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PROPERTIES OF THE ALUMINIUM ALLOY EN AC-51100 AFTER LASER SURFACE TREATMENT

In this paper, the influence of a laser surface treatment on the structure and properties of aluminium alloy has been determined. The aim of this work was to improve the tribological properties of the surface layer of the EN AC-51100 aluminium alloy by simultaneously melting and feeding silicon carbide particles into the molten pool. The silicon carbide powder was introduced into the liquid metal using a gravity feeder within a constant feed rate of 1 g/min. A high power diode laser (HPDL) was used for remelting. Laser beam energies used in experiments were 1.8 kW, 2.0 kW and 2.2 kW, combined with the constant velocity of 50 mm/min. As a result of the laser treatment on the aluminium alloy, a composite layer with greater hardness and wear resistance compared to the based material was obtained.

Keywords: Laser treatment, Aluminium alloy, Silicon carbide, Wear resistance

1. Introduction

Light metal alloys like aluminium or magnesium are being used in advanced constructional solutions. Therefore, the request for obtaining increased mechanical and functional properties is evident [1,2]. Aluminium alloys as engineering materials compared to steel are more expensive to manufacture; however, because of the low density that leads to reduction in the mass of elements and high corrosion resistance, it is being used very often, in particular, where such properties are essential [1-4]. Significant heat treatment – laser alloying – used for aluminium and magnesium alloys is a great way to develop modern materials with unique properties [5-7]. The surface layer formed on the metal has different properties than the substrate, most often hardness, fatigue and corrosion resistance are increased as is high/low temperature and thermal shock resistance. Properties of the layer depend on their microstructure, porosity, material discontinuities, chemical composition, uniformity and phase composition [8-10]. Laser radiation is a novel energy source that is being used for forming the structure and properties of surface layers not only on light alloys. [15]. The use of a laser beam leads to a reduction of porosity and discontinuity in materials on the surface to increase corrosion resistance [15]. Also, tribological properties are susceptible to improvement within laser treatment but best results can be achieved while using precise, suitable energy delivery [10-13].

The aim of this work was to improve the tribological and mechanical properties of the surface layer of the EN AC-51100 cast aluminium alloy by simultaneously remelting and feeding silicon carbide particles into the molten pool of substrate with different laser beam parameters.

2. Materials and method

A High Power Diode Laser (HPDL) was used to improve the wear resistance and hardness of the aluminium alloy surface layer, by laser feeding the silicon carbide particles into the weld pool. The properties of the surface layer were investigated using a hardness test, a microhardness test measured along the depth of the cross-section, and a "ball-on-plate" wear test [14]. The morphology and distribution of silicon carbide particles in the aluminium alloy matrix were examined by scanning electron microscopy (SEM). The shape and size of the particles before the process are presented in Figure 1.

As the substrate, aluminium alloy with magnesium EN AC-51100 was used. Its chemical composition is given in Table 1. SiC powder was used as a reinforcing phase. The gradation

TABLE 1

The chemical composition of EN AC-51100 alloy

Aluminium alloy	The concentration of elements, wt. %								
	Si	Fe	Cu	Mn	Mg	Zn	Ti	Inne	Al
EN AC-51100	0.55	0.55	0.05	0.45	2.5-3.5	0.1	0.2	0.15	Rest

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of SiC particles was from 45 to 180 µm. The silicon carbide powder was introduced into the matrix using an HPDL. The laser had a very high power density up to 10^7 W/cm^2, which makes a limited thermal impact on the substrate that causes only minor thermal stress and strain [10,15,16].

