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Assessment of strategic development perspectives of laser treatment of casting magnesium alloys

A.D. Dobrzańska-Danikiewicz*, T. Tański, S. Malara, J. Domagała-Dubiel
Faculty of Mechanical Engineering, Silesian University of Technology,
ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: anna.dobrzanska-danikiewicz@polsl.pl

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ABSTRACT

Purpose: The purpose of this paper is to assess the strategic perspectives of laser treatment of casting magnesium alloys such as MCMgAl12Zn1 MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 using carbide TiC, WC, VC, SiC and Al_2O_3 oxide powders. The type of powder was taken as a criterion for the technology groups distinguishing in that way five groups of technologies for further research studies.

Design/methodology/approach: In the framework of foresight-materials science researches: the dendrological matrix of technology value, the meteorological matrix of environment influence and the matrix of strategies for technology with the strategic development tracks were made, such researches as: X-ray microanalysis, qualitative X-ray analysis, hardness tests and roughness measurements were carried out under the scanning electron microscope and the light microscopy, as well as technology roadmaps were prepared.

Findings: The outcarried researches pointed out very high potential and attractiveness of the given technologies in the background environment and the promising improvement of mechanical properties of examined materials.

Research limitations/implications: Described materials science and foresight research concerning the cladding and remelting of carbides and oxides in the surface of casting magnesium alloys are a part of a wider research project aiming to define, examine and characterise innovative technology of surface engineering of engineering materials.

Practical implications: The presented results of experimental materials science researches prove a significant positive effect of laser treatment with the use of carbides and oxides on the structure and properties of casting magnesium alloys that is why it is legitimate that they are included in the set of innovative technologies qualified for use in an industrial practice including small and medium enterprises.

Originality/value: The value of this paper is to determine the value of laser treatment technology of casting magnesium alloys in the background environment with recommended procedure strategies, the strategic development tracks and technology roadmaps including the influence of this treatment on the quality, microstructure and properties of surface layers obtained by cladding and remelting casting magnesium alloys.

Keywords: Manufacturing and processing; Laser surface treatment; Magnesium alloys; Foresight; Technology roadmapping

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RESEARCH MONOGRAPH

1. Introduction

One of the tasks under the policy guidelines for science, technology and innovation for decades to come is a knowledge-based economy, which thrives on creating treated as a production and distribution and the practical use of knowledge and information. The basis of economic development are, therefore, production, distribution and implementation and knowledge which is the product of a major contribution to sustainable development. Effects of innovation and thus the competitiveness of manufacturers of products in international markets are of course dependent on the adopted strategy of development of technology [1]. It is necessary to choose a strategy of integration of various advanced fields of science and technology and to achieve synergies in the development of new technologies. Materials processing technologies and new materials are a key range of research and development. which are essential for industry and other areas of application of these technologies. Generalization of the results of a European Foresight on various new materials and different technologies, materials processing [2, 3] is the expectation to produce materials with properties of the products with appropriately shaped structure and ordered by the users. Preparation of materials that meet needs of manufacturers of commercial products at the right time and place, called materials on demand, is a priority of new material technologies and manufacturing processes [4, 5]. Continuing desire of designers is the will to develop and produce the ideal material that would account for both the maximum possible resistance to wear in the operating conditions and high ductility. By their very nature such a combination of properties is impossible to obtain. To one of the most widely studied concept in the world of customization (called tailoring) properties of various elements to the operational requirements. as one of the possibilities if only partial implementation of this postulate, it must be the development of graded materials, including the gradient of appropriately shaped surface properties of the surface layers of engineering materials [4-38]. Gradient properties of these materials are achieved by changing the location of structure, phase composition, chemical composition or arrangement of atoms. As a result of the proper selection of the element material together with the processes determining its structure and properties and a kind and technology of the surface layer, ensuring the required utility properties, the best combination of properties of the core and the surface layer of a produced element is possible. The concept of the gradient structure and materials properties can also deal with the complement of losses in the long-term exploited elements of machines and equipment, and the formation of the structure and surface of re-produced constructional elements being fundamentals of re-manufacturing. Defining the leading technology and strategic research directions for methods of forming the structure and properties of engineering materials surface is a condition for the outworking of own development strategies for many small and medium-sized enterprises and the improvement of their competitiveness, as a result of the application and the development of advanced technologies of surface treatment, as an essential part of manufacturing technologies and determines more flexible adaptation of production to market needs. Surface treatment technologies of engineering materials are most often used in many sectors of industry, and the branch of surface treatment and surface coating is one of the most dynamically developing sectors of economy [3, 4]. In order to direct the development of the most advantageous technological solutions of forming structure and properties of the surface layers of products and their components made from engineering materials, from the viewpoint of improving the competitiveness of enterprises and for the development of their proinnovative activities, for the intensification of the transfer of knowledge to economy, and the improvement of utility properties, production durability and reliability, researches by foresight methods on the prospects for the development of these technologies in relation to different groups of engineering materials are necessary [5, 6, 39-48]. The scale of the own researches planned in this area has become the reason of outworking of the development of methodology and information technology, which would assign, improve and modernise the outcarried foresight researches. Thus the idea of e-foresight [40], with reference to known and commonly used terms [49-51]: e-management, e-business, e-commerce, e-banking, e-logistics, e-services, e-government, e-education always meaning certain activities with the use of computer networks, particularly the Internet was born. The main aim of those researches is to identify priority directions of innovative technologies and strategic research on methods of forming the structure and surface properties of engineering materials, whose development will be crucial over the next 20 years.

Among various processes of surface treatment and manufacturing of gradient materials, the specific role is played by methods of laser surface treatment, described in the literature in the relation to selected engineering materials [35-38, 52-71], and also developed in the own works in the Department of Materials Processing Technology, Management and Computer Science of the Institute of Engineering Materials and Biomaterials, the Silesian University of Technology [72-89]. Advantages which characterise laser surface treatment processes, namely: short process time, flexibility, and operational precision cause that this method takes advantages over other methods used in surface engineering. The main objective of laser remelting of materials surface layers is the formation of structures and related properties. With the creation of chemically homogeneous, fine crystalline surface layer without changing the chemical composition, the increase of resistance mainly wear one and thermal fatigue is achieved. Even better results in the increase of utility properties can be obtained by alloying material surface layer by hard phases of carbides, oxides or nitrides. Mentioned technologies are more often applied to magnesium alloys [90, 91], what among others is the subject of the own work [92-95]. During the last decade in the world the rapid increase of the use of magnesium and its alloys almost in every field of contemporary industry is observed [90-106]. This is due to numerous properties of magnesium, which allow for its use both as a structural element and an addition to other metal alloys. It is 35% lighter than aluminium (2.7 g/cm^3) and more than four times lighter than steel (7.86 g/cm^3). Magnesium alloys in spite of low density (1.7 g/cm^3) also have other advantages such as good ductility, better than in aluminium, noise and vibration damping, very good castability, big dimensional and shape stability, low shrinkage, low density combined with high strength compared to lighter weight. They can also be recycled, which makes recycled alloys having high quality and properties which are very similar to those of original casting alloy and allow to use these materials, instead of newly manufactured magnesium alloys for the construction of minor importance [29, 80, 95-106]. Lower weight and high strength enable to produce components made of this material by casting, plastic deformation, mechanical working or welding. Magnesium alloys including aluminium, manganese, rare earth metals, thorium, zinc and zirconium present the increased strength ratio on weight, making them important materials in applications where weight is important and necessary to reduce the forces of inertia [98]. The need of the application of magnesium alloys is associated mainly with the development of the automotive and aerospace industries.

Advantageous properties of magnesium and its alloys with the advantages of laser surface treatment were the basis of making a series of interdisciplinary foresight and materials science researches to determine the value, attractiveness and potential of laser treatment technology of casting magnesium alloys at the background of micro- and macroenvironemnt together with the outworking of the recommended strategy, strategic development tracks and roadmaps of analyzed technologies, taking into consideration the impact of laser treatment on quality, structure and properties of the surface layers of casting magnesium alloys.

This paper is a practical application of foresight and materials science research methodology [40, 41] to laser surface treatment of Mg-Al-Zn selected alloys basing on the evaluation by a small group of key experts with the intention of repeating this described foresight research with the participation of a wide group of trade experts and on the basis of these evaluations worked out by them in the framework of questionnaire surveys. Casting magnesium alloys: MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 undertook the experimental researches such as laser cladding and remelting with TiC, WC, VC, SiC carbide and Al_2O_3 oxide powders.

Such researches as: X-ray microanalysis, qualitative X-ray analysis, hardness tests and roughness measurements were made under the scanning electron microscope and the light microscope. Materials science and foresight researches are a part of a wider actions aiming to isolate, examine, characterize and define strategic developmental perspectives of priorities and innovative technologies of surface engineering of engineering materials, qualified for the application in industrial practice, including small and medium-sized enterprises.

The consideration of this issue at a higher level of generality leads to generate a set of priority innovative technologies of surface engineering, contributing to the statistical increase in the quality of applied technology in industrial enterprises, stimulating sustainable development and strengthening the knowledge-based economy.

2. Implemented research methodology

The outcarried researches are interdisciplinary and applied methodology of researches deals mainly with technological foresight being an element of the field of knowledge called organisation and management, and surface engineering being a part of the broader understood materials science. At certain stages of researches also methods deriving from artificial intelligence, statistics, information technology, machine building and operation, strategic and operational management were used.

According to the taken methodology performed researches include in turn [41]: selecting groups of technology for experimental and comparative researches, collecting experts' opinions, carrying out multi-criteria analysis and putting its results to a dendrological and meteorological matrix, determining strategy for technology preceded by graduating and making objective results of researches with the use of the formulated mathematical relationships, identifying strategic development tracks and performing a series of specialized materials science researches using professional diagnostic and measurement equipment and making roadmaps of technology. According to the taken methodology of foresight and materials science researches first of all among analysed technologies it is necessary to extract a few as far as possible homogeneous groups, in order to undergo the scheduled researches having experimental and comparative character.

To determine the objective values of given selected technologies or their groups (as in the case of researches described in this paper) a dendrological matrix of value technology is used, and to determine the strength of positive and negative influence of the environment on a given technology a meteorological matrix of environment influence is used. The methodological construction of those both matrices refers to portfolio methods, commonly known in sciences about management, and first of all to BCG matrix [107] owing its incredible popularity because of its simple associations and intuitive reasoning, which serves as an inspiration when creating the methodological assumptions of meteorological and dendrological matrices [41]. To evaluate various groups of technology paying a special attention to their value and influence of the environment a 10-point universal scale of relative states, where 1 is the minimum level 2 – very low, 3 – low, 4 – quite low, 5 – intermediate, 6 – moderate, 7 – quite high, 8 – high, 9 – very high, and the highest value of 10 is the level of excellence was adopted.

A dendrological matrix of technology value presents graphically the results of the evaluation of given groups of technology taking into consideration their potential which is a real objective value and attractiveness of technology that illustrates how technology is subjectively perceived among its potential users. The potential of a given group of technology applied to the horizontal scale and attractiveness of technology applied to the vertical scale of a dendrological matrix is a result of multi-criteria analysis using the results of the experts' evaluation. Depending on the value of the potential and the level of attractiveness of which were identified in the framework of the experts' evaluation given technology can be placed in one of the following quarter of the matrix:

- A sparing aspen which is technology with a limited potential and limited attractiveness in the range, which a future success is unlikely;
- A quaking cypress which corresponds with technologies with a limited potential, but highly attractive, what causes that a success of technology is possible;
- A rooted dwarf mountain pine which is technology with limited attractiveness, but a high potential, so that its future success is possible;
- A wide-stretching oak which corresponds to the best possible situation in which the analysed technology has both a great potential and great attractiveness, which is a guarantee of a future success.

A meteorological matrix of environment influence presents graphically the results of the influence evaluation of external factors on different groups of technologies, which were divided into difficulties and opportunities that influence negatively and positively the analysed technologies. Experts' questionnaire poll on external factors affecting technology took place on the basis of a questionnaire consisting of dozens of questions about micro-and macro environment in strictly defined proportions. Difficulties arising from the environment were put on the horizontal scale of a meteorological matrix, and on the vertical scale of this matrix opportunities that is positive environmental influence factors were put. Depending on the level of the influence of positive and negative factors of the environment on the analysed technology, defined in the framework of the experts' evaluation in a 10-point scale the level of technology is placed in one of the following quarter of the matrix:

- Freezing winter corresponding to the worst possible situation in which the environment brings a large number of problems and few opportunities, which means that success in a given environment is difficult or impossible to achieve;
- Hot summer corresponding to a situation in which the environment brings a lot of opportunities, which, however, are accompanied by many difficulties, meaning that the success of technology in the given circumstances is possible, but is a subject to the risk;
- Rainy autumn corresponding to the neutral position, in which for given technology traps do not wait, but also the environment does not give too many opportunities;
- Sunny spring being the best option denoting friendly environment with lots of opportunities and a little number of difficulties, which means that the success of given technology is guaranteed.

At the next stage of researches their results presented in a graphical form using a dendrological matrix of technology value and a meteorological matrix of environment influence were put on a **matrix of strategy for technology** consisting of sixteen boxes corresponding to each set of versions resulting from the combination of the types of technology and the types of environments. A matrix of strategy for technology presents graphically the place of technology taking into consideration its value and environment influence and indicate the conduct strategy which should be taken with respect to a given technology, taking into account the previously analyzed factors. To allow for transferring specific numerical values of dendrological and meteorological matrices measuring [2x2] to a matrix of strategy for technology measuring [4x4] the terms: the relative value of technology V_n and the relative value of environment influence E_n. and mathematical dependence allowing to graduate and make objective research results were introduced [41].

The next stage of researches comes down to **the strategic development tracks** for different technologies / groups of technologies, which forecast their development successively in: 2015, 2020, 2025 and 2030 in three versions: optimistic, pessimistic and most likely ones, followed by their visualization against a background of a matrix of strategy for technology.

In order to precise the value of the potential and attractiveness of laser treatment of casting magnesium alloys **a series of metallographic researches** using specialized diagnostic and measurement equipment were carried out. The investigations were carried out on test pieces of MCMgAl12Zn1, MCMgAl9Zn, MCMgAl6Zn1, MCMgAl3Zn magnesium alloys in as-cast and after heat treatment state. The chemical compositions of the investigated materials are given in Table 1. A casting cycle of alloys was carried out in an induction crucible furnace using a protective salt bath Flux 12 equipped with two ceramic filters at the remelting temperature of 750±10ºC, suitable for the manufactured material. In order to maintain metallurgical purity of the remelting metal, a refining with a neutral gas with the industrial name of Emgesalem Flux 12 was carried out. To improve the quality of a metal surface a protective layer Alkon M62 was applied. The material was cast in dies with betonite binder because of its excellent sorption properties and shaped into plates of 250x150x25. The casting alloys were heated in an electrical vacuum furnace Classic 0816 Vak in a protective argon atmosphere. The heat treatment involved the solution heat treatment (warming material in temperature 375°C the 3 hours, warmed in the temperature to 430°C, held for 10 hours) and cooled in air and then aged at temperature of 190°C, holding for 15 hours and cooling in air (Table 2). Next, MCMgAl12Zn1, MCMgAl9Zn, MCMgAl6Zn1 MCMgAl3Zn1 magnesium alloys were used as substrate materials to laser surface treatment using a high power diode laser. Plates were polished with 1200-grit SiC paper prior to laser surface treatment to obtain smooth surface and then cleaned with alcohol and dried. Five types of powders were used in a present study for alloying process, namely titanium, tungsten, vanadium and silicon carbides as well as aluminum oxide (Table 3). Laser treatment was made using the Rofin DL020 HPDL high power diode laser in the argon shield gas cover to protect the molten metal pool from oxidation with the technique of the continuous powder supply to the remelted pool area, by feeding the granulate using the TecFlo fluidisation feeder equipped with the powder flow digital controller (Fig. 1a). Powder feeder was connected with the transport gas cylinder and powder feed nozzle (Fig. 1b). A gas feed rate was 5 l/min.

