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Effect of laser alloying on thermal fatigue and mechanical properties of the 32CrMoV12-20 steel

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ABSTRACT

Purpose: The reason of this work was to determine the thermal fatique resistance, the laser treatment parameters, particularly the laser power, to achieve a high value of layer hardness for protection of this hot work tool steel from losing their work stability and to make the tool surface more resistant for work. The purpose of this work was also to determine technological and technical conditions for remelting the surface layer with HPDL.

Design/methodology/approach: In this paper the results of new laser treatment techniques applied in metal surface technology are presented and discussed. There is presented laser treatment with remelting of hot work tool steel 32CrMoV12-28 with ceramic powders especially carbide - TaC, 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). Special attention was devoted to monitoring of the layer morphology of the investigated material and on the particle occurred. Optical and scanning electron microscopy was used to characterize the microstructure and intermetallic phases occurred.

Findings: The layer is without cracks and defects as well as has a considerably higher hardness value compared to the non remelted material. The hardness value increases according to the laser power used so that the highest power applied gives to highest hardness value in the remelted layer.

Research limitations/implications: The results present only four choused laser powers by one process speed rate. Also one powder in form of TaC was used for alloying with the particle size of 10μm.

Practical implications: The aim of this work is the determination of laser treatment technique for alloying and remelting of hot work tool steel.

Originality/value: The originality of this work is based on applying of High Power Diode Laser for improvement of steel mechanical properties.

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

1. Introduction

This paper presents the laser treatment with remelting and alloying of hot work tool steel 32CrMoV12-28 with ceramic powders, especially TaC Tantalum Carbide. The structure investigation, and improvement of mechanical properties, is the practical aim of this work, as well as improvement of hardness as a very important property for practical use.

Hence, power density at the workpiece is limited as well, leaving high-power diode lasers with restricted application opportunities. Crucial for reliability and lifetime of bars is proper heat sinking. Although power efficiency is extremely high, one half of the absorbed pump power has to be removed as waste heat. Mounting high-power diode-laser bars on cooling elements requires high precision and the complete mastering of the electrical, thermal, and mechanical junction process. This is the fundamental concept for direct-diode applications [1-7].

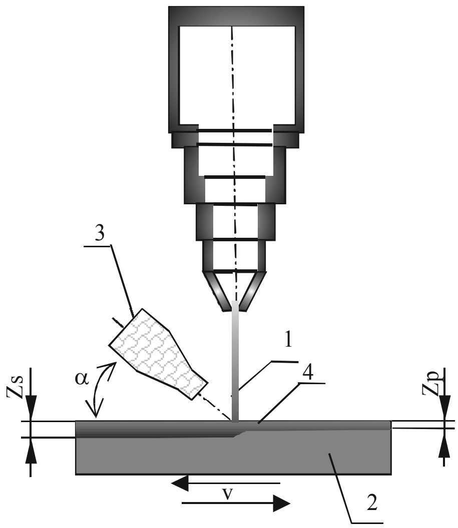


Fig. 1 Working scheme of the HPDL laser Rofin Dl 020 used for remelting and alloying of the hot work tool steel samples

Tantalum carbide is a rarely used tool material sometimes used in metal machining because of its high hardness and high resistance to softening at high cutting speed and at high cutting temperature. Tool life is an important parameter to be considered in tool selection since it will affect tool change scheduling, production planning and unit production cost. The tool life of a hot work tool is commonly determined with an actual machining operation by using the tool with a particular work material under certain working conditions to reach the maximum allowable life time. However, this is also an expensive process since a lot of work material is consumed in the test. The major concern of laser alloying is to avoid defects after treatment such as cracking, bubbles and unacceptably rough surface. The second concern is to achieve a maximum hardness in the surface layer to ensure good working parameters [8-10].

High-power diode lasers are continuously making inroads into industrial applications, as they are compact, easy to cool, yield a power efficiency beyond 50%, which is about five times higher than any other kind of laser has to offer, and their costs are becoming increasingly attractive. To exploit the tremendous application potential of high-power diode lasers, research and development programs are performed in many industrial countries [11-13]

This study was conducted to make clear an effect of TaC powder addition and the solidification rate on structure and properties in the laser melted metal surface of the hot work tool steel 32CrMoV12-28. On the other hand, the solidification mode in the weld metal was changed from the primary ferrite to the primary austenite, as the solidification rate was raised [14-16].

