Provisional chapter

Technology Foresight Results Concerning Laser Surface Treatment of Casting Magnesium Alloys

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Additional information is available at the end of the chapter

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1. Introduction

In accordance with the concept presented, innovations, understood as valuable, innovative ideas, should be the way to achieve economic growth and to solve the contemporary problems of the climate change, increased consumption and depletion of conventional energy sources, food security, healthcare, and the advancing ageing of societies. To tackle this challenge, the European Commission has formulated the Europe 2020 strategy [1] andhas set up the Innovation Union [2]. It is estimated that the level of R&D and innovation investments until 2020 is to reach aggregately 3% of the EU's GDP from public and private funds. In order to achieve satisfactory economic and social effects, the stream of investments should be channelled into those fields of science and industries bringing the highest added value, with special consideration given to the role of small and medium sized enterprises. The aim of foresight research conducted broadly in Europe and Poland, also in the field of material engineering, is a quest for innovative areas deserving financial support [3-7]. Technology foresight serving to identify the priority, innovative technologies and the directions of their strategic development was pursued for materials surface engineering, as well [8]. One of 14 thematic areas analysed under such foresight research are laser technologies in surface engineering. Laser remelting and alloying / cladding is one of the critical technologies having the best development prospects and/or being of key significance for the industry selected for the detailed research carried out with the Delphi method.

Magnesium alloying with aluminium, manganese, metals of rare earths, thorium, zinc and zirconium enhances the strength in relation to the mass index, hence making them an important material where a decreased mass is important and where the forces of inertia must be reduced [9-11]. The advantages of the laser surface treatment processes, i.e.: short process time, flexibility, as well as operational precision, offer the upper hand of this method against the other methods employed in surface engineering. The primary aim of the laser remelting of material surface layers is to modify the structure and the associated properties [9-15]. Heightened resistance to, notably, wear and thermal fatigue is gained by creating a chemically homogenous, fine crystalline surface layer without changing the chemical composition of the material. Even more advantageous effects, such as improved functional properties, are feasible through alloying the material surface layer with the particles of the hard phases of carbides, oxides and nitrides. A need for magnesium alloys stems mainly from the development of the automotive and aviation industry. Rapid growth in the use of magnesium and magnesium alloys nearly in all the fields of the contemporary industry has been seen in the recent decades due to the numerous properties of this metal enabling to use it as a structural component as well as an additive to other chemical metal alloys. It is 35% lighter than aluminium (2.7g/cm3) and over four times lighter than steel (7.86g/cm3) [9-15,18]. Magnesium alloys, besides their low density (1.7 g/cm3), feature other advantages, as well, such as good ductility, the improved suppression of noise and vibrations as compared to aluminium as well as excellent castability, high size and shape stability, little shrinkage, low density combined with high strength and a low mass. They are also recyclable, thus processed alloys with their quality and properties very similar to the originally cast alloys can be obtained so that the materials can be used instead of the newly produced magnesium alloys for less important structures. A lower mass and very high strength allow for the production of parts made of this material by casting, by plastic deformation, mechanical treatment or welding. The advantages of casting magnesium alloys in conjunction with the promising outcomes of laser surface treatment investigations have set a basis for undertaking detailed scientific and research works to identify the influence of laser treatment on the structure and properties of the surface layer in casting magnesium alloys [12-15,18].

The purpose of this study is a comparative analysis of specific technologies of the laser remelting and cladding of casting magnesium alloys of MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 using the carbide powders of TiC, WC, VC, SiC and Al_2O_3 oxide. The type of powder deposited onto the substrate was used as a criterion of technology classification, thus distinguishing between five specific technologies subjected to materials science foresight investigations. The subject of the comparative analysis are the outcomes of investigations into the structure and properties of the analysed materials, performed using specialised research apparatuses, as well as the value of the individual technologies, determined through expert studies according to the custom methodology [9], in relation to the environment as well as the longterm development prospects of the technologies together with the recommended actions strategies and with the forecast multivariant development tracks. The relevance and adequacy of the assessments performed is ensured by the synergic interaction and cross supplementation of the materials science research and foresight methods. The paper also presents the outcomes of foresight research, based on reference data, [8] pertaining to the position of laser technologies in surface engineering, including laser remelting and alloying/cladding. Technology roadmaps, being a comparative analysis tool especially helpful for the small and medium sized enterprises lacking funds for conducting own research in this domain, were established at the last stage of the efforts. The results of the foresight and materials science research presented in this article are part of a broader research project [8, 17] aimed at selecting the priority innovative technologies of materials surface engineering and setting their directions of strategic development, as discussed in a series of publications, *inter alia* [18-24].

2. Materials and research methodology

The research performed is of an interdisciplinary character. The research methodology applied concerns predominantly surface engineering, being part of widely understood material engineering and technology foresight. In turn, technology foresight lies within the domain of the field of science known as organisation and management. The subject of the comparative analysis performedincludes, on one hand, the results of investigations into the structure and properties of casting magnesium alloys treated using the high capacity diode laser, encompassing notably: light and scanning microscopy, X-ray phase quality analysis and an analysis of surface distribution of alloy elements as well as investigations into the properties of mechanical properties, including: hardness, microhardness and roughness. On the other hand,the long term development prospects of the individual technologies together with the recommended management strategies and the forecast multi variant development tracks are determined according to the results of the expert studies with roadmaps and the technology information sheets have been developed for them. The following five homogenous groups were distinguished between from among the technologies analysed for the purpose of experimental and comparative works by adopting, as a criterion of grouping, the type of powder deposited onto the substrate, encompassing respectively:

a.

b.

c.

d.

e.

Scientific researchhave been carried out on test pieces of MCMgAl12Zn1, MCMgAl9Zn, MCMgAl6Zn1, MCMgAl3Zn magnesium alloys in as-cast, after heat and laser treatment states The chemical compositions of the investigated materials are given in Table 1.

The mass concentration of main elements, %							
No.	Al	Zn	Mn	Si	Fe	Mg	Rest
1	12.1	0.62	0.17	0.047	0.013	86.96	0.0985
2	9.09	0.77	0.21	0.037	0.011	89.79	0.0915
3	5.92	0.49	0.15	0.037	0.007	93.33	0.0613

4	2.96	0.23	0.09	0.029	0.006	96.65	0.0361

Table 1. Chemical composition of investigated alloys, %

A casting cycle of alloys has been carried out in an induction crucible furnace using a protective salt bath Flux 12 equipped with two ceramic filters at the melting temperature of 750±10ºC, suitable for the manufactured material. In order to maintain a metallurgical purity of the melting metal, a refining with a neutral gas with the industrial name of Emgesalem-Flux 12 has been carried out. The material has been cast in dies with betonite binder because of its excellent sorption properties and shaped into plates of 250x150x25. The cast alloys have been heated in an electrical vacuum furnace Classic 0816 Vak in a protective argon atmosphere, next MCMgAl12Zn1, MCMgAl9Zn, MCMgAl6Zn1, MCMgAl3ZMCMgAl6Zn1 magnesium alloys were used as substrate materials to laser surface treatment using high power diode laser. Laser surface alloying was conducted by remelting MCMgAl12Zn1, MCMgAl9Zn, MCMgAl6Zn1, MCMgAl3Zn surface and feeding of hard carbide particles and oxide aluminium. The alloying materials were TiC, SiC, WC, VC, Al_2O_3 powders. The powders was supplied by side injection rate of 7±1 g/min (for WC, TiC, VC powders) and 8÷9 g/min for SiC particles, Al_2O_3-4÷5 g/min.

The laser alloying was performed by high power laser diode HPDL Rofin DL 020 under an argon shielding gas. Argon was used during laser remelting to prevent oxidation of the coating and the substrate. The parameters of laser are presented in Table 2. The process parameters during the present investigation were: laser power–1.2÷1.6 kW, scan rate-0.5÷1.0 m/min.

Parameter	Value
Laser wave length, nm	940±5
Focus length of the laser beam, mm	82/32
Power density range of the laser beam in the focus plane [kW/cm^2]	0.8÷36.5
Dimensions of the laser beam focus, mm	1.8x6.8

Table 2. HPDL parameters

The observations of the investigated cast materials have been made on the light microscope LEICA MEF4A. Microstructure investigation was performed using scanning electron microscope (SEM) ZEISS Supra 25. For microstructure evaluation the Secondary Electrons (SE) detection was used, with the accelerating voltage of 5÷25 KV. Qualitative and quantitative chemical composition analysis in micro areas of the investigated coatings was performed using the X-Ray microanalysis (EDS) by mind of the spectrometer EDS LINK ISIS supplied by Oxrord.

Hardness tests were performed using Zwick ZHR 4150 TK hardness tester in the HRF scale. Tensile strength tests were made using Zwick Z100 testing machine.

In order to verify the correctness of the experimental values of hardness after laser cladding of Mg-Al-Zn casting magnesium alloys model uses a designed neural network, constructed on the basis of experimental data: the kind of used powder, the concentration of aluminium in the alloy, the laser power and speed of alloying – as the input variable – and HRF-hardness as the output variable, was used. The data set was divided into three subsets: learning (48 cases), validation (23 cases) and test (24 cases) ones. The fundamentals of the assessment of the network quality were the three characteristics of regression: average absolute error, the quotient of standard deviations, and Pearson's correlation coefficient. The quotient of the standard deviation is a gauge of the model quality used to solve regression problems. It is determined by dividing the standard deviation of prediction error and standard deviation of the output variable. A smaller value indicates a better gauge of the quality of prediction, because the smaller it is, the larger the variance explained by the model is. As a result of design and optimization of selected one way network MLP (multilayer perception) with 4 neurons in input layer – corresponding to the input variable: the nature of the powder (nominal variable), the concentration of aluminium in the alloy, the laser power and speed of alloying (numerical variables) and one numerical output variable (hardness HRF) were selected. For a nominal input variables conversion technique of one of Zn was used, while for numerical input variables and output variable the technique of conversion of variable minimax was used. The number of layers of the network was identified as three layers with two neurons in the hidden layer. The activation function in the input and output layers was defined as a linear with saturation, and in the hidden layer as the logistics, but for all the layers PSP linear functions were used. Networks were taught by methods of backpropagation of errors (50 epochs learners) and conjugate gradients (62 students ages). On the basis of achieved indicators to assess the quality of the neural network i.e., Pearson’s correlation coefficients for a set of test between the calculated and actual values of output: 0.90 in the training set, 0.90 in the validation set and 0.89 in the test set, and the quotient of standard deviations for the training and test sets: <0.47 one can be infer about the accuracy in predicting the value of the output network (HRF hardness).

