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Laser surface treatment of magnesium alloys with silicon carbide powder

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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 and determine the laser treatment parameters.

Design/methodology/approach: The laser treatment of magnesium alloys with alloying SiC powder with the particle size below 75μm 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 was significantly improved as compared to alloy without laser treatment.

Research limitations/implications: The investigations were conducted for cast magnesium alloys MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 and SiC powder with the particle size below 75μm. 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 microhardness of magnesium cast alloys surface layer.

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

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Magnesium alloys are characterized by very low density, high yield point and coefficient of elasticity, which allow to transmit high impact loads. Thanks to these properties magnesium alloys found application in: aircraft industry, automotive industry, office and household equipment. Disadvantages of magnesium alloys are low corrosion resistance and high susceptibility to oxidation, what is a cause of complicated processes of production and processing [1-6].

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

Many applications require from applied magnesium alloys suitably high resistance properties like corrosion resistance and wear resistance. Improvement of these properties attempt to obtain by: coat of polymer layers [7], microarc oxidation of ceramic coating [8], surface layers laser remelting [9], surface layers alloying with various hard particles (carbides or oxides) [10-14]. However laser treatment is not easy to put into use with magnesium alloys because of a lot of defect types like porosity, fractures, oxide inclusions or oxidation are observed during laser treatment [15].

2. Experimental procedure

The investigations have been carried out on test pieces of MCMgAl12Zn1, MCMgAl9Zn, MCMgAl6Zn1, MCMgAl3Zn magnesium alloys in as-cast and after heat treatment states. The chemical compositions of the investigated materials are 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 air and then ageing at temperature of 190 °C and cooling in air. The process of samples preparation depends on surface polishing on sandpaper with granulation of 1200.

Laser alloying was performed by high power diode laser HDPL Rofin DL020 with feeding of hard silicon carbide particles under an argon shielding gas. Argon was used during laser re-melting to prevent oxidation of the surface layer and the substrate. Particle size of silicon carbide powder was below 75 μm. Morphology of silicon carbide was shown on Figure 1. The process parameters during the present investigation were: laser power – 0.5-2.0 kW, scan rate – 0.5-1.0 m/min and powder injection rate – 1-10 g/min.

Fig. 1. Morphology of silicon carbide (SEM)

The observations of the investigated cast materials have been made on the light microscope LEICA MEF4A as well as on the electron scanning microscope Zeiss SUPRA 35 using secondary electrons detecting. The observations have been carried out on crosswise microsection of laser alloyed surface layers, which were mounted in chemohardenable epoxy resin. Test specimens were prepared by grinding and polishing using diamond suspension. The test specimens were etched in Nital with the purpose of microstructure disclose and grain boundary.

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.

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. Description of results

Laser treatment of surface layers was curried out with continuous feeding of SiC powder to molten pool of magnesium alloys. As a means of transport was used argon.

Selection of process parameters was conducted in an introductory investigations the sake of: resultant compound quality, uniform distribution of alloying powder particles inside remelted zone and face geometry of surface layers after laser treatment. Surface layer faces after laser alloying with determined process parameters are regular and flat. The process parameters were determined as: laser power 1.2-2.0 kW, scan rate 0.75 m/min and powder injection rate: 8±1 g/min (as ensure the most stable feeding).

Investigated casting magnesium alloys characterize the different laser radiation absorption. Absorption is the highest for MCMgAl12Zn1 alloy and decrease with a decreasing Al concentration in the alloy composition to the lowest absorption for MCMgAl3Zn1 alloy. In the result a thickness of remelted zone and heat affected zone are changed (Fig. 2). Rise of remelted zone and heat affected zone thicknesses under the influence of Al concentration in the composition of magnesium alloys increasing and laser power increasing are noticeable. During laser alloying with laser power 1.2 kW process proceed stable for MC MgAl12Zn1 and MCMgAl9Zn1 alloys, while for MCMgAl6Zn1 and MCMgAl3Zn1alloys laser alloying process begin on surface layers, but amount of energy delivered to substrate is too low and molten pool of magnesium alloy is crystallized and break the alloying process.

Figure 3 shows the scanning electron micrographs of MCMgAl9Zn1 magnesium alloy surface layer modified by laser alloying with silicon carbide particles with parameters: laser power 2.0 kW, scan rate 0.75 m/min and powder feed rate 8±1 g/min.