The purpose of this work is to study the effect of a HPDL laser Figure 1. melting on the hot work tool steel, especially on their structure and hardness. Special attention was devoted to monitoring of the layer morphology of the investigated material and on the particle occurred.

2. Experimental conditions

The material used for investigation was a hot work tool steel; it has been supplied annealed in form of rods 76 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 chemical composition of the investigated steel is presented in Table 1. For the thermal fatique samples were of the form showed on figure 2.

The samples were heat treated according to the steps for this steel type, at first tempering was performed and then annealing. Austenisation was performed in a vacuum furnace at a temperature of 1040 ºC, the heating time was 0.5h. During the heating to the austenitic temperature two isothermal holds were applied. The first one at the temperature of 585 ºC, the second at 850 ºC. After tempering two annealing operations were performed for the time of 2 h, the first at 550 ºC and the second at 510 ºC. 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. Tantalum carbide powder - Figure 3 - was put to the so prepared and degreased samples. The powder was initially mixed before 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 tantalum carbide powder are presented in Table 3. Based on the preliminary investigations results a high power laser diode HPDL Rofin DL 020 (Figure 2.) with process rate of v = 0.5 m/min was. All other work parameters are presented in Table 2. To ensure good work parameters the investigations were carried out at a constant remelting process rate, changing the laser power in a range of 1.2 – 2.3 kW. For laser power values of 0.4 to 0.8 kW there are no remelted areas present at all.

The samples were mounted in the laser holder for remelting. On each sample surface four laser process trays were made of a length of 25 mm, with the power 1,2; 1,6; 2,0; 2,3 kW (Figure 4.). It could be determined experimentally, that the full protection of the remelted area can be achieved by means of the argon protective atmosphere with the gas flow rate of 20 l/min through a circular nozzle with diameter of 12 mm, which was directed inversely to the direction of the remelting process. For surface preparation the standard metallographic procedure was applied in form of grinding using SiC paper, polishing with 1μm Al_2O_3 polishing paste 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. The thermal fatique investigaton was performed on a special constructed heated induktor connected to a power generator and cooling water supply (figure 3).

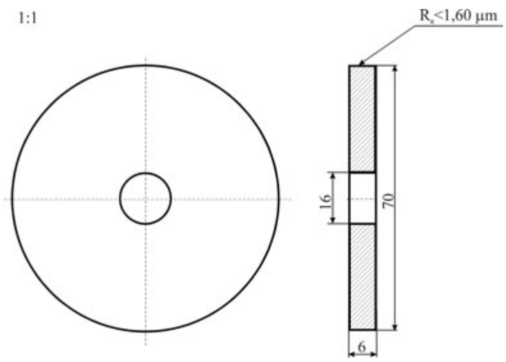


Fig. 2 Shape and size of the sample for thermal fatigue investigations

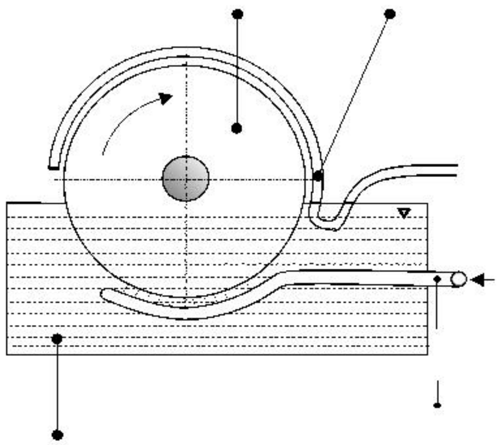


Fig. 3 Outline of the thermal fatique investigation stand for the 32CrMoV12-28 steel samples alloyed with ceramic powders, according to ref. no. [16].

