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Improvement of wear resistance of the hot work tool steel by laser surface feeding with ceramic powders

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ABSTRACT

Purpose: In this paper the result of laser surface feeding or remelting is discussed. The remelted layers which were formed on the surface of the investigated hot work steel were examined and analyzed metallographically and analyzed using a hardness testing machine. The resistance research has been done on the CSM Instruments.

Design/methodology/approach: In this paper the results of laser treatment techniques applied in metal surface technology are presented and discussed. There is presented laser treatment with feeding or remelting of hot work tool steel X40CrMoV5-1 with ceramic powders especially - Al_2O_3 and Si_3N_4, as well as results of laser remelting influence on structure and properties of the surface of the hot work steel, carried out using the high power diode laser (HPDL).

Findings: On the basis of the wear abrasion tests carried out on hot work tool steel it could be found that each of those specimens is characterized by different resistance for the same powders and the power of the laser beam. The metallographic investigations on light microscope show that during feeding or remelting the hot work tool steel with the ceramic powder layer in the whole range of the laser power values used 1.2-2.3 kW the obtained bead face is characteristic of the high roughness, multiple pores, irregularity.

Practical implications: The resistance to abrasive wear is a practical aim of this work as well as improvement of hardness as a very important properties for practical use. It is necessary to continue the research to determine feeding or remelting parameters for demanded properties of hot work tool steels surface layers.

Originality/value: Laser feeding or remelting by using HPDL laser (High Power Diode Laser) and selected ceramic powders can be very attractive for industries.

Keywords: Surface treatment; Heat treatment; Hot work tool steel; Laser melting; Laser feeding

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PROPERTIES

1. Introduction

Having good mechanical properties and good price hot work tool steel is widely used in different parts of industries. Wear is one of the most prevalent problems. Thus surface treatment technology has become the most effective method to improve the service performance of materials. Over the last few years substantial interest has been focused on the field of advancing wear resistance of the steel including laser surface modification. Laser surface treatment has been find to improve the wear resistance of the alloys. This type of surface treatment is used for improvement of the hardness than the substrate, higher fatigue strength, better tribological and anti-corrosion properties, at the simultaneously worse smoothness than the substrate before alloying. Laser treatment is characteristic of the contact less operation, selectivity, and possibility of full automation of the process. There is an opinion that 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. In the present study development of laser surface feeding or remelting with Al_2O_3 and Si_3N_4 of X40CrMoV5-1 hot work tool steel has been attempted [1-19].

2. Experimental conditions

The material used for investigation was a hot work tool steel X40CrMoV5-1; it has been supplied annealed in form of rods 75 mm in diameter and in the length of 3 m. Samples of this material were of the plate form, of the rectangular shape, with dimensions 70 x 25 x 5 mm.

The samples were heat treated according to the steps for this steel type. 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 0.5 h. 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 samples surfaces were grind on a magnetic grinding machine. Special care was set to avoid micro cracks, which can disqualify a sample on future investigation. The powder was initially mixed with the inorganic sodium glass in proportion 30% glass and 70% powder. A paste layer of 0.5 mm in thickness was put on. The properties of Al_2O_3 and Si_3N_4 powders are presented in Table 1. Based on the preliminary investigations results a high power laser diode HPDL Rofin DL 020 with traverse speed v = 0.5 m/min was. The protective gas (argon) blow - in rate was established experimentally as 20 l/min providing full remelting zone protection. All other processing are presented in Table 2. To ensure good processing the investigations were carried out at a constant remelting traverse speed, changing the laser power in a range of 1.2-2.3 kW. The samples were mounted in the laser holder for remelting. On each sample surface four laser process traces were made of a length of 25 mm, with the power 1.2; 1.6; 2.0; 2.3 kW. For surface preparation the standard metallographic procedure was applied in form of grinding using SiC abrasive paper and polishing with Al_2O_3 polishing suspension and drying, the samples were mounted in the thermo hardened resin supplied by Struers. Next the samples were etched in nital at room temperature for the experimentally chosen time selected individually for each remelted area.

