Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 28
ISSUE 2
June
2008

Laser surface treatment of magnesium alloy with WC and TiC powders using HPDL

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Received 27.03.2008; published in revised form 01.06.2008

Manufacturing and processing

ABSTRACT

Purpose: The aim of this work was to improve the surface layer cast magnesium alloy EN-MCMgAl6Zn1 by laser surface treatment. The purpose of this work was also to determine the laser treatment parameter.

Design/methodology/approach: The laser treatment of an EN-MCMgAl6Zn1 magnesium alloy with alloying WC and also TiC powders was carried out using a high power diode laser (HPDL). The resulting microstructure in the modified surface layer was examined using scanning electron microscopy. Phase composition was determined by the X-ray diffraction method using the XPert device. The measurements of microhardness of the modified surface layer was also studied.

Findings: The alloyed region has a fine microstructure with hard carbide particles. Microhardness of laser surface alloyed layer with both TiC and WC particles was significantly 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 5µm This investigation presents different speed rates feed by one process laser power.

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 CO2 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 carbide and titanium carbide.

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

1. Introduction

Magnesium alloys have been used for a wide variety of applications, the reason is their low density and high strength–to–weight ratio. In many industry fields, application of magnesium alloys is limited by their some undesirable properties, namely poor resistance to corrosion and wear [1, 4]. To improve wear resistance and corrosion of magnesium alloys one has to coat the base material. There are a number of possible coating technologies available for magnesium alloys, such as: electrochemical plating, conversion coatings, gas-phase deposition processes, laser surface alloying/cladding. Short processing time, flexibility in operation and precision are very important factors of laser surface treatment over conventional processes. In laser alloying, a laser beam is scanned across the surface of a work piece in order to melt a layer of material in a heat conduction mode. In the molten state, the metal is enriched with alloying elements which may be introduced from either gaseous or solid consumables using a variety of delivery techniques[2, 3, 5-8, 11, 13, 16].

Majumdar et al. [9, 10] have studied magnesium alloys surface cladding by CO_2 laser, they concluded that properties such as corrosion and wear resistance were improved. In order to improve the wear resistance of a commercial magnesium alloy, simultaneous dispersion of Al_2O_3 particles and alloying with Al was carried out by feeding a mixture of the powders. Laser surface alloying of AZ91E alloy with SiC and TiC hard particles by injection process into the molten pool of magnesium, has been used to modify magnesium alloy to improve resistance to sliding wear [12]. Modification of surface layer of Mg alloys AZ91 by laser cladding was also investigated using two different compositions of powder. The powder mixtures were based on NiCrBSi compositions and NiCr with WC powder [14].

In the present study, the laser surface modification was conducted by melting EN-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 investigations have been carried out on test pieces of MCMgAl6Zn1 magnesium alloys after heat treatment states. The chemical composition 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, with succeeding 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 (Table 2).

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.

Two types of carbides were used in present study for alloying process, namely tungsten carbide and titanium carbide. The mesh both of them sizes were up 5µm. The WC and TiC powders was supplied by side injection rate of 6-8 g/min.

The laser cladding was performed by high power diode laser 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 parameters are presented in Table 3. The process parameters during the present investigation were: laser power - 1.6 kW, scan rate - 0.5-1.0 m/min (every 0.25) and powder feed rate of 6-8 g/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 MEF4A as well as on the electron scanning microscope Opton DSM-940 using a secondary electron detection.

The X-ray qualitative microanalysis and the analysis of a surface distribution of cast elements in the examined magnesium cast alloy specimens in as-cast and after heat and laser treatment have been made on transverse microsections on the Opton DSM-940 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.

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 - 130º.

Table 1.
Chemical composition of investigation alloy

Al	Zn	Mn	Si	Fe	Mg	Rest
5.92	0.49	0.15	0.037	0.007	93.33	0.0613

Table 2.
Parameters of heat treatment of investigation alloy

Solution treatment			Aging treatment		
Temperature, °C	Time, h	Cooling	Temperature, °C	Time, h	Cooling
430	10	water	190	15	air

Table 3.
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

The cross-section microhardness of the modified surface layer was measured on Fully-Automatic Microhardness Testing System with a loading time of 15 s and the testing load of 50 g.