On Figure 4 was shown the scanning electron micrographs of MCMgAl3Zn1 magnesium alloy surface layer modified by laser alloying with silicon carbide particles with parameters: laser power 1.6 kW, scan rate 0.75 m/min and powder feed rate 8±1 g/min.

Table 1.
Chemical composition of investigation alloys

Alloy sign	The mass concentration of main elements, %						
	Al	Zn	Mn	Si	Fe	Mg	Rest
MCMgAl3Zn1	12.1	0.62	0.17	0.047	0.013	86.96	0.0985
MCMgAl6Zn1	9.09	0.77	0.21	0.037	0.011	89.79	0.0915
MCMgAl9Zn1	5.92	0.49	0.15	0.037	0.007	93.33	0.0613
MCMgAl12Zn1	2.96	0.23	0.09	0.029	0.006	96.65	0.0361

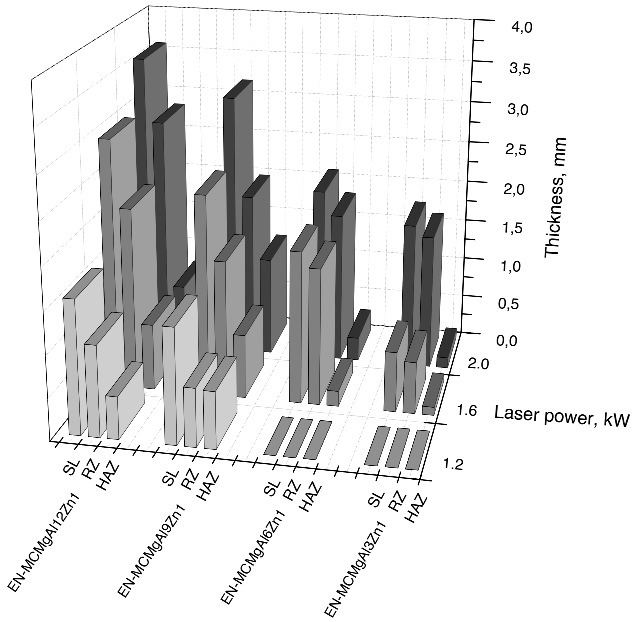


Fig. 2. Diagram of thickness changes of particular areas in the surface layers after alloying SiC powder: SL – surface layer, HAZ – heat affected zone, RZ – remelted zone

Structure of the investigated magnesium cast alloys: MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1 and MCMgAl3Zn1 after heat treatment (before laser treatment) consists of the solid solution α – Mg (matrix) and an intermetallic secondary phase β – $Mg_{17}Al_{12}$ in the forms of plates located mostly at grain boundaries.

In the result of laser alloying, structure of surface layers is defect-free and refinement of structure. Distinct heat affected zone has been occurred for the MCMgAl12Zn1 and MCMgAl9Zn1 alloys after laser treatment (Fig. 3c), while hasn't been occurred for the other alloys (Fig. 4c). Microstructure of alloyed surface layers consists of the dispersion SiC particles in the matrix of magnesium alloy (Fig. 3b and Fig. 4b) – solution α-Mg and intermetallic phase β-$Mg_{17}Al_{12}$. Surface layer morphology in the majority part consists of dendrites, which crystallized in the direction of heat flow, elementary alloy with lamellar eutectic $Mg_{17}Al_{12}$ and Mg inside interdendritic areas.

