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K. LABISZ*, T. TAŃSKI*, D. JANICKI**, W. BOREK*, K. LUKASZKOWICZ*, L.A. DOBRZAŃSKI*

EFFECT OF LASER FEEDING ON HEAT TREATED ALUMINIUM ALLOY SURFACE PROPERTIES

In this paper are presented the investigation results concerning microstructure as well as mechanical properties of the surface layer of cast aluminium-silicon-copper alloy after heat treatment alloyed and/ or remelted with SiC ceramic powder using High Power Diode Laser (HPDL). For investigation of the achieved structure following methods were used: light and scanning electron microscopy with EDS microanalysis as well as mechanical properties using Rockwell hardness tester were measured. By mind of scanning electron microscopy, using secondary electron detection was it possible to determine the distribution of ceramic SiC powder phase occurred in the alloy after laser treatment. After the laser surface treatment carried out on the previously heat treated aluminium alloys, in the structure are observed changes concerning the distribution and morphology of the alloy phases as well as the added ceramic powder, these features influence the hardness of the obtained layers. In the structure, there were discovered three zones: the remelting zone (RZ) the heat influence zone (HAZ) and transition zone, with different structure and properties. In this paper also the laser treatment conditions: the laser power and ceramic powder feed rate were investigated. The surface laser structure changes in a manner, that there zones are revealed in the form of. This carried out investigations make it possible to develop, interesting technology, which could be very attractive for different branches of industry.

Keywords: Manufacturing and Processing, Ceramic powder, Laser Surface Treatment, Aluminium alloys, HPDL laser, Remelting

1. Introduction

A grate number of the engineering applications require a surface layer which is very hard and strong, with a high wear-resistant potential, but on the other hand with relatively soft interior structures contributing a proper ductility. Laser treated surface layers are surfaces, that have excellent metallurgical bonding to the matrix material. Laser coatings are surfaces that have excellent metallurgical bonding to the matrix material. Laser Surface Alloying - LSA is one of the methods of surface treatment, beside for example vacuum techniques [1-7], consisting in the introduction to the matrix material small amount of alloying additives get into the top of the surface layer in the form of ceramic particles. The laser treatment as a part of the new generation techniques applied in metal surface technology is discussed in this paper. High power densities allow precise control of heating and cooling of a small material amount. Laser surface alloying (LSA) is used for improving mechanical and chemical properties of the surface layer. It consists on surface layer enriching with alloying elements and structure changes. The alloying additions used in the laser alloying process are usually light metal alloys, steels, super alloys, reinforced with carbides, nitrides and borides [8-16]. The chemical composition of the surface layer, as well as the mechanical properties, are different from those of the initial alloying material. LSA (laser surface alloying) allows the formation of the surface with low thickness and enhancing the properties, with a high wear resistance, high hardness and fatigue/heat resistance [1-7]. HPDLs are increasingly used in applications like materials processing, cutting or surface hardening, as well as in graphical arts, display applications and medical applications [6-9,15].

The applied technique used is one of the most effective and reproducible techniques used to obtain a composite layer on the surface of alloyed or remelted metals. In the literature, it is difficult to find information on alternative technologies to feed powder into the treated metal materials surface. Typically, using this technique the powder material is getting onto the surface in the form of a paste or loose particle, which are then remelted or alloyed. A huge advantage of these techniques is the sublimation process which occurs prior to feeding and disintegration of a large part of the added ceramic material as a result of high energy laser beam irradiation, before feeding of the powder. A too large powder amount, which deals as a laser beam absorbent, similarly as the heat transfer medium, get to the alloying area or too intensive blowing it into the surface of treated alloy, resulting in excessive, undesired reaction of the additive ceramic material, supported by usually intense decomposition reaction in form of a flame. Following this type of impact between the powder and the substrate material – caused by the laser beam – there are formed on the surface of the treated elements numerous holes and material damages outside the remelted laser tray, as well as large turbulence of the alloyed

* SILESIAN UNIVERSITY OF TECHNOLOGY, DIVISION OF MATERIALS PROCESSING TECHNOLOGY, MANAGEMENT AND COMPUTER TECHNIQUES IN MATERIALS SCIENCE, INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS, 18A KONARSKIEGO STR., 44-100 GLIWICE, POLAND

** SILESIAN UNIVERSITY OF TECHNOLOGY, DEPARTMENT OF WELDING, 18 AKONARSKIEGO STR., 44-100 GLIWICE, POLAND

Corresponding author. krzysztof.labisz@polsl.pl

material and may form irregular, high standing sintered base material composed of the ceramic powder [10-15].

