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Effect of high power diode laser surface alloying on structure of MCMgAl12Zn1 alloy

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ABSTRACT

Purpose: The aim of this work was to improve the properties of the surface layer of the MCMgAl12Zn1 cast magnesium alloy. This improvement can be achieved by modification of surface layer microstructure by melting and simultaneous feeding the silicon carbide particles into the weld pool.

Design/methodology/approach: Laser alloying of the MCMgAl12Zn1 magnesium alloy with the silicon carbide was carried out using high power diode laser HPDL (High Power Diode Laser) with changing process parameters like laser power and scan rate. The structure examination was carried out using the light microscopy and SEM (scanning electron microscopy). The qualitative and quantitative chemical and phase composition were determined by the X-ray diffraction method using the XPert device, TEM (transmission electron microscopy) and EDS (electron dispersive spectroscopy) analysis.

Findings: Microstructure and phase composition of the MCMgAl12Zn1 cast magnesium alloy after laser surface treatment are presented in this paper.

Research limitations/implications: The investigations were conducted for cast magnesium alloy MCMgAl12Zn1, which was remelting and simultaneous feeding the silicon carbide particles into the weld pool. Size of SiC particles was below 75 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: Magnesium alloys; Surface treatment; Laser treatment; Silicon carbide

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

During the last few decades the world has seen a rapid growth of application of magnesium and its alloys almost in every field of today's industry. This is due to numerous characteristics of the metal regarded to herein, which permit its use both as a structural element, and as a chemical addition to other metal alloys. The metal is lighter than aluminum and has bigger tensile strength than steel. Magnesium alloys have low density and other benefits such as: a good vibration damping, 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 [1-11]. Many obvious advantages offered by magnesium and its alloys are due to its special characteristics that put it out of comparison. The automotive industry has crossed the threshold from using magnesium in a protected environment, predominantly interior applications to an unprotected environment. Production magnesium components currently emphasize interior applications, such as steering column brackets, instrument panel, seat frames, steering wheel, and sunroof track assembly etc [5,8,11]. Magnesium alloys have also found their application in manufacturing of mowers, saws, robots, office equipment including computer hardware, sport and medical appliances, in production of movie and video cameras, for rocket parts, space ships, and others [5,8,9,11].

A lot of light metal applications require a special properties of material surface layer. Method which allow to achieve improvement of the chemical, mechanical and tribological properties of the surfaces is a high power laser treatment. The aim of laser treatment (cladding) is the deposition of a cladding onto surfaces of work pieces. The material is deposited by pre-placed powder, powder injection or by wire feeding. The laser beam melts a thin layer of the surface of the work piece together with additional material. After solidification, a small mixture of the top part of the work piece and the coating provides the bonding between substrate and coating. In the laser melt injection process, solid particles are injected in the melt pool, which are trapped after solidification [8-15].

The goal of this paper is presentation of the investigation results of the MCMgAl12Zn1 casting magnesium alloy after laser treatment.

2. Materials and investigations

The investigations have been carried out on test pieces of MCMgAl12Zn1 magnesium alloy after heat treatment. The chemical compositions of the investigated material is given in Table 1. The heat treatment involved the solution heat treatment (warming material in temperature 375 °C the 3 hours, it later warming in the temperature to 430 °C, holding for 10 hours) and cooling in air and then ageing at temperature of 190 °C and cooling in air. The process of samples preparation depends on surface polishing on sandpaper 1200. Laser alloying was performed by high power diode laser HDPL Rofin DL020 (Fig. 1) with feeding of hard silicon carbide particles under an argon shielding gas (Table 2, Fig. 2). Argon was used during laser re-melting to prevent oxidation of the surface layer and the substrate. Particle size of silicon carbide powder was below 75 μm. The process parameters during the present investigation were: laser power – 1.0-2.0 kW, scan rate – 0.5-1.0 m/min and powder injection rate – 8-9 g/min.

