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Mechanical properties and structure changes of the laser alloyed 32CrMoV12-28 steel

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ABSTRACT

Purpose: The reason of this work was to determine 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

The laser treatment as a part of the new generation techniques applied in metal surface technology is discussed in this paper. Laser treatment is presented with remelting 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.

Diode lasers have long been used as light emitters in fiber-optic telecommunications, as barcode readers, and for implementing the write–read functions of optical disks. Nowadays, diode lasers do not merely deliver bits but also optical power. They are increasingly found in applications such as materials processing (welding, cutting, drilling, surface hardening, etc.) as well as in printing and graphical arts, in displays, and medical applications. In fact, since the advent of the high-power diode laser, laser technology is experiencing a fundamental structural change, as this semiconductor device has become the key element of a new breed of laser systems that are competing with gas lasers and lamp-pumped solid-state lasers. Power performance is so far restricted to wavelengths about 940 nm [1-5].

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. [6, 7, 8].

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.

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 [9, 10]

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.

The purpose of this work is to study the effect of a HPDL laser 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.

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 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 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. 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 220, 500, 800 and 1200, polishing with 1µm Al2O3 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.

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
32CrMoV12-28	0.308	0.25	0.37	0.020	0.002	2.95	2.70	0.535

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
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

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.

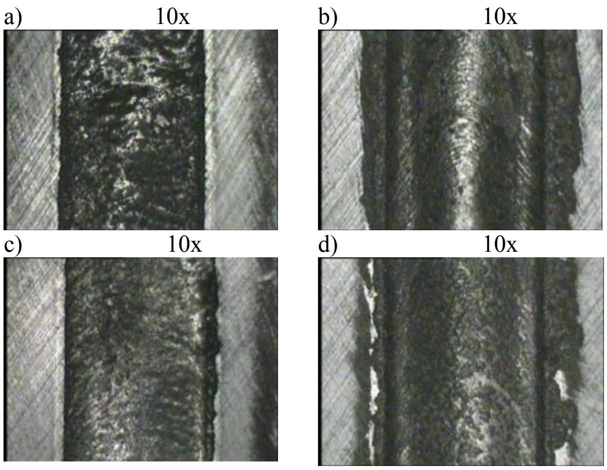

Fig. 1 Shape of the laser tray of the 32CrMoV12-28 steel remelted with TaC powder a) TaC with laser power 1.2kW, b) TaC 1.6 kW, c) TaC 2.0 kW, d) TaC 2.3kW

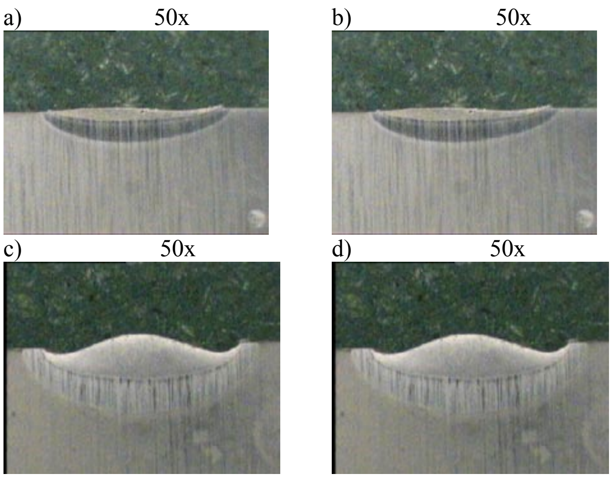

Fig. 2. Shape and thickness of cross-section of the laser remelted samples a) TaC laser by power of 1.2 kW b) TaC 1.6 kW, c) TaC 2.0 kW, d) TaC 2.3 kW

The observations were performed on the cross section 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 Θ: 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.

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 Figure 3 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 figure 4 confirms the presence of TaC particles in the matrix in form of big conglomerates. 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 2. 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 5 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.

4. Conclusions

The performed investigations allow to conclude, that as a result of heat-treatment as well as of remelting of the hot work steel 32CrMoV12-28 with TaC powder high-quality top layer is possible to obtain. 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. Together with increasing of the laser power, also the depth of remelting material grows.

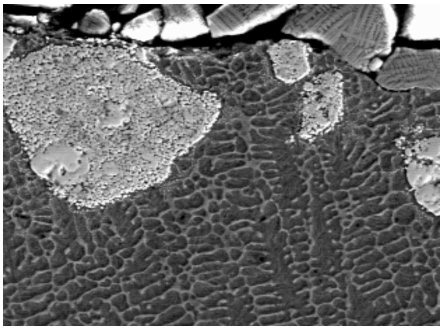

Fig. 3. Microstructure of the 32CrMoV12-28 steel remelted with TaC powder with laser power 1.2kW

a)