Table 1.
Chemical composition of the investigated hot work tool steel 32CrMoV12-28,

	Mass concentration of the elements, %							
steel	C	Si	Mn	P	S	Cr	Mo	V
32CrMo V12-28	0.308	0.25	0.37	0.02	0.002	2.95	2.70	0.535

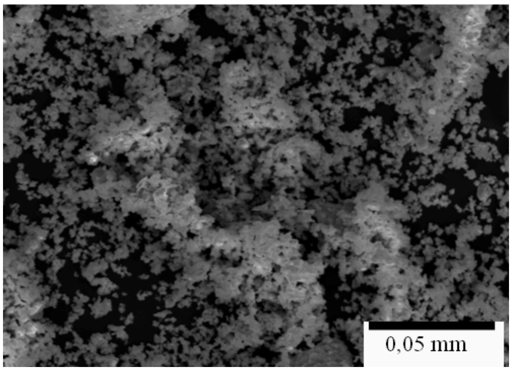
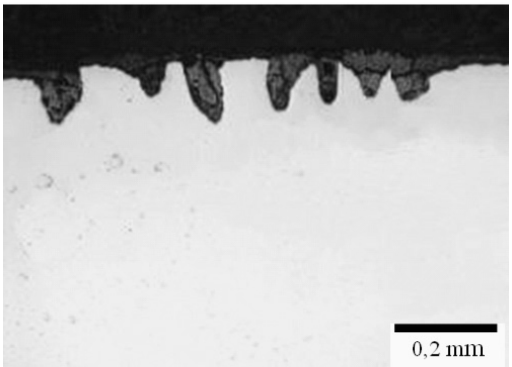


Fig. 4 Tantalum carbide TaC ceramic powder using for alloying with the hot work tool steel

Table 2.
HPDL laser parameters

Parameter	Value
Laser wave length, nm	940 ± 5
Peak power, W	100 ÷ 2300
Focus length of the laser beam, mm	82 /32
Dimensions of the laser beam focus, mm	1.8 x 6.8

a)



b)

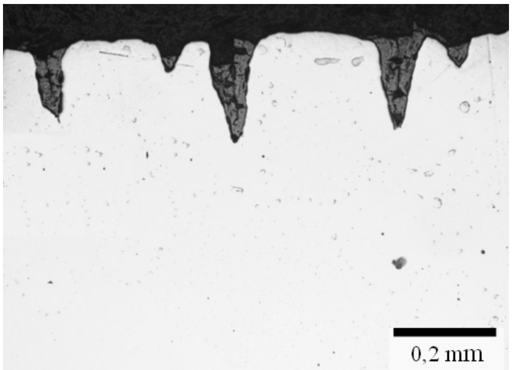
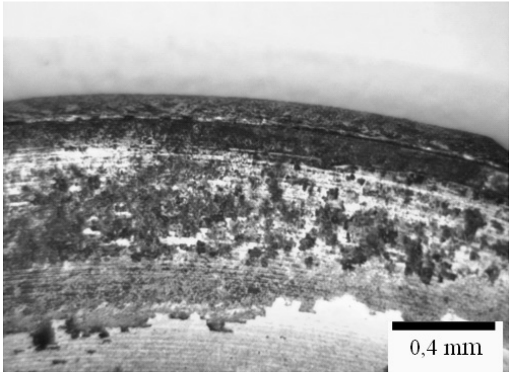


Fig. 5a) Cracks after thermal fatique test on the cross section of the TaC alloyed steel, laser power 1,2 kW, b) cracks after thermal fatique test on the cross section of the TaC alloyed steel, laser power 2,0 kW

c)



d)

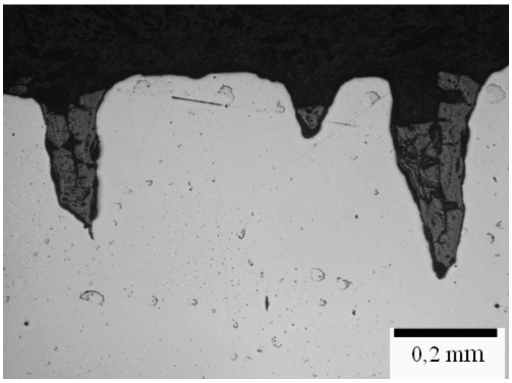


Fig. 6 c) Exfoliation on the surface layer of the steel sample remelted with laser power 2,3 kW, d) cracks after thermal fatique test on the cross section of the remelted steel, laser power 2,0 kW

Structure investigation was performed using the light microscope Leica MEF4A supplied by Zeiss in a magnification range of 50 - 500x. The micrographs of the microstructures were made by means of the KS 300 program using both the digital camera as well as the traditional way using photographic plates Fuji ISO 100, which were scanned in 600 dpi resolution.