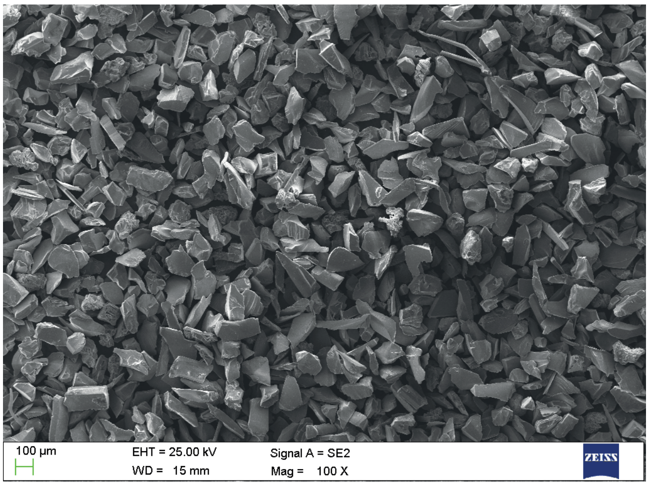

Fig. 1. The morphology of the silicon carbide powder in the initial state

The adverse effect of air on the liquid metal was eliminated by using argon as a protective gas. The particles of silicon carbide were introduced into the molten pool by a rotary powder feeder at a predetermined amount [9,10,17]. The parameters of the process are shown in Table 2.

TABLE 2

The parameters of the laser feeding process

Laser power range	1.8; 2.0; 2.2 kW
Velocity of the laser beam	0.5 m/min
Laser spot size	1.8 x 6.8
Wavelength of the laser radiation	808-940 nm
Reinforcing particles	SiC
Quantity of the powder per minute	1 g/min
Gradation of SiC	45-180 mm

TABLE 3

The parameters of the "ball-on-plate" wear test

Parameter	Value
Load	10 N
Distance	60 m
The length of the test	4 mm
Speed linear motion	4 cm/s

The wear resistance of the composite layers was examined using the "ball-on-plate" tribological test. A silicon nitride ball with a diameter of 6 mm was used in the test. The parameters of the tribological test are presented in Table 3. Before the test, the top surface of the sample was ground with 68 µm grain size abrasive paper. The surface layer after tribological wear was analysed with an SEM with an energy dispersive spectroscopy (EDS) detector. Using SEM, the shape and placement of the silicon carbide particles in the aluminium matrix were determined. The hardness of the obtained composite layers and microhardness along the cross-sectional solidified weld pool were also examined.

3. Results and discussion

To produce a quasi-composite structure of the surface layer of EN AC-51100 aluminium alloy, using a high-power diode laser, the silicon carbides were introduced into the aluminium substrate. The greatest amount of SiC powder embedded in the substrate was observed for the smallest applied laser power of 1.8 kW, which was the effect of the moderate impact of the laser beam (lower heat and lower pressure produced in the melting area) on the ceramic powder placed into the liquid pool, as compared to the higher laser power 2.2 kW.

A small amount of silicon carbide was identified in the surface layer of the melted zone which was obtained by higher laser beam power. This phenomenon was caused by the degradation and dissolution of the powder due to too high a temperature and a greater dispersion of the powder in the volume of the melted pool. The powder is also an absorbent of laser radiation and a heat carrier in the remelting zone. In some cases, it can cause an undesired reaction of additive material: intense flame decomposition.

Observation of the surface topography of the samples after laser treatment showed the uniform distribution of silicon carbide particles on the surface of the aluminium alloy (Fig. 2). On the surface of the melted material, a flash was observed. Unbonded silicon carbide powder was removed from the sample surface by grinding. Surface layer cross-section analysis showed that there was no visible porosity or discontinuity in the material (Fig. 3). Moreover, silicon carbide particles were closely bound with the aluminium alloy matrix. The lack of cracks or pores around the embedded particles may indicate the good wettability of the particles by the matrix material. The results of layer tribological tests confirmed the increase of wear resistance (Fig. 4). The higher power of the laser beam resulted in no difference in wear resistance caused by the minor amount of SiC

TABLE 4

Selected properties of base material and samples after laser treatment

Power of the laser beam, kW	Roughness of the surface Ra mm	Hardness of the surface HRF	Friction coefficient	Dimension of the wear profile		
				Depth, mm	Width, mm	Volume, mm^3
Aluminium alloy EN AC-51100 before the laser treatment						
-	7.69	44.3	0.73	234	3.56	0.00130
Aluminium alloy EN AC-51100 after the laser treatment						
1.8	3.59	57	0.64	60.5	1.37	0.00019
2.0	4.00	55.8	0.68	86.2	1.60	0.00029
2.2	6.26	55	0.71	124	2.34	0.00032

particles embedded in the surface layer. The smallest roughness of the wear track was measured for the material after the laser treatment with the 1.8 kW power beam. The roughness increase with increases in laser beam power. The highest measured roughness was identified for the untreated sample, which was closely related to the amount of powder introduced into the top surface layer. The increase of the quantity of SiC particles on the surface layer provided an increase in wear resistance and, as a result, the wear track was smoother. The greatest depth, width and volume of abrasion were observed for the sample without layers, and the lowest for the material after the laser treatment with the 1.8 kW beam, which confirms the increase of wear resistance of the sample. Measurement results of size and roughness of the wear track surface are shown in Table 4.

