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Effect of laser treatment on microstructure and properties of cast magnesium alloys

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ABSTRACT

Purpose: The goal of this paper is to present the structure and properties of the cast magnesium alloy after laser treatment.
Design/methodology/approach: The laser treatment of magnesium alloys with TiC, WC powders was carried out using a high power diode laser (HDPL). The resulting microstructure in the modified surface layer was examined using optical microscopy, scanning electron microscopy and transmission electron microscope. Phase composition was determined by the X-ray diffraction method using the XPert device. The measurements of hardness and wear resistance of the modified surface layer were also studied.
Findings: The region after laser treatment has a fine microstructure with hard carbide particles. Hardness of laser surface layer with both TiC and WC particles was improved as compared to alloy without laser treatment.
Research limitations/implications: In this research two powders (WC and TiC) were used with the particle size over 5 µm. This investigation presents different laser power by one process speed rates.
Practical implications: The results obtained in this investigation were promising towards 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 originality of this work is applying of High Power Diode Laser for alloying of magnesium alloy using hard particles like tungsten and titanium carbides.
Keywords: Laser treatment; Magnesium alloy; High Power Diode Laser (HPDL); Tungsten carbide; Titanium carbide

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1. Introduction

Magnesium alloys are used for a wide variety of applications, the reason is their low density and high strength–to–weight ratio.

Lower fuel consumption and lower emission of harmful contaminations in the automotive industry result in magnesium growth of use. However, in many industry fields, application of magnesium alloys is limited by their some undesirable properties, namely, poor resistance to corrosion and wear [1, 4]. Therefore, attempts are made to improve abrasion wear resistance, hardness, and also corrosion resistance of the magnesium alloys by their surface treatment. Many surface modification technologies are currently available for magnesium alloys, among others electroplating, conversion coatings, anodizing, hybrid coatings, coatings obtained with the CVD and PVD methods, electron beam deposition, magnetron sputtering, plasma spraying, laser alloying/cladding [11]. Recently, laser surface treatment of magnesium alloys has been reported in a number of studies involving laser surface melting (LSM), laser surface cladding (LSC), fabrication of surface metal matrix composite [2, 8, 9, 10, 12-15].

Laser treatment of the surface layer may be a better alternative comparing to other technologies of the surface layer engineering of magnesium alloys. The important advantages of the laser surface treatment compared to the conventional methods are the following: short processing time, flexibility and operational precision. Possibility of full automatization of the laser treatment process of the magnesium alloys casting is pricewise competitive at the mass production scale [3, 5, 6, 7].

In the present study, the laser surface modification was conducted by melting MCMgAl6Zn1 alloy surface and feeding the WC and TiC particle using High Power Diode Laser (HDPL Rofin DL 020). The effect of the laser parameters on the microstructure was investigated. Phase composition was determined and microhardness values of the laser treated samples were measured.

2. Experimental procedure

The substrate materials used for the investigation were magnesium alloys MCMgAl6Zn1 and MCMgAl9Zn1 after heat treatment condition. The heat treatment involved the heat treatment solution (material pre-heating in the temperature at 375° C for 3 hours, later pre-heating at the temperature of 430° C, holding for 10 hours) and cooling it in water. Next, the specimens were aged at temperature of 190 °C, held for 15 hours and cooled down by the 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 up. The titanium and tungsten carbides particles in size of up 6 µm were used (Fig. 1). The laser treatment was performed by high power diode laser HPDL Rofin DL 020 under 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: 0.75 m/min and powder feed rate of 7±1 g/min.