The observations were performed on the cross section (Figure 5.) of the sample on each of the remelting trays. Metallographic investigations were performed also using the scanning electron microscope DSM 940 supplied by OPTON in a magnification range of 500 - 2000x. Phase composition and crystallographic structure were determined by the X-ray diffraction method using the DRON 2.0 device with a cobalt lamp, with 40 kV voltage. The measurement was performed by angle range of $2\,\Theta$: 35º - 105º.

Hardness measurements results were registered for each remelting area, for this reason the Rockwell hardness tester supplied by Zwick was used according to the PN-EN ISO 6507-1 standard, by a load of 147,2 N for 15 s. Microhardness measurements were performed using the DUH Shimatsu microhardness testing machine.

Table 3
Properties of tantalum carbide powder TaC

Powder	Grain Size, µm	Melting temp. °C	Density g/cm^3	Structure
TaC	10	3880	13.9	regular

3. Results and discussion

Preliminary investigations of the remelted hot work tool steel 32CrMoV12-28 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 (Figure 1 and 2). It can be seen that with the increasing laser power the roughness of the remelted metal surface increases. The layers are showed on Figure 1.

Microstructure presented on Figures 20 to 23 shows a dendritic structure in the remelted area. There are also TaC particles present distributed in the matrix. There is also a clear relationship between the employed laser power and the dendrite size, namely with increasing laser power the dendrites are larger.

The hot work tool steel has a ferritic structure with homogeny distributed carbides in the metal matrix in the annealed state. In areas, which are between the solid and molten state dendritic structure with large dendrites can be found. The EDS point wise analysis shown in Figures 8 and 9 confirms the presence of TaC particles in the matrix in form of big conglomerates. The conglomerate form is clearly shown on Figures 6 and 7 as a result of scanning microscope structural investigations. The required hardenability for this tool steel was achieving after a suitable tempering time, which assures melting of the alloying carbides in the austenite. The structural investigations carried out using the high power diode laser 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 Figure 5.

The average crack deep as a measure of the thermal fatigue increase according to the laser power used for laser alloying and achieves its maximum for 2,3 kW for steel alloyed with tantalum carbide powder. The resistance to the thermal fatigue measured with the average crack deep subjected to steel alloyed with TaC powder is few times smaller compared to the steel after a conventional heat treatment, which was used as the reference material.

It can be state, that in case of TaC powder the difference of the remelted area thickness among the power of 1.2 kW and 2.3 kW is about 20 % larger for the 2.3 kW power. Figure 10 shows the hardness measurements results of the remelted surface for 1.2, 1.6, 2.0 and 2.3 kW laser power. The highest hardness value is achieved for the 2.3 kW laser power. On Figure 11 is showed the microhardness measurement result of the remelted surface for 1.2, kW laser power. The highest value is achieved for alloyed top surface and id decreased with the remelting depth until the hrrdness value of the steel matrix is achieved.

Also a wear test with the metal - metal method was performed, the result of this investigation shows the wear resistance of the alloyed and remelted surface layer. As a measurement standard was chosen the depth of wear trace measured on the cross-section of the steel ball. The wear place images are showed on pictures 12, 14, 16 and 18 and the cross-section depth is presented on picture 13, 15, 17 and 19.

As a result of the performed wear test (Figure12 to 19) can be seen that the resistance increases with increasing laser power and the highest resistance occurs in case of samples alloyed with 2,3 kW power. Compared to the steel remelted only - without any ceramic powder used – can be also clearly state an improvement of the wear resistance a)

b)

c)

d)

