Archives of Materials Science and Engineering

Volume 34
Issue 2
December 2008
Pages 69-74

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

# Characteristic of Mg-Al-Zn alloys after laser treatment

**L.A. Dobrzański [a,*], J. Domagała [a], T. Tański [a], A. Klimpel [b], D. Janicki [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 16.09.2008; published in revised form 01.12.2008

## ABSTRACT

**Purpose:** The structure and the properties of casting magnesium alloy EN-MCMgAl3Zn1, EN-MCMgAl6Zn1, EN-MCMgAl9Zn1 and EN-MCMgAl12Zn1 after laser surface treatment are presented in this paper. The aim of this work was to improve the surface layer cast magnesium Mg-Al-Zn by melting and feeding of TiC particle on the surface. The purpose of this work was to determine the laser treatment parameter.

**Design/methodology/approach:** The experiments were performed using high power diode laser. The laser treatment of an EN-MCMgAl3Zn1, EN-MCMgAl6Zn1, EN-MCMgAl9Zn1, EN-MCMgAl12Zn1 magnesium alloy with alloying TiC powders was carried out using a high power diode laser (HPDL). The resulting microstructure in the modified surface layer was examinated using scanning electron microscopy. Phase composition was determined by the X-ray diffraction method using the XPert device. The measurements of hardness of the modified surface layer was also studied.

**Findings:** The alloyed region has a fine microstructure with hard carbide particles. Hardness of laser surface alloyed layer with TiC particles was significantly improved as compared to alloy without laser treatment for EN-MCMgAl3Zn1 and EN-MCMgAl6Zn1 alloys.

**Research limitations/implications:** In this research one powder - TiC was used with the particle size over 6 μm. This investigation presents different speed rates feed and different laser power value for four type of magnesium alloys.

**Practical implications:** The results obtained in this investigation were promising compared to other conventional processes. High Power Diode Laser can be used as an economical substitute of Nd:YAG and $CO_2$ to improve the surface magnesium alloy by feeding the carbide particles.

**Originality/value:** The originality of this work is applying of High Power Diode Laser for alloying of magnesium alloy using titanium carbide.

**Keywords: Laser alloying; Magnesium alloy; High Power Diode Laser (HPDL); Titanium carbide**

MATERIALS

## 1. Introduction

Magnesium and magnesium alloys were praised the most developing potential materials due to their low density (1.8 g/cm$^3$), high strength-to-weight ratio and high damping capacity. Magnesium alloys had been applied in many fields, such as automobile manufactures, aerospace, electronics. These alloys have become attractive candidate for many industries because of their high specific strength, which leads to weight reduction resulting in considerable economic advantage. It is also foreseen that Mg alloys are able to compete with aluminium alloys [1, 2, 6, 7].

However, the some disadvantageous namely poor resistance to corrosion and wear is the barrier the wider application of magnesium alloy. There are a number of possible coating technologies available for magnesium alloys, such as: electrochemical plating, conversion coatings, gas-phase deposition processes, laser surface alloying/cladding [14].

One of developing methods, aimed in improving hardness and in effect enhancing fatigue and wear behavior of magnesium alloys is laser surface modification processes. The processes can be divided into such with and without filler material and in solid-state and melting processes. Very important factors, such as short processing time, flexibility in operation and precision are main advantages of laser surface treatment over conventional processes. Laser surface melting and laser alloying/cladding are advantageous process for improving corrosion and wear resistance of magnesium alloys. In laser alloying, a laser beam is scanned across the surface of a work piece in order to melt a layer of material in a heat conduction mode. In the molten state, the metal is enriched with alloying elements which may be introduced from either gaseous or solid consumables using a variety of delivery techniques [3, 8-11].

It was observed that laser power and scan rate have a strong influence on the mechanical, tribological and corrosion behaviors of the alloys. Laser applications play an important role in these industrial processes.

Laser surface melting has been reported to improve the corrosion and wear resistance of Mg alloys. The improvement is attributed to the microstructural refinement and solid solution strengthening due to faster cooling rate of the molten surface layer. However, in work [11] reported that laser surface melting does not increase the corrosion of investigated alloys (AZ91D and AM60B). The corrosion and wear resistance of Mg alloys have also been improved by laser surface alloying. Laser cladding of Mg alloys has been used to improve the corrosion resistance and improve the wear resistance by introducing hard ceramic particles, such as $Al_2O_3$ or SiC in the surface layer [4, 5, 12-19].

