Journal
of Achievements in Materials
and Manufacturing Engineering
VOLUME 32
ISSUE 1
January
2009

Microstructure analysis of the modified casting magnesium alloys after heat and laser treatment

L.A. Dobrzański [a],*, T. Tański [a], J. Domagała [a], M. Bonek [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 Departament, Silesian University of Technology,
ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

Received 09.09.2008; published in revised form 01.01.2009

Materials

ABSTRACT

Purpose: In this paper there is presented the structure of the modeling cast magnesium alloy EN-MCMgAl6Zn1 as cast state, after heat treatment and laser treatment.

Design/methodology/approach: The presented results concern X-ray qualitative and quantitative microanalysis as well as qualitative and quantitative X-ray diffraction method, light and scanning microscope. A casting cycle of alloys has been carried out in an induction crucible furnace using a protective salt bath Flux 12 equipped with two ceramic filters at the melting temperature of 750±10ºC, suitable for the manufactured material. The heat treatment involve the solution heat treatment (warming material in temperature 375° C by 3 hour, it elevation temperature to 430° C, warming by 10 hours) and cooling in different cooling mediums as well water, air and furnace. Laser surface melting was carried out with a high power diode laser (HDPL).

Findings: The results of the metallographic examinations confirm the fact that the magnesium cast alloy MCMgAl6Zn1 is characterized by a microstructure of the α solid solution constituting the alloy matrix as well as the ß – $Mg_{17}Al_{12}$ discontinuous intermetallic phase in the forms of plates located mostly at grain boundaries. The results indicate that laser-melted layer contains the fine dendrites. The substrate grains are significantly coarses than in the laser surface remelting zone.

Research limitations/implications: According to the alloys characteristic, the applied cooling rate and alloy additions seems to be a good compromise for mechanical properties and microstructures, nevertheless further tests should be carried out in order to examine different cooling rates and parameters of solution treatment process and aging process. This investigation presents different speed rates feed by one process laser power and in this research was used one powder with the particle size over 5μm.

Practical implications: This work helps to use the new developed laser treatment technique for alloying and remelting of magnesium cast alloys for new application.

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

Keywords: Magnesium alloys; Heat treatment; Laser treatment; Melting; Structure; Precipitation

1. Introduction

A contemporary technological development makes it necessary to look for new constructional solutions that aim at the improvement of the effectiveness and quality of a product, at theminimization of dimension and mass as well as the increasing of reliability and dimension stability in the operation conditions. For a dozen or so years one can observe a rising interest in the non-ferrous metals alloys including magnesium alloys. The dynamic industrial development puts some higher and higher demands to the present elements and constructions. These demands belong production and research newer and newer materials for materials engineering materials with relation to predictable work conditions and arise needs [1, 3, 9, 10, 14]. Magnesium alloys gets a huge importance with present demands for light and reliable construction.

Magnesium alloys have low density and other benefits such as: a good vibration damping and the best from among all construction materials: high dimension stability, small casting shrinkage, connection of low density and huge strength with reference to small mass, possibility to have application in machines and with ease to put recycling process, which makes possibility to logging derivative alloys a very similar quality to original material [1, 8, 10, 14].

A desire to create as light vehicle constructions as possible and connected with it low fuel consumption have made it possible to make use of magnesium alloys as a constructional material in car wheels, engine pistons, gear box and clutch housings, skeletons of sunroofs, framing of doors, pedals, suction channels, manifolds, housings of propeller shafts, differential gears, brackets, radiators and others. A number of companies as well as the use of magnesium and its alloys are still growing. Products made of magnesium and its alloys are still relatively expensive, however customers get high quality products, advanced both in technology and functionality. Generally they are applied in motor industry and machine building, but they find application in a helicopter production, planes, disc scanners, a mobile telephony, computers, bicycle elements, household and office equipment, radio engineering and an air - navigation, in chemical, power, textile and nuclear industrial [9-14].

The rising tendencies of magnesium alloy production, show increased need of their application in world industry and what follows the magnesium alloys become one of the most often apply construction material our century .

