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Functional properties of surface layers of X38CrMoV5-3 hot work tool steel alloyed with HPDL laser

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ABSTRACT

Purpose: Improvement of functional properties alloyed of hot work tool steel surface layers is one of the goals of this paper.

Design/methodology/approach: The material used for investigation was the hot work tool steel X38CrMoV5-3. Remelting and alloying of surface layers were made using the HPDL high power diode laser Rofin DL 020 in the laser power range of 1.2-2.3 kW. The carbide powders were applied on specimens prepared and degreased in this way; the powder was mixed with the sodium glass as inorganic binder in proportion of 30% binder and 70% powder. Paste coating 0.5 mm thick was put down in each case.

Findings: The hardness changes of the surface layers obtained by remelting and alloying with carbides using the high power diode laser are accompanied with the improved tribological properties compared to the conventionally heat treated steel. The highest abrasion wear resistance, more than 2.5 times higher than that of the base material, was revealed in case the steel alloyed with vanadium carbide.

Research limitations/implications: These advantages are the result of features unique to the HPDL, such as: shorter wavelength (thus better beam absorption for most metallic materials, and smaller absorption length) and better temporal beam stability (due to beam integration) compared to Nd:YAG and CO_2 lasers. HPDL materials processing is, therefore, expected to produce better quality and more consistent and repeatable results for applications requiring beam spot sizes larger than 0.5mm diameter. One of the issues of concern in the practical applications of the lasers in materials processing for mass production is the repeatability.

Practical implications: The research results indicate to the feasibility and purposefulness of the practical use of remelting and alloying with the ceramic particles using the high power diode laser for manufacturing and regeneration of various tools from the X38CrMoV5-3 hot-work tool steel.

Originality/value: The laser treatment methods is still the most precise way to improve properties of the surface layers.

Keywords: Properties; Mechanical properties; Surface layers; Alloying; Diode laser; Carbides

1. Introduction

Tool materials are still interested for industry. The reasonable price and good properties decide about the interesting of this materials. Big interest in these steels gives basis for carrying out investigations focused on improvement of the functional properties of these materials. Therefore, improvement of the surface layer of the tool steels has to take fully into account the anticipated tool service conditions. On the other hand, it is essential to obtain the required tool properties, with the adequately high reliability.

The laser has several unique properties used in heat treatment of materials' surfaces. Part of the absorbed heat energy penetrates inside the material during remelting, which results with a high temperature gradient between the liquid material and the base material. Mixing of the molten metal occurs because of the convection motions during laser treatment with remelting. Quick solidification occurs after remelting and mixing the molten metal due to the high temperature gradient.

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 hot-work tool steel.

2. Experimental procedure

Investigations were carried out on test pieces of the X38CrMoV5-3 hot work tool steel with the composition according to PN-EN ISO 4957:2002U standard. Chemical composition of the steel is given 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. 76 mm bars 3 m long, which were soft annealed. Test pieces for structural and tribological tests were made using the test pieces with the following dimensions: 65 x 25 x 5 mm. Specimens prepared like that were subjected to heat treatment consisting in quenching and tempering twice. Austenitising was carried out in vacuum furnace at the temperature of 1040ºC, at the holding time of 0.5 h. Two isothermal stops were used during heating to the austenitising temperature were used - at temperatures of 585ºC and 850ºC. The specimens were tempered twice after quenching, each time for 2 hours, at the temperature of 575°C and next at 560 ºC. Surfaces of specimens were grounded on magnetic grinder after heat treatment. Particular attention was paid to prevent development of micro-cracks that might disqualify the specimen from further examination.

Remelting and alloying of surface layers were made using the HPDL high power diode laser Rofin DL 020 (figure 1) in the laser power range of 1.2÷2.3 kW. The following carbides were used as the alloying material: TaC, NbC, WC, VC, and TiC with the average grain size showed in table 2. The specification of the HPDL laser ROFIN DL 020 are presented in Table 3. Remelting and alloying 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 surface.

It was found out in the preliminary investigations that the maximum speed rate at which the process is stable is 0.5 m/min.

Further experiments were carried out at the constant remelting speed, changing the laser beam power in the 1.2-2.3 kW range during remelting the surface layer of the test pieces. It was revealed that the argon is delivered by the nozzle 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.
Abrasion wear resistance tests of the surface layers were carried out in the metal-ceramic material arrangement according to the ASTM standard.