In the present investigation, the laser surface treatment has been carried out on casting alloy EN MCMgAl3Zn1, EN MCMgAl6Zn1, EN MCMgAl9Zn1, EN MCMgAl12Zn1 alloy with TiC particle using high power diode laser. The effect of the laser parameters on the microstructure was investigated. Phase composition was determined and hardness values of the laser treated samples were measured.

## 2. Material and method

The substrate materials used for the investigation were magnesium alloys EN MCMgAl3Zn1, EN MCMgAl6Zn1, EN MCMgAl9Zn1 and EN MCMgAl12Zn1 after heat treatment states. The heat treatment involved the solution heat treatment (warming material in temperature 375°C for 3 hours, it later warming in the temperature to 430°C, holding for 10 hours) and cooling in water. Nextly, the specimens were ageing at temperature of 190°C and holding for 15 hours and cooling in air.

The chemical compositions of investigated materials were listed in Table 1.

Plates of 50x18x10mm were polished with 1200-grit SiC paper prior to laser surface treatment to obtain smooth surface and then cleaned with alcohol and dried.

The titanium carbide particles in size of up 6 μm were used (Fig. 1). The TiC powder was supplied by side injection rate of 7±1 g/min.

The laser alloying was performed by high power diode laser HPDL Rofin DL 020 under an argon shielding gas. The parameters are presented in Table 2. The process parameters during the present investigation were: laser power - 1.2-2.0 kW, scan rate - 0.5-1.0 m/min (every 0.25) and powder feed rate of 7±1 g/min.

Table 1.
Chemical composition of investigation alloys

| Mass concentration of investigation alloys, % | | | | | | |
|---|---|---|---|---|---|---|
| Al | Zn | Mn | Si | Fe | Mg | Rest |
| 11.894 | 0.55 | 0.22 | 0.050 | 0.02 | 87.2 | 0.066 |
| 9.399 | 0.84 | 0.24 | 0.035 | 0.007 | 89.4 | 0.079 |
| 5.624 | 0.46 | 0.16 | 0.034 | 0.07 | 93.6 | 0.052 |
| 2.706 | 0.21 | 0.10 | 0.032 | 0.005 | 96.9 | 0.047 |

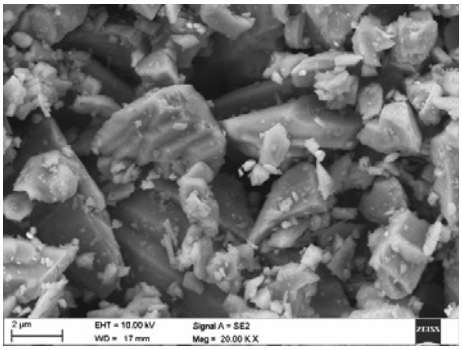



Fig. 1. SEM morphology of the titanium carbide

Table 2.
HPDL parameters

| Parameter | Value |
|---|---|
| Laser wave length, nm | 940±5 |
| Focus length of the laser beam, mm | 82/32 |
| Power density range of the laser beam in the focus plane [kW/cm$^2$] | 0.8-36.5 |
| Dimensions of the laser beam focus, mm | 1.8x6.8 |

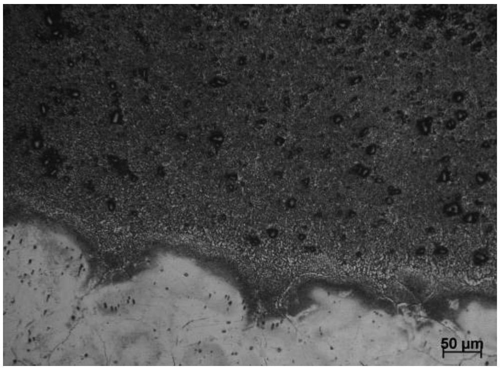
After the laser treatment, specimens were sectioned, ground and polished with 1 μm diamond paste. The samples were mounted in thermosetting resins. In order to disclose grain boundaries and the structure and to distinguish precisely the particular precipitations in magnesium alloys as an etching in nital at room temperature has been used. The observations of the investigated cast materials have been made on the light microscope LEICA MEF4A as well as on the electron scanning microscope Zeiss SUPRA 35 using a secondary electron detection.