3. Discussion of experimental results

3.1. Heat treatment

As a result of metallographic investigations made on the light and scanning microscopes it has been confirmed that the magnesium cast alloys MCMgAl6Zn1 in the cast state are characterized by a microstructure of the solid solution α constituting the alloy matrix as well as the β – $Mg_{17}Al_{12}$ discontinuous intermetallic phase in the forms of plates located mostly at grain boundaries. Moreover, in the vicinity of the β intermetallic phase precipitations the presence of the needle eutectics (α + β) has been revealed (Fig. 1). The chemical analysis of the surface element decomposition and the quantitative micro analysis made on the transverse microsections of the magnesium alloys using the EDS system have also confirmed the evident concentrations of magnesium, silicon, aluminium, manganese and iron what suggests the occurrence of precipitations containing Mg and Si with angular contours in the alloy structure as well as phases with high Mn and Al concentrations that are irregular with a non plain surface, often occurring in the forms of blocks or needles.

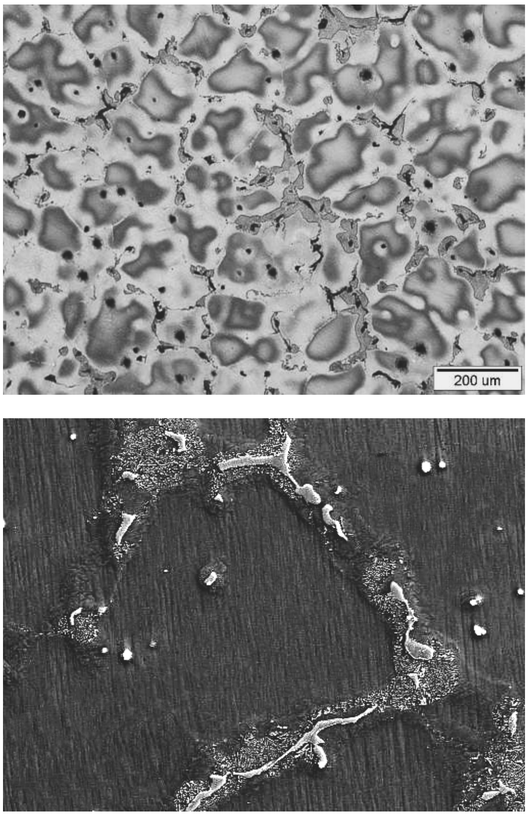

Fig. 1. Microstructure alloy MCMgAl6Zn1 without heat treatment

The applied quench ageing in water with air cooling, causes the precipitation of evenly spread dispersion particles of $Mg_{17}Al_{12}$ phase, occurring also in the form of pseudoeutectic areas (as pseudoeutectic areas was meant the structure created as the result γ phase precipitation out of the solid solution during the cast ageing previously supersaturated with water cooling, showing the morphology close to the eutectics formed out of the liquid phase). There have been revealed, in the structure of the material, the parallel twinned crystals extending along the grain (Fig. 2).

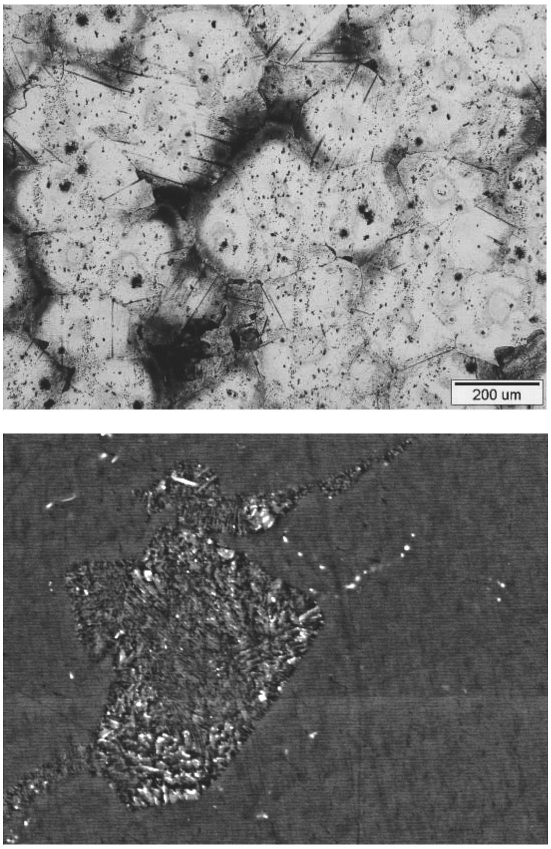

Fig. 2. Microstructure alloy MCMgAl6Zn1 after aging treatment

3.2. Laser treatment

Laser surface modification was conducted by remelting MCMgAl6Zn1 surface and feeding of WC particle (Fig. 3a) and TiC particle (Fig. 3b). Hard particles are immediately distributed throughout the molten zone during laser surface melting operation to form the composite layer distributed in alloyed zone. It is due to a large difference in density between the particles and matrix and differential absorption between the carbides particles and MCMgAl6Zn1 alloy.