Table 1.
Chemical composition of investigation alloys

Kind of alloy	Mass concentration of investigation alloys, %						
	Al	Zn	Mn	Si	Fe	Mg	Rest
MCMgAl9Zn1	9.399	0.84	0.24	0.035	0.007	89.4	0.079
MCMgAl6Zn1	5.624	0.46	0.16	0.034	0.07	93.6	0.052

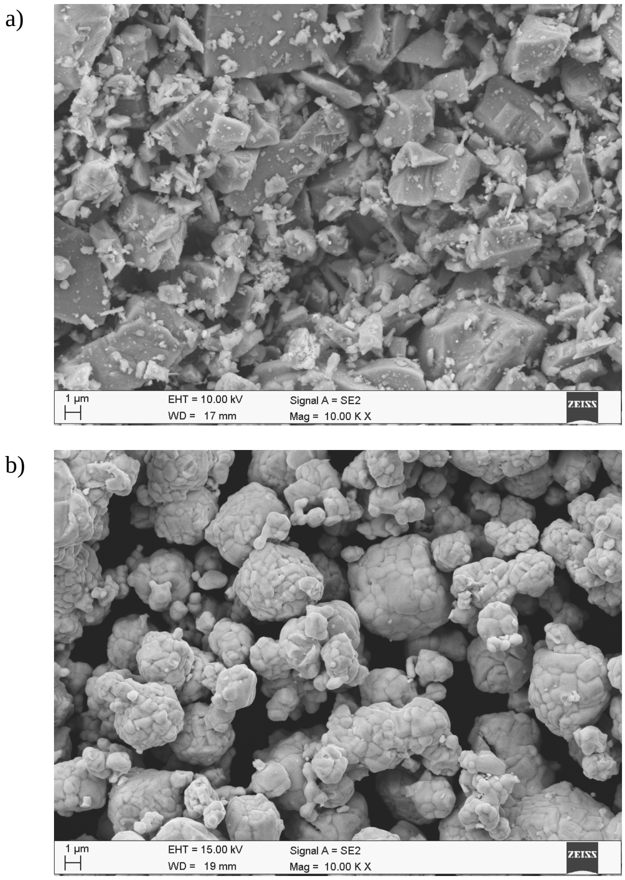


Fig. 1. SEM morphology of the a) titanium carbide, b) tungsten carbide

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 etching in nital at room temperature was used.

The observations of the investigated cast materials were made on the light microscope LEICA MEF4A as well as on the electron scanning microscope SUPRA 35 Zeiss Company using secondary electron detection.

The X-ray quantitative microanalysis and the analysis of chemical composition using the X-ray energy dispersive spectrograph (EDS) of cast elements in the examined magnesium cast alloy specimens after laser treatment were made on transverse microsections on the SUPRA 35 Zeiss company 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.

Observations of thin foil structure were carried out in the JEM 3010 JEOL transmission electron microscope using an accelerating voltage of 300 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: 20º - 140º.

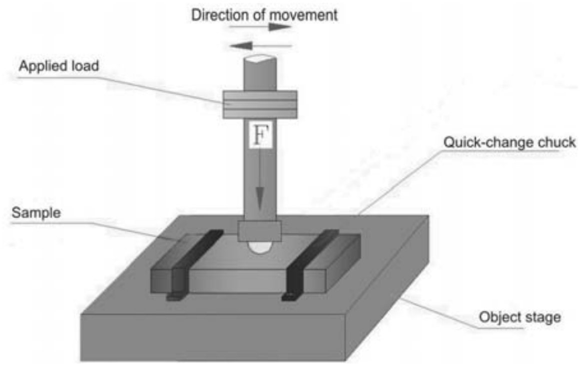


Fig. 2. Pictorial diagram for the abrasive wear investigations in a metal-metal system

Hardness testing of the cast magnesium alloys was made using the Rockwell method according to F scale.

Tests were made on Zwick ZHR 4150TK hardness tester according to PN-EN ISO 6508-1:2007 (U) standard in the "load-unload” mode.

The wear resistance test of cast magnesium alloys in metal-metal system was carried out with the aid of a tool, which was designed in Institute of Engineering Materials and Biomaterials, The Silesian University of Technology (Fig. 2). The investigation was performed with a stable cycle numbers 5000 (120 m), with loads 10 N.

3. Discussion of experimental results

The metallographic examinations results show that the structure of the material solidifying after laser remelting is characteristic of areas occurrences with the diversified morphology connected with crystallisation of the magnesium alloys. The zone after laser treatment is free of cracks and porosity (Figs. 3, 4).