The X-ray qualitative microanalysis and the analysis of a surface distribution of cast elements in the examined magnesium after laser treatment have been made on transverse microsections on the Zeiss SUPRA 35 scanning microscope with the EDS Trident XM4 firmy EDAX dispersive radiation spectrometer at the accelerating voltage of 15 kV.

Phase composition and crystallographic structure were determined by the X-ray diffraction method using the XPert device with a cobalt lamp, with 40 kV voltage. The measurement was performed in angle range of 2 ϴ: 30º-130º.

The hardness of the modified surface layers was measured using Zwick ZHR 4150 TK hardness tester in the HRF scale.

a)




b)

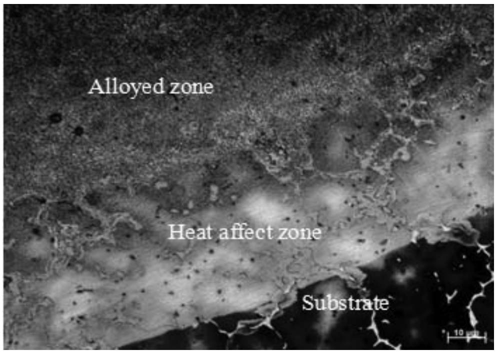



Fig. 2. Microstructure of the interface between the laser-melted zone and the substrate a) EN-MCMgAl6Zn1 alloy, laser power: 1.6 kW, scan rate: 0.75 m/min, b) EN-MCMgAl12Zn1, laser power: 1.2 kW, scan rate: 0.75 m/min

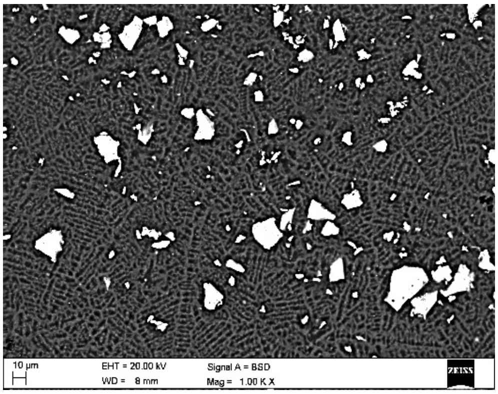
## 3. Discussion of experimental results

The cross-section of the microstructure of specimens after laser alloying was shown in Fig. 2.

The coating consist of the remelting zone, heat affect zone and substrate. It was found that the magnesium alloy with aluminum concentration 3 and 6 wt. % of revealed negligible (no noticeable amount) heat affect zone in opposition to magnesium alloys with aluminum concentration of 9 and 12 wt. %. The depth of the surface alloying layer was varied with laser power and also scan rate. The microstructure of the surface layer consists mainly of a dispersion of TiC particles in the Mg and Al matrix. Figs. 3a and 4a show the SEM morphology of the MCMgAl6Zn1 and MCMgAl9Zn1 alloys surfaces alloying with TiC particles. The coating is free of cracks and porosity. The interface between the alloying zone and substrate shows good metallurgical joint. The structure of the alloyed zone is mainly dendritic of primary magnesium with eutectic of Mg and $Mg_{17}Al_{12}$. The uniform distribution of the particles associated may be noted.

Figs. 3b and 4b show the scanning electron micrographs of the interface between modified zone and the substrate of the MCMgAl3Zn1 and MCMgAl9Zn1 alloy with TiC particle, respectively. The microstructure is characterized by refined grains which are oriented along the direction of heat flow. The refining due to laser surface melting and rapid quenching. The grains of the substrate are significantly coarser than that after laser treatment.

a)




b)

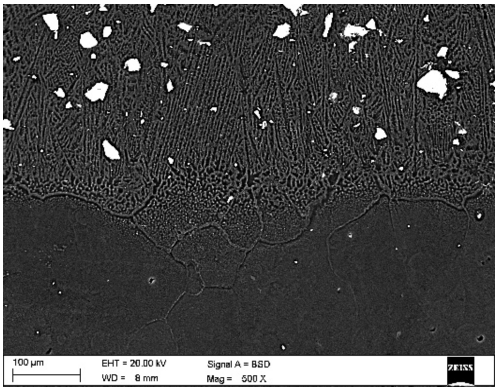



Fig. 3. SEM micrograph of laser modified surface of the MCMgAl3Zn1 alloy with TiC particles: a) top surface of the surface layer, b) interface between modified zone and the substrate