Metallographic examinations of the material structures after laser feeding or remelting of their surface layer were made on Leica MEF4A light microscope. The observations were performed on the cross section (Figs. 2-7) of the sample on each of the remelting traces. 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 wear resistance was measured by the use of device realized dry friction wear mechanism of reciprocating movement condition. The samples preparation for examinations consisted of grinding by the use of abrasive paper with grit # 1200 to obtain flat and smooth surface. On samples prepared in this way there were made investigations with the steel ball 6 diameter as counter-sample from the aluminum oxide Al_2O_3. Investigations were made under load 12 N, by 100 m. Samples after examinations were rinsed in ultrasonic washer to clean its surface, and then the degree of wear was established on the base geometrical measurements of wear track and calculation of its volume. The resistance research has been done on the CSM Instruments. The measurements of roughness and wear track have been made using Surtronic 25 by Taylor Hobson. The experiments has been done at room temperature by the use of device presented on Figure 1.

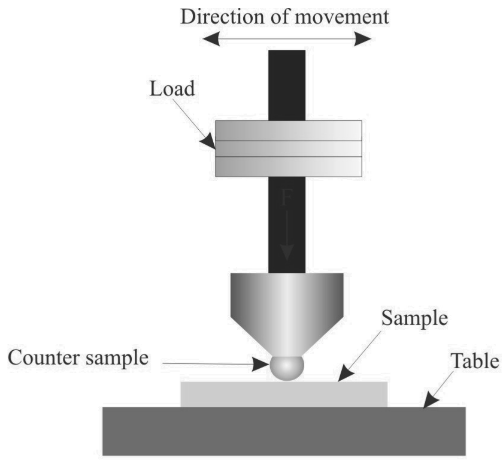

Fig. 1. The device used for wear resistance measurements

The trace of the steel counter face wear and the shape of the surface layer after wear abrasion test has been made by using stereoscopy microscope Discovery V12 by Zeiss coupled to the software for image analysis. Study of surface topography remelted or/and alloyed with Al_2O_3 or Si_3N_4 have been made on LSM Exciter 5 by ZEISS. The analysis of the counter - specimen wear land (Al_2O_3 balls) has been made using the light microscope with the Image - Pro Measure Version 1.3 image analysis system at magnification 50x. As a measurement standard was chosen the depth of wear trace measured on the cross section of the steel-ball.

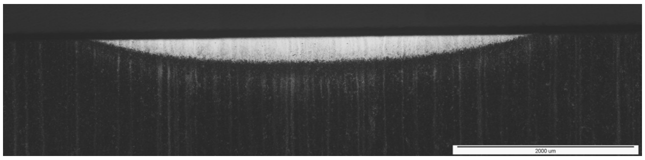

Fig. 2. Shape of cross-section of the laser remelted samples with laser power 1.2 kW

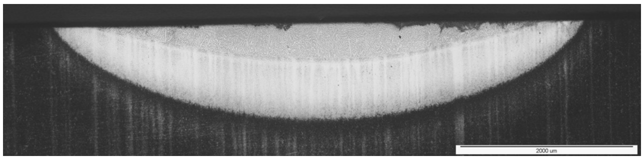

Fig. 3. Shape of cross-section of the laser remelted samples with laser power 2.3 kW

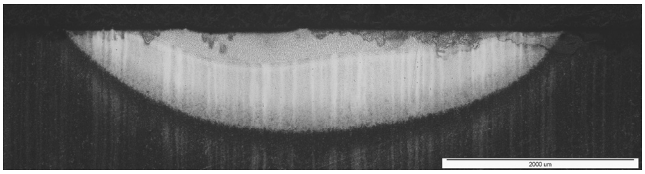

Fig. 4. Shape of cross-section after laser feeding of Al_2O_3, laser power 1.2 kW

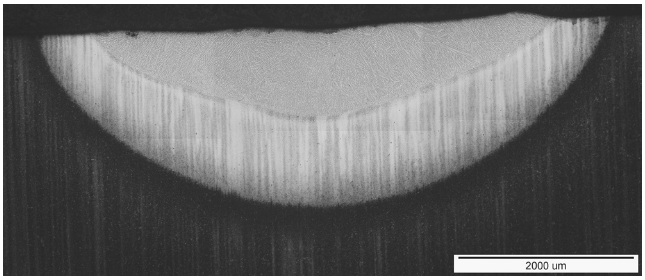

Fig. 5. Shape of cross-section after laser feeding of Al_2O_3, laser power 2.3 kW

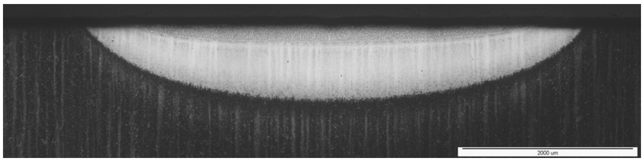

Fig. 6. Shape of cross-section after laser feeding of Si_3N_4, laser power 1.2 kW