One of the method to improve surface magnesium alloys is laser surface modification process. Laser surface melting can create metastable solid solutions at metal surfaces. In this process only surface region is modified. The improved modified surface is associated with refinement of the alloy microstructure. It is due to the rapid cooling of the melted layer. Laser surface melting improved the corrosion resistance magnesium alloys due to the refinement of grain boundary precipitates [1, 5, 6].

The goal of this paper is presentation of the investigation results of the MCMgAl6Zn1 casting magnesium alloy in its as-cast state, after heat treatment and after laser treatment.

2. Experimental procedure

The chemical composition of the investigated materials is given in Table 1. The investigations have been carried out on test pieces of MCMgAl6Zn1 magnesium alloys in as-cast and after heat treatment states (Table 2) and after laser treatment.

Table 1.
Chemical composition of investigation alloy, %

Al	Zn	Mn	Si	Fe	Mg	Rest
5.92	0.49	0.15	0.037	0.007	93.33	0.0613

Table 2.
Parameters of heat treatment of investigation alloy

Sing the state of heat treatment	Solution treatment			Aging treatment		
	Tempe rature [°]	Time [h]	Cooling	Tempe-rature [°]	Time [h]	Cooling
0	As-cast					
1	430	10	air	-	-	-
2	430	10	water	-	-	-
3	430	10	furnace	-	-	-
4	430	10	water	190	15	air

The laser melting was performed by high power laser diode HPDL Rofin DL 020 with a laser power 2.2 kW and process rate of 1.0 m/min, the technical specification is given in Table 3. The surface was under an argon shielding gas.

Metallographic examinations have been made on magnesium cast alloy specimens mounted in thermohardening resins.

Table 3.
HPDL parameters

Parameter	Value
Laser wave length, nm	940±5
Peak power, W	2300
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

In order to disclose grain boundaries and the structure and to distinguish precisely the particular precipitaions in magnesium alloys as an etching reagent a 5% molybdenic acid 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 Opton DSM-940 using a secondary electron detection.

The X-ray qualitative microanalysis and the analysis of a surface distribution of cast elements in the examined magnesium cast alloy specimens in as-cast and after heat and laser treatment have been made on transverse microsections on the Opton DSM-940 scanning microscope with the Oxford EDS LINK ISIS dispersive radiation spectrometer at the accelerating voltage of 15 kV and on the JEOL JCXA 733 x-ray microanalizer.

Phase composition and crystallographic structure were determined by the X-ray diffraction method using the XPert device with a copper lamp, with 40 kV voltage. The measurement was performed by angle range of 2 ϴ: 20º - 140º.

3. Discussion of experimental results

As a result of metallographic investigations made on the light and scanning microscopes it has been confirmed that the magnesium cast alloys MCMgAl6Zn1 in the cast state are characterized by a microstructure of the α solid solution constituting the alloy matrix as well as the β – $Mg_{17}Al_{12}$ discontinuous intermetallic phase in the forms of plates located mostly at grain boundaries. Moreover, in the vicinity of the β intermetallic phase precipitations the presence of the needle eutectics (α +β) has been revealed (Figs. 1a and 2).

There have appeared, after the process of solutioning with cooling in water and in the air, trace quantities of the β ($Mg_{17}Al_{12}$) phase and single precipitations of a Mg_2Si phase in the structure of the alloy. There have not been noticed any locations of eutectic occurrences in the structure (Fig. 1b). After the cooling in the furnace the structure of the α solid solution with many precipitations of the secondary phase β has been revealed (locations resembling eutectics). The precipitations of the β ($Mg_{17}Al_{12}$) phase, located at grain boundaries and the Mg_2Si phase located mostly at the β phase boundary have also been observed. The structure of this alloy is similar to the structure of the as-cast alloy (Fig. 1c). The applied ageing process after the solution heat treatment with cooling in the air has caused the release of the β phase at grain boundaries as well as in the form of pseudo eutectic locations. There have been revealed, in the structure of the material, the parallel twinned crystals (Fig. 1d).

Figs. 3a and 4a show the structure of the cross-section of EN MCMgAl6Zn alloy after laser melting. After laser treatment, the alloys were resolidified as fine grains of α-matrix with adjoining β-containing material. It is due to high cooling rates. The microstructure of the melted zone consist of fine columnar grains growing equiaxial dendrites (Figs. 3b, 4d). The cooling rate has influence the size of dendrites, which was increased from surface to the substrate melt interface. The substrate grains are significantly coarser than in the laser surface melted zone. The interface between fine and coarse grain was showed on the Figs. 4b and 4c. The precipitates are redistributed along the boundaries of the laser surface melted zone.