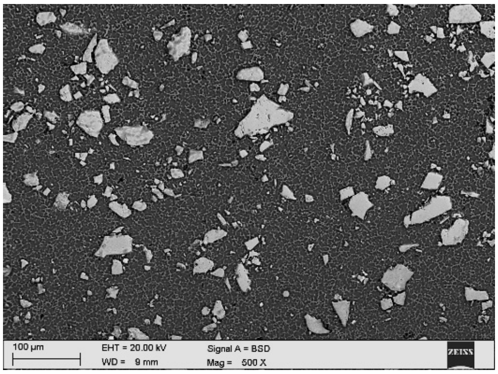
Fig. 5 shows influence laser power and scan rate on the remelting width of the surface alloying layer after laser treatment. The width of the surface alloying layer was varied with scan rate and also laser power. The width of the surface alloying layer increased with power (mainly it's due to increasing of the absorbed energy with the laser power) and decreases with an increase in laser scan rate.

Figs. 6 and 7 show the graph of the regression function showing dependence remelting width from laser power and scan rate for the MCMgAl3Zn1 and MCMgAl12Zn1, respectively.

Fig. 8 shows the X-ray diffraction pattern of the laser surface treated MCMgAl9Zn1 and MCMgAl12Zn1 alloy with TiC particles consists of presence of Mg-$\alpha$, $Mg_{17}Al_{12}$ and TiC peaks.
The chemical analysis (Fig. 9) of the surface element composition and the qualitative microanalysis made on the transverse microsections of the magnesium alloys after laser treatment magnesium alloy with TiC powder (laser power: 1.6 kW, scan rate: 0.75 m/min, powder feed rate: 7±1 g/min) using the EDS system have confirmed the concentrations of magnesium, aluminum, titanium, manganese and zinc which has also effected by laser

modification. It was observed homogeneous distribution of magnesium and aluminum, except for titanium carbide particles. Absence of magnesium, aluminum and zinc and occurrence of applied carbide particles in the zone of hard particles, approves, that TiC particles did not melt or dissolve in magnesium matrix. There is no decomposition of TiC particles during alloying laser.

a)




b)

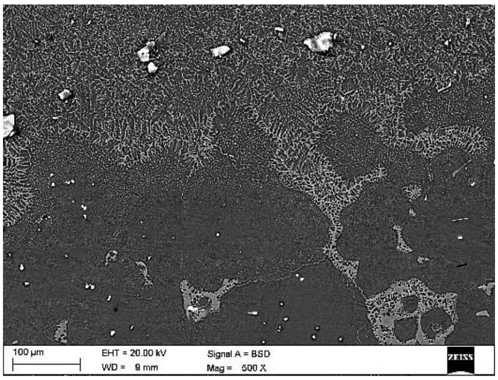



Fig. 4. SEM micrograph of laser modified surface of the MCMgAl12Zn1 alloy with TiC particles: a) top surface of the surface layer, b) interface between modified zone and the substrate

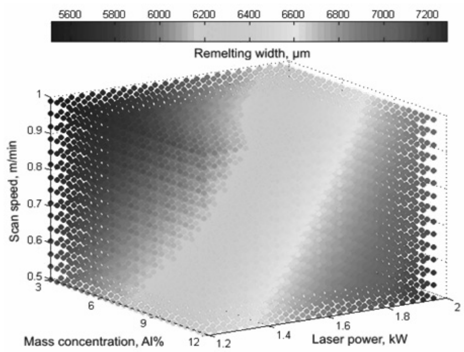



Fig. 5. Graph of the regression function showing dependence of remelting width to aluminium concentration (wt. %), laser power and scan rate

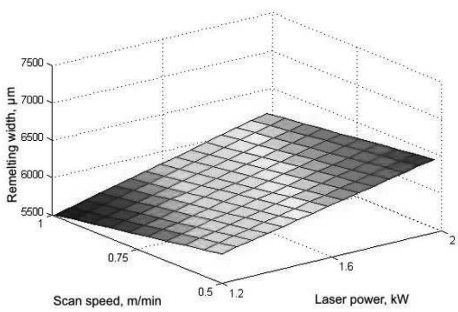



Fig. 6. Graph of the regression function showing dependence of remelting width from laser power and scan rate for the EN-MCMgAl3Zn1

