Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 24 ISSUE 2 October 2007

Modelling of surface layer of the 32CrMoV12-28 tool steel using HPDL laser for alloying with TiC powder

L.A. Dobrzański [a,*], K. Labisz [a], M. Piec [a], A. Klimpel [b]
[a] Division of Materials Processing Technology, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
[b] Welding Department, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

Received 16.03.2007; published in revised form 01.10.2007

Manufacturing and processing

ABSTRACT

Purpose: In this work are presented the performed investigation for the reason to determine the laser treatment parameters, for example 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 conditions for remelting the surface layer with HPDL.
Design/methodology/approach: The research way results of new laser treatment methodology 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 titanium carbide - TiC, 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: A surface layer was comming into existence 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: Four laser powers were choused and implicated by one process speed rate. Also one powder in form of TiC was used for alloying with the particle size of 10μm.
Practical implications: The investigation helps to use the laser treatment technique for alloying of hot work tool steel with different ceramic particles.
Originality/value: The scientific reason of this work is the applying of High Power Diode Laser (HPDL) for improvement of steel mechanical properties, especially the surface.
Keywords: Surface treatment; Heat treatment; Hot work tool steel; Laser melting

1. Introduction

The remelting of hot work tool steel with TiC titanium carbide powder was performed using the high power diode laser (HPDL) (Fig. 1.). The goal of this work is to determine the laser parameters and as well the investigation of the surface layer properties including the remelting zone and the heat influence zone. Standard metallographic investigation using light and electron microscope was performed. Also X-ray diffraction method was performed as well as hardness measurement and microanalysis, for the chemical composition investigation.

Welding of hot work tool steel for die forging and die blocks are typical examples of applications in which diode laser has technological as well as economical advantages over the conventional laser and welding techniques. The welding of these products requires good control over the heat input, short throughput time and low investment. The weld cross-section of a diode laser weld is, because of conduction limited welding process, more suitable for these applications than the keyhole welding. Hardening of a large gear wheel presents also a good example of an application in which the diode laser makes it possible to economically produce structures that have not earlier been possible. Hardening requires a special form of heat delivery in order to ensure evenly hardened zone and acceptable quality. The application was performed with two high power diode lasers. The case studies of these four applications are presented and discussed in details in this paper [1–11].

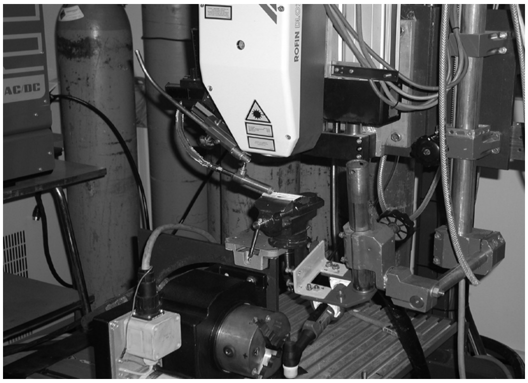

Fig. 1. HPDL laser RofinDL 020

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 TiC titanium carbide (Fig. 2.). 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. Titanium carbide is a 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 [12 - 25].

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

	Mass concentration of the elements, %			
steel 32CrMoV 12-28	C	Si	Mn	P
	0.308	0.25	0.37	0.02
	S	Cr	Mo	V
	0.002	2.95	2.70	0.535

This study was conducted to investigate the influence of TiC 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.

2. Experimental conditions

2.1. Material used for investigation

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.

2.2. Steel heat treatment

The samples were heat treated according to the steps for this steel type. 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. Titanium carbide powder was put to the so prepared samples. A paste layer of 0.5 mm in thickness was put on. The properties of titanium carbide powder are presented in Table 3.

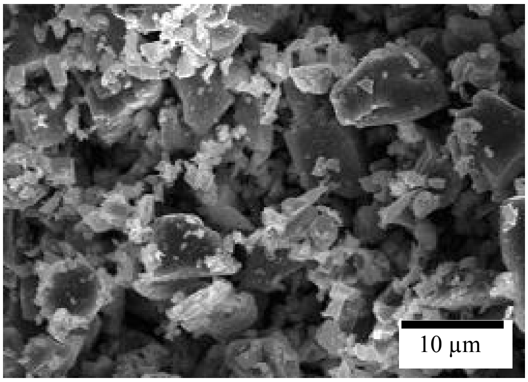

Fig. 2. TiC powder, SEM

Based on the preliminary investigations of a high power laser diode HPDL Rofin DL 020 the process rate was v = 0.5 m/min. 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. 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.