Fig. 1. Laser HPDL Rofin DL 020

a)

b)

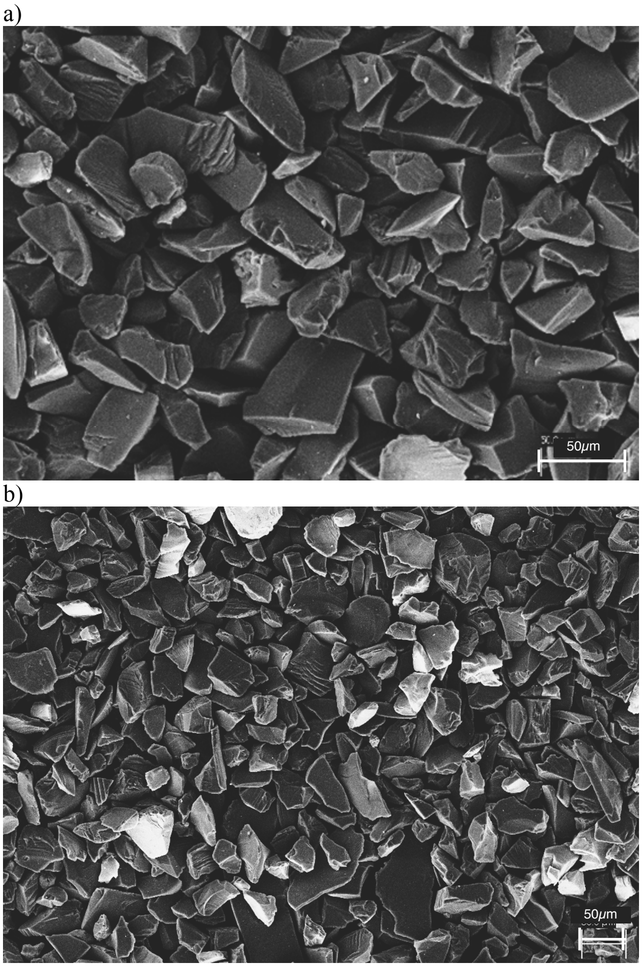

Fig. 2. Morphology of silicon carbide (a, b)

Table 1.
Chemical composition of investigation alloy

The mass concentration of main elements, %						
Al	Zn	Mn	Si	Fe	Mg	Rest
12.1	0.62	0.17	0.047	0.013	86.96	0.0985

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

Metallographic examinations have been made on magnesium cast alloy specimens in cold-setting resins. In order to disclose grain boundaries and the structure and to distinguish precisely the particular precipitaions in magnesium alloys as an etching reagent 5% solution of HNO_3 in C_2H_5OH has been used. The observations of the investigated cast materials have been made on the light microscope LEICA MEF4A and on the electron scanning microscope Zeiss SUPRA 35. The X-ray qualitative and quantitative microanalysis and the analysis of a surface distribution of cast elements in the examined magnesium cast alloy specimens in as-cast and after heat, laser treatment have been 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.

Observations of thin foil structure were carried out in the JEM 3010UHR JEOL transmission electron microscope using an accelerating voltage of 300 kV.

X-ray diffraction patterns were registered on XPert device with a cobalt lamp with 40 kV voltage. The measurement was performed in the angle range of 2Θ: 20º - 130º.

3. Description of results

Selection of process parameters was conducted in an introductory investigations for the sake of: resultant compound quality, uniform distribution of alloying particles inside alloyed zone and surface layer face geometry after laser treatment. The process parameters were determined as: laser power 1.2-2.0 kW, scan rate 0.75 m/min and powder feed rate 8-9 g/min (as ensure the most stable feeding). Surface layer faces after laser alloying with determined parameters are regular and flat (Fig. 3)
Metallographic examinations revealed occurrence of zones after laser alloying: alloyed zone (AZ), heat affected zone (HAZ) and substrate material in the all cases (Figs. 4, 5). The shape and thickness of these zones are depending on laser power and scan rate. Results of the metallographic examinations show that the structure of the material solidifying after laser remelting is characteristic of occurrence of areas with the diversified morphology connected with crystallisation of the magnesium alloys. As a result of laser alloying the defect free structure develops with the clear refinement of grains (Fig. 4). Examinations carried out on the scanning electron microscope confirmed occurrence of the zonal structure of the surface layer of the investigated casting magnesium alloys (Fig. 5). During metallographic examinations of the MCMgAl12Zn1 alloy a uniform distribution was observed of the employed SiC particles in the entire alloyed zone (Figs. 4, 5). In case of alloying with SiC particles with laser power of 1.2 and 1.6 kW carbides are distributed mostly at the layer surface, whereas at 2.0 kW power, the alloying particles are spread in the entire alloyed zone due to the violent mixing of the molten metal in the pool.