The reference data gathered when implementing the FORSURF project [8] was used in order to determine the strategic position of laser technologies in relation to materials surface engineering as well as the position of laser remelting and alloying/cladding in relation to surface engineering laser technologies [8]. The investigations were carried out with the three iterations of the Delphi method according to the idea of e-foresight [25] using information technology including a virtual organisation, web platform and neural networks. The five specific technologies of the remelting and cladding of casting magnesium alloys using the carbide powders of TiC, WC, VC, SiC and Al_2O_3 oxide analysed in this article were evaluated based on the opinions of key experts using the custom foresight and materials science research methodology [16]. A universal scale of relative states, being a single pole positive scale without zero, where 1 is a minimum rate and 10 an extraordinarily high rate, was used in the research undertaken. A strategic position of the relevant technologies is presented graphically with a matrix of strategies for technologies consisting of sixteen fields into which strategic development tracks were entered presenting a vision, comprised of several variants, of the future events for a 20 year timeframe according to the time intervals of 2015, 2020, 2025 and

2030. The matrix of strategies for technologies presents graphically a position of each technology group according to its value and environment influence intensity and identifies a recommended action strategy. This matrix incorporates the results of expert research, transformed with software, visualised by means of two other matrices: dendrological and meteorological matrix. The methodological structure of the both matrices is referring to the portfolio methods commonly known in management sciences, and first of all to BCG [26] matrices enjoying their unparalleled popularity due to a reference to simple associations and intuitive reasoning, becoming an inspiration when elaborating methodological assumptions for the both matrices. A four field dendrological matrix of technology value includes the expert assessments for the relevant technologies according to the potential being the actual objective value of the specific technology group and attractiveness reflecting the subjective perception of the relevant technology group by its potential users. Depending on the potential value and attractiveness level determined in an expert assessment, each of the analysed technologies is placed into one of the matrix quarters. The wide stretching oak is the most promising quarter guaranteeing the future success in which technologies are placed characterised by a high potential and high attractiveness. The soaring cypress characterises the technologies with high attractiveness and a limited potential, and the rooted dwarf mountain pine the technologies with a large potential and limited attractiveness likely to ensure a robust position provided an appropriate strategy is applied. The least promising technologies are placed in the quarter called quaking aspen with their future success having small probability or being impossible. A four field matrix of environment influence presents, in a graphical manner, the results of how the external positive (opportunities) and negative (difficulties) factors impact the technologies analysed. Each of the technologies evaluated by the experts is placed into one of the following matrix quarters. Sunny spring illustrates the most advantageous external situation guaranteeing the future success. Rainy autumn, offering a chance for steady progress, corresponds to a neutral environment, and hot summer symbolises a stormy environment where the technology success is risky but feasible. Frosty winter informs that technology development is difficult or impossible.The results of the foresight materials science research were represented by reference data according to which a series of roadmaps for the analysed laser treatment technologies of casting magnesium alloys were established. The technology roadmaps developed with a custom concept are a convenient tool of a comparative analysis enabling to select the technologies or a group of technologies which is best in terms of the specified criterion and technology information sheets are supplementing them in technical terms.

3. Casting magnesium alloys properties dependent on technological conditions

The shape of the lase tray of the MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 magnesium cast alloys after laser alloying with carbides and aluminium oxide using high power diode laser HPDL is presented on figures. It was found a clear influence of process parameters, in particular the laser power and the used ceramic powder on the laser tray shape and surface topography. The laser tray face after using TiC and WC powders with the feeding technique, has a regular, flat surface (Figure 1,2). In case of vanadium carbide the laser tray surface obtained after alloying is characterised by a flat shape of the remelting area, but with visible discontinuities occurred in the surface layer. Figures 3 and 4 show exemplary laser tray faces after applying the technique with putting on of the ceramic powder paste (two steps process: powder, which was mixed with a binder in form of soda glass or polyvinyl alcohol, placed on the sample surface, and following alloying with laser beam). This technique was not used in the further series of tests due to numerous discontinuities occurring on the remelted surface. The investigated laser treated materials using the powder feeding technique with SiC particles are characterised by a bulge sample surface reching above the substrate material, due to mixing of the alloyed ceramic powder with the substrate material (Fig. 5). The surface layer obtained after the process of aluminium oxide alloying is characterised by occurrence of a small caving in the middle of the laser tray surface for 2.0 kW laser power (Fig.6). Performed investigations show, that the increase of laser power at a constant laser scanning rate influences the size of the area, where structural changes in the surface layer of the Al-Mg-Zn alloys occurs. The laser power is also related to the formation of the remelting zone bottom as well the convexity of the laser tray face, which are strongly influenced by the movements of the liquid metal.

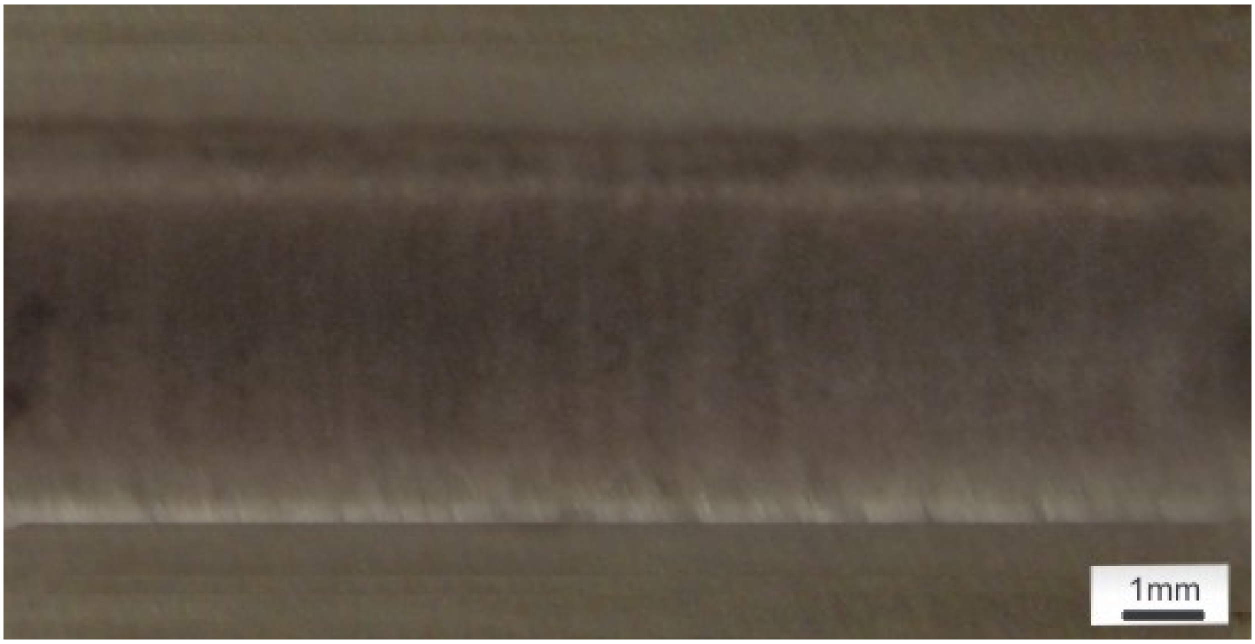


Figure 1. View of the MCMgAl9Zn1 casting magnesium alloy face of weld after laser treatment with TiC, scan rate: 0.75 m/min, laser power: 1.2 kW

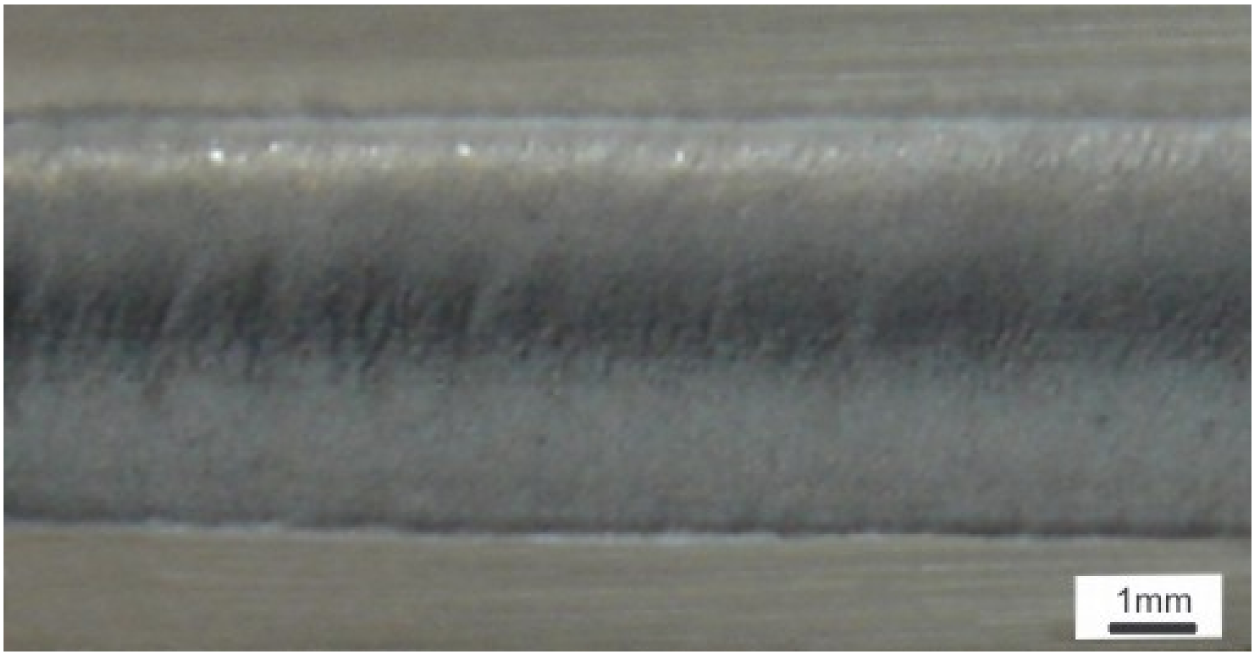


Figure 2. View of the MCMgAl12Zn1 casting magnesium alloy face of weld after laser treatment with WC, scan rate: 0.75 m/min, laser power: 1.2 kW

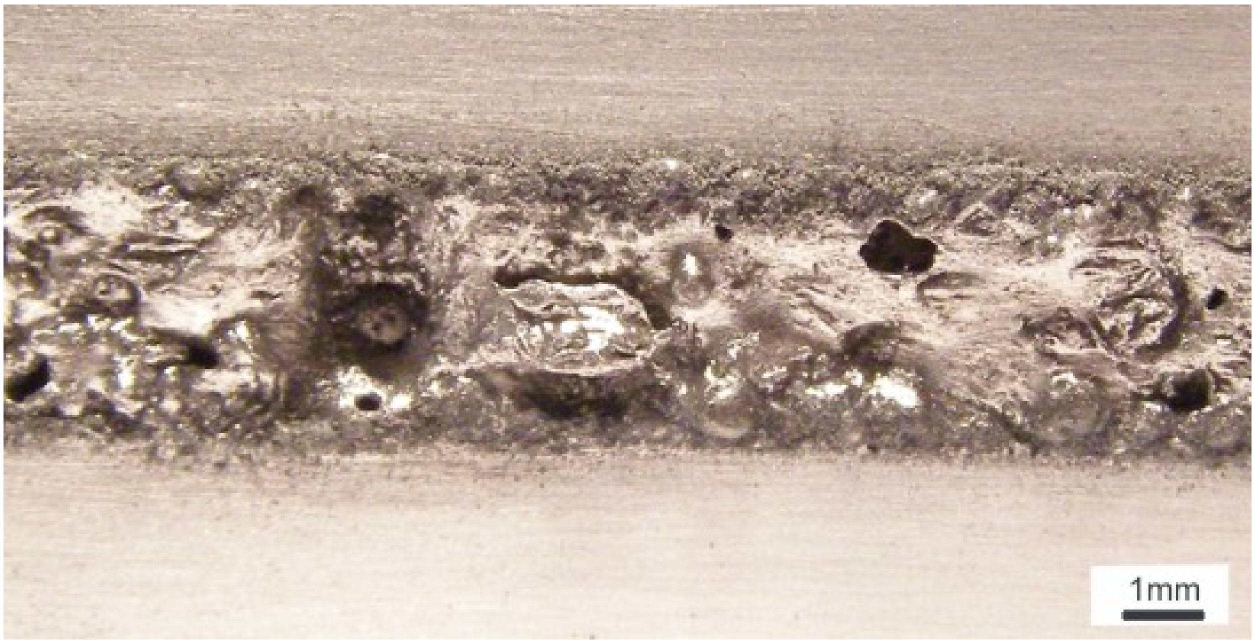


Figure 3. View of the MCMgAl9Zn1 casting magnesium alloy face of weld after laser treatment with WC, scan rate: 1.0 m/min, laser power: 2.0 kW