Table 1.
Chemical composition of examined alloy

	The mass concentration of main elements, %						
Material type	Al	Zn	Mn	Si	Fe	Mg	Rest
MCMgAl12Zn1	12.1	0.62	0.17	0.047	0.013	86.96	0.0985
MCMgAl9Zn	9.09	0.77	0.21	0.037	0.011	89.79	0.0915
MCMgAl6Zn1	5.92	0.49	0.15	0.037	0.007	93.33	0.0613
MCMgAl3Zn	2.96	0.23	0.09	0.029	0.006	96.65	0.0361

Table 2.
Parameters of heat treatment of examined alloy

Sing the state of heat treatment	Conditions of solution heat treatment		
	Temperature, °C	Time of heating, h	Way coolings
0	As-cast		
	Solution treatment		
1	430	10	Water
	Aging treatment		
2	190	15	Air

Table 3.
Properties of powders used to alloying process

Property	WC	TiC	VC	SiC	Al_2O_3
Density, kg/m^3	15.69	4.25	5.36	3.44	3.97
Hardness, HV	3400	1550	2850	1600	2300
Remelting temperature, ^oC	2870	3140	2830	1900	2047
Average of size grain, µm	0.7-0.9	<1.0		<10	1-5
	>5	>6.4	>1.8	<75	80

a) b)

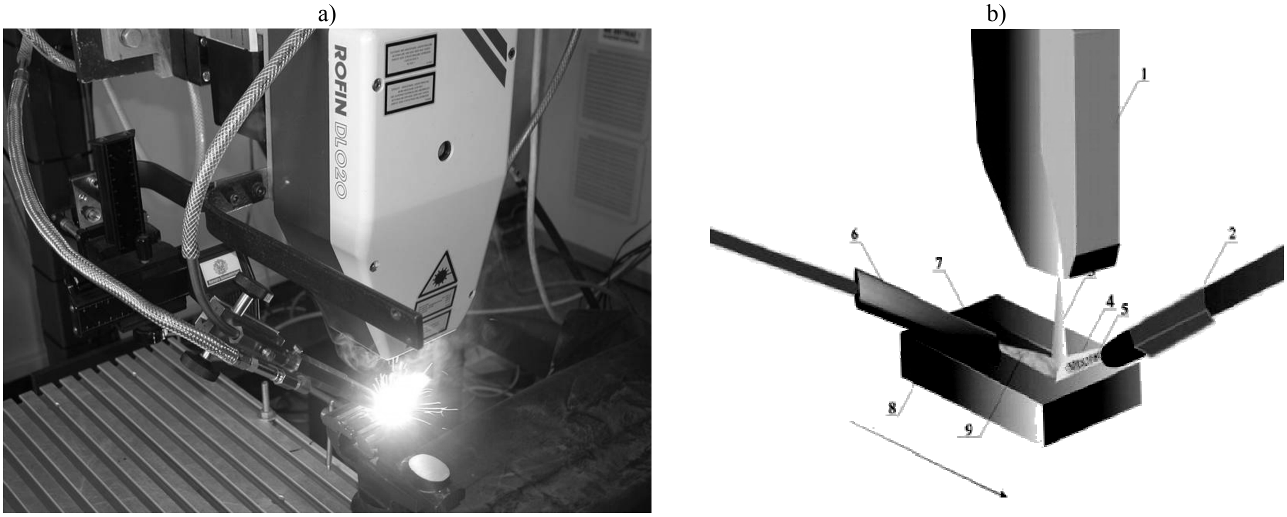

Fig. 1. a) Laser HPDL Rofin DL 020 in working process, b) Laser treatment scheme for casting magnesium alloys: 1 - laser head, 2 - transport gas cylinder and powder feed nozzle, 3 - beam laser, 4 - gas, 5 - powder, 6 - powder feed nozzle, 7 - remelting zone, 8 - base material, 9 - protective gas

Table 4.
HPDL Rofin DL 020 parameters

Laser wave length, nm	808-940
Focus length of the laser beam, mm	82
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	1.8 x 6.8

The laser treatment of casting magnesium alloys was conducted by remelting Mg-Al-Zn substrate and feeding of carbides or oxides particles performed by a high power laser diode HPDL Rofin DL 020 under argon shielding gas. The parameters are presented in Table 4. Argon was used during laser remelting to prevent oxidation of the coating and the substrate. Prior to approach laser treatment, powders were desiccated in the furnace in temperature of 100°C. Experiments were made with the following process parameters: laser power 1.2-2.0 kW; alloying feed rate 0.5-1.0 m/min; powder feed rate: 6-9 g/min. After initial experiments laser power in the range 1.2-2.0 kW was assumed for the investigations, with alloying feed rates of 0.25; 0.50; 0.75; 1.00 m/min. The examinations revealed that the optimum geometry of a single laser path was obtained for alloying with the feed rate of 0.75 m/min. However, for laser treatment with powder injection of Al_2O_3 powder the optimum feed rate was 0.50 m/min and 0.25 m/min, respectively. This distinction probably is the result of different laser radiation absorption for each powder and each magnesium alloy. The optimization of process parameters was made for the sake of mixture quality, distribution uniformity of alloying particles in the remelting zone and substrate geometry after laser treatment.

The metallographic examinations were made on casting magnesium alloys specimens mounted in thermohardenable resins. The observations of the investigated casting materials were made on the light microscope LEICA MEF4A as well as on the electron scanning microscope ZEISS Supra 35. Phase composition and crystallographic structure were determined by the X-ray diffraction method using the X'Pert device with a cobalt lamp, with 40 kV voltage. The measurement was performed in angle range of 2Θ: 20-130º. Hardness tests were made using Zwick ZHR 4150 TK hardness tester in the HRF scale. Roughness measurements of surface layers of laser cladded casting alloys were performed on Taylor Hobson Precision Surtronic 3+. Measuring device is characterized by measuring resolution 0.2 µm and measuring range to 150 µm. Measurements were made on distance 0.8 mm. The X-ray qualitative micro-analysis and the analysis of a surface distribution of casting elements in the examined casting magnesium alloys specimens were made on transverse micro-sections on the ZEISS Supra 35 scanning microscope with the Oxford EDS WDS dispersive radiation spectrometer at the accelerating voltage of 15 kV.

In order to verify the correctness of the experimental values of hardness after laser cladding of Mg-Al-Zn, casting magnesium alloys model used 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, were 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) (Fig. 2) were selected.

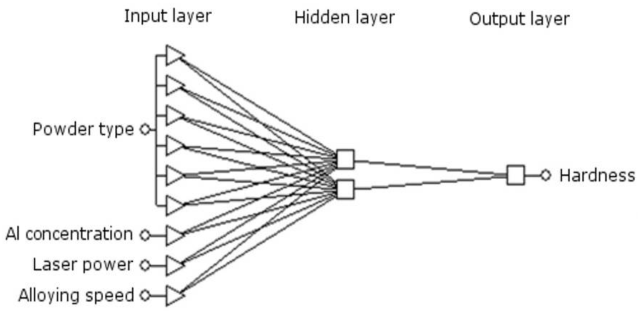

Fig. 2. Scheme of MLP neural network calculates hardness

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 back propagation of errors (50 epochs learners) and conjugate gradients (62 students ages). Table 5 presents the error values, the quotient of standard deviation and correlation coefficients of designed neural networks, which were the basis for evaluating the characteristics of the network. Figure 3 shows a chart comparing the HRF hardness values provided by the network and the experimentally measured and of the trend line for a set of test was determined. 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 inferred about the accuracy in predicting the value of the output network (HRF hardness).

Results of made experimental and comparative researches are source data to create **technology roadmaps**. The arrangement of a technology roadmap worked out for realised researches corresponds to the first quarter of the Cartesian coordinate system. On the horizontal axis there are the forward-looking time intervals, and a time horizon of the whole researches put on the roadmap

Table 5.
Regression statistics of neural network calculating hardness value in data sets

Indicators of quality assessment models	Data set		
	Training	Validating	Testing
Error, HRF	5.35	6.49	5.90
Standard deviation	0.43	0.44	0.46
Pearson's correlation coefficient	0.90	0.90	0.89

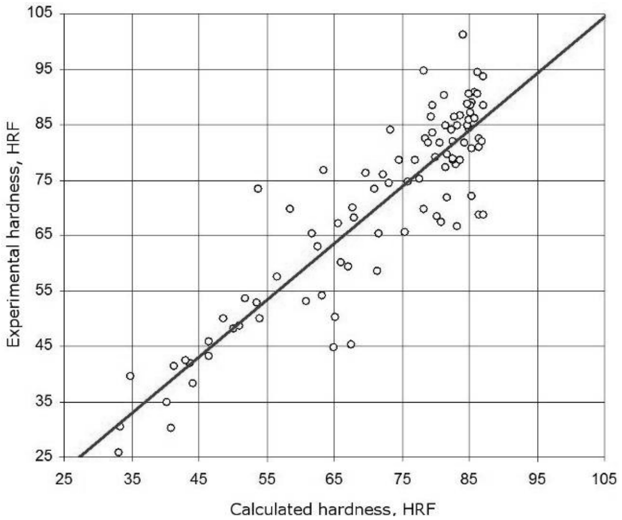

Fig. 3. Real hardness value and calculating value comparison for all test data sets

equals 20. On the vertical axis of a technology roadmap seven main layers, concerning the defined ranges sequentially relating to the questions: When? Why? What? How? Where? Who? How much? are placed. Major layers of a technology roadmap are organized hierarchically starting from the top, most general ones determining causes and reasons for realised actions, through the middle ones characterising a product and ending with technology at lower layers precising organizational and technical details. The middle layers of a technology roadmap are a subject to two types of influence – suction from the upper layers and pushing from the bottom layers. On the roadmap using different arrows the links between its various layers and sublayers, with the division into: cause and effect connections, capital connections, time correlation and two-time correlation of data flows and / or resources are presented. Technology roadmaps are a very convenient tool for comparative analysis, making easier to select the best technology in the respect of selected criteria, and complemented with technological cards containing details of technological specifications allowing for the implementation of technology in industrial practice. An important feature of technology roadmaps is their flexibility, so that if necessary they can complement and extend for additional sublayers adjusting them to user's expectations.

3. Research results of technology values and their development tracks

The results of researches described in this paper include, firstly, the evaluation of the potential and attractiveness of analyzed technologies against the background of micro- and macroenvironment carried out on the basis of opinions of key experts expressed in a 10-point universal scale of relative states and the recommended strategy for dealing with a particular technology, together with strategic development tracks resulting from that evaluation. Then the results of materials science experiments examining the effects of laser cladding and remelting with the use of carbide and oxide powders on structure and properties of surface layers of casting magnesium alloys were presented. Supplementing these researches is the experimental verification of the developed technology carried out to determine quality of manufactured surface layers, made using high power diode lasers on a finished item. It includes the following metallographic researches: light and scanning microscopy, X-ray phase analysis and qualitative analysis, analysis of surface distribution of alloyed elements and examination of mechanical properties, including hardness, microhardness and roughness. On the basis of experimental and comparative research results technology roadmaps, showing a clear uniform format of various kinds of internal and external factors directly and indirectly characterising given technologies taking into consideration ways of interactions, interconnections, and changes of individual factors in time, were created.

Taking as a criterion of the division, a type of powder deposited to the substrate, in order to carry out comparative and experimental works, five homogeneous groups were isolated from the analysed technologies in turn:

(A) Mg-Al-Zn casting magnesium alloys which underwent laser treatment by TiC titanium carbide;
(B) Mg-Al-Zn casting magnesium alloys which underwent laser treatment by WC tungsten carbide;
(C) Mg-Al-Zn casting magnesium alloys which underwent laser treatment by VC vanadium carbide;
(D) Mg-Al-Zn casting magnesium alloys which underwent laser treatment by SiC silicon carbide;
(E) Mg-Al-Zn casting magnesium alloys which underwent laser treatment by Al_2O_3 aluminium oxide.

Each group of technology was evaluated by experts using the 10-point universal scale of relative states paying attention to economic, humanistic, natural, systematic attractiveness and creative, application, quality, developmental, technical potential. Using the multi-criteria analysis a weighted average of the considered criteria (attractiveness and potential) was calculated, and the result obtained for given groups of technology was put on a dendrological matrix of technology value (Fig. 4). The conducted analysis showed that all groups were classified to the most promising quarter called the wide-stretching oak, covering technologies with both great potential and attractiveness. The best result A (9.65, 9.75) was reached by casting magnesium alloys laser treated by titanium carbide, and the worst one used for laser treatment were silicon carbides D (7.55, 8.45).

The evaluation of positive and negative environmental influences of technology on various groups was performed using the meteorological matrix of environment influence. Results of multi-criteria analysis acquired in the questionnaire process of experts evaluation was applied to this matrix, as shown in Fig. 5. The questionnaire used to researches includes a few dozen or so questions about the influence of micro- and macroenvironment on technologies in specific proportions. Results of those researches show that in all groups of technology which were examined environment is extremely favourable, brings a lot of opportunities, and little difficulty. Hence, all evaluated groups of technology were in the quarter of the sunny spring, very well predicting their development. Again the highest grade was achieved by rating a group of technology identified as A (4.04, 7.36), and the lowest group of technologies was marked as E (3.77, 6.02).

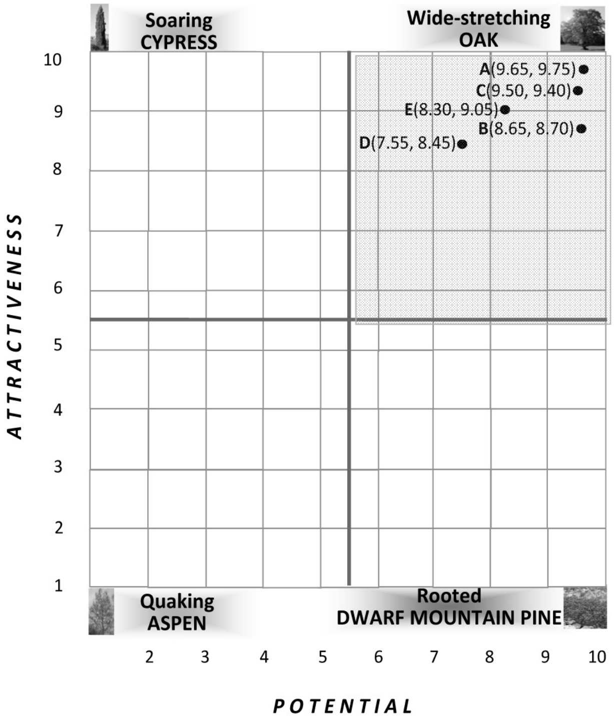

Fig. 4. The dendrological matrix of technology value for the laser cladding and remelting of casting magnesium alloys using TiC (A), WC (B), VC (C), SiC (D) carbide and Al_2O_3 oxide (E) powders

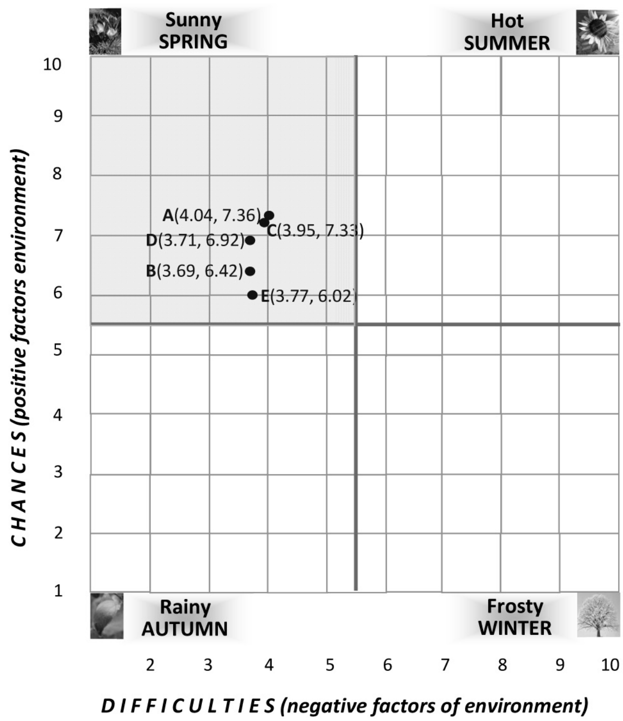

Fig. 5. The meteorological matrix of environment influence for the laser cladding and remelting of casting magnesium alloys using TiC (A), WC (B), VC (C), SiC (D) carbide and Al_2O_3 oxide (E) powders

Results presented in a graphical form using a dendrological matrix of technology value and a meteorological matrix of environment influence were put on a matrix of strategy for technology in the next stage of research work (Fig. 6). This matrix is a graphical representation of individual groups of technology of casting magnesium alloys laser treatment, with carbides and aluminum oxide taking into consideration their values and the environment influence indicating the appropriate strategy for conduct. In order to transfer specific numerical values from a dendrological matrix and a meteorological matrix to a matrix of strategy for technology having other size, mathematical dependence allowing to graduate and make objective research results were used [41]. For all analysed very promising groups of technology, it is recommended to use the strategy of an oak in the spring, relying on developing, strengthening and implementing attractive technology with a great potential in industrial practice with reference to a spectacular success.

