Chapter 9

Heuristic Analysis Application for Magnesium Alloys Properties Improvement

Tomasz Tański, Krzysztof Labisz and
Anna Dobrzańska-Danikiewicz

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/57587

1. Introduction

The modern development of technology makes it necessary to look for new design solutions to improve efficiency and product quality, to minimize size and to increase the reliability and dimensional stability under service conditions. The choice of material is always preceded by an analysis of a number of factors including the requirements like: mechanical, physical and chemical, design, environmental, cost related, availability and weight. The problem of a too high mass verifies strongly the applicability of particular groups of materials. Therefore, over the past few decades, occurs a significant increase in demand for materials with low density and relatively high strength alloys such as titanium, aluminium and magnesium. In this group of materials special attention is devoted to magnesium alloys, which in addition to low densities have also other advantages, such as good damping capacity, the best among all currently known structural materials, high dimensional stability, good fluidity, low shrinkage of casts, a desirable combination of low density and high strength, and it can be used for machine parts operating at temperatures up to 300°C as well as relatively ease recyclability. The high damping capacity and relatively low weight allows to use magnesium alloys for production of fast moving parts where sudden changes in speed occurs. However, magnesium is an undisputed advantage especially its low density (1.7 g/cm^3), which is about 35% less than the density of aluminium (2.7 g/cm^3) and more than four times lower than the density of steel (7.86 g/cm3).

2. Investigation method

Investigations described in this chapter concerns first of all investigation of structure and properties of the described engineering materials, in the state after heat and surface treatment, including the selected group of magnesium alloys, aluminium alloys and steel, as well as heuristic analysis using the methodology of integrated computer prediction, enabling the demarcation of predicted development trends of the analysed groups of materials and technologies of surface treatment and lead to the determination of their strategic development in comparison with other groups of materials and surface engineering technologies. In the initial planning stage of research scope in this investigations, in the context of choosing specific research topics with a comprehensive range of academic disciplines or specialties an innovative analysis was used to select the technology that uses the complex dendro-chronological evaluation matrix. Furthermore, in order to confirm the appropriateness of the proper selection of the investigated substrate material like the described in this paper Mg-Al-Zn cast magnesium alloys, there was performed an analysis using the dendrological selection matrix, considering only three groups of most commonly used construction materials, namely steel, aluminium and magnesium alloys.

In addition, the presented “hard” investigation results concerns the characteristics of synergistic effect of the surface heat treatment on the structure and properties of the cast of magnesium alloys, aluminium alloys and steel. Surface treatment of the analysed materials was made using laser surface treatment methods, including, in particular, laser alloying and feeding of hard ceramic particles in the surface of the material to allow formation of quasi-MMCs composite structure (Metal Matrix Composites) on the surface. Laser surface feeding and alloying was conducted by remelting of magnesium, aluminium alloys and steel surface with hard carbide and oxide particles. The feeding and alloying materials were BN, Si_3N_4, ZrO_2, Al_2O_3, NbC, TaC, VC, WC, TiC, SiC powders. The powders was supplied by side injection rate of 6±1 g/min. The laser feeding was performed by high power laser diode HPDL Rofin DL 020 using the 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, 2.0 kW, scan rate – 0.5-1.0 m/min.

The observations of the investigated materials have been made on the light microscope LEICA MEF4A as well as on the scanning electron microscope (SEM) ZEISS SUPRA 35 and on the JEOL JEM 3010 transmission electron microscope (TEM), at the accelerating voltage of 300 kV.

Hardness tests were made using Zwick ZHR 4150 TK hardness tester in the HRF scale. Microhardness of the cross section of the laser surface remelted layer was measured on Fully-Automatic Microhardness Testing System with a loading time of 15 s and the testing load of 100 g.

3. Investigation results

3.1. First part – Heuristic analysis

In the first step of the heuristic material investigation there should be distinguished among all the available constructional materials and technologies several homogeneous groups of materials for the reason to undertake the planned experimental and comparative analysis. The impact of external positive factors (opportunities) and negative factors (difficulties) on the specific technologies analysed was evaluated using the metrological matrix of environment influence. In consistency with the concept proposed, each of the technologies assessed by the experts for their position against the macro-and microenvironment is placed in one of the quarters of this matrix. A universal scale of relative states, being a single-pole positive scale without zero, where 1 is a minimum value and 10 an extraordinarily high value, was used in the research undertaken. The dendrological matrix of values allows in a relatively easy way to visualize the results of the assessment of individual groups of materials and in a next steps of processing technologies in terms of potential, which is the real objective value of the studied area, the so-called hard values, tangible qualities as well as attractiveness, which reflects the subjective perception of its potential users,the so-called soft properties. The potential of a given group presented on the horizontal axis is the result of multi-criteria analysis carried out on the basis of expertise and extensive knowledge of literature data, taking into account the appropriate proportions of the potential: creativeness, application, quality, and technical development. The vertical axis shows the importance of the attractiveness of the group, which is average mean value of expert and literature data evaluation in the field of research carried out on the basis of specific criteria corresponding to the economic attractiveness, cultural, economic, scientific and systemic. The technologies analysed were first evaluated by key experts for their attractiveness and potential and the result obtained was entered into one of the quarters of dendrological matrix of technology value. The wide-stretching oak is the most promising quarter guaranteeing the future success encompassing the technologies with a high potential and attractiveness. The soaring cypress includes very attractive technologies with a limited potential and rooted dwarf mountain pine symbolises technologies with a high potential and limited attractiveness likely to ensure a strong position for the technology if an adequate strategy is employed. The least promising technologies are entered in the quarter called the quaking aspen with their success being either unlikely or impossible. The evaluation of the technology value made has revealed that all the groups of technologies are characterised by a high potential and attractiveness, thus classified to the most promising quarter called the wide-stretching oak. (Fig. 1).

Investigations of processing technology of the used alloys were tightened to the area of surface engineering only, because there exist a wide variety of available types of coatings and methods for forming structure and properties of the surface layer of engineering materials, including magnesium alloys. The investigations allow to determine precise and complete the way to design preferably summarized core material properties as well as the surface layer of the produced element.

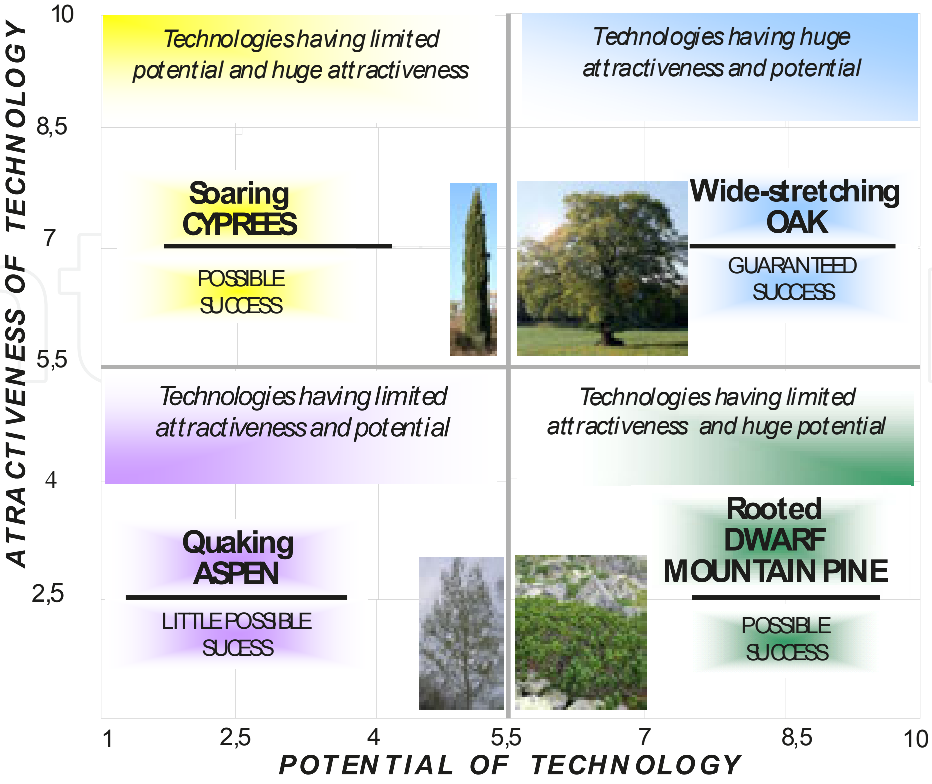

Figure 1. Dendrological matrix of technology value; approach presentation [by A.D. Dobrzańska-Danikiewicz]

For determination of the value of each group of materials, and in the second step of their surface treatment technology, there was applied the weighted scoring method for a comparative assessment used for appropriate qualifications for the specific groups of materials and technologies in the context of their mutual relationship. It should be noted that this technique involves the application of the relativistic principle of evaluation criteria, namely the recognition of differences and existing rules between the different research areas, assumed a specific set of criteria, acting as a selective filter evaluating positively or negatively the investigated object. The weighted scoring method enables the use of multi-criteria evaluation of areas which acts as the perfect model of synthetic evaluation of specific areas, using an interval scale.

Detailed criteria for evaluation of the attractiveness and potential of investigated areas-concerning materials and technologies-investigated in this work are presented in Tables 1 and 3. The listed criteria assigned specific importance, used for following calculation of the weighted values and their sum, which is the basis for comparative analysis, as shown in Tables 2 and 4. Then the multi-criteria results are visualized using a matrix of dendrological values for the investigated area (Figs. 2 and 3). The analysis of preferences clearly indicates, that the highest weighted evaluation, taking into account the criteria in each of the group of materials, are determined for magnesium alloys, which meet a wide range of demands and expectations of modern engineering materials imposed by the ever-changing environment, marked in Fig. 2 as M1 and coloured green. The investigations confirms also, that the aluminium alloys are characterized by a high level of attractiveness.

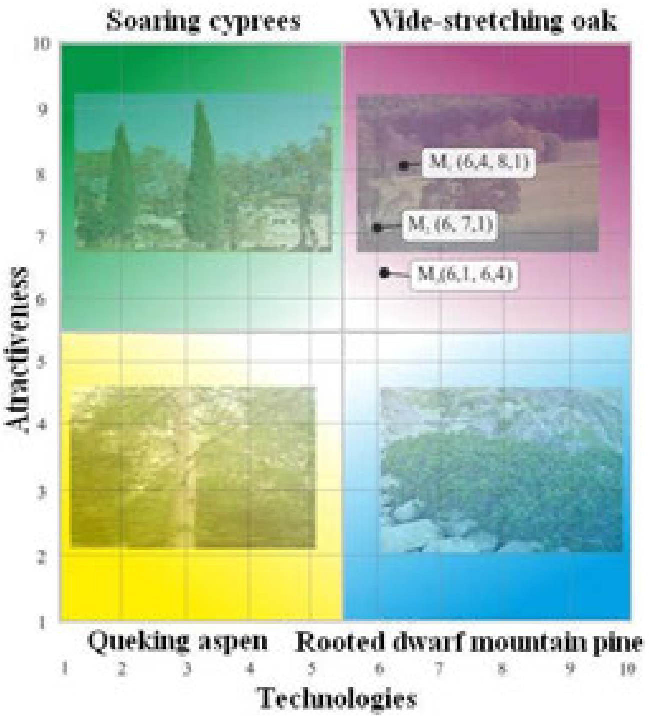

Figure 2. Dendrochronology matrix of values presenting the placement of evaluated groups of materials investigated using computer integrated forecasting of the development