Microstructure of the laser modified layer contains mainly the dispersive particles of titanium or tungsten carbides in the Mg-Al-Zn alloy matrix.

Morphology of the modified area is mainly composed 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 eutectics with the extremely low α-Mg content in the eutectic mixture.

Composite microstructure morphology of the modified area resulted from the change of the alloy from hypoeutectic to the hypereutectic one, depended on layout of the laser treatment elements and changes of the process parameters of the laser treated surface.

During metallographic examinations of the MCMgAl6Zn1 and MCMgAl9Zn1 alloys a uniform distribution was observed of the used TiC and WC carbides particles in the entire remelting zone (Figs. 3a, 4a).

Examinations carried out on the light and scanning electron microscope confirmed occurrence of the zonal structure of the surface layer in the investigated cast magnesium alloys. The dendritic structure is present in the remelted zone, developed according to the heat transfer direction along with the undissolved particles of the carbides. Morphology of the alloyed area, including the content and distribution of carbides particles also is dependent on laser parameters.

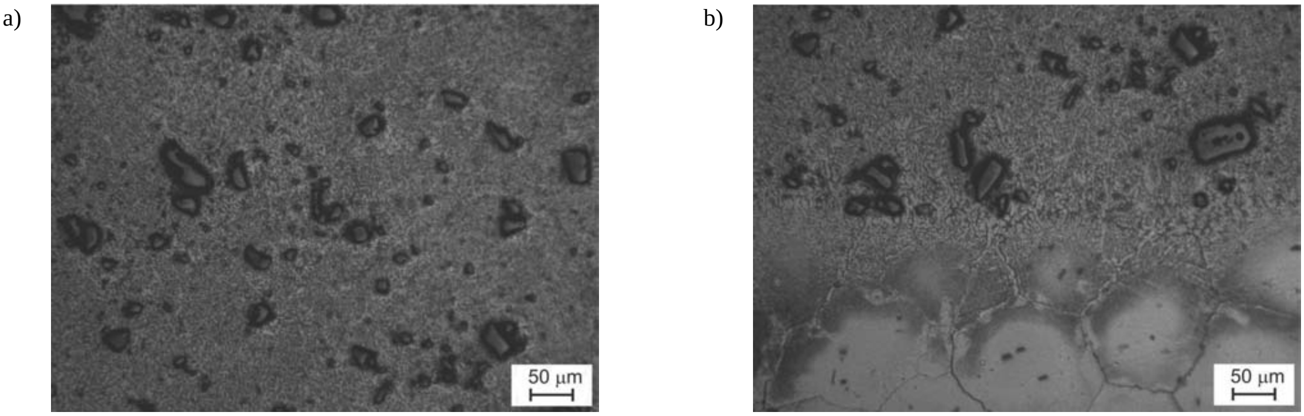


Fig. 3. a) Central zone between remelting area and substrate, b) boundary zone between remelting area and substrate, MCMgAl6Zn1 alloy after laser treatment with TiC powder, laser power 1.6 kW