The next stage of researches comes down to determine the strategic development tracks for specific technology / groups of technologies on the basis of experts' opinions which forecast their development successively in: 2015, 2020, 2025 and 2030 in three variants: optimistic, pessimistic and most likely ones, followed by their visualization at the background of the matrix of strategies for technology. A representative example of a graphical matrix of strategies for technology with the marked strategic development tracks in three versions made for laser treatment of casting magnesium alloys by TiC titanium carbides is presented on Fig. 7.

The most probable strategic development track of this group of technology assumes a change of environment from friendly spring into risky summer maintaining a high potential and attractiveness characteristic for a wide-stretching oak. In the next years the environment will become more stable passing into the phase of autumn. In this case the success of attractive and stable technology on the predictable market while seeking for new markets, new groups of potential customers and new products possible for manufacturing by given technology is foreseen. An optimistic strategic development track for laser treatment of casting magnesium alloys by TiC titanium carbides assumes that despite of the transitional appearance (2015-2020) of numerous difficulties in the environment, opportunities which appear parallelly will be used and in the coming years they will determine the development of this group of technology providing its return to friendly area of sunny spring, which combined with continuing high attractiveness and potential of technology will ensure a spectacular success. A pessimistic version expressed by a third pointed strategic development track of a group of technology assumes that the crisis in the world will become stronger due to an unfavourably growing political and economic situation, what will cause the appearance of an increasing number of problems in the environment (2015), and fewer opportunities

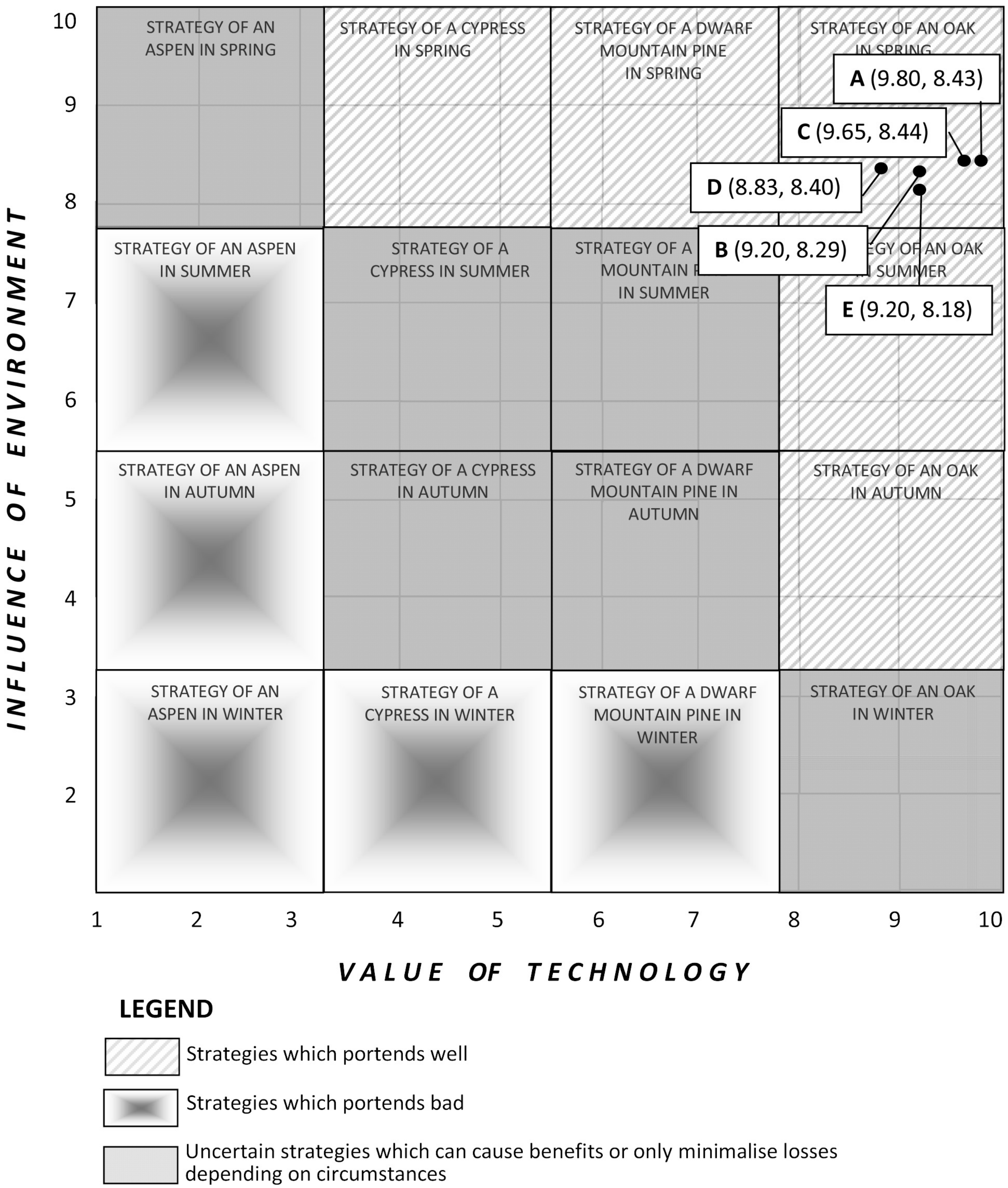

Fig. 6. The matrix of strategies for technology called the laser cladding and remelting of casting magnesium alloys using TiC (A), WC (B), VC (C), SiC (D) carbide and Al_2O_3 oxide (E) powders

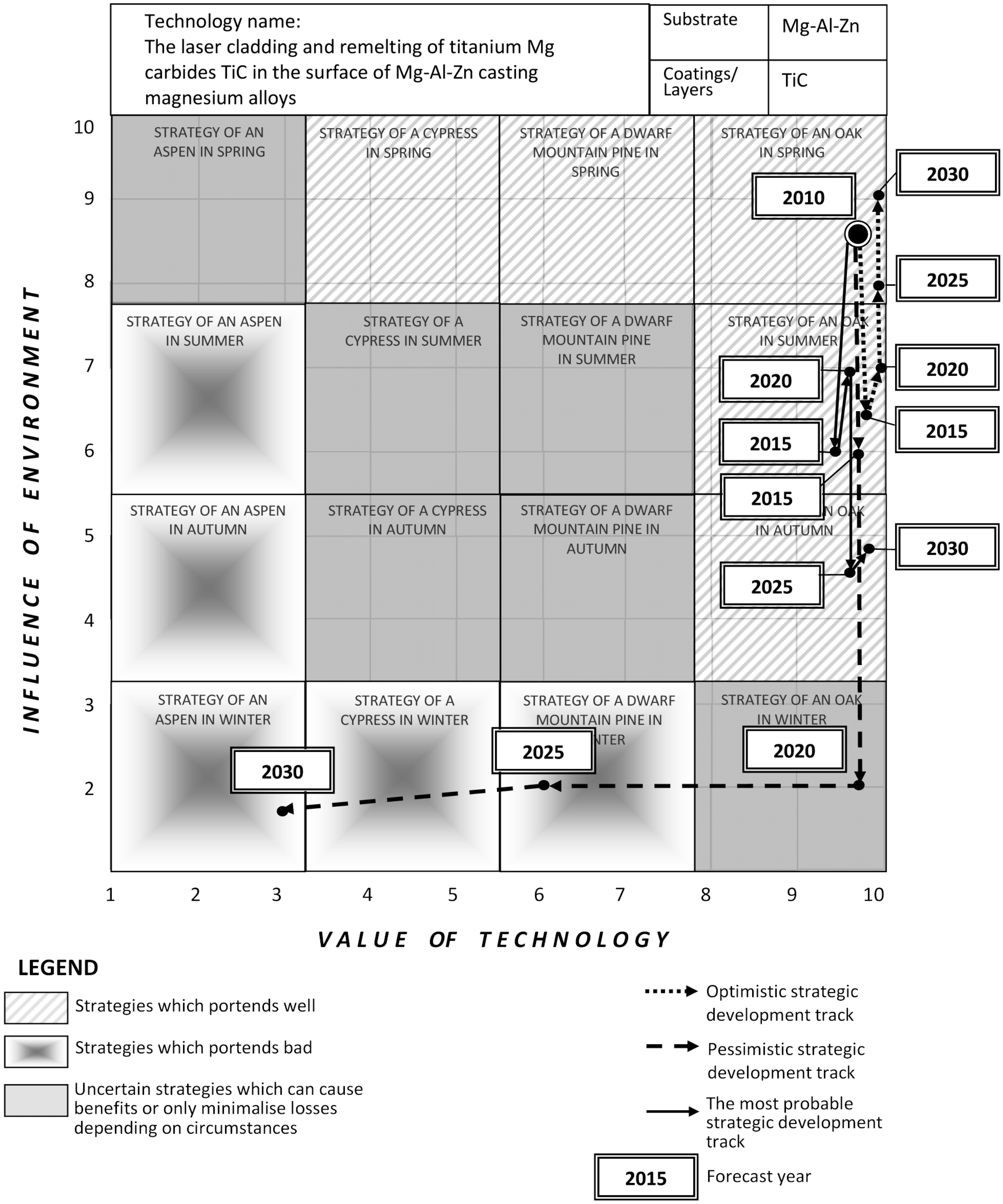

Fig. 7. The strategic development tracks for demonstration technology called the laser cladding and remelting of casting magnesium alloys using TiC (A) carbide powders

Table 6.
Strategic development tracks of laser treatment of Mg-Al-Zn casting magnesium alloys using carbide and oxide powders. Types of strategic development tracks: (O) - optimistic, (P) - pessimistic; (MP) - the most probable

No.	Technology name	Steady state 2010	Type of strategic development tracks	Years			
				2015	2020	2025	2030
1.	The laser cladding / remelting of TiC titanium carbides in the surface of Mg-Al-Zn casting magnesium alloys	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)
2.	The laser cladding / remelting of WC tungsten carbides in the surface of Mg-Al-Zn casting magnesium alloys	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)
3.	The laser cladding / remelting of VC vanadium carbides in the surface of Mg-Al-Zn casting magnesium alloys	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)
4.	The laser cladding / remelting of SiC silicon carbides in the surface of Mg-Al-Zn casting magnesium alloys	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)
5.	The laser cladding / remelting of Al_2O_3 aluminum oxide in the surface of Mg-Al-Zn casting magnesium alloys	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)

what will cause the necessity to function in unfavourable conditions of cold winter in 2020. The economic situation will be unfriendly, resulting in the decrease of interest of the potential users in the analyzed group of technology. Using a huge potential being an objective high value of technologies in 2025 the analyzed group of technology being a rooted dwarf will overcome difficulties and become weaker systematically, so that in 2030, it will move to the area of a trembling aspen in the winter, for which it is recommended to disappear from the market. The numerical values resulting from all researches carried out for five analyzed groups of technology are presented in Table 6. Due to the relatively small differences between the analyzed groups of technology at the macro scale, the path marked out for them adopt a similar direction of strategic development, showing minor discrepancies.

4. Research results of the impact of technological conditions on properties of examined alloys

The outcarried experimental works bowling down to the laser cladding of carbide and oxide powders in the surface of MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 casting magnesium alloys the influence of parameters process like power laser and using powders on shape and surface topography were shown. A view of the casting magnesium alloys face of weld after laser treatment with carbides and aluminium oxide were shown on Figures 8-11. The front view after laser treatment with TiC and WC powders was regular and flat surface (Figs. 8, 9). In case, when VC was used, the front view was characterized by flat surface, however the surface layer was discontinuity (Fig. 10). The magnesium alloys after laser treatment with SiC particles were characterized by convexity of remelting zone over base surface. Surface layer of casting magnesium alloys after laser treatment with Al_2O_3 was characterized by small hollow in central area of bead face for laser power 2.0 kW (Fig. 11). Investigations reveal, that laser power increase by constant beam scanning rate had an influence on the size of the area, where occured structural changes of the surface layer of the Mg-Al-Zn alloys.

On the basis of roughness measurements of the surface of casting magnesium alloys after laser treatment with the titanium, tungsten, vanadium, silicon and aluminium oxide (Fig. 11) it was stated that apart from the applied ceramic powder, the roughness of the surface layers abstained by laser remelting of the Mg-Al-Zn alloys with a power in the range of 1.2-2.0 kW increases and reach a value in the range of R_a = 6.4-42.5 µm.

For each type of substrate (independent of the aluminium content) the highest roughness had the samples after laser treatment by a scanning rate of 0.5 m/min with laser power of 2.0 kW. By a stable scanning rate and a not changed powder feeding, together with an increase of the laser power the surface roughness decreased. Among the investigated Mg-Al-Zn casting magnesium alloys the lowest roughness respectively 4.0 and 5.6 µm have the MCMgAl9Zn1 and MCMgAl12Zn1 materials after treatment with VC powder, by applied laser power of 2.0 kW (Fig. 12).

