Arch. Metall. Mater., Vol. 61 (2016), No 3, p. 1343–1350

DOI: 10.1515/amm-2016-0221

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THE EFFECT OF LASER SURFACE TREATMENT ON STRUCTURE AND MECHANICAL PROPERTIES ALUMINIUM ALLOY ENAC-AlMg9

In this work, the influence of a high power diode laser surface treatment on the structure and properties of aluminium alloy has been determined. The aim of this study was to improve the mechanical and tribological properties of the surface layer of the aluminium alloy by simultaneously melting and feeding tungsten carbide particles into the molten pool. During the process was used high-power diode laser HPDL. In order to remelt the aluminium alloy surface the HPDL laser of 1.8, 2.0 and 2.2 kW laser beam power has been used. The linear laser scan rate of the beam was set 0.5 cm/s. In order to protect the liquid metal during laser treatment was used argon. As a base material was used aluminium alloy ENAC -AlMg9. To improve the surface mechanical and wear properties of the applied aluminium alloy was used biphasic tungsten carbide WC/W_2C. The size of alloying powder was in the range 110-210 µm. The ceramic powder was introduced in the remelting zone by a gravity feeder at a constant rate of 8 g/m.

Keywords: Laser, surface treatment, laser feeding, composite layer, wear resistance, aluminium alloys

1. Introduction

The laser surface treatment of aluminium alloy with feeding powder is injecting directly into the molten pool was investigated by many authors. The dynamic expansion of the industrial economy makes it necessary to find much better and advanced engineering materials able to meet the new demands [1-4]. Research is being designed and conducted it improve functional and mechanical properties of all materials group for industrial use. Very attractive possibilities they give light metal alloys such as aluminium or magnesium [5-6]. The low density of aluminium or magnesium compared to the steel, good resistance to corrosion and a simple possibility the improve wear resistant and mechanical properties the causes are increasingly being used in very important applications like an automotive industry, aerospace and air transport [7-8]. Very important treatment to improving mechanical properties metals such as aluminium, magnesium and elements it's made are developed and widely used surface treatment technologies. Laser beam provides a very precise introduction of energy and consequently the can better and faster to implement industrial operations in the technology of layer treatment. The layer formed on the metal must be characterised by the high fatigue strength and impact resistance, high hardness and toughness, as well as thermal shock, resistance to high and low temperature (creep and fracture toughness), and the appropriate thermal conductivity. The laser emission is also very often used for enhancement of tribological and mechanical properties different engineering materials [9-10]. The properties of the surface layers to a large extent depend on their porous, structure, material discontinuities, uniform chemical composition and phase composition.

Very often in order to determine conditions of laser treatment, there are used numerical methods that would significantly shorten the time to find the best and optimal parameters [10]. Laser technologies is currently often used for forming the structure and properties of the surface layer of not only light but assistive technologies etc. metals steel, titanium alloys, the alloy of nickel and many others materials [11-12]. The laser surface treatment is used for reducing discontinuity and porosity in the material on the top surface, to increase the corrosion resistance [13]. The goal of this work was to improve the tribological, and mechanical properties of the surface layer of the ENAC-AlMg9 cast aluminium alloy by remitting and simultaneous feeding the biphase tungsten carbide particles into the molten pool during laser treatment and the same obtained composite layer on the slightly substrate.

2. Materials and method

The investigation was carried out on cast aluminium alloy with magnesium and silicon ENAC-AlMg9. The chemical composition of applied alloy is shown in Table 1. The structure of the aluminium alloy used in the laser surface treatment was shown in Fig. 1. The top surface of aluminium was remelted using high-power diode laser HPDL. Depth and width of obtained layers were dependent on applied laser beam power. Parameters of applied laser are presented in Table 2.

The laser alloying process was conducted in a shielding gas atmosphere of argon. For the laser feeding the ceramic

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powder of biphasic tungsten carbide was used. The surface morphology of the ceramic powder used in the laser surface treatment is shown in Fig. 2. The grain size of the applied powder was in the range from 110-210 µm. Powder of tungsten carbide dried before laser alloying in a dryer for 24 h at 180 °C in order to completely eliminate moisture. In order that Increase absorption of laser radiation and Increase the efficiency of the process area of the specimen prior to treatment were mechanically ground on laboratory LabPol25 Struers grinding machine with sandpaper of 15mm grain size and the next was flux-coated and dried in an oven at 120. The use of flux from lithium chloride allows dissolve metal oxides formed on the surface of aluminium alloy and increases the absorption of laser radiation by top surface during the process. The parameters of the laser alloying are shown in Table 3.