The coating of the cross-section of the microstructure is shown in Fig. 4. The coating consist of the remelting zone and substrate. The coating is free of crack and porosity. The interface between the alloying zone and substrate shows good metallurgical joint.

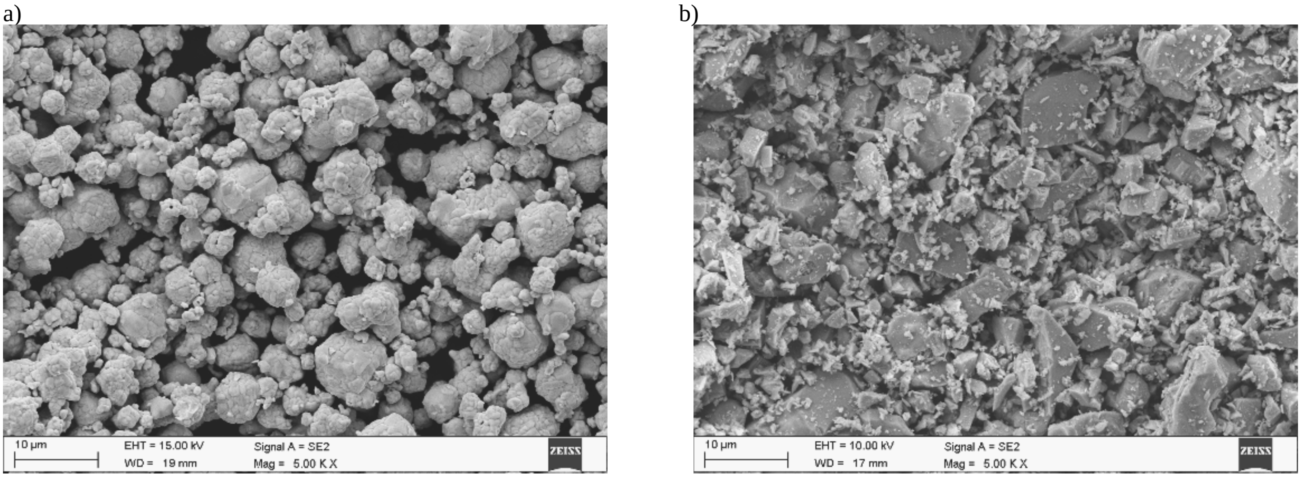

Fig. 3. SEM morphology of the a) tungsten, b) titanium carbide

Fig. 5 a-c show the microstructure of the modified zone MCMgAl6Zn1 with WC laser surface treated.. Fig 5. show the cross section of the coating (laser power: 1.6 kW, scan rate: 0.5 m/min, powder feed rate: 6-8 g/min), top surface of the coating (laser power: 1.6 kW, scan rate: 0.75 m/min, powder feed rate: 6 - 8 g/min), and interface between modified zone and the substrate (laser power: 1.6 kW, scan rate: 0.5 m/min, powder feed rate: 6-8 g/min), respectively. To compare Fig. 3 a-c show the microstructure of modified zone MCMgAl6Zn1 with TiC particle; cross section of the coating (laser power: 1.6 kW, scan rate: 0.75 m/min, powder feed rate: 6-8g/min), top surface of the coating (laser power: 1.6 kW, scan rate: 0.75 m/min, powder feed rate: 6-8 g/min), and interface between modified zone and the substrate (laser power: 1.6 kW, scan rate: 0.75 m/min, powder feed rate: 6-8 g/min), respectively. The microstructure of the coating is defect-free. The morphology of the alloyed zone are mainly dendrites of primary magnesium with eutectic lamella of Mg and $Mg_{17}Al_{12}$ in the interdendritic spacing.

The microstructure of the interface is dendritic. The microstructure of the substrate grains are significantly coarser than that after laser treatment. The zone between remelted zone and substrate is defect free. The composition of the interface, during the laser alloying process, offset toward a eutectic composition. Diffusion of Mg from the surface of the substrate to the alloyed zone, as well a quick cooling rate.

