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Structure changes and mechanical properties of laser alloyed magnesium cast alloys

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ABSTRACT

Purpose: The aim of this work was to investigate structure and mechanical properties of the MCMgAl12Zn1 casting magnesium alloys after laser treatment. The laser treatment was carried out using a high power diode laser (HPDL).

Design/methodology/approach: The laser processing of TiC, WC, SiC particles in MCMgAl12Zn1 and the resulted microstructures and properties are discussed in this paper. The resulting microstructure in the modified surface layer was examined. Phase composition was determined by the X-ray diffraction method using XPert device. The measurements of hardness after laser melt injection was also studied.

Findings: Structure of the solidyifying material after laser alloying is characteristic with occurrences of areas with the diversified morphology, dependent on solidification rate of the magnesium alloys, is characteristic of structure of the solidified material after laser alloying. The MCMgAl12Zn1 casting magnesium alloys after laser alloying demonstrate similar hardness tests results, in reference to hardness of the alloys before their laser treatment.

Research limitations/implications: In this research three powders (titanium carbide, tungsten carbide and silicon carbide) were used to reinforcing the surface of the MCMgAl12Zn1 casting magnesium alloys.

Practical implications: High power diode laser can be used as an economical substitute for CO_2 and Nd:YAG lasers to modify the surface magnesium alloy by feeding the carbide particles.

Originality/value: The originality of this work is applying of High Power Diode Laser for laser treatment of cast magnesium alloy consisting in fusion penetration of the hard particles of titanium, tungsten, and silicon carbides into the remelted surface layer of the alloy.

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

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MATERIALS

1. Introduction

Contemporary engineering development forces search for new design solutions aimed at mass reduction. Magnesium alloys have attracted attention since a dozen years or so in various industry branches, and especially in the aviation and automotives industries for their simultaneous low density and high strength. These properties and their excellent machinability and low inertia qualify magnesium alloys as materials with the wide spectrum of applications. However, in spite of such attractive mechanical properties, their relatively low corrosion- and abrasion wear resistance pose a serious application obstacle [1-7]. 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, called also 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. The intensive fusion of materials takes place in the pool due to motion caused by convection and gravitation and pressure exerted by the laser beam. Rapid cooling and solidification of the molten metal occur because of the big temperature gradient on the boundary of the remelted 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 case of some materials may result in self-quench hardening of the thin substrate layer [8-15].

Laser alloying makes it possible to develop layers with special service properties.

To improve properties of the surface layer of the MCMgAl12Zn1 casting magnesium alloy, its surface laser treatment was done, consisting of fusion penetration of the hard particles of titanium-, tungsten-, and silicon carbides into the remelted surface layer of the alloy using the HPDL high power diode laser.

2. Experimental procedure

The investigations have been carried out on test pieces of 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.

Three types of carbides were used in present study of alloying process, titanium and tungsten carbides with granulation above 6.4 µm and silicon carbide with granulation below 75 µm.

Laser melt injection was performed by high power laser diode HPDL Rofin DL 020 under an argon shielding gas. Argon was used during laser remelting 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 - 0.5-1.0 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 the structure and to distinguish precisely the particular precipitaions 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.

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.

Table 1.
Chemical composition of investigation alloy

Al	Zn	Mn	Si	Fe	Mg	Rest
11.92	0.49	0.15	0.037	0.007	93.33	0.0613

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 MCMgAl12Zn1 casting magnesium alloys was carried out by continuous feeding particles of: titanium, tungsten and silicon carbides into the pool area developed on the alloyed surface in the beam focus spot of the HPDL high power diode laser.

Fig. 1 shows layout of zones on the transverse section of the remelting path of the MCMgAl12Zn1 casting magnesium alloys. 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 casting magnesium alloy. 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.

Examinations carried out on the scanning electron microscope confirmed occurrence of the zonal structure of the surface layer of the investigated casting magnesium alloys (Figs. 2, 3).