TABLE 1

The chemical composition of investigated aluminium alloy

Elements	Si	Mn	Zn	Mg	Al
ENAC-AlMg9	1.32	0.50	0.20	9.24	rest

TABLE 2

Specifications of the HPDL Rofin DL 020

Parameters	Value
Density power, kW/cm²	0.8 ÷ 36.5
Wavelength of the laser radiation, nm	940 ± 5
Power, W	100 - 2300
Dimension of Power beam, mm	1.8 x 6.8 /1.8 x 3.8

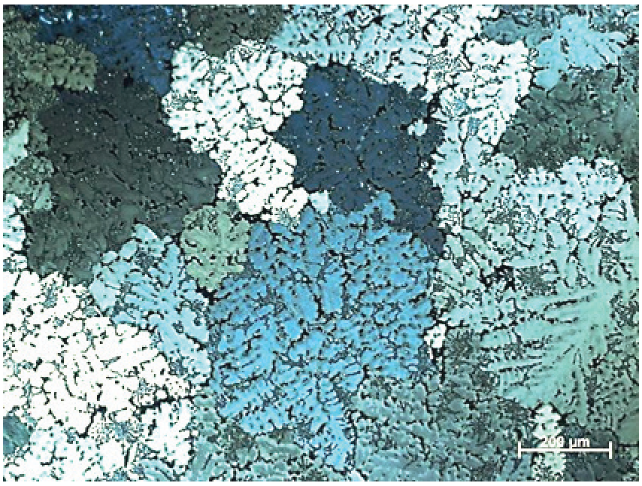


Fig. 1. Structure of aluminium alloy AlMg9

The microstructure of analysed layers was examined by light microscope Axio Observer and a scanning electron microscope Zeiss Supra 35. During the observation in SEM the secondary electron (SE) and backscattered (BSE) detector was used. The analyse the composition of the chemical used in the detector scattered X-ray EDS. The surface topography was Observed using a Zeiss stereomicroscope SteREO Discovery using a magnification in the range from 10 to 100x. Transmission microscopy (TEM) and thin film analysis were carried out in a high-resolution transmission electron microscope S/TEM TITAN 80-300 of FEI company equipped with a STEM scanning system at an accelerating voltage of 250 - 300kW, using an aperture of 10mm, camera length of 330mm and SAD method of collection diffraction.

The surface hardness measurements were performed using a Rockwell test in HRF (60kgf). Hardness on the layers cross-section was measured by the Vickers microhardness test method with a force of 300 Kgf (2.94N).

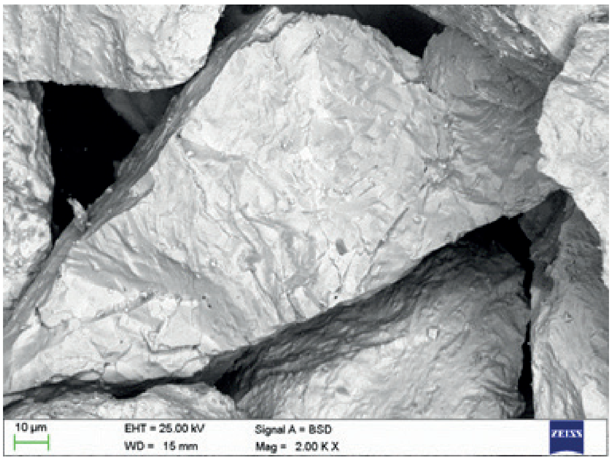


Fig. 2. The morphology of ceramic powder applied to aluminium laser surface feeding

TABLE 3

The parameters of the laser alloying

Laser beam power, kW	1.8, 2.0, 2.2
Shielding gas, l/min	20
Powder feeding g/min	8
Sample initial temperature, K	373
Laser beam scanning rate, m/min	0.5

The wear resistance studies of surface layers and ENAC-AlMg9 were analysed and compared using a rotating sample test the ball-on-disk. Test parameters are shown in Table 4. During the ball-on-disk test, it was registered friction coefficient between tested surface and ceramic counter specimen made of Al_2O_3. The wear dimension of the tracks after the test were measured with a profilometer Sutronic 25 Taylor-Hobson and imaged using a confocal microscope. When measuring the surface roughness by profilometer the Gaussian filter of 0.25 was applied. Moreover, the wear track topography was analysed using a scanning electron microscope in order to reveal rifts and deformation of the surface layer and evaluate wear mechanism. The chemical analysis of processed surface layers was performed using the scattered X-ray detector EDS.

TABLE 4

The ball-on-disk wear test parameters

Load, N	7
Linear speed, cm/s	20
Distance, m	150
Radius, mm	2
Counter specimen	ball – Al_2O_3

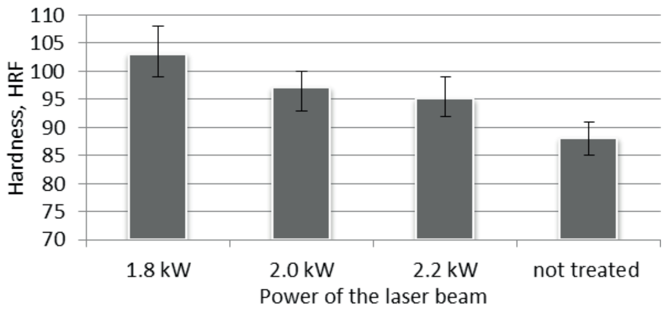


Fig. 3. The hardness of the surface after laser feeding of aluminum alloy and AlMg9Si2Mn without surface-treated

