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Laser Surface Treatment of Mg-Al-Zn Alloys

Leszek Adam DOBRZANSKI[1)]***, Tomasz TANSKI***[1)]***, Szymon MALARA***[1)]***, Justyna DOMAGALA***[1)] and ***Andrzej KLIMPEL***[2)]

1) Division of Materials Processing Technology and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, **Poland**

2) Welding Department, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, **Poland**

leszek.dobrzanski@polsl.pl

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In this paper the structure and properties investigations results of the cast magnesium alloys in the as cast state, after heat treatment and laser surface treatment are presented. The aim of this work was to improve the surface layer properties of the Mg-Al-Zn cast magnesium alloys by melting and feeding of TiC, VC, WC, SiC, NbC and Al2O3 particles onto the surface. Laser processing was carried out using high diode power laser (HDPL). A series of experiments was carried out with varying scan rates and laser power. The resulting surface layers were examined using metallographic optical microscopy, scanning electron microscopy, X-ray diffraction, microhardness measurements and corrosion resistance tests. Mg-Al-Zn alloys after laser treatment are characterized by two zones: alloyed zone (AZ) and heat affected zone (HAZ) with different thickness and shape depending on laser power and ceramic powder used. Alloyed zone is composed mostly of dendrites with the $Mg_{17}Al_{12}$ lamellar eutectic and Mg in the interdendritic areas. The increase of microhardness from about 50 $HV_{0,1}$ to about 200 $HV_{0,1}$ in alloyed zone were observed.

Površinska obrada laserom Mg-Al-Zn legura

Izvornoznanstveni članak

U ovom radu prezentirana je struktura i mehanička svojstva ljevačke magnezijske legure u ljevačkom stanju, nakon toplinske obrade i obrade površine laserom. Cilj ovog rada je unaprijediti svojstva površinskog sloja Mg-Al-Zn ljevačke magnezijske legure taljenjem i dodavanjem čestica TiC, VC, WC, SiC, NbC i Al_2O_3 na površinu. Obrada laserom izvodila se laserom visoke snage na diodi (HDPL). Serija eksperimenata izvodila se varirajući brzinu skeniranja i snagu lasera. Rezultirajući sloj na površini ispitivalo se metalografskim svjetlosnim mikroskopom, scanning elektronskim mikroskopom, difrakcijom x-zrakama, mjerenjem tvrdoće i mikrotvrdoće i testovima korozijske otpornosti. Poboljšanje proizvodne tehnike i kemijskog sastava kao i metoda toplinske obrade dovode do razvoja projektiranja materijala za optimalna fizikalna i mehanička svojstva novorazvijenih legura.

1. Introduction

Contemporary materials should possess high mechanical properties, physical and chemical, as well as technological ones, to ensure long and reliable use. The above mentioned requirements and expectations regarding contemporary materials are met by the non-ferrous metal alloys used nowadays, including magnesium alloys. Magnesium alloys and their derivatives, such as materials from the lightweight and ultra-lightweight family, are characterised by low density (1.5-1.8 g/cm^3) and high strength in relation to their weight [1-6]. Designers are more and more closely cooperating with magnesium alloy manufacturers, which is a good example of the fact that currently about 70 % of magnesium alloy castings are made for the automotive industry. A good capability of damping vibrations and low inertia connected with a relatively low weight of elements have predominantly contributed to the employment of magnesium alloys for the fast moving elements and in locations where rapid velocity changes occur; some good examples may be car wheels, combustion engine pistons, high-speed machine tools, aircraft equipment elements, etc. [1-6]. Many surface modification technologies are available to improve properties of the surface layers of magnesium alloys, among others: electrocoating, anodizing, coating with layers obtained with PVD process, laser alloying/pad welding of their surface. Laser alloying, also called enrichment, features one of the contemporary thermo-chemical treatment methods, whose idea is to enter the alloying elements into the alloyed material where both materials are fused, when at least one of them is in the liquid state. Rapid cooling and solidification of the molten metal occur because of the big temperature gradient on the boundary of the remelted