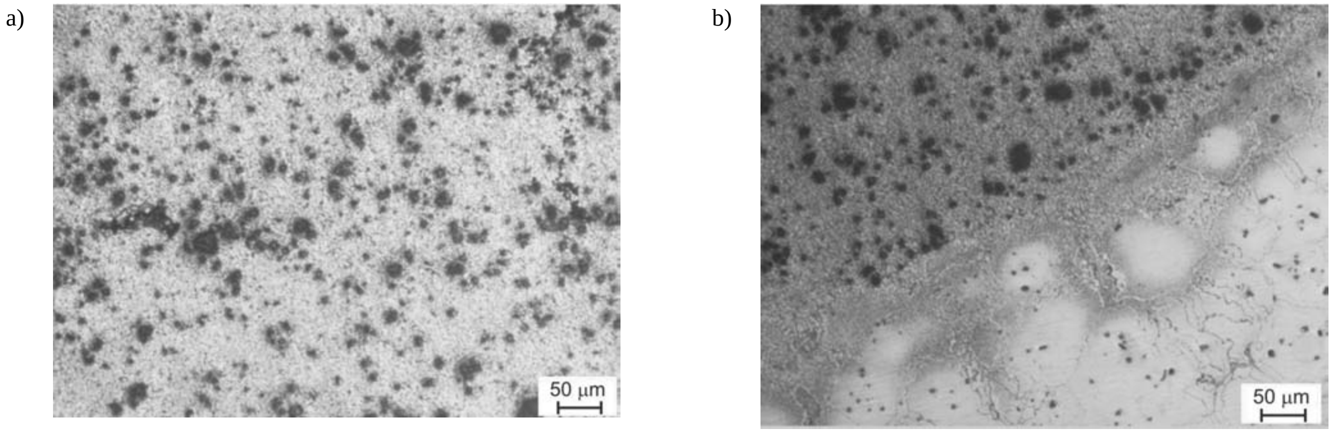
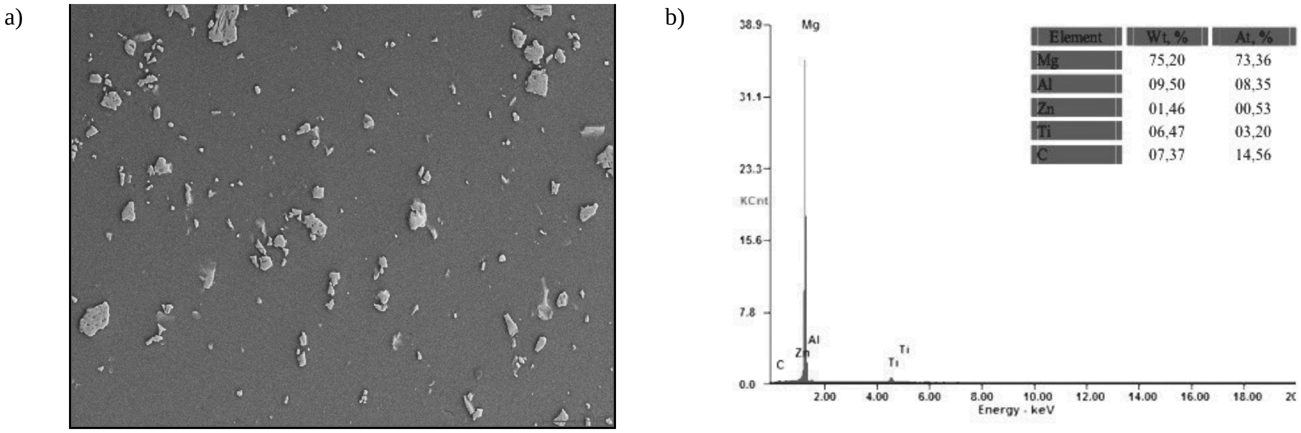
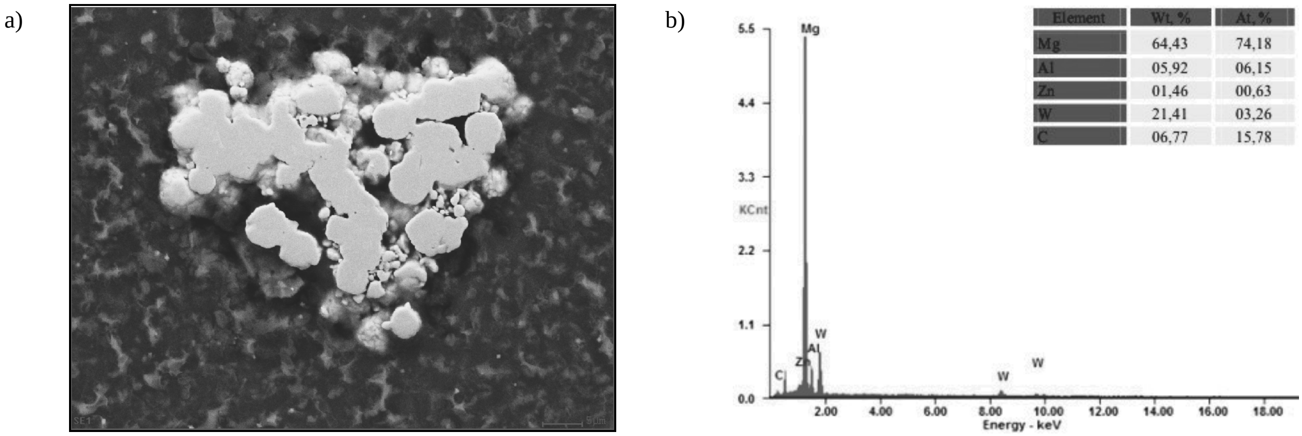


