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Laser surface treatment of magnesium alloys with aluminium oxide powder

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ABSTRACT

Purpose: The aim of this paper was to improve the magnesium cast alloys surface layer by laser surface treatment and to determine the laser treatment parameters.
Design/methodology/approach: The laser treatment of magnesium alloys with alloying Al_2O_3 powder of the particle about 80μm was carried out using a high power diode laser (HPDL). The resulting microstructure in the modified surface layer was examined using scanning electron microscopy. Phase composition was determined by the X-ray diffraction method using the XPert device. The measurements of microhardness of the modified surface layer were also studied.
Findings: The alloyed region has a fine microstructure with hard carbide particles. Microhardness of laser surface alloyed layer was significantly improved as compared to an alloy without laser treatment.
Research limitations/implications: The investigations were conducted for cast magnesium alloys MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 and Al_2O_3 powder of the particle size about 80 μm. One has used laser power in the range from 1.2 to 2.0 kW.
Practical implications: The results obtained in this investigation were promising comparing with the 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 value of this paper is to define the influence of laser treatment parameters on quality, microstructure and microhardness of magnesium cast alloys surface layer.
Keywords: Surface treatment; Magnesium alloys; Laser treatment; Aluminium oxide

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1. Introduction

Magnesium alloys have different interesting specific characteristics including the best strength-to-weight ratio among all commercial alloys. These materials classes have both high thermal conductivity and high damping capacity. Moreover, magnesium alloys have low density and are completely recyclable. As the lightest structural material available so far, magnesium alloys have the potential to replace steel and aluminium in many structural applications. Magnesium is an attractive material to use, primarily because of its lightweight: 36% lighter than Al and 785 lighter than iron. Thanks to lots of required properties like low density, good vibration damping, high dimension stability, small casting shrinkage, combination of low density and huge strength with reference to low mass possibility, magnesium becomes widely applied engineering material. Light metals find application in a lot of manufacturing branches. [1-5]

Machine elements made of cast magnesium alloys find their applications in aerospace, automotive and engineering industry. Magnesium alloys are also used in many other engineering applications where being lightweight is a significant advantage. Magnesium-zirconium alloys tend to be used in relatively low volume applications where they are processed by sand or investment casting, or wrought materials by extrusion or forging. Zirconium-free alloys, principally AZ91 but also other alloys, are used in automotive and various other high volume applications. In the aerospace they are used for aircraft engines and gearbox casings, other applications include electronics, sporting goods, office equipment, sacrificial anodes for the protection of other metals, flash photography and tools. [1-8]

The surface layers properties increase can be achieved by many technologies, i.e.: electroplating, anodizing, PVD, laser alloying or padding. Main advantages of laser treatment are i.e.: short time of process, flexibility or operation precision. Main goal of surface laser treatment is to modernize structure and properties. Wear resistance increase is to create results of chemically homogeneous, fine-crystalline surface layer without chemical changes. More advantageous properties can be achieved by alloying with hard particles of carbides, oxides or nitrides. [9-16]

Laser technologies are the most promising and effective to provide continuous development of materials processing branch as a result of forecasts concerning global economic development. One considers that economies, which make use of laser technologies on a large scale, will be competitive on the global market. [10-16]

2. Experimental procedure

The investigations were carried out on test pieces of MCMgAl12Zn1, MCMgAl9Zn, MCMgAl6Zn1, MCMgAl3Zn as-cast magnesium alloys and after heat treatment. The chemical compositions of the investigated materials are given in Table 1. The heat treatment involved the solution heat treatment (material pre-heating in temperature 375°C for 3 hours, later it was preheated in the temperature to 430°C for 10 hours) and air cooling and then ageing at temperature 190°C and again, air cooling. The process of samples preparation depends on surface polishing with the help of abrasive paper of granulation 1200.

Laser alloying was performed by high power diode laser HDPL Rofin DL020 feeding hard aluminium oxide particles under argon shielding gas. Argon was used during laser remelting to prevent oxidation of the surface layer and the substrate. Particle size of silicon carbide powder was about 80 µm (Table 2). Morphology of silicon carbide was shown on Figure 1.

Selection of process parameters was conducted in introductory investigations for the sake of: resultant compound quality, uniform distribution of alloying powder particles inside remelted zone and face geometry of surface layers after laser treatment. Surface layer faces after laser alloying with determined process parameters are regular and flat. The process parameters during the present investigation were: laser power - 1.2-2.0 kW, scan rate - 0.5-1.0 m/min and powder injection rate – 4±1 g/min. The examinations revealed that the optimum geometry of a single laser path was obtained for alloying with the feed rate of 0.5 m/min.