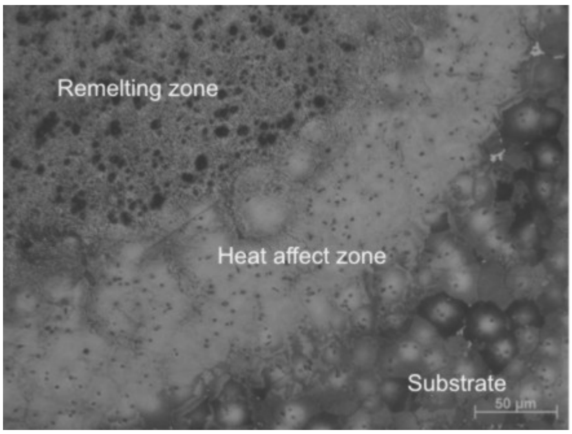

Fig. 1. Remelting path edge of the MCMgAl12Zn1alloy surface layer after alloying with the WC powder, laser power: 2.0 kW, feed rate: 0.75 m/min

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, with the content and distribution of carbides particles included, is dependent on laser parameters.

a) b) c)

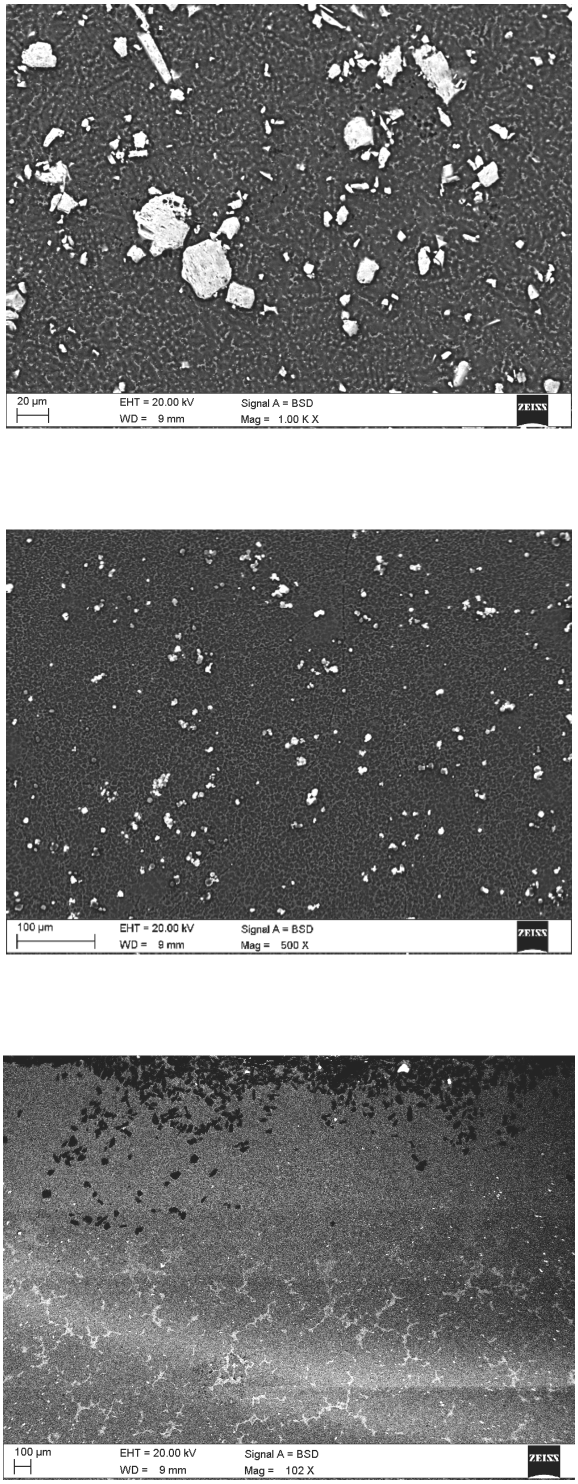

Fig. 2. Central zone between remelting and substrate, MCMgAl12Zn1 alloy after alloying with a) TiC powder, laser power: 2.0 kW, b) WC powder, laser power 2.0 kW, c) SiC powder, laser power: 1.6 kW; feed rate: 0.75 m/min

a) b) c)