The purpose of this paper is to study the effect of an HPDL laser melting on the cast aluminium alloy, especially on their structure and hardness. Special attention was devoted to the monitoring of the layer morphology of the investigated material and on the particle occurred. In this work, there is also presented the laser treatment technique including the alloying of cast aluminium alloys with ceramic carbide powder in the form of silicon carbide (SiC). The structure investigation and improvement of mechanical properties are an aim of this research, and the improvement of surface layer hardness is an important factor for practice applications. In case of CAE PVD and PA CVD process on the surface of other steel grades and light cast alloys to increase the low stiffness of the substrate material [6-8,10,12,16-25].

2. Investigation method and results

2.1. Material for investigation

The material used for investigation was the AlSi9Cu2 aluminium cast alloy. The chemical composition of the investigated light alloy is presented in Table 1.

TABLE 1

Chemical composition of the investigated Al alloy

Concentration of the elements, mass in %							
Alloy	Si	Fe	Cu	Mn	Mg	Zn	Ti
AlSi9Cu2	9.033	0.1873	2.248	0.09	0.1947	0.451	0.0957

The heat treatment was carried out in the electric resistance furnace U117, with a heating rate of 5 °C/min for the heat treatment process with two holds at 300°C and 450 °C performed for 15 minutes. Cooling of the samples after heat treatment was performed in air for the ageing process and in water for the solution heat treatment process. The solution heat treatment temperature was 505°C for 10 hours, and then ageing was performed at 175°C for 12 hours (Table 2). For alloying the ceramic powders SiC powder was used, with properties presented in Table 3.

TABLE 2

Parameters for the heat treatment carried out on the used cast aluminium alloy

Heat treatment parameters of the investigated alloy			
Heat treatment steps	Temperature, °C	Time, h	Cooling type
Solution heat treatment	505	10	air
Ageing	175	12	air

TABLE 3

Properties of the SiC ceramic powder used for alloying

Properties	Value	properties	Value
Hardness, HV	1600	Grain size, μm	125
Density, g/cm^3	3.217	Colour	grey
Melting temperature, °C	2700		

The surface of the samples was after heat treatment specially treated to ensure a lower reflectivity of the laser beam. The surface was coated manually with a carbon – water solution, forming a thin surface film.

2.2. Research methodology

For alloying of the investigated material the HPDL Rofin Dl 020 (Fig. 1a) was applied with the working parameters presented in Table 4. The working parameters should allow to obtain the remelting of the surface layer material as presented on Fig. 1b, ensuring the occurrence of remelting zone (RZ) and heat affected zone (HAZ). The samples were mounted in the laser holder for remelting. On each surface only one laser tray was made with a length of 25 mm, and with a laser power of 2.0 kW. The powder feeder was connected to carrying a gas bottle and powder feed nozzle. The powder feeding was performed in an argon atmosphere, in order to protect the substrate from oxidation. After preliminary attempts for investigation was applied laser power in of 1.2 kW and the feeding speed of 0.25 m/min.

TABLE 4

HPDL laser parameter used for feeding

Laser parameter	Value
Laser wave length, nm	940 ± 5
Peak power range, W	100 - 2300
Dimensions of the laser beam focus, mm	1.8 x 6.8

a) b)