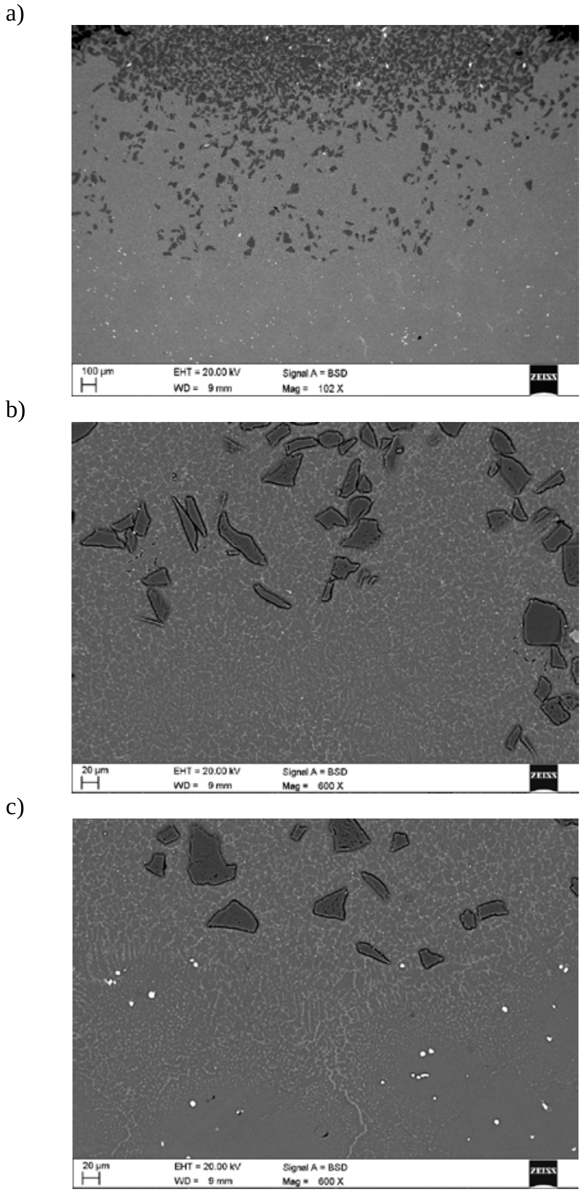


Fig. 3. Scanning electron micrograph laser surface modified MCMgAl9Zn1 with SiC particle a) of the cross-section of the coating, b) top surface of the coating, c) interface between modified zone and the substrate (laser power: 2.0 kW, scan rate: 0.75 m/min, powder feed rate: 8±1 g/min)

a)

b)

c)

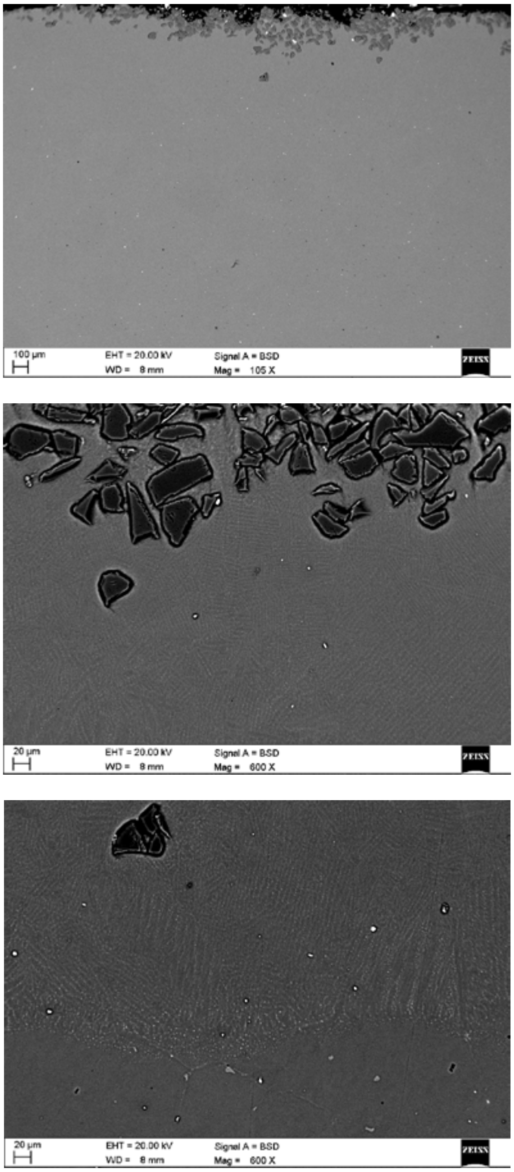


Fig. 4. Scanning electron micrograph laser surface modified MCMgAl3Zn1 with SiC particle a) of the cross-section of the coating, b) top surface of the coating, c) interface between modified zone and the substrate (laser power: 1.6 kW, scan rate: 0.75 m/min, powder feed rate: 8-9 g/min)

Alloying SiC particles are distributed the majority near surface by reason of high powder feeding rate. However, during laser alloying process with high laser power (1.6 kW and 2.0 kW) silicon carbide particles are distributed within whole remelted zone, what is a result of vehement mixing of material inside molten pool (Fig. 3a). When laser power is lower (1.2 kW) and Al concentration in the alloy composition is 6% or 3%, thickness of remelted zone is too low for metal mixing and alloying particles distribution within surface layer (Fig. 4a).

Results of carried out qualitative X-ray diffraction analysis of investigated alloys confirmed appearance of phases: Mg, $Mg_{17}Al_{12}$ and SiC (Fig. 5).