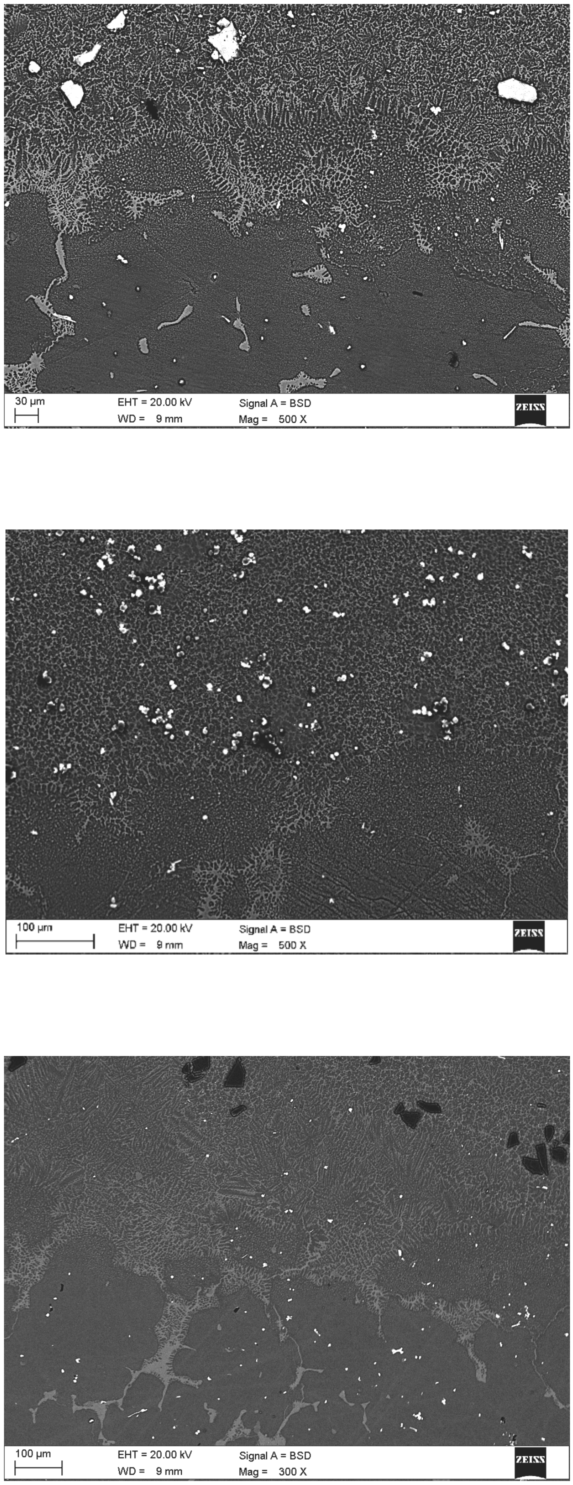

Fig. 3. Boundary zone between remelting and substrate, MCMgAl12Zn1 alloy after alloying with a) TiC powder, b) WC powder, c) SiC powder; laser power: 2.0 kW; feed rate: 0.75 m/min

During metallographic examinations of the MCMgAl12Zn1 alloys a uniform distribution was observed of the employed TiC, WC and SiC carbides particles in the entire remelting zone. However, in case of alloying with SiC particles with laser power of 1.2 and 1.6 kW carbides are distributed mostly within the surface layer (Fig. 2c). At 2.0 kW power, the SiC particles are spread in the entire remelting zone thanks to the violent mixing of the molten metal in the pool.