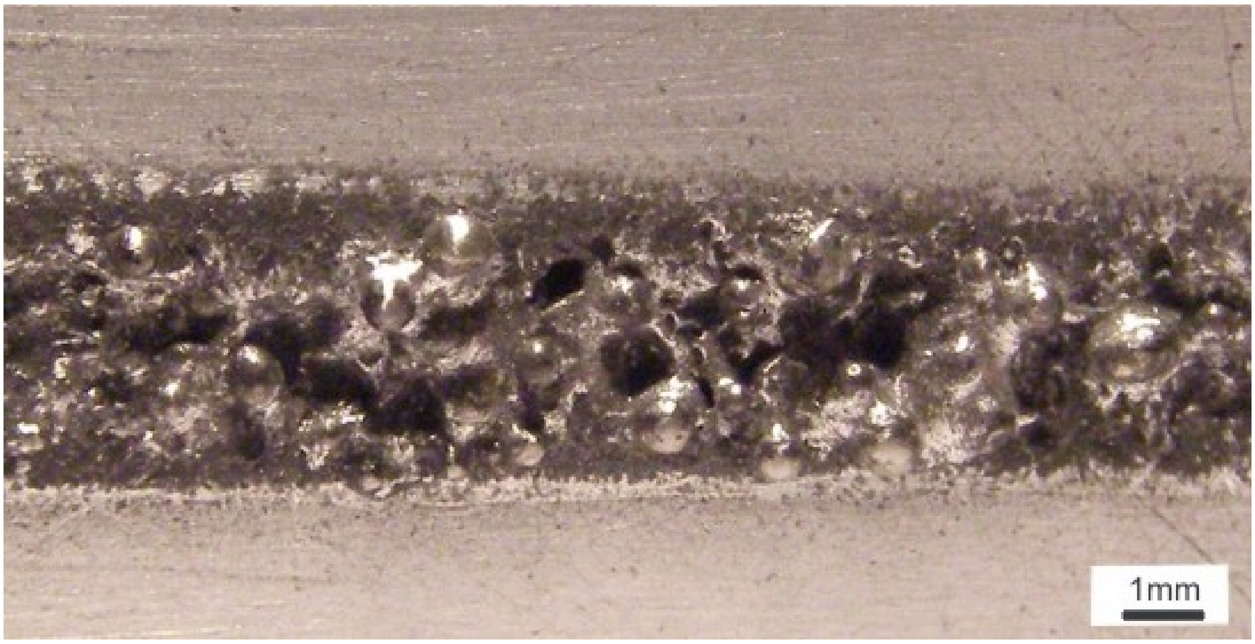


Figure 4. View of the MCMgAl9Zn1 casting magnesium alloy face of weld after laser treatment with TiC, scan rate: 1.0 m/min, laser power: 2.0 kW

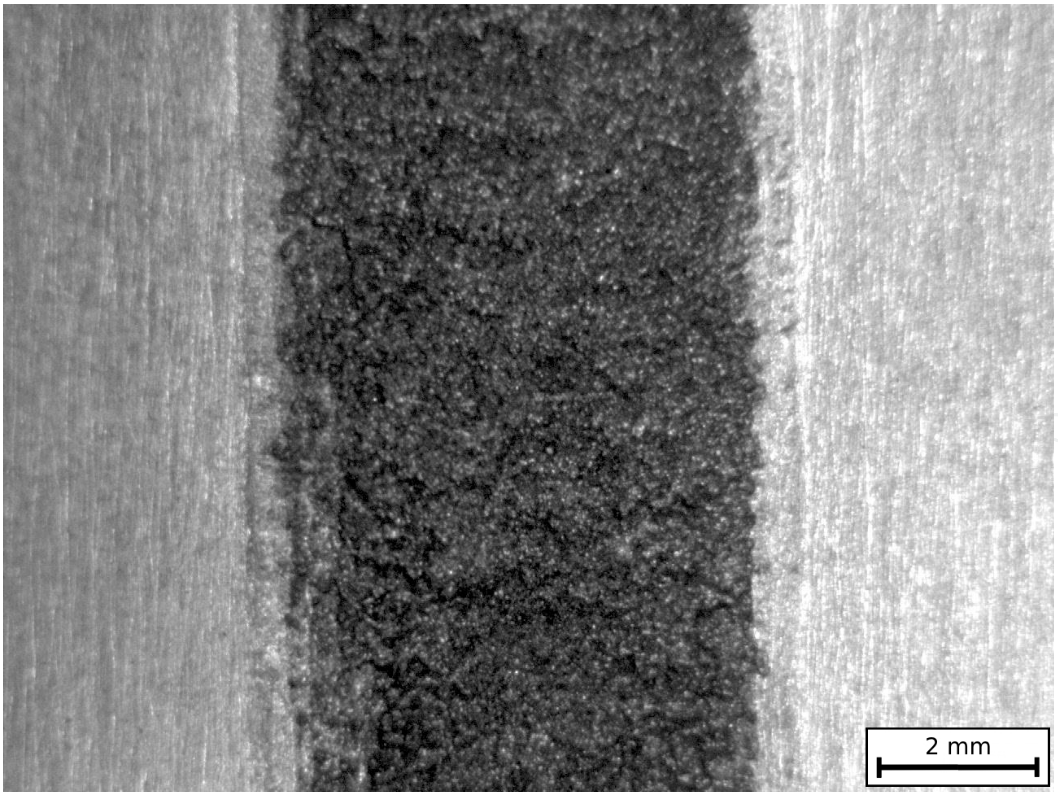


Figure 5. View of the MCMgAl9Zn1 casting magnesium alloy face of weld after laser treatment with SiC, scan rate: 0.75 m/min, laser power: 2.0 kW

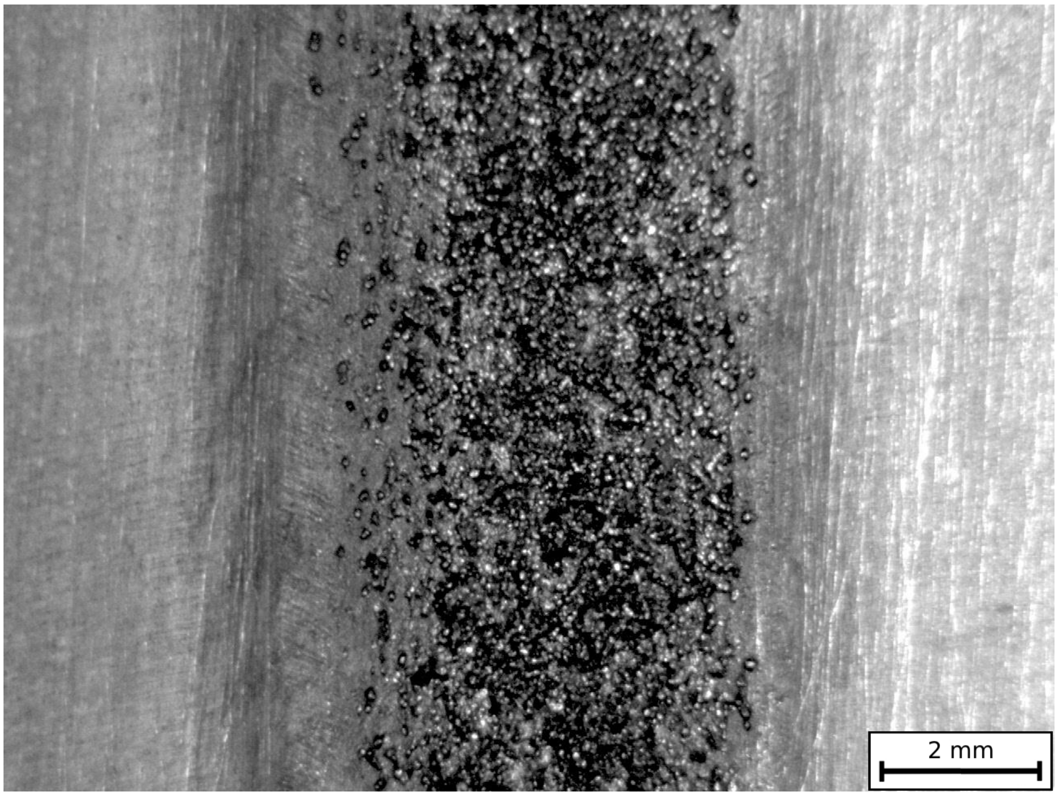


Figure 6. View of the MCMgAl9Zn1 casting magnesium alloy face of weld after laser treatment with Al_2O_3, scan rate: 0.5 m/min, laser power: 2.0 kW

Metallographic investigations results indicate, that the structure of the solidifying material after laser remelting is characterised by occurrence of areas showing a different morphology related to the crystallisation of the investigated magnesium alloys (Fig. 7-14). As a result of laser alloying there is created a defect free structure with clear grain refinement. The structure of the laser modified layer consists mainly of dispersed particles of the TiC, WC, VC, SiC, Al_2O_3 powder placed in the Mg-Al-Zn alloy matrix. Morphology of the remelted zone after laser alloying consists mainly of dendrites with $Mg_{17}Al_{12}$ plate like eutectic and Mg occurred in the interdendritic areas, whose main axes are oriented along the heat transport directions. Moreover the morphology of the composite structure of the area after laser alloying results from the change of the hypo eutectic alloy to an hyper eutectic one, depending on the dissolution and distribution of the ceramic powder used and process parameters applied for the surface layer treatment.

Investigations carried out using the scanning electron microscope have confirmed the presence of zonal structure in the surface layer of the investigated magnesium cast alloys (Figure 7-12). In the remelted zone there occurs a dendritic structure, coming into existence according to the heat transport direction. The dendritic structure occurs together with not dissolved particles of the used carbide or aluminium oxide powder (Fig. 13,14). Morphology of the area after laser alloying, as well the amount and distribution of carbide particles depends on the applied laser parameters. As a result of metallographic investigations of the MCMgAl3Zn1, MCMgAl6Zn1, MCMgAl9Zn1 and MCMgAl12Zn1 alloy there was found evenly distributed particles over the remelting zone (Figure 7-12). In the upper area of the remelting zone in which vanadium carbide was alloyed some turbulences can be seen, which are caused by the convective movement of the melt and the ceramic powder during the remelting process.Chemical composition investigations using energy dispersive X-ray spectrometer (EDS), as well as investigation of surface distribution of the chemical elements carried out on a crosssection of the surface layer of the cast magnesium alloy Mg-Al-Zn using TiC, WC, VC, SiC, Al_2O_3 powders confirms the occurrence of magnesium, aluminium, zinc, manganese, coal, and also respectively titanium, tungsten, vanadium, silicon and oxygen in the laser modified layer, and indicate a lack of solubility of the alloyed particles(Fig. 11-14).