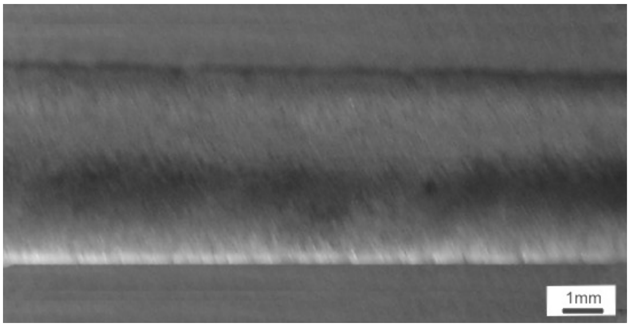

Fig. 8. View of the MCMgAl12Zn1 casting magnesium alloy face of weld after laser treatment with TiC, scan rate: 0.75 m/min, laser power: 1.2 kW

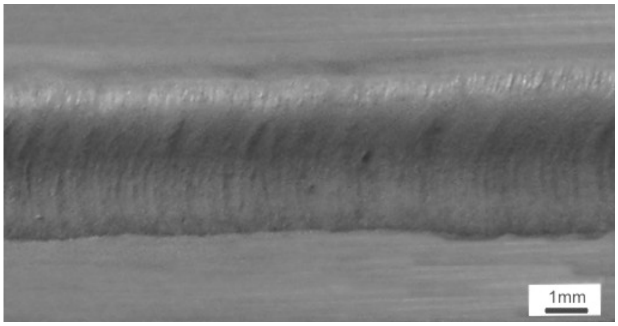

Fig. 9. View of the MCMgAl3Zn1 casting magnesium alloy face of weld after laser treatment with WC, scan rate: 0.75 m/min, laser power: 1.2 kW

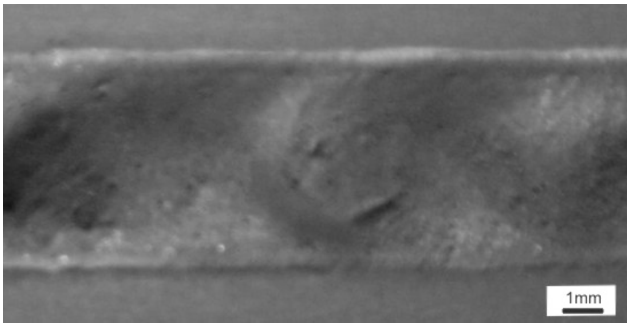

Fig. 10. View of the MCMgAl12Zn1 casting magnesium alloy face of weld after laser treatment with VC, scan rate: 0.75 m/min, laser power: 2.0 kW

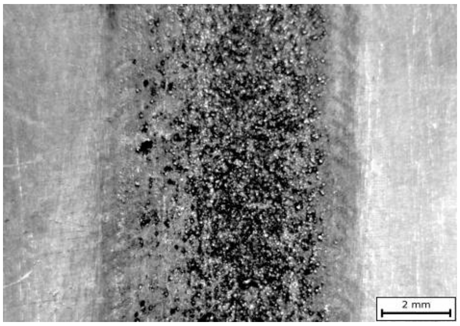

Fig. 11. View of the MCMgAl12Zn1 casting magnesium alloy face of weld after laser treatment with Al_2O_3, scan rate: 0.5 m/min, laser power: 2.0 kW

Maximal measured surface roughness of R_a = 42.5 µm occurs in case of the surface layer of the MCMgAl9Zn1 alloy after laser treatment with SiC powder with laser power of 1.2 kW (Fig. 12). The investigated material after treatment with titanium carbide powder are characterised by roughness in the range of 6.4-13.9 µm (Fig. 12). In case of vanadium carbide powder it was found out that the highest roughness value, by a stable scanning rate of 0.75 m/min, for each type of alloy, had the samples after treatment with 1.2 kW laser power, whereas the highest roughness value had the MCMgAl3Zn1 alloy by applied laser power of 1.2 kW (25.43 µm) (Fig. 12). An increase of the irregularity of the surface after laser treatment was related to the fluctuation of the alloyed material caused by changes of the remelting material tensions as well the laser beam energy absorbed by the alloyed material.

In Figures 13 and 14 the zone placement on the cross section of the remelting laser face of the Mg-Al-Zn casting magnesium alloys is presented. On the basis of the performed metallographic investigations it was found out that in each of the surface layer after surface laser treatment of the MCMgAl12Zn1 and MCMgAl9Zn1 casting magnesium alloys a remelting zone (RZ) as well a heat affected zone (HAZ) occured. These zones, depending on the laser power as well the ceramic powder used had different thickness and shape. In case of the TiC, WC and VC powder for the MCMgAl6Zn1 alloy a very small HAZ, which increased together with the applied laser power was found. In case of alloying of the powder into the MCMgAl3Zn1 substrate only the remelting zone as well the boundary between the remelting zone and the material substrate were present. On the basis of the performed researches it was possible to state that the change of the laser power by a constant alloying rate clearly influences the thickness of both zones in the surface layer. The applied laser power influenced also the shape and the convexity of the remelting zone (Figs. 13, 14), which reached over the surface of the untreated material.

Detailed results of measuring the thickness of the melted zone and heat affected zone on the pictures taken with light microscopy and confirmed by tests in a scanning electron microscope are shown in Figure 15. On the basis of tests, it was found out that the thickness of the analyzed coatings, assessed by computer image analysis, was located in a wide range of measurement and was a function of four variables, namely: laser beam power, alloying speed, type of alloying material and the substrate. Proportional influence of laser power to the thickness of each zone-melted

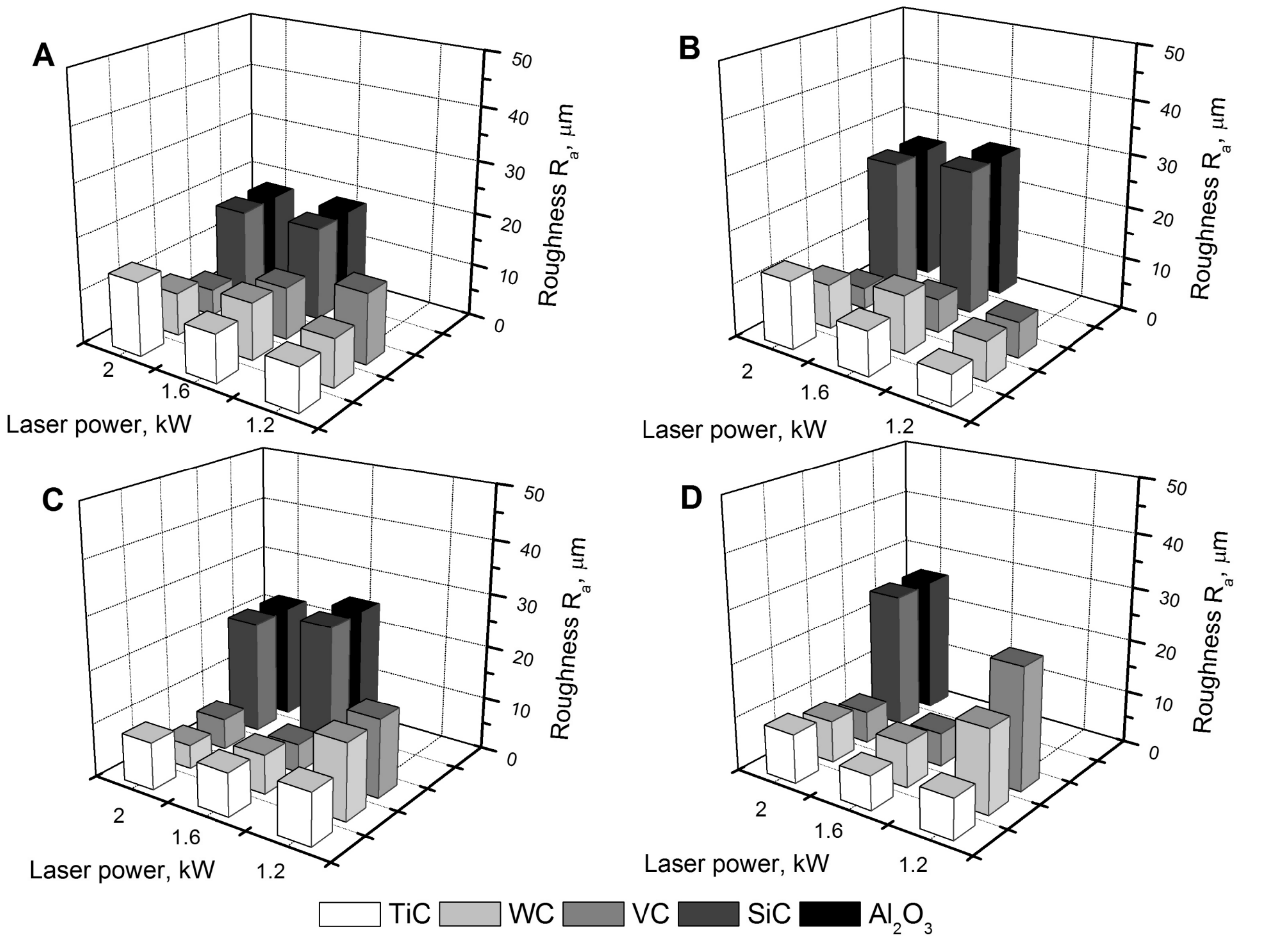

Fig. 12. Laser power and Al mass concentration influence on roughness of alloyed surface layer: A – MCMgAl3Zn1; B – MCMgAl6Zn1; C – MCMgAl9Zn1; D – MCMgAl12Zn1

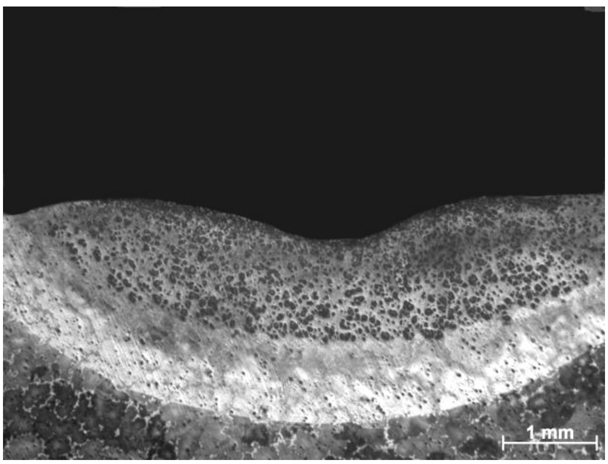

Fig. 13. Surface layer of MCMgAl12Zn1 alloy after laser treatment with TiC particles, scan rate: 0.75 m/min, laser power: 1.6 kW

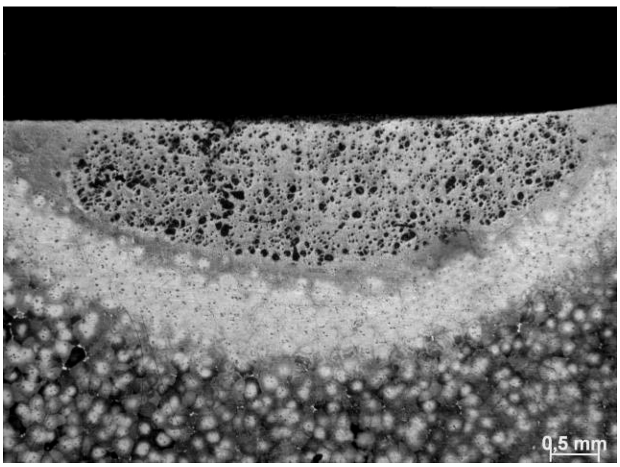

Fig. 14. Surface layer of MCMgAl9Zn1 alloy after laser treatment with WC particles, scan rate: 0.75 m/min, laser power: 2.0 kW

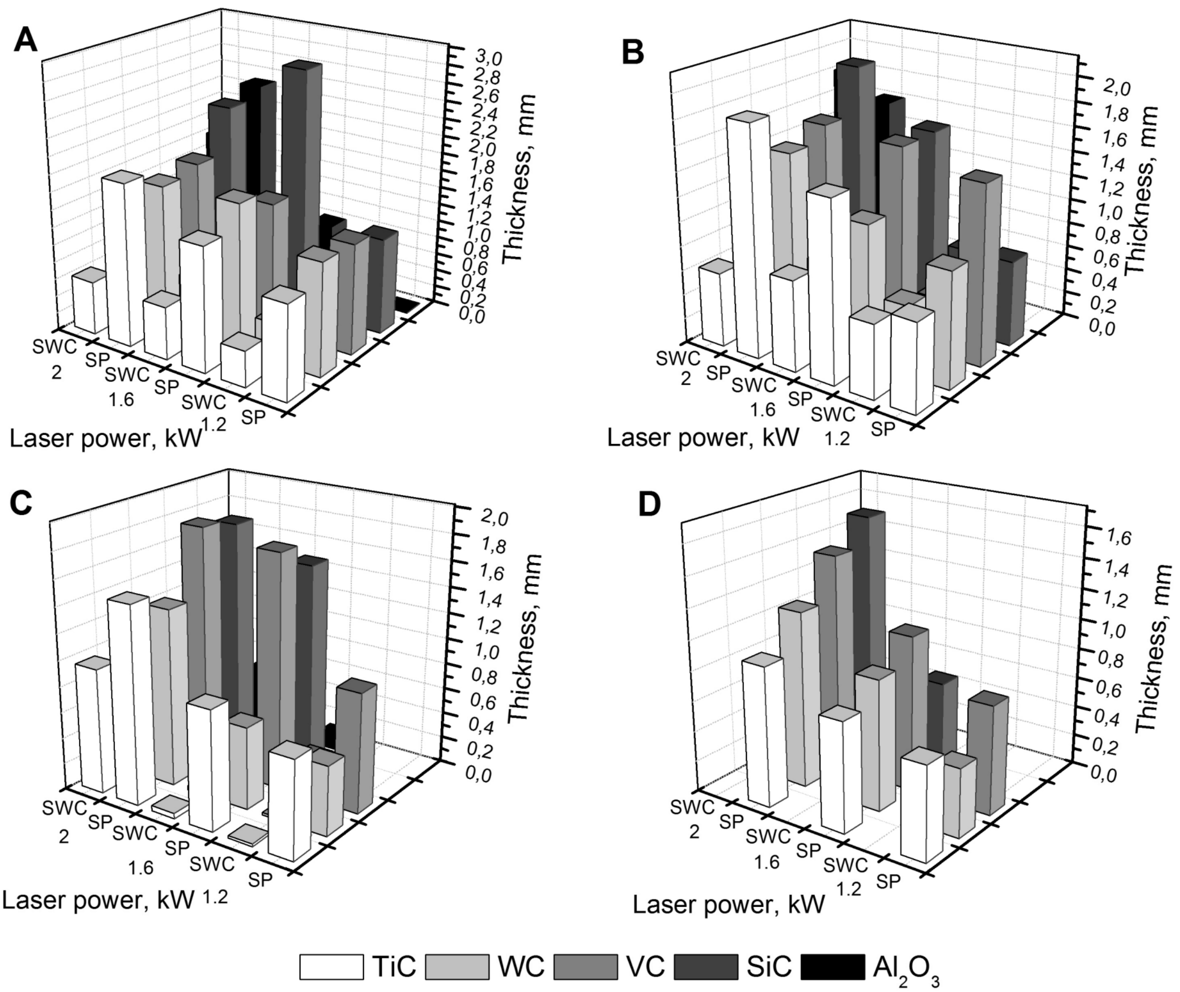

Fig. 15. Effect of laser power and the substrate material on the thickness of the SP melted zone, SWC heat affected zone and the WW surface layer of casting alloys after laser remelting: A – MCMgAl3Zn1, B – MCMgAl6Zn, C – MCMgAl9Zn1, D – MCMgAl12Zn1

zone and heat affected zone (surface layer) was observed. The greatest thickness of the surface layer was observed after alloying of SiC powder to melt MCMgAl12Zn1 (Fig. 15), alloyed with laser power 2.0 kW, respectively 3590 μm. For the other used powders the largest values obtained for the alloy surface layer MCMgAl9Zn1 and MCMgAl12Zn1 (Fig. 15) were in the range 2340-2470 μm. Casting magnesium alloys with aluminium concentrations of 3% (MCMgAl3Zn1) were characterized by the smallest thickness of the surface layer of laser-melted samples. The zone of melted samples from MCMgAl3Zn1, alloyed with carbides of tungsten, titanium, vanadium, for the laser power of 1.2 kW (Fig. 14) was in the range 450-720 μm.

