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Laser surface treatment of cast magnesium alloys

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ABSTRACT

Purpose: The goal of this work was to investigate influence of laser treatment on structure and properties MCMgAl3Zn1, MCMgAl6Zn1, MCMgAl9Zn1 and MCMgAl12Zn1 cast magnesium alloys.

Design/methodology/approach: Tests were made on the experimental MCMgAl3Zn1 MCMgAl6Zn1 MCMgAl9Zn1 and MCMgAl12Zn1 casting magnesium alloys. Laser treatment was made using the Rofin DL020 HPDL high power diode laser in the argon shield gas cover with the technique of the continuous powder supply to the remelted pool area.

Findings: Investigations of the surface layers carried out confirm that laser treatment of the surface layer of the Mg-Al-Zn casting 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. Occurrences were found based on the metallographic examinations of the remelted zone (RZ) and the heat affected zone (HAZ) in alloyed surface layer of the investigated casting magnesium alloy.

Research limitations/implications: This investigation presents different laser power and in this research was used two powders, namely tungsten-, and titanium carbide.

Practical implications: Reinforcing the surface of cast magnesium alloys by adding TiC and WC particles is such a possible way to achieve the possibilities of the laser melt injection process, which is a potential technique to produce a Metal-Matrix Composite (MMC) layer in the top layer of a metal workpiece.

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 carbide.

Keywords: Magnesium alloy; High Power Diode Laser (HPDL); Laser melt injection; Tungsten carbide; Titanium Carbide

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Those magnesium alloys that have low density (1.75-1.85 g/cm^3) and high strength attract big interest in the automotive- and aviation- industries where lightweight materials are required. Lower fuel consumption and lower emission of harmful contamination in the automotive industry results in magnesium use growth. However, the relatively low abrasion wear resistance and low hardness of the magnesium alloys results in effect, in reduction o their use and engineering applications, especially in the aggressive environments. Therefore, attempts are made to improve abrasion wear resistance, hardness, and also corrosion resistance of the magnesium alloys by their surface treatment [1-6]. Many surface modification technologies are available currently 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. However, every coating deposition technology is limited by several main factors, among others, poor adhesion between coating and substrate, vacuum chamber needed, slow deposition, or the inconvenient equipment operation and costly fabrication procedures [7,8].

Laser treatment of the surface layer may be a better alternative compared to other technologies of the surface layer engineering of magnesium alloys [8]. The important advantages of the laser surface treatment compared to the conventional methods are: short processing time, flexibility, and operational precision [9-13]. Reduction of the vehicle mass, and therefore reduction of fuel consumption and environment pollution becomes possible thanks to substitution of the most lightweight constructional materials like magnesium alloys for steel or aluminium alloys. Possibility of full automatization of the laser treatment process of the casting magnesium alloys is pricewise competitive at the mass production scale [1-8].

In the present study, the laser surface modification was conducted by melting MCMgAl3Zn1 MCMgAl6Zn1 MCMgAl9Zn1, MCMgAl12Zn1 alloys surface and feeding the WC and TiC particles using High Power Diode Laser (HDPL Rofin DL 020). The effect of the laser parameters on the microstructure and properties was investigated.

2. Experimental procedure

The investigations have been carried out on test pieces of MCMgAl3Zn1, MCMgAl6Zn1, MCMgAl9Zn1, MCMgAl12Zn1 magnesium alloys after heat treatment states. The chemical composition of the investigated materials 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 water and then ageing at temperature of 190°C, holding for 15 hours and cooling in air.

Plates of 50x18x10 mm were polished with 1200-grit SiC paper prior to laser surface treatment to obtain smooth surface and then cleaned with alcohol and dried.

Powders of titanium and tungsten carbides with granulation above 6 μm were used for alloying.

Injection laser was performed by high power laser diode HPDL Rofin DL 020 under an argon shielding gas. Argon was used during laser re-melting to prevent oxidation of the coating and the substrate. The process parameters during the present investigation were: laser power – 1.2; 1.6; 2.0 kW, scan rate – 0.75 m/min.

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 as an etching in nital at room temperature has been used. The observations of the investigated cast materials have been made on the light microscope LEICA MEF14A as well as on Zeiss SUPRA 35 scanning electron microscope using the secondary electrons detection.

Linear analysis of the chemical composition changes made on transverse microsections on Zeiss SUPRA 35 scanning electron microscope dispersive radiation spectrometer on the Trident XM4 EDAX company.