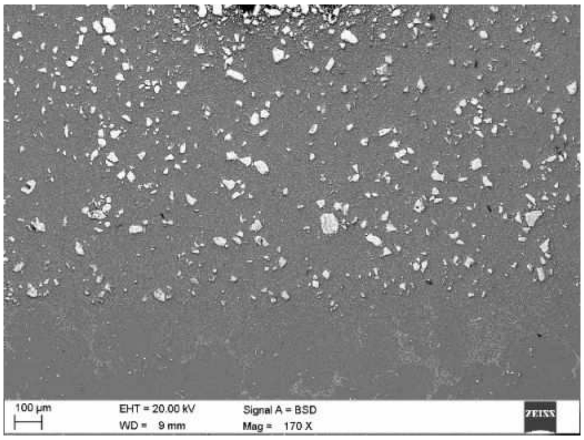


Figure 7. Scanning electron microscope micrograph of cross section laser modified surface of the MCMgAl9Zn1 alloy with TiC (laser power1.6 kW), scan rate: 0.75 [m/min]

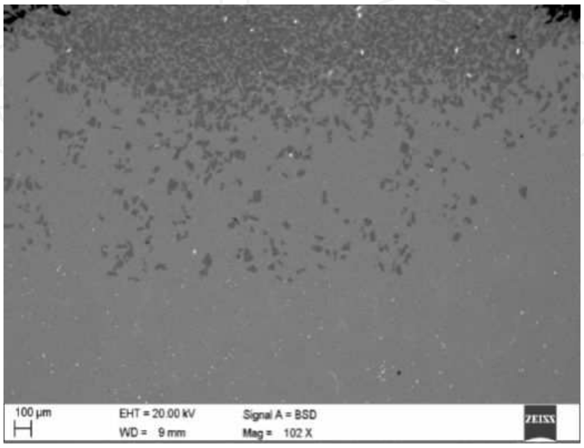


Figure 8. Scanning electron microscope micrograph of cross section laser modified surface of the MCMgAl9Zn1 alloy with SiC (laser power 2.0 kW), scan rate: 0.75 [m/min]

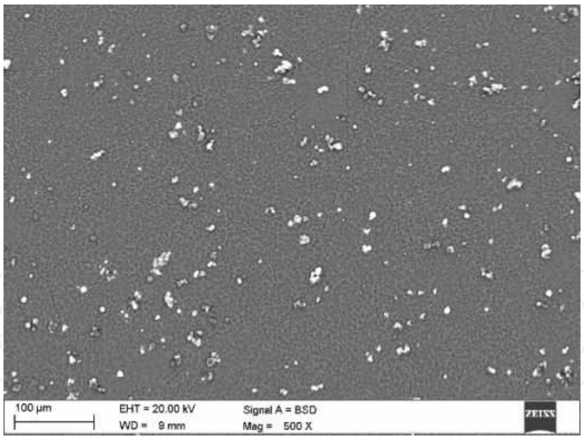


Figure 9. Scanning electron microscope micrograph of laser modified surface of MCMgAl12Zn1 alloy with WC particles of the central modified zone, scan rate: 0.75 [m/min], laser power: 2.0 [kW]

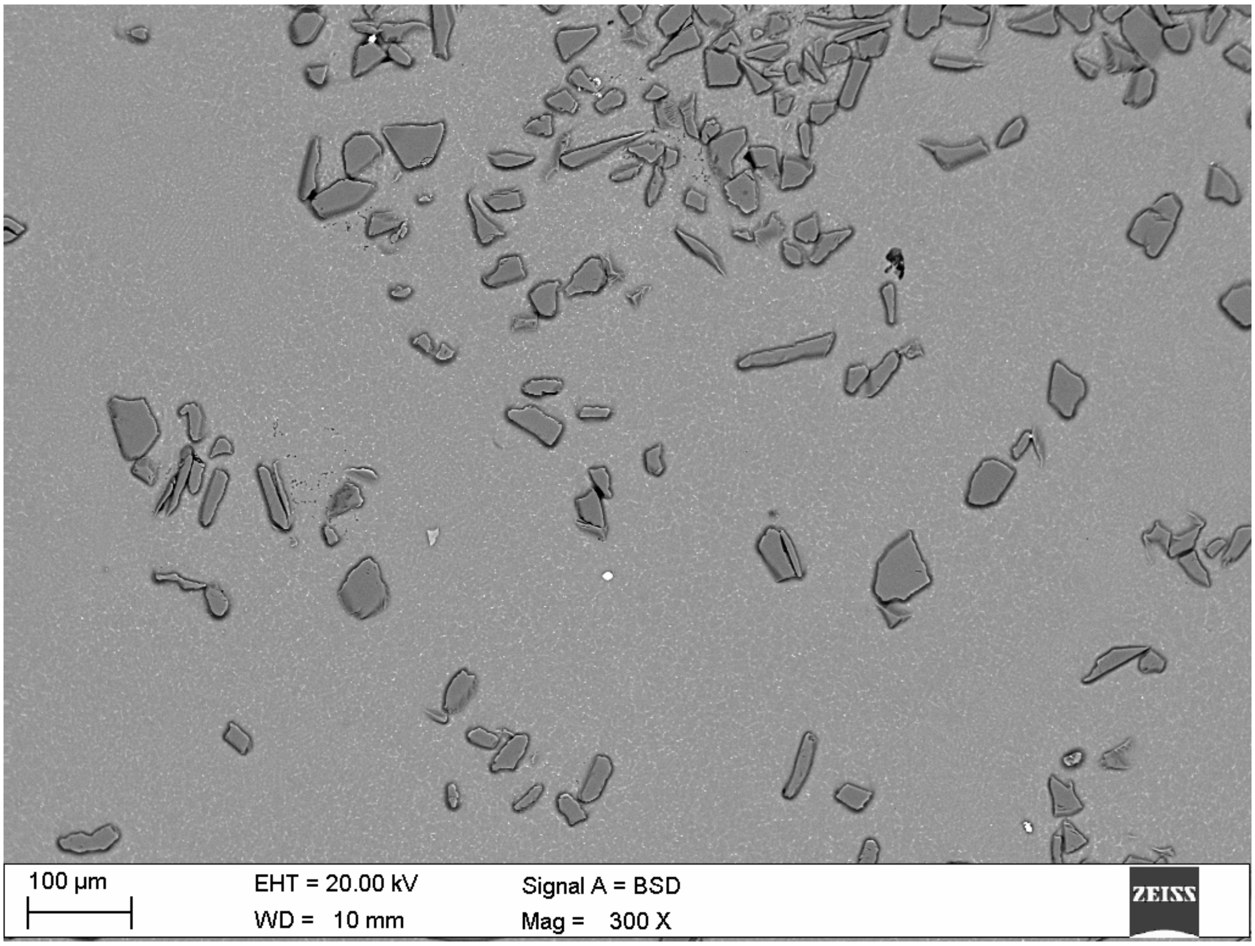


Figure 10. Scanning electron microscope micrograph of laser modified surface of MCMgAl6Zn1 alloy with SiC particles of the central modified zone, scan rate: 0.75 [m/min], laser power: 2.0 [kW]

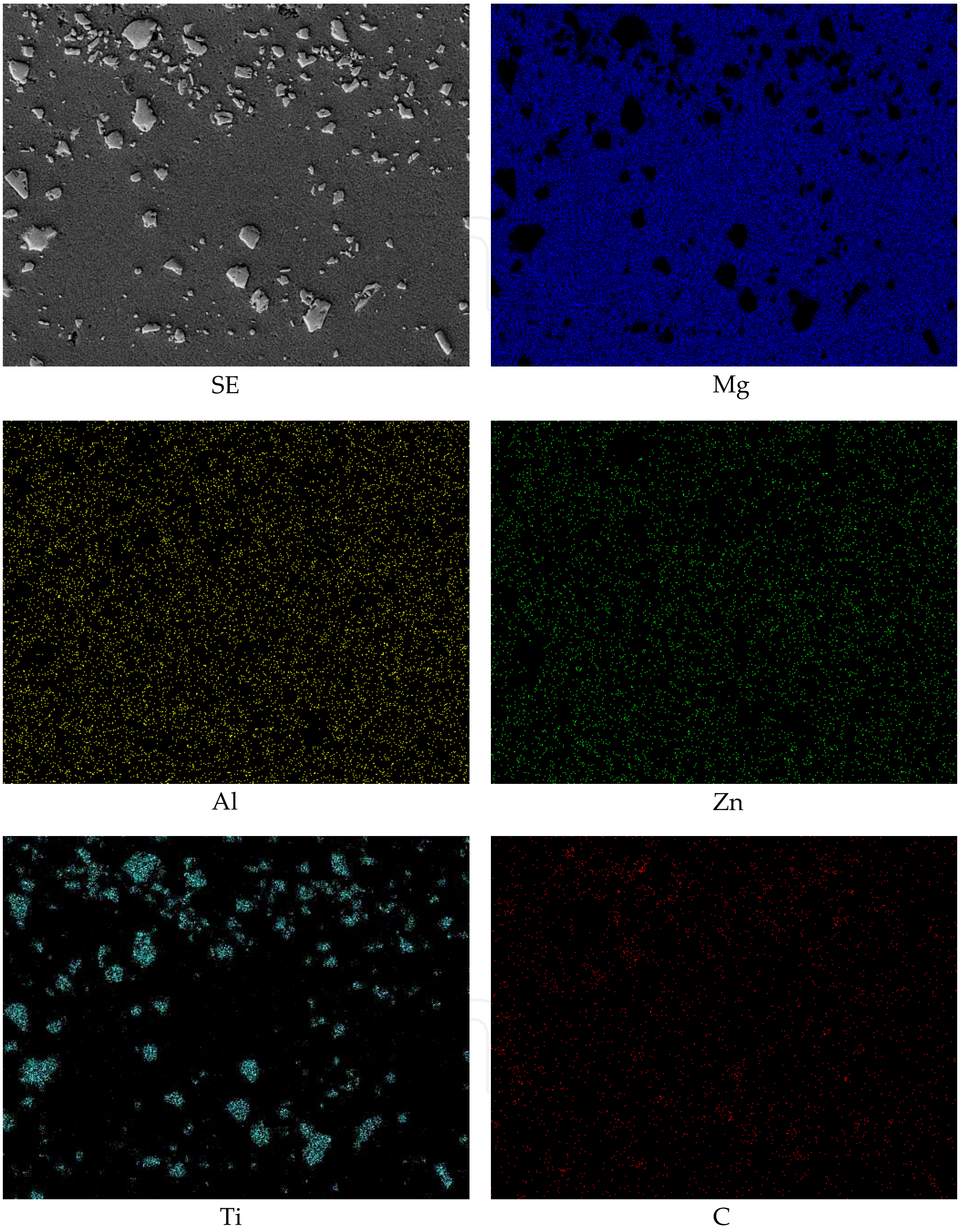
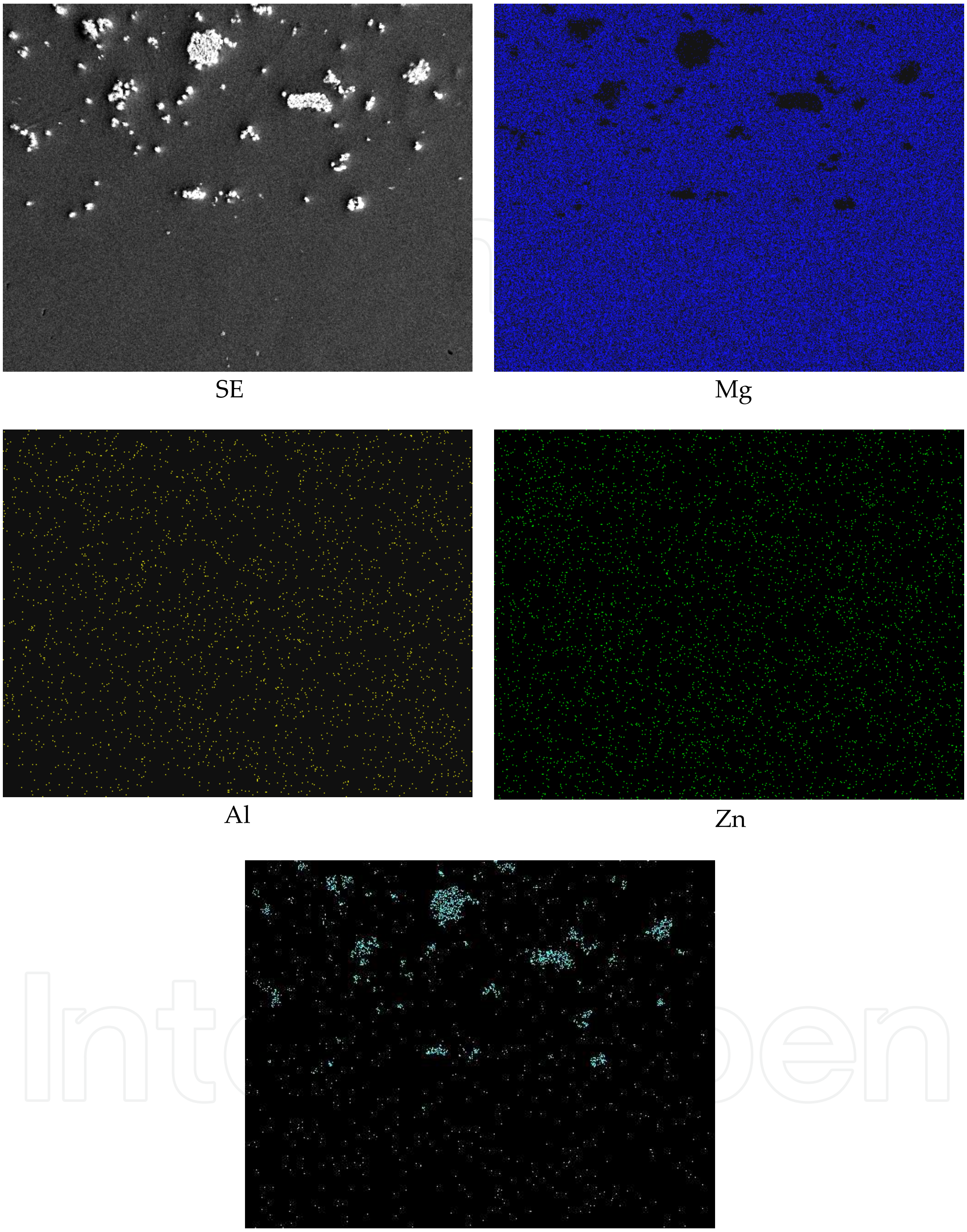