It was noticed that the width of the formed surface layer changes together with the laser power, speed remelting and depending on the type of substrate, of which the most important was the laser power, mainly because the increase of absorbed energy took place together with power increase, while decreases with the increase of remelting speed. The greatest width of penetration for different powders was achieved for alloys MCMgAl12Zn1 and MCMgAl9Zn1, the lowest ones for the alloy MCMgAl3Zn1. The greatest width of the remelting was observed for the alloy after remelting of MCMgAl12Zn NbC powder with a laser power of 2.0 kW – 8320 μm (which is now the largest one), while the lowest one for the MCMgAl3Zn1 alloy after remelting WC powder with a laser power of 1.2 kW – 3540 μm (Fig. 16).

Results of the metallographic investigations showed that the structure of the solidified material after laser treatment was characterised by the occurrence of areas with different morphology connected to the crystallisation of the magnesium alloys (Figs. 17-22). As a result of the laser treatment a structure which was free of defects and with a clear grain refinement was achieved. The structure of the laser modified layer contains mainly dispersive particles of the applied TiC, WC, VC, SiC carbide or Al_2O_3 oxide powder placed in the matrix of the Mg-Al-Zn alloy. Morphology of the treated area after laser treatment was mainly compound of dendrites wit plate shaped $Mg_{17}Al_{12}$ eutectic and Mg present in the interdendritic space, where the main growing axes were directed according to the heat transport directions. This can be interpreted

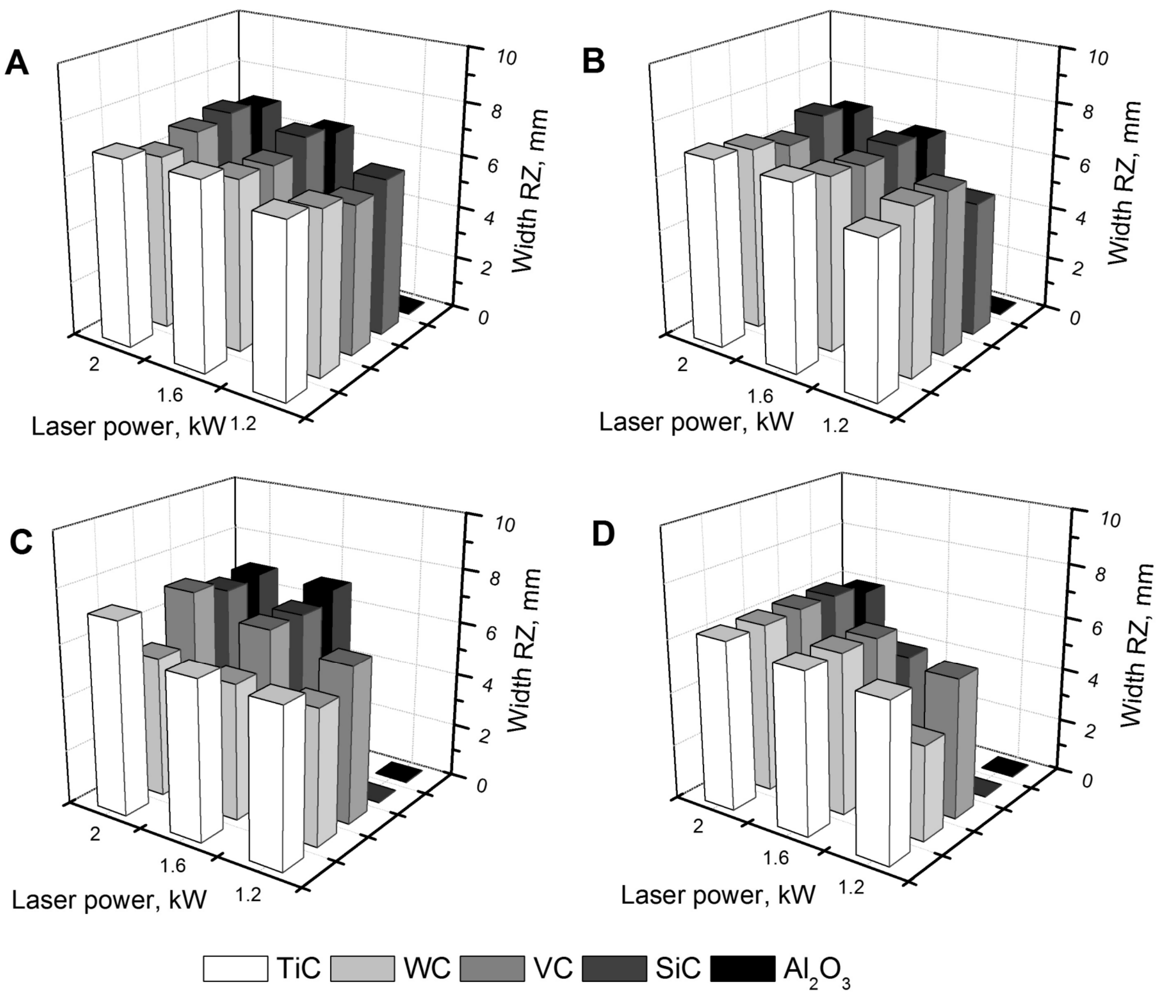

Fig. 16. Dependence of the remelting width from laser power aluminium mass concentration casting magnesium alloys after laser cladding: A – MCMgAl3Zn1, B – MCMgAl6Zn, C – MCMgAl9Zn1, D – MCMgAl12Zn1

with an occurrence of a non-normal eutectic with a small amount of α-Mg in the eutectic solution (Figs. 17-22). Moreover the composite structure of the area after laser treatment results from the hypoeutectic alloy change to a hyper-eutectic one, depending from the alloyed elements distribution and the change of the process condition parameters of the laser treated surface.

Morphology of the treated area after laser treatment was mainly compound of dendrites with plate shaped $Mg_{17}Al_{12}$ eutectic and Mg present in the interdendritic space, where the main growing axes were directed according to the heat transport directions. This can be interpreted with an occurrence of a non-normal eutectic with a small amount of α-Mg in the eutectic solution. Moreover, the composite structure of the area after laser treatment results from the hypoeutectic alloy change to a hypereutectic one, depending from the alloyed elements distribution and the change of the process condition parameters of the laser treated surface.

Investigations carried out on the scanning electron microscope confirmed the occurrence of the zones in the surface layer of the investigated casting magnesium alloys (Figs. 23-28). In the remelted zone a dendritic structure built according to the heat transport directions and the alloyed powder particles of the carbides or aluminium oxide were present. The morphology after surface laser treatment, including the amount and distribution of the carbide particles, depended on the applied laser parameters. On the basis of the metallographic investigations of the uniform distribution of MCMgAl3Zn1, MCMgAl6Zn1, MCMgAl9Zn1, MCMgAl12Zn1 alloys – on the whole remelting zone – of the used carbide particles TiC, WC and Al_2O_3 (Figs. 22-27) was found. In case of cladding of the SiC particles with laser power of 1.2 kW and same cases 1.6 kW, the carbides were mainly located on the top of the surface layer (Fig. 26). For power of 2.0 and 1.6 kW in samples of the MCMgAl12Zn1 and MCMgAl9Zn1 material, caused by a strong movement of the liquid metal in the remelting area, the SiC particles were distributed over the whole area of the remelting zone. After treatment with vanadium carbide in the surface of the casting magnesium alloys there only a sporadical occurrence of the carbide in the remelting area was observed (Fig. 28).

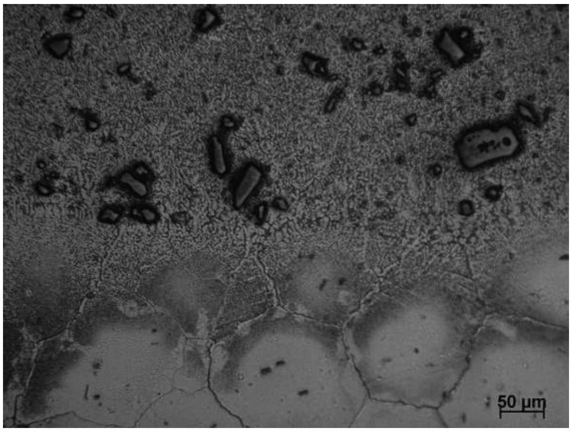

Fig. 17. Remelting path edge of the MCMgAl6Zn1 alloy surface layer after laser treatment with TiC particles, scan rate: 0.75 m/min, laser power: 1.6 kW

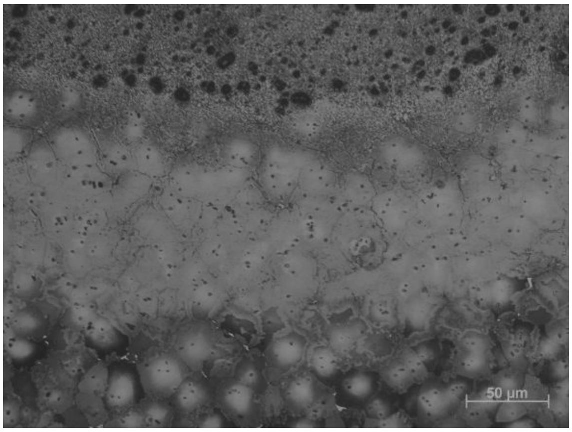

Fig. 18. Structure of the interface between the laser-melted zone, heat affected zone and the substrate of the MCMgAl12Zn1 alloy after laser treatment with WC particles, scan rate: 0.75 m/min, laser power: 2.0 kW

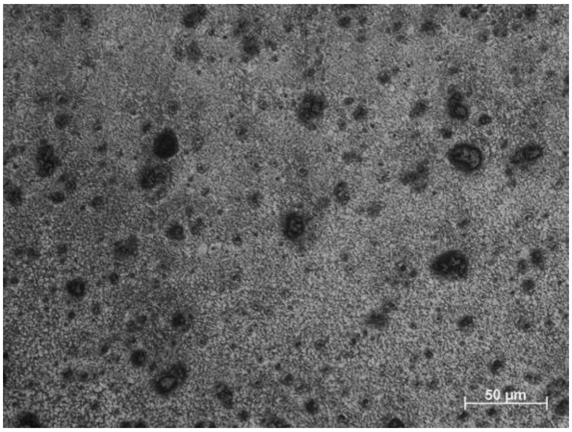

Fig. 19. Central zone of the MCMgAl12Zn1 alloy surface layer after laser treatment with WC particles, scan rate: 0.75 m/min, laser power: 2.0 kW

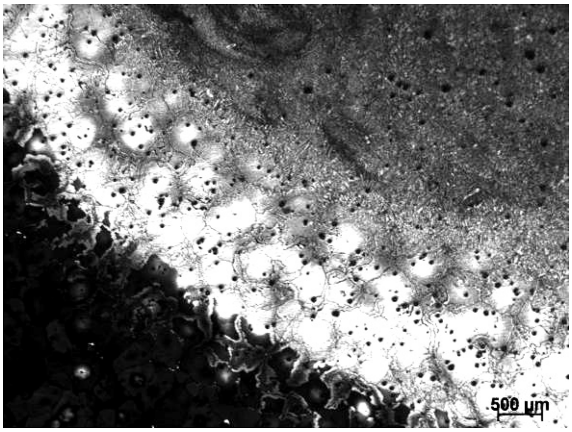

Fig. 20. Remelting path edge of the MCMgAl9Zn1 alloy surface layer after laser treatment with WC particles, scan rate: 0.75 m/min, laser power: 2.0 kW

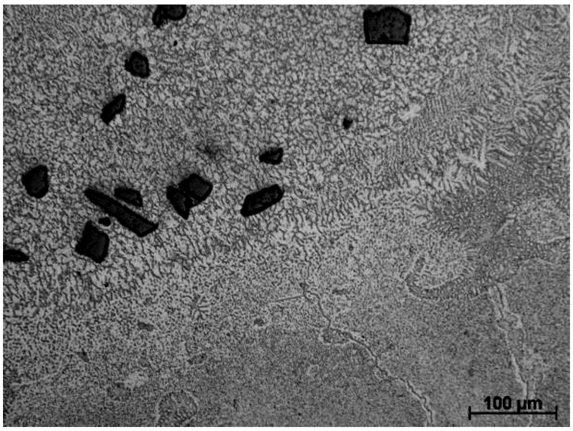

Fig. 21. Border zone of the MCMgAl12Zn1 alloy surface layer after laser treatment with SiC particles, scan rate: 0.75 m/min, laser power: 1.6 kW

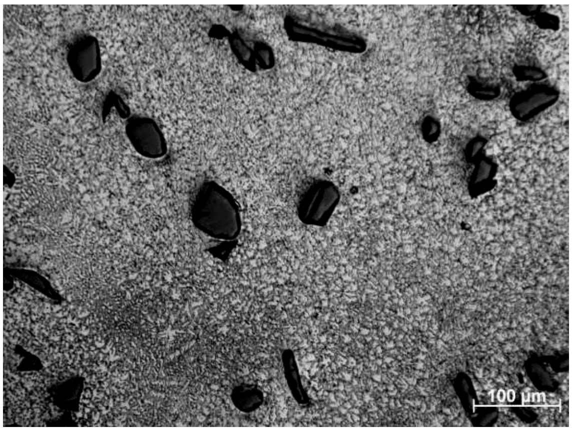

Fig. 22. Central zone of the MCMgAl6Zn1 alloy surface layer after laser treatment with SiC particles, scan rate: 0.75 m/min, laser power: 2.0 kW

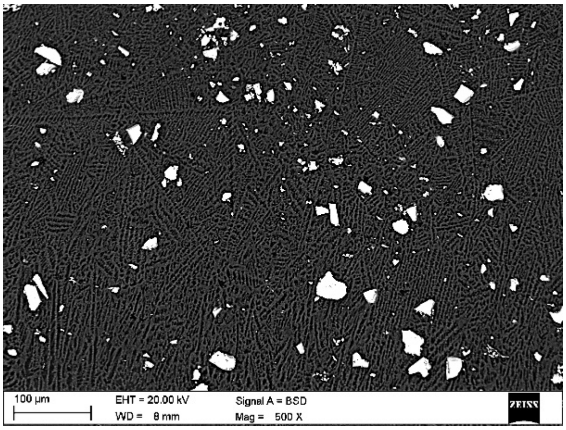

Fig. 23. Scanning electron microscope micrograph of laser modified surface of MCMgAl3Zn1 alloy with TiC particles of the central modified zone, scan rate: 0.75 m/min, laser power: 1.2 kW

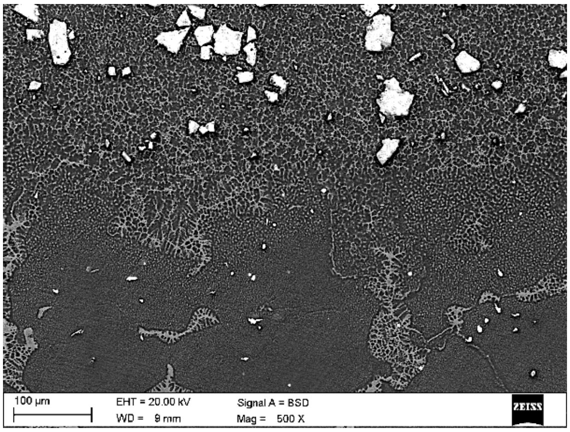

Fig. 24. Scanning electron microscope micrograph of laser modified surface of the MCMgAl9Zn1 alloy with TiC particles at the interface between the modified zone and the substrate, scan rate: 1 m/min, laser power: 1.6 kW