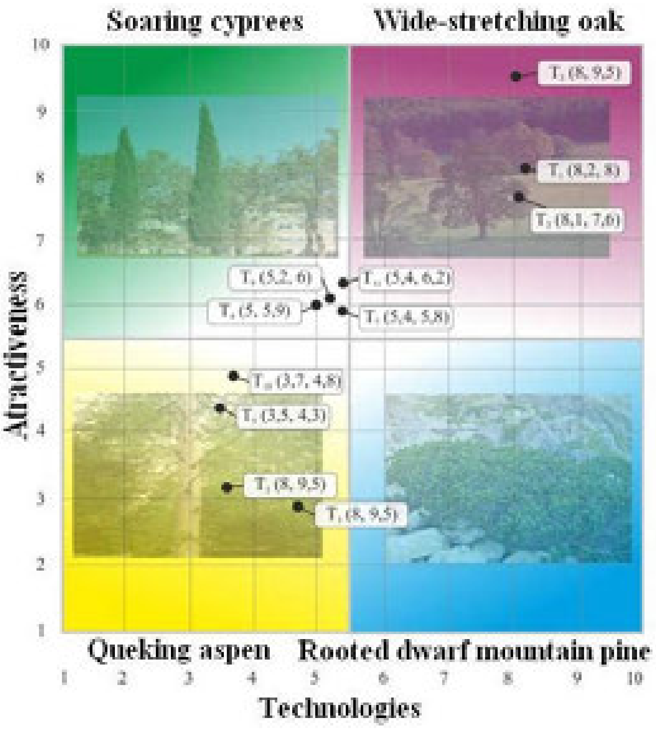

Figure 3. Dendrochronology matrix of values presenting the placement of evaluated groups of technologies investigated using computer integrated forecasting of the development

No.	Potential	Importance
Criterion 1	Low specific gravity of the material	0,4
Criterion 2	Ability for vibration damping	0,1
Criterion 3	Good castability	0,1
Criterion 4	High mechanical properties and good weldability	0,2
Criterion 5	High corrosion resistance	0,2
No.	**Attractiveness**	**Importance**
Criterion 1	Availability of the half-finished product (raw material, chemical element)	0,4
Criterion 2	Recycling possibility	0,1
Criterion 3	Low production costs and the final price of the produced material	0,2
Criterion 4	Low level of complexity of the production technology	0,1
Criterion 5	The variety of technologies for semi-fabrication of the material and the wide choice of processing technologies possible to implement (heat treatment, plastic deformation, surface treatment)	0,2

Table 1. Particular criteria for evaluation of the potential and attractiveness of material groups using for material engineering-heuristic investigations

Designation	Group of material	Potential						Attractiveness					
		Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	weighted average	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	weighted average
M_1	Magnesium alloys	4	0,8	0,8	0,6	0,2	**6,4**	4	0,9	1,2	0,4	1,6	**8,1**
M_2	Aluminium alloys	2,8	0,5	0,7	0,8	1,2	6	2,8	0,7	1,2	0,8	1,6	7,1
M_3	Steels	1,6	0,4	0,5	1,8	1,8	6,1	2	0,4	1,6	0,8	1,6	6,4

Table 2. Multi-criterion analysis of the investigated materials groups using engineering-heuristic methods

The highest evaluation are replaced in the group of technologies (the quadrant of a large oak) by laser technologies and PVD/CVD methods, indicated in Fig. 3 as green coloured T1, T2 and

T3 points-selected as the most suitable surface treatment technologies for magnesium alloys, far exceeding the other analysed coated methods. Other techniques were evaluated in the area of the quadrant of trembling aspen or soaring cypress which may indicate, in the case of technology in the area of a trembling aspen a slow displacement of these methods by newer more environmentally friendly and versatile technology.

However, in case of technologies, which are placed in the area of soaring cypress there it is a need for further research and investments enabling them to develop. The only exception to the assumptions may be layering paint technologies that typically are located in the square of rooted dwarf mountain pine, in relation to painting. This technology is unattractive, but widely used due to its simple mechanism for layering and low application cost. However, according to the established criteria concerning the potential and attractiveness for future application specific to the substrate materials (magnesium alloy); the painting techniques are qualified for the quarter trembling aspen. The selected technologies-T1, T2 and T3 were characterised in detail in the following description.

No.	Potential	Importance
Criterion 1	The possibility to obtain complex coatings (complex, multi-layered, multi-phase, gradient, composite, metastable, nanocrystalline)	0,3
Criterion 2	Large choice of coating material; wide range of deposited coatings properties	0,2
Criterion 3	The possibility to obtain hard surface layers with special protective properties (corrosion resistant, wear resistant)	0,2
Criterion 4	Layers with good adhesion to the substrate	0,2
Criterion 5	The possibility to obtain in a single process step graded layers with defined chemical composition and structure	0,1
No.	**Attractiveness**	**Importance**
Criterion 1	Environmental friendly deposition process (no harmful products of chemical reactions and the need for their recycling)	0,2
Criterion 2	Possibility to produce coatings with properties impossible to obtain with other methods	0,3
Criterion 3	Wide range of further development of the technology	0,2
Criterion 4	Possibility of full automation of the manufacturing process of coating	0,1
Criterion 5	Necessity for high precision of the deposition processes	0,2

Table 3. Detailed criteria for the assessment of the potential and attractiveness of the group of investigated material science and heuristic technologies

Designation	Technology group	Potential						Attractiveness					
		Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	weighted average	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	weighted average
T_1	PVD techniques, including also the Cathodic Arc Deposition	2,7	1,6	1,8	1,2	0,9	**8,2**	1,8	2,7	1,6	0,9	1	**8**
T_2	CVD techniques, including the PACVD	2,7	1,6	1,8	1,2	0,8	**8,1**	1,4	2,7	1,6	0,9	1	**7,6**
T_3	Laser feeding/ alloying/remelting	2,7	1	1,8	2	0,5	**8**	1,8	2,7	2	1	2	**9,5**
T_4	Thermal spraying	1,5	1	1,4	0,6	0,5	5	1,2	1,8	0,6	0,9	1,4	5,9
T_5	Anodisation	0,6	0,2	1,2	1,2	0,3	3,5	1,2	1,5	0,2	0,4	1	4,3
T_6	Galvanic technologies	0,9	1	1,2	1,4	0,2	4,7	0,4	0,9	0,2	0,9	0,4	2,8
T_7	Laser ablation-PLD	1,5	1	1	1,4	0,5	5,4	1,6	1,2	1,2	0,6	1,2	5,8
T_8	Painting coating	0,3	0,8	1	1,4	0,1	3,6	0,6	0,6	0,2	0,9	0,8	3,1
T_9	Ion implantation	1,5	1	1	1,2	0,5	5,2	1,4	1,8	1,2	0,6	1	6
T_{10}	Arc nitriding	0,6	0,4	1,2	1,2	0,3	3,7	0,8	1,8	0,6	0,8	0,8	4,8
T_{11}	Hybrid technologies (multiplex)	1,5	1	1,2	1,2	0,5	5,4	1	2,7	1,2	0,5	0,8	6,2

Table 4. The results of multi-criteria analysis of the investigated groups of technologies

3.2. Second part – Material engineering investigations

The developed technologies focusing on hybrid surface layers, so-called quasi-composite MMCs structures (characterized by phase composition gradient, chemical composition and functional gradient) in the process of laser alloying and/or feeding with ceramic particles into the surface of the treated materials provide a complete and comprehensive solution for modelling of engineering materials. Currently, the concept of functional lightweight materials is a priority and the most investigated worldwide field of material science and engineering concerning the production and processing of new developed engineering materials. Previous studies about the effects of laser beam effect on various materials, including magnesium alloys as well as tool steels, based on the authors own long-term investigation, summarizing the experience of laser surface treatment reveal that, there are chemical composition and structure changes which are different from those occurring during conventional heat treatment. This causes, that the laser treated elements shows relatively high hardness (Fig. 4) and thermal fatigue (Fig. 5), especially for VC-alloyed steel surface (Figs. 6, 7 and 10, 11) compared to the traditionally treated materials.

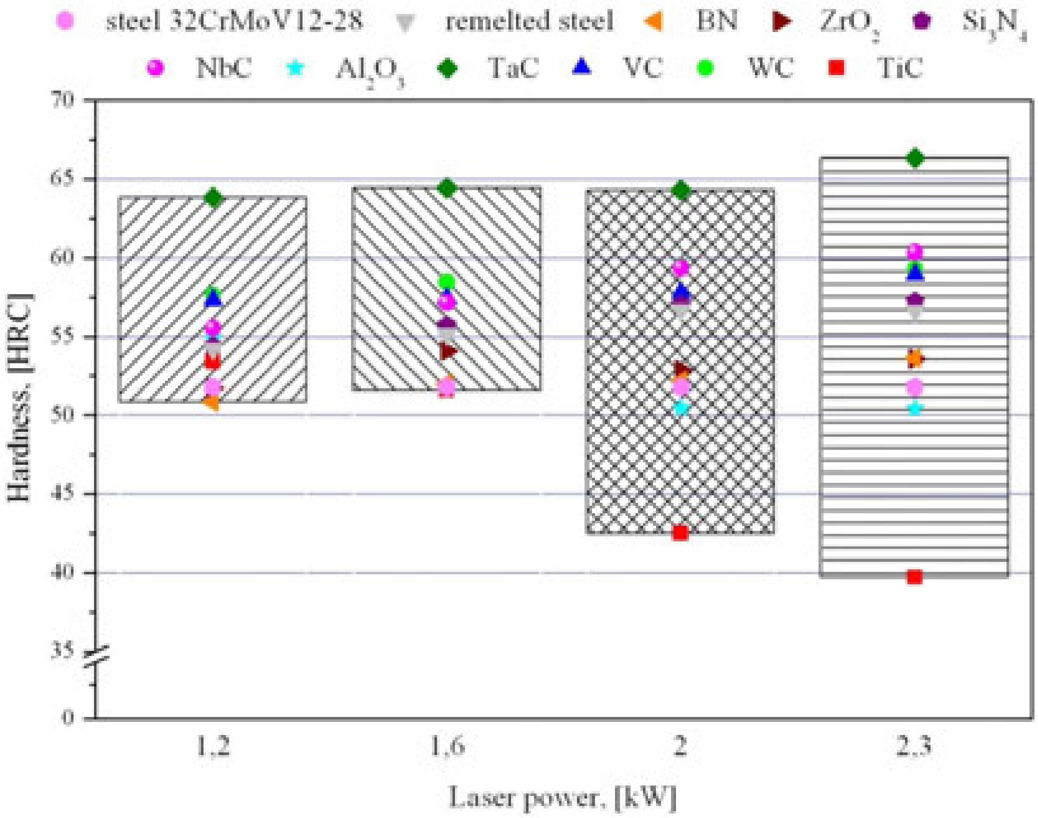

Figure 4. Hardness measurement results of the 32CrMoV12-28 steel alloyed with ceramic powders

Similar relationship can be found in case of Si_3N_4 powder alloying, with lower hardness and surface roughness compared to the VC alloying variant (Figs. 8, 9 and 12, 13).

The performed investigations of the alloyed hot work tool steel 32CrMoV12-28 show a clear effect of the applied ceramic powder used for alloying (Figs. 8, 9). It can be also clearly recognised the influence of the used laser power in the range of 1.2; 1.6; 2.0 and 2.3 kW on the shape and thickness as well as the particle distribution of the remelted material. It can be seen that with the increasing laser power the distribution of the remelted metal in the steel substrate increases. Microstructure presented on Figs. 8, 9 shows a dendritic structure in the remelted area. There are also VC particles present distributed in the matrix confirmed by the transmission electron microscope using the selected area diffraction pattern. There is also a clear relationship between the employed laser power and the dendrite size, namely with increasing laser power the dendrites are larger, this relationship is valid for the Si_3N_4 powder alloying.

In general the hot work tool steel has a ferritic structure with homogeny distributed carbides in the metal matrix in the annealed state. In areas, which are between the solid and molten state dendritic structure with large dendrites can be found in case of Si_3N_4 powder (Fig. 14) or a fine grained structure in case of VC alloying (Fig. 15). The EDS point wise chemical composition analysis confirms the presence of carbide ceramic particles in the matrix in form of big conglomerates. The required hardenability for this tool steel was achieving after a suitable tempering time, which assures melting of the alloying carbides in the austenite. The structural investigations carried out using the high power diode laser allows to compare the surface layer as well as the shape and depth of the remelting area. It was noticed that the depth of remelting area grows together with the increasing laser power (Fig. 16).

