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# Structure and properties of surface layer of hot-work tool steels alloyed using high power diode laser

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**Manufacturing and processing**

## ABSTRACT

**Purpose:** In this paper the results of remelting and alloying laser parameters on the structure and properties of the surface layer of the X40CrMoV5-1 and 32CrMoV12-28 hot work tool steels, using the high power diode laser (HPDL) are presented.

**Design/methodology/approach:** The effect was determined of the main alloying parameters on hardness, abrasive wear resistance and roughness. The hot work tool steels conventionally heat treated were used as reference material and the tantalum carbide was used as an alloying material. The remelted layers which were formed in the surface of investigated hot work tool steels were metallographically examined and analyzed using a hardness testing machine.

**Findings:** It was found out in examinations of the surface layer that it can be possible to obtain high quality top layer with higher hardness and abrasive wear resistance compared to material after conventional heat treatment.

**Research limitations/implications:** The surface layer and its properties are elements which are critical for lifetime of tools and parts of machines and also for lifetime of whole technical equipment. If the working surface of a tool or its part is exposed to rough friction, an intensive mass and volume loss occurs. In this case it is reasonable to produce a surface layer which is extremely wear resistant to avoid the mass and volume loss.

**Originality/value:** The research results of this type of heat treatment show that there is a possibility of applying the worked out technology to manufacturing or regeneration of chosen hot working tools.

**Keywords:** Laser remelting; Laser alloying; High Power Diode Laser (HPDL); Tantalum carbide

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## 1. Introduction

The future direction of research for improvement of materials properties is a laser modification of the tool surface layer structure either by a laser remelting or alloying. Laser alloying of metals with a variety of elements such as carbides powders have been demonstrated as an effective methods of modification of the surface properties. A high power laser beam may be used as a source of heat to melt or alloy the near surface region of a substrate. Hardness, wear resistance, and corrosion resistance of materials can be significantly improved. The technique o8uf laser surface alloying is now finding practical applications.

The basic and most often applied materials for manufacturing hot-work tools and also metal forms used in casting are alloyed hot-work steels. Hot-work tool steel belongs to that group of martensitic steel used in the production of forging tools. The microstructure of hot-work tool steel changes several times during the complex thermo-plastic treatment. The aim of this processing is to obtain high wear and thermal fatigue resistance.

It may be expected that the wear resistance as well as hardness and chemical stability will be increased in materials in which additional, more stable and hard molecules were introduced to the native material [1-10].

## 2. Materials and experimental procedure

The investigations were 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 2.

Test pieces for the examinations were obtained from the vacuum melting and made as the O.D. 75 mm round bars. Samples of those materials were of the plate form, of the rectangular shape, with dimensions 70x25x5 mm. Pre-heating to the austenitizing temperature was done in two steps, with an isothermal stop. Austenisation of the 32CrMoV12-28 was performed in a vacuum furnace at the temperature of 1040 °C; the pre-heating time was 0.5h. During pre-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 of quenching and tempering; austenitizing was carried out in the vacuum furnace at 1020 °C with the soaking time 0.5h. Two isothermal holds were used during pre-heating to austenitizing 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 the next at 510 °C. The test pieces were sand blasted and machined on a magnetic grinder after the heat treatment.

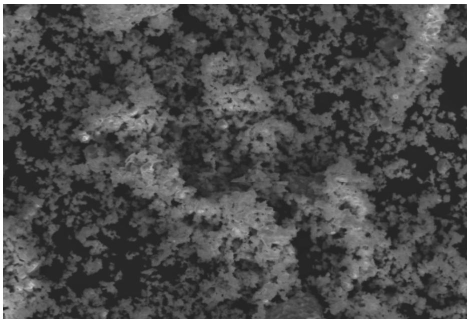

Fig. 1. Tantalum carbide powder (SEM), magnification 2000x

Next, powder layer of TaC (Figure 1) bounded with the sodium glass inorganic binding agent was put down onto the degreased specimens. Properties of the TaC powder are presented in Table 1. Next, the test pieces were melted with the Rofin DL 0.20 high power diode laser (HPDL). 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) blown-in rate was established experimentally as 20 l/min providing full remelting zone protection.