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. 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.

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

Also temperature measurement was carried on during the remelting process, the exact temperature changes are showed in Figure 12. It can be recognized, that the temperature is constant during the whole process. At the beginning of the process an increase of the temperature can be observed, followed by an decrease to ca. 2000 - 2500º C.

Table 3.
Properties of tantalum carbide powder TiC

Powder	Grain Size, µm	Melting temp. °C	Density g/cm^3
TiC	5	3140	4,259

The hot work tool steel has a ferritic structure with homogeny distributed carbides in the metal matrix in the annealed state. The required hardenability for this tool steel was achieving after a suitable tempering time, which assures melting of the alloying carbides in the austenite. In areas, which are between the solid and molten state dendritic structure with large dendrites can be found.

3. Results and discussion

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. The layers achieving by the alloying process are showed on Figure 6. The results allows to state that with the increasing laser power the roughness of the remelted metal surface increases.

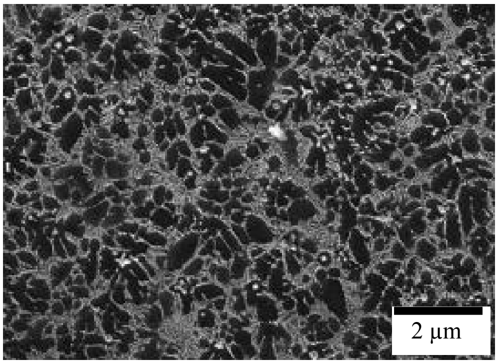

Fig. 3. Structure of the surface layer after remelting with TiC powder using 2.3 kW laser power

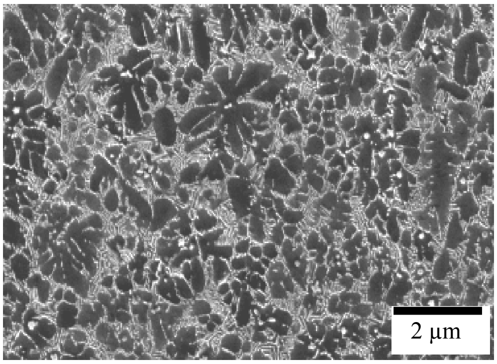

Fig. 4. Structure of the surface layer after remelting with TiC powder using 2.3 kW laser power

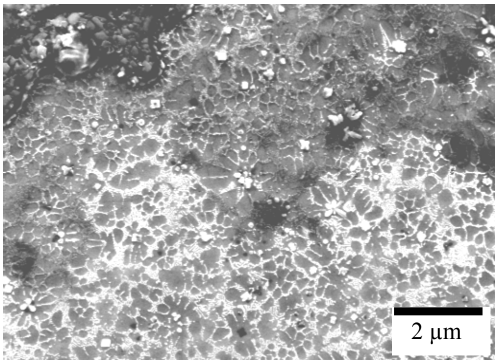

Fig. 5. Structure of the surface layer after remelting with TiC powder using 1.2 kW laser power

By mind of the performed investigation using the HPDL laser it could be state the changes in the remelted area depth and its structure. 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 7. It can be hold 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.