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.

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.

3. Discussion of experimental results

Laser treatment of the MCMgAl3Zn1, MCMgAl6Zn1, MCMgAl9Zn1 and MCMgAl12Zn1 casting magnesium alloys was carried out by continuous feeding of the carbide particles of: titanium and tungsten into the pool area developed on the alloyed surface using the high power diode laser.

The clear effect of process parameters was observed, and especially of the laser beam power and particles used on beam face shape and surface topography. The beam face, after alloying with TiC and WC powders with the feeder, is characteristic of the regular, flat surface (Fig. 1).

Table 1.
Chemical composition of investigation alloy

Type of alloy	The mass concentration of main elements, %												
	Al	Zn	Mn	Cu	Si	Fe	Ni	Sn	Pb	Be	Zr	Ce	Mg
MCMgAl12Zn1	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
MCMgAl9Zn1	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
MCMgAl6Zn1	5.624	0.46	0.16	0.0024	0.034	0.07	0.0017	0.0009	0.034	0.0003	0.003	0.01	93.6
MCMgAl3Zn1	2.706	0.21	0.10	0.0018	0.032	0.005	0.0020	0.0008	0.013	0.0001	0.003	0.01	96.9

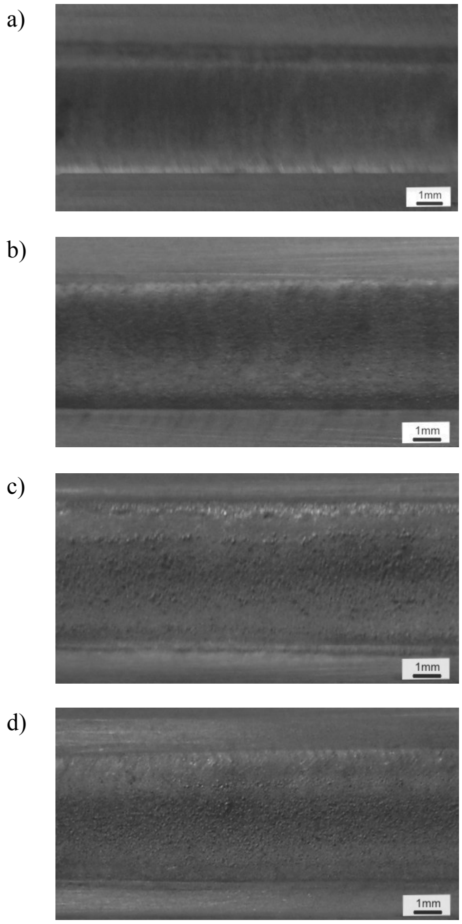

Fig. 1. View of the bead face of the surface layer of the casting magnesium alloys after innudation of TiC powder: a) MCMgAl9Zn1, laser power: 1.2 kW, b) MCMgAl3Zn1, laser power: 1.2 kW; after inundation of WC powder: c) MCMgAl12Zn1; laser power: 1.6 kW, d) MCMgAl3Zn1; laser power: 1.6 kW, at the constant innudation feed rate of 0.75 m/min

The metallographic examinations results show that the structure of the material solidifying after laser remelting is characteristic of occurrences 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. Microstructure of the laser modified layer contains mostly the dispersive particles of the employed carbide in the Mg-Al-Zn alloy matrix (Figs. 2, 3). 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.

