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Influence of the laser modification of surface on properties and structure of magnesium alloys

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ABSTRACT

Purpose: The aim of this work was to improve the surface layer cast magnesium cast alloys by laser surface treatment, determine the laser treatment parameters and examine structure and properties.

Design/methodology/approach: The laser treatment of magnesium alloys with alloying SiC and TiC powders with the particles size below 75μm and over 6.4μm was carried out using a high power diode laser (HPDL). The resulting microstructure in the modified surface layer and was examinated using scanning electron microscopy. The X-ray qualitative and quantitative microanalysis and the analysis of a surface distribution of cast elements in the examined magnesium cast alloy was examined. The measurements of hardness and roughness 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 was dropped as compared to alloy without laser treatment. The roughness of layer surface increased after laser alloying and values are bigger for SiC alloying particles.

Research limitations/implications: The investigations were conducted for cast magnesium alloys MCMgAl12Zn1 and MCMgAl9Zn1 and also TiC and SiC powders. 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 to compared 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 work is definition of the influence of laser treatment parameters on quality, microstructure and hardness of magnesium cast alloys surface layer.

Keywords: Surface treatment; Magnesium alloys; Laser treatment; Silicon carbide, Titanium carbide

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PROPERTIES

1. Introduction

Magnesium alloys reveal very low density, high yield point and coefficient of elasticity, which allow to transmit high impact loads. Having such properties magnesium alloys have found applications in: aircraft and automotive industries, office and household equipment. Among faults of magnesium alloys there are low corrosion resistance and high susceptibility to oxidation, which make complicated their production and processing [1-6].

Magnesium casting alloys are used in the aircraft industry to manufacture parts of high load supporting structure and reaction engine, in the automotive industry to production of wheel rings, body parts and interior equipments, while in the electronic industry for shell of mobile phones, notebooks, cameras, video cameras and others [1-6].

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 laser treatment. There are several laser surface treatments, namely surface hardening, alloying, cladding and laser melt injection. In laser alloying the laser beam melts the surface locally while a second material is added to the melt pool. After rapid solidification, the composition, the morphology and properties on the top layer of the workpiece is changed. However, laser treatment has appeared not to be easy to put into use with magnesium alloys because of a lot of defect types like porosity, fractures, oxide inclusions or oxidation observed during laser treatment [7-15].

2. Experimental methodology

Tests were made on the experimental MCMgAl12Zn1 and MCMgAl9Zn1 casting magnesium alloys after heat treatment. The chemical compositions of the investigated materials were dependant on the variable aluminium concentration range, suitably to every alloy type, changing in the range from 9-12%. Chemical compositions of alloys are given in Table 1.

The heat treatment of magnesium alloys involved the solution heat treatment (thrre-hour long material warming at temperature 375 °C, followed by ten-hour-warming at the temperature up to 430 °C, holding for 10 hours) and cooling in air and then aging at temperature of 190 °C and cooling in air. Substrate surface was prepared by grinding with 1200 granularity SiC abrasive paper.

Laser alloying was produced using the high power diode laser Rofin DL020 HPDL in the argon shield gas cover to protect the weld pool from oxidation with the technique of the continuous powder supply to the weld pool, by feeding the granulate with the use of the TecFlo fluidization feeder equipped with the powder flow digital controller. Powder feeder was connected with the transport gas cylinder and powder feed nozzle. Powders of silicon carbide with granulation below 75 µm (Fig. 1a) and titanium carbide with granulation above 6.4 µm (Fig. 1b) were used for alloying. Experiments were made under the following process parameters: laser power 1.2 – 2.0 kW; speed of alloying 0.25 – 1.00 m/min; powder feeding rate: 6-9 g/min. After initial experiments laser power in the range 1.2-2.0 kW was assumed for the investigations, with speed of alloying of 0.25; 0.50; 0.75; 1.00 m/min. The examinations revealed that the optimum geometry of a single laser bead was obtained for alloying with the speed of 0.75 m/min.

The metallographic examinations were made on the transverse sections of the test pieces after laser alloying with the silicon- and titanium carbides, which were mounted in the chemically cured resin. The microsections were prepared by grinding and buffing using the diamond abrasive slurry. The microsections were etched in nital to reveal the material structure and grain boundaries. Structural observations were made with LEICA MEF4A light microscope and Zeiss SUPRA 35 scanning electron microscope using the secondary electrons detection.