Figure 11. The area analysis of chemical elements alloy MCMgAl6Zn1 after laser treatment with TiC, scan rate: 0.75 [m/min], laser power: 1.6 [kW]: image of the secondary electrons (SE) and maps of elements' distribution



SE

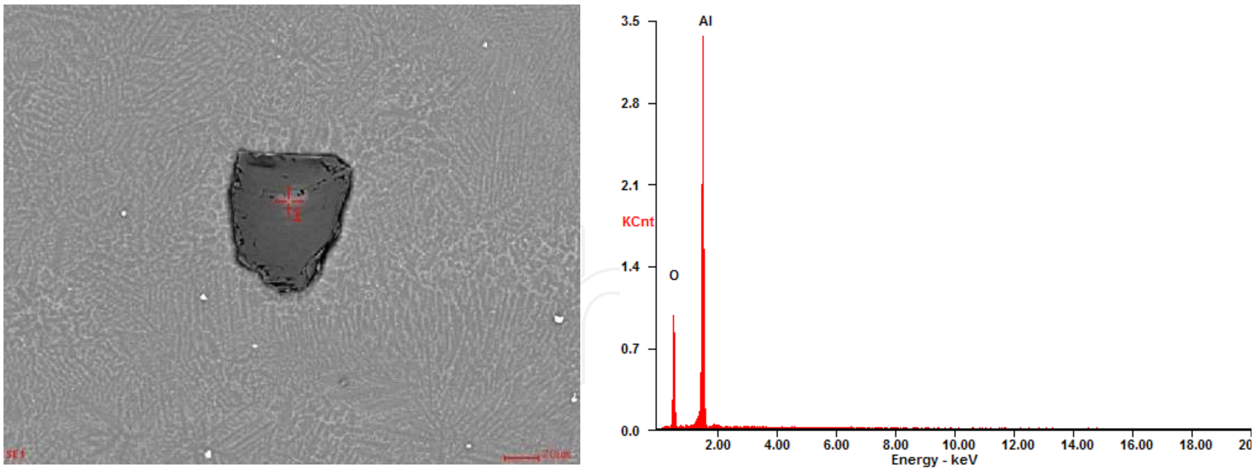
Mg

Al

Zn

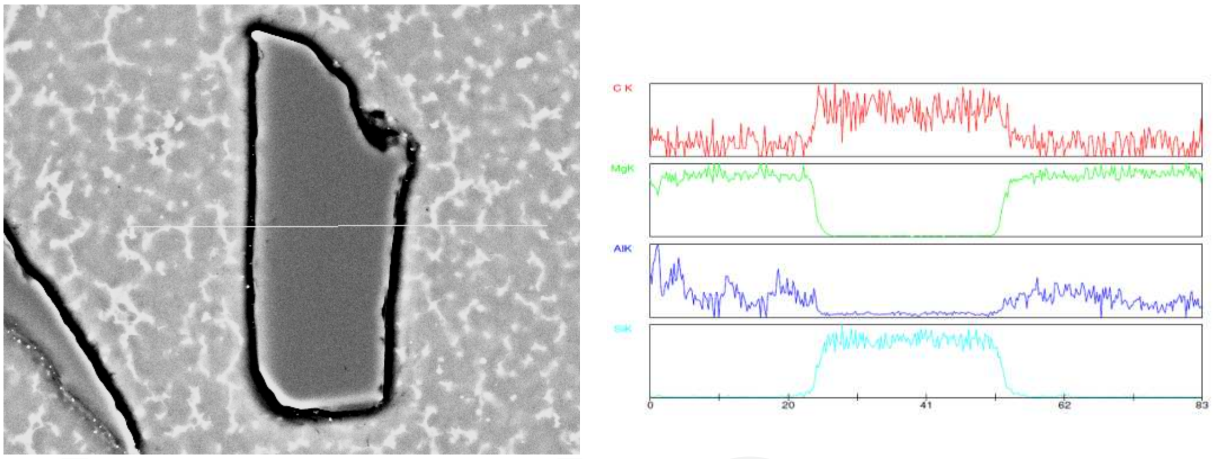
W

Figure 12. The area analysis of chemical elements alloy MCMgAl6Zn1 after laser treatment with WC, scan rate: 0.75 [m/min], laser power: 2.0 [kW]: image of the secondary electrons (SE) and maps of elements' distribution



(a) (b)

Figure 13. Structure of the laser modified surface of MCMgAl9Zn1 alloy with Al_2O_3 particles of the central modified zone, scan rate: 0.5 [m/min], laser power: 2.0 [kW], a) SEM micrograph, b) EDS microanalysis of the Al_2O_3 particles with surface layer in point 1 marked on Fig. 13 a



(a) (b)

Figure 14. Scanning electron microscopy micrograph of MCMgAl9Zn1 alloy after laser alloying with SiC particles, laser power: 2.0 kW, scan rate: 0.75 m/min, powder feed rate: 0.75 m/min, a) SEM micrograph, b) linear analysis of the chemical composition changesmarked on Fig. 14 a

Hardness measurements results of the Mg-Al-Zn cast magnesium alloy after remelting and alloying with WC, TiC, VC, NbC, SiC carbides and Al_2O_3 oxide (Figure 15) show, that in most cases laser treatment of the surface layer causes an hardness increase. The highest hardness increase of 56 HRF compared to the hardness results achieved for the material after standard heat treatment was obtained for the MCMgAl3Zn1 alloy alloyed with TiC powder with laser power of 1.2 kW and laser scanning rate of 1.0 m/min. For the MCMgAl6Zn1 alloy the highest hardness (93.4 HRF) after laser treatment was measured for the material alloyed with TiC powder with laser power of 1.2 kW and laser canning rate of 0.75 m / min.