Fig. 4. a) Central zone between remelting area and substrate, b) boundary zone between remelting area and substrate, MCMgAl9Zn1 alloy after laser treatment with WC powder, laser power 1.6 kW



Element	Wt, %	At, %
Mg	75,20	73,36
Al	09,50	08,35
Zn	01,46	00,53
Ti	06,47	03,20
C	07,37	14,56

Fig. 5. a) Microstructure of the MCMgAl9Zn1 cast magnesium alloy with TiC powder, laser power 2.0 kW, b) EDS line analysis of the laser treatment samples



Element	Wt, %	At, %
Mg	64,43	74,18
Al	05,92	06,15
Zn	01,46	00,63
W	21,41	03,26
C	06,77	15,78

Fig. 6. a) Microstructure of the MCMgAl6Zn1 cast magnesium alloy with WC powder, laser power 2.0 kW, b) EDS line analysis of the laser treatment samples

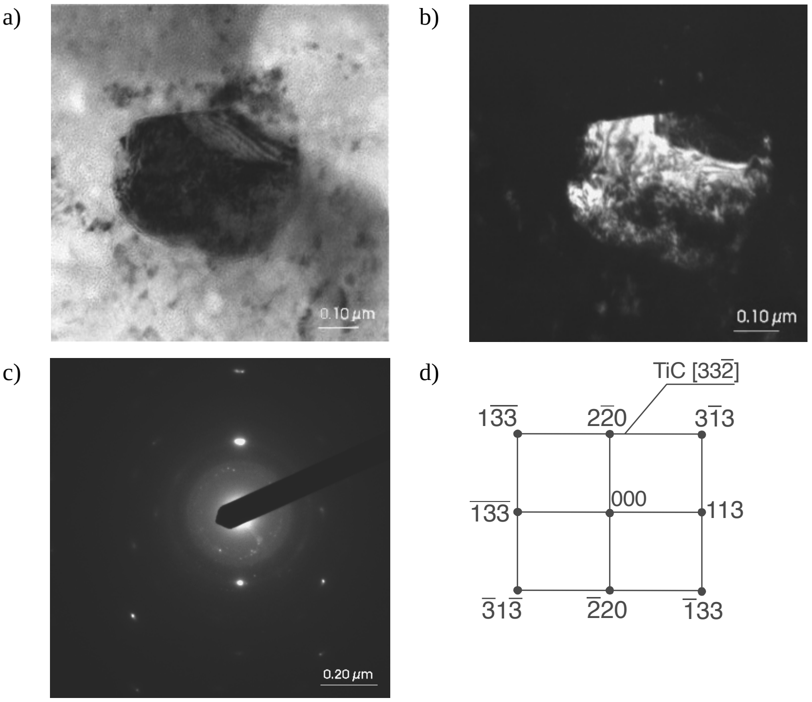


Fig. 7. Structure of the thin foil of cast magnesium alloy MCMgAl9Zn1 after laser treatment with TiC (TEM): a) light field; b) dark field from the 2-20 reflex TiC, c) diffraction pattern from the area as in a); d) solution of the diffraction pattern from c)