As a result of the surface decomposition of elements and the x-ray quantitative micro analysis made using the EDS energy dispersive radiation spectrometer, the presence of the main alloy additions Mg, Al, Mn, Zn and also Fe and Si included in the magnesium cast alloys in as-cast and after the heat treatment has been confirmed.

The chemical analysis of the surface element decomposition and the qualitative micro analysis made on the transverse microsections of the magnesium alloys using the EDS system have also confirmed the evident concentrations of magnesium, silicon, aluminium, manganese and zinc (Fig. 5).

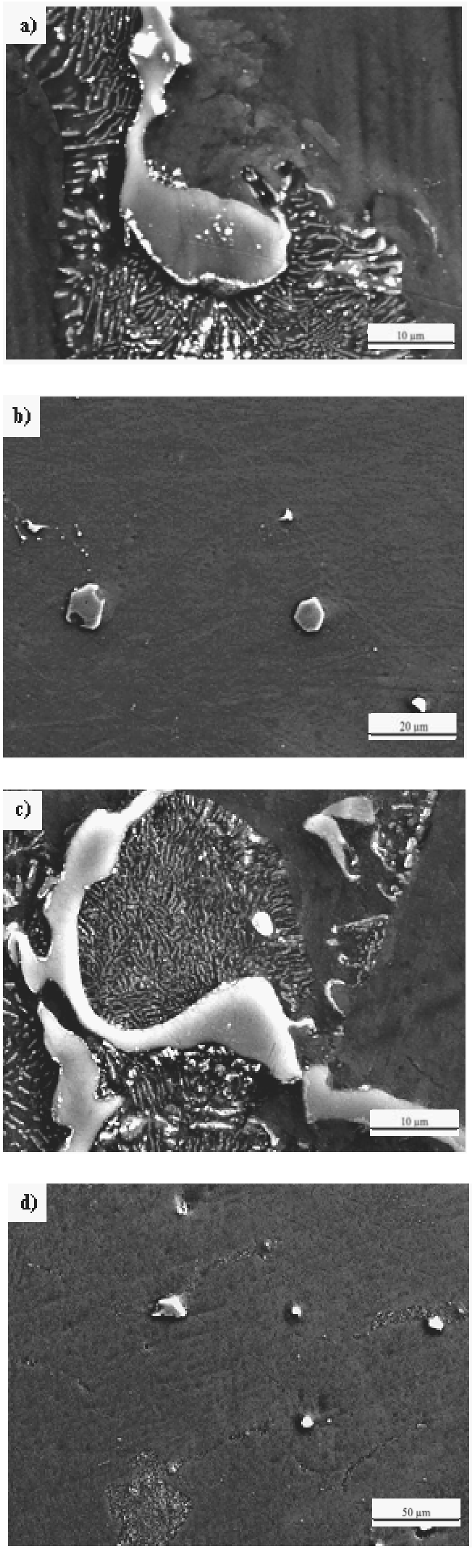

Fig. 1. Microstructure alloy MCMgAl6Zn1: a) without heat treatment, b) after cooling in the water, c) after cooling in the furnace, d) after aging treatment

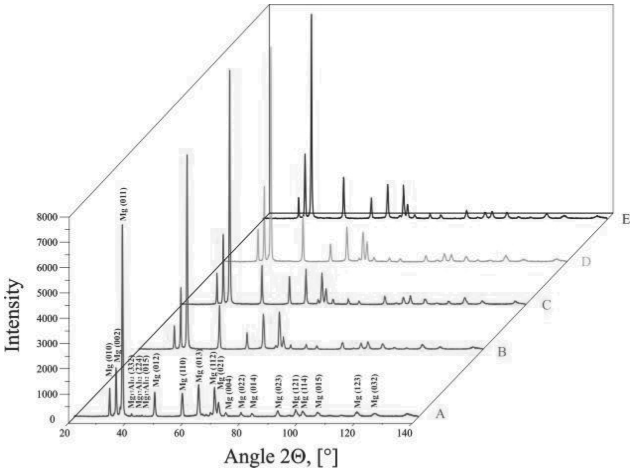

Fig. 2. XRD patterns of the magnesium cast alloy MCMgAl6Zn1: A–without heat treatment, B–after solution treatment with cooling in water, C–after solution treatment with cooling in the air, D–after solution treatment cooled with the furnace, E–after aging treatment