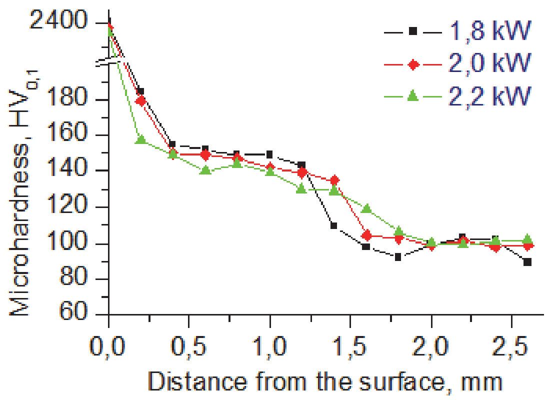


Fig. 4. The microhardness of cross-sectional layers obtained during laser surface treatment with the power of 1.8, 2.0 and 2.2 kW

3. Results and discussion

Laser surface feeding of the ENAC AlMg9 alloy by ceramic powder particles of biphase tungsten carbide WC/W2C resulted in a homogeneous, hard and wear resistant surface layer. The obtained surface layer on the surface aluminium alloy was characterized by a relatively flat and smooth face with no visible cracks, voids and porosity of the surface. On the top surface of the layer identified a number of undissolved tungsten carbide particles.

Measurements carried out shown an increase the hardness of the surface after laser surface treatment. The average hardness of the aluminium alloy without the laser surface treatment was about 88 HRF. The hardness of the composite layers was depend on the laser power. The highest increase was measured for the layers obtained with the laser beam power 1.8 kW (103 HRF) while the smallest for the surface treated with the power of 2.2kW (95 HRF). A smaller increase of hardness is the result of a larger remelting area with higher laser power at the same amount of supplied powder. Results of hardness measurements were presented in the Fig. 3.

The carried out research showed the impact of the applied beam laser power on the topography and roughness of the remelted face. The increase of the laser power results in a decrease of the powder amount on the top surface and results in a reduction in roughness of the surface. During laser feeding with the power 1.8 kW, most of the ceramic powders remain on the surface top, thereby increases its roughness, while at higher power (2.2kW) a part of introduced particles as a result of an interaction of the convective molten metal movements was moved to the bottom of the remelting area. The highest roughness was measured for the layers obtained as a result of laser remelting aluminium alloy with 1.8 kW power beam. The roughness of this surface was in the range of Ra = 10.2 to Ra = 12 mm, while for the laser power was chosen as 2.0kW and 2.2kW, whereas the roughness was respectively 9.2 and 8.1 mm.

The highest microhardness of the cross-section was measured for the layers obtained with the laser power of 1.8kW while the minimum value was measured for the composite produced with the 2.2kW power beam. Significant micro-hardness changes were caused by an inhomogeneous distribution of tungsten carbide and intermetallic phases deployed in the melted area by gravity and convection moves. Simultaneously analysis of measurement showed that with the distance from the top surface of composite layers microhardness was decreases. The average microhardness to a depth of about 0.2 mm for the layers obtained with the laser power 1.8 kW was 184 $HV_{0.1}$ while in the case of melting area obtained with the power of 2.2 kW – 157 $HV_{0.1}$. For 2.0 kW power beam, the average microhardness (to a depth of about 0.2 mm from the top) was about 179 $HV_{0.1}$. The result of microhardness measurements was presented in figure 4.

Profile analysis of the wear trace after the wear resistance “ball-on-disk” test show a significant increase of the wear resistance of samples with a composite layer obtained by laser feeding using ceramic carbide powder into the surface layer of the AlMg9 alloy. On the surface of the wear trace of the tested aluminium alloy without laser treatment were found craters in the material and the wear material (wear product) consists

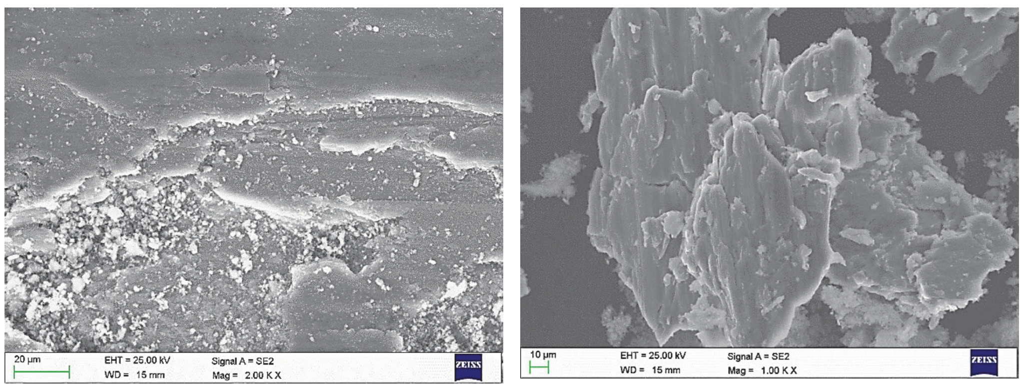


Fig. 5. Wear track (a), and wear product (powder) (b) of AlMg9 alloy after tribological test ball on disk