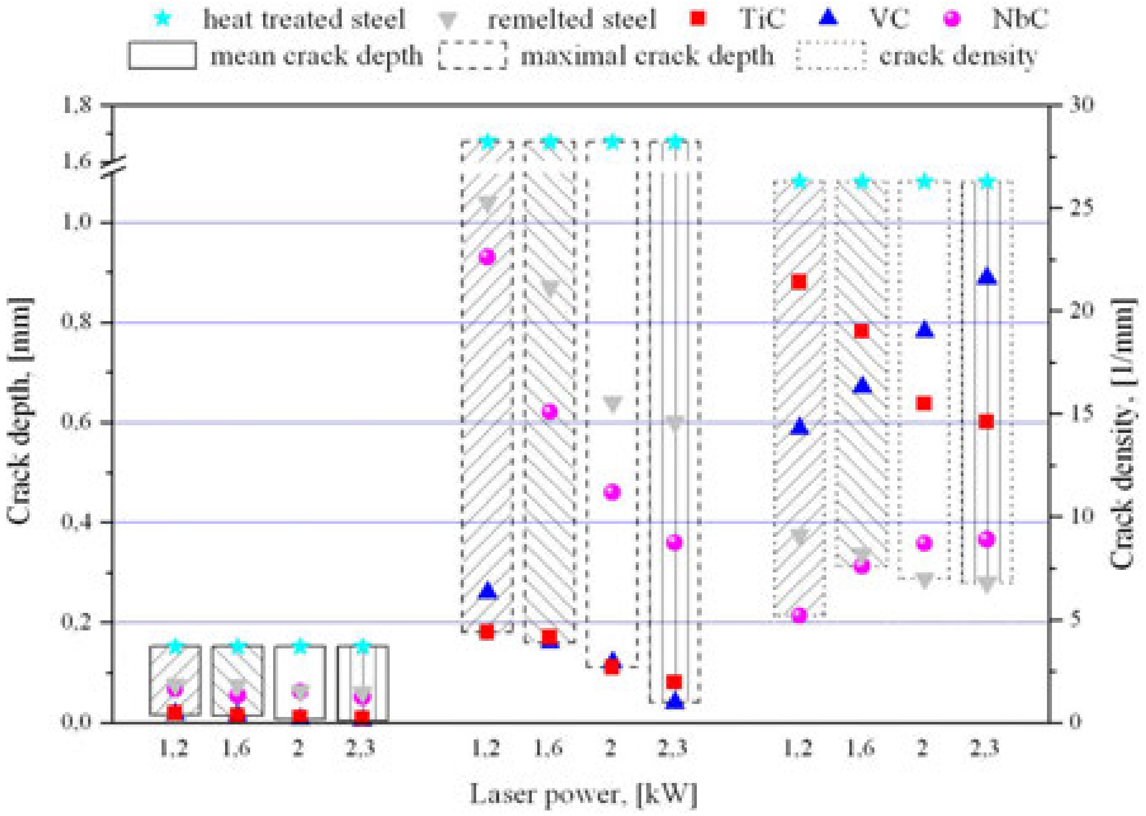

Figure 5. Influence of laser power and the type of alloyed surface layer of the 32CrMoV12-28 steel on mean crack depth, maximal crack depth and crack density occurred during the thermal fatigue test

It was found, that in case of VC powder the difference of the remelted area thickness is several times higher in case of 2.3 kW power compared to 1.2 kW laser power. Also for the same laser power (2.3 kW) the surface layer thickness increases from 1.9 mm for WC powder to 2.2 mm for TiC powder and to 2.3 mm in case of the VC powder (Fig. 16).