Symbols/Oznake

AZ	- Alloyed zone - područje legiranja	HPDL	- high power diode laser - laserska dioda visoke snage
HAZ	- Heat Affected Zone - područje utjecaja topline	HV	- Vickers hardness - tvrdoća po Vickersu
SEM	- Scanning electron microscope - elektronski mikroskop	Θ	- Azimuth of electron scanning - Azimut skeniranja električnim mikroskopom
SE	- secondary electrons - sekundarni elektroni		

surface layer and substrate. Cooling rates acquired at these conditions reach 10^{11} K/s, whereas the solidification rates exceed 20 m/s in many cases, which in relation to some materials may result in self-quench hardening of the thin substrate layer. Laser alloying makes it possible to develop layers with special service properties [2,3,7-9].

2. Experimental procedure

The investigations have been carried out on test pieces of the MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1 and MCMgAl3Zn1 magnesium alloys after heat treatment performed. The chemical composition of the investigated material is presented in Table 1. The heat treatment involved the solution heat treatment (heating of the material in a temperature of 375 °C for 3 hours, next heating in the temperature at 430 °C, hold for 10 hours) and cooling in water with next ageing at a temperature of 190 °C, hold for 15 hours and cooling in air.

Plates of dimension of 50x18x10 mm were polished with 1200-grit SiC paper prior to laser surface treatment to obtain a smooth surface and then cleaned with alcohol and dried. Six types of carbides were used in the present study for the alloying process, namely titanium, vanadium, tungsten, silicon and niobium carbides and aluminium oxide (Table 2).

Laser melt injection was performed by a 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 kW, scan rate 0.25÷1.0 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 structure and to distinguish precisely the particular precipitations occured in magnesium alloys, nital was used as an etching agent at room temperature. The observations of the investigated cast materials have been made on the optical microscope LEICA MEF14A as well as on Zeiss SUPRA 35 scanning electron microscope using secondary (SE) electrons detection. Phase constitution and crystallographic structure were determined by the X-ray diffraction method using the XPert device with

Table 1. Chemical composition of the investigation alloys

Tablica 1. Kemijski sastav istraživanih legura

	Mass concentration of main alloying elements / Maseni udio glavnih elemenata legure, %						
	Al	Zn	Mn	Si	Fe	Mg	Rest
MCMgAl12Zn1	12,1	0,617	0,174	0,0468	0,0130	86,9507	0,0985
MCMgAl9Zn1	9,09	0,77	0,21	0,037	0,011	89,7905	0,0915
MCMgAl6Zn1	5,92	0,49	0,15	0,037	0,007	93,3347	0,0613
MCMgAl3Zn1	2,96	0,23	0,09	0,029	0,006	96,6489	0,0361

Table 2. Alloyed powders properties

Tablica 2. Svojstva legiranih prahova

Powder / Prah	Grain size / Veličina zrna, μm	Density / Gustoća, g/cm^3	Melting point / Talište, ºC	Hardness / Tvrdoća, HV
TiC	>6.4	4,25	3140	1550
VC	>6.4	5,36	2830	2850
WC	>6.4	15,69	2870	3400
SiC	<75	3,44	1900	1600
NbC	<75	7,60	3500	2100
Al_2O_3	80	3,97	2047	2300

a cobalt lamp, with 40 kV voltage. The measurement was performed at an angle range of 2Θ: 20º - 140º. 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 a loading time of 15 s and the testing load of 100 g.

3. Discussion of results

Laser treatment of the casting magnesium alloys was carried out by continuous feeding of the carbide particles of: titanium, vanadium, tungsten, silicon and niobium and aluminium oxide into the pool area developed on the alloyed surface in the laser beam focus spot using the HPDL high power diode laser. As a investigation result an alloyed zone (AZ) and a heat affected zone (HAZ) in every alloyed surface layer were found based on metallographic examinations (Figs. 1-6). These zones have different thickness and shape depending on laser power and ceramic powder used. Based on the results of the metallographic investigations, one may state that the laser power changes at the constant speed of alloying results clearly in growth of both zones in the surface layer (Table 3). Applied laser power also affects the shape and convexity of the alloyed zone, raising it above the surface of material subjected to treatment.