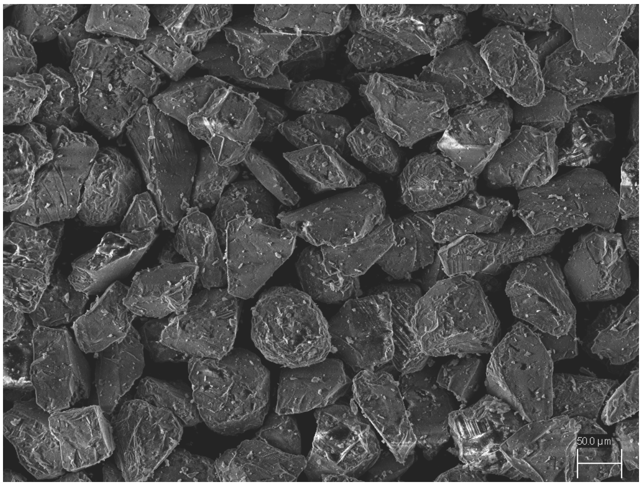


Fig. 1. Morphology of aluminium oxide (SEM)

Table 1.
Chemical composition of investigated alloys

	The mass concentration of main elements, %						
	Al	Zn	Mn	Si	Fe	Mg	Rest
MCMgAl3Zn1	12.1	0.62	0.17	0.047	0.013	86.96	0.0985
MCMgAl6Zn1	9.09	0.77	0.21	0.037	0.011	89.79	0.0915
MCMgAl9Zn1	5.92	0.49	0.15	0.037	0.007	93.33	0.0613
MCMgAl12Zn1	2.96	0.23	0.09	0.029	0.006	96.65	0.0361

Table 2.
Properties of aluminium oxide powder used for alloying process

Density, kg/m^3	3.97
Hardness, HV	2300
Melting temperature, °C	2047
Average size grain, µm	80

Laser alloying was made using the Rofin DL020 HPDL high power diode laser in the argon shield gas cover to protect the molten metal pool against oxidation with the technique of the continuous powder supply to the remelted pool area, by feeding the granulate using the TecFlo fluidization feeder equipped with the powder flow digital controller. Powder feeder was connected with the transport gas cylinder and powder feed nozzle. Gas feed rate was 8 l/min. Argon was used during laser alloying to prevent oxidation of the coating and the substrate.

The laser alloying of magnesium alloys was conducted by remelting Mg-Al-Zn surface and feeding the aluminium oxide particles performed by high power laser diode HPDL Rofin DL 020 under argon shielding gas. The laser parameters are presented in Table 3.

Table 3.
HPDL Rofin DL 020 parameters

Laser wave length, nm	808 - 940
Focal length of the laser beam, mm	82
Power density range of the laser beam in the focal plane, kW/cm^2	0.8 - 36.5
Dimensions of the laser beam focal length, mm	1,8 x 6,8

Measurements of the zones thickness in surface layers in the investigated cast materials were made on the light microscope LEICA MEF4A. The micro structural observations were made on the electron scanning microscope Zeiss SUPRA 35 using secondary electrons detection. The observations are carried out on crosswise microsection of laser alloyed surface layers, which were deposited in chemohardenable epoxy resin. Test specimens were prepared by grinding and polishing with the use of diamond suspension. The test specimens were etched in Nital in the purpose of microstructure and grain boundary disclosure.

The X-ray qualitative and quantitative microanalysis and the analysis of surface distribution of cast elements in the examined magnesium cast alloy specimens in as-cast and after heat, laser treatment are made on transverse microsections on the Zeiss SUPRA 35 scanning microscope with the EDAX Trident XM4 dispersive radiation spectrometer at the accelerating voltage of 20 kV.

Phase composition and crystallographic structure were determined by the X-ray diffraction method using the XPert device with a cobalt lamp, of 40 kV voltage. The measurement was performed in angle range of 2Θ: 30º - 120º.

Microhardness of the cross section of the laser surface melted layer was measured on Future-Tech Fully-Automatic Microhardness Testing System FM-ARS 9000 with loading time of 15 s and the testing load of 100 g.

Roughness measurements of surface layers of laser alloyed cast alloys were performed on Taylor Hobson Precision Surtronic 3+. Measuring device is characterized by measuring resolution 0.2 µm and measuring range to 150 µm. Measurements were made on distance 0.8 mm.