Microstructure of the laser modified layer contains mostly the dispersive particles of the employed SiC particles in the Mg-Al-Zn alloy matrix. Morphology of the alloyed area is composed mostly of dendrites with the $Mg_{17}Al_{12}$ lamellar eutectic and Mg in the interdendritic areas, whose main axes are oriented according to the heat transfer directions (Fig. 6, Table 3). This may be explained by occurrence of the abnormal eutectic with the extremely low α-Mg content in the eutectic mixture. The dendritic structure is present in

a) b)

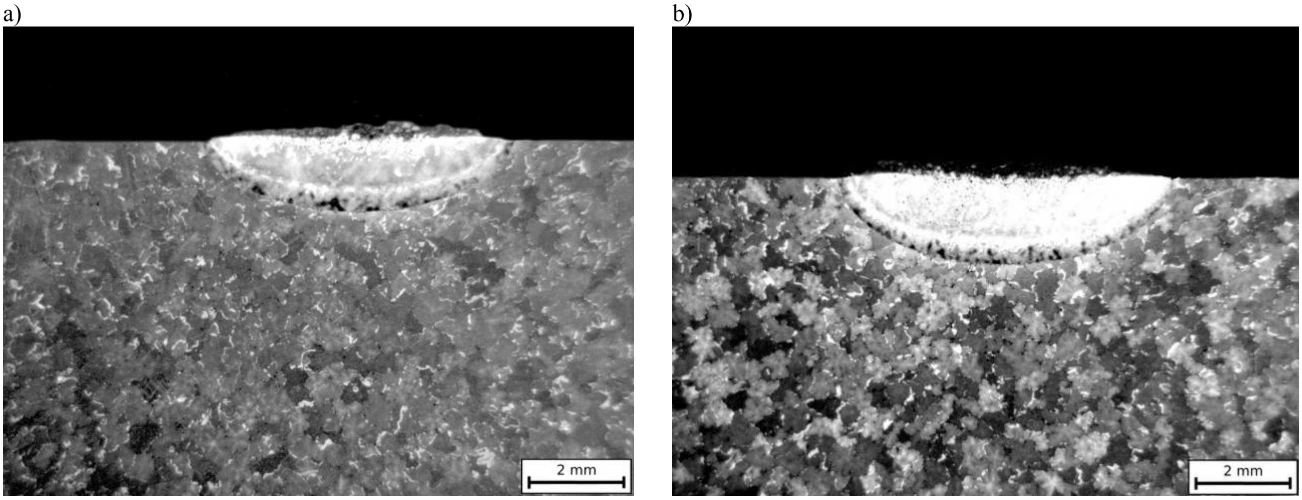

Fig. 3. Surface layer of MCMgAl12Zn1 alloy after laser alloying with SiC powder: laser power: a) 1.2 kW, b) 1.6 kW, scan rate: 0.75 m/min, powder feed rate: 8-9 g/min