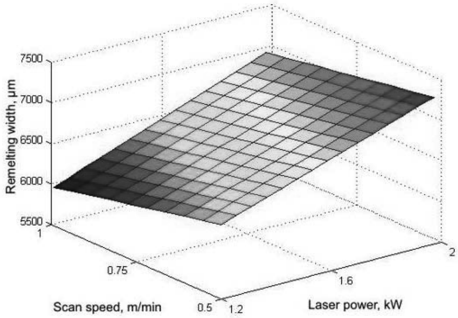
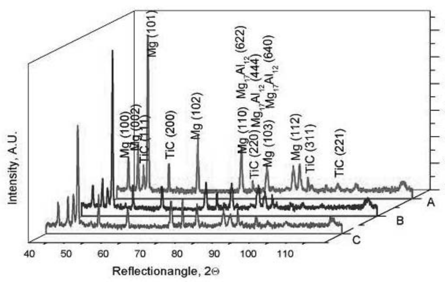



Fig. 7. Graph of the regression function showing dependence of remelting width from laser power and scan rate for the EN-MCMgAl12Zn1

a)




b)

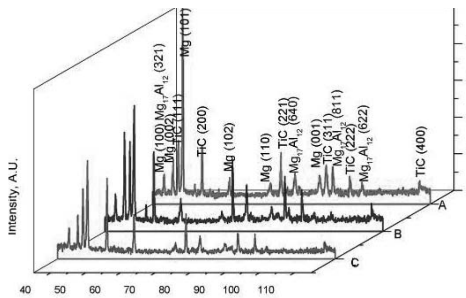



Fig. 8. X ray diffraction pattern of the: a) ENMCMgAl9Zn1, b) ENMCMgAl12Zn1 cast magnesium alloy after laser alloying with TiC: powder feed rate: 7±1 [g/min], scan rate: 0.75 [m/min], laser power: A-1.2[kW],B-1.6 [kW], C-2.0[kW]

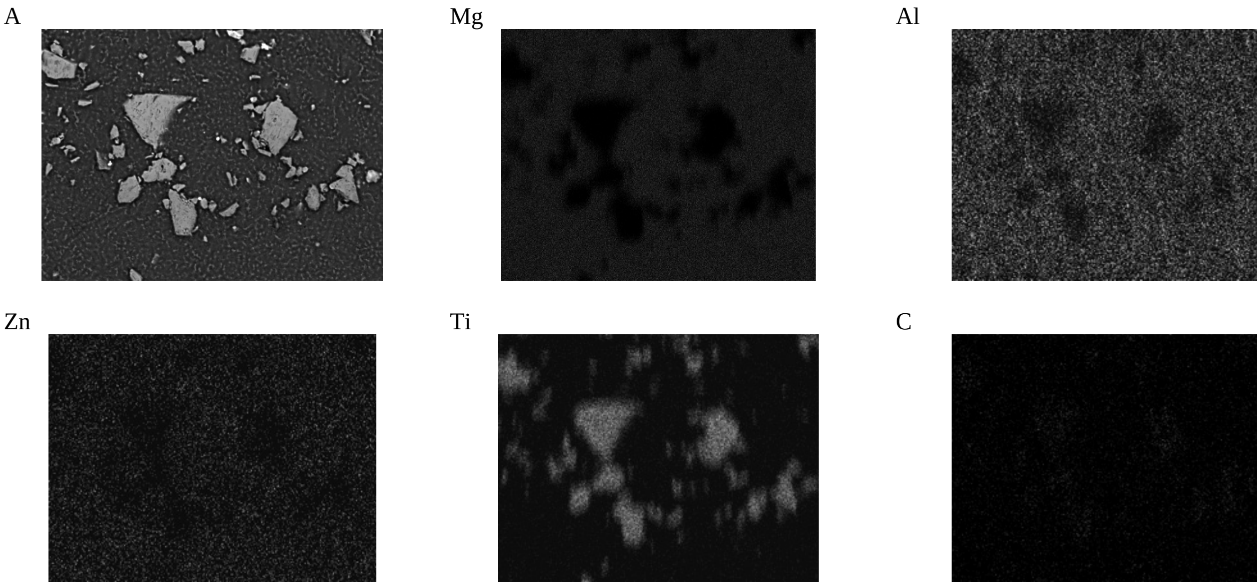



Fig. 9. SEM micrograph of the MCMgAl9Zn1 after laser alloying: image obtained using the secondary electrons (A) and X-ray mapping