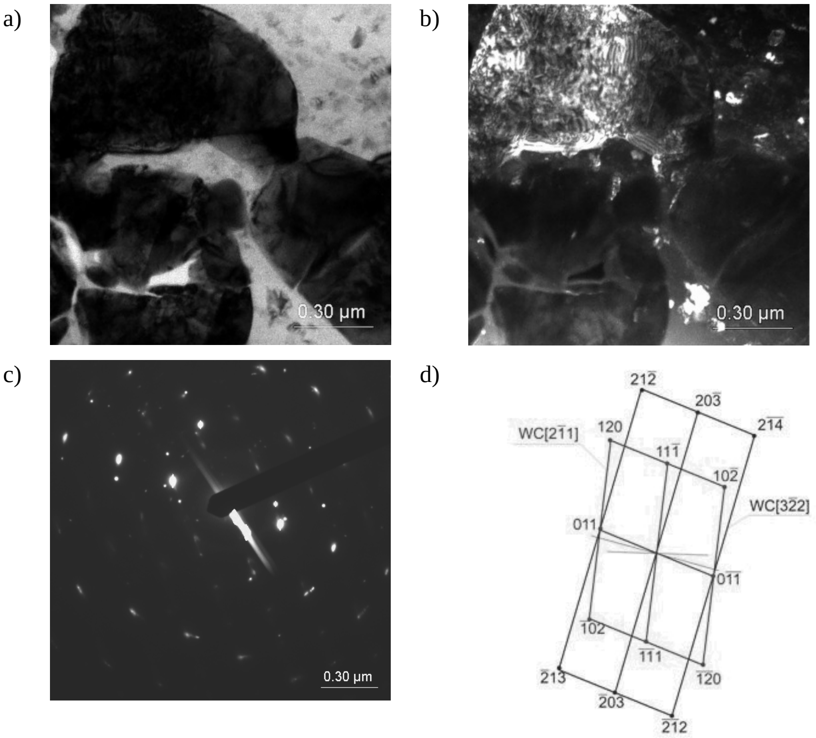


Fig.8. Structure of the thin foil of cast magnesium alloy MCMgAl6Zn1 after laser treatment with WC (TEM): a) light field; b) dark field from the 011 reflex WC, c) diffraction pattern from the area as in a); d) solution of the diffraction pattern from c)

Examination of the chemical composition using the X-ray energy dispersive spectrograph (EDS) and the X-ray quantitative microanalysis made on the transverse section of the surface layers of the Mg-Al-Zn cast magnesium alloys with the used TiC and WC powders confirm occurrence of magnesium, aluminium, zinc, carbon, and also titanium and tungsten, respectively, in the laser modified layer and indicate to the insolubility of the carbides particles (Figs. 5, 6).

Examinations of thin foils in the transmission electron microscope of cast magnesium alloys after laser treatment confirm that surface layer after laser treatment these alloys containing the type of phases were put down onto the based substrate TiC and WC, respectively (Figs. 7, 8).

Figures 9-12 present X-ray diffraction patterns of the Mg-Al-Zn cast magnesium alloys after laser treatment with powders of titanium and tungsten carbides.

Phases α – Mg, and β – $Mg_{17}Al_{12}$ were identified, as well as reflexes coming from the employed powders in all analysed cases.

Hardness tests results of the MCMgAl6Zn1 and MCMgAl9Zn1 cast magnesium alloys after laser inundation of TiC and WC carbides are presented in Fig. 13.

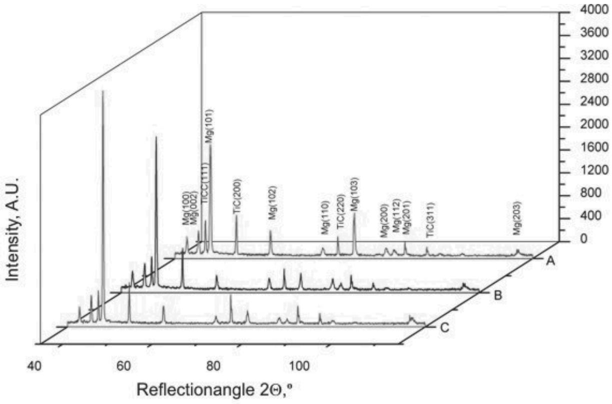


Fig. 9. X ray diffraction pattern of the: MCMgAl6Zn1 cast magnesium alloy after laser alloying with TiC: scan rate: 0.75 m/min, laser power: A-1.2 kW, B-1.6 kW, C-2.0 kW