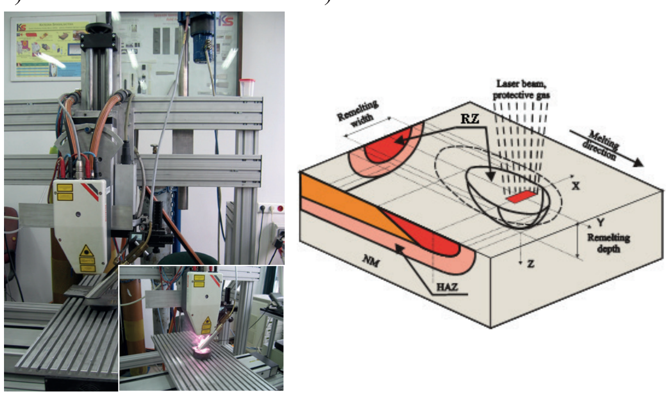

Fig. 1. a) High power diode laser Rofin 020 stand, b) Scheme of the structural changes occurring in the surface layer of the steel after remelting with laser, NM – native material, HAZ - heat effected zone, RZ – remelted zone

Phase identification of the obtained surface structure was carried out using scanning electron microscope Supra 35 with secondary and back scattered electron detection. This microscope was also equipped with Energy Dispersive Spectrometer for analysis of chemical composition of the investigated samples. Hardness tests were measured using Rockwell hardness tester, the load was chosen according to the HRF standard.

The analysis of surface layer phase composition was carried out using the X-ray diffraction method (XRD) on the X-ray apparatus Panalytical X'Pert using the filtered radiation of a cobalt lamp. Diffraction pattern was achieved by a different angle of incidence of the primary beam in the range of 30º to 110º.

Wear resistance investigations were performed using the ball-on-plate method. The tungsten carbide ball with a diameter of 3 mm was used as the counterpart. The tests were performed at room temperature by a defined time using the following test conditions: load, Fn-5N, wear path of 2.5 mm, speed rate of 0.05 m/s.

3. Results and discussion

The carried out laser alloying of the Al-Si-Cu cast alloys with SiC powder with a constant scan rate of 0.25 m/min – producing very rough surface (Fig. 2) - allows to determine the remelting zone with dendritic structure (Figs. 3, 4, 5). This structure occurs in all presented in this article cases (Figs. 6, 7). There was also confirmed the presence of SiC particles in the remelted surface layer, both for the treated and non-treated aluminium surface fed with powder feed rate of 1.2 g/min. However, for the treated surface the amount of powder particles present in the surface layer is higher.

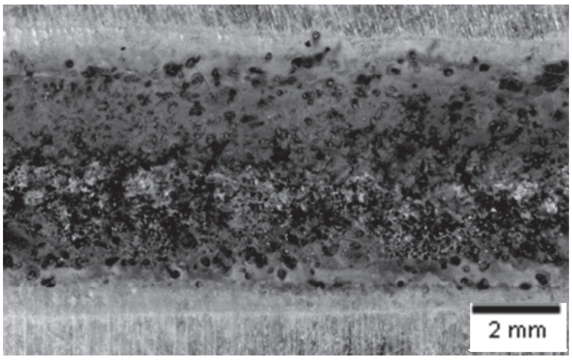

Fig. 2. Surface layer of the Al-Si-Cu alloy, 2.0 kW laser power, 0.25 m/min laser speed, 1.2 g/min powder feed rate

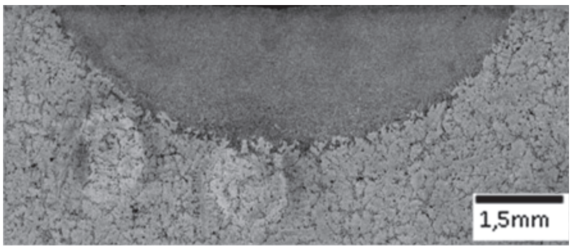

Fig. 3. Surface layer cross-section of the Al-Si-Cu alloy, 2.0 kW laser power, 0.25 m/min laser speed, 1.2 g/min powder feed rate