3. Description of experimental results

Investigated magnesium casting alloys are characterized by the different laser radiation absorption. Absorption is the highest for MCMgAl12Zn1 alloy and it is reduced with decreasing Al concentration in the alloy composition. As a result of it, thickness of alloyed zone and heat affected zone are changed (Fig. 2). Rise of alloyed zone and heat affected zone thicknesses under the influence of Al concentration in the composition of magnesium alloys increasing and laser power increasing are noticeable. During laser alloying with laser power 1.2 kW, for all magnesium alloys, process is started on surface layers, but amount of energy delivered to substrate is too low and molten pool of magnesium alloy is crystallized and breaks the alloying process. The same case is when alloying MCMgAl3Zn1 with laser power 1.6 kW. For other alloys and parameters the process proceeds stably.

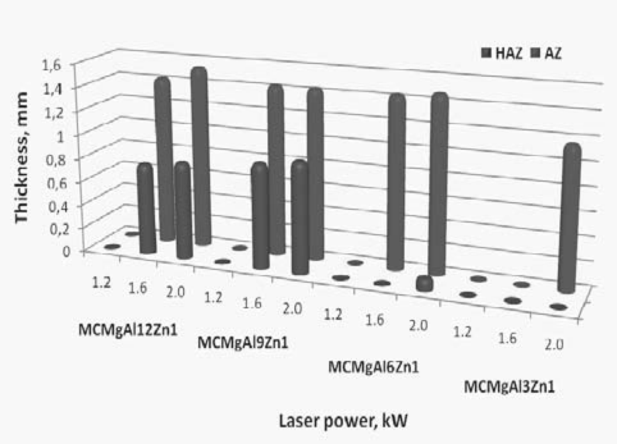


Fig. 2. Diagram of thickness changes of particular areas in the surface layers after alloying Al_2O_3 powder: HAZ - heat affected zone, AZ - alloyed zone

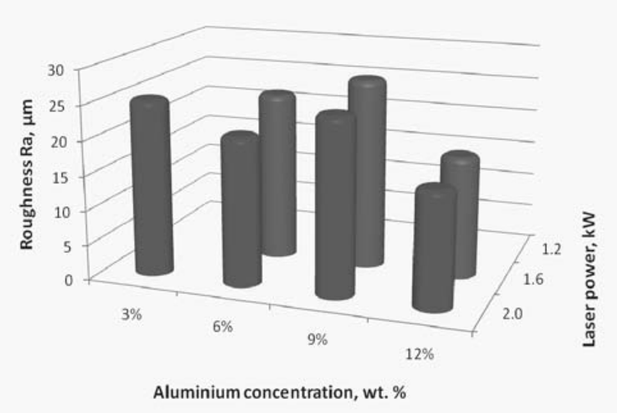


Fig. 3. Diagram of roughness dependence on laser power and aluminium concentration (wt. %) magnesium alloys after laser treatment using Al_2O_3 powder

It was found, based on roughness measurement results of the casting magnesium alloys after laser treatment with oxide aluminium, (Fig. 3) that regardless of the ceramic powder employed the roughness of surface layers obtained by alloying the Mg-Al-Zn magnesium alloys with the laser beam and the power within 1.2-2.0 kW range grows in comparison with the prepared substrate and it is within the Ra = 16.6-27.5 µm range. Minimum value of roughness was measured for MCMgAl12Zn1 alloy and laser power 2.0 kW that was equal 16.6 µm. The highest values of roughness occur for MCMgAl9Zn1 alloy and the maximum is for laser power 1.6 kW that is equal 27.5 µm.

Microstructure of the investigated magnesium cast alloys before the laser treatment consists of the solid solution α-Mg (matrix) and an intermetallic secondary phase $\beta\text{-}Mg_{17}Al_{12}$ in the forms of plates located mostly at grain boundaries.

Fig. 4 shows the SEM morphology of the magnesium alloys surfaces alloying with Al_2O_3 particles. Arrangement of alloying particles in the alloyed zone is depended on laser power. In this case ceramic particles are located mainly at the lower area of the alloyed zone for the whole applied laser power. In the result of laser alloying, microstructure of surface layers is defect-free and very refined. Microstructures of surface layers after laser alloying consist of dispersed aluminium oxide particles in the matrix of magnesium alloy (Fig. 4). Surface layer morphology consists of dendrites, which are crystallized in the direction of heat flow, elementary alloy with lamellar eutectic $Mg_{17}Al_{12}$ and Mg inside interdendritic areas.