The hardness measurement results of the composite layers and base material showed a significant increase in the surface layer hardness of about 44 to 57 HRF (Tab. 4). The microhardness measurement along the depth of the cross-section of the solidified pool showed an increase in hardness of 2500 HV, but only in the areas with a presence of carbides at a depth of about 50 μm. The microhardness of the remelted zone at a depth of +2.5 mm across the top surface was from 97 to 69 HV (Fig. 5).

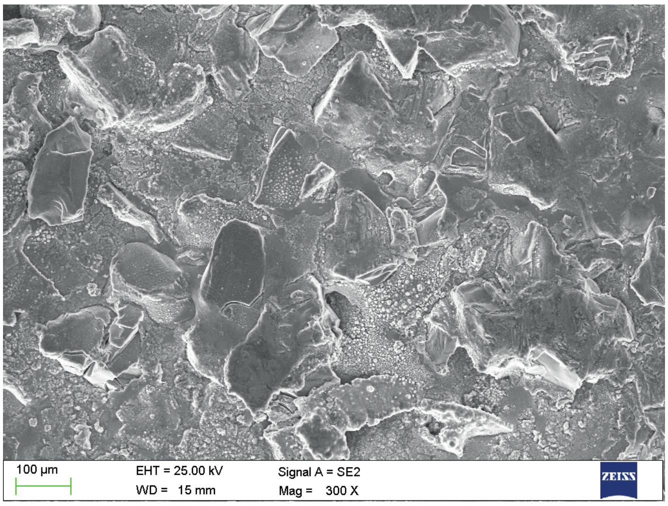

Fig. 2. The surface topography of EN AC-51100 alloy after laser treatment with the 2.0 kW beam power

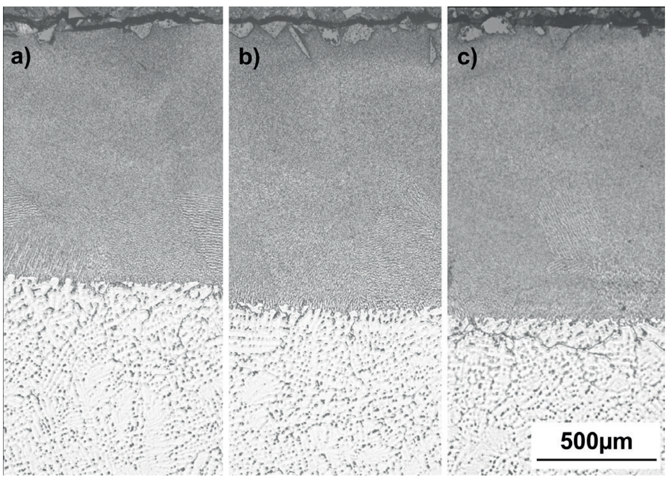

Fig. 3. The microstructure of EN AC-51100 alloy after laser treatment with the a) 1.8, b) 2.0, c) 2.2 kW beam power

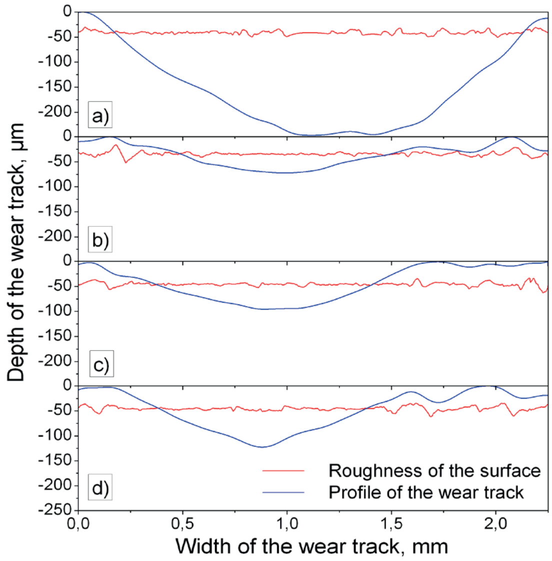

Fig. 4. Roughness and wear profile after the "ball-on-plate" test of: a) base material and samples with composite surface layers obtained using laser treatment with the: b) 1.8, c) 2.0 and d) 2.2 kW beam power