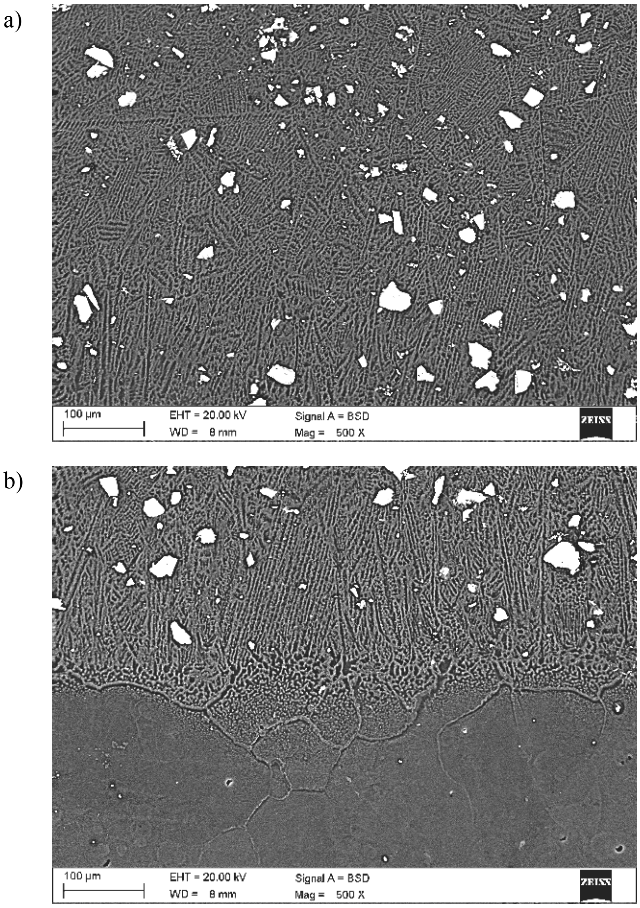

Fig. 2. a) Central zone between remelting and substrate, b) boundary zone between remelting and substrate, MCMgAl3Zn1 alloy after alloying with TiC powder, laser power: 1.2 kW, feed rate: 0.75 m/min

Examinations carried out on the scanning electron microscope confirmed occurrence of the zonal structure of the surface layer of the investigated casting 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 used. Morphology of the alloyed area, including the content and distribution of carbides particles also is dependant on laser parameters. During metallographic examinations of the MCMgAl3Zn1, MCMgAl6Zn1, MCMgAl9Zn1, and MCMgAl12Zn1 alloys a uniform distribution was observed of the employed TiC and WC carbides particles in the entire remelting zone (Figs. 2a, 3a).

Occurrences were found based on the metallographic examinations of the remelted zone (RZ) and the heat affected zone (HAZ) in every alloyed surface layer of the investigated MCMgAl12Zn1 and MCMgAl9Zn1 casting magnesium alloy (Figs. 3b, 4). These zones have different thickness depending on laser power and ceramic powder used. A slight HAZ was observed in case of alloying with TiC and WC powders of the MCMgAl6Zn1 alloys, growing with the laser power increase. In case of alloying the MCMgAl3Zn1 alloys only the remelted zone develops and the boundary between the remelted zone and the native material (Fig. 2b).

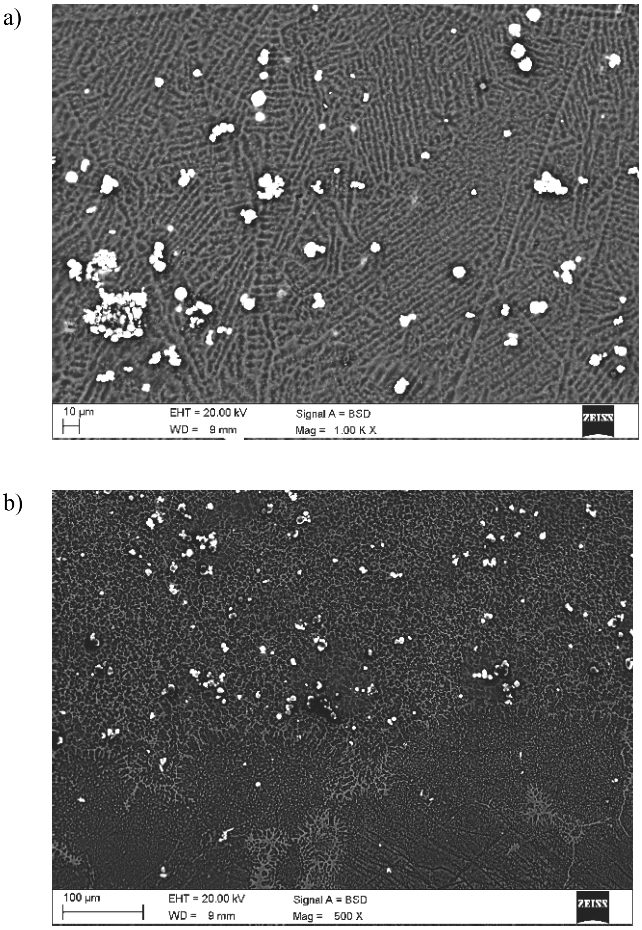

Fig. 3. a) Central zone between remelting and substrate, b) boundary zone between remelting and substrate, MCMgAl12Zn1 alloy after alloying with WC powder, laser power: 1.6 kW, feed rate: 0.75 m/min

Effect of laser power and substrate material on thickness of the: remelted zone RZ, heat affected zone HAZ, and surface layer SL of the casting magnesium alloys alloyed with titanium carbide and tungsten carbide are presented on Figs. 5a and 5b, respectively.