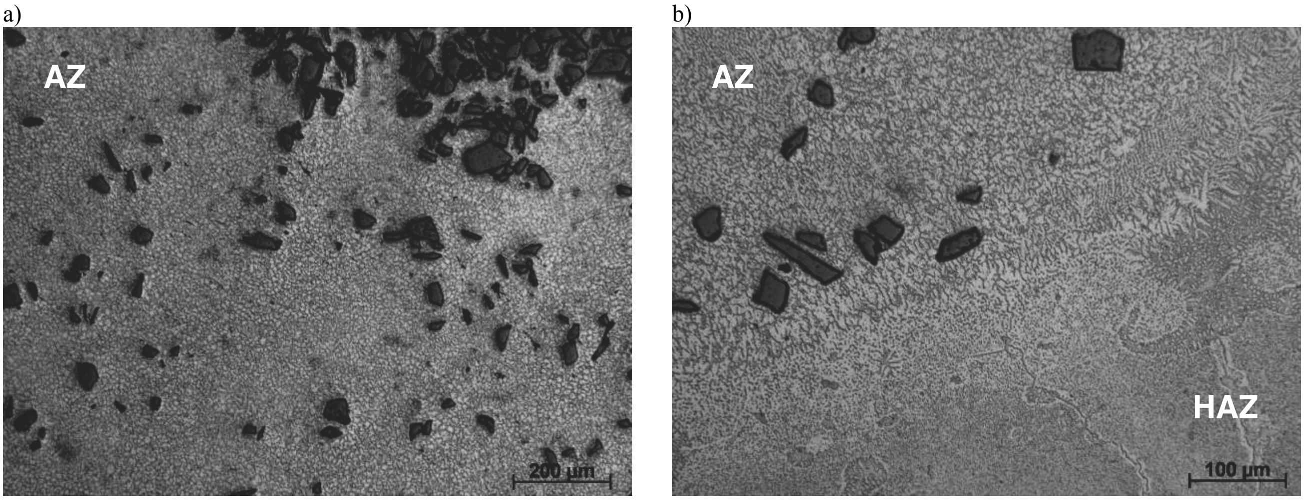

Fig. 4. Microstructure of central area of SiC powder alloyed zone – laser power 2.0 kW (a) and boundary between alloyed zone (AZ) and heat affected zone (HAZ) – laser power 1.6 kW (b) of MCMgAl12Zn1 alloy, scan rate: 0.75 m/min, powder feed rate: 8-9 g/min

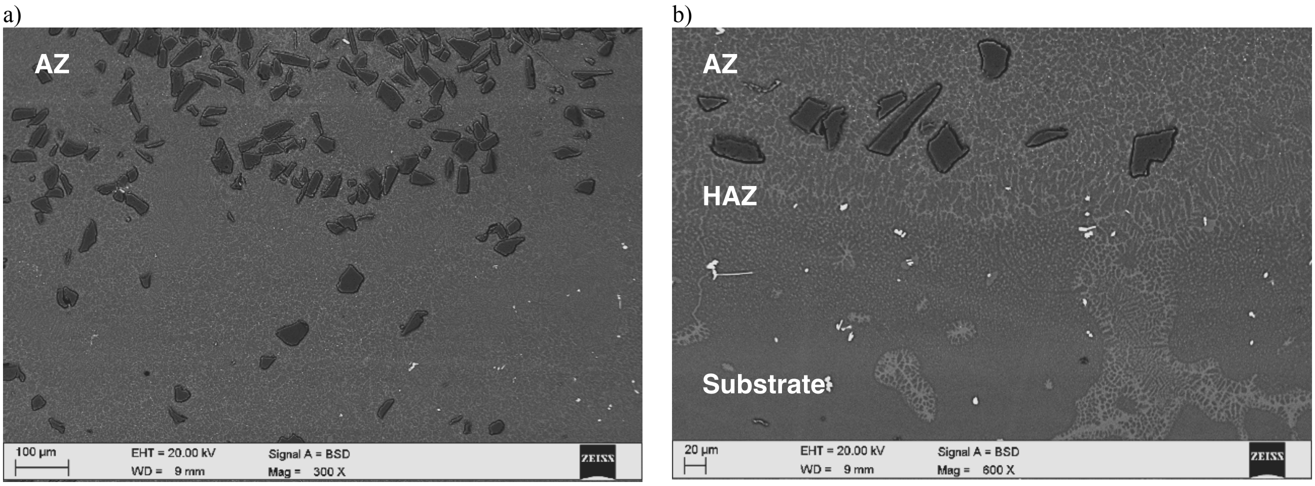

Fig. 5. MCMgAl12Zn1 alloy SEM of a) central area of SiC powder alloyed zone (AZ) – laser power 1.6 kW, b) boundary between alloyed zone and substrate – laser power 1.6 kW, scan rate: 0.75 m/min, powder feed rate: 8-9 g/min

the alloyed zone, developed according to the heat transfer direction along with the undissolved particles of the silicon carbide. The analysis of thin foils after the laser alloying process validated the fact that the structure of the MC MgAl9Zn1 cast alloy consists of the silicon carbide particles in alloyed zone (Fig. 7). Morphology of the alloyed area, including the content and distribution of carbide particles also is dependent on laser parameters. Results of carried out qualitative X-ray diffraction analysis of investigated alloys confirmed occurrence of phases: Mg, $Mg_{17}Al_{12}$ and SiC (Fig. 8). Other phases contained silicon weren't revealed, what confirms lack of alloying particles dissolvableness.