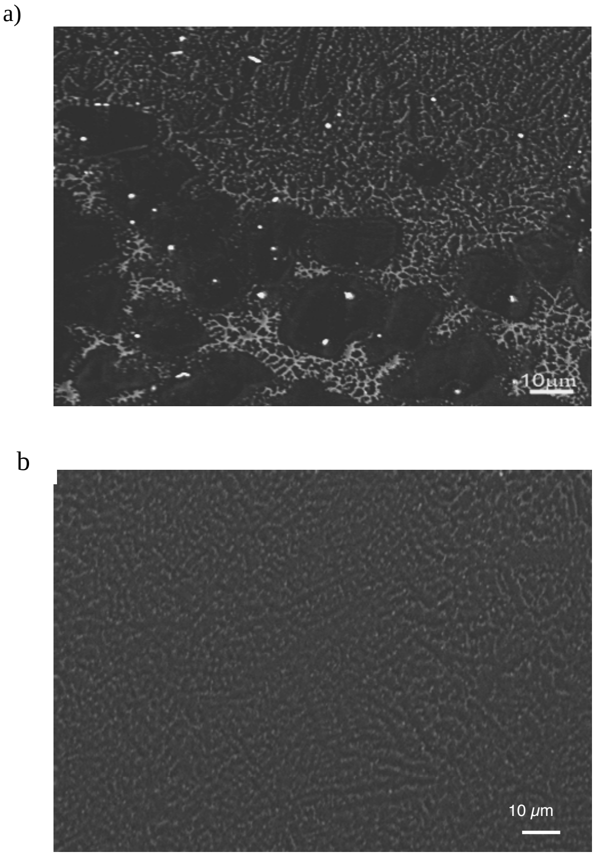

Fig. 3. Scanning electron micrograph of the remelted surface layer a) the cross-section of laser surface melted, b) fine dendrite microstructure of laser treated Mg alloy sample

This suggests the occurrence of precipitations containing Mg and Si with angular contours in the alloy structure as well as phases with high Mn and Al concentrations that are irregular with a non plain surface, often occurring in the forms of blocks or needles. A prevailing participation of magnesium and aluminium and a slight concentration of Zn has been ascertained in the alloy matrix as well as in the location of eutectics and big precipitations that arouse at phase boundaries identified as $Mg_{17}Al_{12}$ (Fig. 5).

Fig. 6 show the surface microstructure of the laser remelted zone and the distribution of Mg, Al, Zn by X-ray mapping. The grain boundaries are enriched with Al, Zn and Mn. There is more Al in the laser melted layer than in the substrate. This was demonstrated by Dube et al. who reported that relatively enrichment in aluminum was likely caused by the preferential evaporation of magnesium from the melt pool during laser melting'. Zinc loss occurs in laser melted layer, it is due to vapor pressure.

4. Summary

The results of the metallographic examinations made on the light and scanning microscopes confirm the fact that the magnesium cast alloy MCMgAl6Zn1 is characterized by a microstructure of the α solid solution constituting the alloy matrix as well as the ß – $Mg1_7Al_{12}$ discontinuous intermetallic phase in the forms of plates located mostly at grain boundaries. Moreover, in the vicinity of the ß intermetallic phase precipitations the presence of the needle eutectics (α + ß) has been revealed. The applied ageing process after the solution heat treatment has caused the release of the ß phase at grain boundaries as well as in the form of pseudo eutectic locations. In the structure of the material, the parallel twinned crystals extending along the whole grain have been revealed. The laser melted layers show a dendritic microstructure, which is characterized by fine columnar grains oriented to the solid-liquid interface. The substrate grains are significantly coarses than in the laser surface remelting zone.