Examinations carried out on the scanning electron microscope confirmed the occurrence of the zonal structure of the surface layer of the investigated cast magnesium alloys (Figs. 7-9). The dendritic structure is present in the alloyed zone (Figs. 4-9), 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 carbide particles also depends on laser parameters applied. 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 an 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 on the layout of the alloyed elements and changes of the process parameters of the laser treated surface.

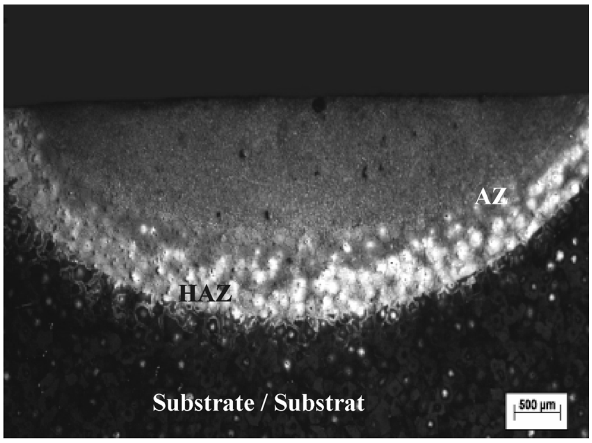

Figure 1. Surface layer of the MCMgAl9Zn1 alloy alloyed with WC powder, laser power 1.2 kW, scan rate 0.75 m/min

Slika 1. Površinski sloj legure MCMgAl9Zn1 s WC prahom, snage lasera 1.2 kW, brzinom s keniranja 0.75 m/min

Figure 7 presents X-ray diffraction patterns of the Mg-Al-Zn casting magnesium alloys after laser alloying with TiC, VC, WC and SiC powders. Phases α – Mg, and β – $Mg_{17}Al_{12}$ were identified for all Mg-Al-Zn alloys, as well as reflexes coming from the employed powders in all analyzed cases. Researches were revealed a lack of dissolution of alloyed powder particles during laser alloying process.

Table 3. Thickness of the alloyed zone (AZ) and the heat affected zone (HAZ) of the MCMgAl12Zn1 alloy alloyed with a rate of 0.75 m/min

Tablica 3. Debljina legirane zone (AZ) i zone utjecaja topline (HAZ) legura the MCMgAl12Zn1 legirane brzinom 0.75 m/min

Powder / Prah	Laser power / Snaga lasera, kW	Thickness /Debljina, µm	
		AZ	HAZ
TiC	1.2	1,07	0,41
	1.6	1,41	0,60
	2.0	1,85	0,61
VC	1.2	1,25	0,43
	1.6	1,46	0,60
	2.0	1,70	0,55
WC	1.2	1,28	0,45
	1.6	1,67	0,67
	2.0	1,63	0,54
SiC	1.2	1089	507
	1.6	2182	761
	2.0	2828	1181

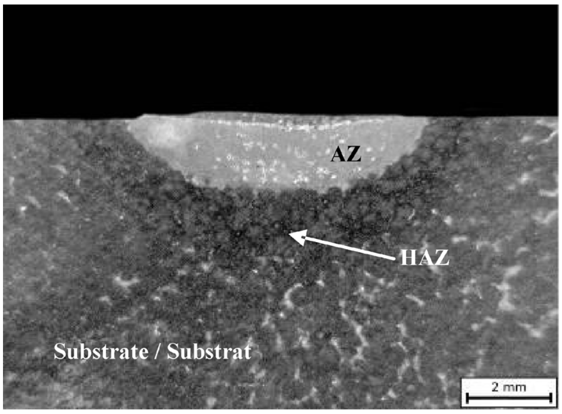

Figure 2. Surface layer of the MCMgAl6Zn1 alloy alloyed with Al2O3 powder, laser power 2.0 kW, scan rate 0.50 m/min