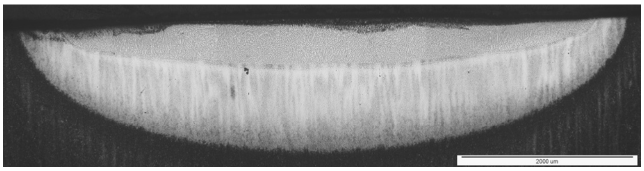

Fig. 7. Shape of cross-section after laser feeding of Si_3N_4, laser power 2.3 kW

Table 1.
Properties of Al_2O_3 and Si_3N_4 powders

Powder	Hardness, HV	Melting temp., °C	Density, kg/m^3
Al_2O_3	2300	2047	3.90-3.99
Si_3N_4	1600	1200	3.44

Table 2.
HPDL (High Power Diode Laser) laser parameters

Parameter	Value
Laser wave length, nm	940 ± 5
Peak power, W	100 + 2300
Focus length of the laser beam, mm	82/32
Power density range of the laser beam in the focus plane [kW/cm²]	0.8-36.5
Dimensions of the laser beam focus, mm	1.8 x 6.8

The structural investigations carried out using the light microscope allows to compare the surface layer as well as the shape and depth of the remelting area. It was noticed that the depth of remelting area grows together with the increasing laser power, which was confirmed by the results presented on Figures 14-16.

3. Results and discussion

Preliminary investigations of the remelted or feed with Al_2O_3 and Si_3N_4 powders hot work tool steel X40CrMoV5-1 show a clear effect of the laser power respectively 1.2; 1.6; 2.0 and 2.3 kW on the shape and thickness of the remelted material. It can be seen that with the increasing laser power the roughness of the remelted metal surface increases. Microstructure presented on Figures 8-13 show a dendritic structure in the remelted area. There is also a clear relationship between the employed laser power and the dendrite size, namely with increasing laser power the dendrites are larger.