Table 1.
Properties of the TaC powder

| Type of coating | Hardness [HV] | Melting point [°C] | Density [g/cm$^3$] |
|---|---|---|---|
| TaC | 1600 | 3780-3985 | 14.5 |

The measurements of Rockwell hardness were performed using Zwick ZHR hardness intender equipped with electronic sensor that allows the direct readout of the hardness values.

Table 2.
Chemical composition of X40CrMoV5-1 and 32CrMoV12-28 hot work tool steels

| | Mass concentration of the elements, % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Steel grade | 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 | 0.535 | - |

Test results were analysed statistically. The wear rate tests were made on a device prepared according to the ASTM standard. The measurement of mass decrement after the wear abrasion test was performed on a laboratory weight with sensibility up to 0.0001g. Metallographic examinations of the material structures after laser alloying of their surface layer were made on Leica MEF4A light microscope with magnifications from 50 to 500x and also on DSM OPTON scanning microscope with magnifications from 50 to 2000x. Roughness measurements were carried out on the Taylor-Hobson „Surtronic 3+" profilometre on test pieces on which four remelting paths had been previously made.

## 3. Investigation results

It was revealed, based on the metallographic examinations (Figures 2-3), that structure of the solidified material after laser alloying is characteristic about occurrences of areas with the diversified morphology connected with crystallisation of the steel. In effect of convection movements of material in the liquid state, conglomerates of carbides arrange themselves in a characteristic swirl. In the effect of laser alloying with powders of carbide TaC, consolidation through enrichment of surface layer in alloying additions coming from dissolving carbides takes place. Introduced particles of carbides and in part remain undissolved, creating conglomerates being a result of fusion of undissolved powder grains into molten metal base.

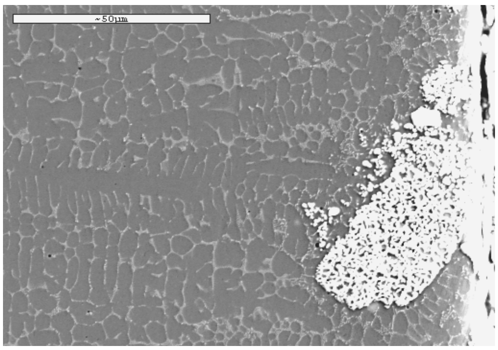

Fig. 2. Microstructure of the X40CrMoV5-1 steel alloyed TaC powder, power range 1.6 kW

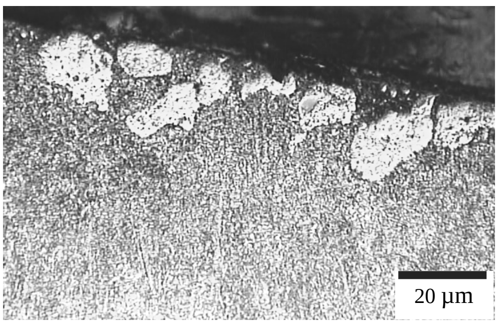


Fig. 3. Microstructure of the 32CrMoV12-28 steel alloyed TaC powder, power range 1.6 kW

Laser alloying of surface layer of investigated steels in the whole range of used laser power, causes size reduction of dendritic microstructure with direction of crystallization consistent with the direction of heat being carried away from the zone of impact of laser beam (Figures 4-5).

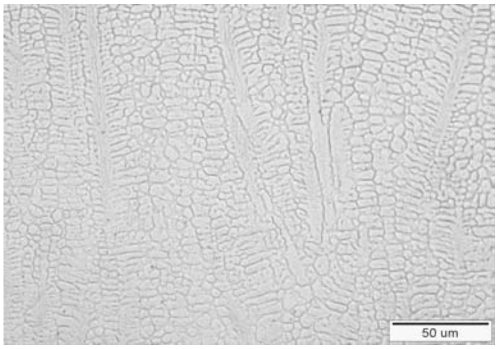


Fig. 4. Microstructure of the X40CrMoV5-1 steel alloyed TaC powder, power range 2.0 kW