The results of the analysis of the EDS chemical composition confirm the presence of the main alloy additions Mg, Al, Mn, Zn and also Fe and Si included in the magnesium cast alloys in as-cast and after the heat treatment. The chemical analysis of the surface element decomposition and the quantitative micro analysis made on the transverse microsections have also confirmed the evident concentrations of magnesium, silicon, aluminium, manganese and iron what suggests the occurrence of precipitations containing Mg and Si with angular contours, as well as phases with high Mn and Al concentrations that are irregular, with a non plain surface, often occurring in the forms of blocks or needles. The laser melted layer is enriched in Al i Mn. The molten laser surface and the substrate have precipitates of compound of Mg, Al, Zn.

Acknowledgements

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

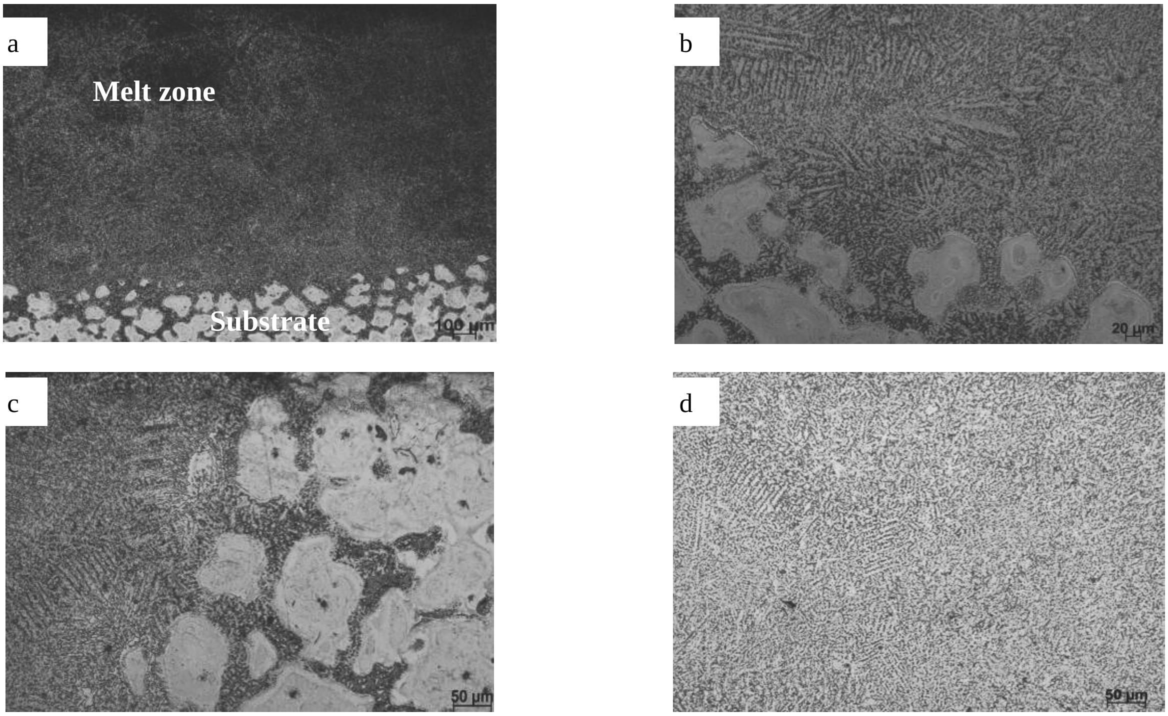

Fig. 4. Optical micrograph of a) the cross-section of remelted laser surface, b, c) the substrate-melt interface of Mg alloy, d) dendrite microstructure