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.

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 2Θ: 30º - 120º.

Hardness testing of the casting magnesium alloys were made using Rockwell method according to scale F. Tests were made on Zwick ZHR 4150TK hardness tester according to PN-EN ISO 6508-1:2007 (U) standard in the "load-unload" mode.

Roughness Ra tests of the laser alloyed surface layers of the casting magnesium alloys were done using Taylor Hobson Precision Surtronic 3+ device. The device is characteristic of the measurement resolution of 0.2 µm and the maximum measured

a)
b)

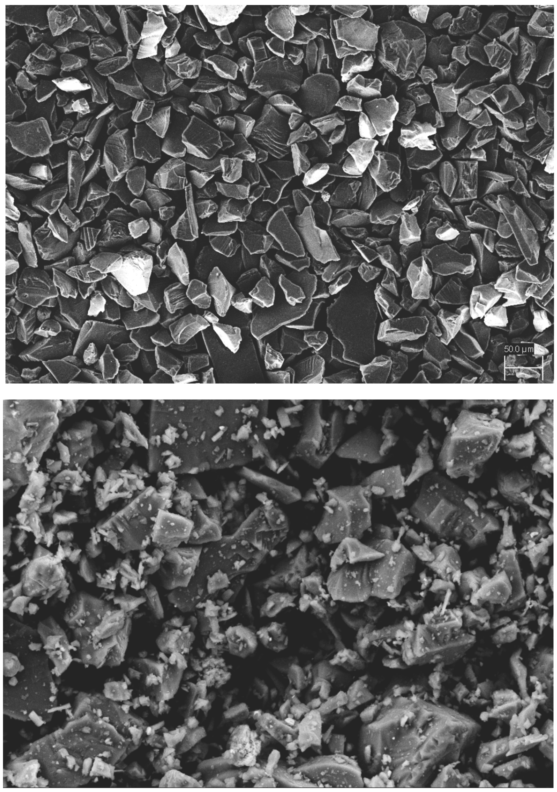

Fig. 1. Morphology of powder of: a) silicon carbide, b) titanium carbide (SEM)

Table 1.
Chemical compositions of investigated magnesium alloys

Al	Zn	Mn	Cu	Si	Fe	Ni	Sn	Pb	Be	Zr	Ce	Mg
11.894	0.55	0.22	0.0064	0.050	0.02	0.0008	0.0007	0.045	0.0006	0.003	0.01	87.2
9.399	0.84	0.24	0.0018	0.035	0.007	0.0009	0.0042	0.059	0.0005	0.003	0.01	89.4

value of 150 μm. Surface hardness tests were made on the measuring distance of 0.8 mm.

3. Discussion of experimental results

3.1. Structure

Occurrences were found based on the metallographic examinations of the alloyed zone (AZ) and the heat affected zone (HAZ) in every alloyed surface layer of the investigated MCMgAl12Zn1 and MCMgAl9Zn1 casting magnesium alloy. These zones have different thickness and shape depending on laser power and ceramic powder used. Basing on the results of the metallographic investigations one may state that the laser power change at the constant speed of alloying results clearly in growth of both zones in the surface layer (Table. 2). Laser power used affects also the shape and convexity of the alloyed zone rising it above the surface of material subjected to treatment.

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 (Fig. 2-5). As a result of laser alloying the defect free structure develops with the clear refinement of grains. Microstructure of the laser modified layer contains mostly the dispersive particles of the employed SiC or TiC carbide 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. This may be explained by occurrence of the abnormal eutectic with the extremely low α-Mg content in the eutectic mixture. Moreover, composite microstructure morphology of the alloyed area resulted from the change of the alloy from hypoeutectic to the hypereutectic one, depending o layout of the alloyed elements and changes of the process parameters of the laser treated surface.

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. 6-9). The dendritic structure is present in the alloyed zone, developed according to the heat transfer direction along with the undissolved particles of the carbides used or aluminium oxide. Morphology of the alloyed area, including the content and distribution of carbides particles also is dependant on laser parameters.