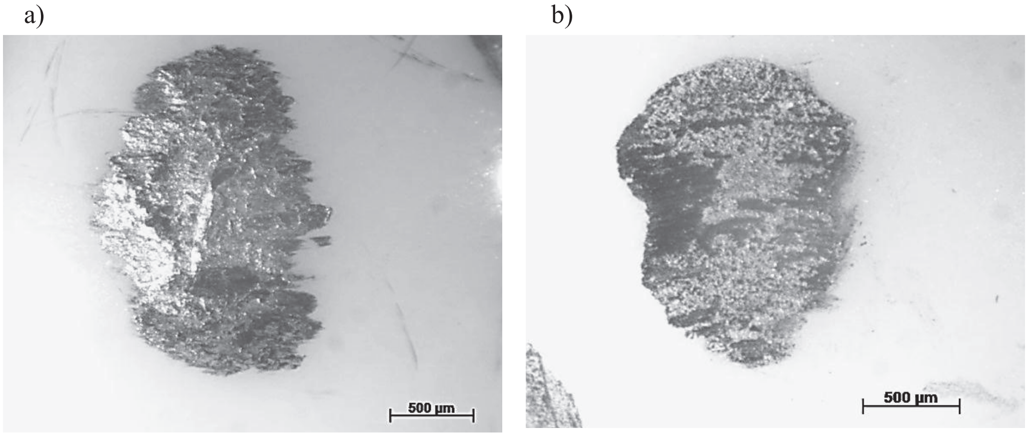


Fig. 6. Counter specimen of the tribological test a) aluminium alloy AlMg 9 b) a composite layer obtained from a 1.8 kW power laser beam

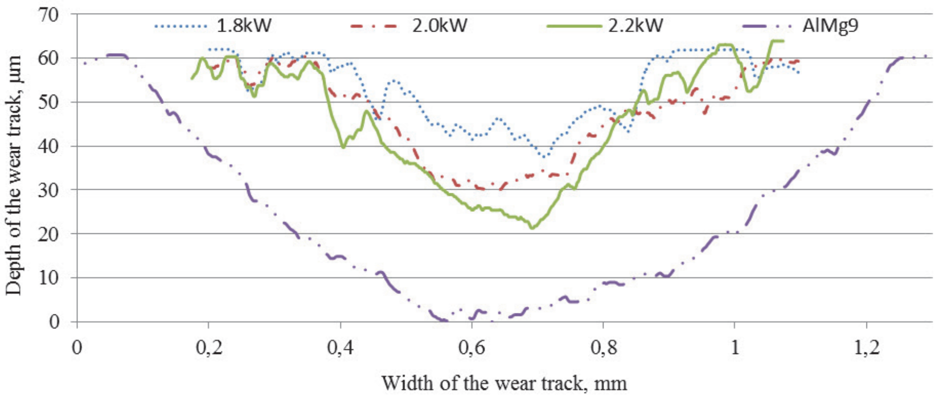


Fig. 7. Wear track of composite layers and aluminum alloy AlMg9 after tribological test ball on disk

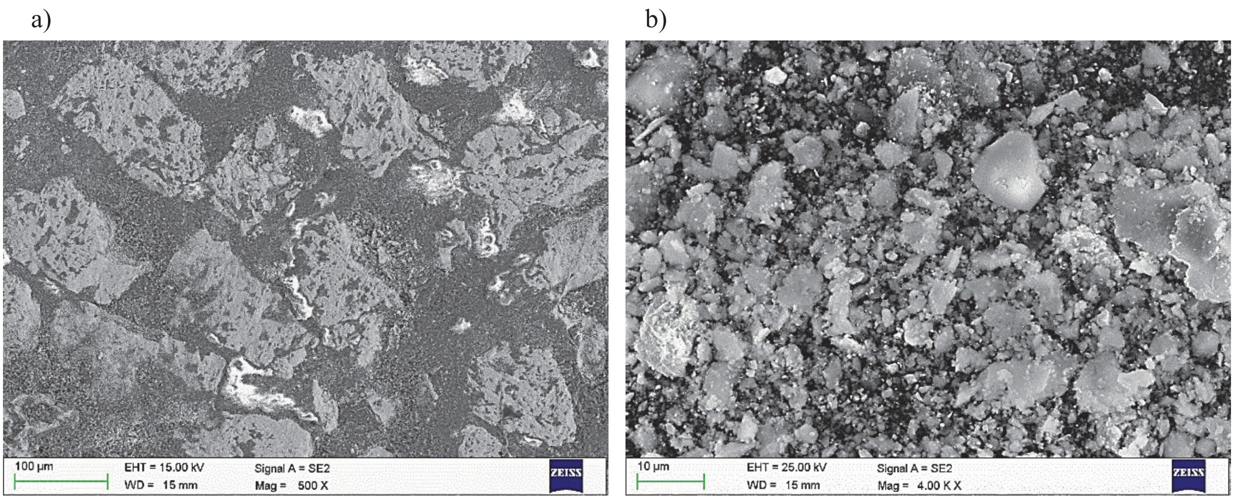


Fig. 8. Wear track (a), and wear product (powder) (b) of composite layers (1,8kW) after tribological test ball on disk

mostly of large flakes Fig. 5a, b. In addition, on the surface of the ceramic counter-samples (Al_2O_3 balls with a diameter of 6mm) occurs accretion adhered to the surface of the substrate material - Al-Mg alloy (Fig. 6a). The average wear volume of the profile after the wear resistance "ball-on-disk" test was 0.88 mm^3 for the AlMg9 alloy. The profile diagram and roughness curve are shown in Fig. 7.