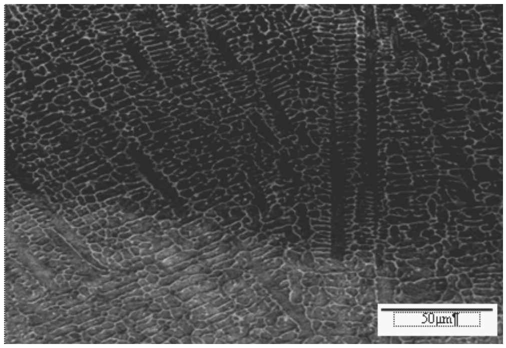


Fig. 5. Microstructure of the 32CrMoV12-28 steel alloyed TaC powder, power range 2.0 kW, magnification 500x

Hardness tests of the X40CrMoV5-1 and 32CrMoV12-28 hot-work alloy tool steels after alloying with TaC indicate that in most cases laser treatment of surfaces layers causes growth of their hardness (Figs. 6 - 7). Hardness of the surface layer of the X40CrMoV5-1 steel alloyed with tantalum carbide increases to 60.3 HRC at the laser beam power equal to 2.3 kW and for 32CrMoV12-28 steel for 66 HRC at the same laser beam power.

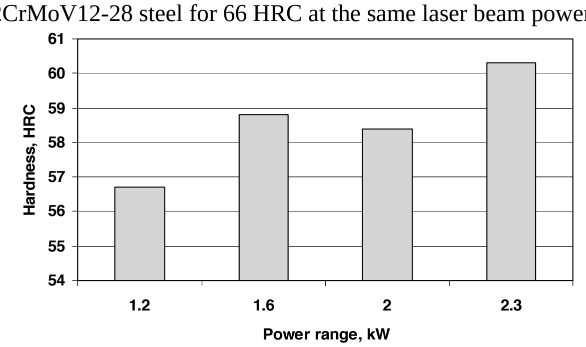


Fig. 6. Change of the average X40CrMoV5-1 steel surface layer hardness alloying with the TaC with the variable power laser

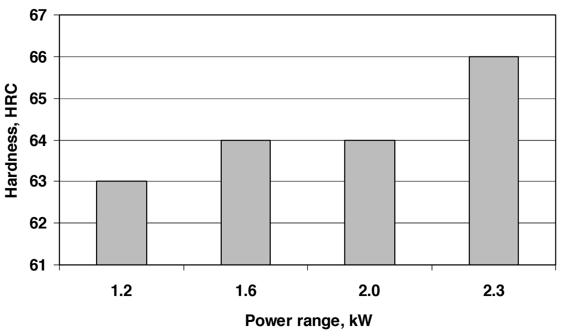


Fig. 7. Change of the average 32CrMoV12-28 steel surface layer hardness alloying with the TaC with the variable power laser

Table 3.
Results of wear resistance test X40CrMoV5-1 and 32CrMoV12-28 hot work tool steels after alloying with high power diode laser HPDL

| Type of coating | Laser power range used for alloying, kW | Mass decrement after abrasion wear, g |
|---|---|---|
| TaC | 1.2 | 0.6372 |
| | 1.6 | 0.675 |
| | 2.0 | 0.7405 |
| | 2.3 | 0.6814 |
| Type of coating | Laser power range used for alloying, kW | Mass decrement after abrasion wear, g |
| TaC | 1.2 | 0.7165 |
| | 1.6 | 0.7078 |
| | 2.0 | 0.7295 |
| | 2.3 | 0.7376 |

Roughness of the surface layers obtained by alloying the steel with the laser beam with the power from 1.2 to 2.3 kW is within the range of $R_a$=4.9-8.6 µm for the X40CrMoV5-1 and $R_a$=6.8-14.4 µm for the 32CrMoV12-28 steel and grows proportionally to the laser beam power (Figures 8 - 9).