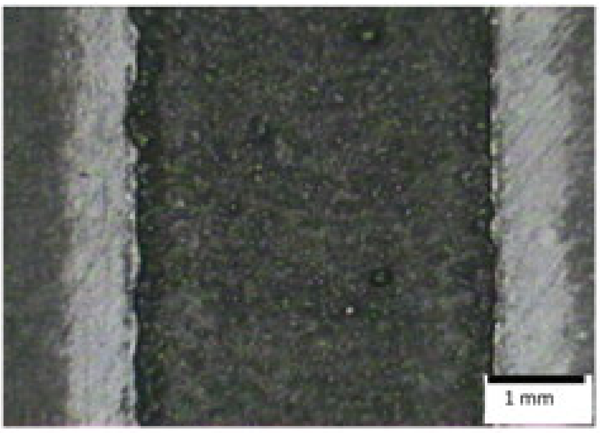

Figure 6. 32CrMoV12-28 steel alloyed with VC powder, laser power 1.2 kW

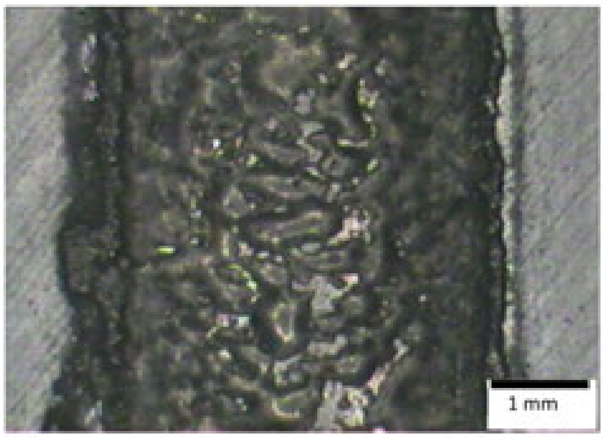

Figure 7. 32CrMoV12-28 steel alloyed with VC powder, laser power 2.3 kW

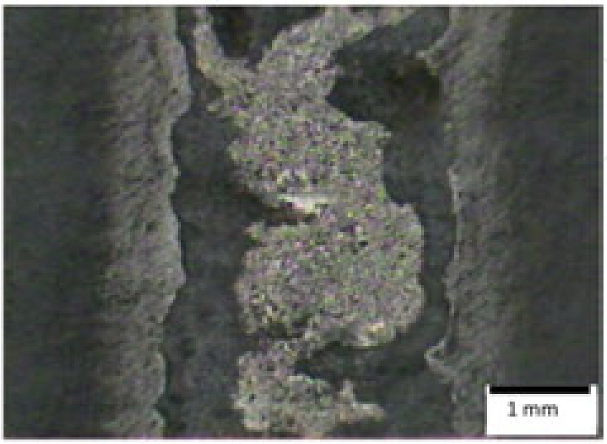

Figure 8. .32CrMoV12-28 steel alloyed with Si_3N_4 powder, laser power 1.2 kW

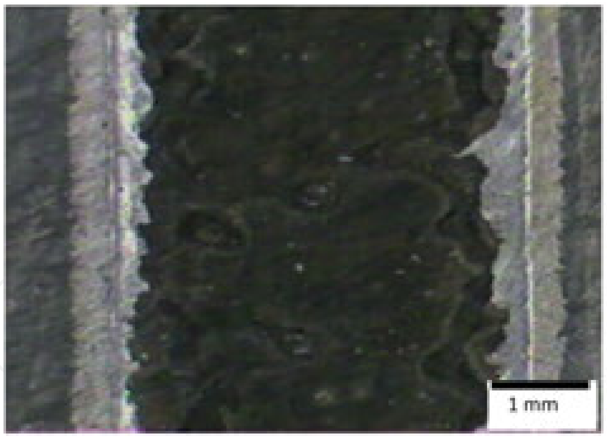

Figure 9. 32CrMoV12-28 steel alloyed with Si_3N_4 powder, laser power 2.3 kW

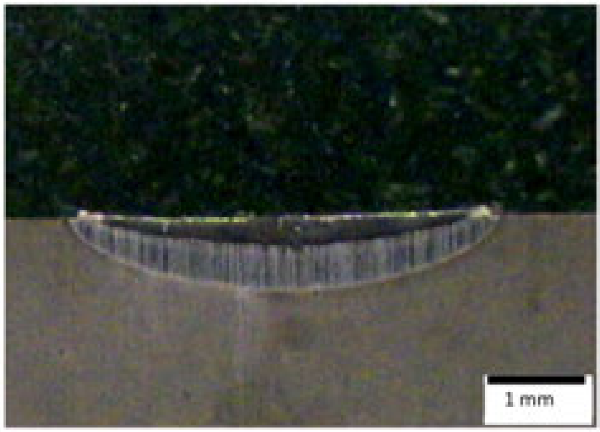

Figure 10. 32CrMoV12-28 steel alloyed with VC powder, laser power 1.2 kW

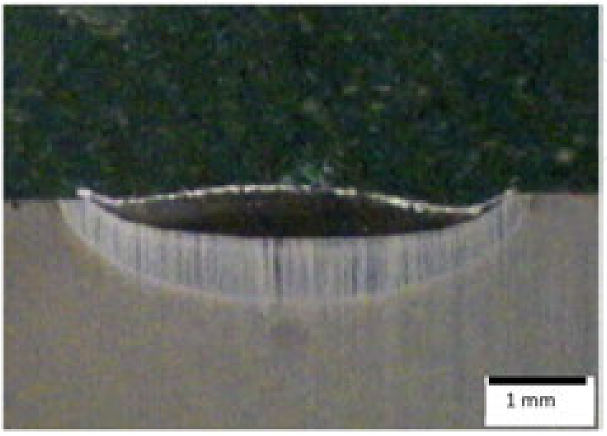

Figure 11. 32CrMoV12-28 steel alloyed with VC powder, laser power 1.2 kW

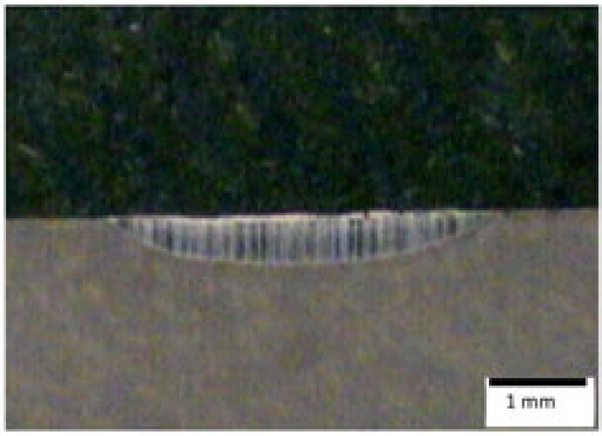

Figure 12. 32CrMoV12-28 steel alloyed with Si_3N_4 powder, laser power 1.2 kW

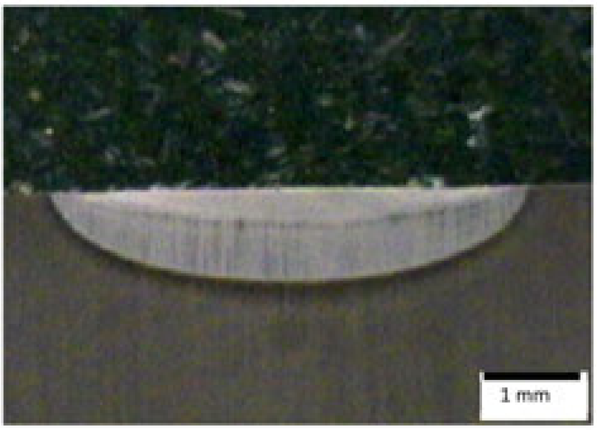

Figure 13. 32CrMoV12-28 steel alloyed with Si_3N_4 powder, laser power 2.3 kW

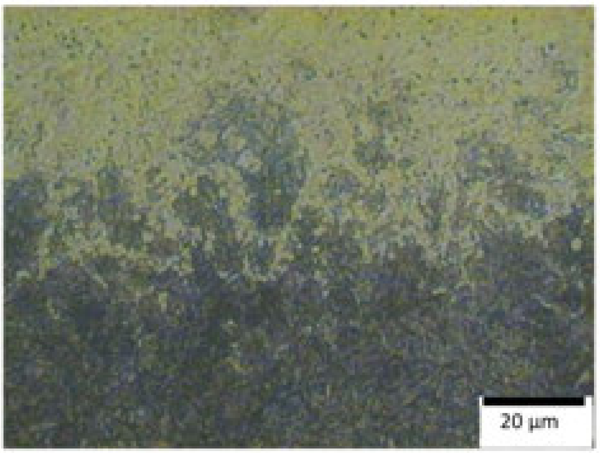

Figure 14. 32CrMoV12-28 steel alloyed with Si_3N_4 powder, laser power 1.2 kW

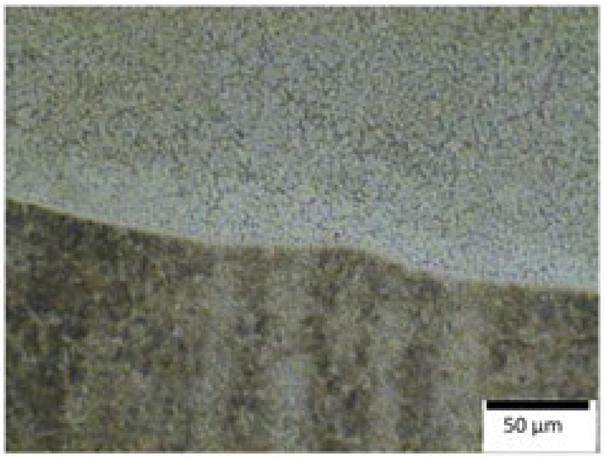

Figure 15. 32CrMoV12-28 steel alloyed with VC powder, 1.2 kW

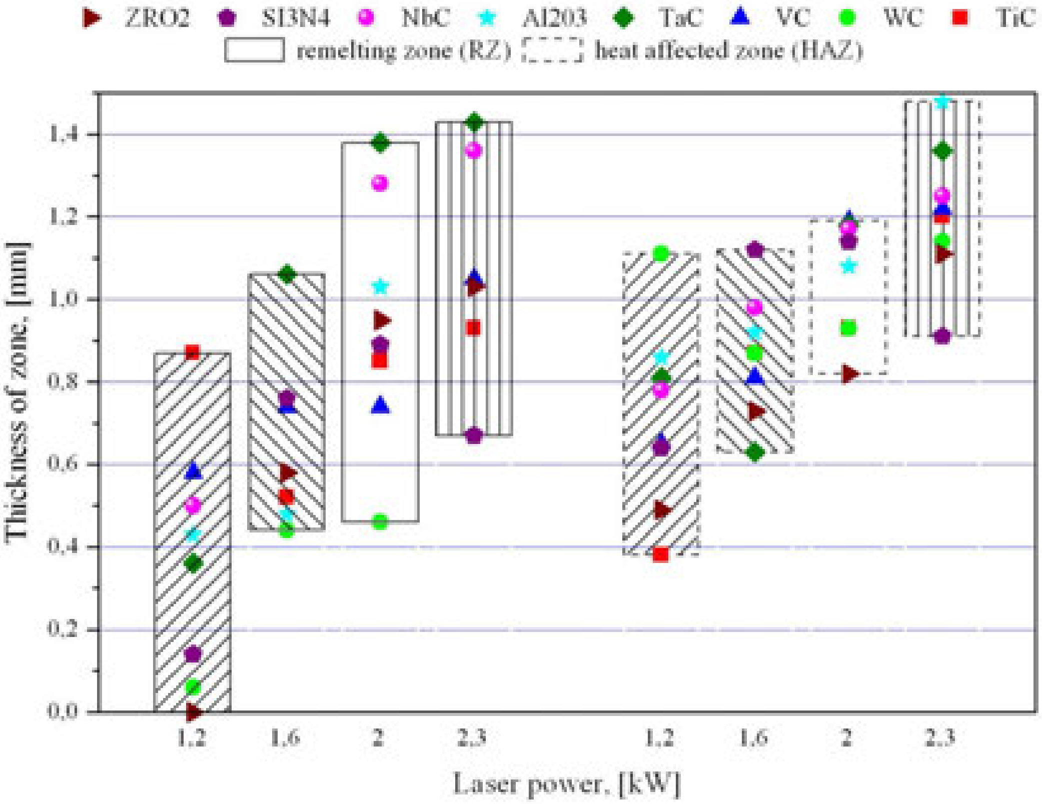

Figure 16. Influence of laser power on thickness of the remelted zone RZ, heat affected zone HAZ and the surface layer 32CrMoV12-28 steel after laser alloyed.

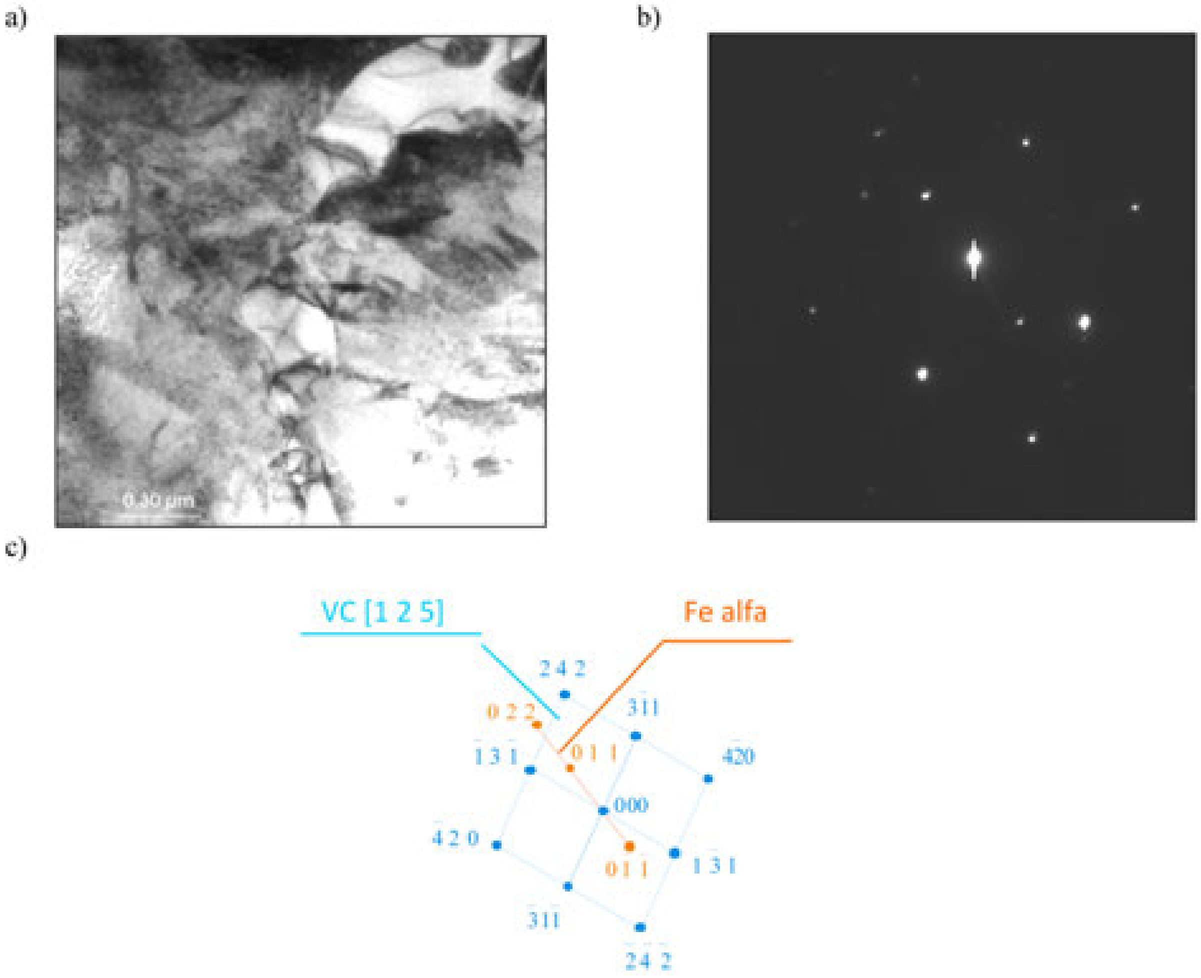

Figure 17. Thin foil structure of the 32CrMoV12-28 steel after VC alloying, laser power– 2,0 kW, a) bright field, b) diffraction pattern of the VC particle revealed in Fig. 17a, c) solution of the diffraction pattern from Fig. 17c

Similar relationships were found in case of magnesium alloys, where the used WC, VC, SiC, Al_2O_3 and TiC powder particles are present in the laser treated magnesium surface. Effect of laser feeding conditions, namely: laser power, feeding speed, type of the used ceramic powder and the applied substrate on hardness and hardness increase of the surface layer of the cast magnesium samples were investigated using the Rockwell hardness method. The measured hardness of the surface was obtained in the range from 32.4 to 105.1 HRF (Fig. 18). As a result of the performed investigations it was found, that the highest hardness increase was observed in case of MCMgAl6Znl and MCMgAl3Znl magnesium cast alloys – as materials with low concentration (<6%) of aluminium, which is mainly responsible for precipitation strengthening of the studied, laser treated alloys, fed with ceramic particles.

Also in this case the surface layer is relatively rough, compared to the non-treated material (Fig. 19, 20). After laser feeding, there was revealed-based on the performed metallographic investigations which were carried out on light microscope-the presence of several zones in the remelted surface layer of the cast magnesium alloys, with the thickness and the powder particles occurrence depending on the laser processing parameters and the used powder and substrate type (Figs. 21, 22). Starting from the top zone of the surface layer there occurs one zone rich in non-dissolved particles located on the surface of magnesium alloys, the second zone is the remelting area zone (RZ), with the thickness and shape directly depending on the applied laser power. Finally there occurs also the heat affected zone (HAZ) (Figs. 23, 24).

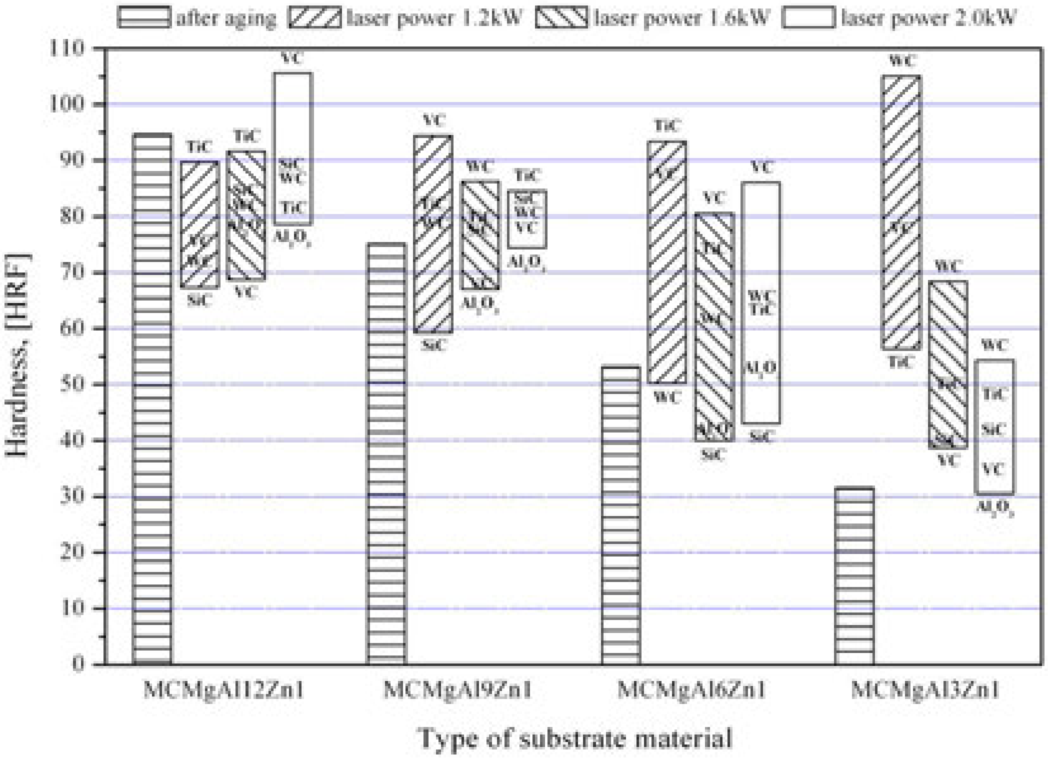

Figure 18. Hardness measurements results of cast Mg-Al-Zn magnesium alloys samples, after aging and laser feeding

