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The comparision of tribological properties of the surface layer of the hot work tool steels obtained by laser alloying

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ABSTRACT

Purpose: The paper presents the investigation results of the influence of laser remelting or alloying on the abrasive wear resistance of the X40CrMoV5-1 and 32CrMoV12-28 hot work tool steels surface, using the high power diode laser (High Power Diode Laser).
Design/methodology/approach: The main goal of this work was to compare the abrasion wear resistance of those two steels before and after laser treatment consisting on remelting or alloying with carbide powders. The reason of this work was also to determine the laser treatment parameters, particularly the laser power, to achieve surface layer with better properties for example hardness which is connected with abrasive wear resistance of surface layers.
Findings: A modification of tool steels surface using a laser beam radiation, as well as coating them with special pastes containing particles such as vanadium 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. Surface layer obtained due to laser modification is characteristic of different properties than the native material.
Research limitations/implications: The results present only four selected laser powers by one process speed rate. Also carbide powders were used for alloying with the particle size in a chosen range.
Practical implications: The alloyed layers which were formed on the surface of the hot work steel have shown significant improvement. Good properties of the laser treatment make these layers suitable for various technical and industrial applications.
Originality/value: Structural and tribological behaviour of surface layer achieved by alloying and remelting using high diode power laser and selected ceramic powders were compared.
Keywords: Laser treatment; Carbide powder; High Power Diode Laser, Abrasive wear resistance

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1. Introduction

The hot work tool steels belong to the group of steels used in the production of forging tools. Tool steels feature a widely used group of tool materials, especially interesting because of their low price and very good functional properties. It can be observed a permanently increasing interest in hot work tool steel development. This situation gives the basis for carrying out investigations focused on the improvement of the functional properties of these materials [1, 2]. The working surfaces of many technologically applied materials work in specific conditions and are endanger to different kinds of wear, namely abrasive, thermal and adhesive. The process called the surface modification aims at the reconstruction of the worn out surface of machine parts and the supplementation of decrements.

The principal way of increasing the abrasion resistance of tools made of tool steel is a conventional heat treatment. Its consists in quenching and tempering causing a substantial growth of hardness of the material and connected with that the decrease of its plasticity [2]. During the complex thermo - plastic treatment the microstructure of hot work tool steel changes several times. The aim of this processing is to obtain high wear and thermal fatigue resistance, which causes the significant hardness increase and deterioration of the plasticity of these steels connected with it [3, 4]. Laser treatment is used to prevent it and holds a particular position among modern, extremely intensively developing methods of machine elements and tool surface shaping. This way allows the formation of surface layers with a thickness range of tenth parts of millimeters and its characterized by a high hardness and resistance to abrasion, at the same having required plasticity of base material [5]. This type of heat treatment is a part of the new generation techniques applied in metal surface technology and represents the especially promising tool for solving the contemporary surface engineering problems thanks to the physical properties of the laser beam. Laser manufacturing techniques belong to the most promising and efficient ones for ensuring the development in many industry branches and especially those in which materials processing dominates [6-9]. Laser surface alloying (LSA) 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 [10, 11]. 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. 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 [12-15].

2. Material ve method

The investigations have been carried out on test pieces from the X40CrMoV5-1 and 32CrMoV12-28 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 samples were heat treated according to the steps for those steels type. Austenisation of the 32CrMoV12-28 was performed in a vacuum furnace at a temperature of 1040 °C, the heating time 0.5h During the heating to the austenitic temperature two isothermal holds were applied. The first one at the temperature of 585 °C, the second at 850 °C. After tempering two annealing operations were performed for the time of 2h, the first at 550 °C and the second at 510 °C. Specimens from X40CrMoV5-1 tool steel were twice subjected to heat treatment consisting in quenching and tempering; austenizing was carried out in the vacuum furnace in 1020 °C with the soaking time 0.5h. Two isothermal holds were used during heating up to the austenizing temperature, the first at the temperature of 640 °C and the second at 840 °C.