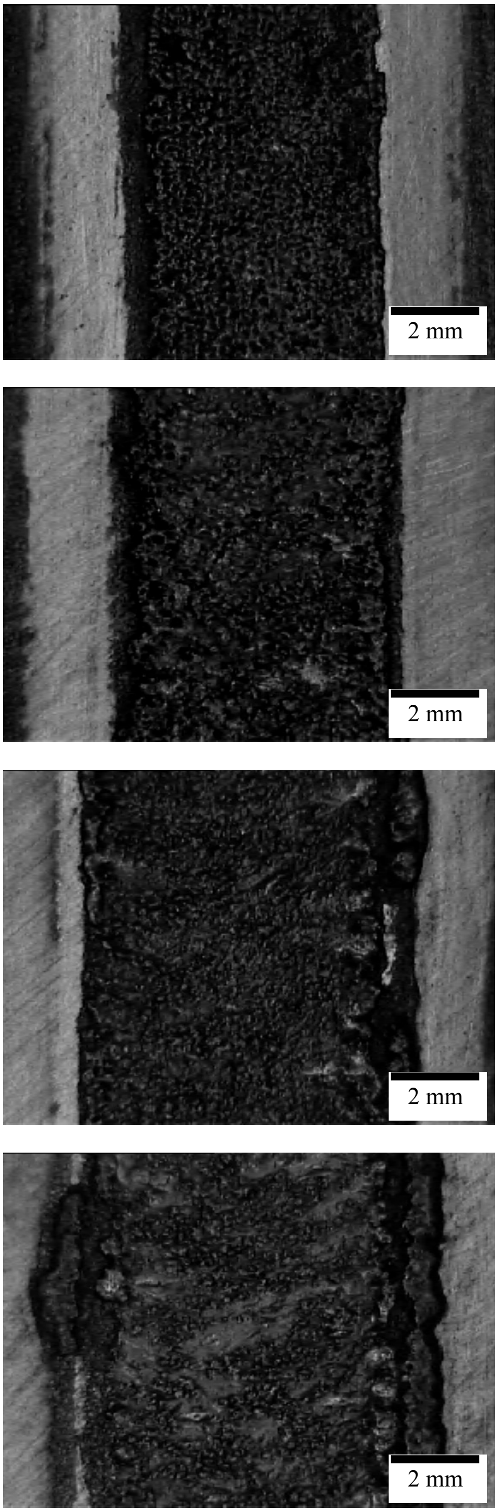

Fig.6. Shape of the laser tray of the 32CrMoV12-28 steel remelted with TiC powder a) laser power 1.2 kW, b) 1.6 kW, c) 2.0 kW, d) 2.3kW

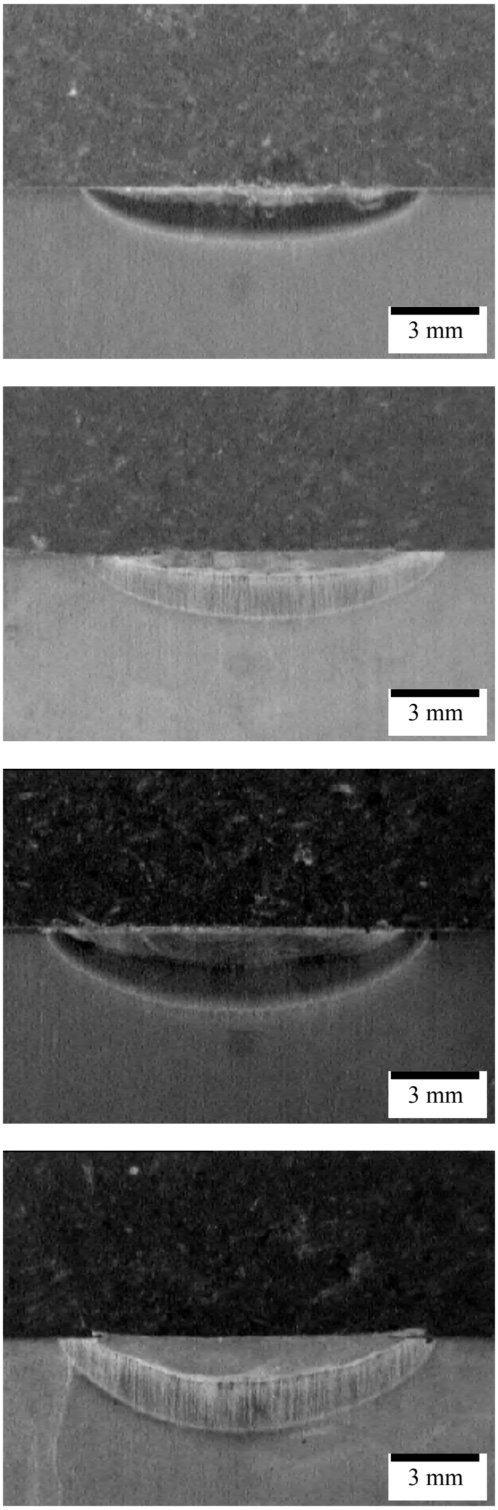

Fig.7. Shape and thickness of cross-section of the laser remelted samples a) TiC laser by power of 1.2 kW, b) TiC 2.0 kW, c) TiC 2.3 kW