Analysis of wear traces and the substrate after the abrasion wear test of the obtained composite coatings do not confirm the extraction of carbide particles embedded in the surface, which reflects good fusion with the aluminium - magnesium alloy substrate (8 a, b). It was further found, that the increase in laser power while maintaining a constant laser scan rate and a constant amount of supplied powder preferably does not affect the tribological wear resistance. The highest wear resistance was obtained for a layer produced with the lowest power of the laser beam (1.8kW), whereas the lowest wear resistance was achieved for the layer fed with tungsten carbide powder into the surface of the AlMg9 alloy with a power of 2.2 kW (Fig. 7). The average wear volume in case of the layers obtained by laser feeding with tungsten carbide powder and a power of 1.8 kW is 0.11mm^3. Increasing the laser power to 2.2 kW during the laser surface treatment results in a reduction of the wear resistance and increase the wear volume to 0.17mm^3 (Fig. 7). After the test tribological wear resistance test, there were detected damages in the surface of the counter-sample in the form of grinded areas in contact places with the tested aluminium layer (Fig. 6b).

On the basis of the carried out investigations, it was shown, that the average friction coefficient between the AlMg9aluminum alloy and ceramic counter-sample made from Al_2O_3 has changed during the test. In the first step (the initial running) is was registered the friction coefficient between a pure (without being adhered aluminium) surface of the counter-sample Al_2O_3 and the surface of the tested alloy. Abrupt changes of the friction coefficient (0-45m) are caused by adhering the adhesive surface of the aluminium alloy to the ceramic counter-sample and, consequently, pulling out material from the substrate. After a distance of about 45 meters, it can be seen a stabilisation of the measured friction coefficient at a value of 0.38. This is due to the covering the counter-sample with the substrate material (Fig. 9).

The obtained results showed that the introduction ceramic particles in the surface layer of aluminium –magnesium alloy results in a significant increase of the friction coefficient. The highest value of the friction coefficient was recorded for the AlMg9 alloy the feeding of tungsten carbide powder with a laser power of 1.8 kW - 0.97, where the lowest value was obtained for the layer fed with silicon carbide into the surface of the AlMg9 alloy with the laser beam power of 2.2kW. Increasing the laser power during the feeding of tungsten carbide powder in the AlMg9 alloy matrix reduces the friction coefficient to a value of 0.79 for the used laser beam power of 2.0 kW the and 0.73 in the case of laser feeding with a power of 2.2kW (Fig. 9).

Based on the carried out investigations it was found the occurrence of a varying structure depending on the crystallization process. In almost all obtained layers produced on the studied Al-Mg alloys by a mind of laser surface treatment in the intermediate zone separating the liquid and solid phases there were identified structures of small size dendrites, arranged in the direction of heat transfer during solidification. In many cases, it was also discovered changes the dendrites growth direction (Fig. 10a).

In addition, the entire volume of the obtained layers by laser feeding of tungsten carbide particles has revealed the presence of characteristic turbulence pattern caused by the convection motion of the melt and the ceramic powder introduced during

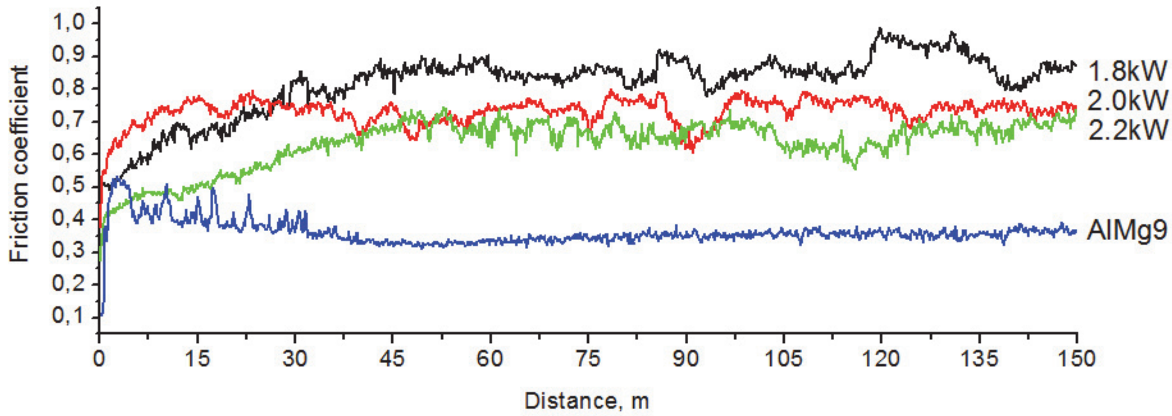


Fig. 9. Graph of friction coefficient after tribological test ball on disk of aluminum alloy AlMg9 and composite layers