Figure 19. Surface layer of the MCMgAl9Zn1 alloy after WC powder feeding, laser power 2.0 kW, laser scan rate 0.5 m/min

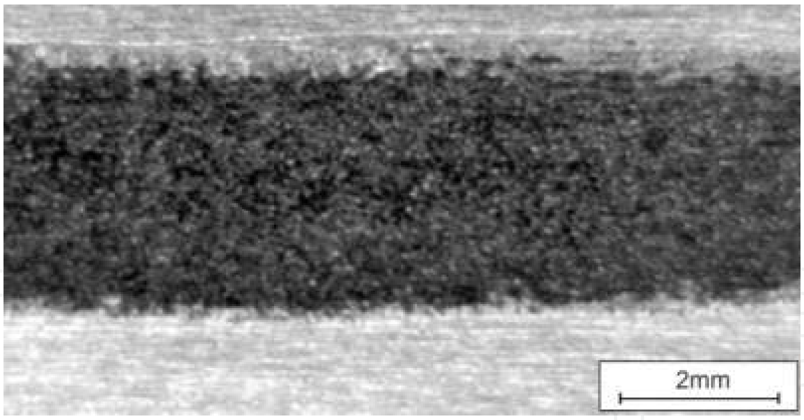

Figure 20. Surface layer of the MCMgAl3Zn1 alloy after SiC powder feeding, laser power 1.6 kW, laser scan rate 0.75 m/min

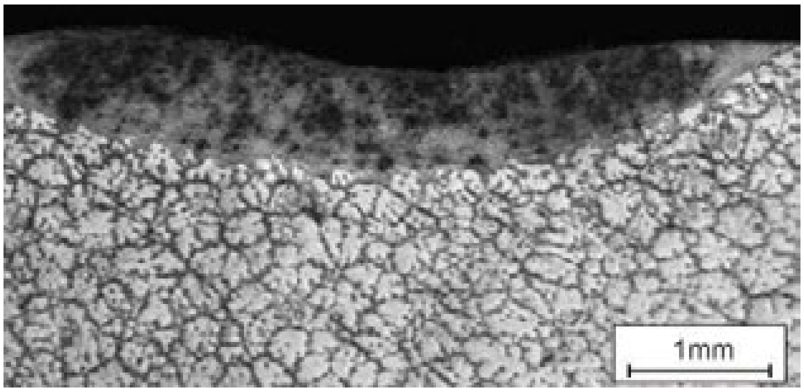

Figure 21. Surface layer of the MCMgAl3Zn1 alloy after WC powder feeding, laser power 1.6 kW, laser scan rate 0.75 m/min

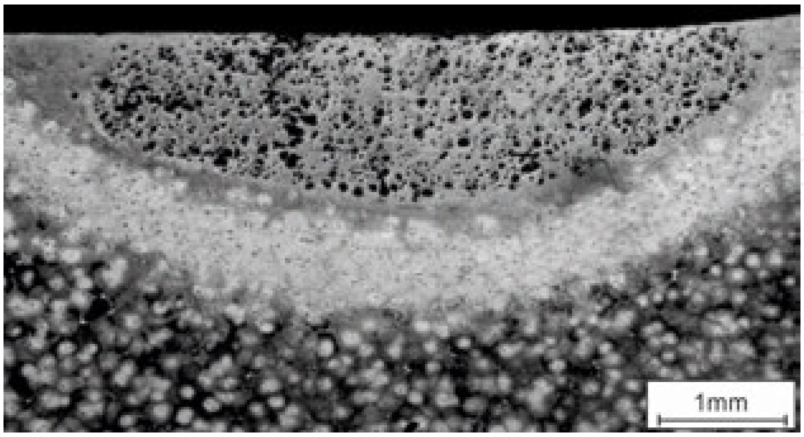

Figure 22. Surface layer of the MCMgAl9Zn1 alloy after WC powder feeding, laser power 2.0 kW, laser scan rate 0.75 m/min

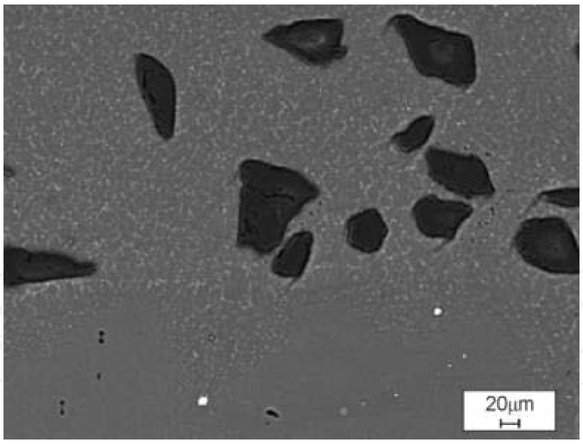

Figure 23. Central zone of the surface layer of the MCMgAl6Zn1 alloy after Al_2O_3 powder alloying, laser power 2.0 kW, laser scan rate 0.50 m/min

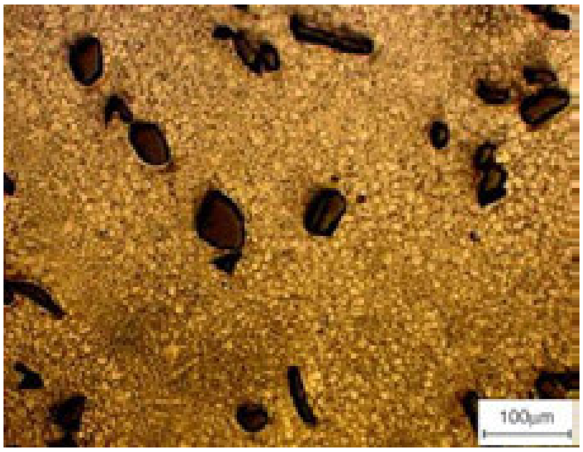

Figure 24. Central zone of the surface layer of the MCMgAl6Zn1 alloy after SiC powder alloying, laser power 2.0 kW, laser scan rate 0.50 m/min

These zones, depending on the used laser power and the applied ceramic powder are of varying thickness and shape (Fig. 25). It is possible to obtain such an effect of significant refinement of the grains only because of a fast heat transport from the remelting liquid metal lake through magnesium substrate of high thermal capacity and very good thermal conductivity, which results with the increase of grain boundaries amount representing a solid barrier for the dislocations movement and therefore reinforcement of the material.

The structure of the solidified material after laser treatment is characterised, like mentioned before, with a zone like structure with diversified morphology related to the crystallisation of magnesium alloys, containing particle of the alloying powders (Figs. 26, 27), serving also like dislocation barrier. Multiple change of crystal growth direction has been observed for these areas. In the area located on the boundary between the solid and liquid phase, minor dendrites occur with their main axes oriented along to the heat transport directions.

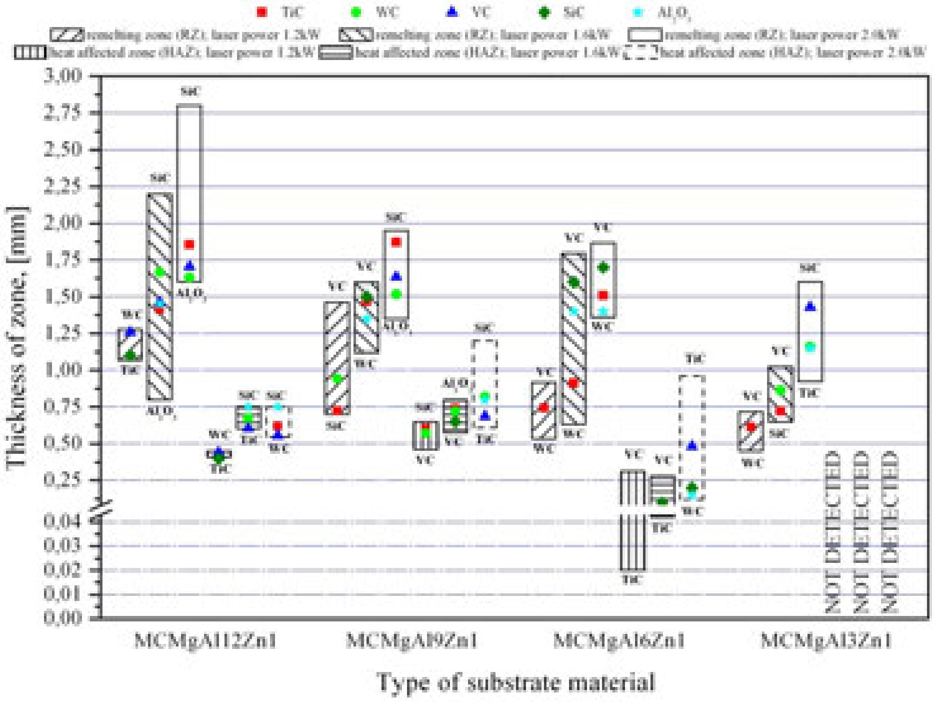

Figure 25. Influence of laser power on thickness of the remelted zone RZ, heat affected zone HAZ and the surface layer of cast magnesium alloys after laser feeding

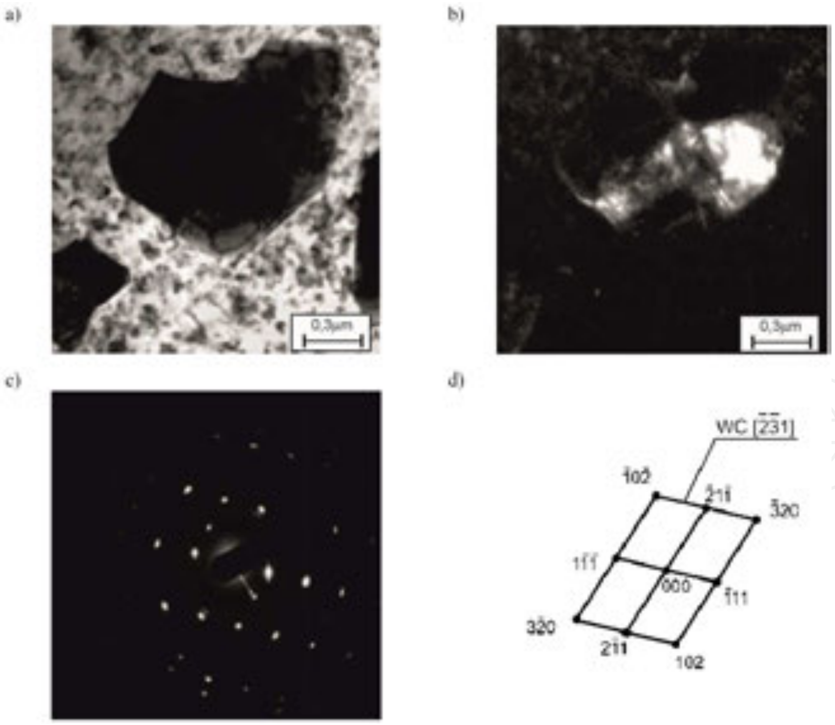

Figure 26. Structure of the MCMgAl6Zn1 magnesium cast alloy after laser feeding with WC powder, laser power 1.6 kW, a) bright field, b) dark field image from the [0-13] reflection c) diffraction pattern from the particle in Fig. a, d) solution of the diffraction pattern from Fig. c

The obtained results carried out by the team of authors concerning laser surface treatment of aluminium alloys reveal, that the highest hardness occurs in case of ZrO_2 powder alloying. In the initial planning step of investigations, there were choose specific research topics, using the innovative science-heuristic analysis for selection of the investigated material (substrate) like the Al-Si-Cu alloys based on the hardness results (Fig. 28).