During metallographic examinations of the MCMgAl12Zn1 and MCMgAl9Zn1 alloys a uniform distribution was observed of the employed SiC and TiC carbides particles in the entire alloyed zone (Fig. 2, 3, 6-9). 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 (Fig. 9). At 2.0 kW power, the SiC particles are spread in the entire alloyed zone (Fig. 5) due to the violent mixing of the molten metal in the pool.

Linear analysis of the chemical composition changes (Fig. 10), examination of the chemical composition using the X-ray energy dispersive spectrograph (EDS) (Fig.11) and the X-ray quantitative microanalysis (Table 3) made on the transverse section of the surface layers of the Mg-Al-Zn casting magnesium alloys with SiC and TiC powders used confirm occurrences of magnesium, aluminium, zinc, manganese, carbon, and also silicon and titanium, respectively, in the laser modified layer and indicate to the insolubility of the alloying particles.

Table 2.
Thickness of alloyed zone (AZ), heat affected zone (HAZ) and surface layer (SL = AZ + HAZ)

Substrate	Alloying material	Laser power, kW	SL depth, μm	AZ depth, μm	HAZ depth, μm
MCMgAl12Zn1	SiC	1.2	1596	1089	507
		1.6	2980	2182	798
		2.0	3589	2828	761
	TiC	1.2	1480	1070	410
		1.6	2010	1410	600
		2.0	2470	1850	620
MCMgAl9Zn1	SiC	1.2	1372	696	676
		1.6	2407	1639	768
		2.0	3175	1976	1199
	TiC	1.2	1320	720	600
		1.6	2200	1460	740
		2.0	2480	1870	610

3.2. Mechanical properties

Hardness tests results of the Mg-Al-Zn casting magnesium and aluminium alloys after laser alloying with the SiC and TiC carbides indicate that for the MCMgAl12Zn1 and MCMgAl9Zn1 alloys hardness grows slightly, and deteriorates at some alloying parameters. Alloy hardness values after heat treatment were 91.4 HRF and 78.4 HRF for the MCMgAl12Zn1 and MCMgAl9Zn1 alloys respectively. The biggest surface layer hardness drop was observed for the MCMgAl9Zn1 and MCMgAl12Zn1 alloys alloyed with SiC powder at laser power of 1.2 kW of 24 HRF and 19 HRF respectively. The biggest hardness increase of about 6 HRF was measured for the MCMgAl9Zn1 after alloying with TiC carbide at laser power of 2.0 kW.

It was found based on roughness measurement results of the casting magnesium alloys after laser alloying with the silicon and titanium carbides that regardless of the ceramic powder employed the roughness of surface layers obtained by remelting the Mg-Al-Zn magnesium and aluminium alloys with the laser beam with the power within the 1.2 ÷ 2.0 kW range grows in comparison with the prepared substrate and is within the Ra = 5.8 – 19.2 μm range. In two cases (alloying with SiC powder at laser power of 1.2 kW) roughness measurement was impossible due to the too small device measurement range. Roughness growth occurs along with the laser power increase and aluminium concentration in the alloy. The MCMgAl9Zn1 alloy is an exception, as after alloying with TiC

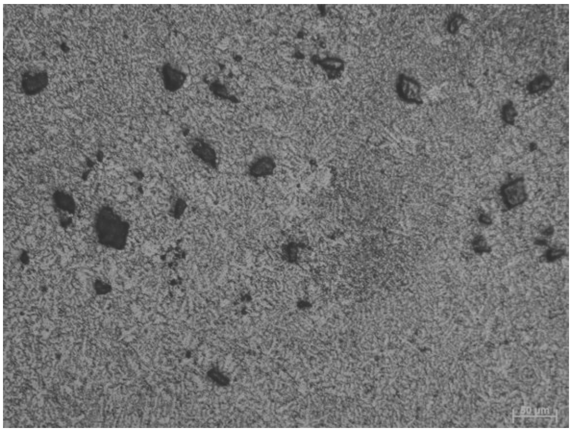

Fig. 2. Central area of alloyed zone of MCMgAl12Zn1 alloy after laser alloying with TiC particles and laser power 1.2 kW