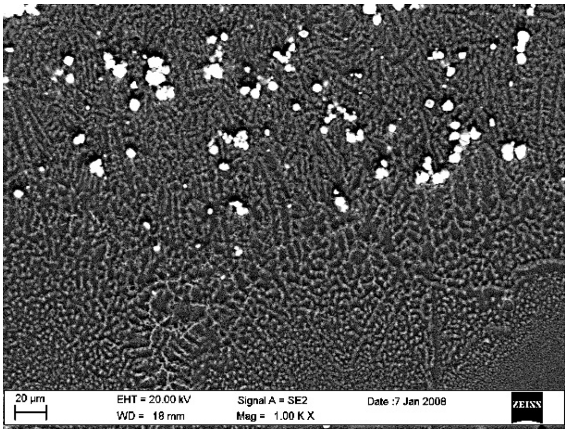

Fig. 25. Scanning electron microscope micrograph of laser modified surface of the MCMgAl6Zn1 alloy with WC particles at the interface between the modified zone and the substrate, scan rate: 0.5 m/min, laser power: 1.6 kW

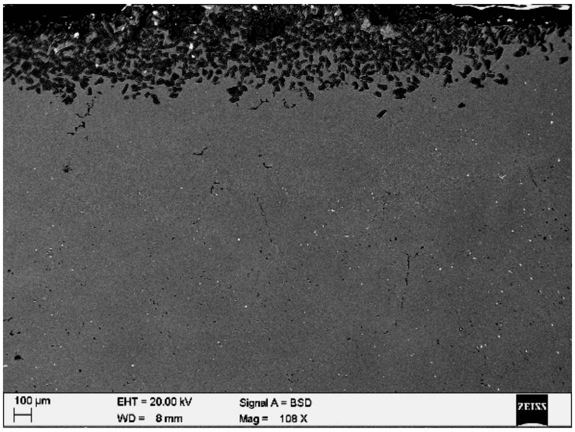

Fig. 26. Scanning electron microscope micrograph of laser modified surface layer of the MCMgAl6Zn1 alloy with SiC particles, scan rate: 0.75 m/min, laser power: 1.6 kW

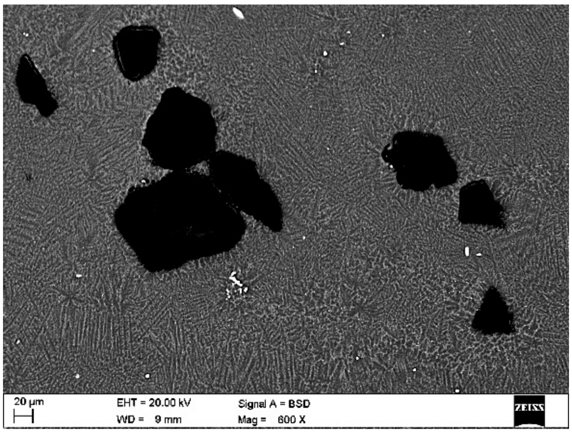

Fig. 27. Scanning electron microscope micrograph of laser modified surface of MCMgAl12Zn1 alloy with Al_2O_3 particles of the central modified zone, scan rate: 0.5 m/min, laser power: 1.6 kW

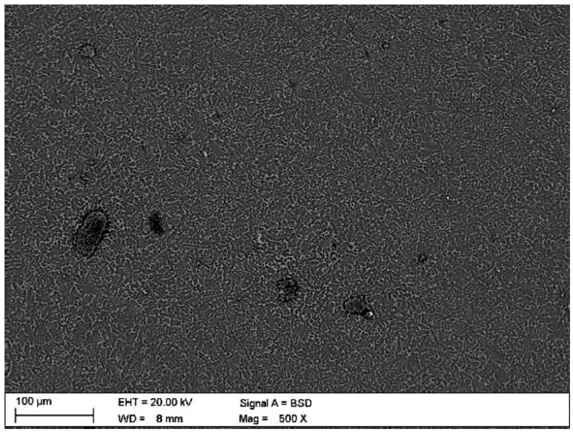

Fig. 28. Scanning electron microscope micrograph of laser modified surface of MCMgAl12Zn1 alloy with VC particles of the central modified zone, scan rate: 0.75 m/min, laser power: 1.6 kW

X-ray diffraction diagrams of Mg-Al-Zn casting magnesium alloys after laser treatment with WC, TiC, VC, SiC carbides and Al_2O_3 oxide confirm the occurrence of α-Mg phase, γ-$Mg_{17}Al_{12}$ phase, as well of picks coming from the powders using for cladding (Figs. 29-33).

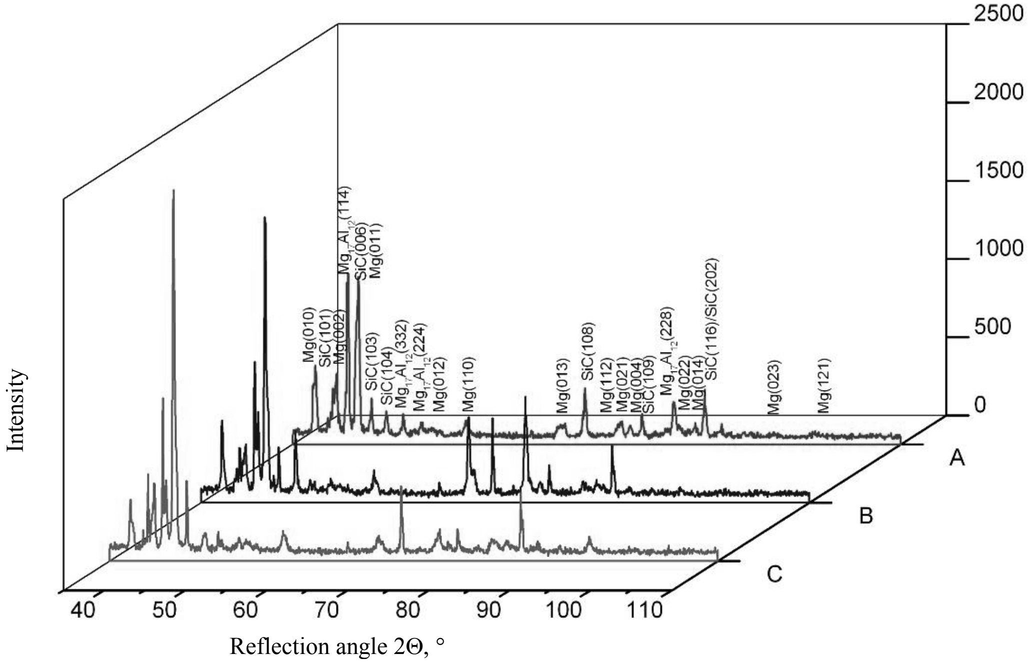

Fig. 29. X-ray diffraction pattern of MCMgAl12Zn1 casting magnesium alloys after laser treatment by silicon carbide powder, scan rate: 0.75 m/min, laser power: A – 1.2 kW, B – 1.6 kW, C – 2.0 kW

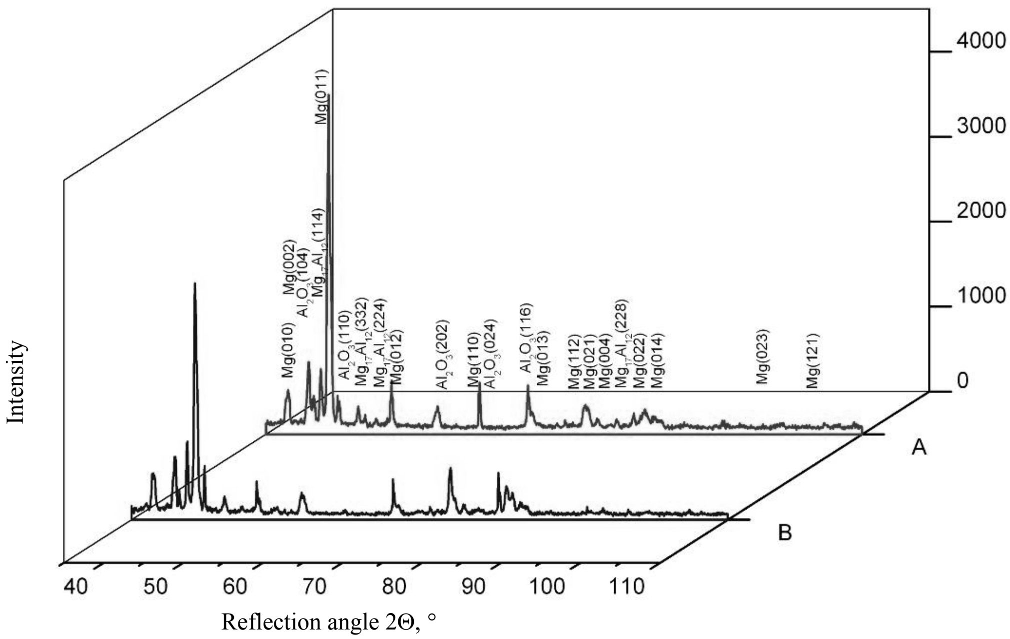

Fig. 30. X-ray diffraction pattern of MCMgAl12Zn1 casting magnesium alloys after laser treatment by aluminium oxide powder, scan rate: 0.75 m/min, laser power: A – 2.0 kW, B – 1.6 kW

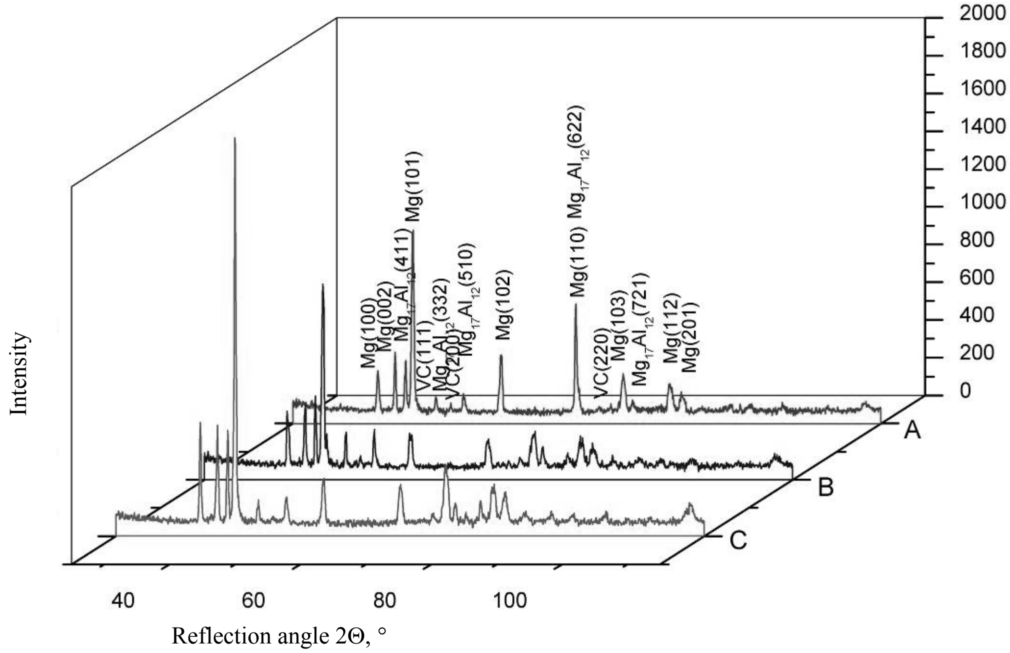

Fig. 31. X-ray diffraction pattern of MCMgAl12Zn1 casting magnesium alloys after laser treatment by vanadium carbide powder, scan rate: 0.75 m/min, laser power: A – 1.2 kW, B – 1.6 kW, C – 2.0 kW

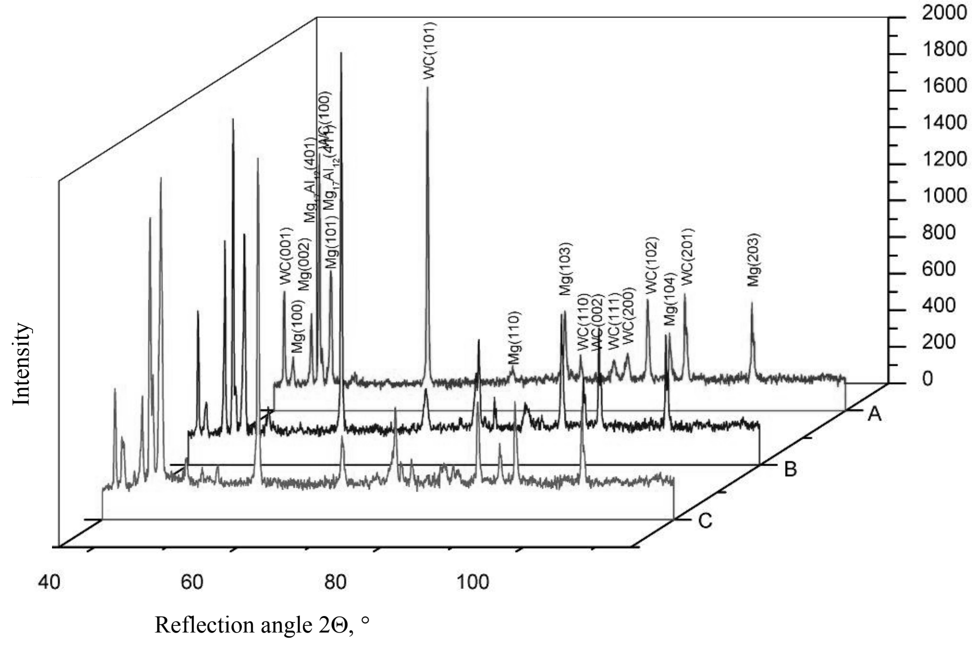

Fig. 32. X-ray diffraction pattern of MCMgAl12Zn1 casting magnesium alloys after laser treatment by tungsten carbide powder, scan rate: 0.7 m/min, laser power: A – 1.2 kW, B – 1.6 kW, C – 2.0 kW

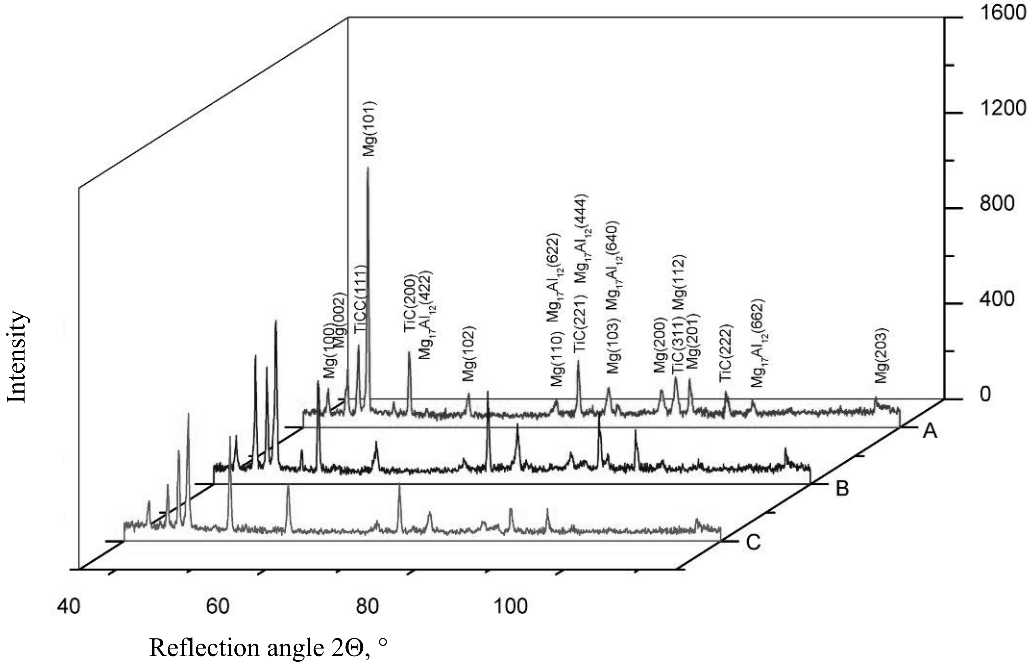

Fig. 33. X-ray diffraction pattern of MCMgAl12Zn1 casting magnesium alloys after laser treatment by titanium carbide powder, scan rate: 0.75 m/min, laser power: A – 1.2 kW, B – 1.6 kW, C – 2.0 kW

The results of measurements of hardness of Mg-Al-Zn casting magnesium alloys after laser cladding and remelting of WC powder, TiC, VC, SiC and Al_2O_3 (Fig. 34) showed that in most cases, for MCMgAl6Zn1 and MCMgAl3Zn1 alloys laser treatment of surface layer the hardness increase, while for alloys MCMgAl12Zn1, MCMgAl9Zn1 hardness did not increase, on the contrary, at certain used parameters of treatment became slightly worse. The largest increase in hardness by 56 HRF in relation to the hardness of the usual heat treatment was obtained for the MCMgAl3Zn1 magnesium alloy after treatment TiC powder with a laser power of 1.2 kW and the alloying speed 1.0 m/min. For the highest hardness of the MCMgAl6Zn1 alloy (93.4 HRF) after laser treatment was measured at the surface layer of the TiC powder alloying with 1.2 kW laser power and alloying speed 0.75 m/min (Fig. 34). However, the greatest decrease in hardness of the surface layer was observed for alloys and MCMgAl12Zn1 MCMgAl9Zn1 after alloying SiC powder with a laser power of 1.2 kW and the alloying speed 0.75 m/min. The study indicates that the hardness increase occurred with decreasing laser power and increase of the concentration of aluminium in the alloy, as well as the descending alloying speed. In the case of fusing powdered tungsten carbide and vanadium, the largest increase in hardness occurred for alloys: MCMgAl6Zn1 and MCMgAl3Zn1. In the case of alloys: MCMgAl12Zn1 and MCMgAl9Zn1 hardness remained at a similar level as in the case of material after the conventional heat treatment.