Two test pieces of each type of the investigated surface coatings were examined according to the requirements of the ASTM standard. The ceramic material - quartz sand with the granularity of 212-300 μm - is delivered by the nozzle with the flow rate of about 350 g/min during the test. The nozzle is between the examined test piece and the rubber wheel with the diameter of 229 mm. The test piece is loaded with the constant force of 130 N and is pressed down to the rotating rubber wheel. This wheel, rotating at the constant speed of 200 rpm, makes 6000 rotations during the test.

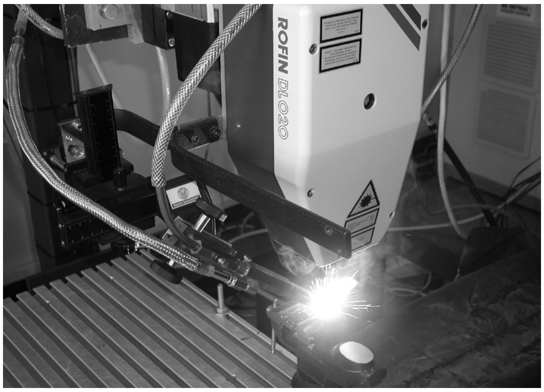

Fig. 1. Alloying process of ceramic particles of hot work tool steel using high power diode laser HPDL Rofin DL 020

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. The X38CrMoV5-3 conventionally heat treated steel was used as reference material. The mass loss of the investigated layers was determined using the following relationship 1:

$$\text{Mass loss} = \frac{\Delta m \text{ specimen with carbide [g]}}{\Delta m \text{ heat treated specimen [g]}} \times 100\ \% \quad (1)$$

Abrasion resistance wear tests of the surface layers in the metal-metal arrangement were carried out using the device designed at the Faculty of Mechanical Engineering of the Silesian University of Technology.

The test piece was examined on which two remelting or alloying beads were made for each of the surface layers. Preparation of the test pieces for examinations consists in grinding the surface with the 1200 grit abrasive papers, to remove the remains of the non-remelted powder. Particular attention was paid to prevent removal of the remelted zone.

Table 1.
Chemical composition of X38CrMoV5-3 steel

The mass concentration of main elements, %							
C	Si	Mn	P	S	Cr	Mo	V
0,372	0,42	0,43	0,022	0,002	4,95	2,72	0,42

Table 2.
Physical composition of applied powders

Powder	Grain sice, µm	Melting temperature,°C	Density g/cm^3	Hardness, HV
Niobium carbide	10	3500	7,6	2100
Tantalum carbide	10	3880	15,03	1725
Vanadium carbide	1,5	2830	5,36	2850
Titanium carbide	3	3140	4,25	2800
Tungsten carbide	5	2770	15,6	2600

Table 3
Specification of the HPDL ROFIN DL 020 diode laser

Wavelength of the laser radiation, nm	808 ± 5
Maximum output power of the laser beam (continuous wave), W	2300
Power range, W	100-2300
Focal length of the laser beam, mm	82 / 32
Laser spot size, mm	1.8 × 6.8
Power density range in the laser beam, kW/cm^2	0.8-36.5

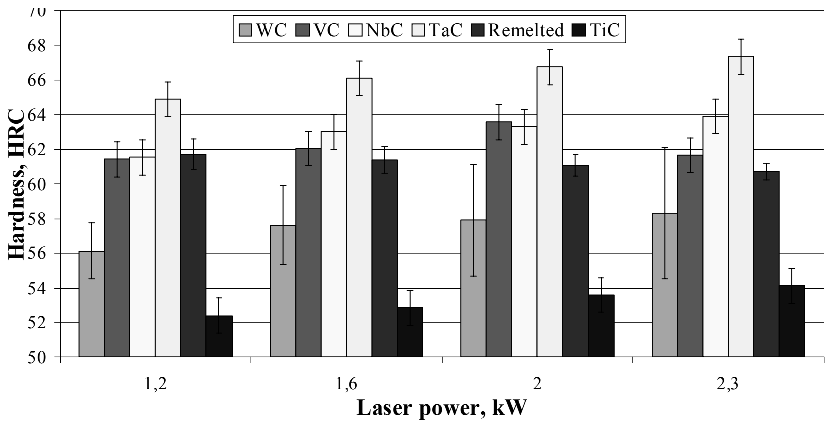

Fig. 2. Changes of the average hardness of the X38CrMoV5-3 steel surface layer after alloying with carbides