The specimens were tempered twice after quenching, each time for 2 hours at the temperature 560 °C and next at 510 °C. After heat treatment the surface of specimens were grounded on magnetic grinder. Special care was set to avoid micro cracks, which can disqualify samples in future investigations. Next, the paste of VC (Figure 1) carbide powder was put down onto the degreased specimens. A paste layer of 0.05 mm in thickness was put on. The properties of vanadium carbide powder are presented in Table 2. The samples of the 32CrMoV12-28 and X40CrMoV5-1 steels were mounted in the laser holder and next were remelted with the Rofin DL 020 high power laser beam (HPDL).

Table 1.
Chemical composition of 32CrMoV12-28 and X40CrMoV5-1 steels

Steel type	Mass concentration of the elements, %								
	C	Si	Mn	P	S	Cr	Mo	V	W
X40CrMoV5-1	0.41	1.09	0.44	0.015	0.010	5.40	1.41	0.95	0.01
32CrMoV12-28	0.308	0.25	0.37	0.20	0.002	2.95	2.70	5.35	-

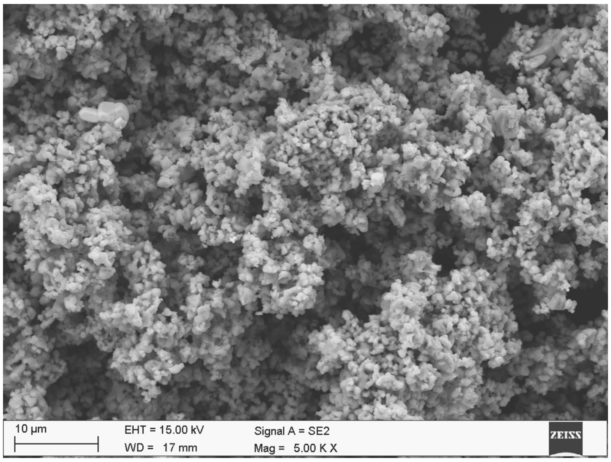


Fig. 1. SEM morphology of the vanadium carbide

Table 2.
Selected properties of VC powder

Powder	Grain size, [µm]	Melting point, [°C]	Density, [g/cm^3]	Hardness, [HV_{30}]
VC	1.5	2830	5.36	2850

After the remelting and alloying, the samples have been mechanically processed, which consisted in removing not remelted ceramic powders layers. The alloyed test pieces were cut on the Struers device in the plane perpendicular to the remelting direction. The cutting disk was water cooled. The test pieces were mounted in the thermosetting resin. The mounted test pieces were next machined in two operations: grinding and polishing. Etching of specimens was carried out in NITAL, at room temperature. Etching time for each test pieces was selected individually for each remelted test piece run. After etching, the test pieces were rinsed in the ultrasonic washer in the ethyl alcohol, and next dried with the compressed air. Metallographic examinations of the material microstructures after laser alloying surface layer were made on Zeiss Leica MEF4A light microscope in a magnification range of 50-500x. The observations were performed on the cross section of the samples on each of the remelting trays (Figs. 2 and 3). Metallographic investigations were performed also using the scanning electron microscope DSM 940 supplied by OPTON.

Abrasion wear resistance tests of the surface layers in the metal - ceramic material arrangement were carried out on a device developed in the Department of Welding of the Silesian University of Technology according to the ASTM G65 standard (Fig. 4). The surface layer obtained consisted of four adjacent welding sequences. Two test pieces of each type of the investigated gradient surface coatings were examined according to the requirements of the standard. The ceramic material - quartz sand with the granularity of 212-300 µm - was delivered by the nozzle with the flow rate of about 350 g/min during the test. The nozzle was between the examined test piece and the rubber circle with the diameter of 229 mm. The test piece was loaded with the constant force of 130 N and was pressed down to the rotating rubber wheel. The test pieces before and after the grindability examinations were weighed on the analytical balance with the accuracy of 0.0001g to check the mass loss, depending on the used particles and laser power. 32CrMoV12-28 and X40CrMoV5-1 conventionally heat treated steels were used as reference materials.

a) b)