Fig. 6 shows the X-ray diffraction pattern of the laser surface treated MCMgAl9Zn1 alloy with TiC and WC particles consists of presence of Mg-α, $Mg_{17}Al_{12}$ and also TiC or WC peaks, respectively.

Basing on the results of the metallographic investigations one may state that the laser power change at the constant alloying feed rate results clearly in growth of both zones in the surface layer.

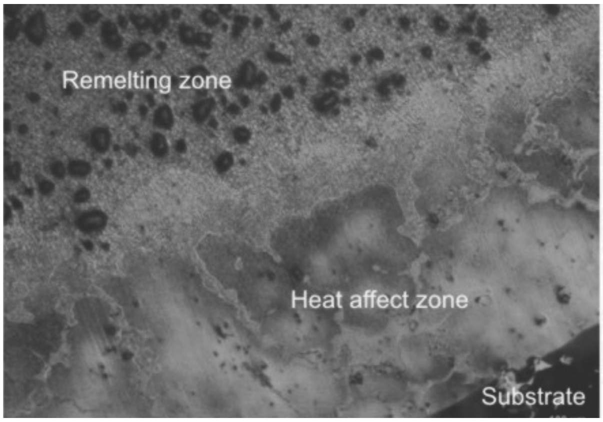

Fig. 4. Remelting path edge of the MCMgAl12Zn1alloy surface layer after alloying with the TiC powder, laser power: 1.6 kW, feed rate: 0.75 m/min

Linear analysis of the chemical composition changes (Fig. 7) examination of the chemical composition made on the transverse section of the surface layers of the Mg-Al-Zn casting magnesium alloys with TiC powders used confirm occurrences of magnesium, aluminium, titanium and carbon in the laser modified layer.

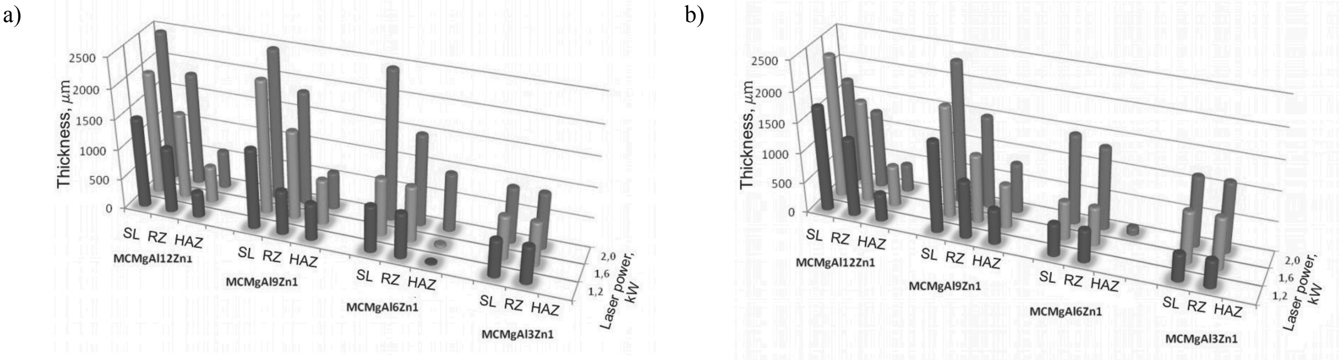

Fig. 5. Effect of laser power and substrate material on thickness of the: remelted zone RZ, heat affected zone HAZ, and surface layer SL of the casting magnesium alloys alloyed with a) titanium carbide, b) tungsten carbide