Linear analysis of the chemical composition changes (Fig. 9) and the elements distribution analysis using the X-ray energy dispersive spectrograph (EDS) (Fig. 10) made on the transverse section of the surface layers of the Mg-Al-Zn casting magnesium alloy with SiC powder used confirm occurrences of magnesium, aluminium, zinc, carbon, and also silicon in the laser modified layer and indicate to the undissolvableness of the alloying particles.

Table 3.
Summary of EDS analysis of the regions marked in Fig. 6

Region	Element	The mass concentration of main elements, %	
		mass	atomic
1	Mg	90.31	31.18
	Al	9.69	8.82
2	Zn	3.13	1.23
	Mg	63.64	67.17
	Al	33.23	31.60
3	C	22.97	41.05
	Zn	3.69	1.21
	Mg	23.65	20.88
	Al	20.70	16.47
	Si	24.30	18.57
	Mn	04.69	01.83

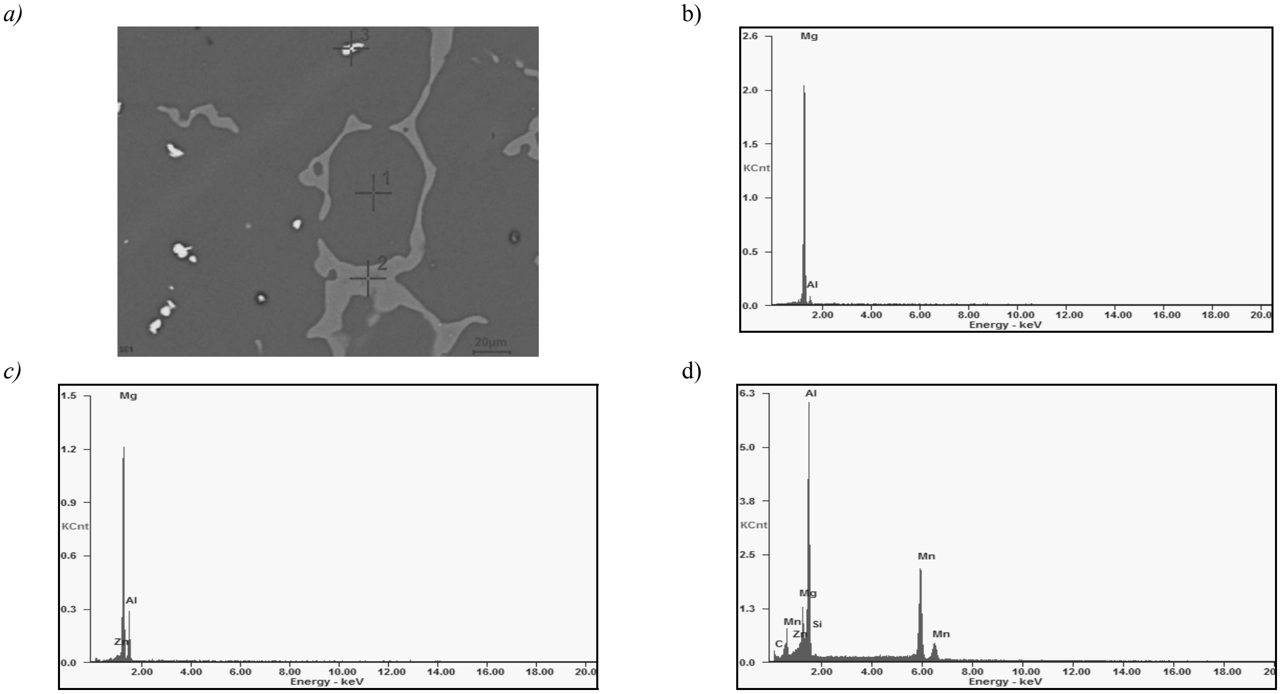

Fig. 6. Microstructure of HAZ of MCMgAl12Zn1 alloy after laser alloying with SiC particles and laser power 1.2 kW (a) and X-ray energy dispersive spectrographs of analysis 1(b), 2 (c) and 3 (d)