Slika 2. Površinski sloj legure MCMgAl9Zn1 s Al2O3 prahom, snage lasera 2.0 kW, brzinom skeniranja 0.50 m/min

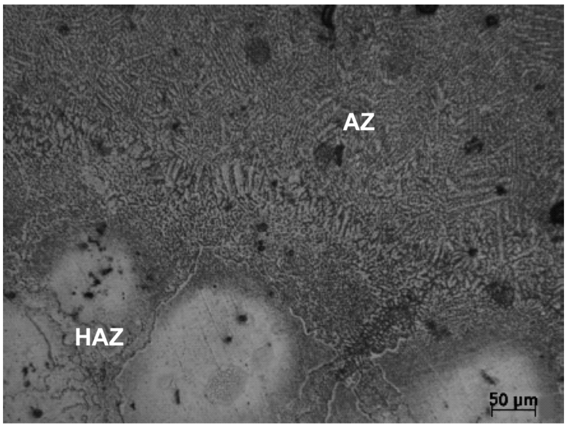

Figure 3. Boundary between THE alloyed zone and heat affected zone of THE MCMgAl9Zn1 alloy after alloying with TiC, laser power 1.2 kW, scan rate: 0.75 m/min

Slika 3. Granica između legirane zone i zone utjecaja topline legure MCMgAl9Zn1 nakon legiranja s TiC, snaga lasera 1.2 kW, brzina skeniranja 0.75 m/min

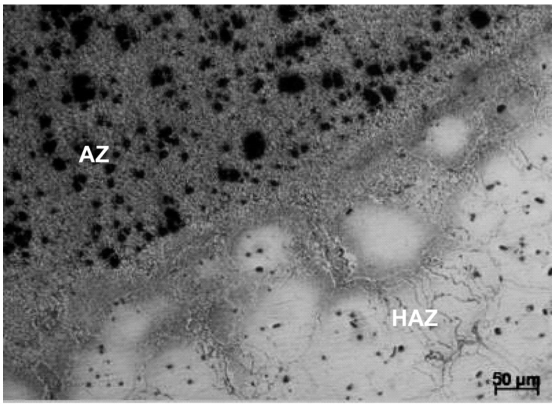

Figure 4. Boundary between alloyed zone and heat affected zone of the MCMgAl9Zn1 alloy after alloying with WC, laser power 1.6 kW, scan rate: 0.75 m/min

Slika 4. Granica između legirane zone i zone utjecaja topline legure MCMgAl9Zn1 nakon legiranja s WC, snaga lasera 1.6 kW, brzina skeniranja 0.75 m/min

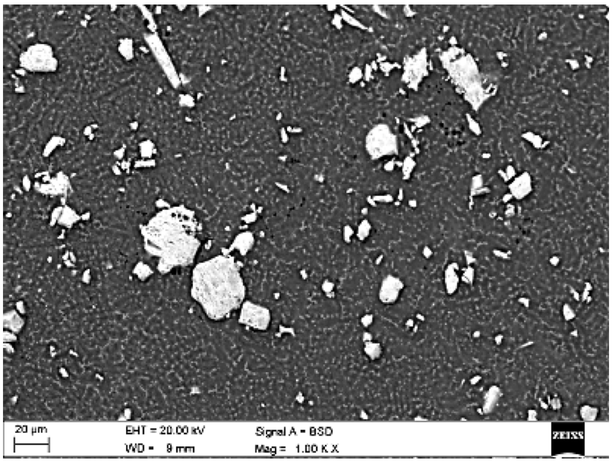

Figure 5. Centre of alloyed zone of the MCMgAl12Zn1 alloy after alloying with TiC, laser power: 2.0 kW, a scan rate: 0.75 m/min (SEM)

Slika 5. Centar legirane zone legure MCMgAl12Zn1 nakon legiranja s TiC, snaga lasera: 2.0 kW, brzina skeniranja: 0.75 m/min (SEM)