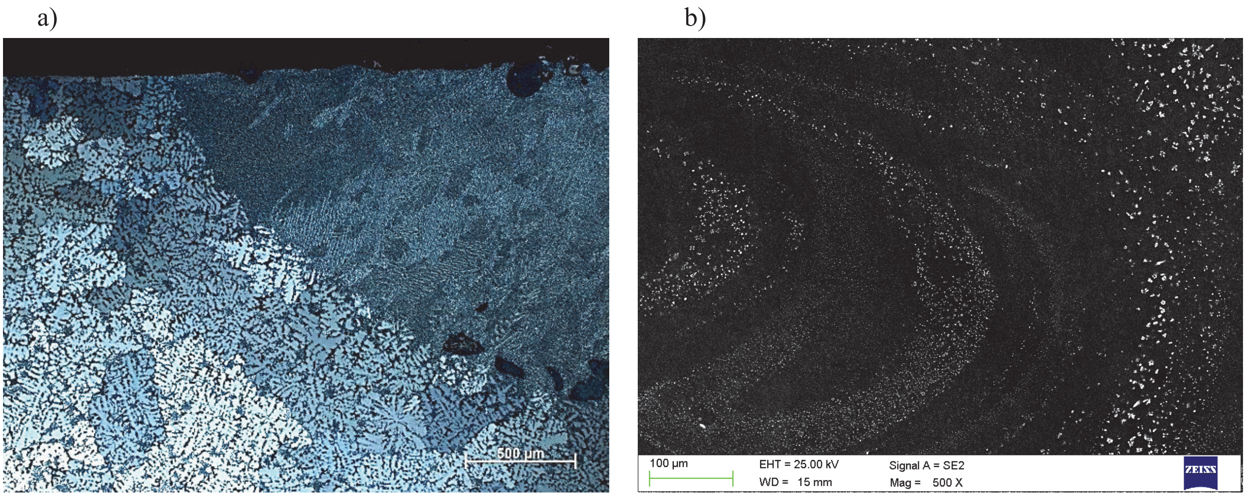
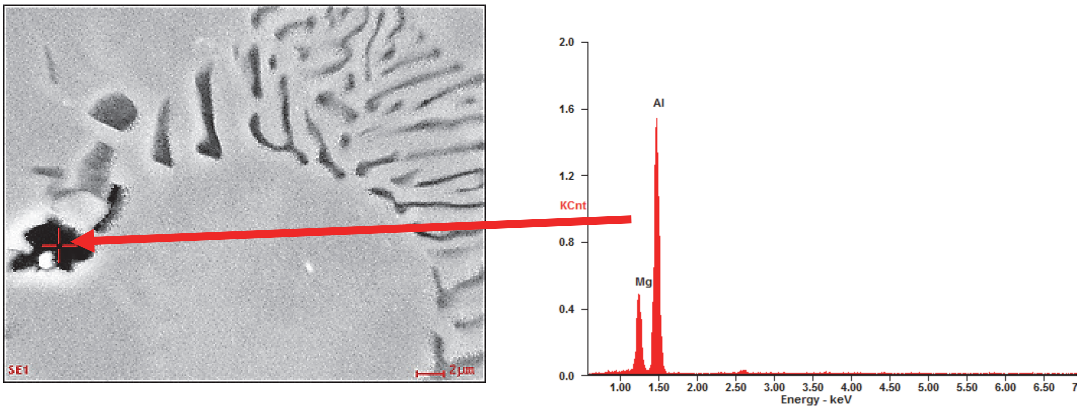


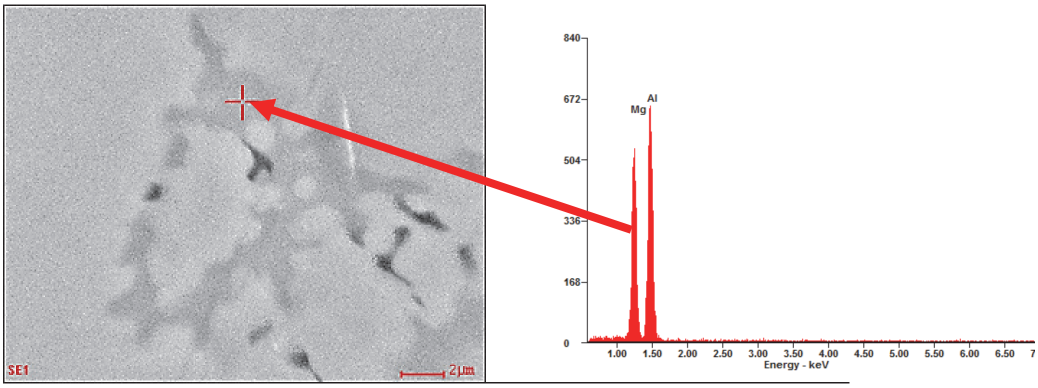
Fig. 10. Structure of layer obtained during the laser treatment with power 2,0kW

a)



	Mg	Al
Wt %	19,08	79,26

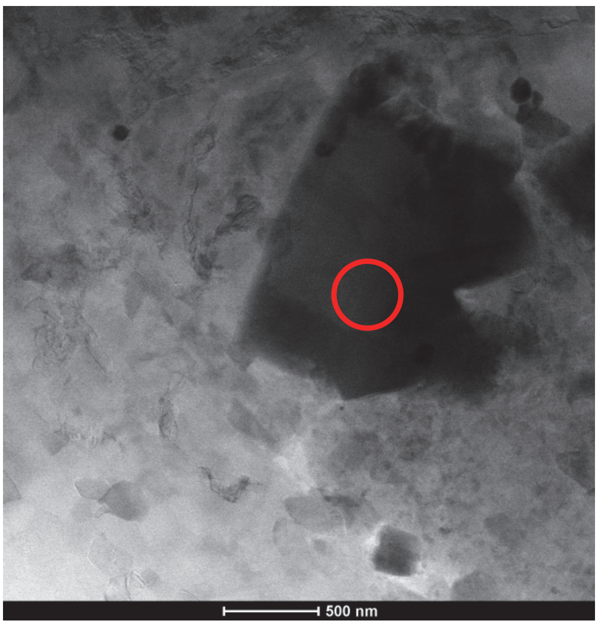
b)