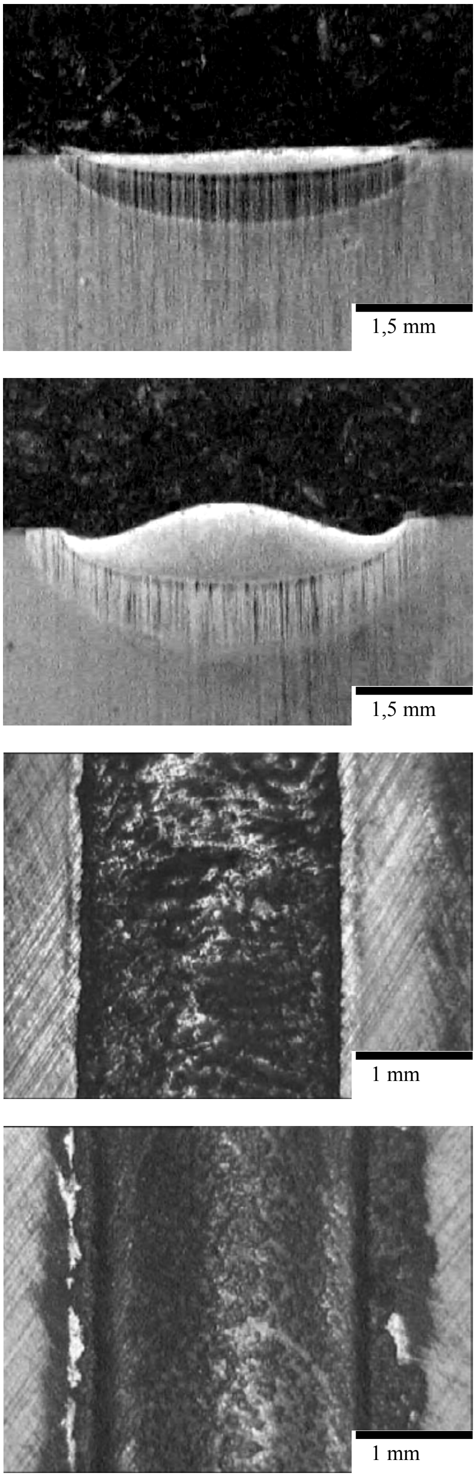


Fig. 7. Shape and thickness of cross-section of the laser remelted samples a) laser by power of 1.2 kW b) 2.3 kW; Shape of the laser tray of the 32CrMoV12-28 steel remelted with TaC powder c) with laser power 1.2 kW, d) TaC 2.3kW

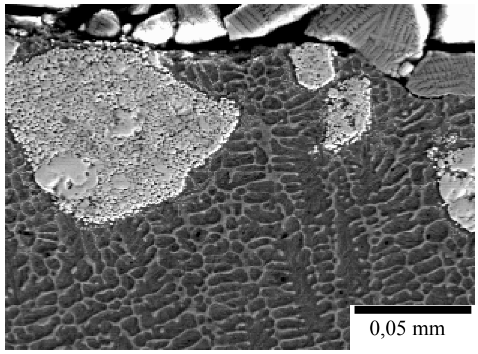


Fig. 8. Microstructure of the 32CrMoV12-28 steel remelted with TaC powder with laser power 1.2kW

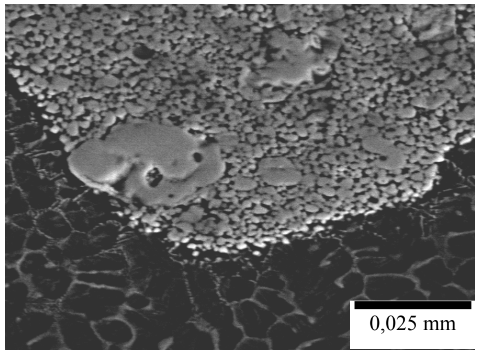


Fig. 9. Microstructure of the 32CrMoV12-28 steel remelted with TaC powder with laser power 1.2kW

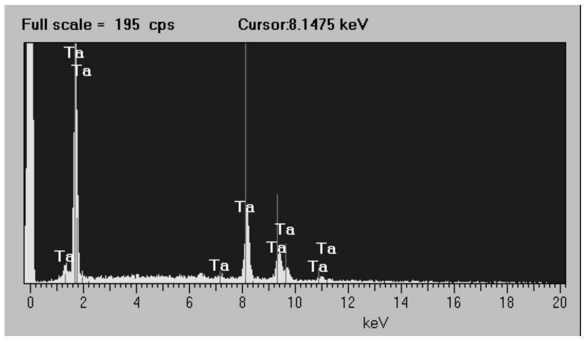


Fig. 10. EDS point wise analysis of the 32CrMoV12-28 steel remelted with TaC powder with laser power 1.2kW