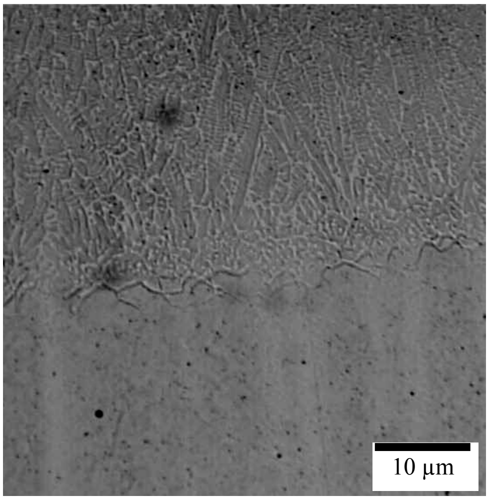

Fig. 8. Structure of the surface layer after remelting with TiC powder using 1.2 kW laser power

It can be seen that with the increasing laser power the roughness of the remelted metal surface increases. 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. Microstructure presented on Figures 3, 4, 5 and 8 shows a dendritic structure in the remelted area and also the TiC particles in the steel 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 EDS point analysis, shows on Figures 9, 10 and 11 the chemical composition of the alloyed area, there are no big TiC particles present so in case of TiC powder the titanium are mostly dissolved in the steel matrix.

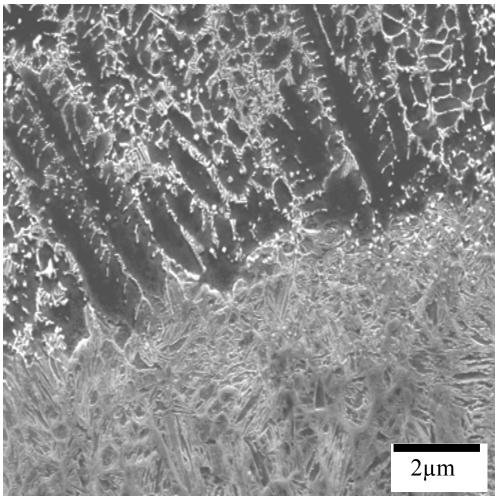

Fig. 9. Structure of the surface layer after remelting with TiC powder using 1.6 kW laser power