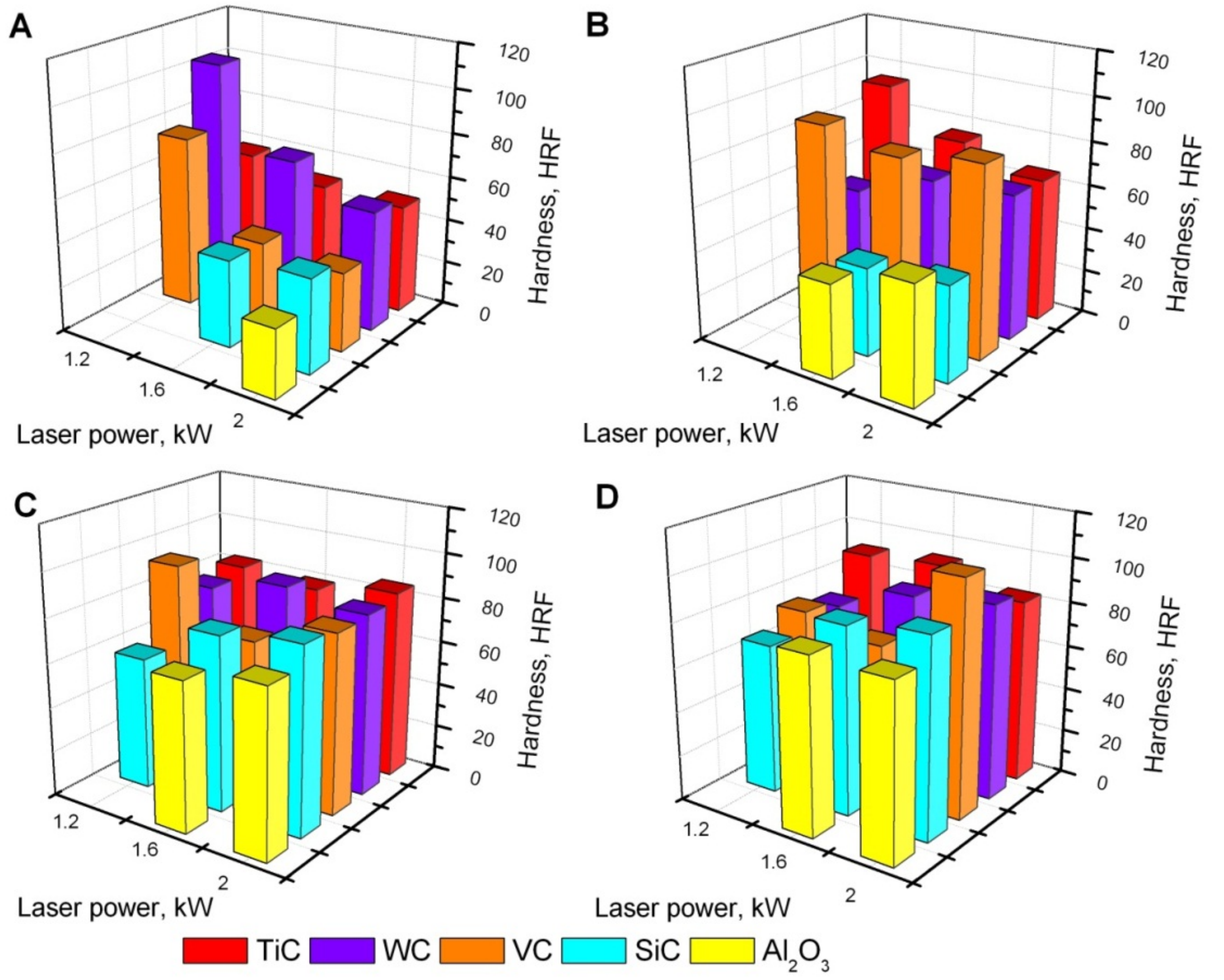
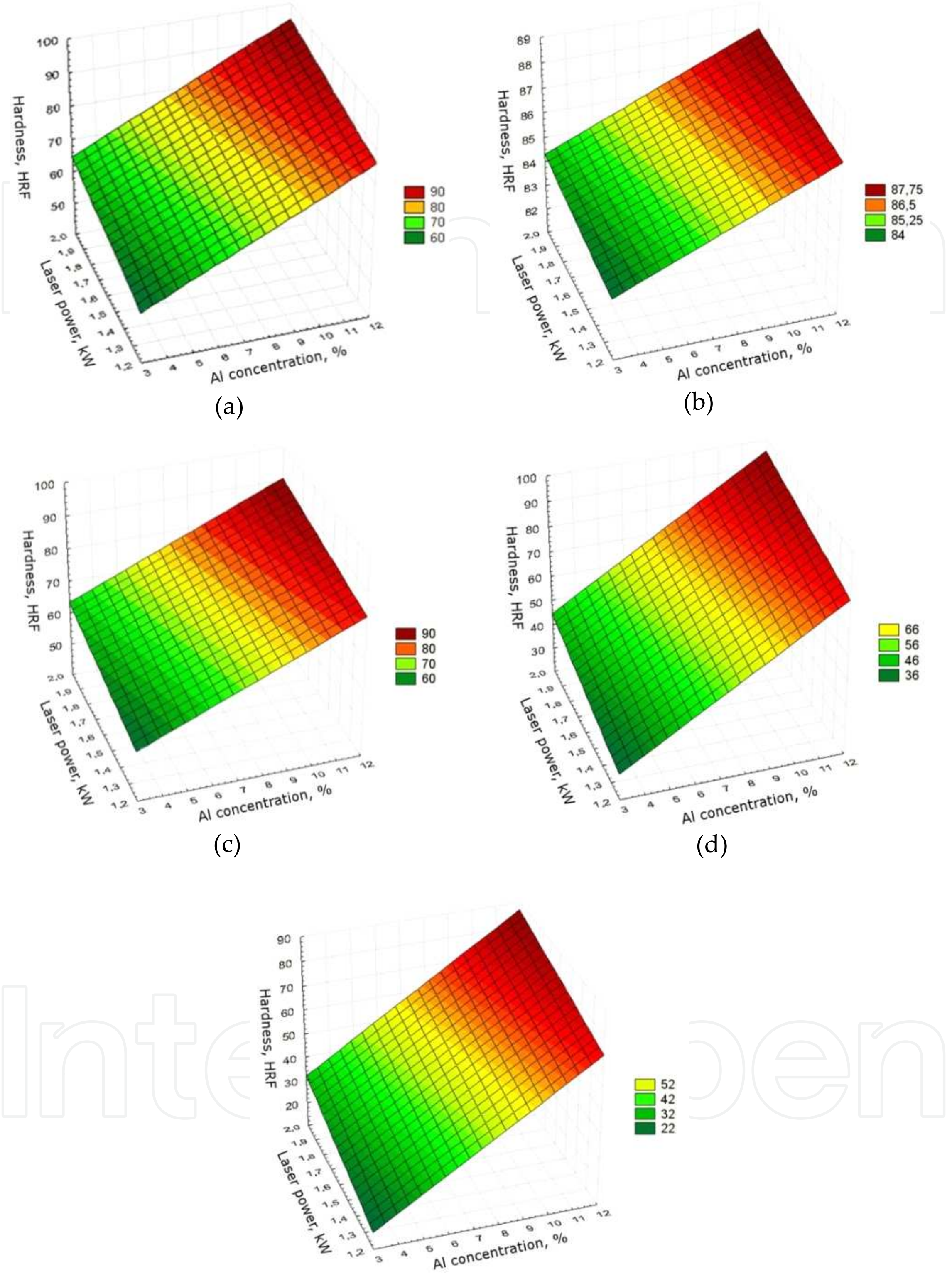


Figure 15. Change in the average hardness of the surface layer of casting magnesium alloys after laser treatment: A – MCMgAl3Zn1, B – MCMgAl6Zn, C – MCMgAl9Zn1, D – MCMgAl12Zn1

Furthermore, on the basis of the outworked neural network model diagrams of the impact of laser power, concentration of aluminium, and also the type of powder on the hardness of the analyzed casting magnesium alloys after laser treatment of the surface layer (Figs. 16) were made. The diagrams in most cases concern the remelting speed of 0.75 m/min, corresponding to the optimum geometry of the path of the laser. The obtained results clearly show that MCMgAl12Zn1 casting magnesium alloys alloyed by TiC and WC powders with a laser power of 2.0 kW and a speed of 0.75 m/min. are characterised by the highest hardness.



(a)

(b)

(c)

(d)

(e)

Figure 16. Simulation of the laser power and aluminium concentration (wt. %) influence on hardness of casting magnesium alloys after laser alloyed with: a) TiC, b) VC, c) WC, d) SiC, e) Al_20_3particles, scan rate 0.75 m/min (a-d), scan rate 0. 5 m/min (e)

4. Forecasted development of laser technologies in surface engineering

The reference data gathered when implementing the FORSURF project for surface properties formation leading technologies of engineering materials and biomaterials was used in order to determine the strategic position of laser technologies in relation to materials surface engineering as well as the position of laser remelting and alloying/cladding in relation to surface engineering laser technologies [8]. Over 300 independent experts from many countries representing scientific, business and public administration circles have taken part in the FORSURF technology foresight. The experts have completed approx. 650 multiquestion surveys and held thematic discussions during 10 Workshops. A collection of 140 critical technologies, 10 for each thematic group, was selected for the above 14 thematic groups from the initially inventoried approx. 500 specific technology groups. The scientific and research methods of evaluating the state of the art for a particular concept, technology review and a strategic analysis with integrated methods were used for this purpose, including: extrapolation of trends, environment scanning, STEEP analysis, SWOT analysis, expert panels, brainstorming, benchmarking, multicriteria analysis, computer simulations and modelling, econometric and static analysis. Next, the technologies were thoroughly analysed with three iterations of the Delphi method carried out in consistency with the idea of e-foresight using information technology encompassing a virtual organisation, web platform and neural networks, with a universal scale of relative states being a singlepole positive scale without zero, where 1 is a minimum rate and 10 an extraordinarily high rate.

Foresight investigations with the sample size of 198 have revealed a very robust strategic position of laser technologies among other materials surface engineering technologies. The experts found that that laser technologies have the best industrial application prospects in the group of all the analysed materials surface engineering technologies in the nearest 20 years. 78% of the surveyed held such a view. Nearly a three fourth of the respondents (73%) maintain that numerous scientific and research studies will be devoted to such technologies in the analysed time horizon.70% of the persons surveyed claim that the thematic area of “Laser technologies in surface engineering” is crucial and its importance should be absolutely rising so that an optimistic scenario can come true of the country’s/Europe/World development, i.e. “Race won” assuming that the potential available is adequately utilised to fulfil the strategic objectives of development and so that people, statistically, are better off, social attitudes are optimistic and the prospects for the coming years bright. 81% of the surveyed persons argue that the significance of laser technologies in relation to other materials surface engineering technologies will be growing, whereas 18% maintain it will remain on the same level with only 3 individuals asserting that the role will diminish over the next 20 years. The excellent results of technology foresight elaborated based on the reference data point to, therefore, the anticipated key role of laser technologies for the advancement of the overall materials surface engineering (mezo scale) and for the development of the entire domestic/European/global economy (macro scale) [23]. The results of the foresight research discussed, presenting the position of laser technologies against materials surface engineering as a whole, are provided on Fig.17.

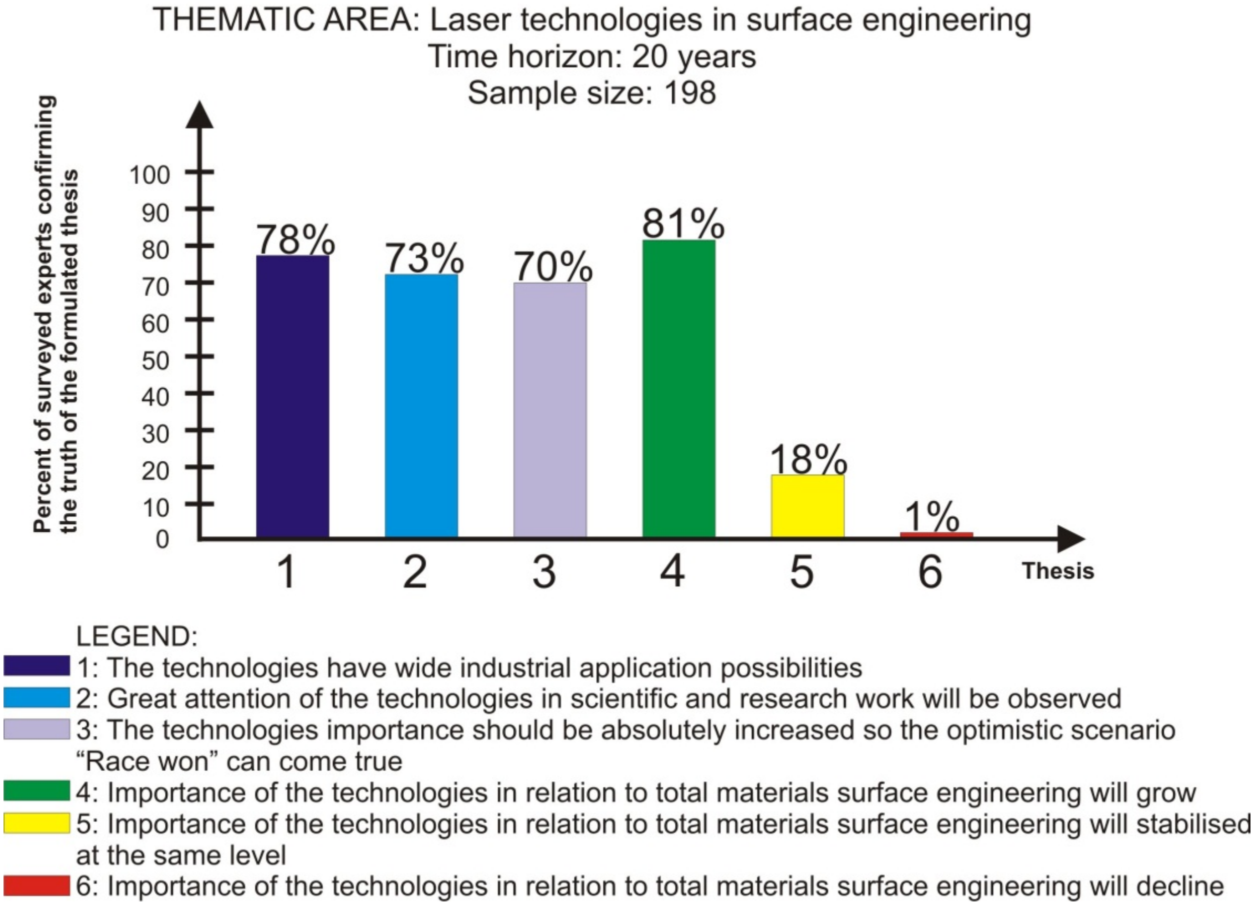


Figure 17. The position of laser technologies against materials surface engineering as a whole [30]

The position of laser remelting and alloying/cladding vis-à-vis other laser technologies in surface engineering has undergone a thorough foresight study made by the selected key experts, specialists in the field of laser technologies. The two technology groups analysed are characterised by stable, predictable development prospects. 40 % of the experts surveyed maintain that the technology group of laser alloying/cladding, characterised by its late maturity, falls within the group of critical technologies and its importance should be absolutely rising so that an optimistic scenario of the country's/Europe/World development, i.e. "Race Won" comes true in the nearest 20 years. 20% of the experts attending the study held a similar view for the base technology of laser remelting.