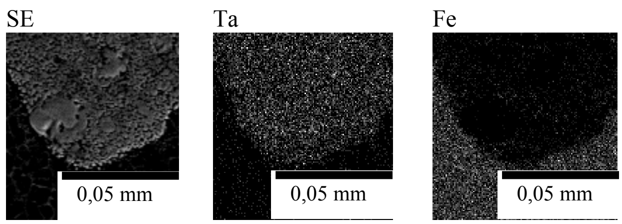


Fig. 11. EDS surface analysis of the 32CrMoV12-28 steel remelted with TaC powder with laser power 1.2kW

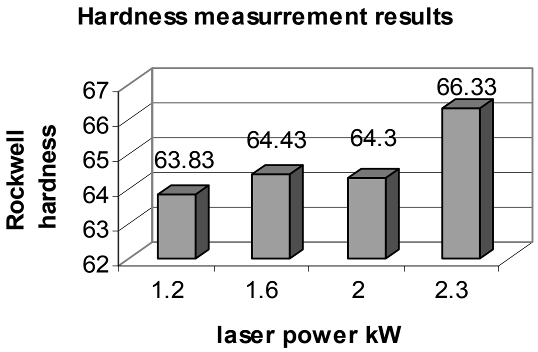


Fig. 12. Hardness measurements results of the remelted surface

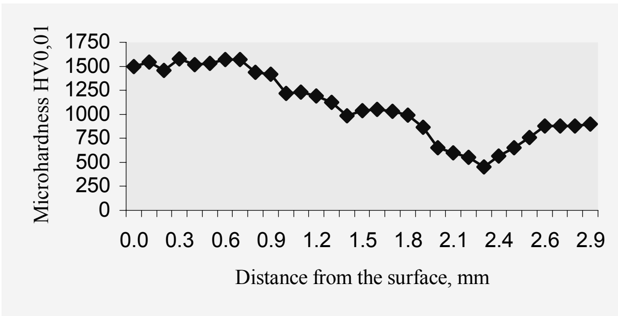


Fig. 13. Hardness measurements results of the remelted surface

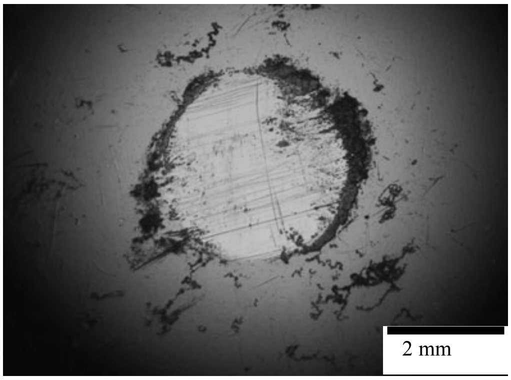


Fig. 14. Wear test trace on the surface of the steel ball after 1000 cycles, steel after remelting, laser power 2,0 kW

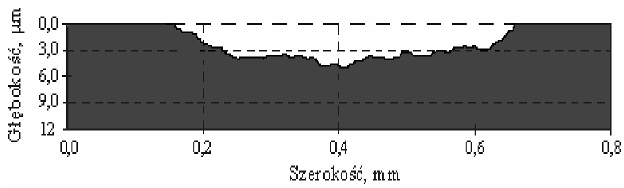


Fig. 15. Shape and depth of the wear trace on the steel ball, steel after remelting, laser power 2,0 kW

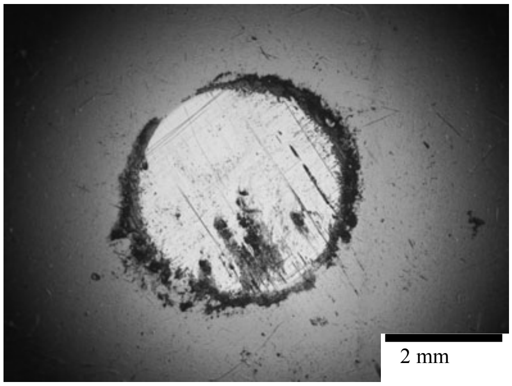


Fig. 16. Wear test trace on the surface of the steel ball after 1000 cycles, steel after remelting, laser power 1,6 kW