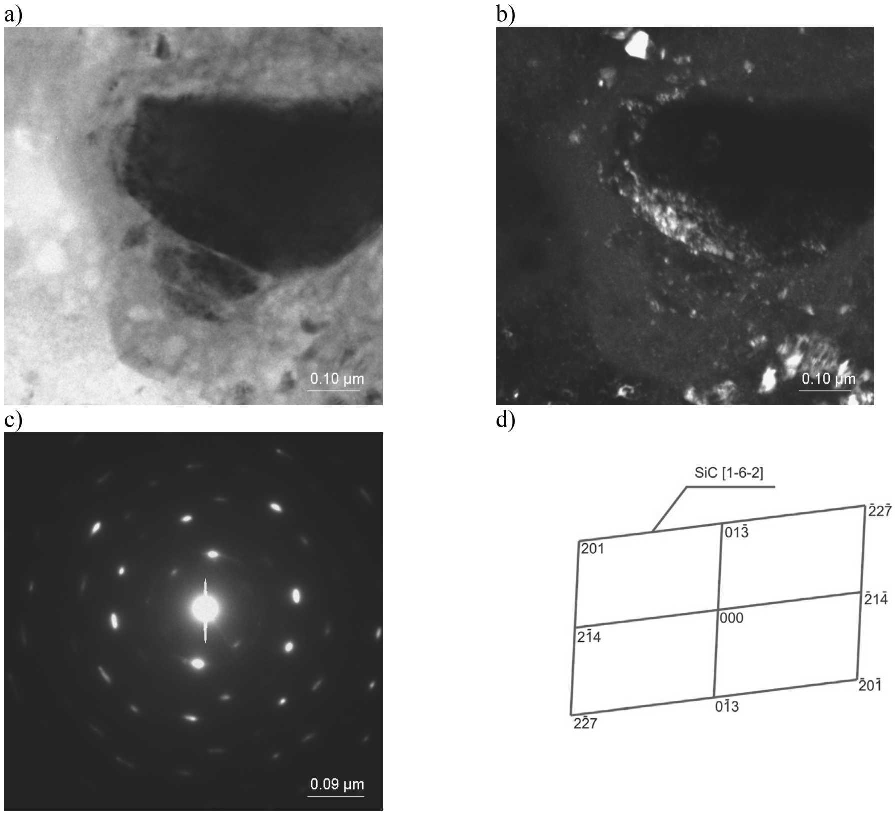

Fig. 7. TEM image of the alloyed zone (AZ) of MCMgAl12Zn1 alloy after laser alloying SiC particles and laser power 1,6 kW with selected area diffraction pattern