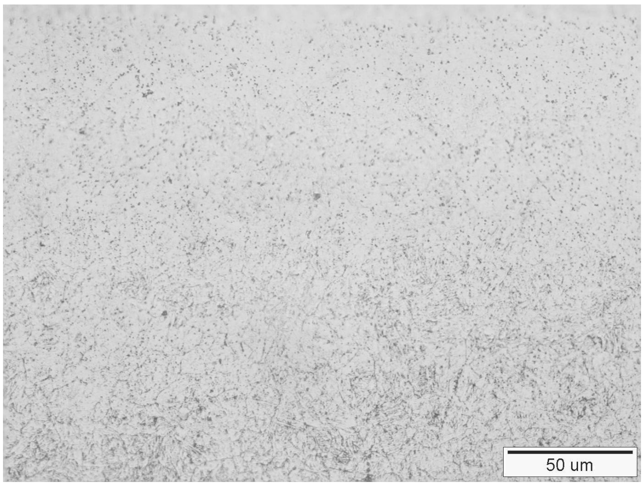

Fig. 8. Structure of the surface layer after remelting with 1.2 kW

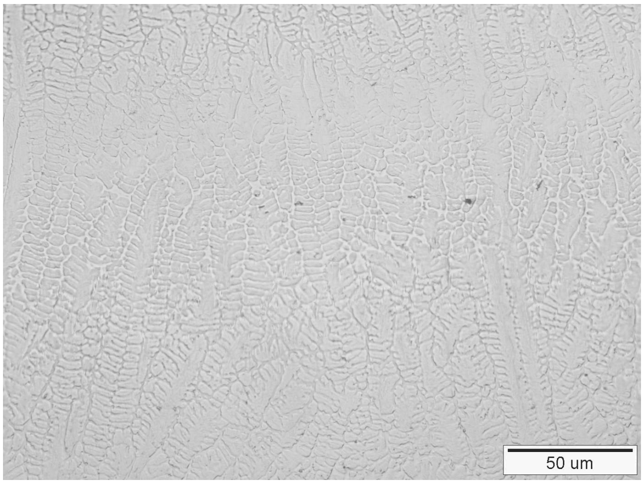

Fig. 9. Structure of the surface layer after remelting with 2.3 kW

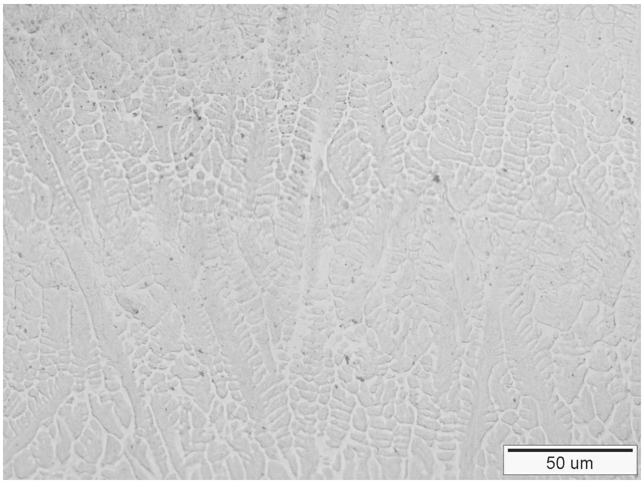

Fig. 10. Structure of the surface layer after feeding with Al_2O_3 using 1.2 kW power laser

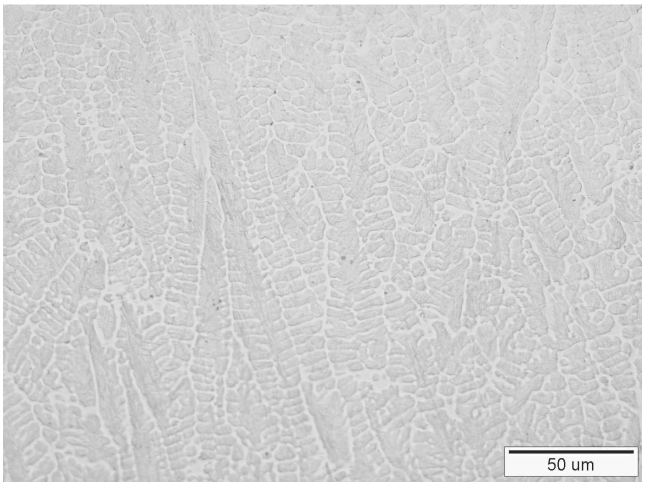

Fig. 11. Structure of the surface layer after feeding with Al_2O_3 using 2.3 kW power laser

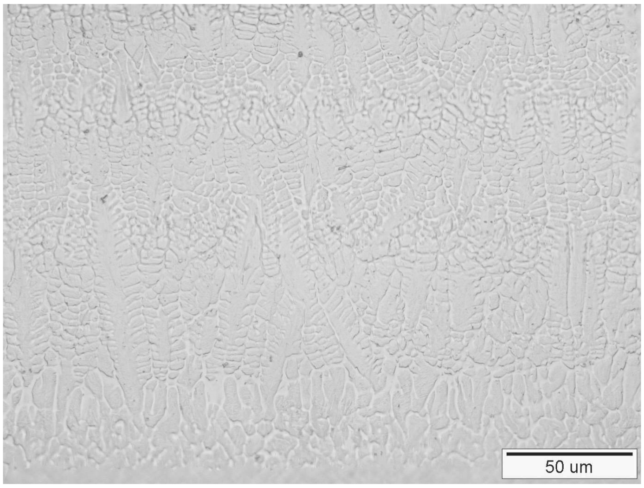

Fig. 12. Structure of the surface layer after feeding with Si_3N_4 using 1.2 kW power laser

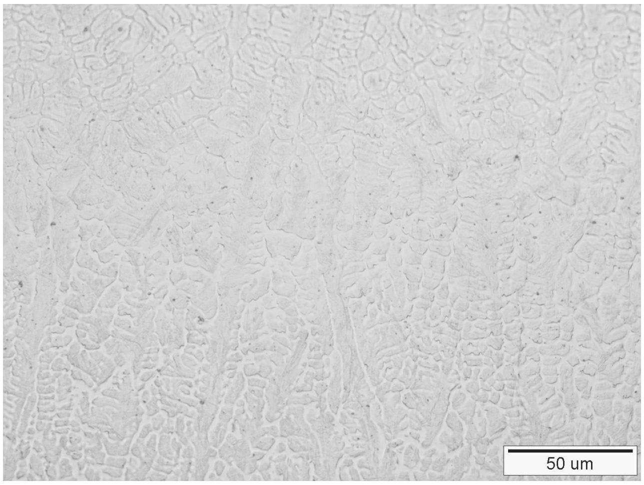

Fig. 13. Structure of the surface layer after feding with Si_3N_4 using 2.3 kW power laser