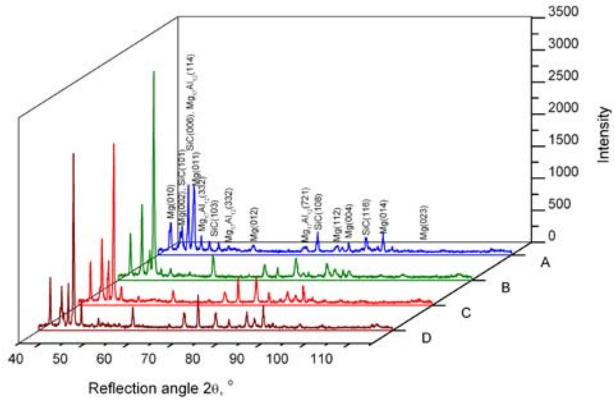
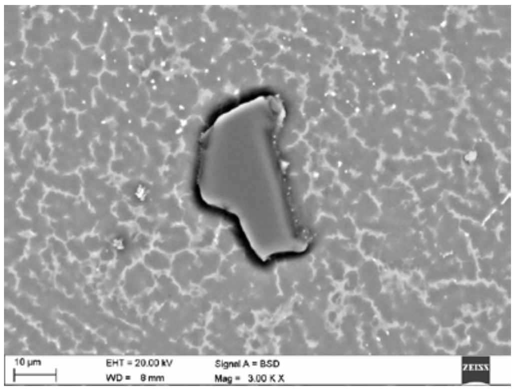


Fig. 5. X ray diffraction pattern of the: A – MCMgAl12Zn1, B - MCMgAl9Zn1, C – MCMgAl6Zn1, D – MCMgAl3Zn1 cast magnesium alloy after laser alloying with SiC: powder feed rate: 8-9 g/min, scan rate: 0.75 m/min, laser power: 2.0 kW

a)



b)

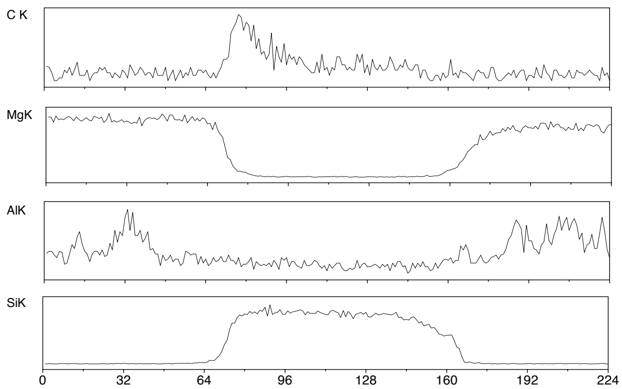


Fig. 6. Scanning electron microscopy micrograph of MCMgAl9Zn1 alloy after laser alloying with SiC particles, laser power: 2.0 kW, scan rate: 0.75 m/min, powder feed rate: 8-9 g/min, a) SEM micrograph, b) linear analysis of the chemical composition changes