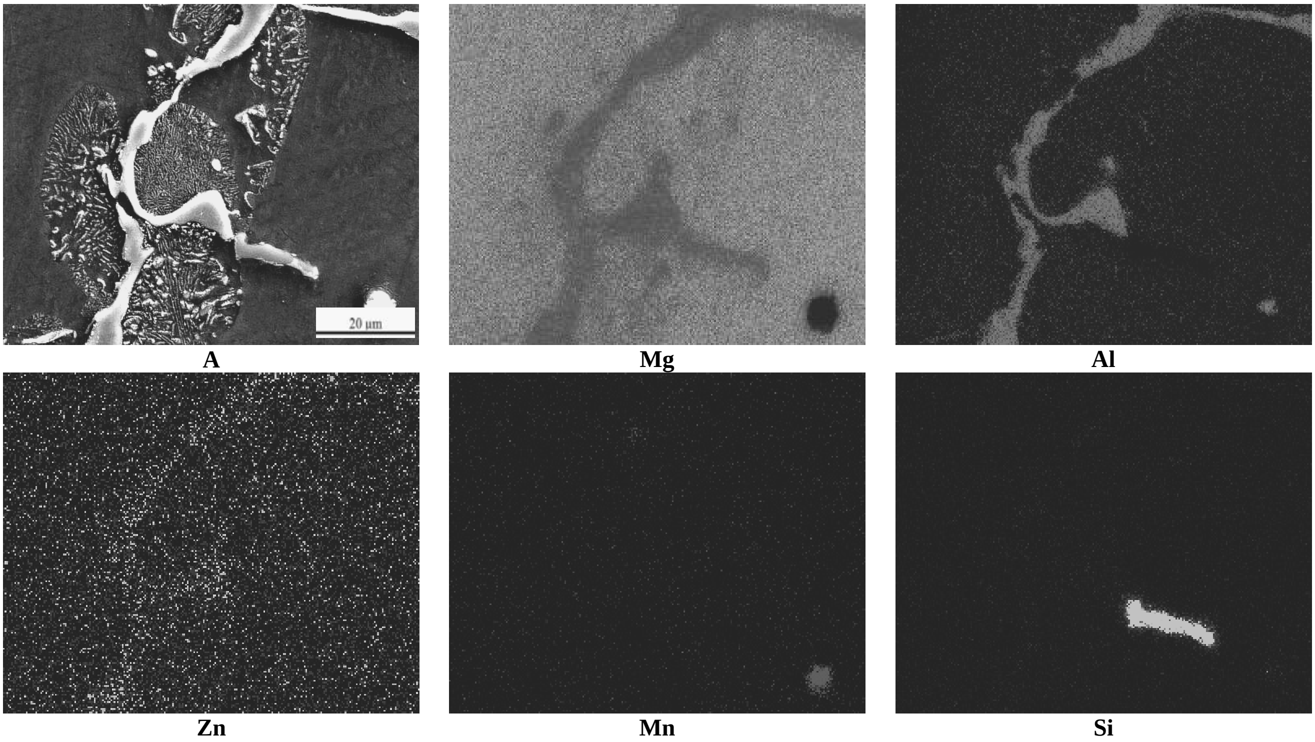

Fig. 5. X-ray mapping of the MCMgAl6Zn1 alloy structure after cooling with the furnace: secondary electrons image (A) and maps of elements' distribution