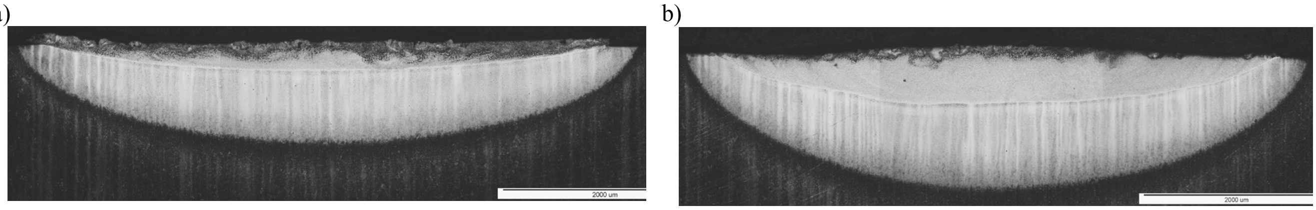


Fig. 2. Remelted and heat affected zone in the surface layer of the X40CrMoV5-1 hot work tool steel alloyed with VC, scanning rate 0.5 m/min., a) power range 1.2 kW, b) power range 2.0 kW, mag. 50x

a) b)

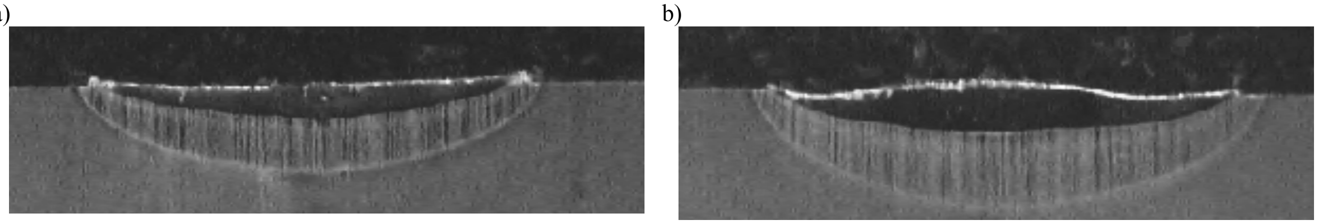


Fig. 3. Remelted and heat affected zone in the surface layer of the 32CrMoV12-28 hot work tool steel alloyed with VC, scanning rate 0.5 m/min., a) power range 1.2 kW, b) power range 2.0 kW, mag. 50x

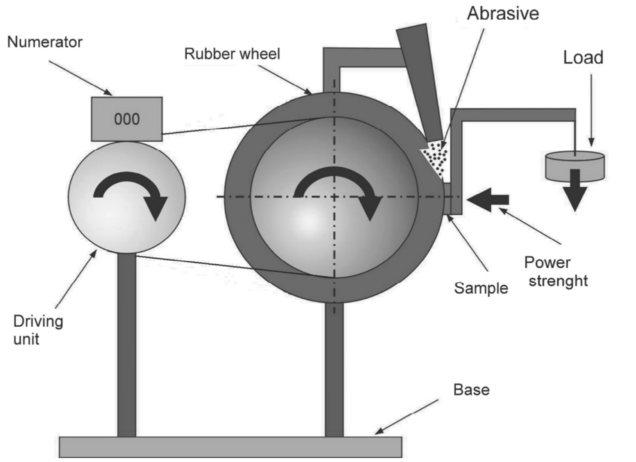


Fig. 4. Experimental stand for the abrasive wear investigations in a metal - ceramic system according to the ASTM G65

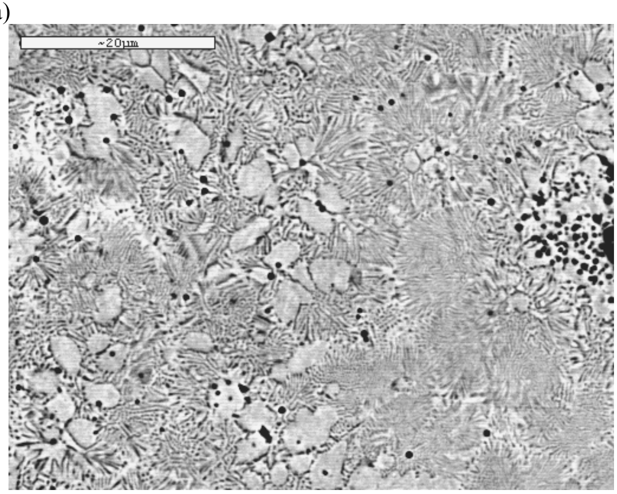
The. measurement of a mass decrement after the wear abrasion test has been performed on a laboratory weight with the sensibility up to 0,0001g. According to the standard, the results of the tests can be considered reliable only in the case when the trace created after the experiment is uniform.

