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Effect of laser treatment on changes of the surface layers properties of the hot work alloy tool steels

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Abstract: The paper presents results of the structure and properties examinations of the X40CrMoV5-1 hot work alloy tool steel alloyed with ceramic powders using the high power diode laser. The effect was determined of the main alloying parameters on properties and structure of the surface layer of the steel, and also the dependence of the remelted layer thickness on the laser power used for remelting.

Keywords: Laser alloying, Hot work alloy tool steel, High power diode laser HPDL, Surface layer.

1. INTRODUCTION

The development of technology and civilisation impose new challenges to materials used commonly on the industrial scale, and the hot work alloy tool steels are the materials to which higher and higher demands are posed pertaining to their reliability and service life. Therefrom, the need arises to improve continuously the materials existing to date, or to search for new ones, which will meet the constantly increasing expectations. Economical considerations dictate, however, manufacturing and implementing new materials; therefore, the costly materials are used no more, being replaced with the less expensive ones after their relevant surface treatment [1, 5, 6].

The main method of improving the abrasive wear resistance of tools made from alloy steel is usually their heat treatment consisting in quenching and tempering, which causes the significant hardness increase and deterioration of the plasticity of these steels connected with it. Laser alloying is used to prevent it and to improve simultaneously the technological properties of the surface layer of the tool steel, and to extend thus the service life of tools [1 - 4].

Laser enrichment (alloying) of the surface layer of materials with alloying additions is a new method of the thermo-chemical treatment. Laser modification by the appropriate selection of the alloying elements and process parameters makes it possible to obtain the surface layers with the structure and parameters comparable to the high-alloy steels. The surface layer rich with the alloying elements is usually characteristic of the higher hardness than the substrate, higher fatigue strength, better tribological and anti-corrosion properties, at the simultaneously worse smoothness than the substrate before alloying.

Laser alloying (LSA-Laser Surface Alloying) is the state-of-the-art thermo-chemical treatment process, consisting in enrichment of the surface layers of materials with the alloying elements and change of their structure. Laser radiation is used in this process, featuring currently the only source of energy with the power density exceeding even 10^9 W/ cm^3. The high energy densities and the controlled energy distribution in the laser beam focus area make heating possible and melting at high rates of the small metal volumes, at the simultaneously minimum heat influence on the substrate metal and at the minimum line energy values. Because of the laser alloying, the hot work alloy tool steels, attain the surface layer of a small thickness and specific properties, i.e.: high abrasion wear-, erosion-, and corrosion resistance, resistant to the aggressive chemical agents attack, with the high hardness and simultaneously high fatigue strength and high heat resistance [2, 3, 4, 6, 7].

2. INVESTIGATION METHODOLOGY

Investigations were carried out on test pieces from the hot work X40CrMoV5-1 high-speed tool steel. Chemical composition of steel is given in Table 1. Test pieces for examinations were obtained from the vacuum melt and made as the O.D. 76 mm round bars. The specimens' material was delivered in the annealed state, from which cubicoid 70x25x6 mm test pieces were cut out. The test pieces were heated to the austenitizing temperature gradually, with holding at 650°C for 15 min, and next they were austenitized in the vacuum furnace at the temperature of 1020°C. Cooling was carried out in hot oil. The test pieces were tempered twice after quenching, each time for 2 hours in the temperature range of 500-550°C.

Test pieces were sand blasted and machined on a magnetic grinder after heat treatment. Next, powder layer 0.5 mm thick of ZrO_2 and VC bounded with the sodium glass inorganic binding agent was put down onto the degreased specimens. Selected ZrO_2 and VC 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.

Table 1.
Chemical composition of X40CrMoV5-1 steel

Type of steel	Mean concentration of elements (wt) [%]								
X40CrMoV5-1	C	Mn	Si	Cr	W	Mo	V	P	S
	0,41	0,44	1,09	5,40	0,01	,41	0,95	0,015	0,010

Table 2.
Selected properties of ZrO_2 and VC powders

Type of coating	Hardness [HV]	Melting point [°C]
ZrO_2	1375	2677
VC	2850	2740

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

Wavelength of the laser radiation	808 nm ±5 nm
Maximum output power of the laser beam (continuous-wave)	2300 W
Laser power range	100 ÷ 2300 W
Focal length	82 mm / 32 mm
Laser spot size	1.8 × 6.8 mm / 1.8 × 3.8 mm
Range of the laser intensity	0.8÷36.5 kW/cm^2

3. EXPERIMENTAL PROCEDURE

ROFIN DL 0.20 high power diode laser (HPDL) was used for alloying the X40CrMoV5-1 steel. Its technical specification is given in Table 4. It is a high power laser, a versatile one, and used in materials engineering for pad welding, welding, remelting, and surface enrichment. The laser system consists, among others, of the following modules: rotating work table, movable in the X-Y plane, nozzle with the feeder of powder for enrichment or pad welding, protective gas nozzle, laser head, power supply and cooling systems, and the computer system controlling the laser operation and work table positioning. Figure 1 presents the schematic diagram of the laser alloying process, due to remelting the substrate material with the alloying material layer put down on it.