Results of carried out qualitative X-ray diffraction analysis of investigated surfaces layers (Fig. 5) confirmed appearance of phases Mg, $Mg_{17}Al_{12}$ and Al_2O_3.

On Figs. 6 and 8 a scanning electron microscope micrograph and analysis are presented of the chemical composition changes of MCMgAl12Zn1 and MCMgAl9Zn1 alloy and aluminium oxide particle. Ceramic particles have not been undergone dissolution during laser alloying, which is confirmed by linear analysis of chemical composition changes. This case does not converge on results of qualitative X-ray diffraction analysis (Fig. 5), which have not revealed phases including such elements as oxygen different from aluminium oxide in the surface layers.

The results of chemical analysis of the surface layer element distribution (Fig. 9) and the qualitative microanalysis, which were made on the transverse microsection of MCMgAl9Zn1 alloy after laser alloying with laser power 2.0 kW using the EDS system, have confirmed the concentrations of magnesium, aluminium, zinc and oxygen.

Surface layer cross-section microhardness profiles depend on distance from the surface was presented in Fig. 10. Measurements have shown that microhardness is increasing in alloyed zone, which is a considerable result refinement of magnesium phase microstructure (100-200 $HV_{0.1}$) and very hard aluminium oxide particles appearance in this areaValues of microhardness about 700 $HV_{0.1}$ are result of measurements very close to ceramic particles. Measured microhardness of substrate was in the range from 50 to 90 $HV_{0.1}$.

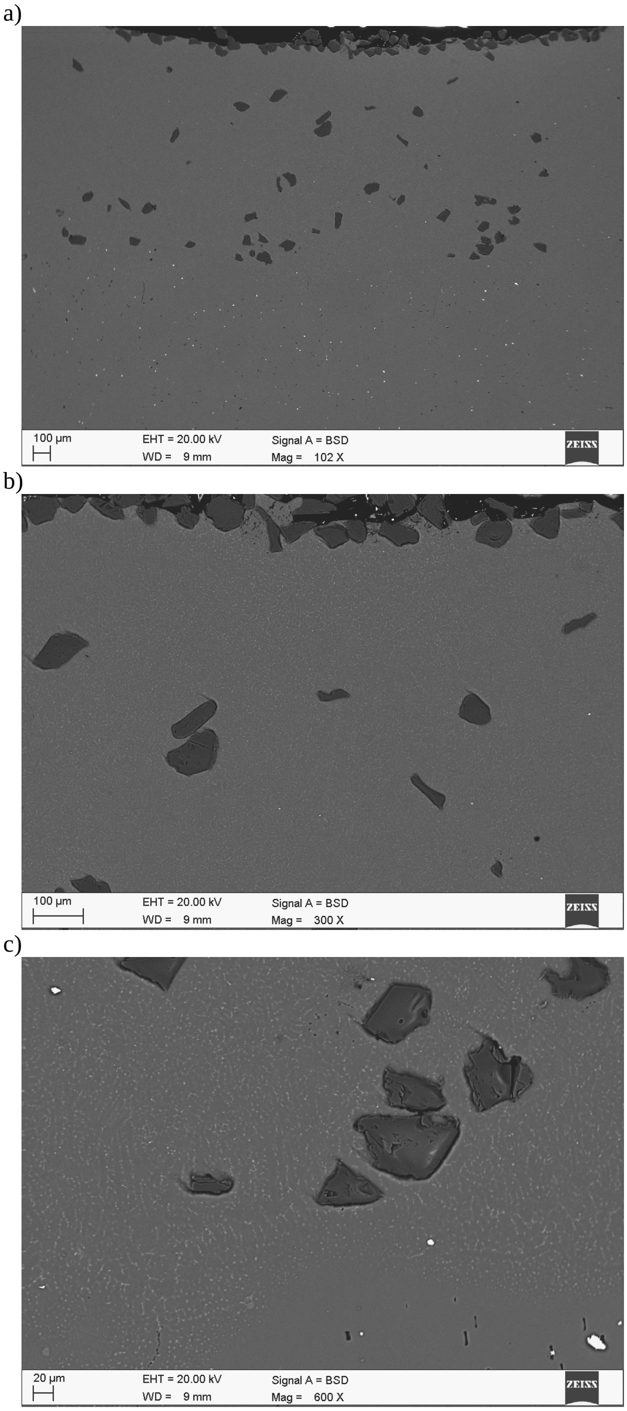


Fig. 4. Scanning electron microscope micrograph showing a laser surface modified by MCMgAl6Zn1 alloy with Al_2O_3 particles: a) cross-section of the surface layer, b) top of the surface layer, c) interface between modified zone and the substrate (laser power 1.6 kW)