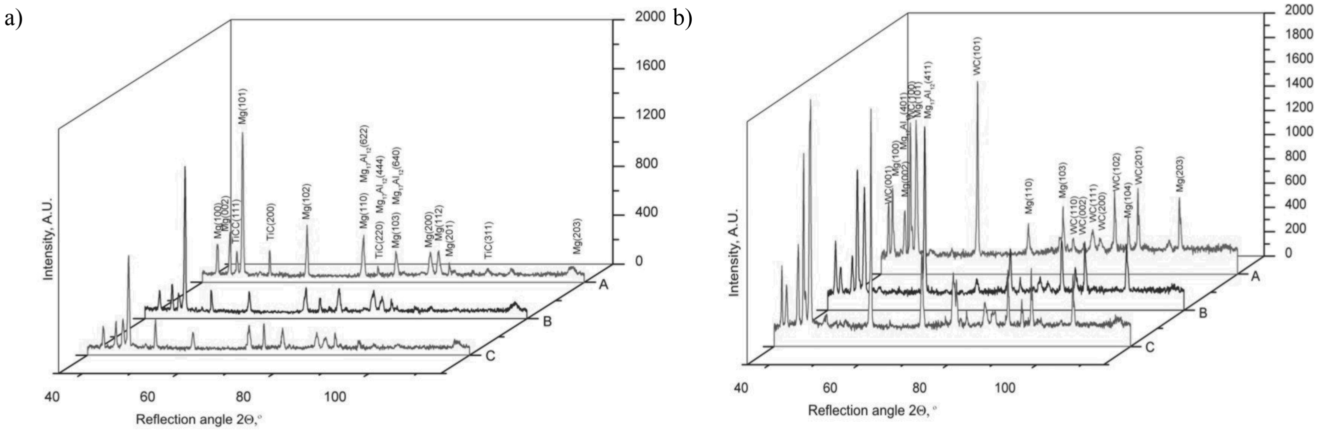

Fig. 6. X ray diffraction pattern of the: ENMCMgAl9Zn1 cast magnesium alloy after laser alloying with a) TiC, b) WC, powder feed rate: 7±1 [g/min], scan rate: 0.75 [m/min], laser power: A-1.2 kW,B-1.6 kW, C-2.0 kW

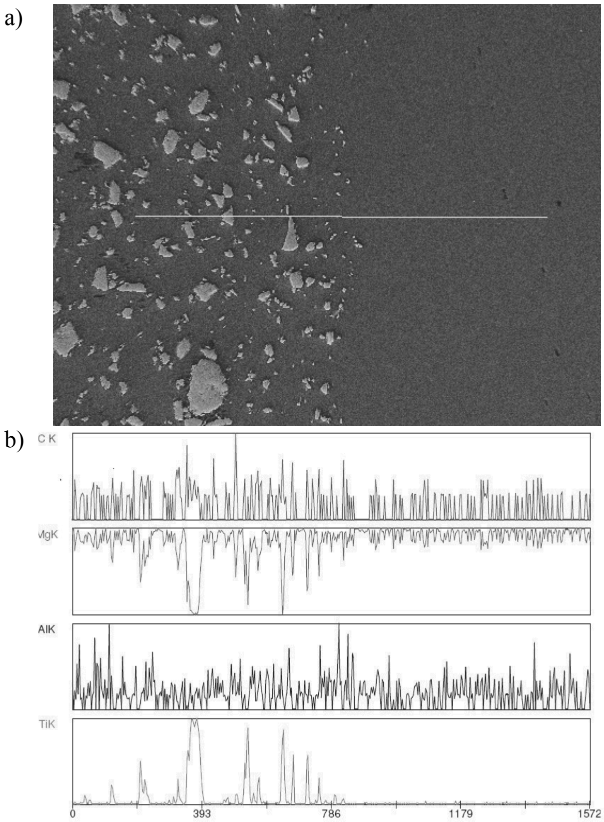

Fig. 7. Boundary between the alloyed layer and matrix of the MCMgAl9Zn1 casting magnesium alloy after laser alloying with the TiC particles, a) structure, b) linear analysis if the chemical composition changes

Hardness test results of the Mg-Al-Zn casting magnesium alloys after laser remelting and alloying with WC, TiC carbides reveal that in most cases for the MCMgAl6Zn1, MCMgAl3Zn1 materials their laser surface treatment results in their hardness growth; whereas, for the MCMgAl12Zn1, MCMgAl9Zn1 alloys their hardness does not increase, and to the contrary, for some alloying parameters used deteriorates slightly.