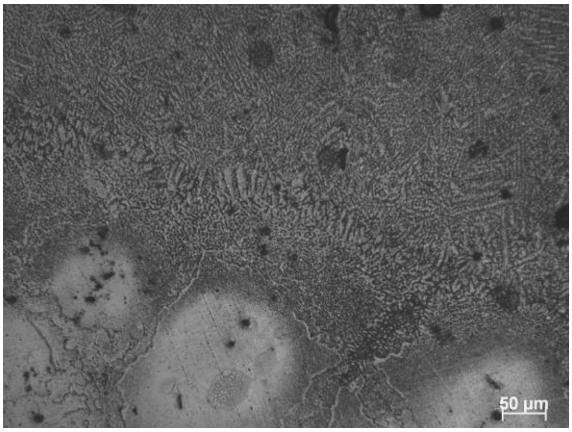

Fig. 3. Boundary between alloyed zone and heat affected zone of MCMgAl9Zn1 alloy after laser alloying with TiC particles and laser power 1.2 kW

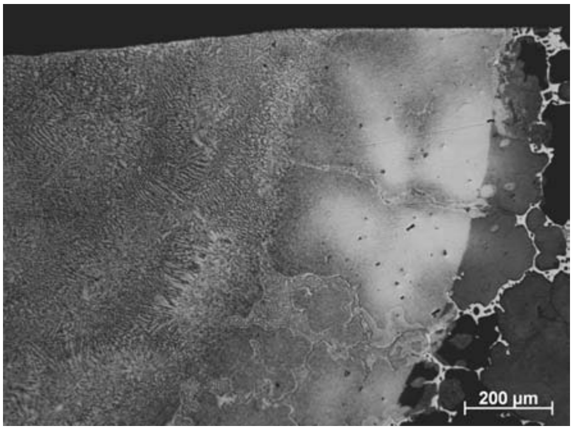

Fig. 4. Edge of alloyed zone of MCMgAl12Zn1 alloy after laser alloying with SiC particles and laser power 2.0 kW

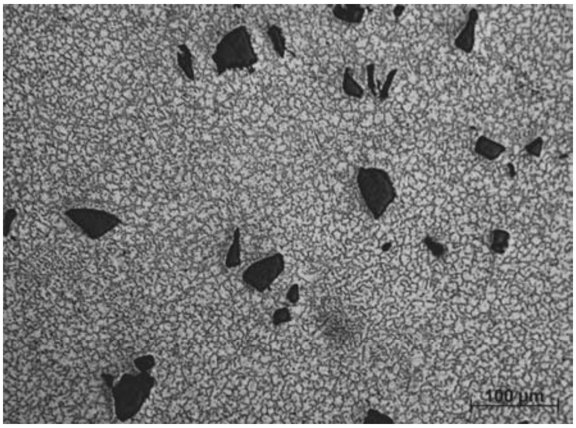

Fig. 5. Central area of alloyed zone of MCMgAl12Zn1 alloy after laser alloying with SiC particles and laser power 2.0 kW

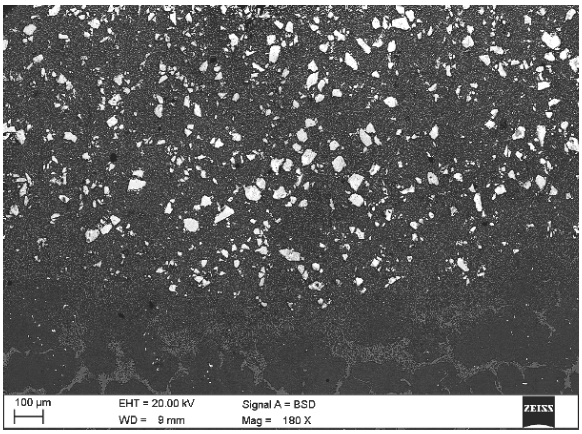

Fig. 6. Central area of alloyed zone of MCMgAl9Zn1 alloy after laser alloying with TiC particles and laser power 1.6 kW (SEM)