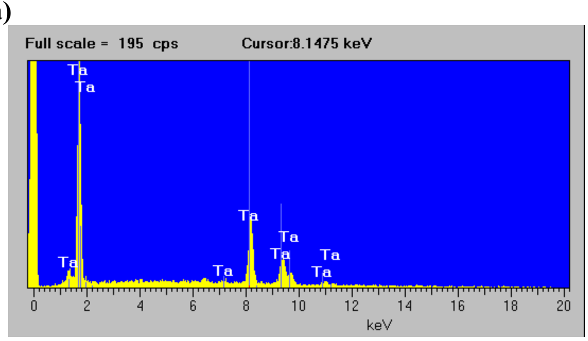

Fig. 4. EDS point wise analysis of the 32CrMoV12-28 steel remelted with TaC powder with laser power 1.2kW

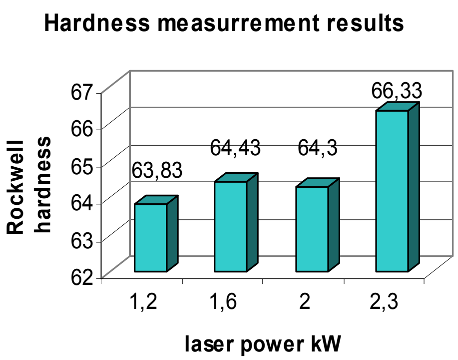

Fig. 5. Hardness measurements results of the remelted surface

The surface of the remelted area is more regular, less rough and more flat with increasing laser power. The metallographic investigations on scanning microscope using EDX analysis confirm the occurrence of tantalum carbide TaC. TaC particles are present in the matrix mostly in form of conglomerates, only a minor part of tantalum is dissolved in steel.

References

[1] L.A. Dobrzański, Fundamentals of Materials Science and Physical Metallurgy. Engineering Materials with Fundamentals of Materials Design, WNT, Warszawa – 2002 (in Polish).

[2] L.A. Dobrzański, K. Labisz, M. Piec, A. Klimpel,“Influence of remelting and alloying parameters on structure and properties of gradient surface layer of hot work tool steel using tungsten carbide”, The 4th International Conference - Coatings and Layers, Demänovská dolina, Slovakia, 205-211 – 2005 (in Polish).

[3] L.A. Dobrzański, K. Labisz, M. Piec, A. Klimpel, A. Lisiecki, “Influence of vanadium carbide ceramic powder on structure and properties of hot work tool steel alloyed with HPDL laser”, 2nd International Conference on Manufacturing Engineering ICMEN, Kassandra-Chalkidiki, Greece, 185-191 – 2005.

[4] L.A. Dobrzański, K. Labisz, M. Piec, A. Klimpel, Modeling of surface laser of the 32CrMoV12-28 tool steel using HPDL laser for alloying with TiC polder, CAM3S Contemporary Achievement in Mechanics, Manufacturing and Materials Science, 6th – 9th December 2005, Gliwice – Zakopane, Poland.

[5] L.A. Dobrzański., M. Piec., K. Labisz, A. Lisiecki, A. Klimpel, “Laser treatment of surface layer of chosen hot work tool steels”, Worldwide Congress of Materials and Manufacturing Engineering and Technology COMMENT 2005, Proceedings of the 13th International Scientific Conference, Gliwice-Wisła, 183-186 – 2005.

[6] L.A. Dobrzański, J. Mazurkiewicz, E. Hajduczek, Journal of Mat. Proc. Tech. 157-158, 472-484 – 2004.

[7] A. Klimpel, High Power Diode Laser in Welding, Welding Review nr 8, Warszawa – 1999 (in Polish).

[8] J. Kusiński, J. Przybyłowicz, S. Kąc, A. Woldan, Structure na properties change In case of laser remelting of surface layers and coatings, Metallurgist, 14-20 – 1999 (in Polish).

[9] K. Dae-Hwan, H. Seong-Hyeon, K. Byoung-Kee, Fabrication of ultrafine TaC powders by mechano-chemical process, Materials Letters, 87-92 – 2004.

[10] X. Changqing, J. Zhanpeng, Interfacial reactions in an explosively-welded tantalum clad steel plate, Surface and Coatings Technology, 278-282 – 2000.

[11] J. Pieniążek, J.S. Skrzypek, W. Ratuszek, F. Biczyk, Laser remelting of powders including intermetallic phases of the Fe-Al-Me Type, XXXII School of Materials Science Engineering– 2004 (in Polish).

[12] K. Obergfell, V. Schultze, , O. Vöhringer, Mat. Sci. and Eng. A355, 348-356 – 2003.

[13] L.J. Yang, Wear coefficient of tungsten carbide against hot-work tool steel disc with two different pin settings., Science Direct, 234-240 – 2004.

[14] S. Yahong, H. Satoshi, Y. Masato, U. Hitoshi, T. Hironobu, Fatigue behavior and fractography of laser-processed hot work tool steel., Science Direct, 128-134 – 2004.

[15] L.A. Dobrzański, M. Bonek, A. Klimpel, A. Lisiecki, Alloying of the WCLV steel with tungsten carbide using High Power Diode Laser HPDL”, Gliwice – 2002 (in Polish).