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.

3. Results and discussion

The microstructure of the solidifying material after laser alloying is diversified and is dependant on the solidification rate of investigated steels. Occurrence of microstructure with big dendrites was revealed in areas at the interface the solid and liquid phases. There is clean relation ship between the employed laser power and undissolved carbide powder grains into the molten steel substrate. Carbides remain undissolved in certain cases, forming conglomerates (Fig. 5). Increasing the laser power results in decrease of the portion of the undissolved carbides depressively hardening the remelted matrix of the steel surface layer. 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. After the laser alloying of steel with the VC this carbide dissolve partially originating conglomerates of carbides, and the laser power increase causes their partial melting, the local concentrations of vanadium exceed the equilibrium concentrations in the alloyed surface layer.

a)



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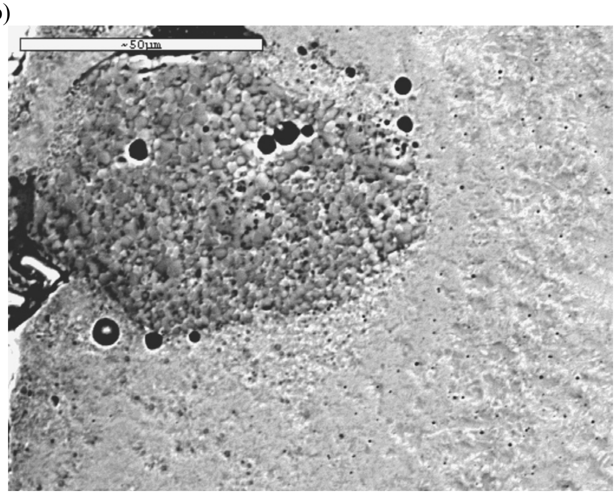


c)

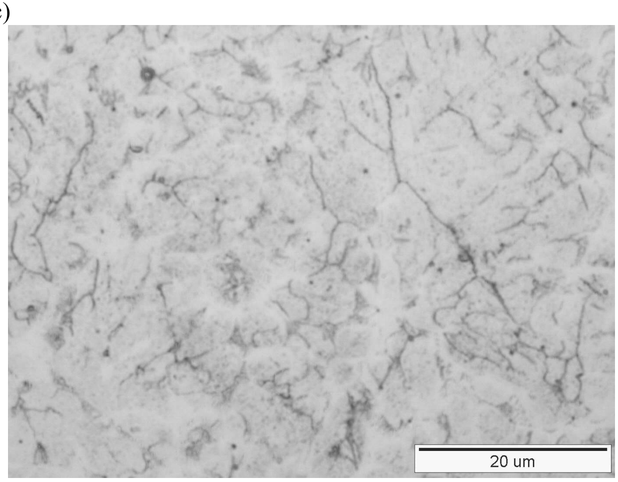
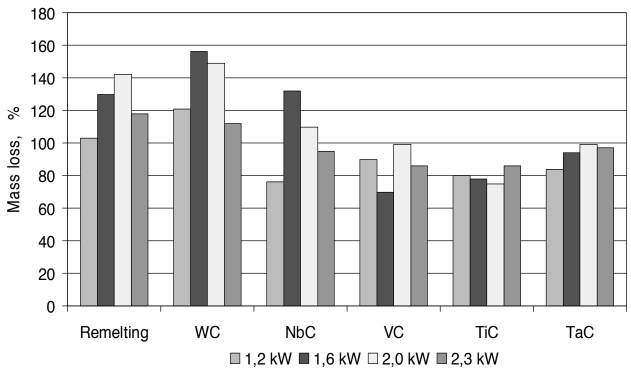