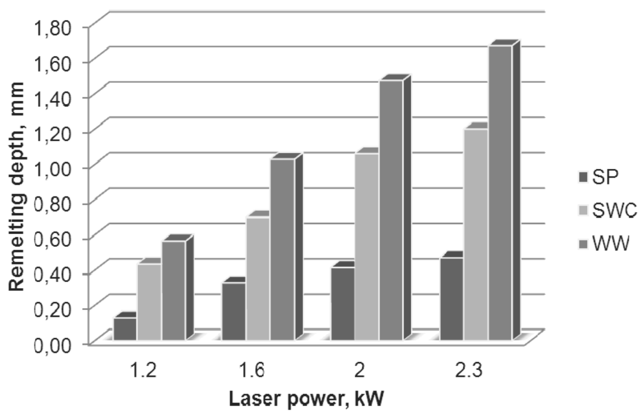

Fig. 14. Laser power effect on the remelting zone depth of X40CrMoV5-1 hot work tool steel remelted, power laser 1.2-2.3 kW

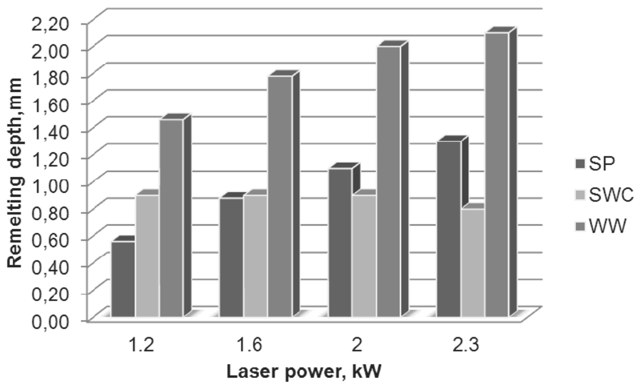

Fig. 15. Laser power effect on the remelting zone depth of X40CrMoV5-1 hot work tool steel after laser feeding of Al_2O_3, laser power 1.2-2.3 kW

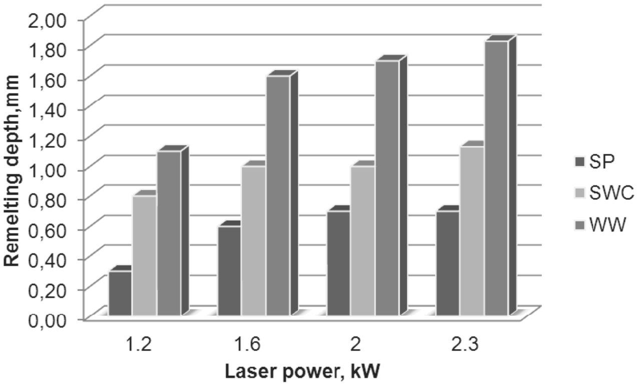

Fig. 16. Laser power effect on the remelting zone depth of X40CrMoV5-1 hot work tool steel after laser feeding of Si_3N_4, laser power 1.2-2.3 kW

Figure 17 shows the average hardness measurements results of the fed or remelted surface for 1.2, 1.6, 2.0 and 2.3 kW laser power. The highest hardness value is achieved for the 2.0 and 2.3 kW laser power after laser feeding of Si_3N_4, while the lowest hardness value is achieved for the 1.2 kW after laser remelting surface layer of the X40CrMoV5-1 tool steel.

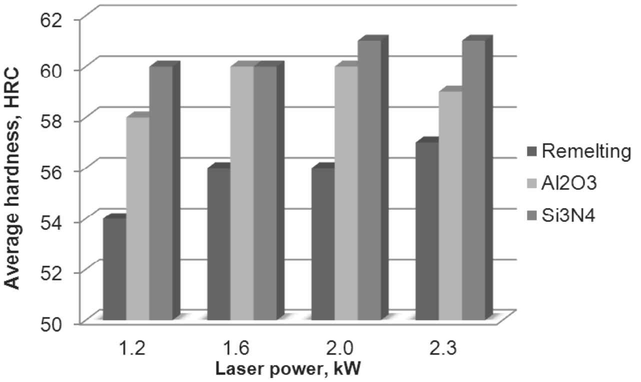

Fig. 17. Hardness measurements results after laser feeding of Al_2O_3 or Si_3N_4 surface layer of the X40CrMoV5-1 tool steel