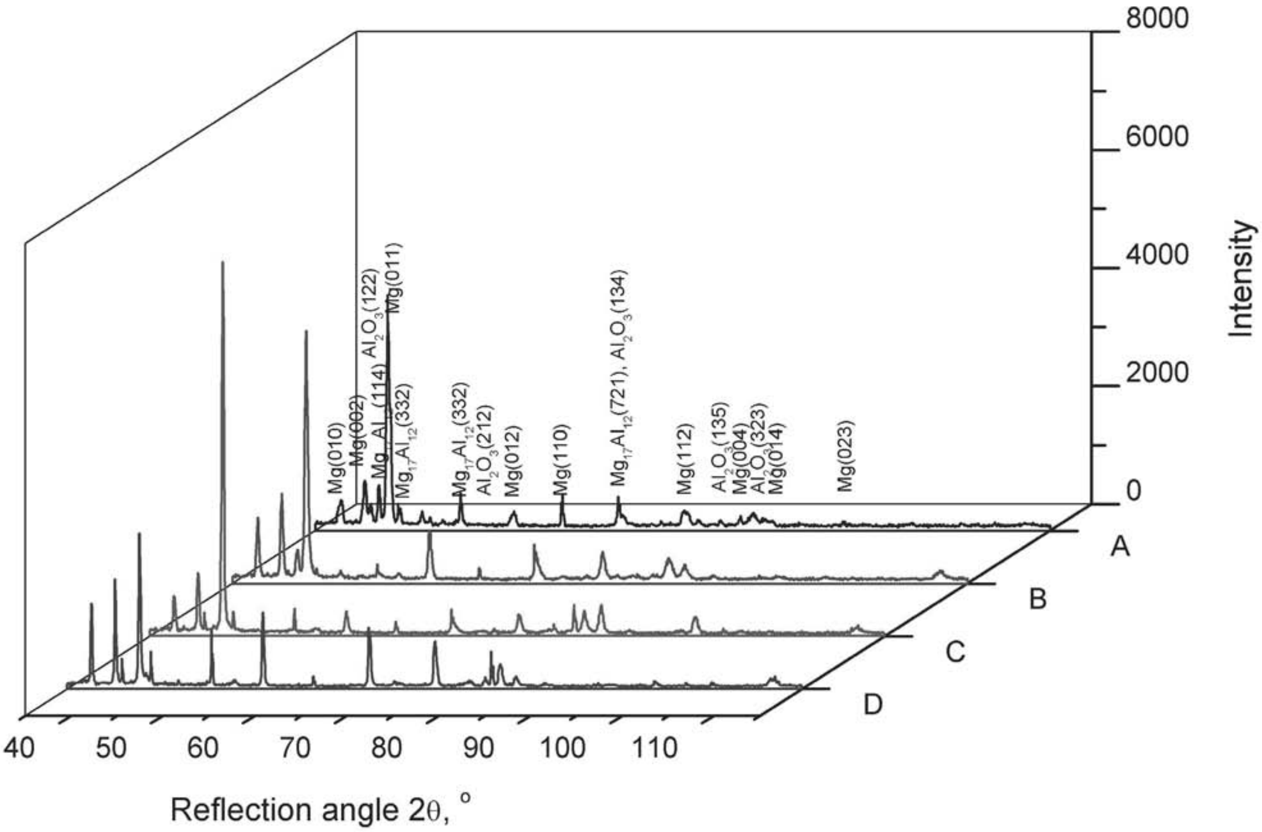


Fig. 5. X-ray diffraction pattern of the: A – MCMgAl12Zn1, B – MCMgAl9Zn1, C – MCMgAl6Zn1, D – MCMgAl3Zn1 alloys after laser alloying with aluminium oxide powder and laser power 2.0 kW