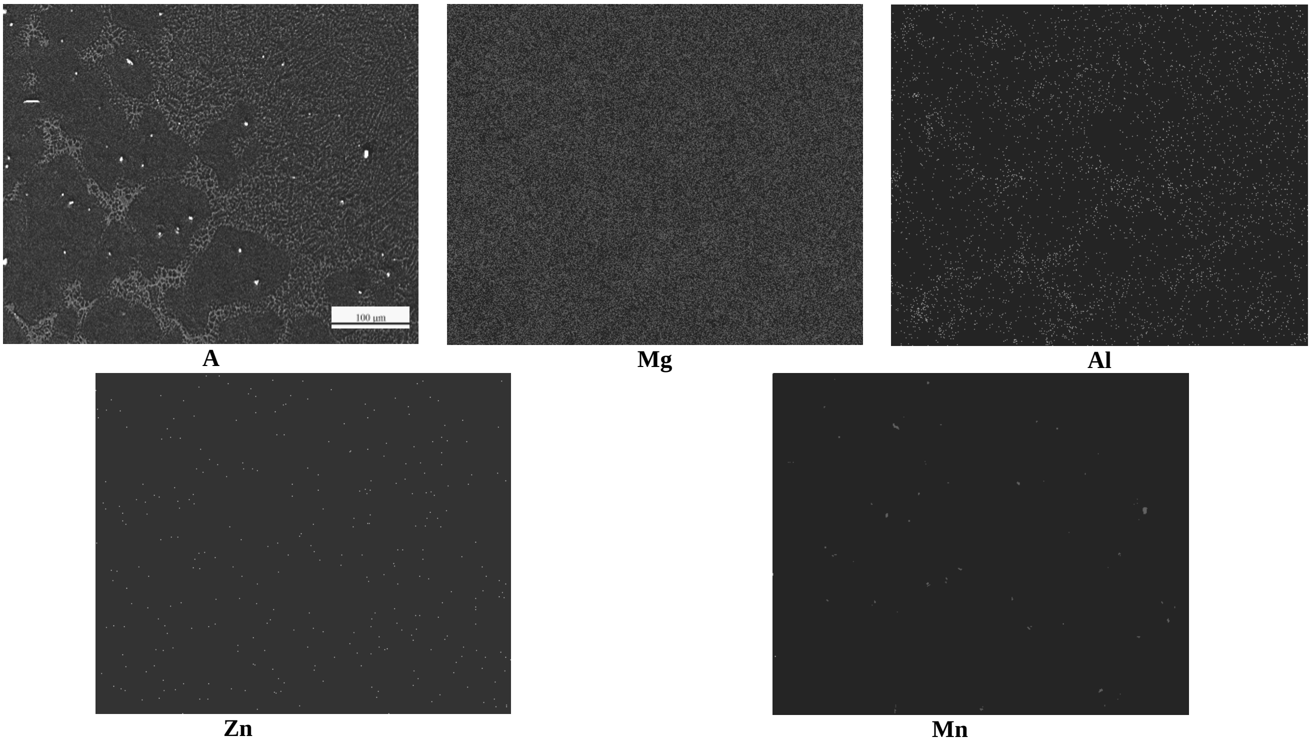

Fig. 6. X-ray mapping of the surface microstructure of (A) laser surface melted magnesium alloy and maps of elements' distribution

References

[1] 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.

[2] H. Baker, Physical properties of magnesium and magnesium alloys, The Dow Chemical Company, Midland, 1997.

[3] L.A. Dobrzański, T. Tański, L. Čížek, Heat treatment impact on the structure of die-cast magnesium alloys, Journal of Achievements in Mechanical and Materials Engineering 20 (2007) 431-434.

[4] L.A. Dobrzański, M. Bonek, E. Hajduczek, A. Klimpel, Development of surface layers alloyed by HPDL laser on hot-work tool steel, Materials Forum 29 (2005) 184-189.

[5] D. Dube, M. Fiset, A. Countur, I. Nakatsugawa, Characterization and performance of laser melted AZ91D and AM60B, Materials Science and Engineering A299 (2001) 39-45.

[6] 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.

[7] A. Fajkiel, P. Dudek, G. Sęk-Sas, Foundry engineering XXI c. Directions of metallurgy development and light alloys casting, Publishers Institute of Foundry Engineering, Cracow, 2002.

[8] K.U. Kainer, Magnesium - Alloys and Technology, Wiley-VH, Weinheim, 2003.

[9] S. Guldberg, N. Ryum, Microstructure and crystallographic orientation relationship in directionally solidified Mg–$Mg_{17}Al_{12}$-eutectic, Materials Science and Engineering A289 (2000) 143-150.

[10] A. Kiełbus, T. Rzychoń, R. Cibis, Microstructure of AM50 die casting magnesium alloy, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 135-138.

[11] N.V. Ravi Kumar, J.J. Blandin, C. Desrayaud, F. Montheillet, M. Suéry, Grain refinement in AZ91 magnesium alloy during thermomechanical processing, Materials and Engineering A359 (2003) 150-157.

[12] T. Tański, L.A. Dobrzański, L. Čížek, Influence of heat treatment on structure and properties of the cast magnesium alloys, Journal of Advanced Materials Research 15-17 (2007) 491-496.

[13] R.M. Wang, A. Eliezer, E. Gutman, Microstructures and dislocations in the stressed AZ91D magnesium alloys, Materials Science and Engineering A344 (2002) 279-287.

[14] M. Yong, A Clegg, Process optimization for a squeeze cast magnesium alloy, Journal of Materials Processing Technology 145 (2004) 134-141.