Microstructure investigations of the aluminium alloys fed with WC, SiC Al_2O_3 and ZrO_2 ceramic powders (Figs. 29-38) were performed light microscopy. Like in the previous case also here the roughness of the surface increases (Figs. 29, 30). It was also found out, that in case of ZrO_2 powder alloying (Fig. 33) there was obtained a layer film, whereas in case of WC (Fig. 34) there are present particles in the surface layer; in both cases there are no pores or cracks in the produced coating or any defects and failures occurs in this layer. For the WC powder the particles are partially present on the bottom of the remelted zone.

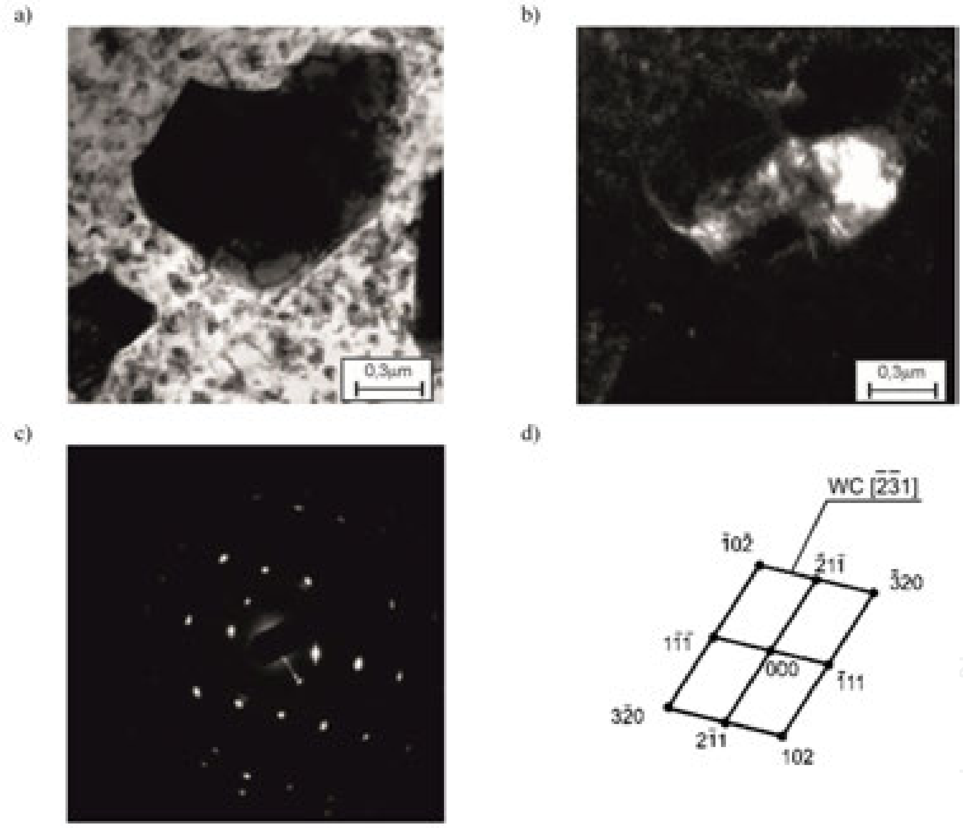

Figure 27. Structure of the MCMgAl6Zn1 magnesium cast alloy after laser feeding with WC powder, laser power 2.0 kW, a) bright field, b) diffraction pattern from the particle in Fig. a, c) solution of the diffraction pattern from Fig. b

Further investigations should revealed the exact morphology and nature of these sublayers after alloying with different ceramic powders, carried out under different process parameters. Moreover there can be recognised, that the obtained surface are characterised by a well formed structure without any breaks or defects, they are uniformly horizontally deposited in the substrate surface. Occasionally occurred discontinuities of the layer can be recognised as a product of the heat transfer processes and may be neutralised by properly adjusted powder quality and powder feed rate. However in some cases the surface can reveal a very irregular shape (Fig. 35) with decomposition of the fed particles (Fig. 36). It was also found that the examined layers consists of three subzones – the remelted zone, the heat influence zone with a dendritic structure and the substrate material (Figs. 37, 38).

The thickens of the powder feed depth can be determined in the range up to 2.1 mm (Fig. 39) in case of the HAZ of WC powder fed with laser power of 1.5 kW for the AlSi9Cu4 alloy and 1.9 mm for the AlSi9Cu alloy.

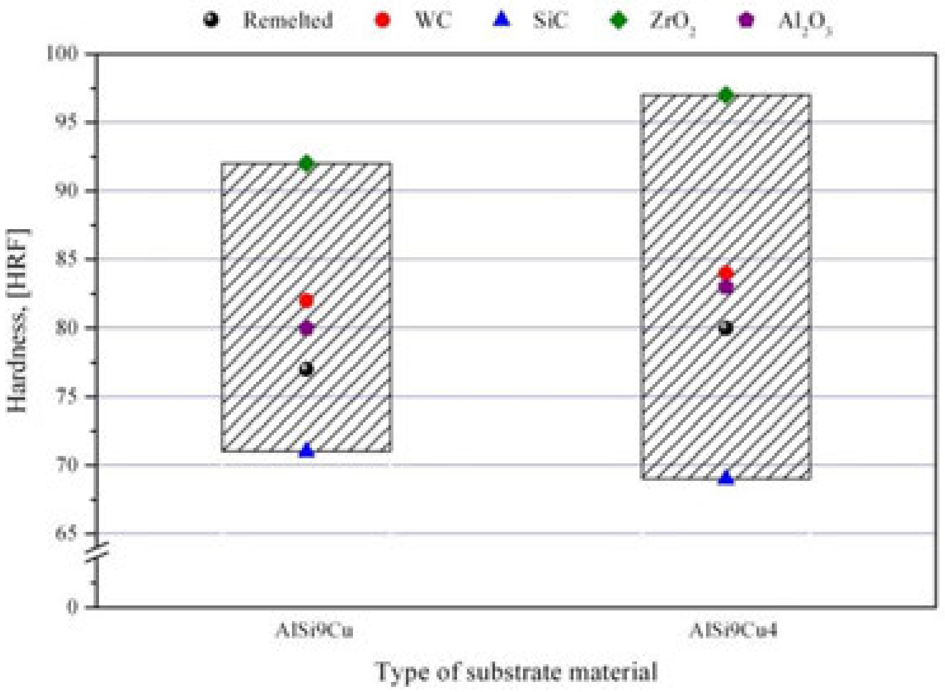

Figure 28. Hardness measurements results of cast Al-Si-Cu aluminium alloys samples, after aging and laser feeding

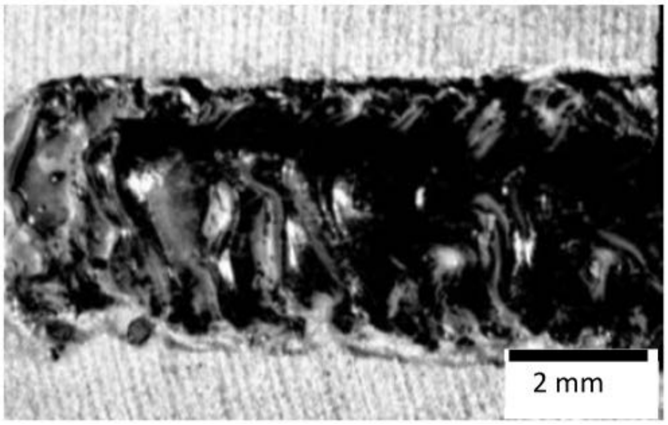

Figure 29. AlSi9Cu alloy Al_2O_3, laser power 2.0 kW, 1g/min, laser scan rate 0.5 m/min

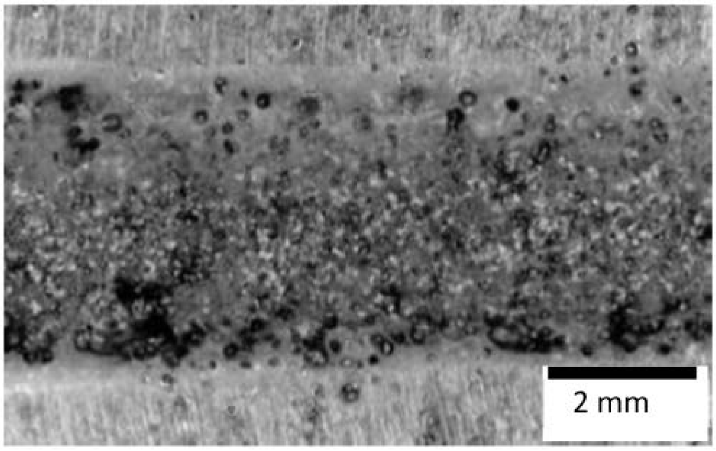

Figure 30. Surface layer of the AlSi9Cu alloyed with WC powder AlSi9Cu, laser power 1.5 kW, 1.5g/min, laser scan rate 0.25 m/min

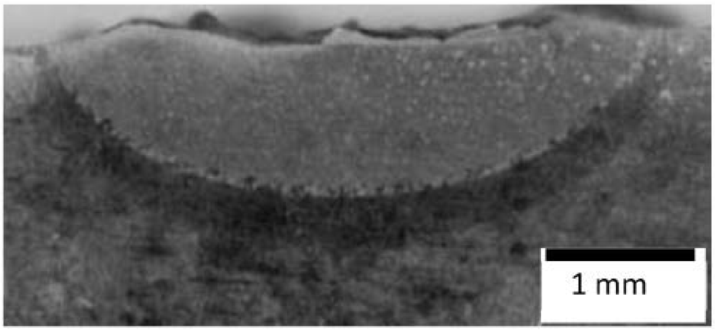

Figure 31. Cross-section of the AlSi9Cu alloy after Al_2O_3, powder feeding, laser power 2.0 kW, 1g/min, laser scan rate 0.5 m/min

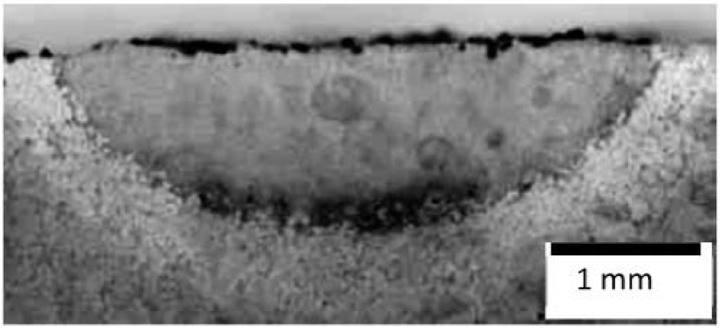

Figure 32. Cross-section of the AlSi9Cu alloy, laser power 1.5 kW, 1.5g/min, laser scan rate 0.25 m/min