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. 35-39) 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.

The outcarried works were included also experimental verification of the outworked technology. The study on the ready item was conducted on an experimental MCMgAl6Zn1 alloy whose surface was improved by the use of laser techniques thanks to the use of laser melting techniques of titanium carbide particles with overlapping paths of remelting using laser power 1.6 kW and alloying speed 0.75 m/min. In order to determine the quality of the outworked surface layers, made by the use of high power diode lasers, on the ready item metallographic studies were

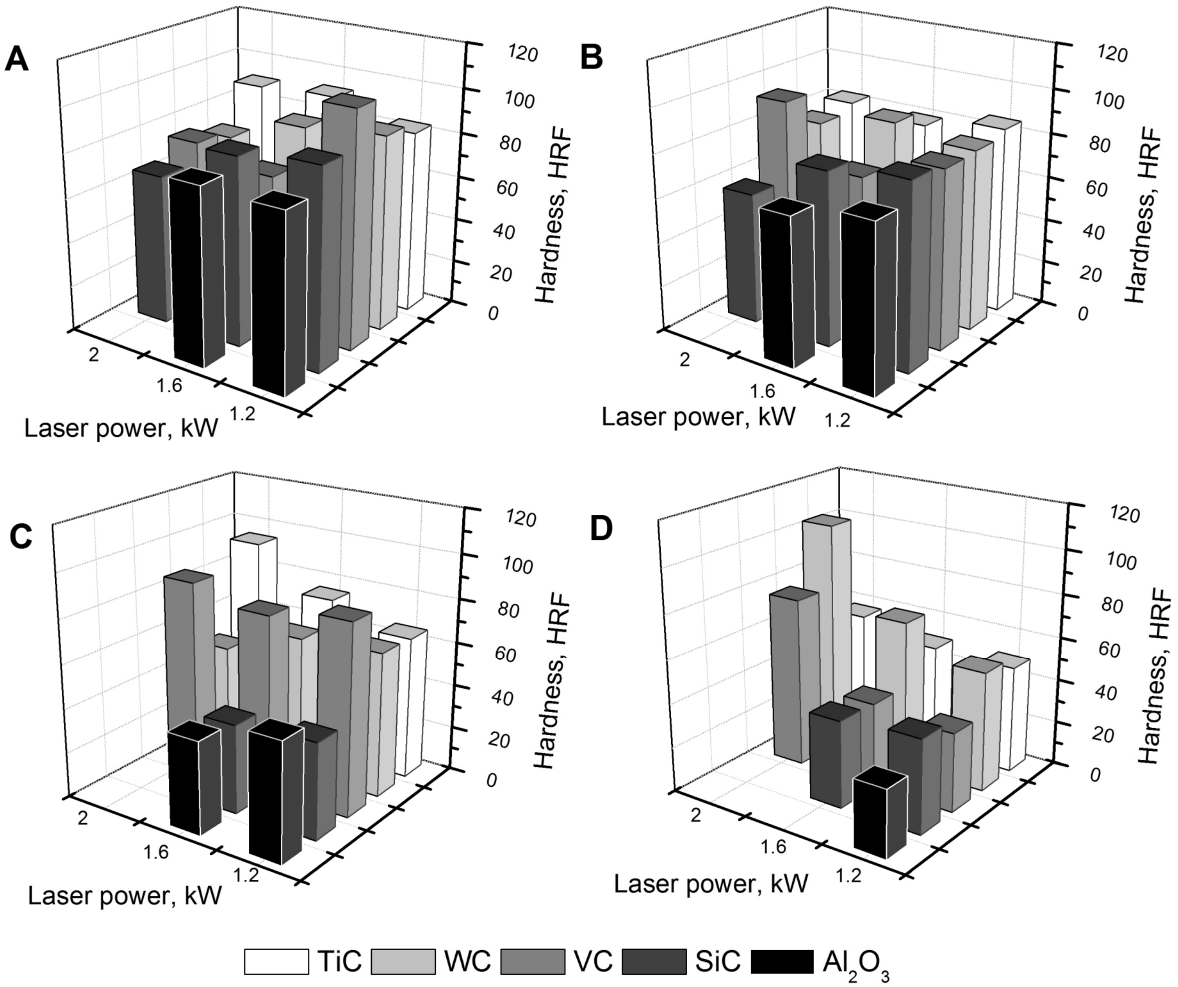

Fig. 34. Change in the average hardness of the surface layer of casting magnesium alloys after laser treatment: A – MCMgAl3Zn1, B – MCMgAl6Zn, C – MCMgAl9Zn1, D – MCMgAl12Zn1

conducted, including: light microscopy (Figs. 40, 41), scanning and X-ray phase analysis and qualitative analysis of the surface distribution of alloying elements and the researches of mechanical properties, including hardness, microhardness and surface roughness.

The results of microhardness in the cross-section of laser paths in a function of distance from the surface of samples of the casting magnesium alloy reinforced with TiC particles (Fig. 42) indicated that in the middle of the run and the overlap run the microhardness of alloyed surface increases in comparison to material substrate for about 20 HV 0.05. The measurements taken in the middle of the run (2 mm from the surface) were characterized by a mild change in hardness from about 1970 HV 0.05 at the surface to about 55 HV 0.05 into the material (Fig. 40). In case of change of microhardness measurements on the overlap run one can observe more visible differences of about 70 HV 0.05 at the surface to about 60 HV 0.05 at a distance of 1 mm from the surface of the material (Fig. 40). This is probably due the fact thicker remelting zone in the central part compared to the thickness of the zone of the overlap run. As a result of research of hardness of magnesium alloy laser treatment by titanium carbide hardness of the surface layer equal to 69.6 ± 2 HRF, increased on average by about 20% of the hardness of the material subjected only to treatment of precipitation hardening was measured. Roughness R_a of the surface layer obtained by remelting of magnesium alloy by the laser beam power of 1.6 kW was 6.02 ± 1.1 μm.

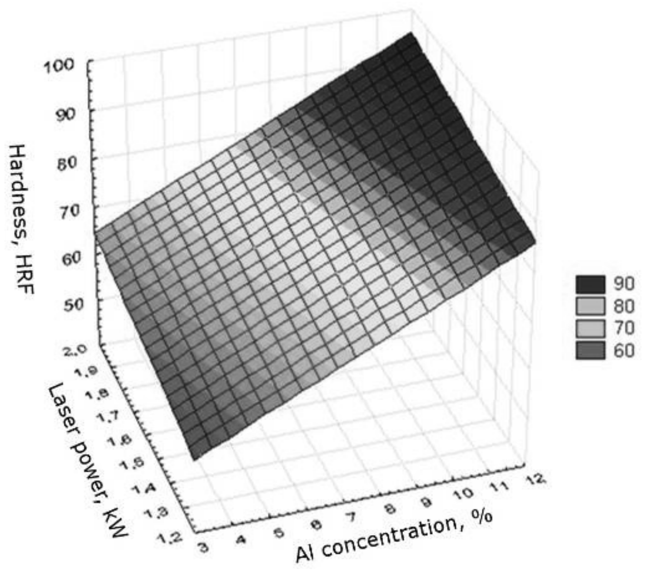

Fig. 35. Simulation of the laser power and aluminium concentration (wt. %) influence on hardness of casting magnesium alloys after laser treatment with TiC particles, scan rate 0.75 m/min

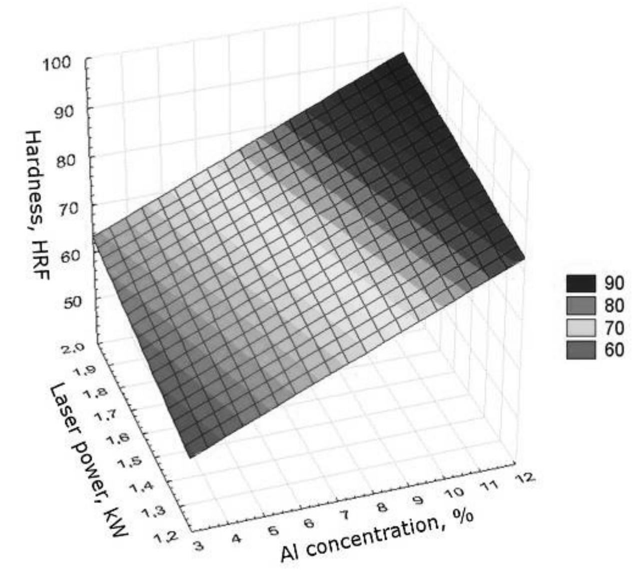

Fig. 36. Simulation of the laser power and aluminium concentration (wt. %) influence on hardness of casting magnesium alloys after laser treatment with VC particles, scan rate 0.75 m/min

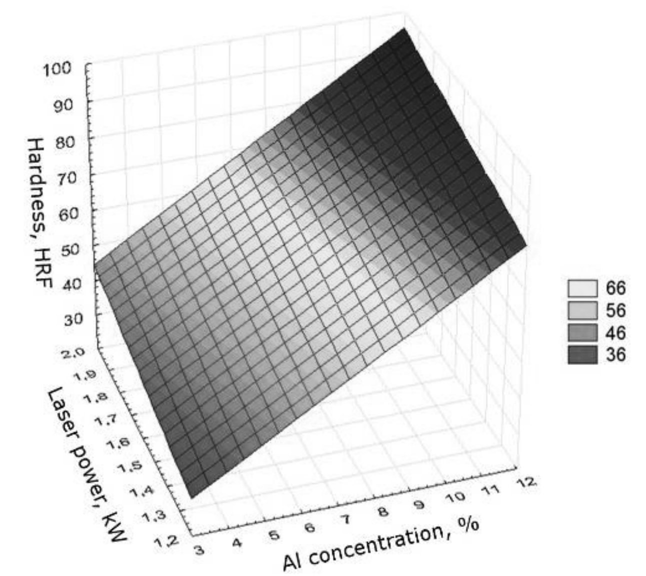

Fig. 37. Simulation of the laser power and aluminium concentration (wt. %) influence on hardness of casting magnesium alloys after laser treatment with WC particles, scan rate 0.75 m/min

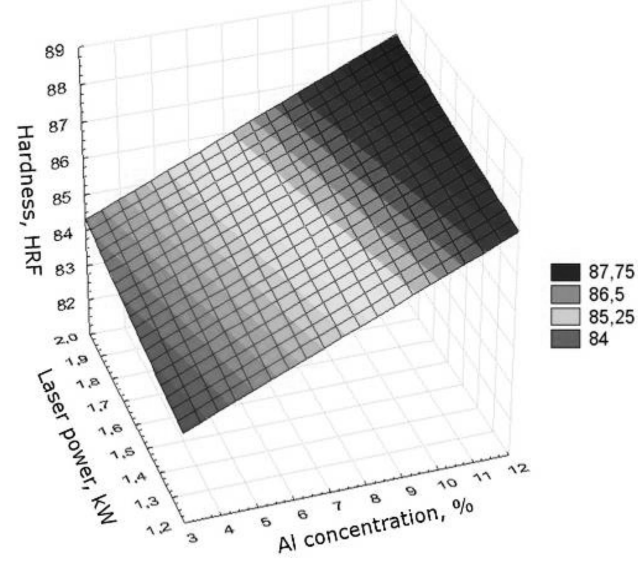

Fig. 38. Simulation of the laser power and aluminium concentration (wt. %) influence on hardness of casting magnesium alloys after laser treatment with SiC particles, scan rate 0.75 m/min

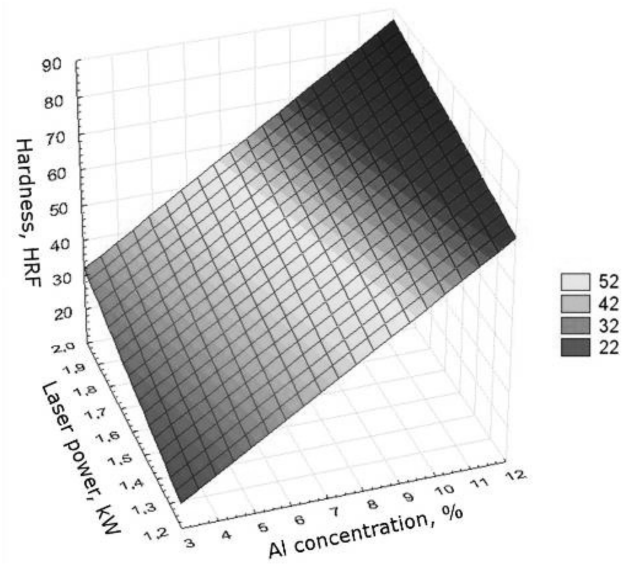

Fig. 39. Simulation of the laser power and aluminium concentration (wt. %) influence on hardness of casting magnesium alloys after laser treatment with Al_2O_3 particles, scan rate 0.5 m/min

Fig. 40. View of the MCMgAl6Zn1 casting magnesium alloy face of weld after laser treatment with TiC, scan rate: 0.75 m/min, laser power: 1.6 kW

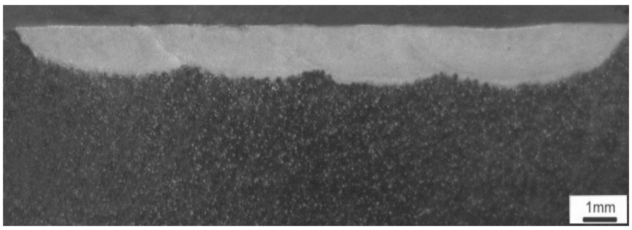

Fig. 41. Surface layer of MCMgAl6Zn1 alloy after laser treatment with TiC particles, scan rate: 0.75 m/min, laser power: 1.6 kW

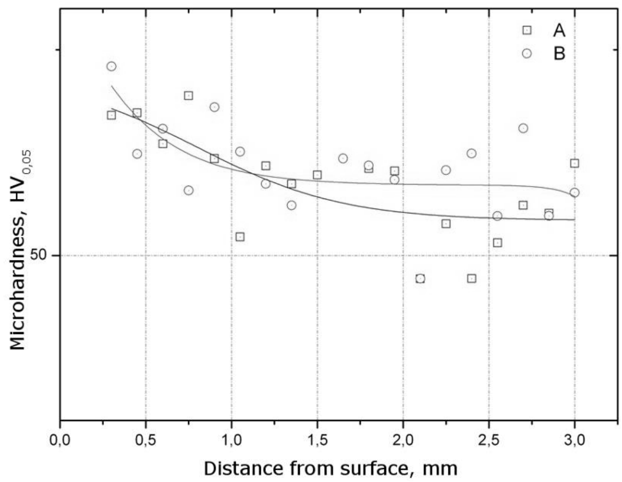

Fig. 42. Cross-section microhardness profile from the MCMgAl6Zn1 substrate with TiC particles, scan rate: 0.75 m/min, laser power: 1.6 kW: A – measurements in the middle run, B – measurements in overlap run

In Figure 43 as a result of observation in the light microscope the boundary of remelting of the surface layer and the central zone was presented. Remelting zone is characterized by defect-free structure with a clear fragmentation of grains, which consists mainly of TiC carbide particles dispersed in the MCMgAl6Zn1 alloy matrix. Results of the analysis of phase composition in Figure 44 confirm the presence in the structure α-Mg and γ-$Mg_{17}Al_{12}$ phase and also in the structure of the surface layer of the used powder which alloys TiC, what was also proved by researches of the surface distribution of elements (Fig. 45).