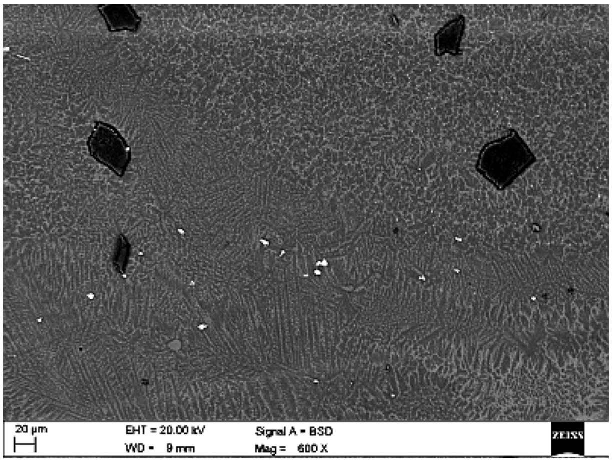

Figure 6. Boundary between the alloyed zone and heat affected zone of the MCMgAl9Zn1 alloy after alloying with SiC, laser power 1.6 kW, scan rate: 0.75 m/min (SEM)

Slika 6. Granica između legirane zone i zone utjecaja topline legure MCMgAl9Zn1 nakon legiranja s SiC, snaga lasera 1.6 kW, brzina skeniranja: 0.75 m/min (SEM)

Microhardness, test results, depending on distance from surface (Fig. 8), has shown that microhardness increases in the surface layer. The increase of hardness in the alloyed zone is resulting from considerable structure refinement of magnesium containing phase (100-300 $HV_{0,1}$) and very hard carbides particles (about 1500-1600 $HV_{0,1}$) occurrence in this area. Values between 300 and 800 $HV_{0,1}$ are connected with the influence of carbide and oxide particles on the microhardness of the areas near to the hard particles. Increase of alloying particles quantity causes also the increase of microhardness of alloyed surface.

4. Conclusion

Surface layer examinations confirm that it is possible to carry out surface layer alloying of the cast magnesium alloys using the HPDL high power diode laser with beam power values in the range of 1.2÷2.0 kW and with an alloying feed rates of 0.25÷1.0 m/min. Laser alloying of the TiC, VC, WC, SiC carbides and Al_2O_3 oxide powders, whose melting points are much higher than the melting points of the investigated alloys, causes inundation of the non-dissolved powder particles into the molten substrate. Strong circulation of the molten metal occurs, followed by sudden solidification when the laser beam has passed. The width of the surface layer increases with the applied laser power increase. Alloyed area is composed of dendrites with the $Mg_{17}Al_{12}$ and Mg lamellar eutectic in the interdendritic areas, whose main axes are oriented according to the heat transfer directions. A lack of dissolution of carbide and oxide particles during laser alloying process and microhardness increasing of the alloyed zone were revealed. These results lead to an conclusion that laser surface treatment of Mg-Al-Zn alloys should be further developed and investigated particularly for instance for large surface elements application.

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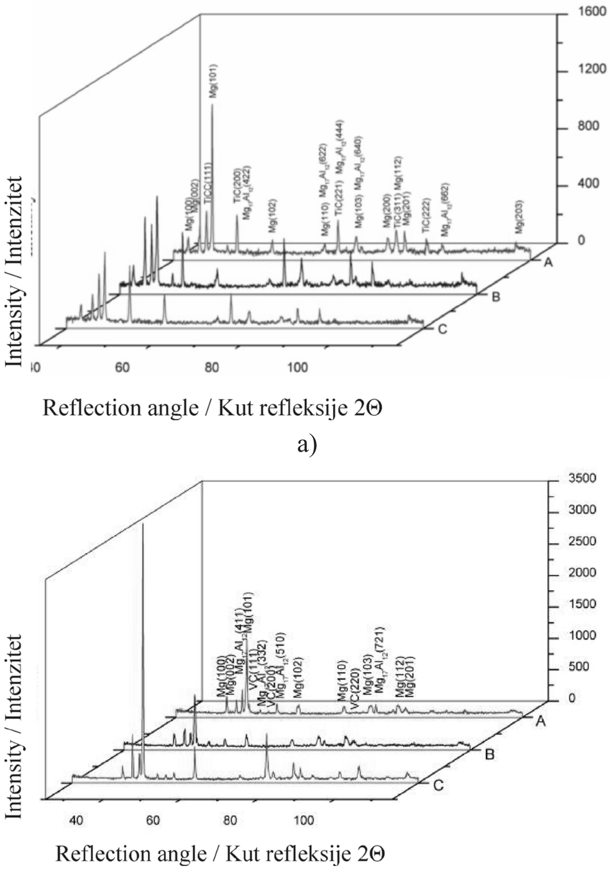