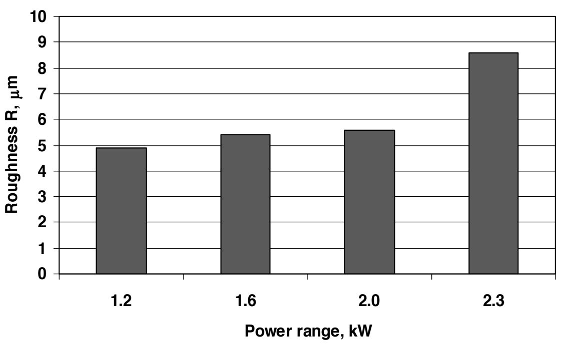


Fig. 8. Effect of the laser power on the X40CrMoV5-1 steel surface layer roughness laser alloyed with TaC

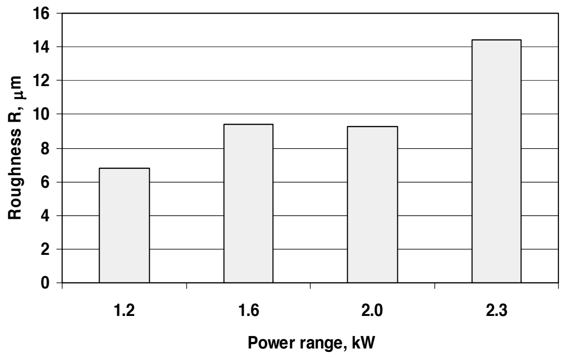


Fig. 9. Effect of the laser power on the 32CrMoV12-28 steel surface layer roughness laser alloyed with TaC

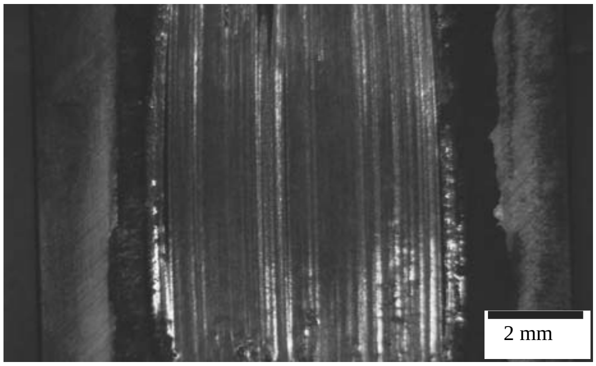


Fig. 10. Surface layer of the test piece from the X40CrMoV5-1 tool steel alloyed TaC, after the wear test, with the following parameters: feed rate-0.5 m/min, the power range 2 kW

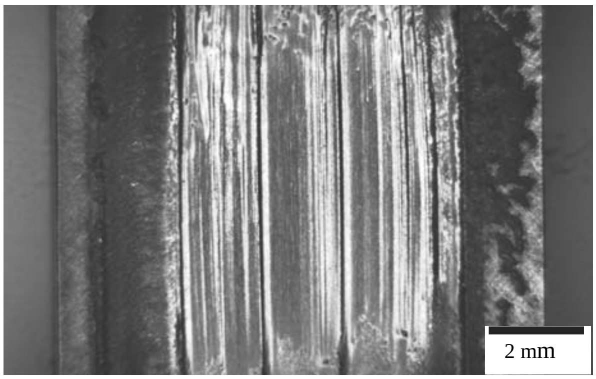


Fig. 11. Surface layer of the test piece from the 32CrMoV12-28 tool steel alloyed TaC, after wear test, with the following parameters: feed rate-0.5 m/min, the power range 2 kW

The increase of hardness of surface layer obtained throughout alloying with TaC by high power diode laser is accompanied by increase of tribological properties (Figures 10-11), when comparing to the steel processed with conventional heat treatment. As chosen materials referring to the achieved results of experiments, these are steels after a conventional heat treatment – X40CrMoV5-1 and 32CrMoV12-28 for which the average mass decrements are0.7405 g and 0.7376 g, respectively. Table 3 presents the achieved results of the wear abrasion test.

## 4. Conclusions

Changes of the surface layers' hardness formed as a result of alloying with carbide powder are accompanied by increased tribological properties in comparison to the conventionally heat treated steels. A modification of tool steels surface using a laser beam radiation, as well as coating them with special pastes containing particles such as tantalum carbides allows for 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 operation. Surface layer obtained due to laser modification is characteristic for different properties than the native material. Laser alloying with the TaC results in structure refinement in the entire investigated laser power range.

## Additional information

The paper was published also in the Archives of Materials Science.

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