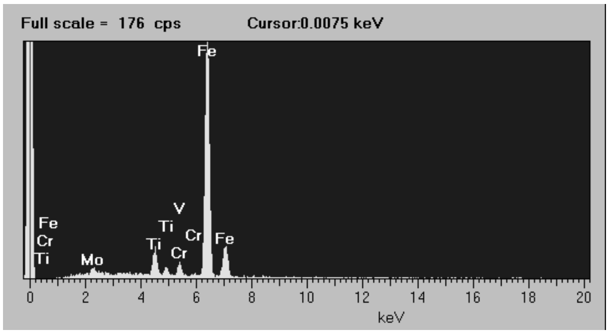

Fig. 10. EDS point-wise microanalysis, performed in the point marked on Figure 9

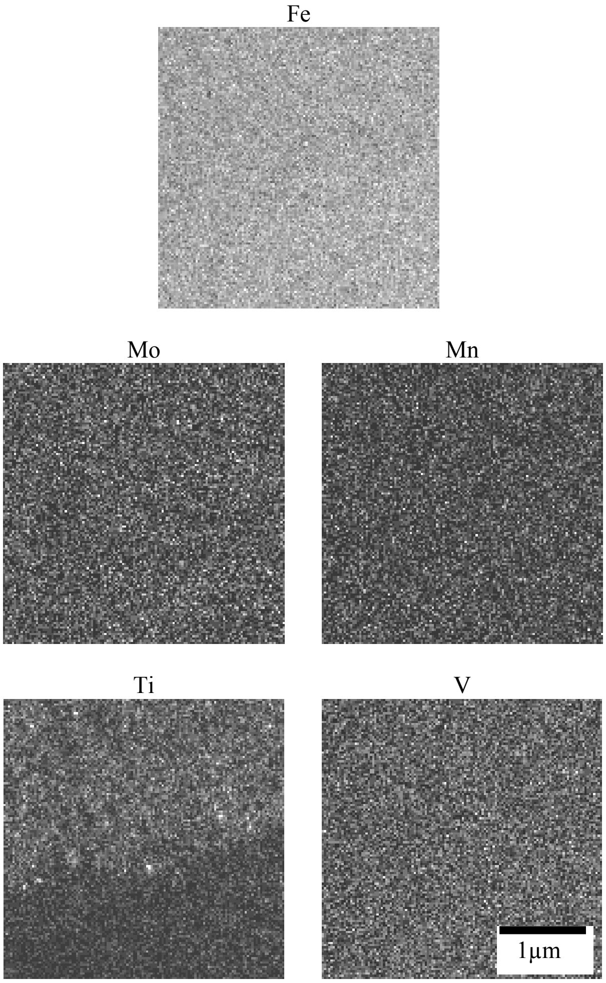

Fig. 11. EDS surface microanalysis of the area presented on Figure 9

In the steel matrix after tempering martensitic structure is achieved, in the martensite are dissolved the alloyed additives, which is confirmed by the X-ray analysis, which is presented on Figures 17 and 18, this investigation is also performed for each laser power used. For the TiC alloyed steel only small titanium carbide picks are present, Figure 19.

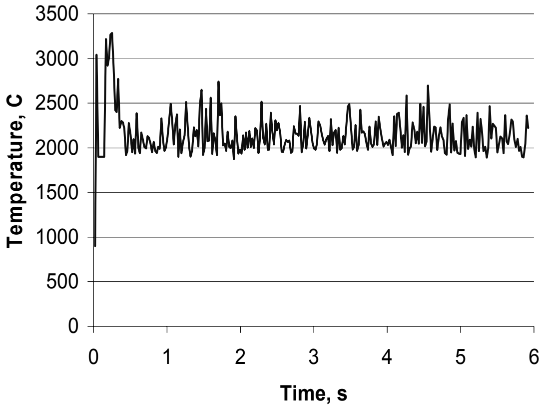

Fig. 12. Temperature change in the sample during the alloying process with 2.3 kW laser power with TiC powder

One can be state that in case of TiC powder the difference of the remelted area thickness among the power of 1.2 kW and 2.3 kW is about 50 % larger for the 2.3 kW power. Figures 13 to 16 shows the microhardness measurements results of the remelted surface for 1.2, 1.6, 2.0 and 2.3 kW laser power. Were can be seen that the hardness of the remelted zone is smaller the the microhardenssvalue of the non remelted area.

On Figure 19 there are presented the results of hardness measurements of the alloyed surface layer. There can be found that the hardness value of the surface layer decreases together with the laser power and has the smallest value by power 2,3 kW. This results confirm also the microhardness investigation, where the TiC alloyed zones have a smaller hardness values compared to the steel matrix. It can be also seen that the hardness of the laser alloyed samples with the laser power of 1,2 kW and 1,6 kW is comparable with the value achieved after a conventional heat treatment of this hot work tool steel.