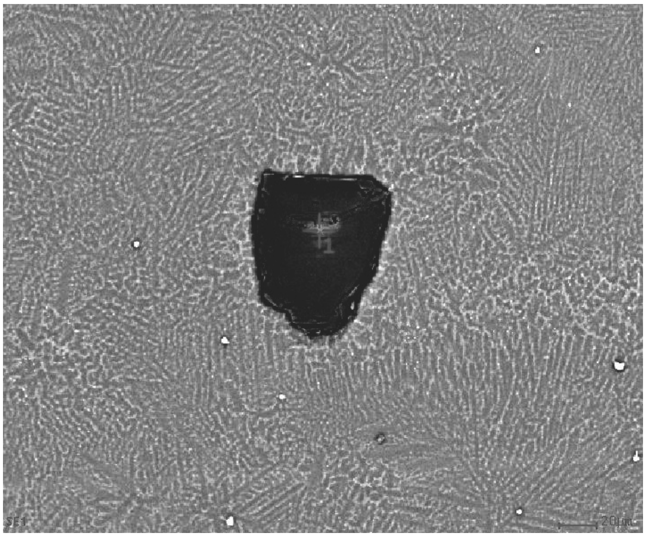


Fig. 6. The X-ray quantitative microanalysis alloyed zone of MCMgAl9Zn1 alloy, after laser alloying with laser power 2.0 kW

Table 4.
Point wise chemical composition analysis from Fig. 6

Analysis	Element	The mass concentration of main elements, %	
		weight	atomic
1	O	44.30	57.29
	Al	55.70	42.71

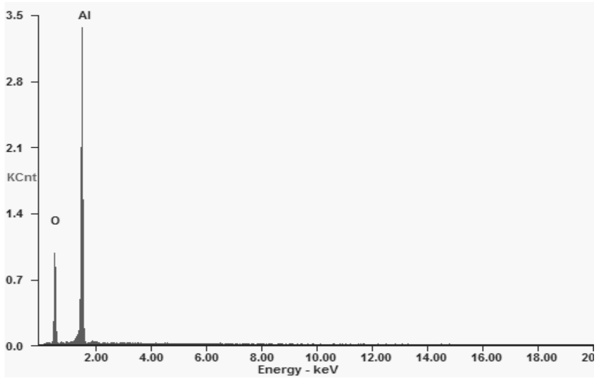


Fig. 7. Spectrum of the point wise chemical composition analysis of item 1 on Fig. 6