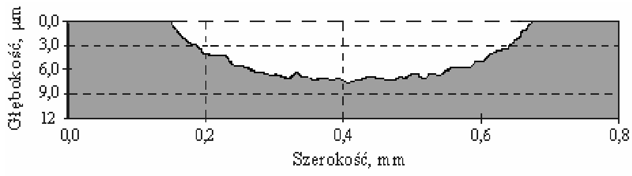


Fig. 17 Shape and depth of the wear trace on the steel ball, steel after remelting, laser power 1,6 kW

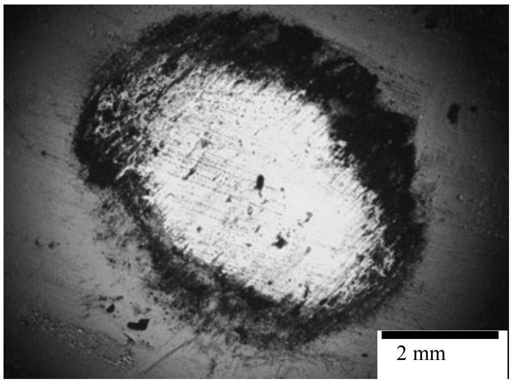


Fig. 18. Wear test trace on the surface of the steel ball after 1000 cycles, steel after alloying with TaC ceramic powder, laser power 2,0 kW

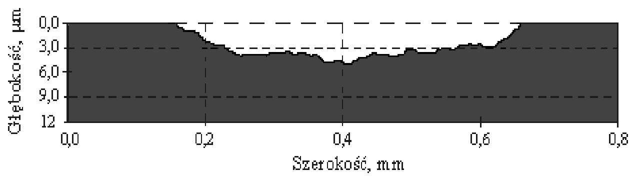


Fig. 19. Shape and depth of the wear trace on the steel ball, steel after alloying with TaC ceramic powder, laser power 2,0 kW

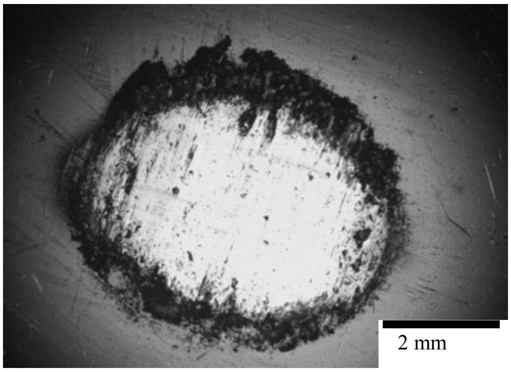


Fig. 20 Wear test trace on the surface of the steel ball after 1000 cycles, steel after alloying with TaC ceramic powder, laser power 1,6 kW

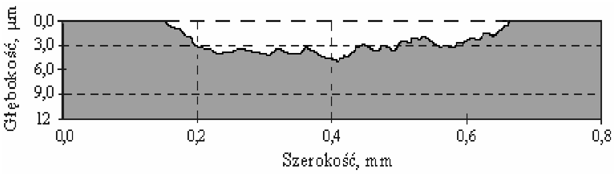


Fig. 21 Shape and depth of the wear trace on the steel ball, steel after alloying with TaC ceramic powder, laser power 1,6 kW

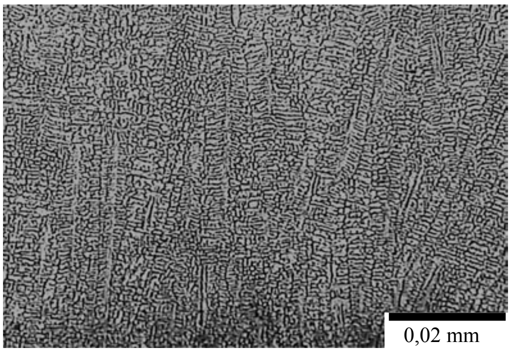


Fig. 22 Microstructure of the 32CrMoV12-28 steel remelted with TaC powder with laser power 1.2kW