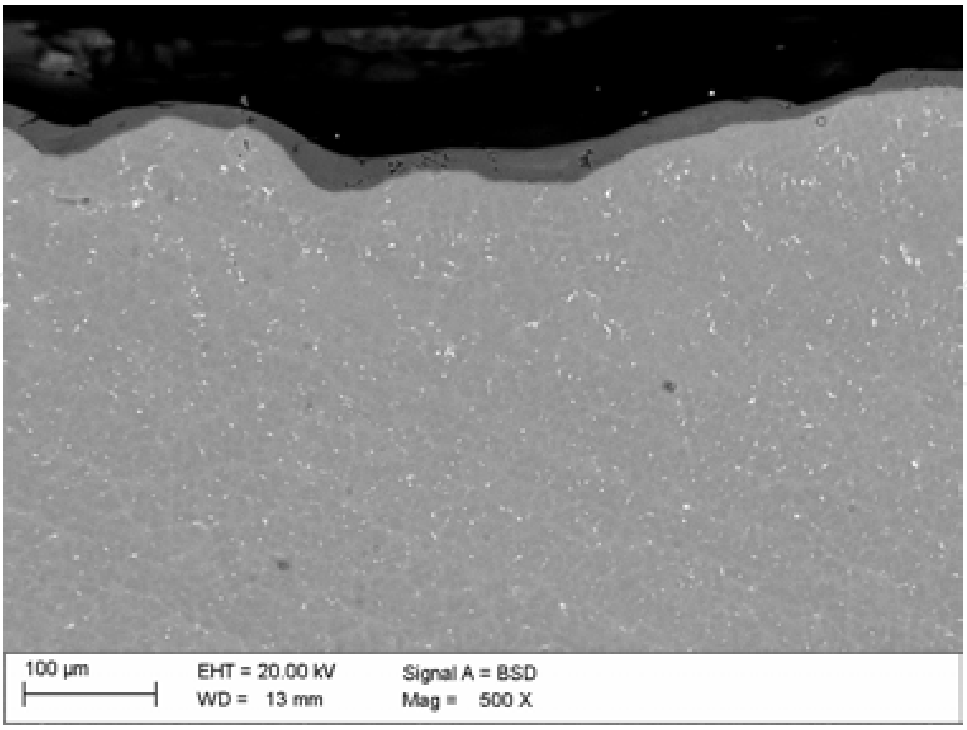

Figure 33. Surface layer of the AlSi9Cu alloy after Al_2O_3 powder feeding, laser power 1.5 kW, 1g/min, laser scan rate 0.5 m/min

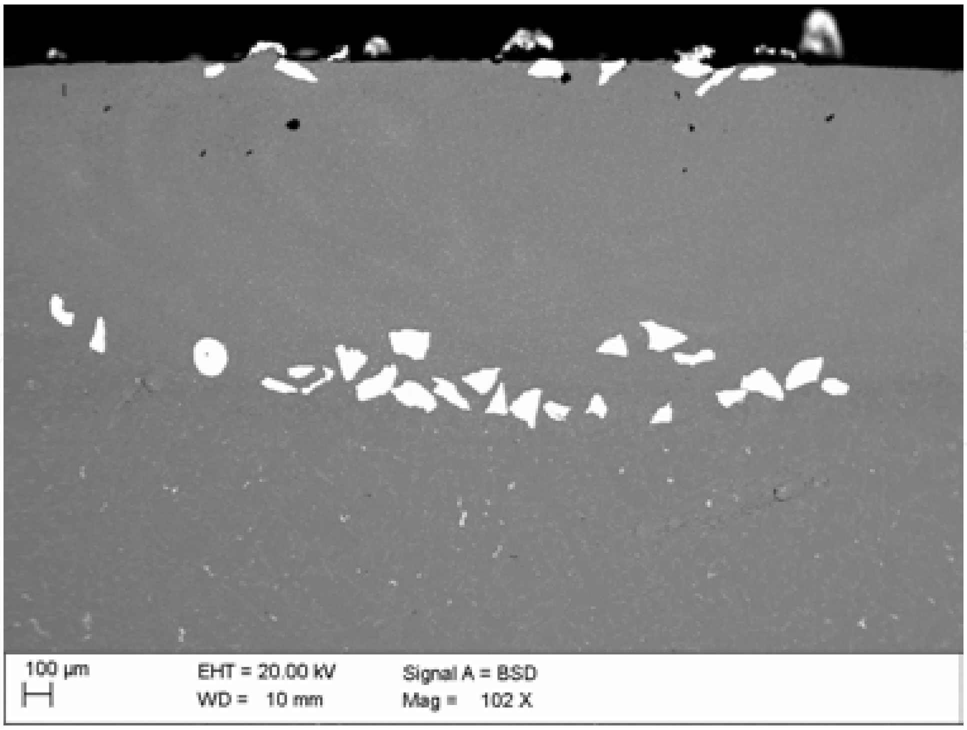

Figure 34. Surface layer of the AlSi9Cu alloy after WC powder feeding, laser power 2.0 kW, 1.5g/min, laser scan rate 0.25 m/min

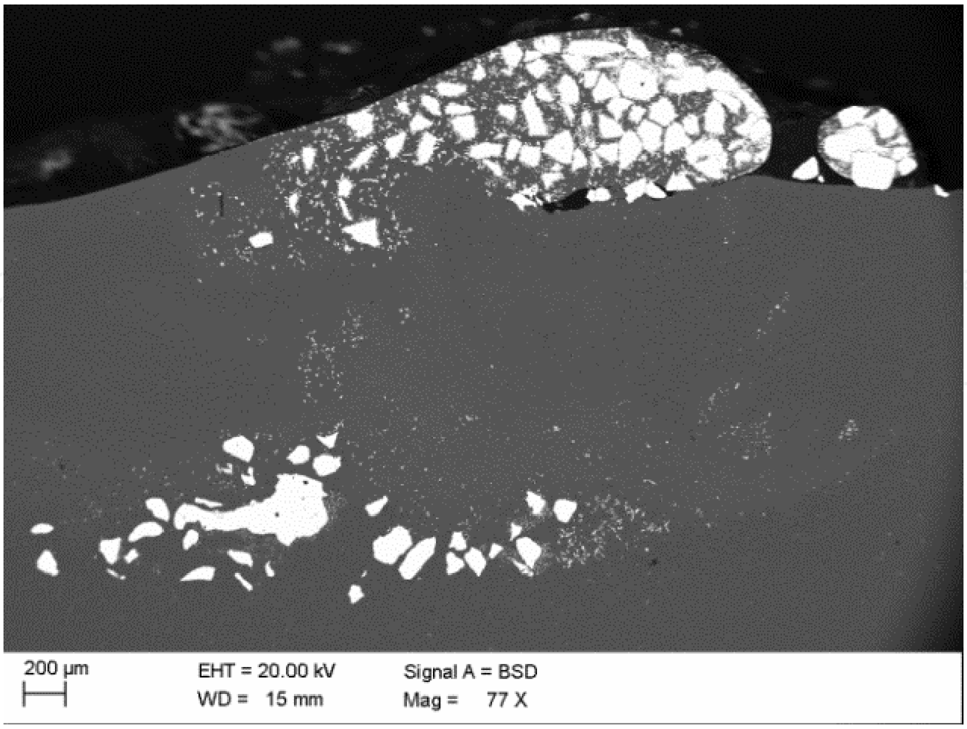

Figure 35. Surface layer of the AlSi9Cu alloy after WC powder feeding, laser power 2.0 kW, 8.0 g/min, laser scan rate 0.25 m/min

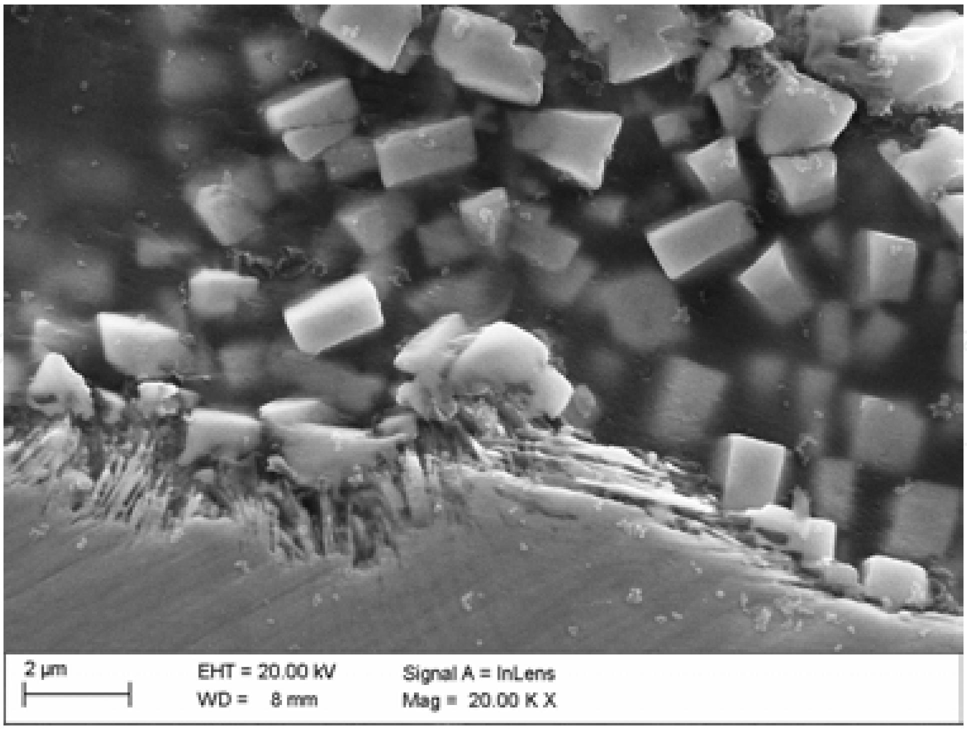

Figure 36. Surface layer of the AlSi9Cu alloy after WC powder feeding, laser power 1.5 kW, 1.5 g/min, laser scan rate 0.25 m/min

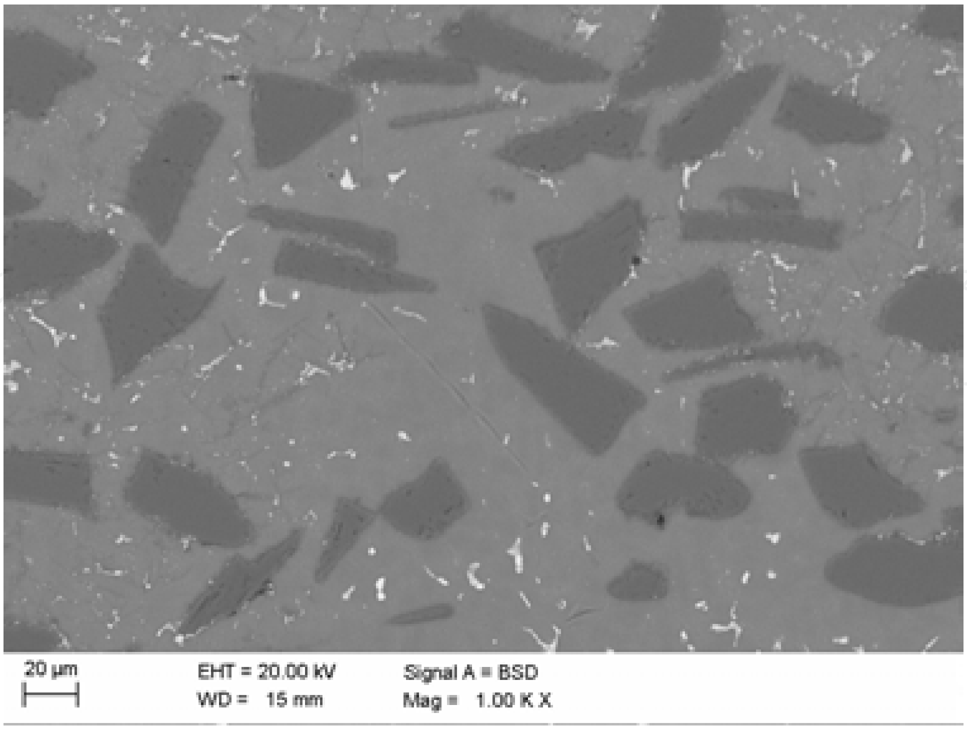

Figure 37. Structure of the surface layer of the AlSi9Cu4 alloy, fed with SiC powder, laser power 2.0 kW, 1.5 g/min, laser scan rate 0.25 m/min