The roughness of surface layers obtained by feeding or remelting the investigated steel with Al_2O_3 or Si_3N_4 powders with the 1.2 to 2.3 kW laser beam is within the range of R_a = 1.26- 12.8 µm. The minimum surface roughness was revealed on the surface layer developed by remelting with the 1.2 kW laser beam. However, the maximum roughness occurs on surface of the layer after laser feeding of Al_2O_3 powder. Roughness of the surface layers obtained by feeding the steel with the laser beam with the power from 1.2 to 2.3 kW grows proportionally to the laser beam power (Fig. 18).

On Figures 19-23 is shown the depth of wear trace measured on the cross section of the steel-ball. The smallest wear area was observed in case of the surface layers remelted with 1.2 and 2.3 kW, and the biggest area was found in case of feeding Al_2O_3 and Si_3N_4 powders with 1.2 and 2.3 kW.

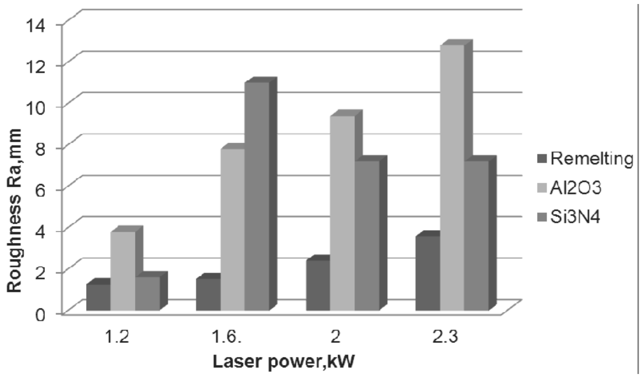

Fig. 18. Effect of laser power on the roughness of the X40CrMoV5-1 steel after feeding or remelting with laser power 1.2-2.3 kW

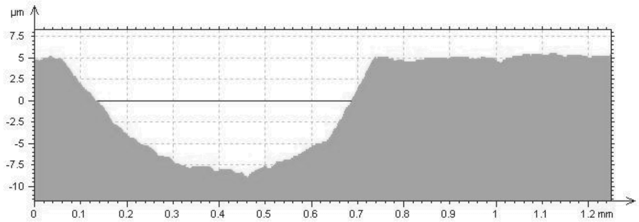

Fig. 19. Shape and depth of the wear trace on the steel ball, steel after remelting, laser power 2.3 kW, traverse speed v =0.5 m/min

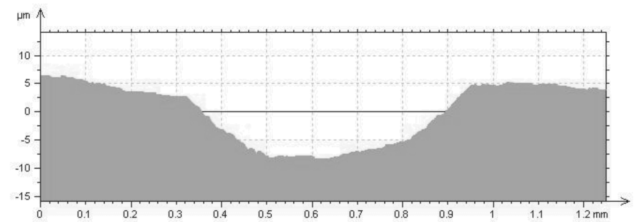

Fig. 20. Shape and depth of the wear trace on the steel ball, steel after feeding of Al_2O_3, laser power 1.2 kW, traverse speed v =0.5 m/min

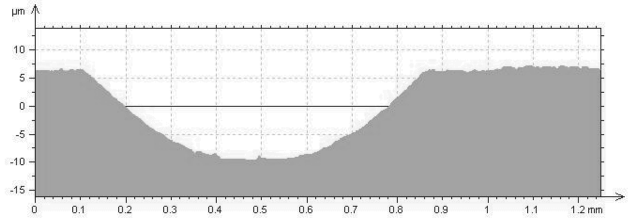

Fig. 21. Shape and depth of the wear trace on the steel ball, steel after feeding of Al_2O_3, laser power 2.3 kW, traverse speed v =0.5 m/min

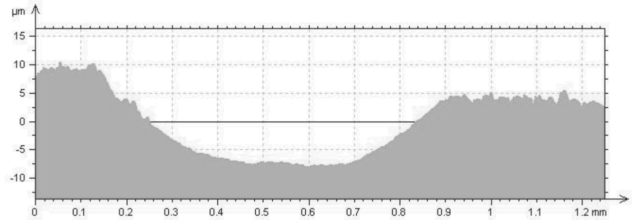

Fig. 22. Shape and depth of the wear trace on the steel ball, steel after feeding of Si_3N_4, laser power 1.2 kW, traverse speed v =0.5 m/min