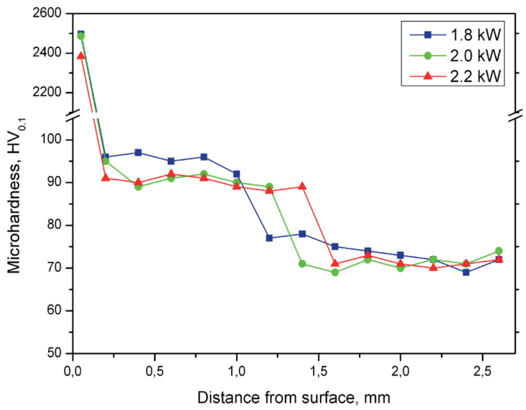

Fig. 5. Microhardness profiles measured along the depth of the cross-sections of composite layers obtained by laser treatment

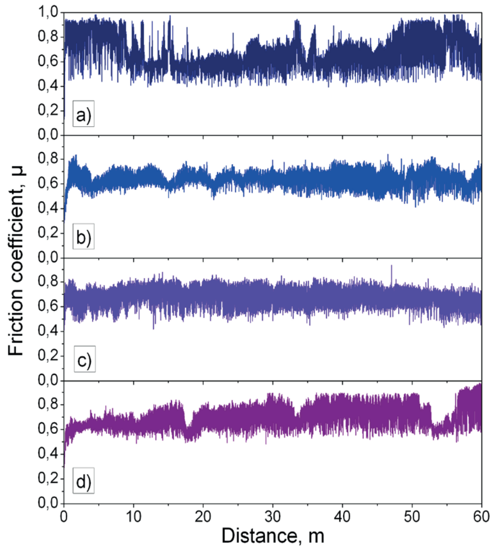

Fig. 6. The friction coefficient as a function of the distance registered during the "ball-on-plate" test for a) base material and samples after laser treatment with the: b) 1.8, c) 2.0 and d) 2.2 kW beam power

To identify the abrasion resistance of the surface layers, the friction coefficient was analysed during the “ball-on-plate” test (Fig. 6). The research showed that the friction coefficient for samples with silicon carbide particles embedded in the surface layer was not only lower, but also has considerably less fluctuation as compared to the base alloy. In the begging, for all samples treated with a laser beam, the friction coefficient increased slightly. This was caused by a lack of oxide film and the presence of partially embedded silicon carbide on the surface that reduced roughness. Measurements of the friction coefficient as a function of distance confirmed that, after the removal of the silicon carbide particles embedded in the matrix substrate, there was a significant increase in the friction and wear coefficients of the substrate. This was caused by the intensification of wear on the mechanism in the remelted zone by micro-cutting. The mechanism of tearing out incoherent particles of SiC from the matrix had an adverse effect on the wear rate of the composite surface layer because hard particles behave like micro-blades, which increase the degradation of the surface (micro-cutting). For the sample, after the laser treatment with 2.2 kW beam power, the layer was interrupted after 55 metres, which was confirmed by a sudden increase in the friction coefficient to 0.9. The EDS analysis confirmed that the wear products of laser treated samples contained silicon carbide particles. It indicates that during wear test, SiC reinforcing particles were partially torn out from the aluminium substrate. Within the analysis of the wear product, aluminium alloy particles were observed to be breaking off. The wear product and the chemical composition analysis are shown in Figure 7 and Table 5.

TABLE 5

The results of EDS point analysis of the wear product after the “ball-on-plate” test of the sample after laser treatment with the 2.2 kW beam power

Element	Wt%	At%
CK	25.6	42.6
OK	7.9	9.9
AlK	6.9	5.1
SiK	59.6	42.4

Regarding the analysis of the wear product, the samples without laser treatment showed the presence of large particles detached from the surface of the substrate material (Fig. 8). This kind of wear product confirmed that the dominant mechanism was destructive chipping.