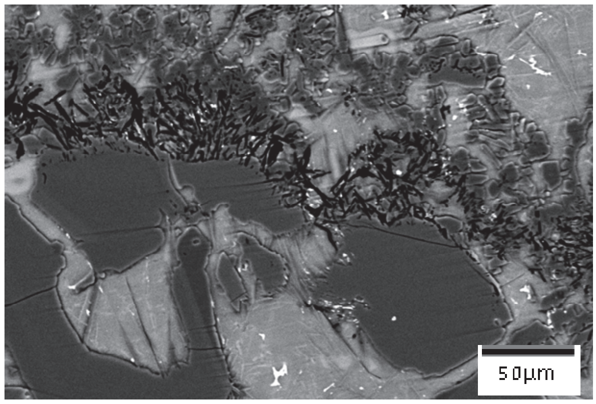

Fig. 4. Structure of the Al-Si-Cu alloy, 2.0 kW laser power, 0.25 m/min laser speed, 1.6 g/min powder feed rate, coated surface

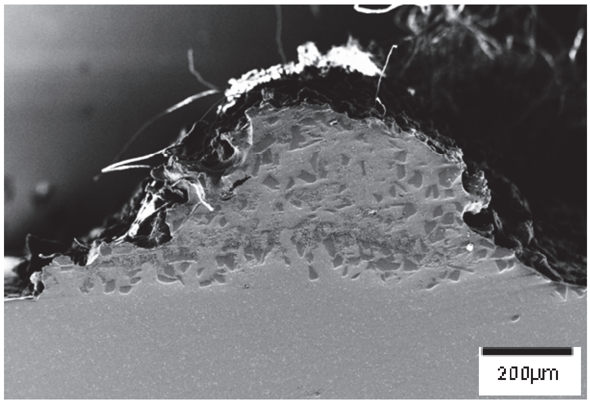

Fig. 5. Structure of the Al-Si-Cu alloy, 2.0 kW laser power, 0.25 m/min laser speed, 1.6 g/min powder feed rate, coated surface

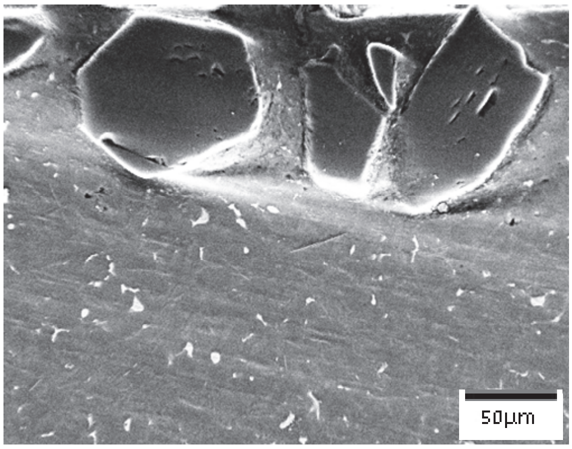

Fig. 6. Structure of the Al-Si-Cu alloy, 2.0 kW laser power, 0.25 m/min laser speed, 1.2 g/min powder feed rate, coated surface

In case of alloying of the surface layer using SiC powder, there were found powder particles in the matrix for power 2.0 kW – the powder particles are well distributed (Fig. 7), with a negligible effect on the increase of the mechanical properties of the alloyed surface layer with the parameters. Investigations performed using the EDS chemical composition mapping (Figs. 8-11) have revealed the occurrence of Si-containing particles, due to the fact that carbon is not measurable using the applied EDS detector, but this result is sufficient to compare the occurrence size and shape of the fed SiC particles in the aluminium matrix.

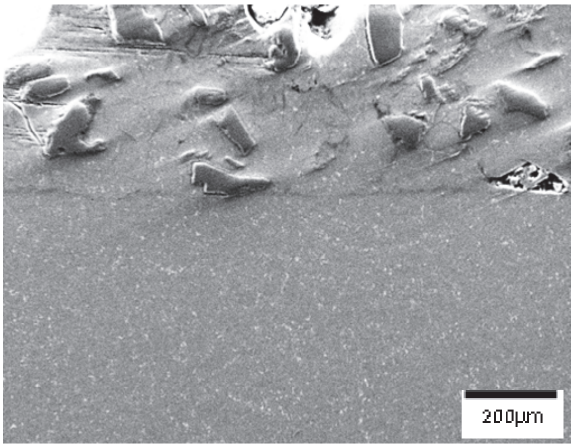

Fig. 7. Structure of the Al-Si-Cu alloy, 2.0 kW laser power, 0.25 m/min laser speed, 1.2 g/min powder feed rate, without surface coating