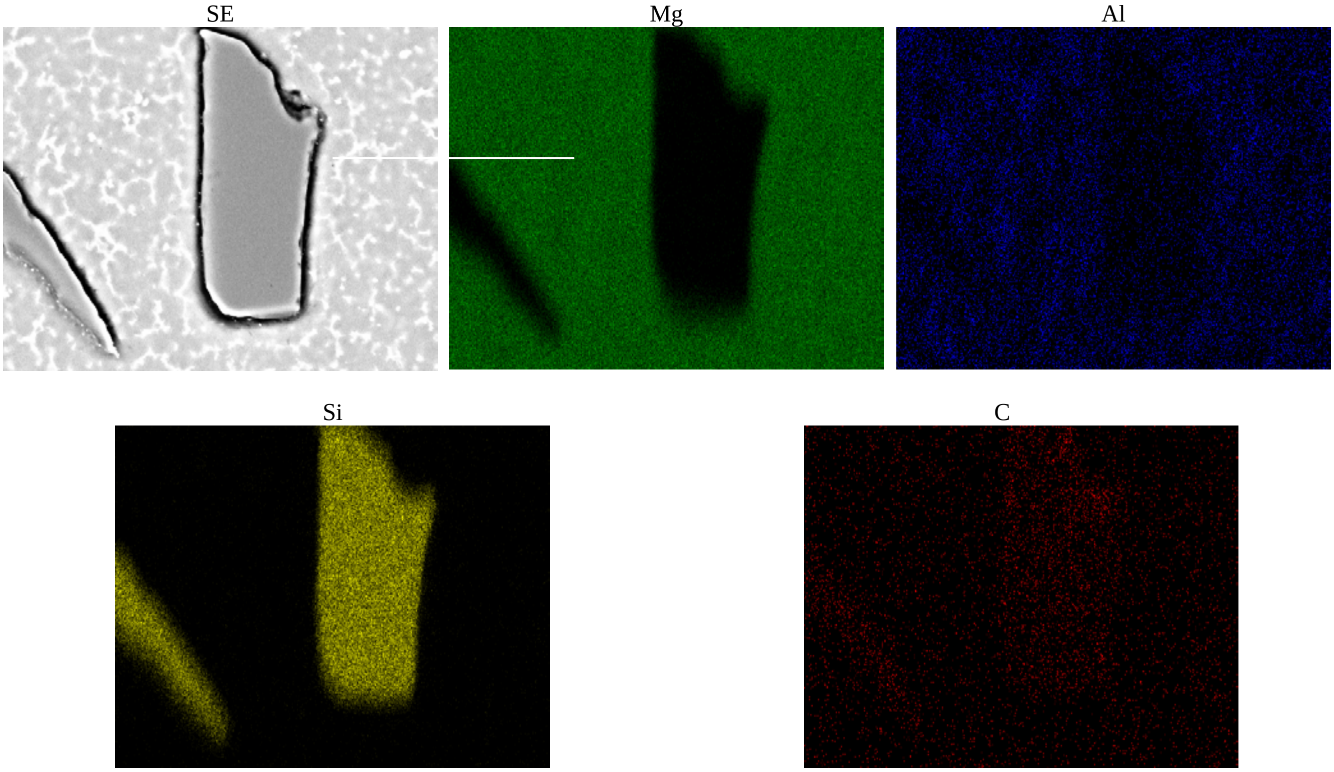


Fig. 7. X-ray mapping of the microstructure MCMgAl9Zn1 alloying layer and the distribution of Mg, Al, Si, C

Alloying particles of silicon carbide during laser process don't undergo dissolution, what was confirmed by linear analysis of the chemical composition changes (Fig. 6). This result is converge with qualitative X-ray diffraction analysis, which results weren't revealed in the surface layers phases including elements as silicon or carbon different than silicon carbide. Mg, Al, C and Si elements occurrence was confirmed by linear analysis of the chemical composition changes.

The results of the chemical analysis (Fig. 7) of the surface element composition and the qualitative microanalysis made on the transverse microsection of MCMgAl9Zn1 magnesium alloy after laser alloying (laser power: 2.0 kW, scan rate: 0.75 m/min, powder feed rate: 8±1 g/min) using the EDS system have confirmed the concentrations of magnesium, aluminum, manganese, zinc and SiC. The homogeneous distribution of magnesium and aluminum, except for carbide or oxide particles was observed.

Microhardness depend on distance from surface measurements (Fig. 8) shown that microhardness increasing in the surface layer. The increasing of hardness in remelted zone is resulted in considerable refinement of structure of magnesium phase (100-300 $HV_{0,1}$) and very hard carbides particles (about 1500-1600 $HV_{0,1}$) appearance in this area. The results of measurements shown that microhardness close hard silicon carbide particles increasing to value over 300 $HV_{0,1}$. In the heat affected zone of MCMgAl9Zn1 alloy (Fig. 8b) microhardness insignificant decreasing below hardness of substrate material, whereas in the other magnesium alloys in this zone microhardness is close to substrate material (50-90 $HV_{0,1}$).

4. Summary

The results of investigations indicate that laser treatment of cast magnesium alloys EN-MCMgAl3Zn1, EN-MCMgAl6Zn1, EN-MCMgAl9Zn1, EN-MCMgAl12Zn1 with silicon carbide particles is feasible. However, as a result of different properties of each cast magnesium alloys and each applicable powders is necessary determine process parameters. Main parameter, which influences on the structure, quality and thickness of surface is laser power.

Carried out coatings are free of cracks and porosity. The interface between the alloying zone and substrate shows good metallurgical joint. The structure of the remelted zone is mainly dendritic of primary magnesium with eutectic of phase α-Mg and intermetallic phase $\beta\text{-}Mg_{17}Al_{12}$. Magnesium alloys with aluminum concentration 9 and 12 wt. % reveal heat affected zone in opposition to alloys with aluminum concentration 3 and 6 wt. %.