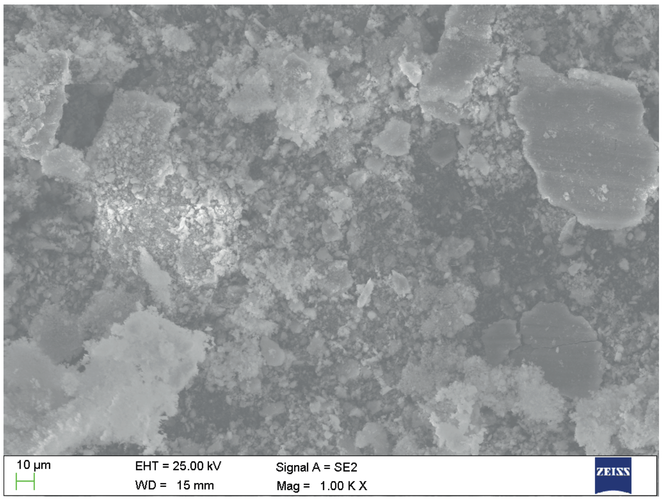

Fig. 8. The wear product after the “ball-on-plate” wear test of the base material

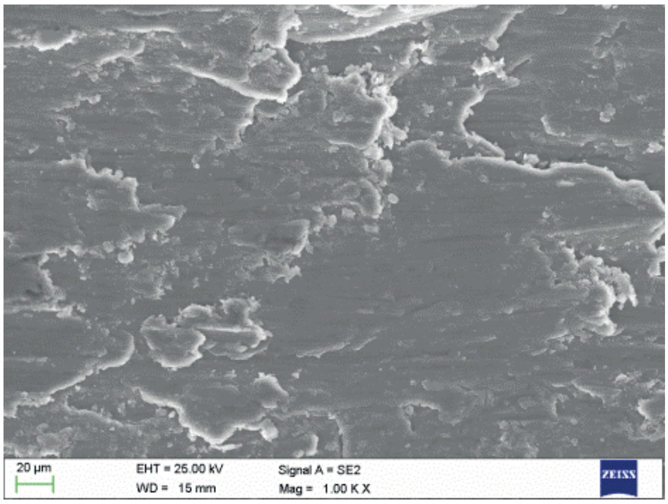

Fig. 9. Wear trace on the surface of the base material after the “ball-on-plate” wear test, distance 60 m, load 10 N

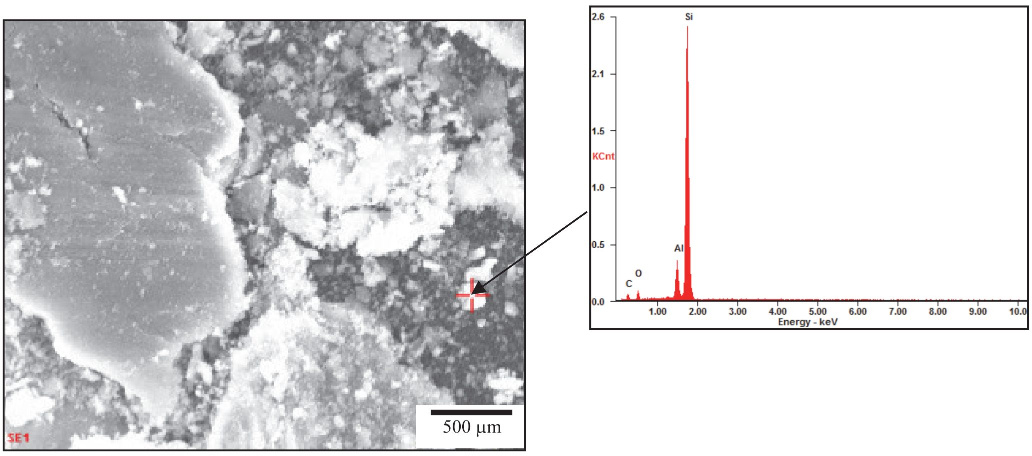

Fig. 7. The wear product after the “ball-on-plate” wear test of the sample after laser treatment with the 2.2 kW beam power (a) and results of EDS point analysis of the surface damage (b)

a) b)