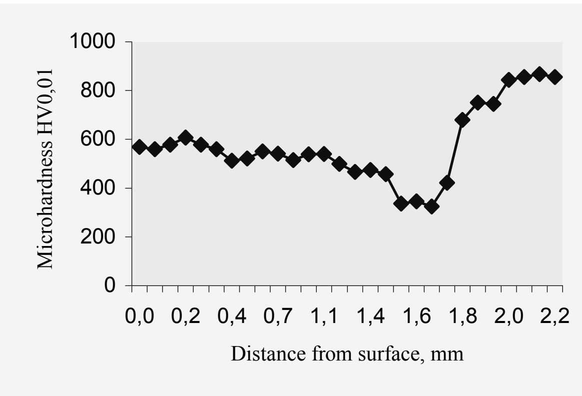

Fig. 13. Microhardness change of the surface layer of the 32CrMoV12-28 steel after laser alloying with titanium carbide TiC, laser power 1.2 kW

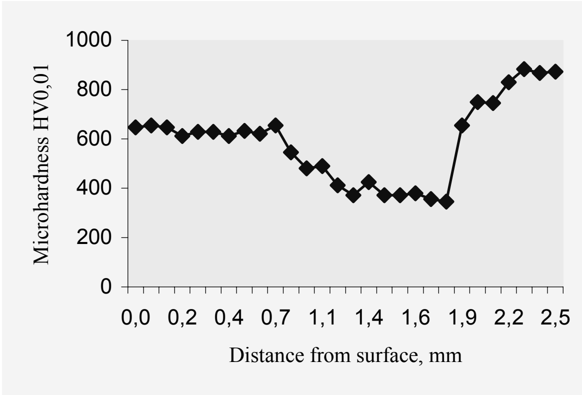

Fig. 14. Microhardness change of the surface layer of the 32CrMoV12-28 steel after laser alloying with titanium carbide TiC, laser power 1.6 kW

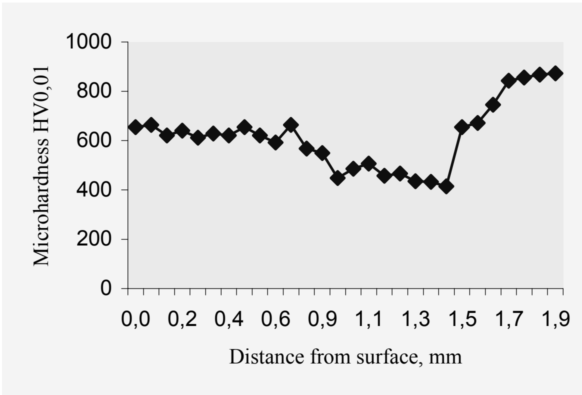

Fig. 15. Microhardness change of the surface layer of the 32CrMoV12-28 steel after laser alloying with titanium carbide TiC, laser power 2.0 kW

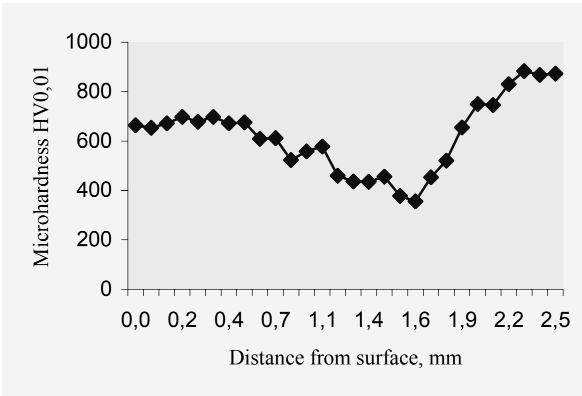

Fig. 16. Microhardness change of the surface layer of the 32CrMoV12-28 steel after laser alloying with titanium carbide TiC, laser power 2.3 kW

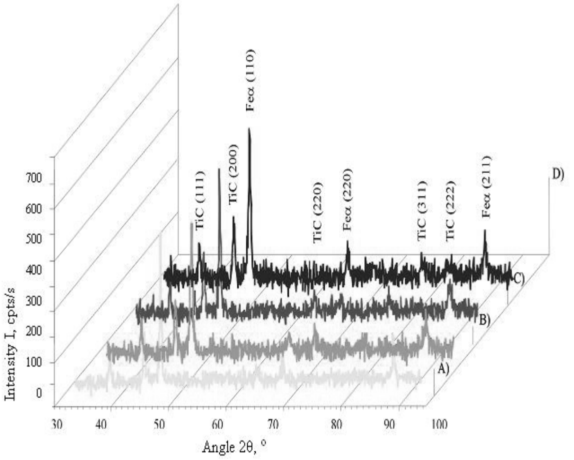

Fig. 17. X - ray diffraction of the Ti alloyed sample, using 1.2; 1.6; 2.0 and 2.3 kW laser power