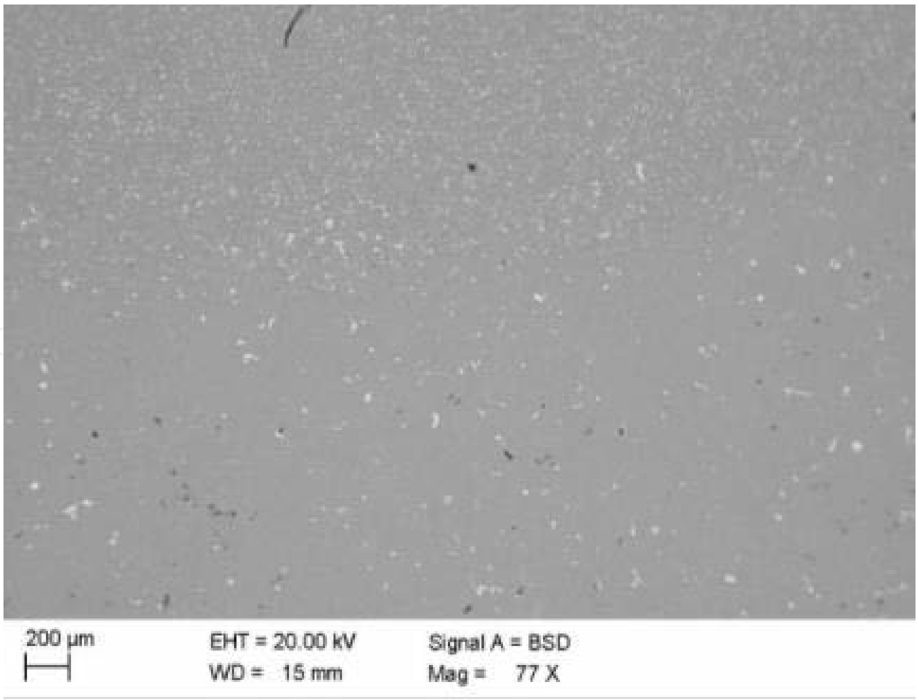

Figure 38. Transition zone between the surface layer and AlSi9Cu4 alloy substrate, fed with SiC powder, laser power 2.0 kW, 1.5 g/min, laser scan rate 0.25 m/min

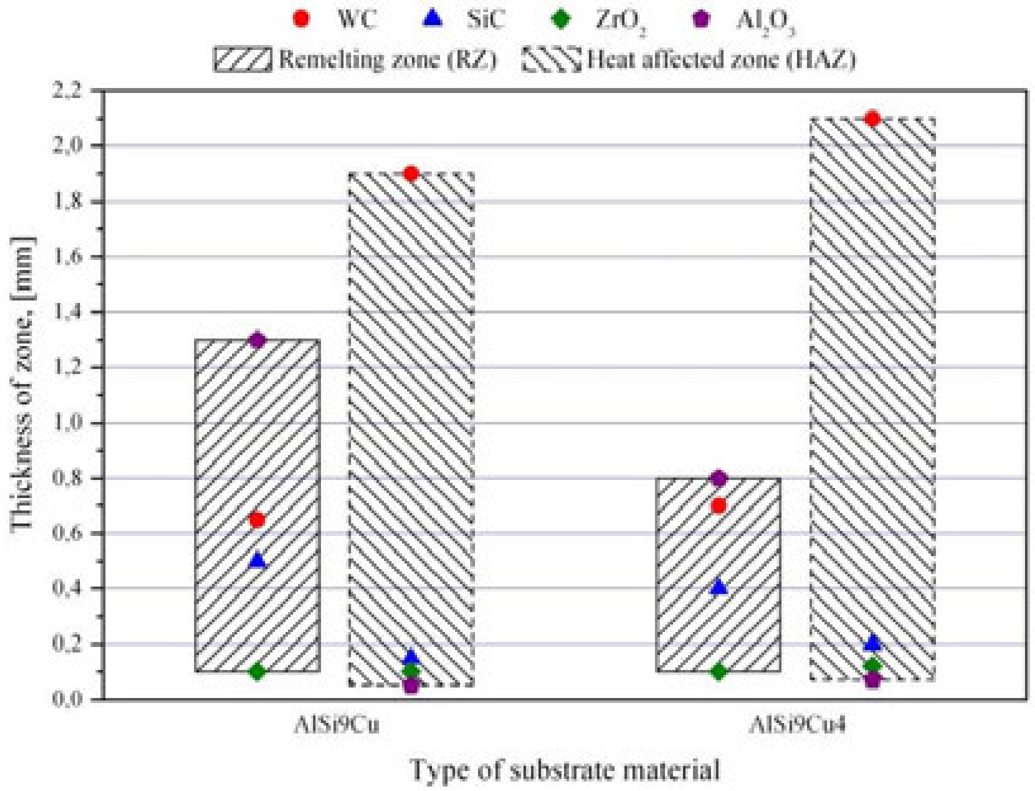

Figure 39. Influence of laser power on thickness of the remelted zone RZ, heat affected zone HAZ and the surface layer of cast aluminium alloys after laser feeding

4. Investigation results

The investigation results presented in this work reveals the positive impact of laser surface treatment on the microstructure quality and proprieties of the investigated steel as well as cast magnesium and aluminium alloys and promise further improvement in the mechanical and functional properties of the tested material, especially hardness. Laser remelting, alloying and feeding with vanadium and tungsten carbide and silicon nitride as well as aluminium oxide powders influences the refining of the structure within the entire range of laser power and the different grain size in specific zones of the investigated alloys surface layer. Considering the three groups of materials subjected to an expert evaluation using a dendrological matrix being inherent part of materials surface engineering development prediction methods, magnesium casting alloys has achieved the best position.

Concluding the following finding can be point out:

- the carried out heuristic investigations point out a very good current strategic position of the technology for the laser surface treatment of cast magnesium alloys and its possible extensive development.

The metallographic examinations carried out give grounds to state that the ceramic powder alloying or feeding process will be carried out successfully in case of the aluminium alloy substrate, the powder particles will be distributed uniformly in the investigated surface layer, and that the particular layers is without cracks and failures and tightly adhere to the cast aluminium material matrix. In this part of research following conclusion can be made:

- the laser surface treatment process gives satisfied results and allows to obtain high quality surface in most cases of the applied ceramic powders,
- the surface layer are without cracks and of a maximal thickness in the range of 2 mm,
- the surface layers consists of three zones: the remelting zone the heat influence zone and substrate material as well as sometime of an additional intermediate zone.

Steel, aluminium and magnesium are the most commonly used constructional materials after laser surface treatment, moreover there are suitable in applications as components in the automotive industry. The expected range of applications for cast magnesium alloys Mg-Al-Zn surface treatment using the high performance diode laser can be interesting especially for the automotive industry, where small product weight is required, good strength properties of components and ability to repair finished parts.

Acknowledgements

This research was financed partially within the framework of the Scientific Research Project No. 2011/01/B/ST8/06663 headed by Dr Krzysztof Labisz.

Author details

Tomasz Tański, Krzysztof Labisz and Anna Dobrzańska-Danikiewicz

Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice, Poland

References

[1] T. Tański, K. Lukaszkowicz, Structure and properties of PVD coatings deposited on the aluminium alloys, Surface Engineering 28/8 (2012) 598-604.

[2] T. Tański, K. Labisz, Electron microscope investigation of PVD coated aluminium alloy surface layer, Solid State Phenomena 186 (2012) 192-197.

[3] T. Tański, L.A. Dobrzański, L. Čížek, Influence of heat treatment on structure and properties of the cast magnesium alloys, Journal of Advanced Materials Research, 15-17 (2007) 491-496

[4] L.A. Dobrzański, T. Tański, J. Trzaska, Optimization of heat treatment conditions of magnesium cast alloys, Materials Science Forum, Vols. 638-642 (2010), 1488-1493

[5] T. Tański, Characteristics of hard coatings on AZ61 magnesium alloys, Journal of Mechanical Engineering 59/3 (2013) 165-174.

[6] A.D. Dobrzańska-Danikiewicz, T. Tański, J. Domagała-Dubiel, Unique properties, development perspectives and expected applications of laser treated casting magnesium alloys, Archives of Civil and Mechanical Engineering 12 (2012) 318–326.

[7] L.A. Dobrzański, K. Labisz, E. Jonda, A. Klimpel, Comparison of the surface alloying of the 32CrMoV12-28 tool steel using TiC and WC powder, J. Mater. Process. Technol. 191\ 1/3, 321-325 (2007)

[8] L.A. Dobrzański, M. Krupiński, K. Labisz, B. Krupińska, A Grajcar, Phases and structure characteristics of the near eutectic Al-Si-Cu alloy using derivative thermo analysis, Materials Science Forum, Vols. 638-642 (2010) 475-480

[9] W. Ozgowicz, K. Labisz, Analysis of the state of the fine-dispersive precipitations in the structure of high strength steel Weldox 1300 by means of electron diffraction, Journal of Iron and Steel Research, International 18 (2011)135-142

[10] M. Piec, L.A. Dobrzański, K. Labisz, E. Jonda, A. Klimpel, Laser alloying with WC Ceramic Powder in hot work tool steel using a High Power Diode Laser (HPDL), Advanced Materials Research, vol. 15-17 (2007) 193-198

[11] M. W. Richert, B. Leszczyńska-Madej, W. Pachla, W. J. Skiba, The microstructure and properties of hydrostatically extruded polycrystalline aluminium Al99.5, Archives of Metallurgy and Materials, 57/4 (2012) 911-917.

[12] T. Tański, L.A. Dobrzański, L. Čížek, Influence of heat treatment on structure and properties of the cast magnesium alloys, Journal of Advanced Materials Research, 15-17 (2007) 491-496.

[13] L.A. Dobrzański, T. Tański, J. Trzaska, Optimization of heat treatment conditions of magnesium cast alloys, Materials Science Forum 638-642 (2010) 1488-1493.

[14] L.A. Dobrzański, R. Maniara, J. Sokolowski, W. Kasprzak, M. Krupinski, Z. Brytan, Applications of the artificial intelligence methods for modeling of the ACAlSi7Cu alloy crystallization process, Journal of Materials Processing Technology 192 (2007) pp. 582-587.

[15] L.A. Dobrzanski, W. Sitek, M. Krupinski, J. Dobrzanski, Computer aided method for evaluation of failure class of materials working in creep conditions, Journal of Materials Processing Technology 157, 2004, 102-106,

[16] 14. Dobrzański, L.A., Grajcar, A., Borek, W., Microstructure evolution of C-Mn-Si-Al-Nb high-manganese steel during the thermomechanical processing, Materials Science Forum 638 (2010) 3224-3229.

[17] L.A. Dobrzański, W. Borek, Hot-rolling of advanced high-manganese C-Mn-Si-Al steels, Materials Science Forum, Materials Science Forum 706-709 (2012) 2053-2058.

[18] T. Tański, Characteristics of hard coatings on AZ61 magnesium alloys, Journal of Mechanical Engineering 59/3 (2013) 165-174.

[19] A. Klimpel, D. Janicki, A. Lisiecki, Z. Wilk, Laser welding technologies: High power diode laser application examples, Welding International 24/9 (2010) 689-698.

[20] L.A. Dobrzański, T. Tański, J. Trzaska: Optimization of heat treatment conditions of magnesium cast alloys, Materials Science Forum, Vols. 638-642 (2010), pp 1488-1493.

[21] G. Abbas, L. Li, U. Ghazanfar, Z. Liu, Effect of high power diode laser surface melting on wear resistance of magnesium alloys, Wear 260 (2006) 175-180.

[22] D. Dube, M. Fiset, A. Couture, I. Nakatsugawa, Characterization and performance of laser melted AZ91D and AM60B, Materials Science and Engineering A 299 (2001) 38-45.

[23] Y. Jun, G.P. Sunb, S.S. Jia, Characterization and wear resistance of laser surface melting AZ91D alloy, Journal of Alloys and Compounds 455 (2008) 142-147.

[24] K.G Watkins, M.A McMahon, W.M Steen, Microstructure and corrosion properties of laser surface processed aluminium alloys: a review, Materials Science and Engineering: A 231/1–2 (1997) 55–61.

[25] K. Labisz, T. Tański, D. Janicki, HPDL energy absorption on anodised cast Al-Si-Cu alloys surfaces during remelting, Archives of Foundry Engineering 12/2 (2012) 45-48.

[26] A.D. Dobrzańska-Danikiewicz, T. Tański, J. Domagała-Dubiel, Unique properties, development perspectives and expected applications of laser treated casting magnesium alloys, Archives of Civil and Mechanical Engineering 12/3 (2012) 318-326.

IntechOpen