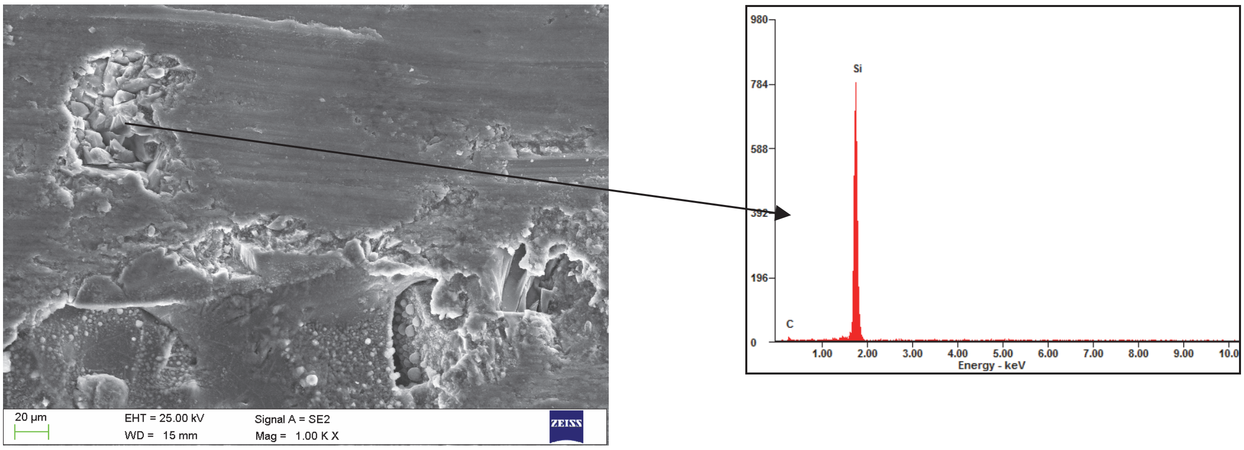

Fig. 10. Wear trace on the surface after laser treatment with the 2.0 kW beam power after the "ball-on-plate" wear test, distance 60 m, load 10 N (a) and results of EDS point analysis of the surface damage (b)

Tribological test trace observations using SEM and chemical composition analysis using X-ray spectrometry confirmed the nature of the wear of the base material and the samples after laser treatment. The trace on the surface of the base material showed a visible loss caused by fissures, wear and ridging of material particles from the substrate. On the surface after laser treatment, plastically deformed areas and micro-cutting caused by the tearing of silicon carbide particles from the substrate (Fig. 9) was observed. Moreover, large craters exposing agglomerates of the silicon carbide were noticed. Their shapes and sizes were evidence of the aluminium part detaching from the surface. Wear test results for surface after the laser treatment and their chemical composition analysis of scoring damage are shown in Figure 10. The study confirmed the occurrence of silicon carbide particles in the aluminium alloy matrix. The carbon peak is hardly visible what is related with a small atomic number ($Z = 6$). A quantity EDS analysis of light elements is usually difficult mostly because weak signal and the strong absorption of the low energy X-ray by the sample itself.

4. Conclusions

The results of the analysis showed that the final layer obtained with laser treatment has greater hardness and better wear resistance compared to the base material. Tribological test results demonstrated that the best wear resistance occurred within composite layers obtained using the lowest power laser (1.8 kW). The increase of laser beam power during the process of introducing silicon carbide particles in the aluminium alloy matrix by the HPDL did not cause an increase in the wear resistance of obtained composite layers. The analysis of the friction coefficient at a function of distance confirmed that the introduction of silicon carbide particles into the aluminium alloy matrix reduced the friction coefficient from 0.73 measured for the material without the laser treatment to 0.64 for the sample with embedded SiC particles with the 1.8 kW power beam. The metallographic examination confirmed that the dominant wear mechanisms of samples after the laser treatment were micro-cutting and fissuring. For the samples without the laser treatment, the dominant mechanisms were fissuring, abrasion and chipping from the substrate.

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