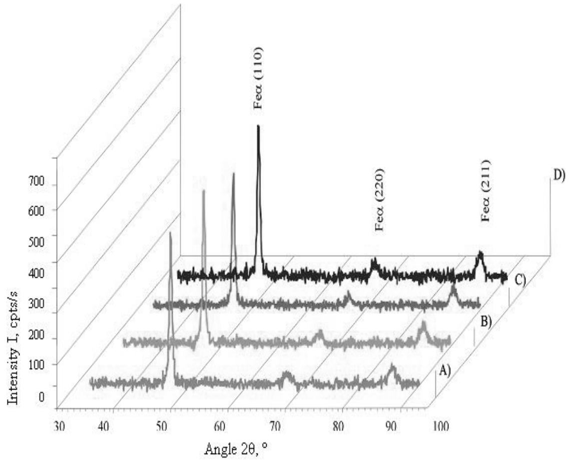

Fig. 18. X - ray diffraction of the remelted sample, using 1.2; 1.6; 2.0 and 2.3 kW laser power

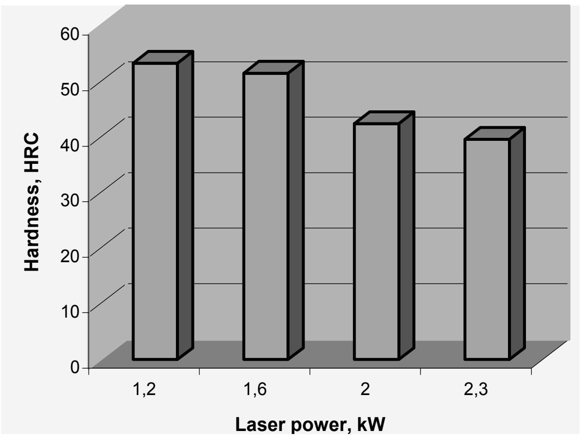

Fig. 19. Hardness of the surface layer of the alloyed steel remelted with TiC powder using HPDL laser

4. Conclusions

On the basis of the performed investigations can be hold, that the hot work steel 32CrMoV12-28 alloyed with TiC powder has achieved a high-quality top layer. The layer is without cracks and defects and has a higher hardness compared to the non remelted material. The hardness value increases together with the laser power used so that the highest power applied gives the highest hardness value in the remelted layer. With increasing the laser power the depth of remelting material is growing as well. With increasing laser power the surface of the remelted area is more regular, smooth and flat Also the occurance of the titanium carbide TiC particles could be confirmed. 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 investigation have also revealed different zones in the surface laeyr, the remelted zone, the heat influence zone, and the steel matrix as the non affected zone. It can be summrize that this technique is a grat metho for modelling of tools ofhot work tool steel surface layer, which can be deeple recognized in following studys and investigations.

Acknowledgements

Investigations were partially financed within the framework of the Polish State Committee for Scientific Research No PBZ-KBN-100/T08/2003 and within the framework of the Scholarship No S-028-2005 from the International Visegrad Fund for Marek Piec Ph.D., Eng.

References

[1] L.A. Dobrzański, Engineering materials and materials design. Fundamentals of materials science and physical metallurgy, WNT, Warsaw, 2006 (in Polish).
[2] 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, Proceedings of the 2nd International Conference on Manufacturing Engineering ICMEN, Kassandra-Chalkidiki, 2005, 185-191.
[3] L.A. Dobrzański, K. Labisz, M. Piec, A. Klimpel, Modelling 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, 2005, 122-126.
[4] L.A Dobrzański, M. Piec, K. Labisz, M. Bonek, A. Lisiecki, A. Klimpel, Laser treatment of surfach layer of choosen hot work tool steel, Mechanic 3 (2005) 351-355 (in Polish).
[5] F.F.P. Medeiros, A.G.P. Da Silva, C.P. De Souza, Synthesis of niobium carbide at low temperature and its use in hardmetal, Powder Technology 126 (2002) 155-160.