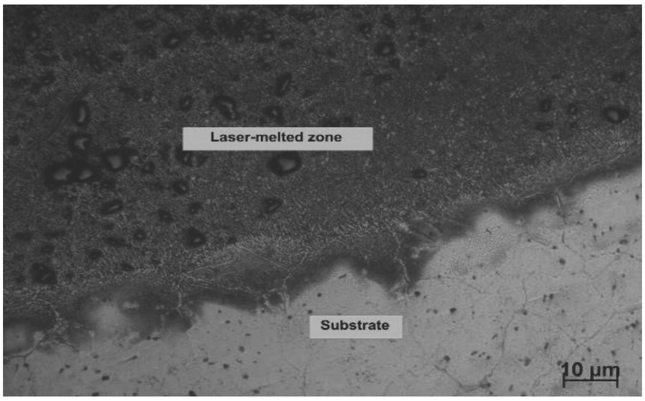

Fig. 4. Microstructure of the interface between the laser-melted zone and the substrate

Scan rate has an influence on the modified layer which varies with as the scan rate grows. The width of the alloyed zone decreases with scan rate. Increase in scan rate reduces the interaction time and reduces the coupled energy density. Using the improper scan rate or laser power during the laser operation can lead to formation of crater, porosity and also surface evaporation.

X-ray diffraction patterns for different laser treated layers as well as that for the substrate are shown in Fig. 7 and 8 for tungsten and titanium carbide, respectively. In case when the alloying material was tungsten carbide, Mg, WC and low intensity peaks of $Mg_{17}Al_{12}$ are phases existing in the laser treated layers. From Fig. 8 the X-ray diffraction profile of the MCMgAl6Zn1 with TiC consists of presence of Mg, $Mg_{17}Al_{12}$ and TiC peaks.

The chemical analysis (Fig. 10) of the surface element composition and the qualitative microanalysis made on the transverse microsections of the magnesium alloys after laser treatment magnesium alloy with WC powder (laser power: 1.6 kW, scan rate: 0.5 m/min, powder feed rate: 6-8 g/min) using the EDS system have confirmed the concentrations of magnesium, aluminium, tungsten, carbide and zinc which has also effected by laser modification. Fig. 11 a-d show the surface microstructure of the laser surface remelted MCMgAl6Zn1 with TiC particle and the distribution of Mg, Al, Zn, Ti and C lased with a power of 1.6 kW and a scan rate of 0.75 m/min.

During the laser alloying process, high cooling and solidification rate of the laser-generated pool produced contributed to the pulse-laser rapid heating rate and the high thermal conductivity of the magnesium alloy, hence, fine, dense and granular structure coating is generated. This modified structure in this process a higher hardness compared with that of the coarse grain size of the substrate.

The microhardness of the modified surface was measured from the top towards the clad-substrate interface along the cross-sectional plane. Fig. 9 and 10 show the microhardness curves of the cross-section of the coating.