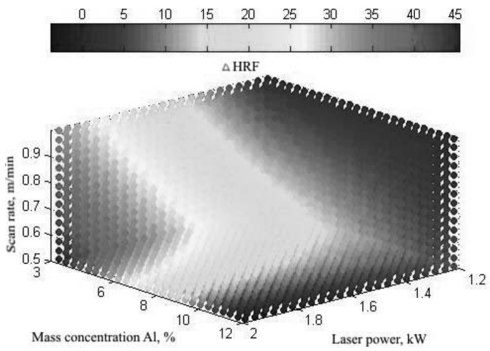



Fig. 10. Graph of the regression function showing dependence of hardness increment to aluminium concentration (wt.%), laser power and scan rate

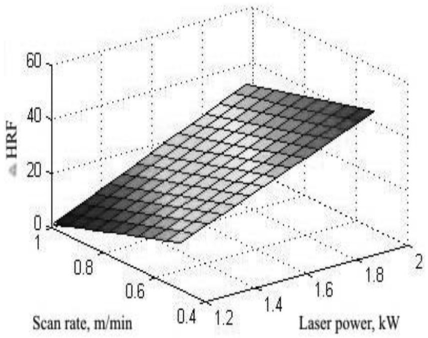



Fig. 11. Graph of the regression function showing dependence of hardness increment from laser power and scan rate for the EN-MCMgAl3Zn1

Fig. 10 shows the graph of the regression function showing interdependence of increment of hardness and aluminium mass concentration, laser power and scan rate. The biggest increment hardness of the modified zone was observed for the MCMgAl3Zn1 and MCMgAl6Zn1 alloys. For the MCMgAl3Zn1 alloy the hardness increases 2-3 times (the avarage hardness this alloy after heat treatment – 30.65 HRF, the avarage hardness after alloying laser with hard TiC particles – 86.86 HRF under the following processing condition: laser power of 2.0 kW, scan rate of 0.5 m/min). Hardness increasity of almost 2 times for MCMgAl6Zn1 was observed (hardness after heat treatment – 53.97 HRF, after alloying laser – 93.42 HRF). About 10-15% hardness increase for MCMgAl9Zn1 alloy after alloying laser with TiC particles was observed. Hovewer, for MCMgAl12Zn1 alloy after laser treatment the hardness increases insignificantly or decrease slightly as compared to that of as-received Mg alloy. Moreover, the hardness of the particles reinforced layer was found to vary with laser parameters.

Fig. 11 and 12 show graph of the regression function showing dependence increment hardness from laser power and scan rate for the MCMgAl3Zn1 and MCMgAl9Zn1.

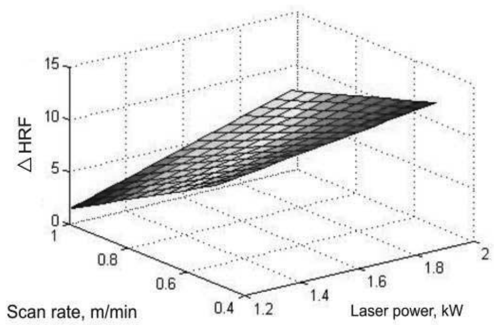



Fig. 12. Graph of the regression function showing dependence of hardness increment from laser power and scan rate for the EN-MCMgAl9Zn1

## 4. Conclusions

High Power Diode Laser has been used for surface modification of Mg-Al-Zn magnesium alloy. The cross section of the alloyed surface layer consists of the remelted zone, heat affect zone and magnesium alloy substrate. The heat affect zone for the magnesium alloy with aluminum concentration 3 and 6 wt. % is negligible in opposition to magnesium alloys with 9 and 12 wt. % of aluminum. The results of microstructure examination of the investigated Mg-Al-Zn alloys reinforced with TiC particles confirm that the surface layer is free of cracks and porosity, with good metallurgical bond between the alloyed zone and the substrate.

X-ray mapping indicate a significant segregation of aluminium and zinc in magnesium matrix. The X-ray phase analysis of the investigated magnesium alloys after laser treatment with TiC particles indicates the presence of Mg, $Mg_{17}Al_{12}$ and TiC.