[6] K. Dae-Hwan, H. Seong-Hyeon, K. Byoung-Kee, Fabrication of ultrafine TaC powders by mechano-chemical process, Materials Letters 58 (2004) 3839-3979.
[7] X. Changqing, J. Zhanpeng, Interfacial reactions in an explosively-welded tantalum clad steel plate, Surface and Coatings Technology 130 (2000) 29-32.
[8] E. Hajduczek, L.A. Dobrzański, J. Adamczyk, Effect of heat treatment on structure and properties of experimental hot-work tool steel 47CrMoWVTiCeZr16-26-8, Proceedings of the 5th International Congress on Heat Treatment of Materials, Budapest, Hungary, 2 (1986) 976 -982.
[9] A. Klimpel, High power diode laser in welding, Review of Welding 8 (1999) 32-38 (in Polish).
[10] J. Kusiński, J. Przybyłowicz, S. Kąc, A. Woldan, Structure and properties change in case of laser remelting of surface layers and coatings, Metallurgist 4 (1999) 14-20 (in Polish).
[11] K. Dae-Hwan, H. Seong-Hyeon, K. Byoung-Kee, Fabrication of ultrafine TaC powders by mechano-chemical process, Materials Letters 58 (2004) 87-92.
[12] X. Changqing, J. Zhanpeng, Interfacial reactions in an explosively-welded tantalum clad steel plate, Surface and Coatings Technology 130 (2000) 278-282.
[13] E Ohmura, F. Fukuyo, K. Fukumutsu, H. Morita, Internal modified-layer formation mechanism into silicon with nanosecond laser, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 381-384.
[14] L.J. Yang, Wear coefficient of tungsten carbide against hot-work tool steel disc with two different pin settings, Wear 257 (2004) 234-240.
[15] A. Klimpel, A. Lisiecki, The mechanism of diode laser butt joint welding, Proceedings of the 2nd International Conference on Advances in Production Engineering, Warsaw, 2001, 44-50.
[16] S. Yahong, H. Satoshi, Y. Masato, U. Hitoshi, T. Hironobu, Fatigue behavior and fractography of laser-processed hot work tool steel, Vacuum 73 (2004) 128-134.
[17] L.A. Dobrzański, M. Bonek, A. Klimpel, A. Lisiecki, Alloying of the WCLV steel with tungsten carbide using High Power Diode Laser HPDL, Journal of Achievements in Materials and Manufacturing Engineering 14 (2006) 123-126.
[18] Hamedi M, Optimizing tensile strength of low-alloy steel joints in upset welding, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 341-344.
[19] L.A. Dobrzański, K. Labisz, A. Klimpel, Effect of laser alloying on thermal fatigue and mechanical properties of the 32CrMoV12-20 steel, Journal of Achievements in Materials and Manufacturing Engineering 19 (2007) 235-238.
[20] L.A. Dobrzański, K. Labisz, A. Klimpel, Influence of the alloying material on structure and properties of the laser alloyed hot work tool steel, Metallurgy Committee of Polish Academy of Science, Gliwice, 2006, 669-674 (in Polish).
[21] R. Teghil, L. D'Alessio, M. Zaccagnino, D. Ferro, V. Marotta, G. Maria De, TiC and TaC deposition by pulsed laser ablation: a comparative approach, Applied Surface Science 42 (2001) 1568-1574.
[22] S. Yahong, H. Satoshi, Y. Masato, U. Hitoshi, T. Hironobu, Fatigue behavior and fractography of laser-processed hot work tool steel, Vacuum 73 (2004) 655-660.
[23] F.M.L. Arantes, R.E. Trevisan, Experimental and theoretical evaluation of solidification cracking in weld metal, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 407-410.
[24] J. Okrajni, A. Marek, G. Junak, Description of the deformation process under thermomechanical fatique, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 15-24.
[25] L. Achab, E.H. Amara, N. Mebani, N. Allalou, F. Hamadi, Numerical thermodynamic field medelling of a metallic substance during laser welding, Journal of Achievements in Materials and Manufacturing Engineering 19 (2006) 94-99.