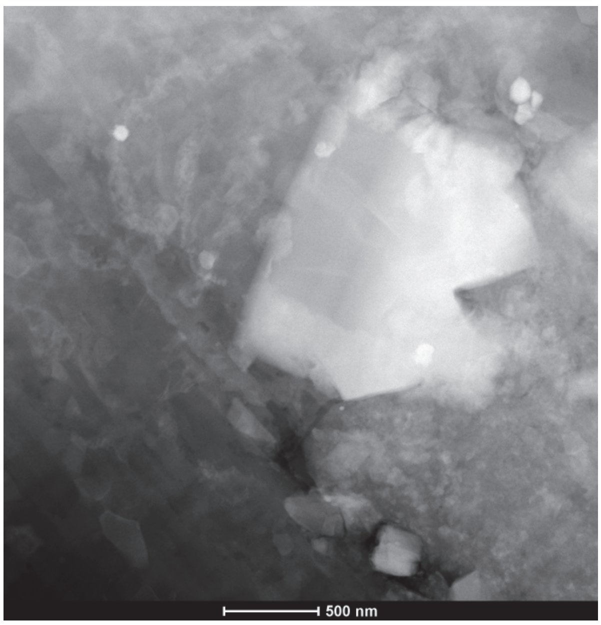
	Mg	Al
Wt %	35,04	64,96

Fig 11. Analysis of chemical composition in spot of remelted area after laser treatment with the power of 2.0 kW, a) Al_4Mg b) $AlMg_2$

a)



b)



a) b)

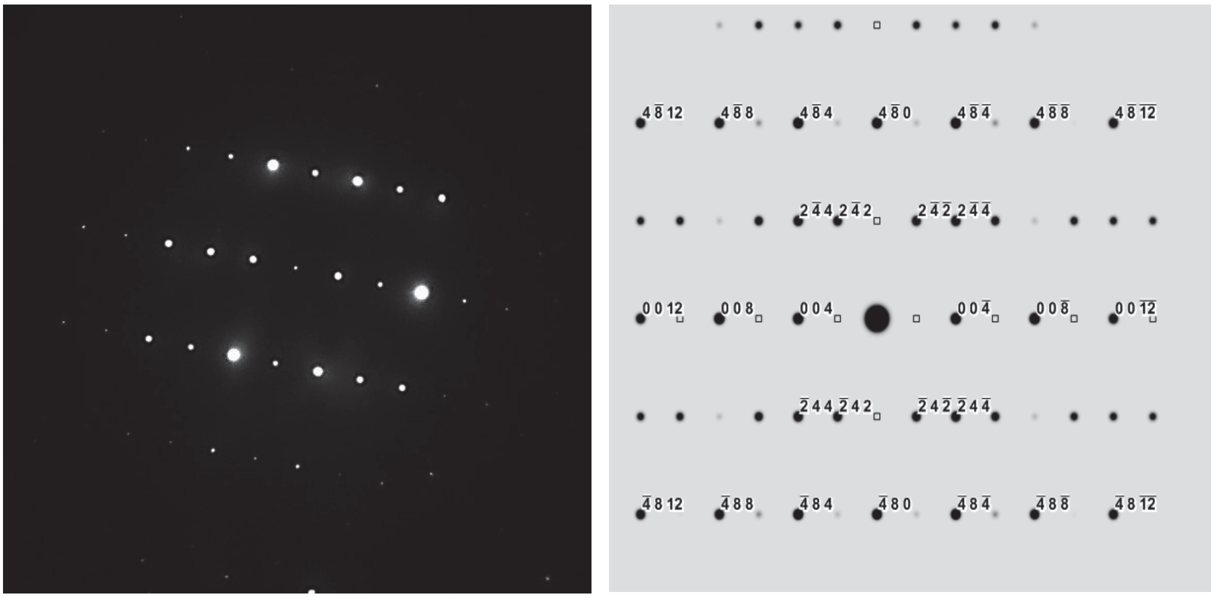


Fig. 12. Structure of the thin film from the remelted area of aluminium alloy after laser treatment with the power 2.2 kW; a) bright field image, b) dark field image, c) diffraction pattern from the area showed in fig a, and d) diffraction solution ($Al_{18}Mg_3W_2$), direction [210]

a) b)