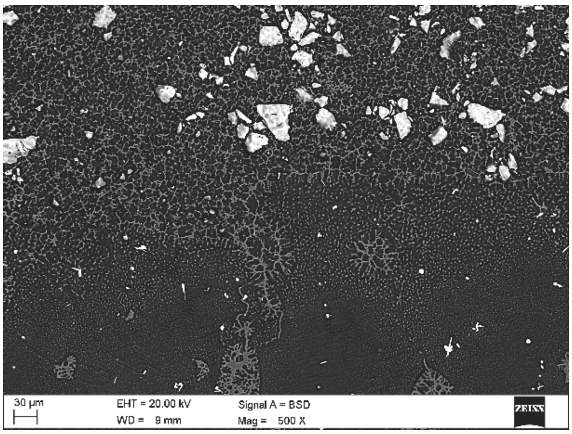

Fig. 7. Boundary between alloyed zone and heat affected zone of MCMgAl9Zn1 alloy after laser alloying with TiC particles and laser power 1.6 kW (SEM)

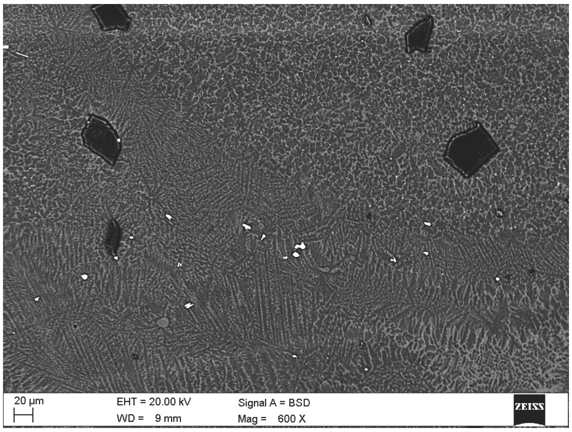

Fig. 8. Boundary between alloyed zone and heat affected zone of MCMgAl12Zn1 alloy after laser alloying with SiC particles and laser power 1.6 kW (SEM)

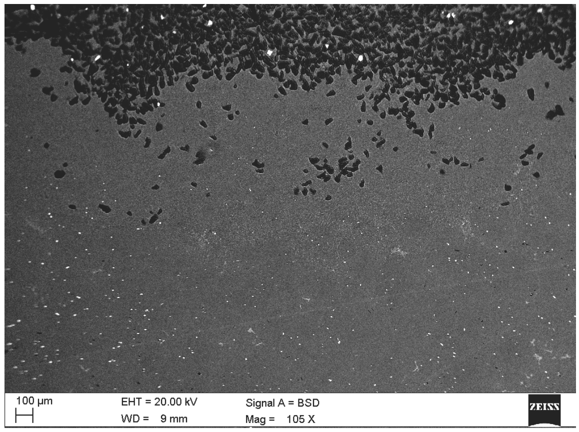

Fig. 9. Surface layer of MCMgAl9Zn1 alloy after laser alloying with SiC particles and laser power 1.6 kW

a) b)

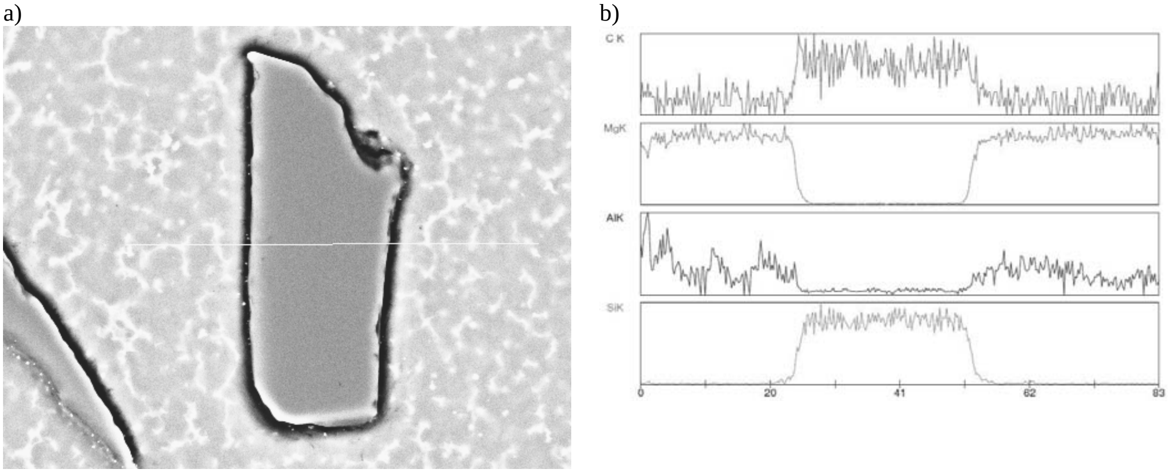

Fig. 10. SiC particles in the central area of alloyed zone of MCMgAl9Zn1 alloy after laser alloying with laser power 2.0 kW: a) structure, b) linear analysis of the chemical composition changes

a) b) c)