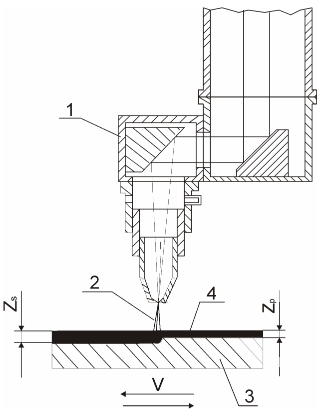


Figure 1. Schematic diagram of the laser alloying process, due to remelting the substrate material with the alloying material layer put down on it: 1 – laser focusing system, 2 – laser beam, 3 – alloyed material, 4 – alloying material, Zs - depth of the alloyed layer, Zp - thickness of the alloying layer.

It was 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.

The test pieces were machined after alloying, to remove the non-remelted ZrO_2 and VC layer, and further the metallographic microsections were made of them.

The remelted and enriched 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 within 12 min (7 min for heating the resin and 5 min for cooling the specimen). The mounted test pieces were next machined in two operations: grinding and polishing.

The initial grinding of each test piece was done on the water moistened abrasive papers with the successive numbers of 220, 500, 800, and 1200. The initial grinding time for all test pieces was 4 min, and the test piece load was 250 N. The finishing grinding was done using the DP – Plan type disk, on which the diamond abrasive slurry with the abrasive grain size of 9 μm was sprayed. Each specimen was ground for 5 min with 250 N load. In addition the disk was moistened with the cutting fluid.

Two-stage polishing was carried out. At the first stage, all test pieces were polished on the DP-Plan disk with the diamond slurry of the 6 μm grain size. Polishing time was 5 min and load value was 200 N. At the second stage, the test pieces were polished on the DP-Nap disk with the diamond slurry of the 1 μm grain size for 3 min with the load value of 150 N. Disks were moistened with the cutting fluid at both grinding stages. The metallographic microsections were etched after their preparation.

Etching of specimens was carried out in NITAL with the following composition: 2-5 ml HNO_3 nitric acid, 100 ml C_2H_5OH ethyl alcohol, 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. Microsections prepared in this way were observed on the light microscope.

Metallographic examinations of the material structures after laser alloying of their surface layer were made on Olympus PME3 light microscope with magnifications from 50 to 200x.

3. INVESTIGATION RESULTS

Basing on observations of structure photographs taken on the light microscope (Figs 2-3) one can state that during alloying the steel with the ZrO_2 and VC 0.5 mm thick layer in the entire range of the laser power values used (1.2 kW÷2.3 kW) the obtained run face is characteristic of the high roughness, multiple pores, irregularity, and flashes at the borders. At higher alloying laser power values run face convexity appears.

a) 

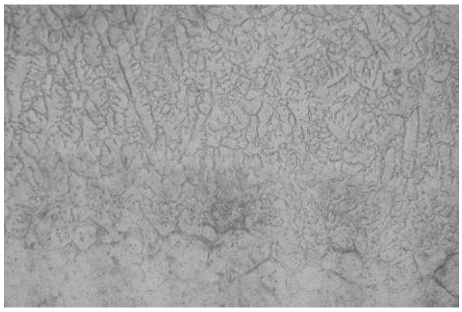
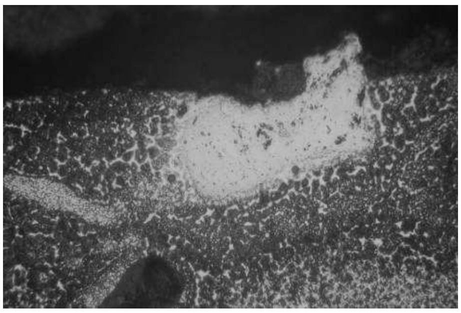
b) 

Figure 2. Surface layer structure of the test piece from the X40CrMoV5-1 tool steel after alloying with the ZrO_2 ceramic powder using the HPDL diode laser, a) magnification 100x, b) magnification 200

c) 

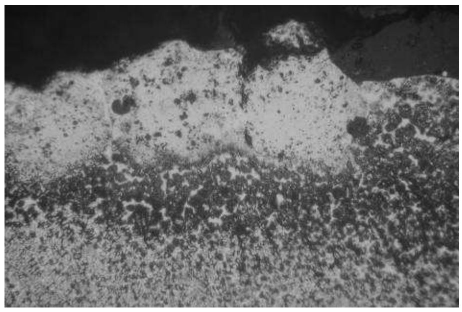
d) 

Figure 3. Surface layer structure of the test piece from the X40CrMoV5-1 tool steel after alloying with the VC ceramic powder using the HPDL diode laser, c,d) magnification 100x

It was revealed, basing on the metallographic examinations that the structure of the material solidifying after laser remelting is characteristic of occurrences of areas with the diversified morphology connected with crystallisation of the steel.