5. Laser surface treatment of casting magnesium alloys in the future

The long run development prospects were identified based on the materials science experiments and expert studies performed by means of the custom methodology [9] for the individual groups of specific technologies, including the laser treatment of casting magnesium alloys, i.e. respectively: (A) titanium carbide TiC, (B) tungsten carbide WC, (C) vanadium carbide VC, (D) silicon carbide SiC and (E) aluminium oxide $Al_2O_{3.}$ The recommended action strategies and the predicted multivariant development tracks and technology roadmaps were also developed and information sheets were prepared.

As part of the research conducted, the key experts in the first place assessed the analysed technology groups with a universal scale of relatives states consisting of ten points (max: 10, min: 1) for their attractiveness and potential and the result obtained was entered into the dendrological matrix of technology value [18]. The analysis made has shown that all the groups of technologies were classified to the most promising quarter called widestretching oak, encompassing the technologies with a high potential and attractiveness. The best score of A(9,65; 9,75) was attained for casting magnesium alloys undergoing laser treatment with titanium carbide, and the lowest score of D (7,55; 8,45) was seen for those where silicon carbides were used for laser treatment. Positive and negative environment influence on the relevant technology groups was evaluated with a meteorological matrix of environment influence. The results of a multicriteria analysis of the experts' scores acquired in the survey-taking process were entered into the matrix [18]. The results of the studies made reveal that the environment for all the technology groups subjected to the studies is unusually favourable, bringing multiple opportunities and few difficulties. Hence, all the analysed technology groups were found in the quarter corresponding to sunny spring, boding very well for their development. Again, the technology group referred to as A (4,04; 7,36) scored highest, and the lowest score was given to the technology group called E (3,77;6,02). The results of the studies presented graphically with the dendrological and meteorological matrix were at the next stage of the scientific pursuits entered into the matrix of strategies for technologiesby means of the softwaredeveloped for this purpose (Fig.18). The matrix presents, in a graphical manner, a position of the relevant technology groups of the laser treatment of casting magnesium alloys with carbides and aluminium oxide according to its value and environment influence intensity and identifies an appropriate action strategy. The oak in spring strategy is recommended for all those analysed technology groups that are boding well. The strategy consistsin developing, strengthening and implementing an attractive technology with a large potential in the industrial practise to achieve a spectacular success.

The next stage of the research consists of identifying the strategic development tracks for the individual technologies/technology groups according to the experts' opinions, representing a forecast of their development for the years of: 2015, 2020, 2025 and 2030 according to the three variants: optimistic, pessimistic and the most probable one. They are next visualised against the technology strategy matrix. The numerical values, being an outcome of all the investigations performed for the three analysed groups of technologies, are listed in Table 3. Due to relatively small differences between the individual analysed groups of technologies at a macro scale, the strategic development tracks established for them have a similar direction, showing minor differences and are discussed further on with a representative example of the laser treatment of casting magnesium alloys with titanium carbide TiC.

The most probable strategic development track of the leaser treatment of casting magnesium alloys with titanium carbide TiC assumes that the environment conditions shift from friendly spring to risky summer while maintaining a high potential and attractiveness characteristic for widestretching oak. The environment will become more stable in the subsequent years transiting into the autumn phase. It is anticipated that an attractive, stable technology will become successful at the predicted market with other markets being sought for along with the new groups of potential clients and new products manufacturable with the specific technology. An optimistic laser treatment development track for casting alloys with titanium carbide TiC assumes that althougha number of temporary (2015-2020) difficulties occur in the environment, the opportunities emerging at the same time can be exploited with those opportunities defining the development of this technology group in the further years ensuring their return to the friendly area of sunny spring. This, combined with the maintaining high attractiveness and technology potential, will ensure a spectacular success. A pessimistic variant defined by the third strategic development track for the technology group envisages that the global downturn would become even harsher due to the unfolding disadvantageous political and economic situation. This will cause more and more difficulties in the environment (year of 2015) and fewer and fewer opportunities making it necessary to operate in 2020 in the unfavourable conditions of frosty winter. The economic circumstances will be unfriendly, making the potential users less interested in the technology group. In 2025 the analysed technology group, being rooted dwarf mountain pine, by using a large potential representing an objectively high value of the technology, will make attempts to withstand the difficulties while regularly weakening, so that it transits to the field of quaking aspen in winter in 2030 with withdrawal from the market being then advisable.

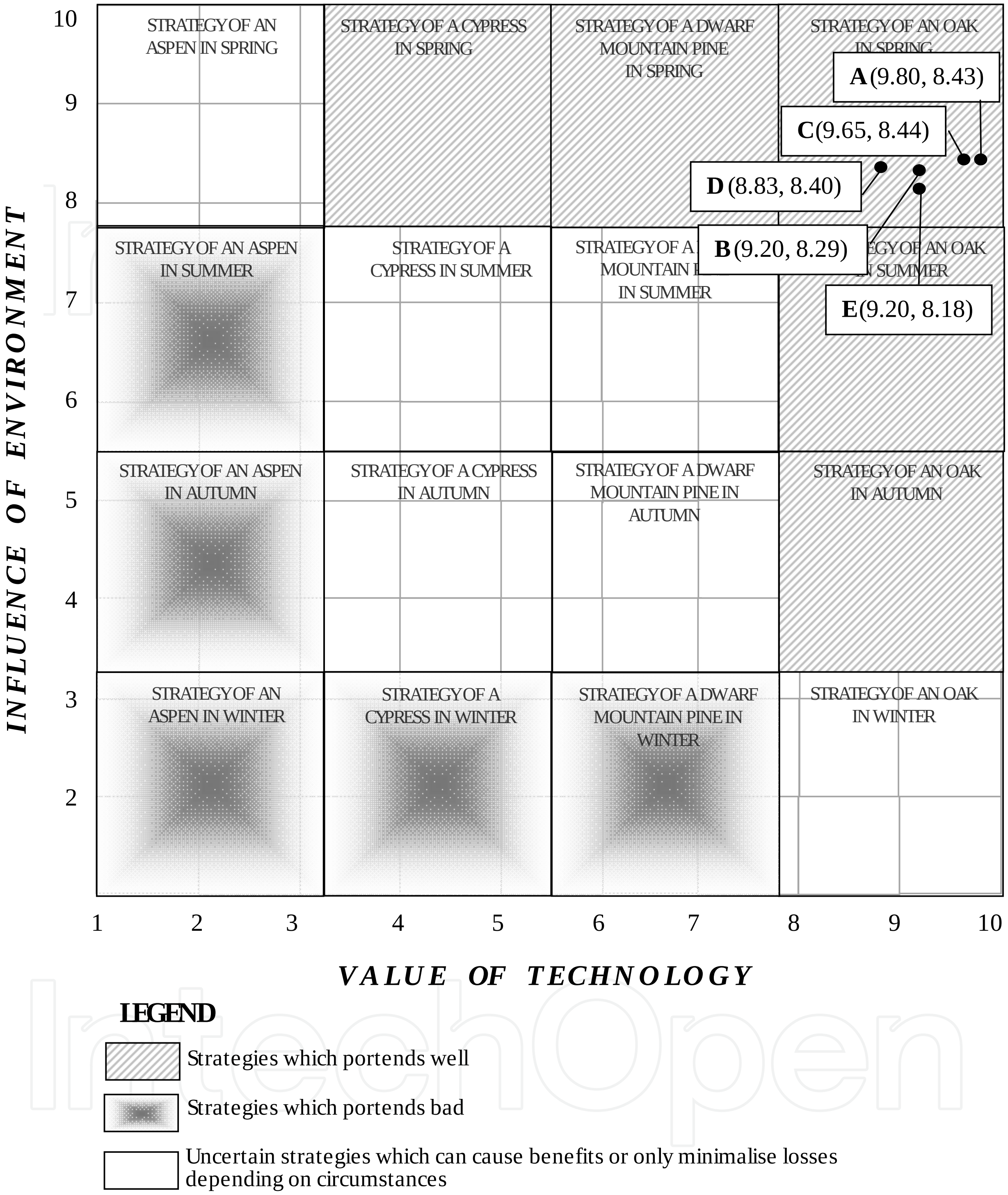


Figure 18. The matrix of strategies for technology called the laser cladding and remelting of casting magnesium alloys using TiC (A), WC (B), VC (C), SiC (D) carbide and Al2O3 oxide (E) powders [18]

Technology		Steady state 2010-11	Type of strategic development tracks	Years			
Symbol	Name			2015	2020	2025	2030
(A)	The laser treatment of TiC in the Mg-Al-Zn surface	Strategy of an oak in spring A (9.8, 8.4)	(O)	(9.8, 6.5)	(9.9, 7.0)	(9.9, 8.0)	(9.9, 9.0)
			(P)	(9.8, 6.0)	(9.8, 2.0)	(6.0, 2.0)	(3.0, 1.8)
			(MP)	(9.7, 6.0)	(9.8, 7.0)	(9.8, 4.5)	(9.9, 4.8)
(B)	The laser treatment of WC in the Mg-Al-Zn surface	Strategy of an oak in spring B (9.2, 8.3)	(O)	(9.2, 5.6)	(9.3, 6.2)	(9.4, 7.0)	(9.4, 8.0)
			(P)	(9.2, 5.3)	(9.2, 1.6)	(5.7, 1.6)	(3.0, 1.4)
			(MP)	(9.2, 5.6)	(9.2, 6.0)	(9.3, 3.9)	(9.3, 4.2)
(C)	The laser treatment of VC in the Mg-Al-Zn surface	Strategy of an oak in spring C (9.7, 8.4)	(O)	(9.7, 6.2)	(9.8, 6.5)	(9.8, 7.5)	(9.8, 8.5)
			(P)	(9.7, 5.7)	(9.7, 1.8)	(5.9, 1.8)	(3.0, 1.5)
			(MP)	(9.6, 5.7)	(9.7, 6.5)	(9.7, 4.0)	(9.8, 4.3)
(D)	The laser treatment of SiC in the Mg-Al-Zn surface	Strategy of an oak in spring D (8.8, 8.4)	(O)	(8.8, 5.6)	(8.8, 6.0)	(8.9, 7.0)	(9.0, 8.2)
			(P)	(8.8, 5.7)	(8.7, 1.7)	(5.9, 1.7)	(3.0, 1.4)
			(MP)	(8.8, 5.6)	(8.8, 5.4)	(8.8, 4.0)	(8.9, 4.3)
(E)	The laser treatment of Al_2O_3 in the Mg-Al-Zn surface	Strategy of an oak in spring E (9.2, 8.2)	(O)	(9.2, 5.6)	(9.4, 6.0)	(9.4, 7.1)	(9.4, 8.1)
			(P)	(9.2, 5.2)	(9.2, 1.5)	(5.6, 1.5)	(3.0, 1.4)
			(MP)	(9.2, 5.6)	(9.3, 6.0)	(9.3, 4.0)	(9.3, 4.1)