a)

b)

Figure 7. X-ray diffraction pattern of the cast magnesium alloy after laser alloying with a) MCMgAl12Zn1 alloyed with TiC, b) MCMgAl6Zn1 alloyed with VC; scan rate: 0.75 m/min, laser power: A-1.2 kW, B-1.6 kW, C-2.0kW

Slika 7.Uzorak za difrakciju X-zrakama lijevane magnezijske legure nakon legiranja laserom s a) MCMgAl12Zn1 legirano s TiC, b) MCMgAl6Zn1 legirano s VC; brzina skeniranja: 0.75 m/min, snaga lasera: A-1.2 kW, B-1.6 kW, C-2.0kW

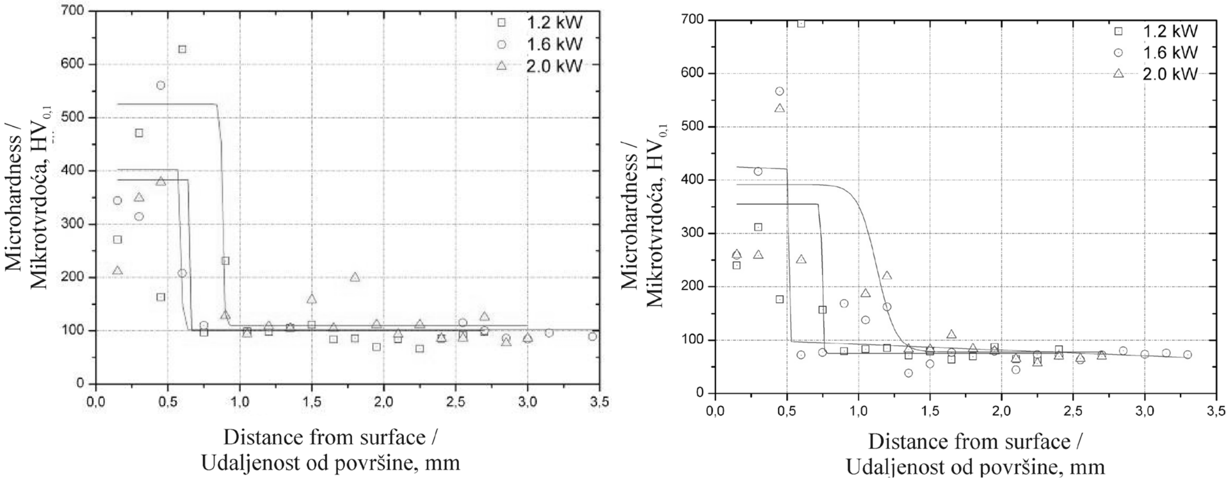

Figure 8. Cross-section microhardness profile from the surface: a) MCMgAl12Zn1 alloy, b) MCMgAl6Zn1 alloy alloyed with SiC powder, scan rate: 0.75 m/min

Slika 8. Raspodjela mikrotvrdoće po poprečnom presjeku od površine: a) legura MCMgAl12Zn1, b) legura MCMgAl6Zn1 legirana s SiC, brzina skeniranja 0.75 m/min

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