Tests were carried out on surfaces prepared in this way using the steel ball with 8.7 mm diameter as the counter-specimen. The load of 10 N and the constant number of cycles of 1000 were determined in the preliminary tests. Test pieces were rinsed in the ultrasonic washer to clean them before and after the test. Wear profiles were registered for the investigated surface layer, and also the wear trace of the counter-specimen to compare the test results for each type of the test pieces coated with various alloying particles at various laser power values.

3. Discussion of experimental results

Remelting and laser alloying with all the listed carbides influence the structure dispersion in all the examined laser power range and the diversity of grain size in respective zones of the surface layer. What follows as a result of structure dispersion is the hardness increase of steel surface as well as the increase of the abrasive wear resistance.

In the surface layers there are remelting and heat-effected zones whose thickness is dependent on the applied laser power and the ceramic material used.

The thickness of the obtained hot work tool steel surface layer increases with the growth of the laser power from 1,2 – 2,3kW. The structure of the solidified material after the laser remelting is characterized by the diversified morphology connected with the multiple change of the crystal growth direction from little dendrites to tiny equiaxed grains in the near-surface zone. The main axes of the dendrites are directed according to the heat abstraction directions on the border of the solid and liquid phases with the carbides' clusters arranged according to the whirls caused by a convectional movement in the pool of the metallic liquid as well as partly unremelted conglomerates NbC, TaC, VC, WC and TiC as a melting material in the middle area of the remelted zone (figure 3). A very fast process of the heat abstraction from the remelted zone through the core of a material with a multiply bigger heat capacity decides about the martensite transformation of the austenite arisen as a result of crystallization, and the partially twined lath martensite, formed this way, is characterized by big lathes' dispersion with their length several times shorter in comparison to martensite lathes after a conventional heat treatment. The hardness changes of surface layers (figure 2) obtained as a result of remelting and alloying with carbides with the use of a high power diode laser usually accompanies the increased tribological properties in relation to the conventionally quenched steel.

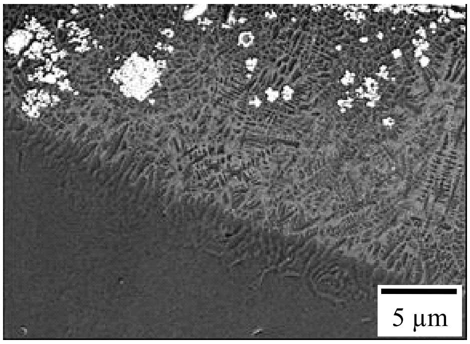

Fig. 3. The surface layer of TaC carbide alloyed hot work tool steel, with laser power of 1,2 kW, (SEM)

4. Summary

The realized investigations allow concluding, that results of heat-treatment and remelting of the hot work steel X38CrMoV5-3 with ceramic powders 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 realized alloying show of influence parameters by the use of diode laser HPDL on the structure and properties of hot work tool steel. If the increase laser power depth of remelting is higher and the surface is more regular, less roughness and more flat. In the case of alloying of carbides surface layer does not show proportion dependence on the roughness of surface from the laser beam. This is resulted of setting mechanism of carbides in the surface layer steel X38CrMoV5-3. Depth of alloying increase proportion together with the laser power and is above two time more relation to some melting for all analysed powers laser. The metallographic investigations on the scanning microscope using the EDX analysis confirm the occurrence of ceramic particles in surface layer.

The hardness changes of the surface layers obtained by remelting and alloying with carbides using the high power diode laser are accompanied with the improved tribological properties compared to the conventionally heat treated steel. The highest abrasion wear resistance, more than 2.5 times higher than that of the native material, was revealed in case the steel alloyed with vanadium carbide. The research results indicate to the feasibility and purposefulness of the practical use of remelting and alloying with the carbides using the high power diode laser for manufacturing and regeneration of various tools from the X38CrMoV5-3 hot-work tool steel.

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