It was found out that employing the higher laser power affects the remelting zone depth (Fig.4) and that the remelted zone bottom gets corrugated due the influence of the strong movements of the liquid (Figs. 5 a,b – 6 c,d).

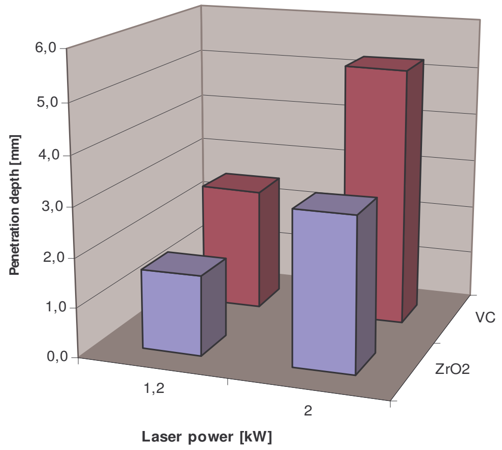


Figure 4. Plot showing the remelting laser power effect on the remelting zone depth

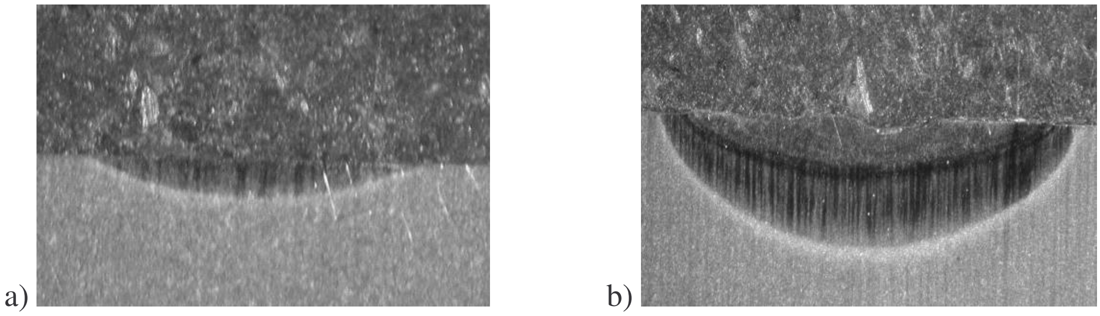


Figure 5. Transverse section of the zone alloyed with the HPDL laser; thickness of the ZrO_2 layer – 0.05 mm, beam scanning rate – 0.5 m/min, laser power – a) 1.2 kW, b) 2.0 kW, magnification 16x

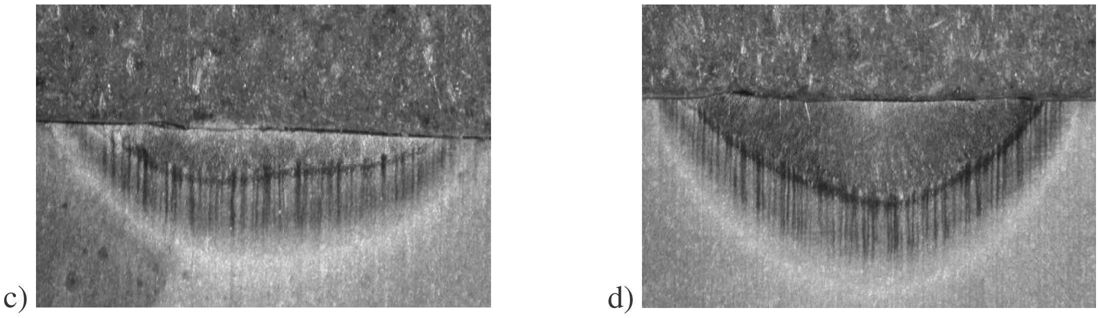


Figure 6. Transverse section of the zone alloyed with the HPDL laser; thickness of the VC layer – 0.05 mm, beam scanning rate – 0.5 m/min, laser power – c) 1.2 kW, d) 2.0 kW, magnification 16x

4. SUMMARY

The laser alloying tests of the X40CrMoV5-1 steel surface layer with the ZrO_2 and VC powders revealed that with the correctly selected alloying parameters, like scanning rate, laser power, and gas protection method, it is possible to obtain the flat remelting face with no cracks and with low roughness.

The surface layer is obtained due to remelting of the investigated steel, in which one can differentiate the remelted zone (RZ) having the dendritic structure, and the heat affected zone (HAZ) as well as the intermediate zone (IZ). Growth of dendrites occurs from the remelted zone and heat affected zone boundary in the direction of heat removal. The dendrite grains at the boundary between the remelted and heat affected zones (RZ/HAZ) are fine, which is caused by the high temperature gradient.

Between the remelted- and the heat affected zones (RZ/HAZ) there is a boundary, consisting from the fine dendrite grains, originated at the very crystallisation beginning, immediately after the laser beam impact on the material was over (X40CrMoV5-1 steel), and the fusion line consisting of the partially melted grains of the heat affected zone (HAZ). The chemical composition and crystalline structure of the coating change due to the intensive convection motion of the molten metal in the weld pool due to laser remelting and succeeding solidification.

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