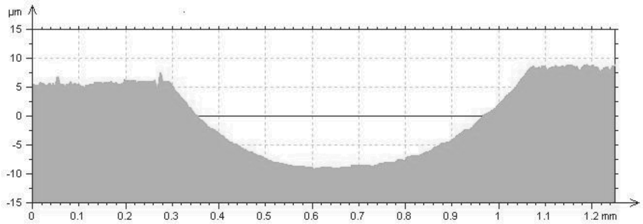

Fig. 23. Shape and depth of the wear trace on the steel ball, steel after feeding of Si_3N_4, laser power 2.3 kW, traverse speed v =0.5 m/min

The average volume of the abrasion trace developed in contact of the investigated surface layer with the counter-specimen material (Al_2O_3) was calculated based on the abrasion wear resistance tests and it was found out that the smallest abrasion trace volume is characteristic of the surface layer laser with fed Al_2O_3 with laser power of 1.2 kW, and the biggest one, was for the surface layer with fed Si_3N_4 with laser power of 2.3 kW. The fact that the abrasion wear resistance of the investigated surface layers laser with fed Al_2O_3 or Si_3N_4 powder gets smaller, instead of its expected growth, may be caused by the nonhomogeneous distribution of the ceramic particles coming from the alloying materials in the steel matrix. Only in case of remelting the surface layer alone, without using any materials for feeding, the abrasion wear resistance growth is observed, i.e., lower abrasion trace volume, along with the growth of the laser power used for laser remelting. Figures 24-25 present the worn surface of X40CrMoV5-1 steel alloyed Al_2O_3 or Si_3N_4 powders.

Figures 26-27 present counter-specimen wear caused by abrasion of the surface layer of the hot work tool steel after feeding of Al_2O_3 or Si_3N_4 and Figures 28-30 show changes of topography of the investigated steels' surface layers after the abrasion wear tests.

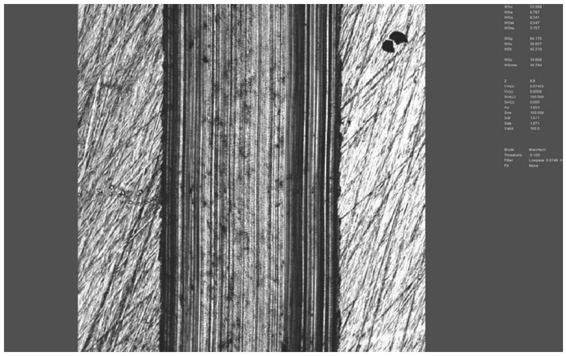

Fig. 24. The worn surface of X40CrMoV5-1 steel after feeding of Al_2O_3, laser power 1.2 kW

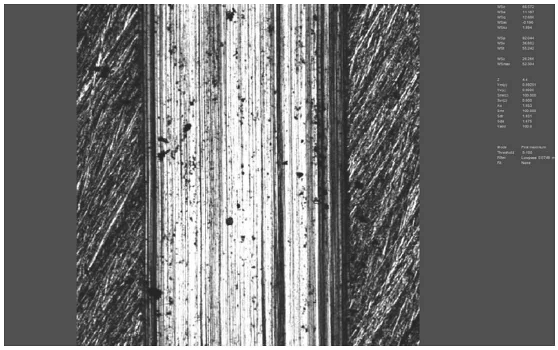

Fig. 25. The worn surface of X40CrMoV5-1 steel after feeding of Si_3N_4, laser power 2.3 kW

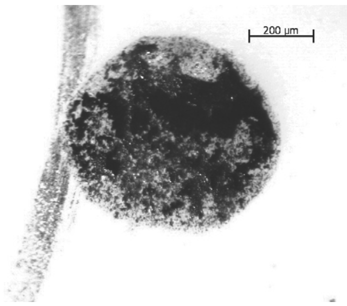

Fig. 26. Counter-specimen wear caused by abrasion of the surface layer of the hot work tool steel after feeding of Al_2O_3, laser power 1.2 kW