Results of microhardness investigation show hardness increase in the remelted zone (values from 100 to 700 $HV_{0,1}$) compare to substrate material (50-90 $HV_{0,1}$). The increasing of microhardness value is an effect of refinement of structure of magnesium alloys and very hard carbides particles appearance within surface layer area.

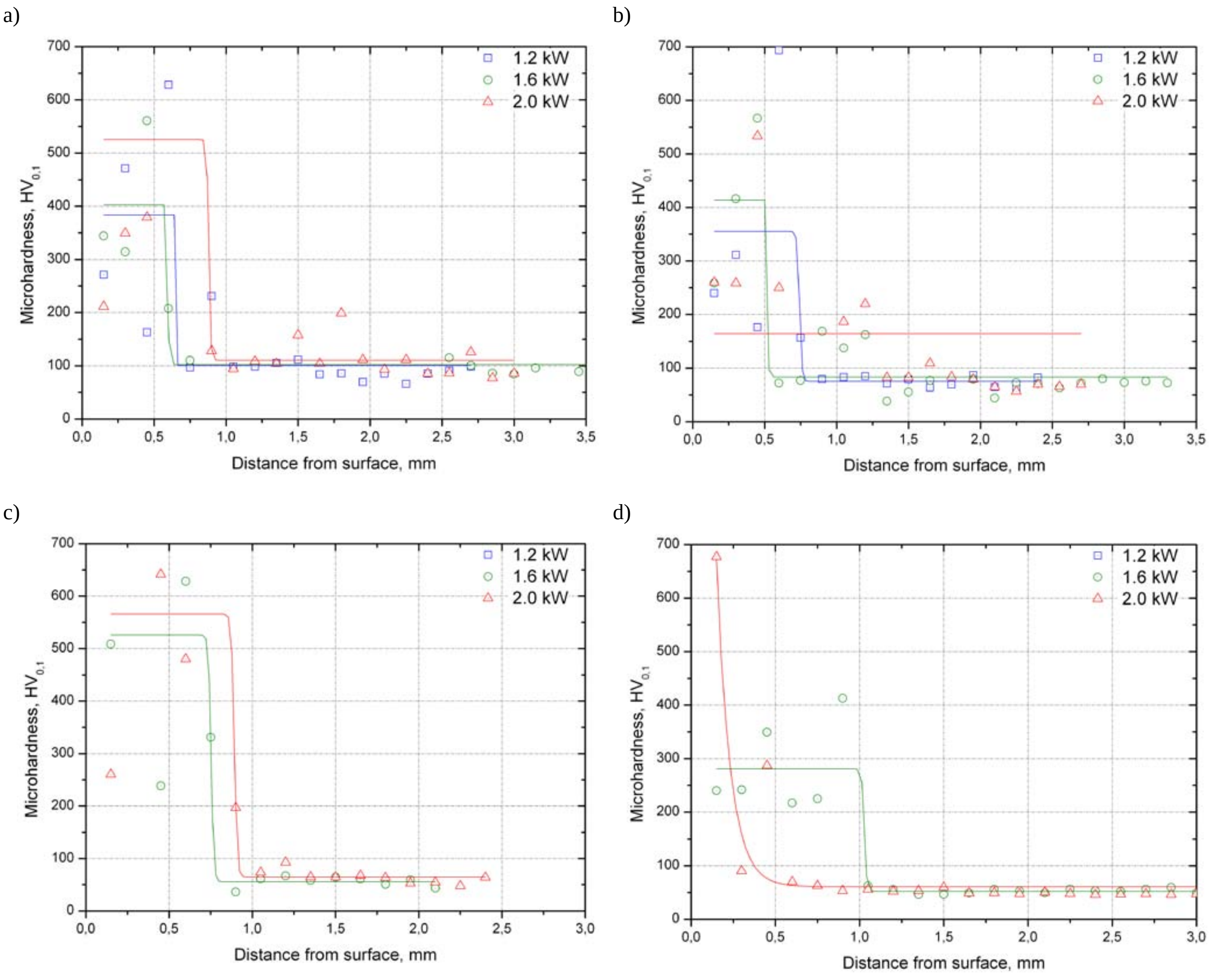


Fig. 8. Cross-section microhardness profile from the surface: a) MCMgAl12Zn1, b) MCMgAl9Zn1, c) MCMgAl6Zn1, d) MCMgAl3Zn1 alloy with SiC particles, scan rate: 0.75 m/min

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