik: Heat treatment and laser alloying of tool steels, Welding review, nr. 8-10, 2002, pp. 169-171.

[3] L.A. Dobrzański, M. Bonek, E. Hajduczek, A. Klimpel, Lisiecki A.: Application of high power diode laser (HPDL) for alloying of X40CrMoV5-1 steel surface layer by tungsten carbides, Journal of Materials Processing Technology, Vol. 155-156, 2004, pp. 1956-1963.

[4] A. Klimpel, A. Lisiecki: HDPL laser welding of FEP04 steel plates, Proceedings of the Scientific Conference Materials and Mechanical Engineering, M^2E'2000, Gliwice, May, 2000, pp. 269-274.

[5] A. Klimpel: High power diode laser application for alloying and surfacing, Welding review, nr 6, 2001, pp.1-6.

[6] A. Klimpel, R. Gruca, A. Lisiecki: Laser surfacing with ceramic powders, International Symposium IPM, Warszawa-Rynia 8-10, December, 1999, pp. 78-86.

[7] A. Klimpel: High power diode laser in welding, Welding review, nr.8, 1999, pp. 1-7.

[8] Lin Li: The advances and characteristics of high-power diode laser materials processing, Optics and Lasers in Engineering, Vol. 34, 2000, pp.231-253.

[9] J. Kusiński, J. Przybyłowicz, A. Woldan: Laser alloying of surface layers and surface layers overlaying on metal bases, VI Symposium of Laser Technique – Reports, Szczecin-Świnoujście, 1999, pp. 354-368.

[10] A. Lisiecki: Laser alloying of WCL steel with ceramic powders, Welding review, nr.8-10,2002, pp. 131-133.

[11] T. Burakowski: Metal surfaces engineering: basis, devices and technologies, WNT, Warsaw, 1995.

[12] J. Kusiński: Lasers and their application in material engineering, "Akapit" Publishing, Kraków, 2000.

[13] L.A. Dobrzański, M. Bonek, A. Klimpel, Lisiecki Surface layer's structure of X40CrMoV5-1 steel remelted using the high power diode laser (HPDL), Proceedings of the 11 th International Science Conference on AMME' 2002, Gliwice-Zakopane, 2002, pp. 269-273 .

[14] L.A. Dobrzański, M. Bonek, E. Hajduczek, A. Klimpel: Tribological behavior of the X40CrMoV5-1 steel alloyed with tungsten carbide using the high power diode laser, International Science and Engineering Conference Machine- Building and Tehnosphere of the 21thc., Sevastopol, Ukraine, 2004, pp. 63-68.