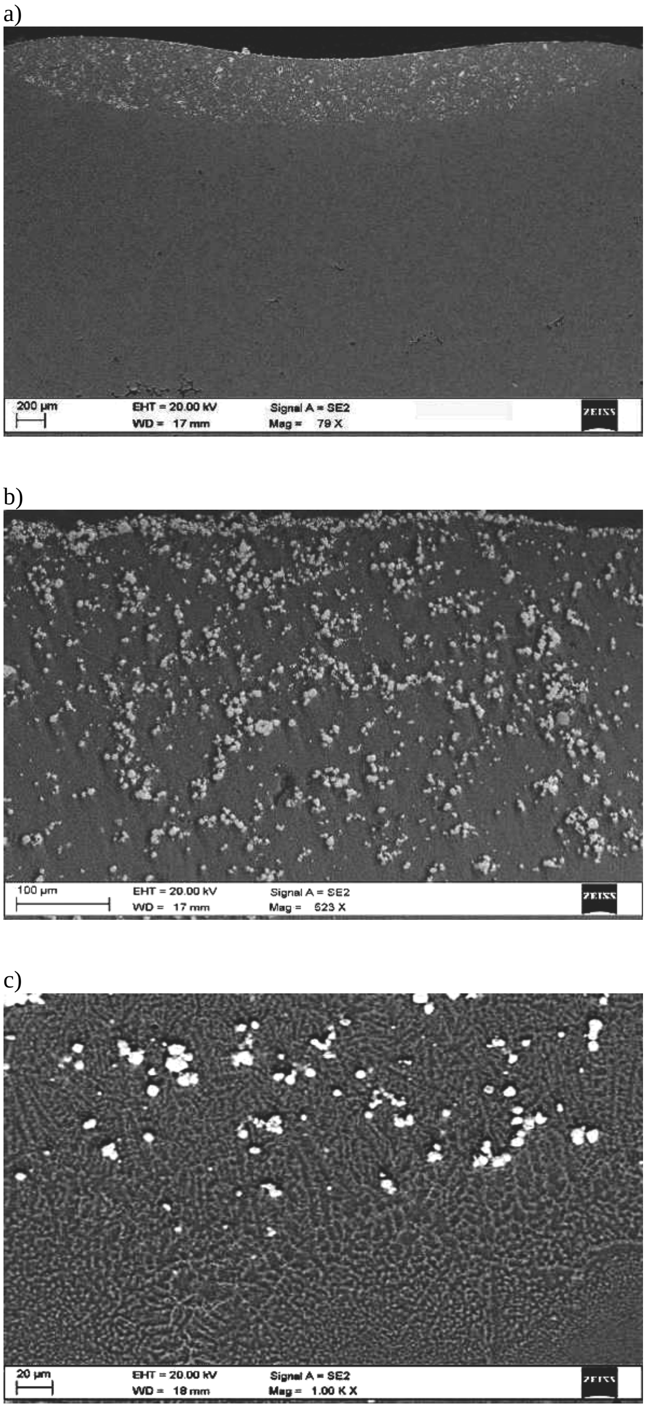

Fig. 5. Scanning electron micrograph laser surface modified MCMgAl6Zn1 with WC particle a) of the cross-section of the coating (laser power: 1.6 kW, scan rate: 0.5 m/min, powder feed rate: 6-8 g/min), b) top surface of the coating (laser power: 1.6 kW, scan rate: 0.75 m/min, powder feed rate: 6-8 g/min), b) interface between modified zone and the substrate (laser power: 1.6 kW, scan rate: 0.5 m/min, powder feed rate: 6-8 g/min)