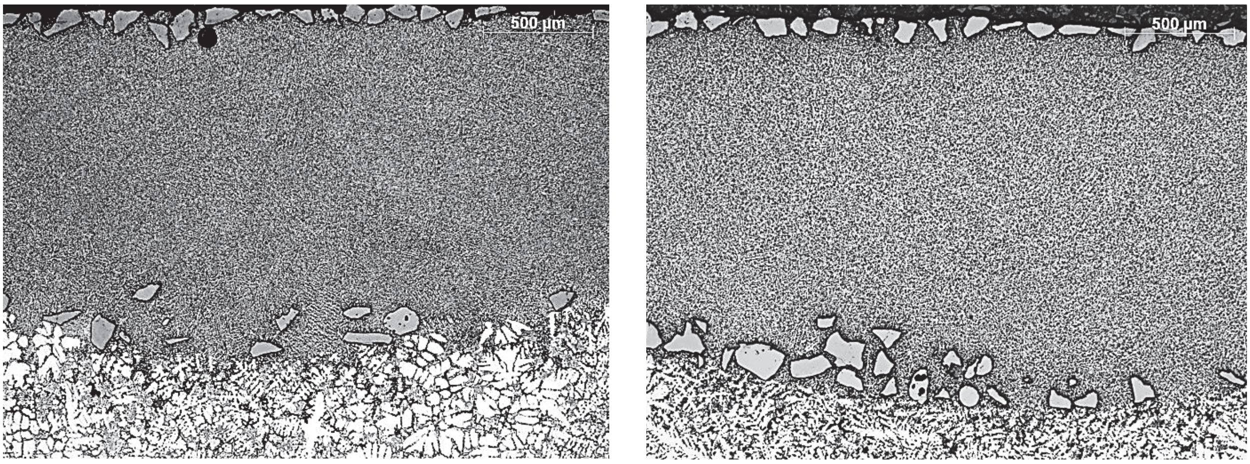


Fig. 13. Structure of the composite layer after laser surface treatment with the power: a) 1.8 and b) 2.2 kW

feeding. As a result of rapid crystallization and solidification of the remelted zone the convection occurring in the liquid during laser feeding become "frozen" (Fig. 10b).

Based on carried out investigations in the scanning and transmission electron microscope were identified the following phase precipitations $AlMg_2$, Al_4Mg, $Al_{18}Mg_3W_2$ (Fig 11a, b, 12). Depending on the used conditions, the laser surface treatment reveals a variety of mechanisms, and the intensities of mixing of the liquid metal and ceramic powder particles in the weld during remelting. At the highest laser power the turbulence of molten metal, the convection movements and gravitational influence cause an intense fall of the fed tungsten carbide particles at the bottom of the remelting zone in the aluminium surface layer (Fig. 12).

The highest share of carbides embedded in the alloy to a depth of 250 µm measured from the face was detected for the lowest laser power of1.8 kW -16%. Together with the laser power increase the share of carbides in the face area was decreased (Tab. 5). Increasing the laser power in each of the analysed the effect of reducing the share of the sintered powder in the melting area subsurface as well as an increase cases causes an decrease of the intensity of the convective movements caused by the temperature difference between the surface and the bottom of the liquid remelting zone and as a result the fed carbide particles move to the bottom of the remelting zone. Furthermore, increasing the laser power results in increased temperature of the treated surface which in turn allows to obtain a deeper remelting zone (Figs. 13-14). The large temperature difference between the central area of the liquid metal pool and the flanges causes that the surface tension forces directed from the centre of the remelting zone, where the temperature is the highest, to the edges. The surface tension force caused by the temperature gradient is strictly dependent on the used laser power and proportional to the thermal conductivity of the molten metal, thereby increasing the heat transfer into the material and, as a result, increasing also the depth of the resulting remelting zone.

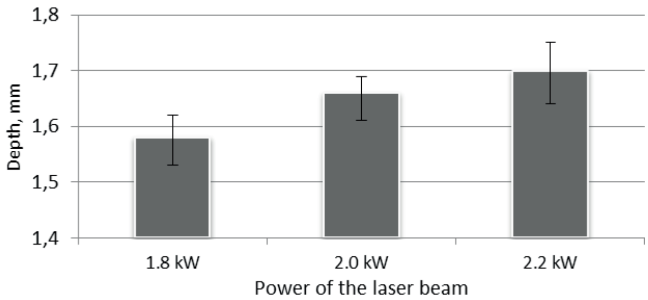


Fig. 14. Depth of layers obtained during the laser surface treatment

TABLE 5

The share of tungsten carbide in various areas of layers obtained during laser surface treatment with the power 1.8, 2.0 and 2.2kW

Power beam laser, kW	250mm from the top surface	500 mm from the heat affected zone
1,8	16%	10%
2,0	13%	18%
2,2	12%	20%

4. Conclusions

In this article are presented investigations on opportunities to improve the mechanical and tribological properties of surface layers obtained on aluminium - magnesium alloys by laser feeding of tungsten carbide powder into the aluminium matrix. On the basis of performed tests involving wear resistance and hardness measurements, it was found that the highest properties of the obtained surface were achieved at the lowest laser power of 1.8kW. Increasing the laser power without any change in the laser scan speed and the supplied ceramic powder does not cause any increase of the hardness and wear resistance. As a result, of the laser feeding with a power of 1.8 kW a layer was achieved with a hardness of about 15HRF higher compared to the substrate. Analysis of the results also showed a significant increase in the friction coefficient for the samples with the composite layer. The resulting layers were characterized by a friction coefficient reaching from 2.55 (1.8 kW) to 1.92 (2.2 kW) times higher compared to the pure AlMg9 alloy. As a result, of the laser feeding a layer was obtained with multi-phase tungsten carbides WC/W_2C and phase Al_4Mg, $AlMg_2$, as well as $Al_{18}Mg_3W_2$ which significantly raise the hardness of the layers.

Acknowledgements

This publication was financed by the Ministry of Science and Higher Education of Poland as the statutory financial grant of the Faculty of Mechanical Engineering SUT.

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