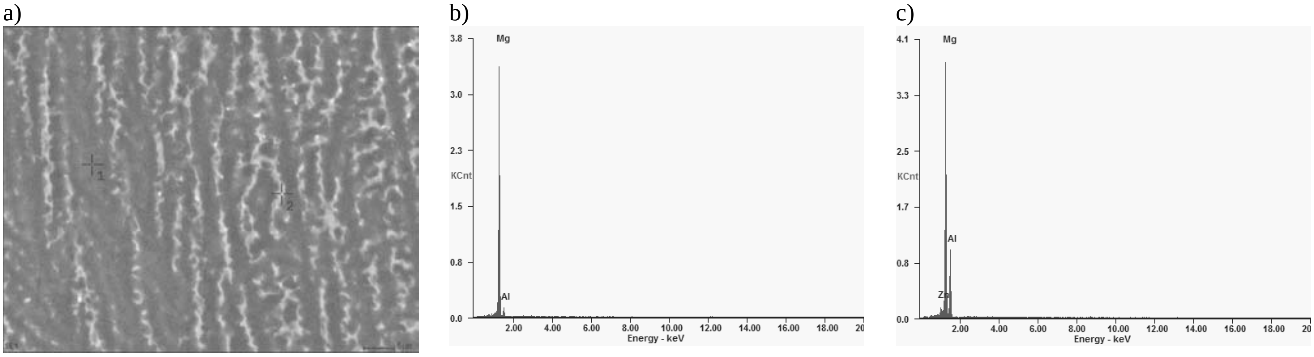

Fig. 11. Microstructure of alloyed zone of MCMgAl12Zn1 alloy after laser alloying with TiC particles and laser power 1.6 kW (a) and X-ray energy dispersive spectrographs: b) analysis 1, c) analysis 2

Table 3
Chemical composition and quantitative microanalysis of MCMgAl9Zn1 alloy after laser alloying with SiC particles and laser power 2.0 kW

Analysis	Element	Element concentration, %	
		mass	molecular
1	C	7.02	17.35
	Zn	1.55	0.71
	Mg	17.72	21.63
	Al	36.39	40.04
	Si	0.21	0.23
	Mn	37.10	20.05
2	C	16.47	31.55
	Si	83.53	68.45

powder the surface roughness decreases along with the growing laser power. The lowest roughness is characteristic for surface layers after alloying the MCMgAl9Zn1 alloy with TiC powder at laser power of 2.0 kW and the MCMgAl12Zn1 alloy at laser power of 1.6 kW. The highest roughness is characteristic of the surface layers of the casting magnesium alloys after alloying with SiC at laser power of 2.0 kW.

4. Conclusions

Magnesium alloys have achieved significant importance in this century, as was shown in bibliography review. According to specialists forecasts the economic conditions and the on-going progress in the area of technology and fabrication of the magnesium alloys will make it possible shortly to substitute aluminium alloys for them in most of their applications. Therefore, investigations on improvement of properties of these materials and their surface layers are desired.

Investigations of the surface layers carried out confirm that alloying of the surface layer of the Mg-Al-An casting magnesium and aluminium alloys is feasible using the HPDL high power diode laser ensuring better properties compared to alloys properties after the regular heat treatment after employing the relevant process parameters. Surface layers fabricated by alloying with SiC and TiC the casting magnesium and aluminium alloys (MCMgAl12Zn1 and MCMgAl9Zn1) demonstrate the clear effect of the alloyed material, parameters of the alloying process, and especially of the laser beam power and type of the ceramic particles on structure and mechanical properties of the surface layers. with Occurrence of areas with the diversified morphology dependent on solidification rate of the magnesium alloys is characteristic of the structure of the solidified material after laser alloying. 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.

Alloying conditions, substrate type as well as the powder type used affect the hardness tests results of the Mg-Al-An casting magnesium and aluminium alloys. Decrease of hardness at most laser treatment parameters was observed.

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