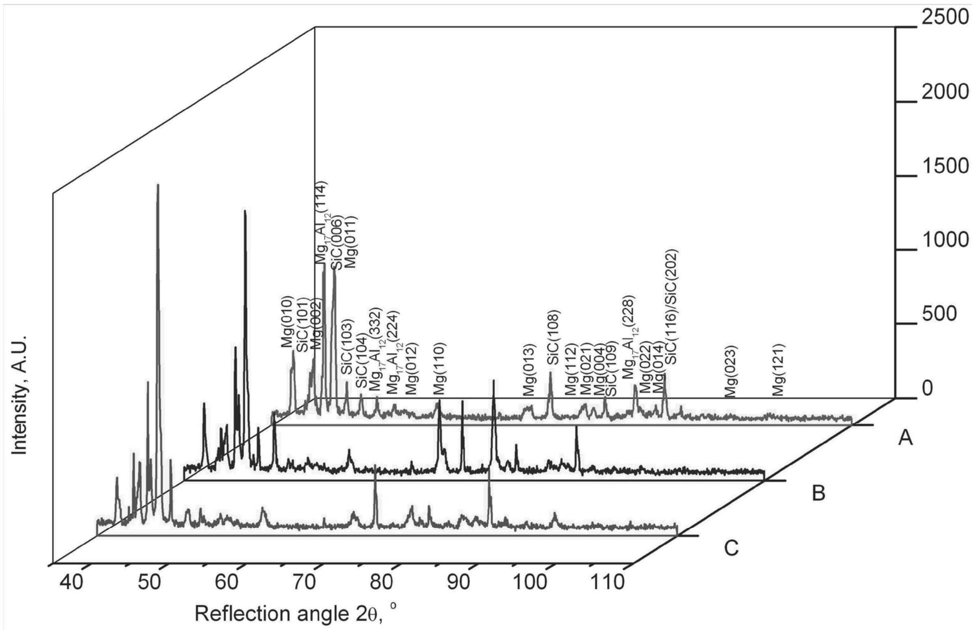

Fig. 8. XRD patterns of the MCMgAl12Zn1 alloy after laser alloying with SiC particles and laser power: A – 1.2 kW, B – 1.6 kW, C – 2.0 kW

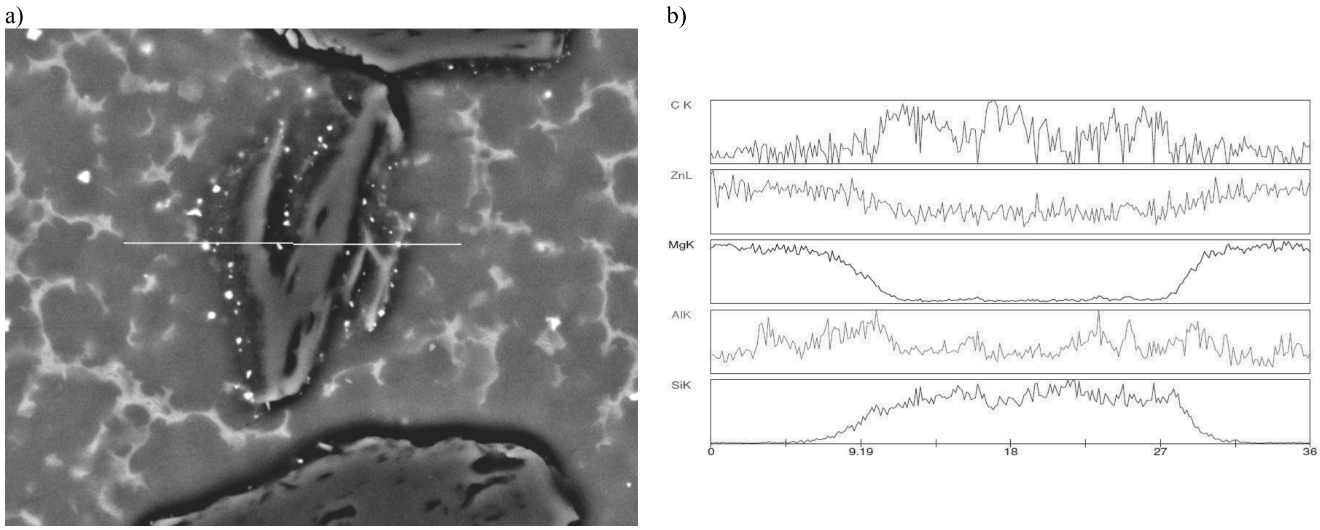

Fig. 9. Scanning electron microscopy micrograph of MCMgAl12Zn1 alloy after laser alloying with SiC particles, laser power: 1.6 kW, scan rate: 0.75 m/min, powder feed rate: 8-9 g/min, a) SEM micrograph, b) linear analysis of the chemical composition changes