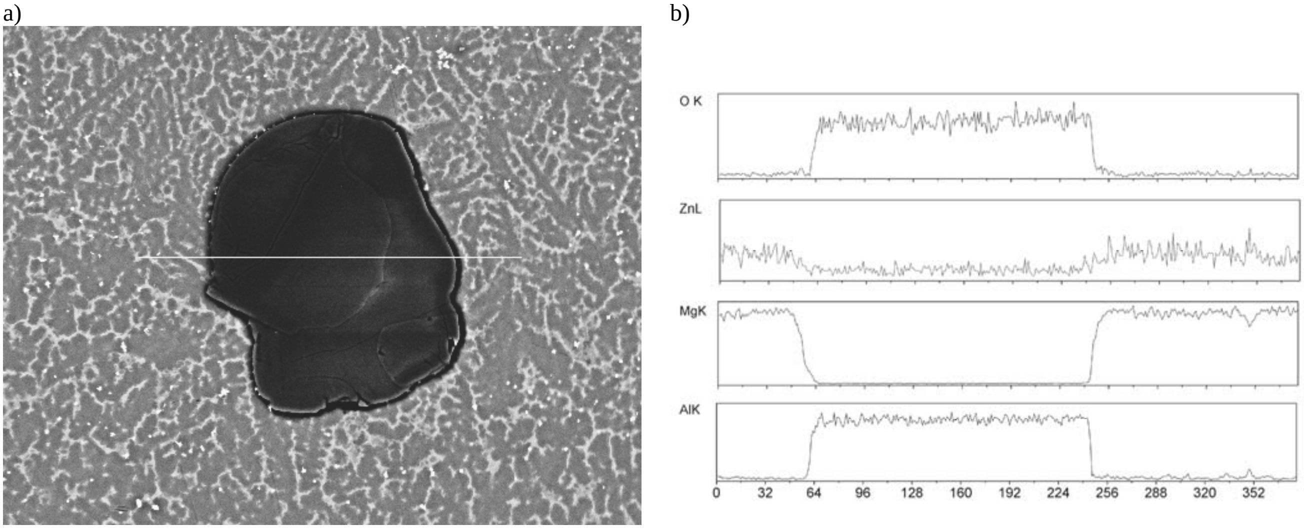
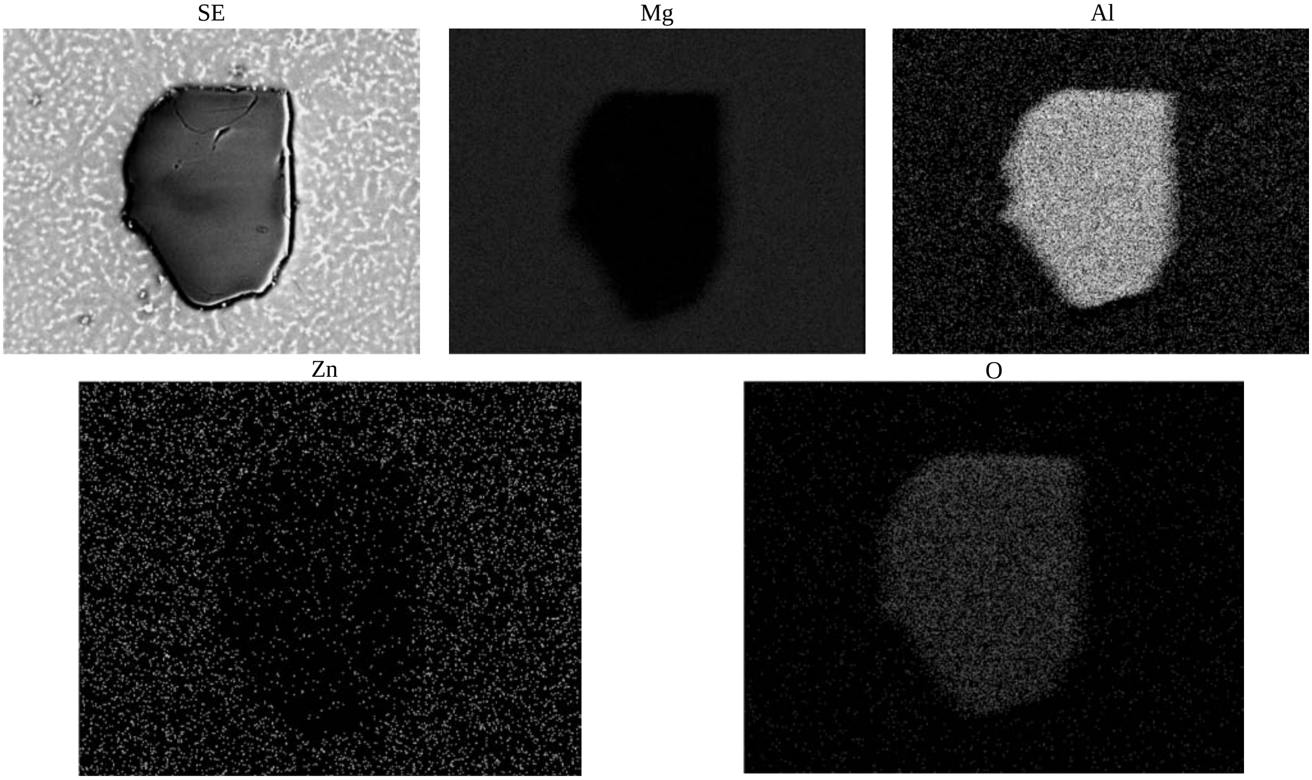


Fig. 8. Scanning electron microscope micrograph of MCMgAl12Zn1 alloy after laser alloying with aluminium oxide particles, laser power 2.0 kW: a) SEM micrograph, b) linear analysis of the chemical composition changes


SE

Mg

Al

Zn

O

Fig. 9. X-ray mapping of the microstructure MCMgAl9Zn1 alloyed layer with laser power 2.0 kW and the distribution of Mg, Al, Zn and O