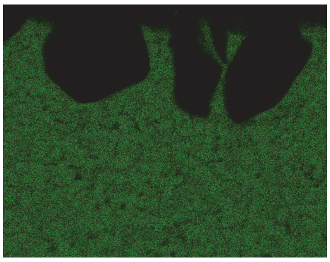

Fig. 8. Area analysis of chemical elements with Al distribution map, from area in Fig. 6

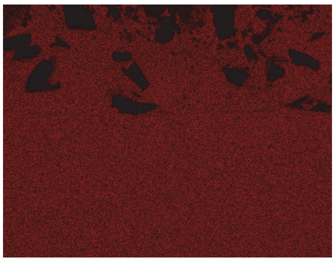

Fig. 9. Area analysis of chemical elements with Al distribution map, from area in Fig. 7

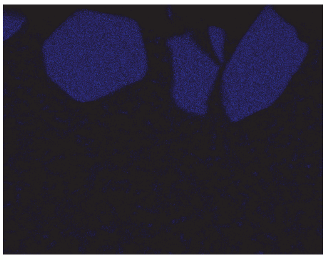

Fig. 10. Area analysis of chemical elements with Si distribution map, from area in Fig. 6

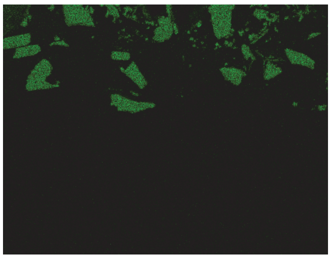

Fig. 11. Area analysis of chemical elements with Si distribution map, from area in Fig. 7

Scanning electron microscopy investigations have also determined the thickness measurement of the obtained remelting surface, ranging up to 1.5 mm. Exactly date concerning the remelting depth is presented in Table 5.

Observations of the cross section confirm that there exist for all samples alloyed with SiC powder, a fluently transition zone between the obtained zones – alloying- and heat influence zone. The sublayers have a varying thickness, where the upper zone is in up to 1.6 mm in thickness, and the HAZ (heat influence zone) has a constant thickness equal 0.9 mm.

Qualitative phase composition analysis performed using the X-Ray diffraction method with the Bragg-Brentano technique has allowed it to confirm and to identify the particular phases of the substrate and ceramic powder (Fig. 12). The low volume amount of the remaining phases occurred in the material has allowed it unequivocally to make an identification on the basis of the achieved X-ray diffractions. Reflexes coming from the Al substrate were found on every X-Ray diffraction from the laser treated surface, as well as the SiC phase was confirmed, what is caused by significant surface layer thickness of <1,9 mm, much higher, than the thickness of X-Rays penetration into the investigated material. Wear resistance test presented on Fig. 13 have revealed a slightly higher wear resistance of the laser treated surface after coating with a thin carbon layer compared to the non-coated surface with relatively high reflectivity. The reason for this is probably the occurrence of bigger SiC particles in the surface layer. Because in non-coated Al surface the reflected energy is absorbed by the SiC ceramic powder, what leads to its breaking and partition into smaller particles – with lower input on the wear resistance and hardness (Table 5). Concerning the wear resistance investigations based on the obtained wear resistance profile of the ball-on-plate tested cross-section place after feeding with SiC powder, it was found that the surface with coating has a higher wear resistance compared to the surface without surface coating (Fig. 13), this is possible due to the decreased reflectance of the surface, allowing better feeding of the ceramic particles into the aluminium matrix. Similar relationship is observed for the hardness measurements result, where the highest hardness is obtained for the surface coated samples – equal 78 HRF vs. 75 HRD for the non-coated material.