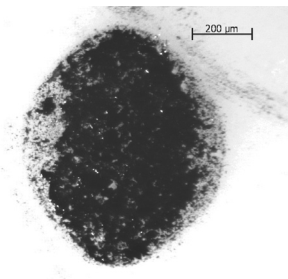

Fig. 27. Counter-specimen wear caused by abrasion of the surface layer of the hot work tool steel after feeding of Si_3N_4, laser power 2.3 kW

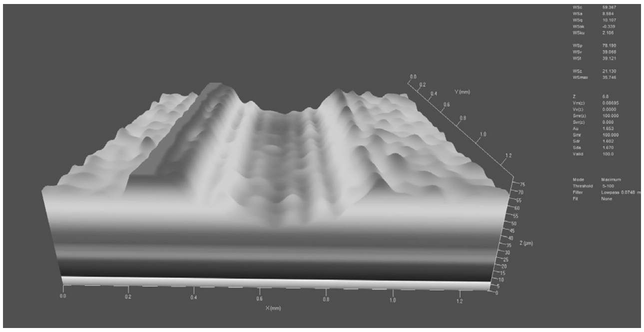

Fig. 28. Topography of the surface layer of the steel remelted, laser power 2.3 kW

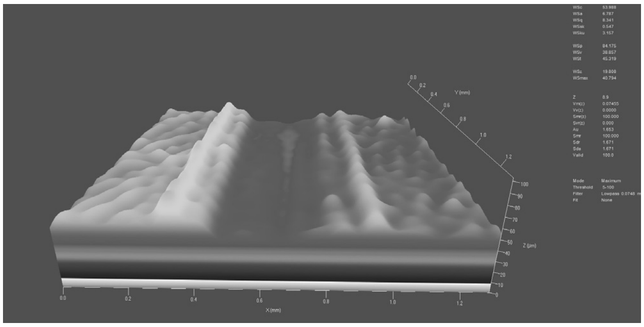

Fig. 29. Topography of the surface layer of the steel after feeding of Al_2O_3, laser power 1.2 kW

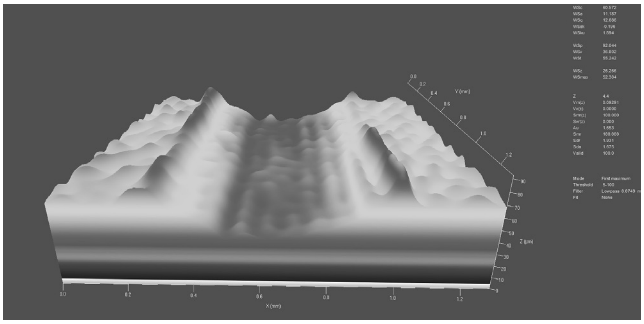

Fig. 30. Topography of the surface layer of the steel after feeding of Si_3N_4, laser power 2.3 kW

4. Conclusions

This work presents laser treatment with remelting or feeding of hot work tool steel X40CrMoV5-1 with Al_2O_3 or Si_3N_4 powders. This type of surface treatment is used for improvement of properties of the surface layer by changing the structure and improvement of the abrasion wear resistance, mostly by introduction of enrichment material particles to the material matrix.

Basing on observations of structure photographs taken on the light microscope one can state that during remelting or feeding the steel with the Al_2O_3 or Si_3N_4 in the entire range of the laser power values used (1.2-2.3 kW) the obtained bead face is characteristic of the high roughness, multiple pores and irregularity. At higher alloying laser power values bead face convexity appears. At the constant laser beam scanning rate the beam power change affects clearly the area size in which structural changes occur in the surface layer of the steel.

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). 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, and the fusion line consisting of the partially melted grains of the heat affected zone (HAZ).

The hardness value increases according to the laser power used in case of Al_2O_3 or Si_3N_4 powder so that the highest power applied gives the highest hardness value in the remelted layer, and decreases only in only in one case by feeding with Al_2O_3 powder using 2.3 kW power laser. Also the surface of the remelted area is more rough with increasing laser power. This stems from the fact that the alloying material is fluctuating due to the varied surface tension of the material being remelted and by the laser radiation energy being absorbed by the alloying material.

During laser feeding with powders containing Al_2O_3 or Si_3N_4 their partial fusion may occur in the molten metal pool, or else the particles may remain undissolved originating conglomerates because of inundation of the undissolved grains of the powders into the molten metal substrate. Increasing the laser power results in decrease of the portion of the undissolved powders dispersively hardening the remelted matrix of the steel surface layer.

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