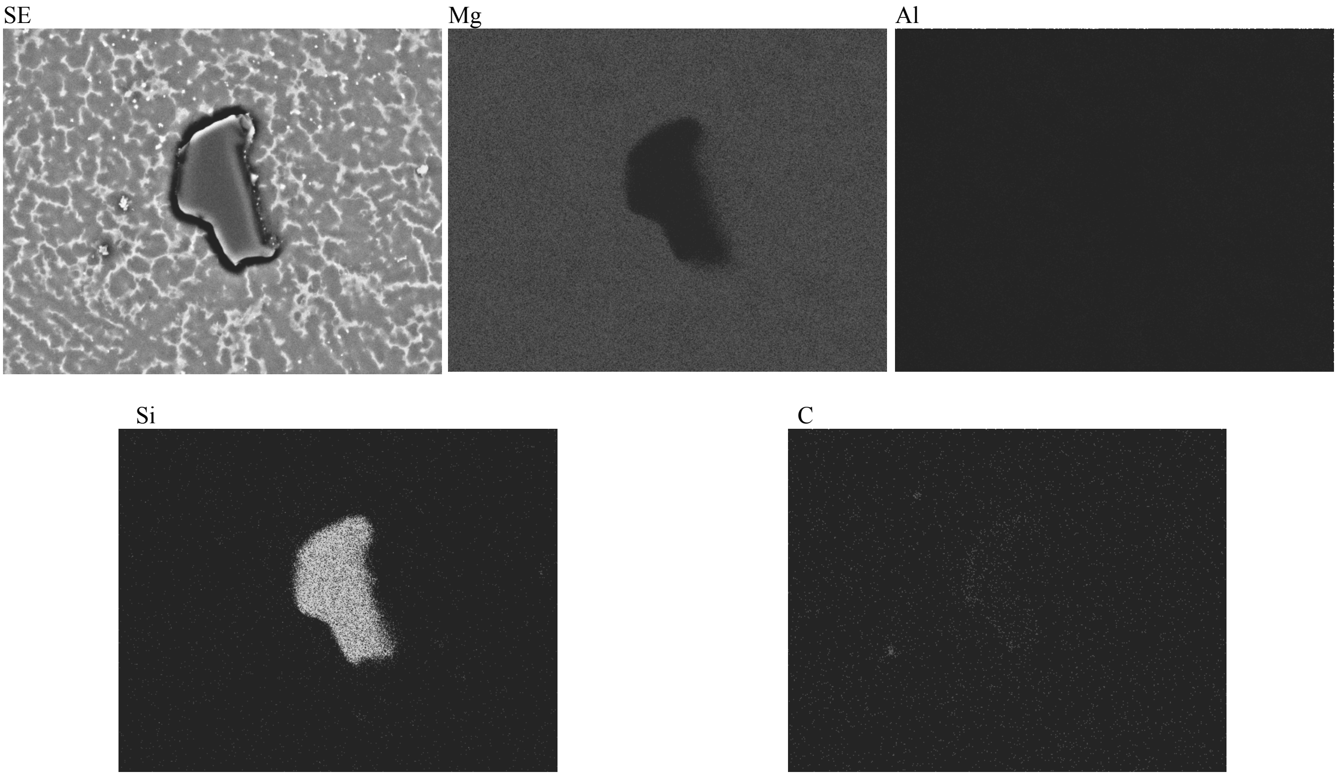

Fig. 10. X-ray mapping of the microstructure MCMgAl12Zn1 alloying layer and the distribution of Mg, Al, Si, C

4. Summary

The results of investigations indicate that laser treatment of cast magnesium alloy MCMgAl12Zn1 with SiC particles is feasible. Laser power is the main parameter, which influences on the structure, quality and thickness of surface. Carried out coatings are free of cracks and porosity. Magnesium alloy after laser alloying reveal alloyed zone (AZ) with silicon carbide particles spaced in whole zone and heat affected zone (HAZ), which is boundary between alloyed zone and substrate material. Due to laser alloying structure develops with the clear refinement of grains containing mostly the dispersive particles of the carbide used in the casting magnesium alloy matrix. The structure of the alloyed zone is mainly dendritic of primary magnesium with eutectic α+β and undissolved alloying SiC particles. The lack of SiC particles dissolvableness was confirmed by linear analysis of the chemical composition changes and elements distribution analysis using the X-ray energy dispersive spectrograph (EDS) and also by X-ray diffraction examinations. The results show that is possible to make surface layers on cast magnesium alloys with ceramic particles in the microstructure. This surfaces should reveal better mechanical and abrasiveness properties than cast magnesium alloys in initial state.

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EUROPEAN REGIONAL DEVELOPMENT FUND

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