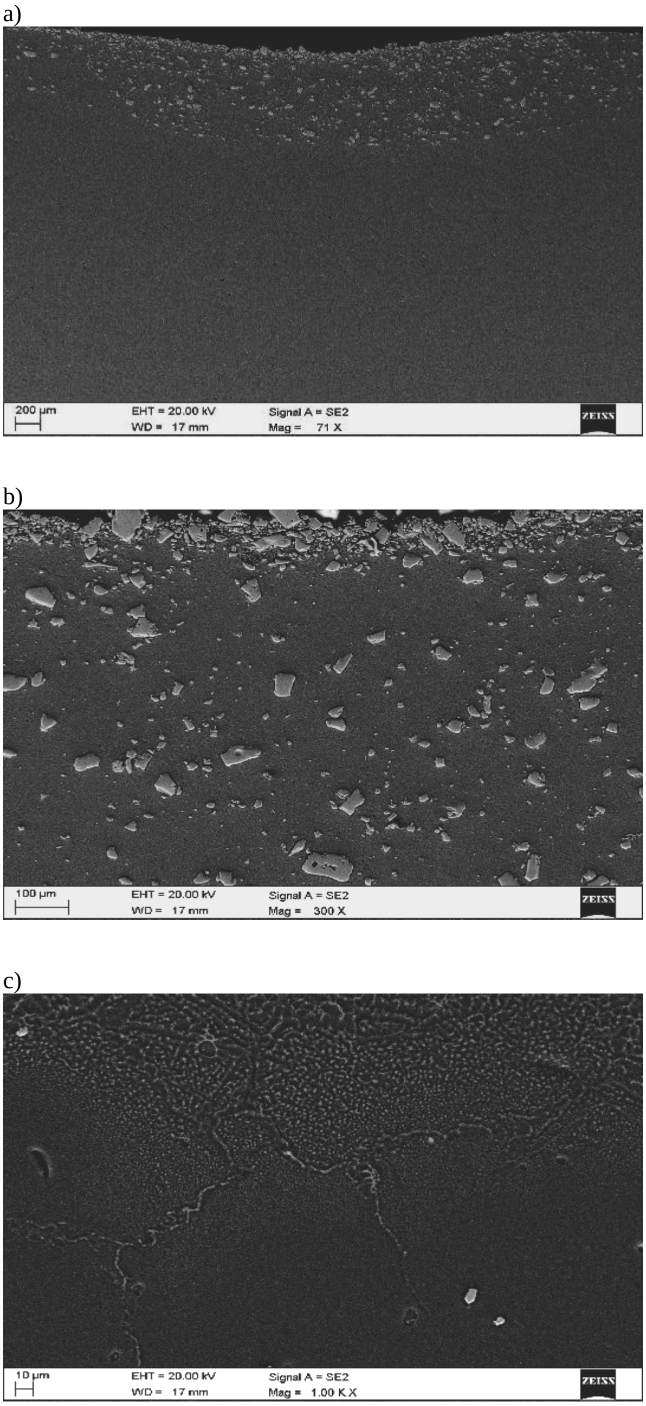

Fig. 6. Scanning electron micrograph laser surface modified MCMgAl6Zn1 with TiC particle a) of the cross-section of the coating (laser power: 1.6 kW, scan rate: 0.5 m/min, powder feed rate: 6-8 g/min), b) top surface of the coating (laser power: 1.6 kW, scan rate: 0.75 m/min, powder feed rate: 6-8 g/min), b) interface between modified zone and the substrate (laser power: 1.6 kW, scan rate: 0.5 m/min, powder feed rate: 6-8 g/min)

The microhardness of the modified zone is increased as compared to that of as-received Mg alloy both WC and TiC alloying layer, due to the enhancement of hard particles WC and also the grain refinement has positive effect on the improvement of the microhardness. There is the little fluctuation in the readings in some region, possibly because of the random distribution of hard particle carbide in the surface modified layer. In case, when penetration take place in hard particle (WC or TiC) microhardness is much bigger than the measures were from matrix. The microhardness of surface layers varied in the ranges 70-250 $HV_{0.05}$ and 70-200 $HV_{0.05}$, for MCMgAl6Zn1 alloy where clad material was WC and TiC powders, respectively.

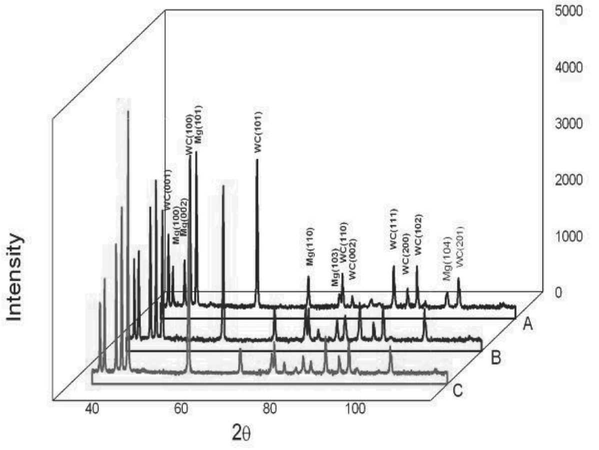

Fig. 7. XRD results of the laser treated layer with WC powders (A-laser power:1.6 kW, scan rate 0.5m/min, B-laser power: 1.6 kW, scan rate 0.75m/min, C-laser power: 1.6 kW, scan rate 1.0 m/min)

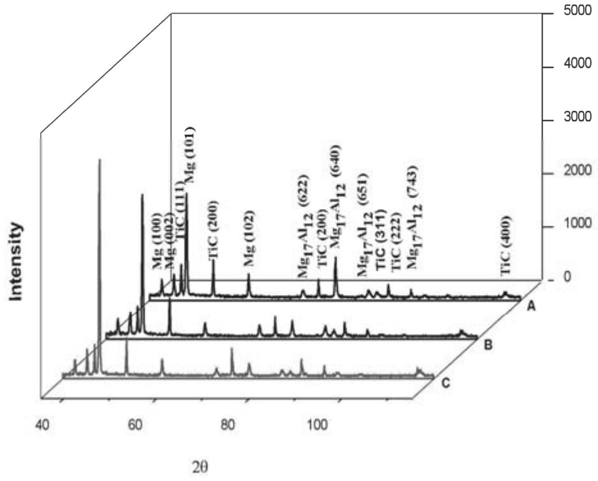

Fig. 8. XRD results of the laser treated layer with TiC powders (A-laser power:1.6 kW, scan rate 0.5m/min, B-laser power:1.6 kW, scan rate 0.75m/min, C-laser power: 1.6 kW, scan rate 1.0 m/min)

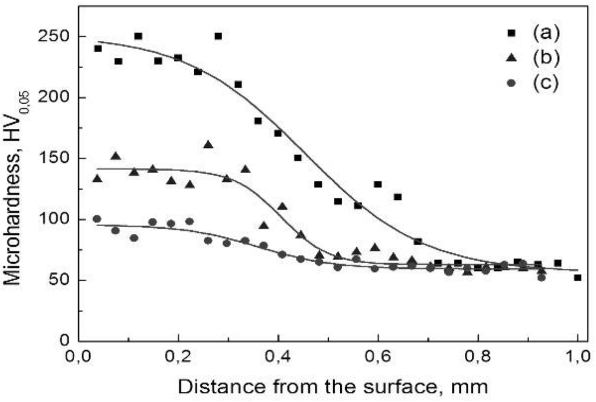

Fig. 9. Cross-section microhardness profile from the surface – WC particle, laser power: 1.6 kW, scan rate: a) 0.5m/min, b) 0.75 m/min, c) 1.0 m/min