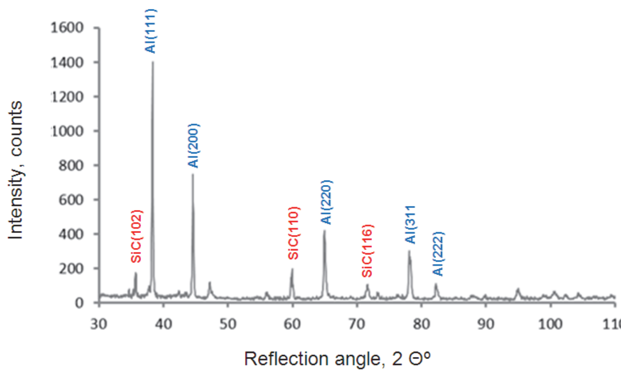

Fig. 12. X-Ray diffraction of the SiC fed Al surface layer according to the Bragg-Bretano method

TABLE 5

Surface layer hardness and depth of the alloying zone and heat influence zone

Hardness and remelting depth of the surface layer			
Remelting conditions		SiC 1.2 g/min, 2.0 kW, AlSi9Cu2	SiC 1.2 g/min, 2.0 kW, AlSi9Cu2, coated surface
Alloying zone depth, mm		1.2	1.6
Heat influence zone depth, mm		0.9	0.9
Hardness, HRF	matrix	73	73
	surface layer	75	78

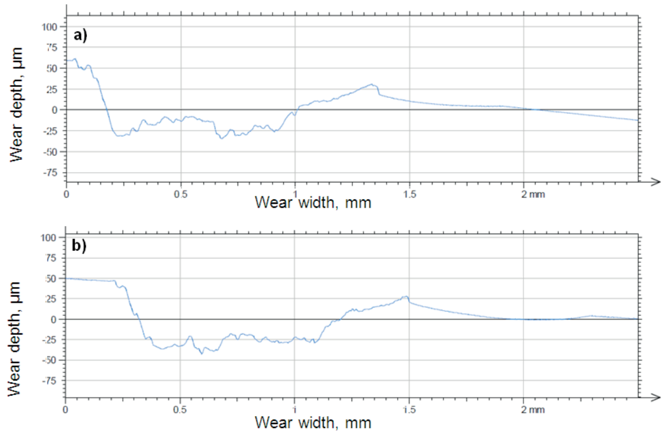

Fig. 13. Wear resistance profile of the ball-on-plate tested cross-section place after feeding with SiC powder, a) coated surface, b) non-coated surface

4. Conclusion

It was found, that the amount of the applied ceramic powder as well as the laser power must be determined individually for the used SiC ceramic powder. For selected remelting for comparison purposes, the feeding rate was chosen as 0.25 m/min. The feeding rate increase will reduce the time of the laser beam impact on the material, and thus the effect of limiting the amount of energy absorbed by the substrate and ultimately leads to a reduction of the extent of structural changes. The use of higher laser power > 1.5 kW or similarly a lower laser scan rate causes the evaporation the material from the surface and the formation of craters, while the use of very low power and very high speed fusing can cause improper melting characterized by the non-uniform distribution of particles in the matrix feathered cast alloy Al-Si-Cu. Proper selection of the feeding parameters enables the occurrence of proper well-structured surface of the material, and the production of a single composite consisting of a matrix and embedded hard ceramic particles. Determining the process it should take into account several important factors, including the following: the difference of density and surface tension between the particles used carbide or oxide and matrix alloy beam energy absorption differences between those used powders and cast aluminium alloys and varying thermal conductivity of the applied ceramic powder, which significantly affects the amount of external heat supplied (from the laser beam) to the substrate, enabling so to obtain better remelting of evenly distributed and dispersed reinforcing phase particles. The detected morphological defects are related to the laser surface treatment process itself. Also the presence of cavities was confirmed, which were formed in the remelted material. In general, it can be stated that the preliminary coating of the surface is an appropriate method for lowering the reflectivity of the aluminium surface. The increase of the laser energy absorption leads, based on bigger SiC particles fed into the Al matrix to higher wear resistance and hardness of the obtained composite surface layer. SEM investigations have allow to determine the thickness measurement of the obtained remelting surface, ranging up to 1.5 mm, with a hardness of the surface layer up to 78 HRF, slightly higher compared to the non-treated material.

There are also some further investigations including other ceramic powders as well as other substrate material from the Al-Si-Cu group. The future investigations will enable a more accurate analysis of zone between different sublayers and allow also a more precise definition of the obtained layers morphology. In next papers there will be also revealed some structure details in case of tungsten carbide powder feeding.

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