Table 3. Strategic development tracks of laser treatment of Mg-Al-Zn castingmagnesium alloys using carbide and oxide powders. Types of strategic development tracks: (O) -optimistic, (P) - pessimistic; (MP) - the most probable [18]

6. Technology roadmapping

A series of roadmaps of the technology groups analysed was created on the basis of the results of experimental and comparative studies. The roadmaps serve as a comparative analysis tool permitting to select the technologies or technology groups best in terms of the criterion defined [27-29]. The roadmaps, prepared with a custom concept, have their set up corresponding to the first quarter of the Cartesian system of coordinates. The following time intervals, respectively: current situation (2010-11), goals fulfilment methods (2020) and long-term objectives (2030) are provided on the axis of abscissa, i.e. time layer, concept layer, product layer, technology layer, spatial layer, staff layer and quantitative layer, made up of more detailed sublayers. The uppermost layers of the technology roadmap are most general and determine the allsocial and economic reasons and causes of the actions taken. The middle layers are characterising a product and its manufacturing technology. The bottom layers are determining organisational and technical matters concerning the place, contractor and costs. Cause and effect relationships, capital ties, time correlations and twodirectional data and/or resources flow take place between the individual layers and sublayers as signified graphically with the different types of arrows. Fig.19 presents a representative technology roadmap drafted for the laser cladding of vanadium carbide VC particles into the surface of casting magnesium alloys Mg-Al-Zn. Table 4 presents an aggregate list containing the selected data being an extract from all the technology roadmaps developed for the analysed casting magnesium alloys subjected to laser treatment. The technology information sheetsare detailing out andsupplementing the technology roadmaps. They containtechnical information very helpful in implementing a specific technology in the industrial practice, especially in SMEs lacking the capital allowing to conduct own research in this field.

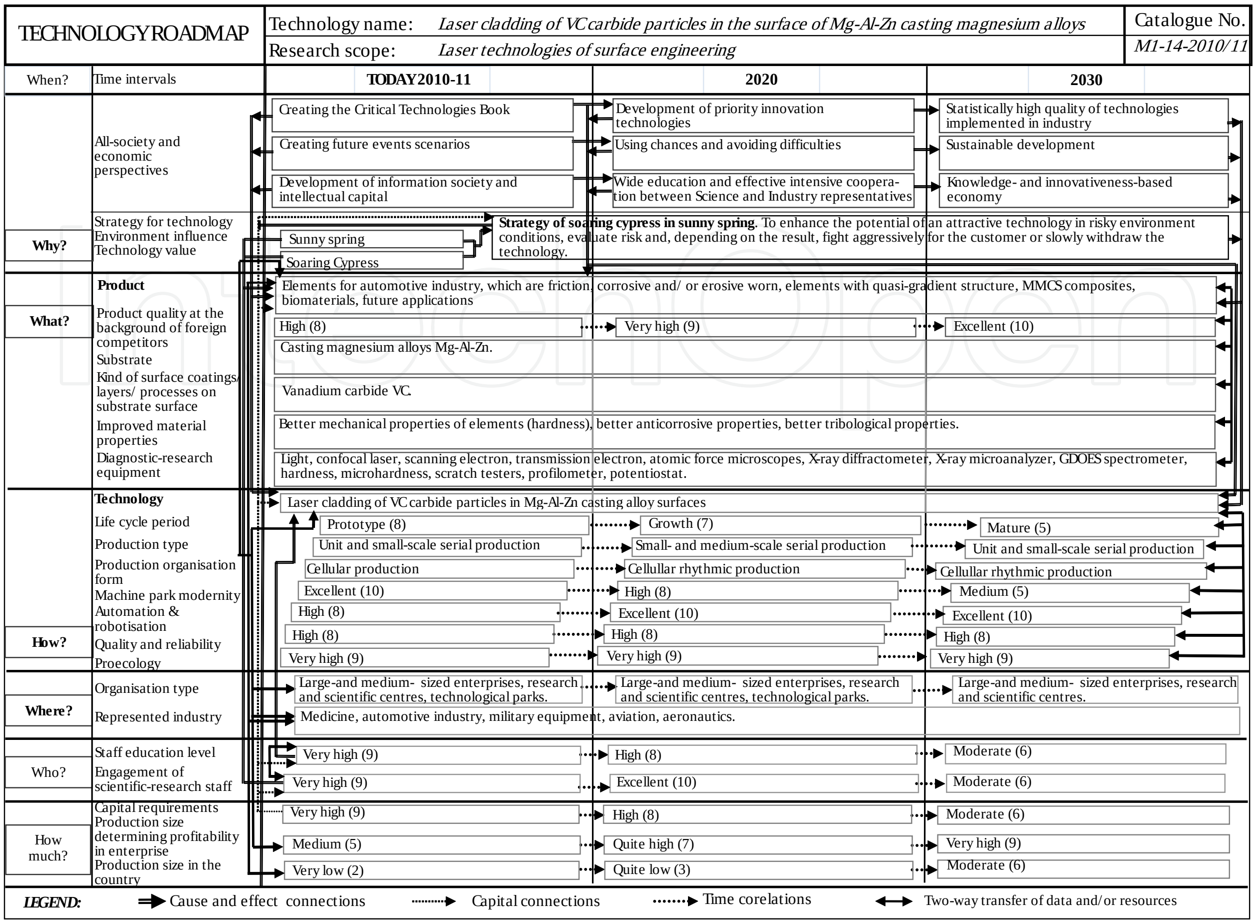


Figure 19. Demonstrating technology roadmap for laser cladding of TiC in the substrate of Mg-Al-Zn casting magnesium alloys

Technology symbol	Analysed factors																							
	(1)			(2)			(3)			(4)			(5)			(6)			(7)			(8)		
	Time horizon																							
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
(A)	8	7	3	10	8	5	8	9	10	10	9	9	10	8	6	10	8	5	5	7	8	3	5	8
(B)	8	7	5	10	8	5	7	8	8	8	8	8	9	5	5	9	9	4	6	7	8	2	5	7
(C)	8	7	5	10	8	5	8	8	8	9	9	9	9	8	6	9	8	6	5	7	9	2	4	6
(D)	8	7	5	8	8	5	6	8	9	8	9	9	9	5	5	9	7	5	6	7	8	3	6	9
(E)	8	7	3	8	8	6	8	8	9	7	7	9	9	5	5	7	7	7	5	7	8	2	5	7

LEGEND

Technology symbol	Analysed factors	Time horizon
(A) The laser treatment of TiC in the Mg-Al-Zn surface	(1) Live cycle period (2) Machine park modernity	

(B) The laser treatment of WC in the Mg-Al-Zn surface	(3) Quality and reliability (4) Proecology	a: 2010-11 years b: 2020 year c: 2030 year
(C) The laser treatment of VC in the Mg-Al-Zn surface	(5) Staff education level (6) Capital requirements	
(D) The laser treatment of SiC in the Mg-Al-Zn surface	(7) Production size determining profitability in enterprise	
(E) The laser treatment of Al_2O_3 in the Mg-Al-Zn surface	(8) Production size in the country	
Note: Research results are presented in universal scale of relative state, where:1 is minimal and 10 is excellent level.		

Table 4. Selected source data used for preparation of technology roadmaps for investigated laser treated casting magnesium alloys

7. Summary

This chapter of the book presents the results of interdisciplinary foresightsmaterials science research pertaining to five groups of specific technologies including the highcapacity diode laser treatment of casting magnesium alloys with, respectively: (A) titanium carbide TiC, (B) tungsten carbide WC, (C) vanadium carbide VC, (D) silicon carbide SiC and (E) aluminium oxide Al_2O_3. Materials science investigations were carried out in particular including light and scanning microscopy, X-ray phase qualitative analysis and surface distribution analysis of alloy elements. Investigations into mechanical properties were also held including hardness, microhardness and roughness as well as expert studies. The longterm development prospects of casting magnesium alloys subjected to laser treatment were identified using a custom methodology, along with the recommended action strategies and the forecast multi variant development tracks. The results of the foresight research [8] based on reference data [8] for the position of laser technologies were also presented, including remelting and laser alloying/cladding against materials surface engineering in general.

The results presented for the materials science research reveal a promising improvement in the mechanical properties of the material investigated. Laser cladding and remelting with all the carbide and oxide powders referred to above influences the refinement of structure within the entire investigated scope of laser power and also influences the varied grain size in the individual zones of the surface layer of the alloys investigated. Two zones occur in the surface layers: remelting zone (RZ) and heataffected zone (HAZ) with their characteristic values (layer thickness) depending on the laser power used and the alloying material used. The structure of the material solidifying after laser remelting is characterised by a varied morphology and consists of dispersive particles of the TiC, WC, VC, SiC carbide or Al_2O_3 oxide applied, of dendrites with the lamellar eutectic of $Mg_{17}Al_{12}$ and Mg in interdendritic areas, with their main axes being oriented towards the directions of heat evacuation and also of precipitates containing Mg and Si, as well as of phases with a high concentration of Mn and Al. In addition, a morphology of the composite structure of an alloyed area was obtained by changing a hypoeutectic to hypereutectic alloy, depending on the arrangement of the alloyed elements and by changing the surface laser treatment process parameters. In the Mg-Al-Zn casting magnesium alloys subjected to remelting and alloying with carbides and oxide, the maximum hardness of approx. 103 HRF was achieved for the MCMgAl12Zn1 alloy alloyed with titanium carbide at the laser power of 1.2 kW and at the alloying rate of 0.5 m per min., as a result of grain refinement and the occurrence of hard particles of the powders applied.

One should conclude while analysing the results obtained for the research that it is feasible to use the investigated Mg-Al-Zn alloys and their treatment technologies also in an alternative fashion for the surface layers ensuring possibly the most favourable “quasigradient” properties on the section of the products in the industrial practise. Widespreadpotential applications are identified especially for the aviation and automotive industry where the following properties are required: a small mass density of products, higher wear resistance, improved strength parameters of elements as well as repairing the ready elements. The best developmental and applicational prospects stemming from an analysis of mechanical properties of the casting magnesium alloys subjected to laser treatment are exhibited by those materials into which the particles of titanium carbide TiC (technology A) and vanadium carbides VC (technology C) were cladded. An analytical tool likely to facilitate the future implementation of the technologies analysed, in particular in small and mediumsized enterprises, are the roadmaps and technology information sheets, prepared at the last stage of the research works, containing concise knowledge and the results of the experimental and expert works were used for this purpose.

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