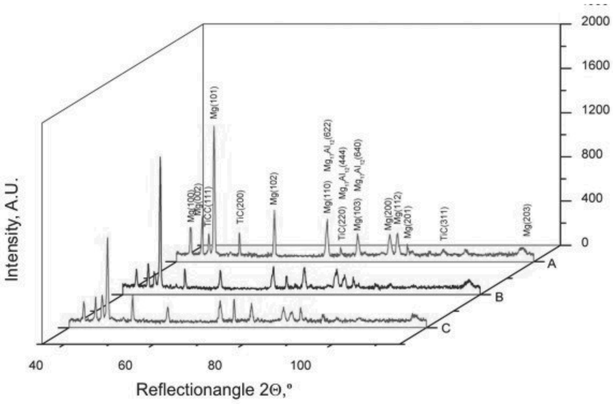


Fig. 10. X ray diffraction pattern of the: MCMgAl9Zn1 cast magnesium alloy after laser alloying with TiC: scan rate: 0.75 m/min, laser power: A-1.2 kW, B-1.6 kW, C-2.0 kW

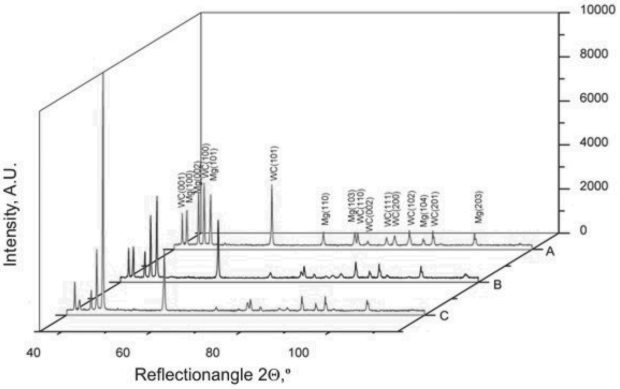


Fig. 11. X ray diffraction pattern of the: MCMgAl6Zn1 cast magnesium alloy after laser alloying with WC: scan rate: 0.75 m/min, laser power: A-1.2 kW, B-1.6 kW, C-2.0 kW

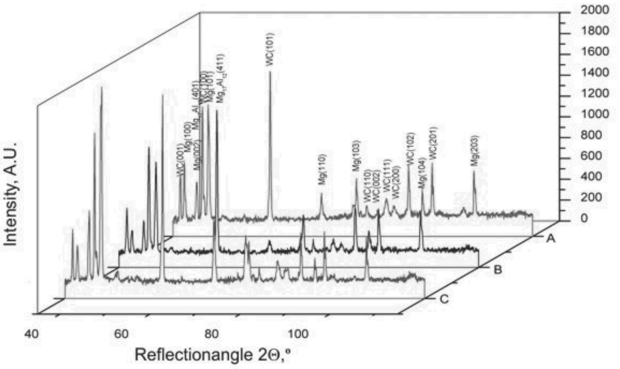


Fig. 12. X ray diffraction pattern of the: MCMgAl9Zn1 cast magnesium alloy after laser alloying with WC: scan rate: 0.75 m/min, laser power: A-1.2 kW, B-1.6 kW, C-2.0 kW

The highest hardness increment of the modified zone was observed for the MCMgAl6Zn1 alloys. Hardness increase of almost 2 times for MCMgAl6Zn1 with TiC particles was observed.

Hardness test results of the Mg-Al-Zn cast magnesium alloys after laser treatment with TiC and WC carbides reveal that in most cases for the MCMgAl6Zn1 materials their laser surface treatment results in hardness growth. Whereas, the carried out tests show that for the MCMgAl9Zn1 alloys hardness remains the same at the similar level as in case of materials without laser treatment, or – for some laser parameters – deteriorated slightly.

To compare the wear resistance, simulating the working conditions of the cast magnesium alloys, the abrasive wear investigations were made in a metal-metal system (Fig. 14).