It was found out, based on the experiments carried out, that width of the analysed layers, evaluated in the computer image analysis made on pictures from the light microscope and confirmed by examinations on the scanning electron microscope is a function of four variables - laser beam power, alloying feed rate, alloying material type and also substrate type. Plot of the regression function describing relationship of the layer width alloyed with tungsten and silicon carbide with alloying parameters and also substrate type are presented on Figs. 4, 5, and Figs. 6, 7, respectively.

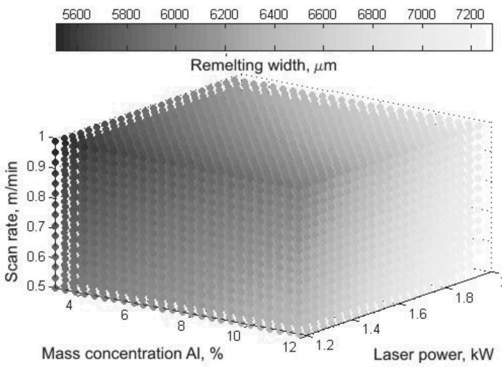

Fig. 4. Plot of the regression function describing relationship of the remelting width with the mass portion of aluminium in magnesium alloys, laser power, and also alloying feed rate for the material laser alloyed with titanium carbide

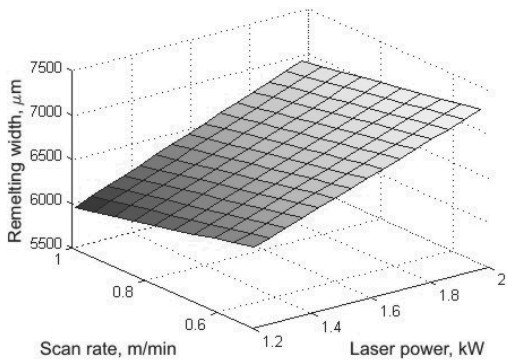

Fig. 5. Plot of the regression function describing relationship of the remelting width from the employed alloying feed rate and laser power for the MCMgAl12Zn1 casting magnesium alloy

It was observed that width of the developed surface layer changes with the laser power, alloying feed rate, and depending on substrate type; with the laser power being most important, mostly because the increase of the absorbed power occurs along with the power growth, and decreases with the growth of the alloying feed rate. The biggest remelting width was observed for the MCMgAl12Zn alloy alloyed with SiC powder with laser power 2.0 kW – 7920 μm (Figs. 6, 7). The date above confirm results obtained in case of alloying the casting magnesium alloys with the tungsten carbide powders (Fig. 8).

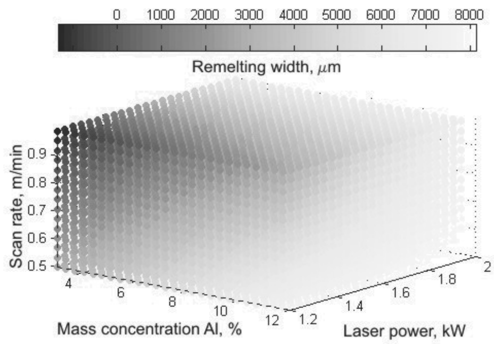

Fig. 6. Plot of the regression function describing relationship of the remelting width with the mass portion of aluminium in magnesium alloys, laser power, and also alloying feed rate for the material laser alloyed with silicon carbide

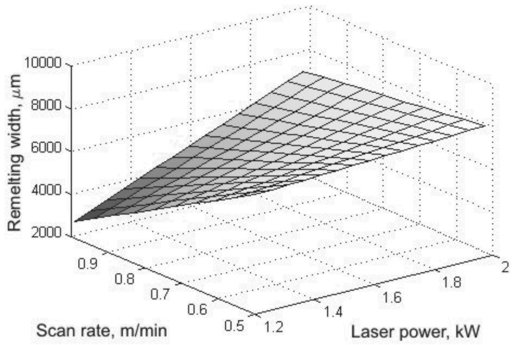

Fig. 7. Plot of the regression function describing relationship of the remelting width from the employed alloying feed rate and laser power for the MCMgAl12Zn1 casting magnesium alloy