Fig. 5. Surface layer of the steel X40CrMoV5-1 after alloying with VC powder, laser power a) 1.6 kW, b) 1.2 k W, c) 2.3 kW

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. Hardness of the X40CrMoV5-1 steel surface layer alloyed with carbides grows compared to steel hardness attained after the conventional heat treatment, and its growth is proportional to laser beam power used in the laser alloying process. The highest hardness fot this steel of 62.6 HRC is characteristic of the surface layer alloyed with the VC vanadium carbide with the laser beam power of 2.0 kW. One can state based on the hardness tests of the 32CrMoV12-28 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.

a)



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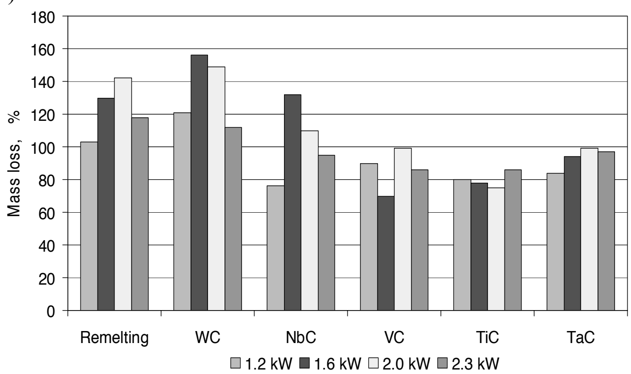

Fig. 6. Mass loss in comparison to the applied ceramic powder in the surface layer of the a) X40CrMoV5-1, b) 32CrMoV12-28

Gradient hardness changes of the surface layers of the investigated steels, obtained by alloying with carbides using the high power diode laser, are usually accompanied by improvement of their tribological properties compared with the conventionally heat treated steel represented by their average mass loss (Fig. 6).

Improvement of the tribological properties is connected with the increase of steel hardness which is caused next with structure refinement. In case of the 32CrMoV12-28 steel the lowest average mass loss occurs on surfaces alloyed with vanadium carbide. 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 dissolving 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. 7).

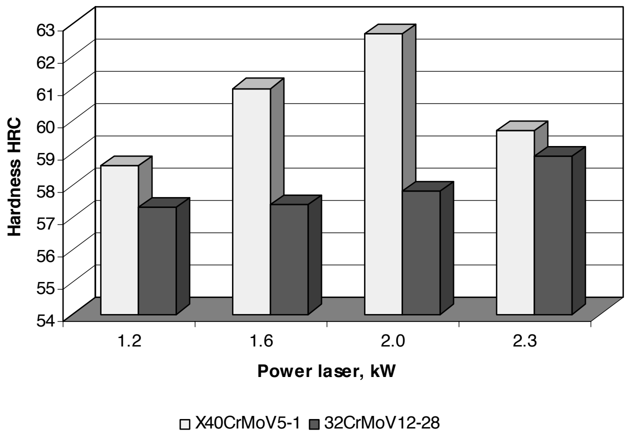

Fig. 7. Average hardness changes of the surface layer of the: a) X40CrMoV5-1, b) 32CrMoV12-28 steels alloyed wit VC carbides with 1.2-2.3 kW laser power

4. Conclusions

The presented research results give grounds to the statement that the fabricated gradient surface layers, especially those made using the vanadium carbide powders 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 hot work tools service conditions, especially employing the thermal fatigue resistance-, hardness-, and abrasion wear resistance tests.

A modification of tool steels surface using a laser beam radiation, as well as coating them with special pastes containing particles such as vanadium 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. Surface layer obtained due to laser modification is characteristic of different properties than the native material. Laser alloying with the VC results in structure refinement in the entire investigated laser power range

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Additional information

Selected issues related to this paper are planned to be presented at the 16th International Scientific Conference on Contemporary Achievements in Mechanics, Manufacturing and Materials Science CAM3S'2010 celebrating 65 years of the tradition of Materials Engineering in Silesia, Poland and the 13th International Symposium Materials IMSP'2010, Denizli, Turkey.

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