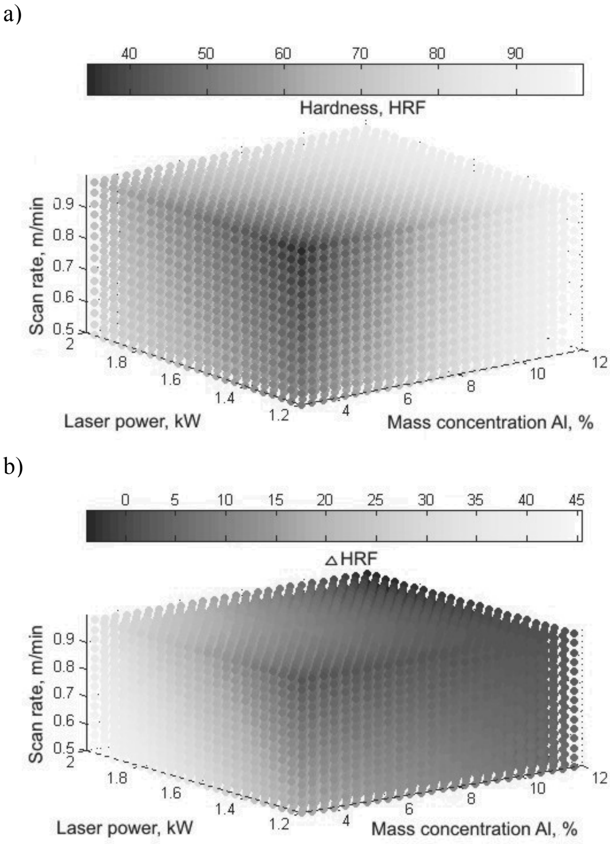

Fig. 8. Plot of the regression function describing relationship of the a) hardness, b) increment hardness with the mass portion of aluminium in magnesium alloys, laser power, and also alloying scan rate for the material laser alloyed with titanium carbide

The effect of alloying conditions (laser power, alloying feed rate) with the TiC powder and substrate type on hardness and its growth was described with the regression function (Fig. 8). It was found based on the regression function variability analysis that hardness growth occurs along with the laser power decrease and with the aluminium concentration in the alloy growth and also with the lowering alloying feed rate.

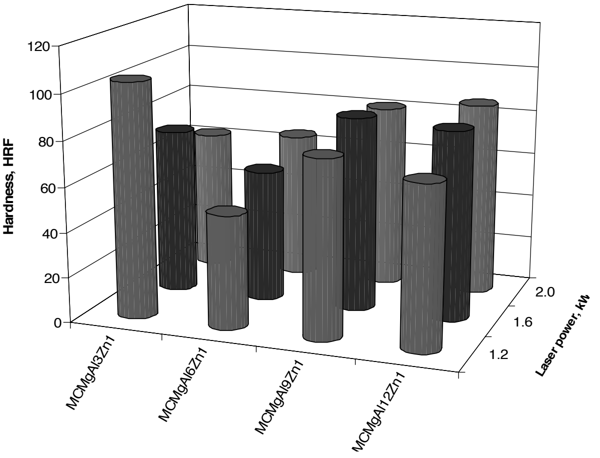

Fig. 9. Average hardness change of the casting magnesium alloys surface layer after laser alloying with tungsten carbide with the varying laser power values and constant alloying feed rate of 0.75 m/min

The date above confirm results obtained in case of alloying the casting magnesium alloys with the tungsten carbide powders, corresponding to the biggest hardness increase which occurred for the MCMgAl3Zn1 and MCMgAl6Zn1 alloys also in this case (Fig. 9). As regards the MCMgAl9Zn1 and MCMgAl12Zn1 alloys, their hardness remains at the similar level as in case of materials without laser treatment.

4. Conclusions

Laser power in the 1.2-2.0 kW range ensures capability to obtain the flat, regular remelting paths, with high surface smoothness. Alloying with TiC and WC powders whose melting point is significantly higher than the melting points of the casting alloys does not result in development of new phases because the inundated carbides particles do not dissolve. Two zones occur in the surface layer of the investigated casting magnesium alloys: remelting zone (RZ) and the heat affected zone (HAZ), whose thickness grows along with the increase of the laser power employed. High cooling rate causes occurrences of the super-fast phase transformations; therefore, the fine-grained structure occurs in the material, responsible for hardness growth. The highest hardness increase was observed for the MCMgAl3Zn1 alloys. Laser power increase affects also significantly hardness growth; however, this relationship cannot be confirmed in case of the MCMgAl3Zn1 alloyed with WC carbide. The MCMgAl12Zn1 casting magnesium alloys after laser alloying demonstrate similar hardness tests results, in reference to hardness of the alloys before their laser treatment.

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