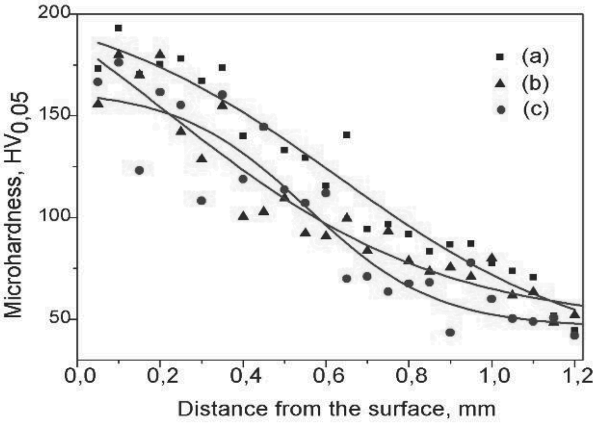

Fig. 10. Cross-section microhardness profile from the surface – TiC particle, laser power: 1.6 kW, scan rate: a) 0.5m/min, b) 0.75 m/min, c) 1.0 m/min

4. Conclusions

High power diode laser has found a suitable source of heat to successfully produce the composite surface layer on the MCMgAl6Zn1 alloy by laser modification and feeding the WC or TiC powder. The laser treatment on MCMgAl6Zn1 alloy produce a fine dendritic microstructure. The microstructure of the surface modified layer consists of particles was used carbide (tungsten carbide or titanium carbide) in the matrix Mg and Al. The detailed X-ray diffraction analysis shows the presence of mainly Mg α, $Mg_{17}Al_{12}$ phase and also peaks tungsten carbide or titanium carbide. The surface modified layer microhardness was significantly improved compared to the substrate microhardness value due to grain refinement and presence hard particle (tungsten carbide or titanium carbide).