The highest wear resistance increment of the modified zone was observed for the MCMgAl6Zn1 alloys with TiC particles.

The laser surface treated alloy with TiC shows a lower wear rate than the as-cast alloy, as expected from the increased surface hardness after laser treatment.

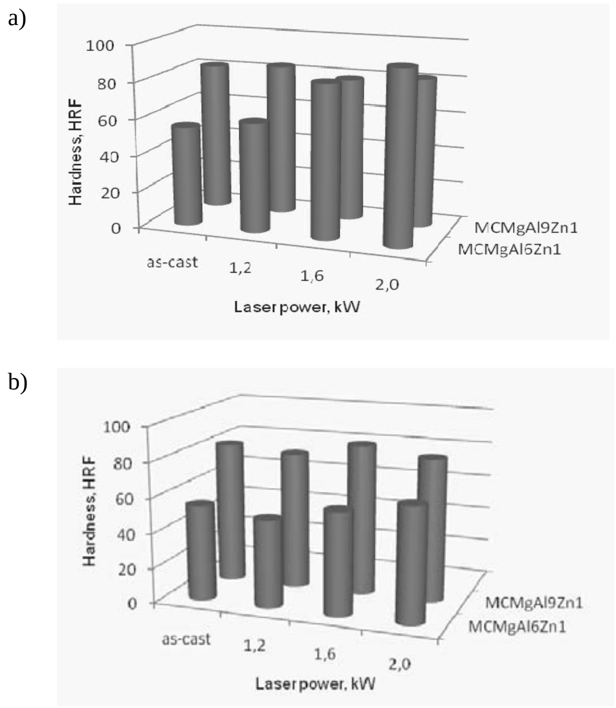


Fig. 13. Average hardness change of the cast magnesium alloys surface layer after laser treatment with a) titanium- and b) tungsten carbides with the varying laser power values and constant alloying feed rate of 0.75 m/min

Improvement in wear resistance is due to laser surface treatment and solid solution hardening. Furthermore, wear resistance in the laser treatment layer also varied with the laser parameters. The superior wear resistance behaviour of laser surface treatment layer is attributed to the refined microstructure and homogenous redistribution of hard particles in the surface layer.

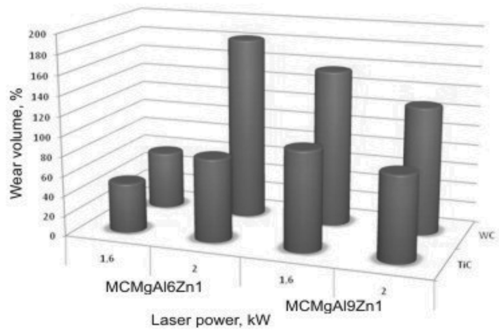


Fig. 14. Wear resistance test of cast magnesium alloys after laser treatment with TiC and WC

4. Summary

In the present study, an attempt was made to study the solidification microstructure and properties of MCMgAl6Zn1 and MCMgAl9Zn1 cast magnesium alloys after surface laser treatment. The modified layer, free of cracks or pores was formed under the condition of laser power: 1.2-2.0 kW and scan rate 0.75 m/min using the HPDL high power diode laser.

Laser treatment with the TiC and WC carbides powders, whose melting points are much higher than the melting points of the investigated alloys, causes inundation of the undissolved powder particles in the molten substrate.

Investigations of the carried out surface layers confirm that laser treatment of the surface layer of the MCMgAl6Zn1 and MCMgAl9Zn1 cast magnesium 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.

The detailed X-ray diffraction analysis shows the presence of mainly Mg, phase $Mg_{17}Al_{12}$ and peaks TiC or WC, respectively.

The hardness increase from 54, 74 HRF to 94, 52 HRF for laser surface layer of MCMgAl6Zn1 magnesium alloys with TiC, due to the presence of the hard particles. The wear resistance of the surface layer was significantly improved as compared to the substrate. Furthermore, the layer with TiC exhibited a higher wear résistance than that with WC.

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