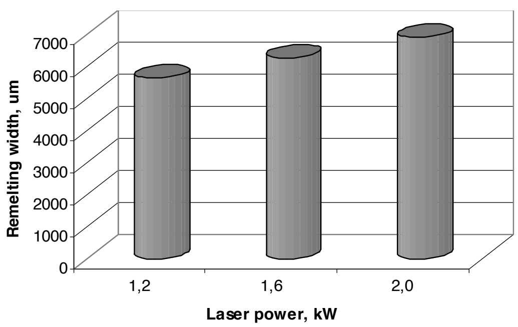

Fig. 8. Average remelting width change of the casting magnesium alloys surface layer after laser alloying with tungsten carbide with the varying laser power values and constant alloying feed rate of 0.75 m/min

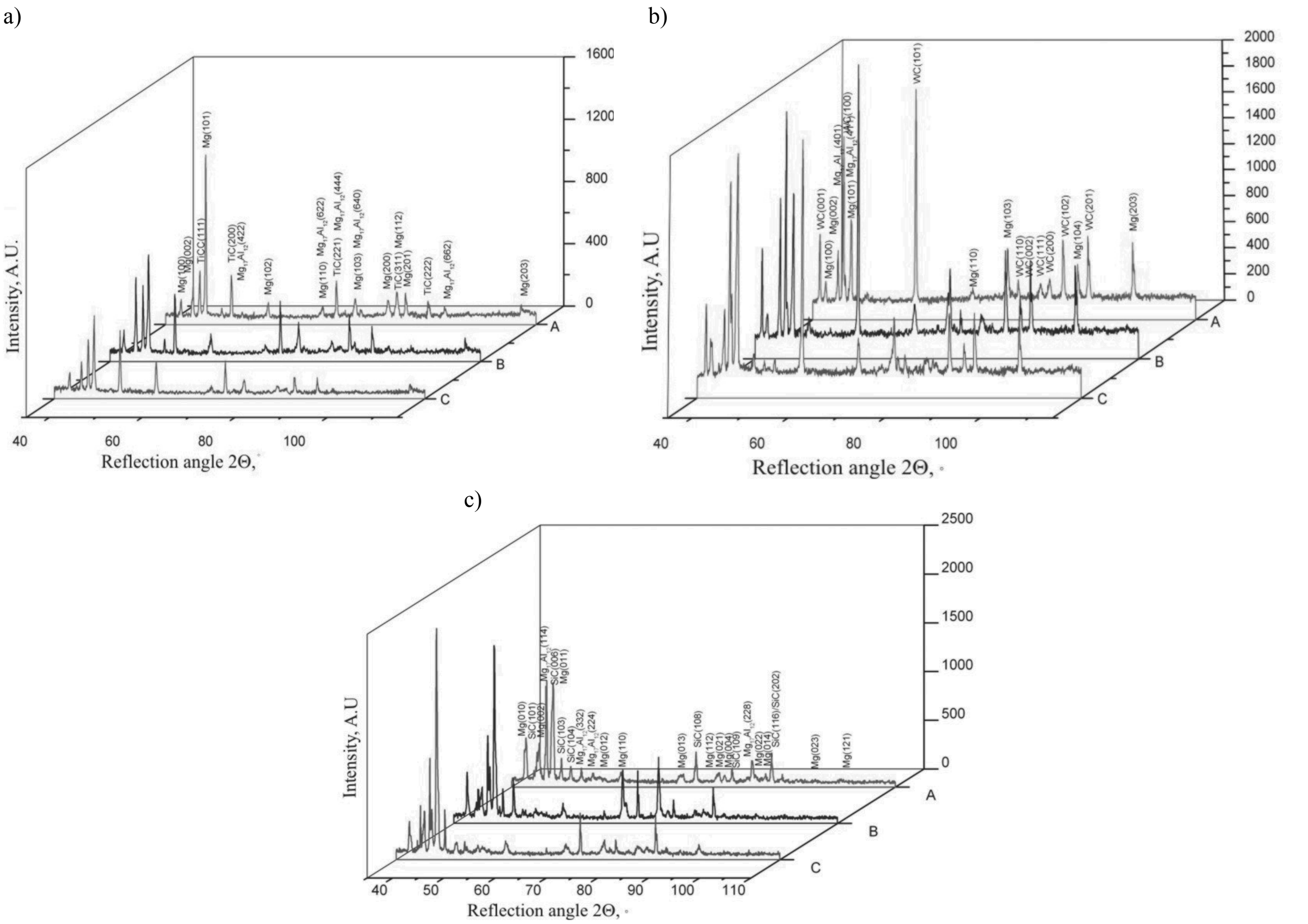

Fig. 9. X ray diffraction pattern of the: MCMgAl12Zn1, cast magnesium alloy after laser alloying with a) TiC, b) WC, c) SiC: powder feed rate: 7±1 g/min, scan rate: 0.75 m/min, laser power: A-1.2 kW, B-1.6 kW, C-2.0kW

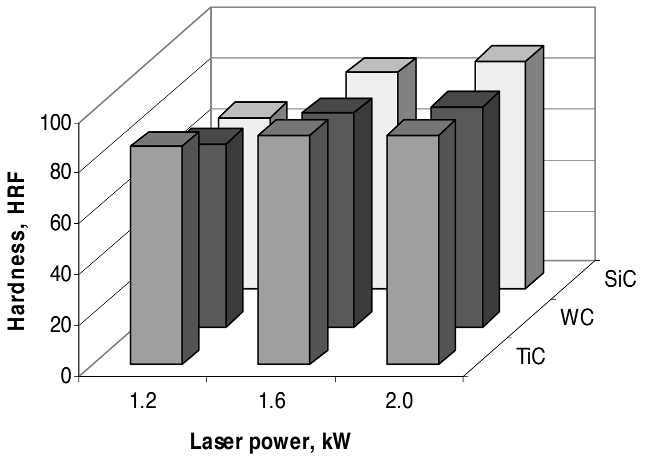

Fig. 10. Average hardness change of the casting magnesium alloys surface layer after laser alloying with titanium-, tungsten-, and silicon carbides with the varying laser power values and constant alloying feed rate of 0.75 m/min

Figure 9 present X-ray diffraction patterns of the Mg-Al-Zn casting magnesium alloys after laser alloying with powders of WC, TiC, SiC carbides. Phases α – Mg, and β – $Mg_{17}Al_{12}$ were identified, as well as reflexes coming from the employed powders in all analyses cases.

Hardness tests results of the MCMgAl12Zn1casting magnesium alloys after laser inundation of WC, TiC, and SiC carbides are presented in Fig. 10. Tests carried out show that for the MCMgAl12Zn1 alloys hardness remains at the similar level as in case of materials without laser treatment, or – for some alloying parameters – deteriorated slightly. Alloy hardness values after heat treatment was about 92 HRF for the MCMgAl12Zn1. The biggest surface layer hardness drop was observed for the MCMgAl12Zn1 alloys alloyed with SiC powder at laser power of 1.2 kW of 19 HRF.

4. Conclusions

Examinations of the surface layers confirm that it is feasible to carry out alloying of the surface layers of the MgAl12Zn1 casting magnesium alloys using the HPDL high power diode laser with the beam power values of 1.2-2.0 kW and with the alloying feed rates of 0.5-1.0 m/min. Alloying with the TiC, WC, and SiC carbides powders, whose melting points are much higher than the melting points of the investigated alloys, causes innudation of the undissolved powder particles into the molten substrate. Strong circulation of the molten metal occurs, followed by sudden solidification when the laser beam has passed. Width of the surface layer grows with the employed laser power increase. 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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