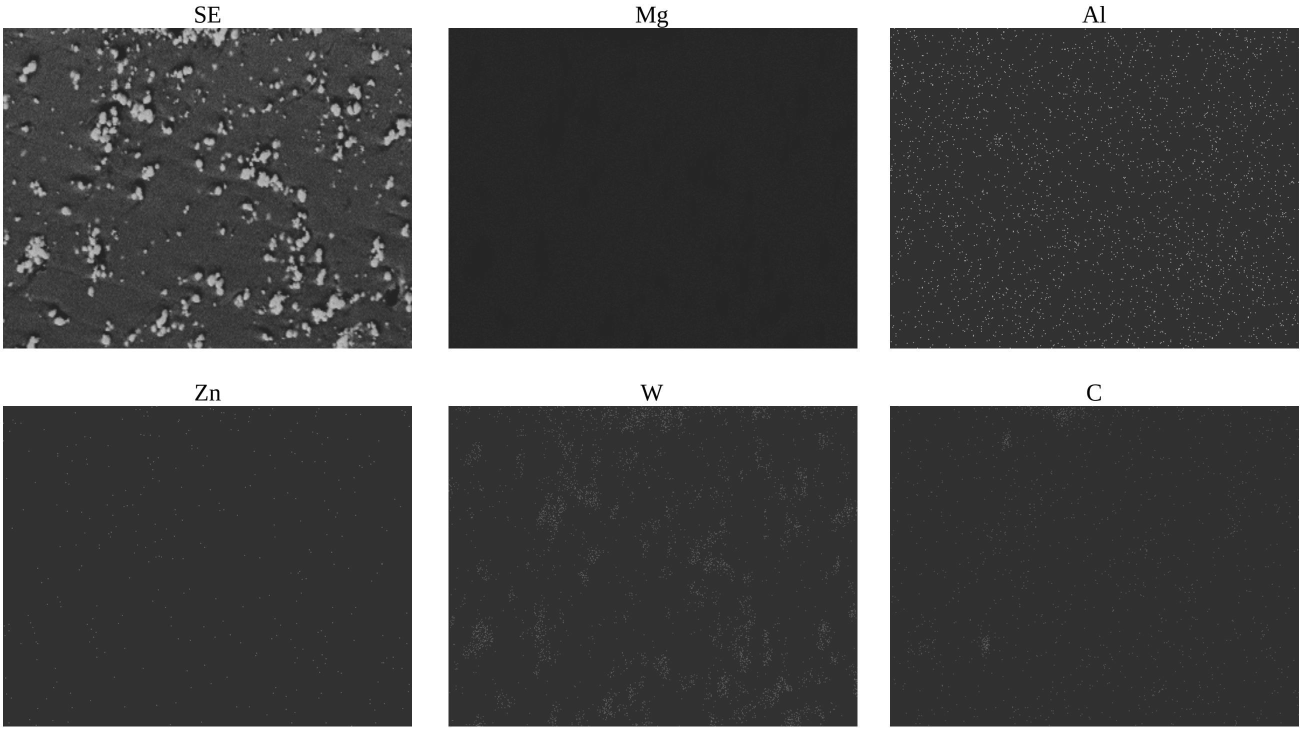

Fig. 11. X-ray mapping of the microstructure ENMCMgAl6Zn1 alloying layer and the distribution of Mg, Al, Zn, W, C

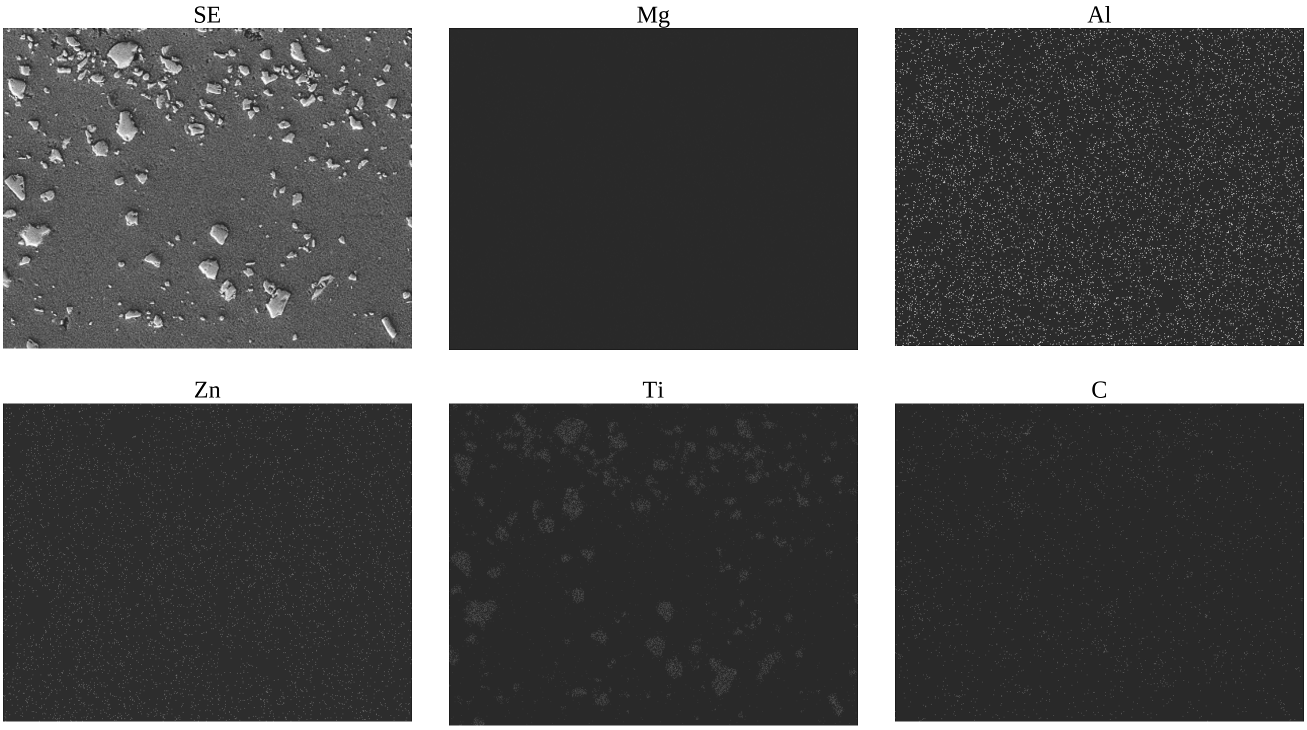

Fig. 12. X-ray mapping of the microstructure ENMCMgAl6Zn1 alloying layer and the distribution of Mg, Al, Zn, Ti, C

Acknowledgements

This research work is financed in part within the framework of science financial resources in the period 2007-2008 as a research and development project R15 0702 headed by Prof. L.A. Dobrzański.

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