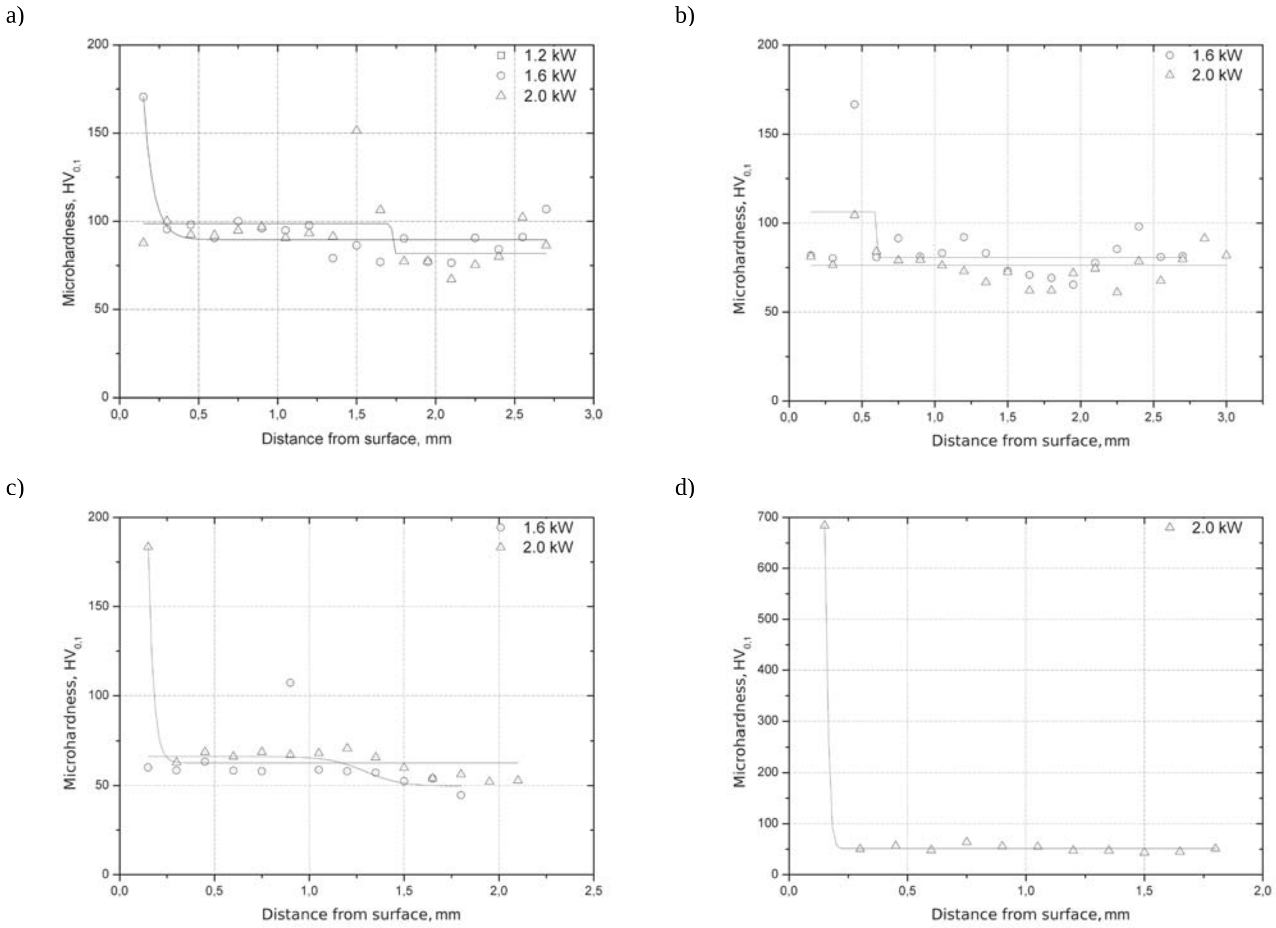


Fig. 10. Cross-section microhardness profile from the surface of: a) MCMgAl12Zn1, b) MCMgAl9Zn1, c) MCMgAl6Zn1, d) MCMgAl12Zn1 alloy with aluminium oxide particles

4. Summary

The results of investigations indicate that laser treatment of cast magnesium alloys EN-MCMgAl3Zn1, EN-MCMgAl6Zn1, EN-MCMgAl9Zn1, EN-MCMgAl12Zn1 with aluminium oxide particles is feasible. However, as a result of different properties of each cast magnesium alloys it is necessary to determine process parameters to stabilize laser alloying process.

Laser power is a main parameter affecting the structure, quality and thickness of a surface. Received coatings are free of cracks and porosity. The interface between the alloying zone and substrate shows a good metallurgical joint. The structure of the alloyed zone is mainly dendritic of primary magnesium with eutectic phase α-Mg and intermetallic phase β-$Mg_{17}Al_{12}$. Microhardness investigation shows that hardness increases in the alloyed zone to values from 100 to 700 $HV_{0,\ 1}$, when hardness of substrate is in the range from 50 to 90 $HV_{0,1}$. The microhardness value growth is an effect of refinement of a magnesium alloys structure and very hard carbides particles appearance within surface layer area.

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