The average hardness of the alloyed zone was significantly improved as compared to Mg-Al-Zn matrix.

## Acknowledgements

This research work is financed in part within the framework of science financial resources in the period 2007-2008 as a research and development project R15 0702 headed by Prof. L.A. Dobrzański.

## References

[1] E.F. Horst, B.L. Mordike, Magnesium Technology, Metallurgy, Design Data, Application, Springer-Verlag, Berlin Heidelberg, 2006.
[2] G. Abbas, L. Li, U. Ghazanfar, Z. Liu, Effect of high power diode laser surface melting on wear resistance of magnesium alloys, Wear 260 (2006) 175-180.
[3] M. Bonek, L.A. Dobrzański, Functional properties of laser modified surface of tool steel, Journal of Achievements in Mechanical and Materials Engineering 17 (2006) 313-316
[4] L.A. Dobrzański, J. Domagała, T. Tański, A. Klimpel, D. Janicki, Laser surface treatment of magnesium alloy with WC powder, Archives of Materials Science and Engineering, 30/2 (2008) 113-116.
[5] L.A. Dobrzański, J. Domagała, T. Tański, A. Klimpel, D. Janicki, Laser surface treatment of magnesium alloy with WC and TiC powders using HPDL, Journal of Achievements in Materials and Manufacturing Engineering 28/2 (2008) 179-186.
[6] L.A. Dobrzański, T. Tański, L. Čížek, J. Domagała, Mechanical properties and wear resistance of magnesium casting alloys, Journal of Achievements in Materials and Manufacturing Engineering 31 (2008) 83-90.
[7] L.A. Dobrzański, T. Tański, L. Čížek, Heat treatment impact on the structure of die-cast magnesium alloys, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 431-434.
[8] L.A Dobrzański, K. Labisz, M. Piec, A. Klimpel, Modelling of surface layer of the 31CrMoV12-18 tool steel using HPDL laser for alloying with TiC powder, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 27-34.
[9] L.A. Dobrzański, K. Labisz, M. Piec, A. Klimpel, Mechanical properties of the surface layer of the laser alloyed 32CrMoV12-28 steel, Archives of Materials Science and Engineering 29/1 (2008) 57-60.
[10] L.A. Dobrzański, A. Polok, E. Jonda, Structure and properties of surface layers obtained by alloying of the hot work tool steels, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 329-332.
[11] D. Dube, M. Fiset, A. Couture, I. Nakatsugawa, Characterization and performance of laser melted AZ91D and AM60B, Materials Science and Engineering A299 (2001) 38-45.
[12] J. Dutta Majumdar, R. Galun, B.L. Mordike, I. Manna, Effect of laser surface melting on corrosion and wear resistance of a commercial magnesium alloy, Materials Science and Engineering A361 (2003) 119-129.
[13] J. Dutta Majumdar, B. Ramesh Chandra, R. Galun, B.L. Mordike, I. Manna, Laser composite surfacing of a magnesium alloy with silicon carbide, Composites Science and Technology 63 (2003) 771-778.
[14] J.E. Gray, B. Luan, Protective coatings on magnesium and its alloys – critical review, Journal of Alloys and Compounds 336 (2002) 88-113.
[15] H. Hiraga, T. Inoue, Y. Kojima, S. Kamado, S. Watanabe, Surface modification by dispersion of hard particles on magnesium alloy with laser, Materials Science Forum 253 (2000) 350-351.
[16] S. Ignat, P. Sallamand, D. Grevey, M. Lambertin, Magnesium alloys laser (Nd:YAG) cladding and alloying with side injection of aluminium powder, Applied Surface Science 225 (2004) 124-134.
[17] P. Kołodziejczak, W. Kalita, A. Kolasa, Modification of surface layer of Mg alloy by laser cladding, Advances in Proceedings of the International Conference. Production Engineering, APE'2007, 459-468.
[18] A.H. Wang, H.B. Xia, W.Y. Wang, Z.K. Bai, X.C. Zhu, C.S. Xie, YAG laser cladding of homogenous coating onto magnesium alloy, Materials Letters 60 (2006) 850-853.
[19] Y.Gao, C. Wang, M. Yao, H. Liu, The resistance to wear and corrosion of laser-cladding $Al_2O_3$ ceramic coating on Mg alloy, Applied Surface Science 253 (2007) 5306-5311.