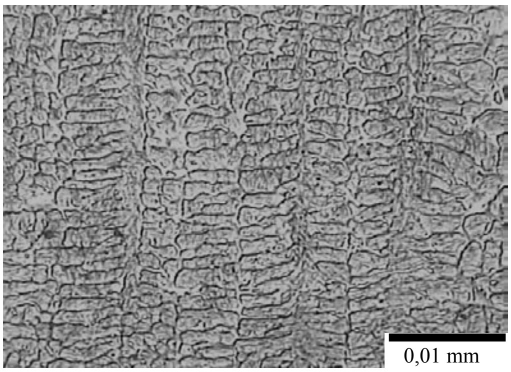


Fig. 23 Microstructure of the 32CrMoV12-28 steel remelted with TaC powder with laser power 2.3kW

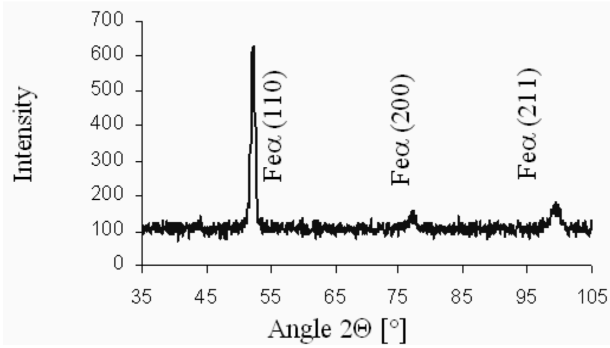


Fig. 24. X-Ray analysis of the alloyed sample

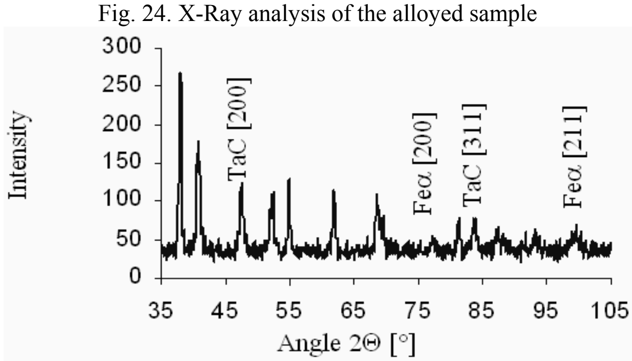


Fig..25. X-Ray analysis of the alloyed sample

5. Conclusions

The laser remelting and alloying show a huge dependence of used diode laser parameters on the structure and properties of the applied hot work tool steel 32 CrMoV12-28. On the basis of the performed investigations it is possible to conclude, that as a result of heat-treatment as well as remelting of the hot work steel 32CrMoV12-28 with the ceramic TaC powder can be possible to obtain high-quality surface layer which contain no cracks and defects as well as of much more higher hardness and microhardness value compared to the material which was not remelted. In case of TaC powder the increasing laser power depth of remelting material is higher and the surface is more regular. The hardness value increases according to the laser power used in case of tungsten carbide powder so that the highest power applied gives to highest hardness value in the remelted layer, and decreases in case of the titanium carbide powder. Also the surface of the remelted area is more regular less rough and more flat with increasing laser power. The metallographic investigations on the scanning microscope using the EDX analysis confirm the occurrence of tantalum carbide TaC, which is present in the matrix mostly in form of clusters, a small amount of tantalum is dissolved in the steel matrix. Also the X-Ray analysis - Figures 24 and 25 - confirms the occurrence of the used TaC powder in the steel matrix, so there are no new phase come into existence in reasonably amount.

The performed investigations allow to conclude, that the surface of the remelted area is more regular, less rough and more flat with increasing laser power. The metallographic investigations on scanning and light microscope reveal a dendritic structure which is present in the heat influence zone in samples alloyed with every applied laser power. In can be stat that the dendrite size increases with the increased laser power.

The same parallelism of properties and laser power increase can be state in case of the wear test performed be mind of the metal - metal method. As a result of this investigation can be hold that with increased laser power increase also the wear resistance of the alloyed surface layer of the worked steel. The resistance increases also compared to the steel remelted only without any ceramic powder used, that confirms the application of ceramic powder for appliance of the Tanatalum Carbide ceramic powder as a material for improvement of mechanical properties.

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