5. Technology roadmapping results of examined laser treated alloys

On the basis of achieved results of experimental and comparative researches a series of roadmaps of the analyzed groups of technology were created. A representative roadmap prepared for laser cladding of TiC titanium carbide particles in the surface of Mg-Al-Zn casting magnesium alloys are shown in Table 7. The horizontal axis of a roadmap corresponds to time intervals, and the vertical axis to seven main layers answering the questions in turn: When? Why? What? How? Where? Who? How much? The upper layers were divided into more sublayers arranged hierarchically Detailed starting from the upper ones being the most general one Determining Premises, Causes and Reasons of the Realized actions through the middle ones characterizing a product and technology in lower layers of the technology precising an organizational and technical details at the end. The summary worked out on the basis of data contained in given roadmaps prepared for all the analyzed groups of techno-logy is presented in Table 8.

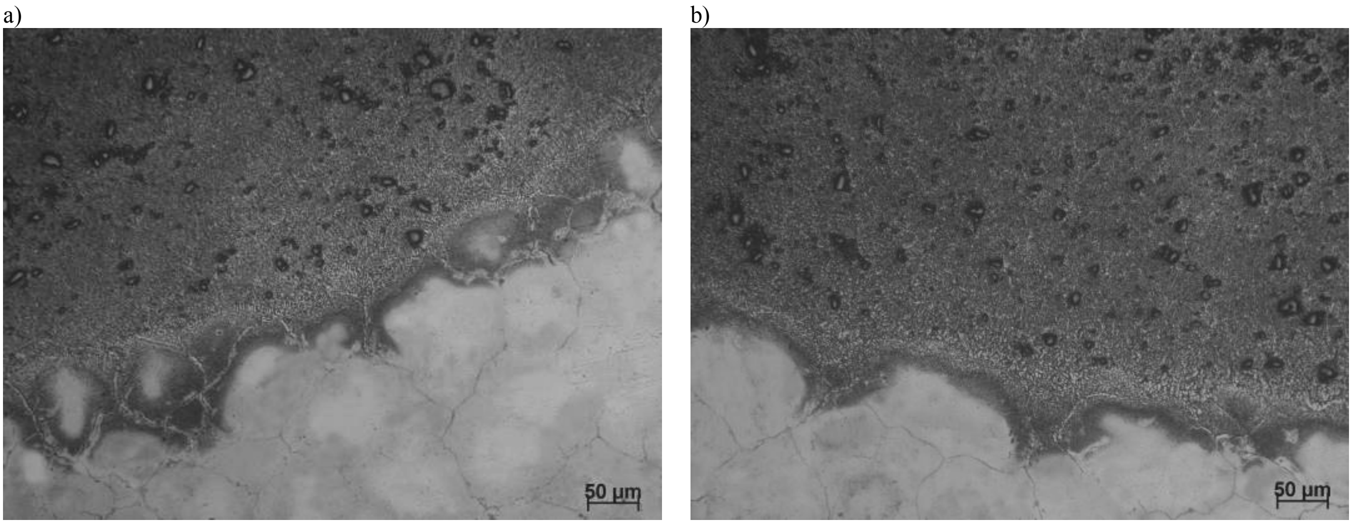

Fig. 43. Boundary between alloyed zone and heat affected zone of MCMgAl6Zn1 alloy after laser treatment with TiC particles, scan rate: 0.75 m/min, laser power: 1.6 kW

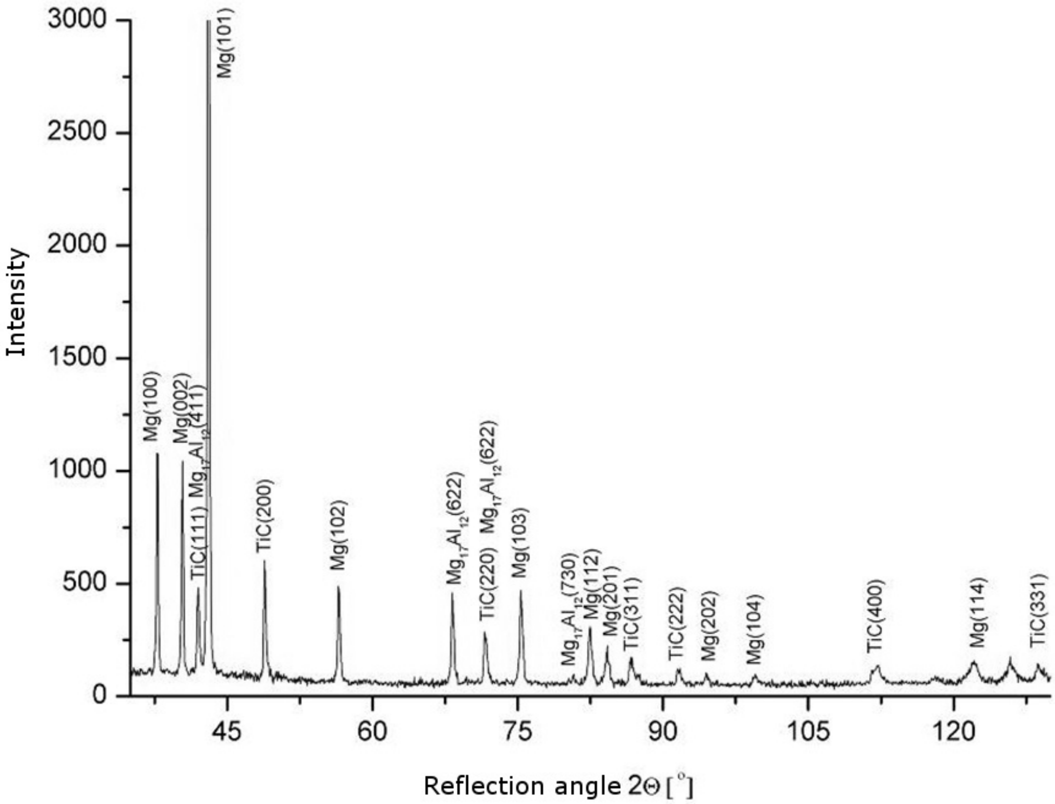

Fig. 44. X-ray diffraction pattern of the MCMgAl6Zn1 casting magnesium alloy after laser treatment with TiC particles, scan rate: 0.75 m/min, laser power: 1.6 kW

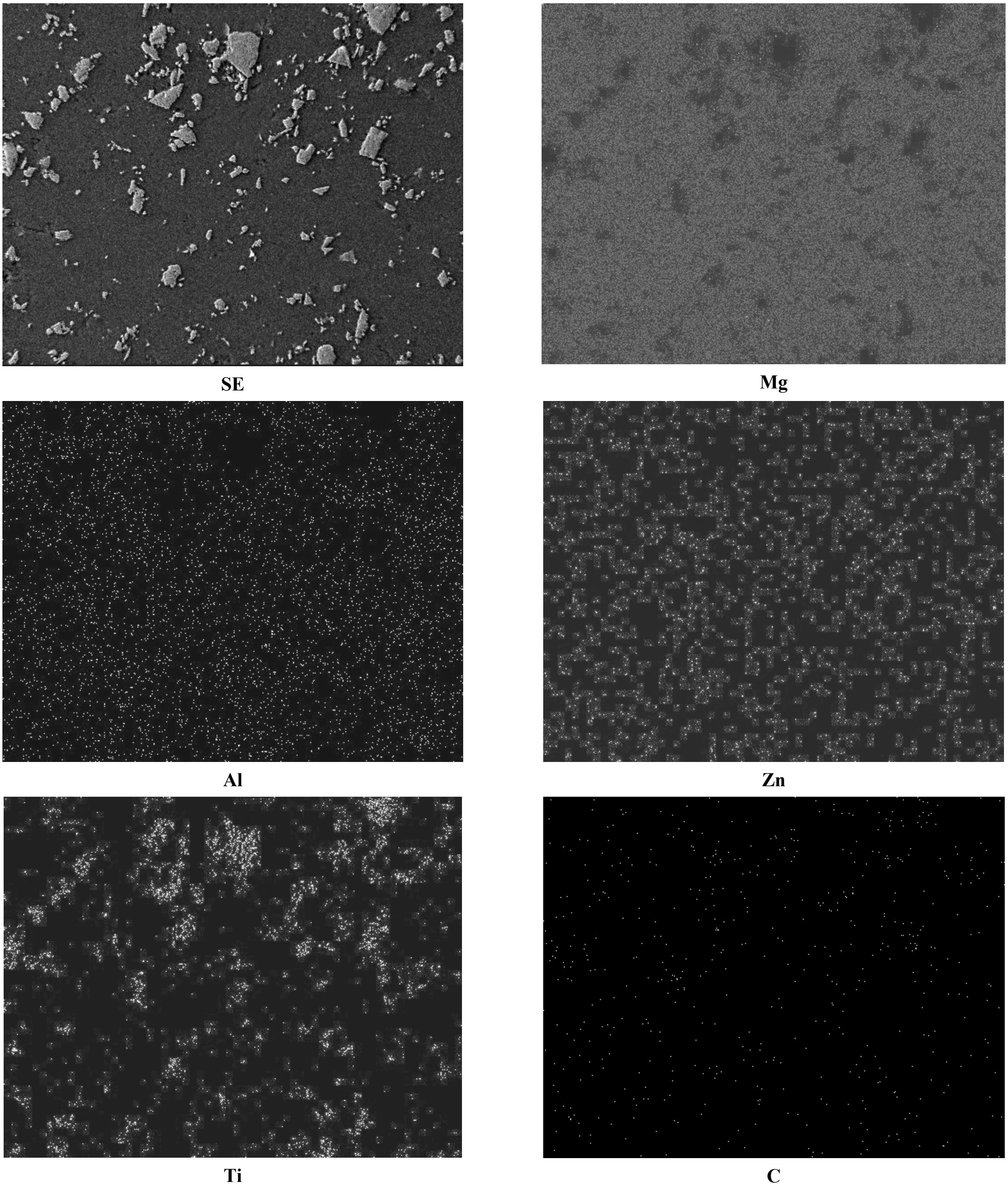

Fig. 45. X-ray mapping of the microstructure MCMgAl6Zn1 cladding layer and the distribution of Mg, Al, Zn, Ti, C, scan rate: 0.75 m/min, laser power: 1.6 kW

Table 7.
Demonstrating technology roadmapping for laser cladding of TiC carbide particles in the substrate of Mg-Al-Zn casting magnesium alloys

TECHNOLOGY ROADMAP		Technology name: *Laser cladding of TiC carbide particles in the surface of Mg-Al-Zn casting magnesium alloys*		Catalogue No:
		Research scope: *Laser technologies in surface engineering*		*M1-12-2010*
When?	Time intervals	TODAY 2010	2020	2030
	All-society and economic perspectives	Creating scenarios of future events	Development of priority innovation technologies	Statistically high quality of technologies
		Creating the Book of information cards concerning future technologies	Using chances and avoiding difficulties	Sustainable development
		Development of information society and intellectual capital	Cooperation to increase innovativeness and competitiveness of economy and intellectual	Knowledge-based economy
Why?	Strategy for technology	Strategy o an oak in spring		
	Environment influence	Sunny spring		
	Technology value	Wide-stretching oak		
What?	**Product**	Working parts of tools and machines, dies, punches, engine components, brake	Dies, punches, engine components, brakes, pedals, housing of equipment and machines	Elements of vehicles, biomaterials
	Product quality at the background of foreign competitors	Excellent (10)	Very high (9)	Moderate (6)
	Surface	Casting magnesium alloys Mg-Al-Zn		
	Kind of surface coatings/layers	Titanium carbide TiC		
	Improved material properties	Increase of mechanical properties of elements (hardness), increase of corrosion resistance, improvement of tribological properties		
	Diagnostic-research equipment	Light, confocal laser, scanning electron, transmission electron, atomic force microscopes, X-ray diffractometer, X-ray microanalyzer, GDOES spectrometer, hardness, microhardness, scratch testers, profilometer, potentiostat		
How?	**Technology**	Laser cladding of TiC carbide particles in Mg-Al-Zn casting alloy surfaces		
	Life cycle period	Prototype (8)	Growth (7)	Base (3)
	Production type	Unit and small-scale seria	Small- and medium-scale serial	Mass
	Production organisation form	Cellular non-rhythmic	Linear rhythmic	Linear
	Machine park modernity	Excellent (10)	High (8)	Medium (5)
	Automation & robotisation	Excellent (10)	Excellent (10)	Excellent (10)
	Quality and reliability	High (8)	Very high (9)	Excellent (10)
	Proecology	Excellent (10)	Very high (9)	Very high (9)
Where?	Organisation type	Large and medium-sized enterprises, research and scientific centres, technological parks	Large and medium-sized enterprises, research and scientific centres, technological parks	Small and medium-sized enterprises, research and scientific centres, technological parks
	Represented industrial branches	Medicine, automotive industry, sports, military equipment, aviation, aeronautics	Medicine, automotive industry, sports, military equipment, aviation, aeronautics, civil engineering	Medicine, automotive industry, aviation and others
Who?	Staff education level	Excellent (10)	High (8)	Moderate(6)
	Engagement of scientific-research staff	Excellent (10)	Excellent (10)	High (8)
How much?	Capital requirements	Excellent (10)	High (8)	Medium (5)
	Production size determining profitability in firm	Medium (5)	Quite high (7)	High (8)
	Production size in the country	Low(3)	Medium (5)	High (8)

LEGEND: ⇒ Cause and effect connections; ·······▶ Capital connections; ·······▶ Time corelations; ◀—▶ Two-way transfer of data and/or resources

Table 8.
Selected main source data used for preparation of roadmaps for laser treatment of Mg-Al-Zn casting magnesium alloys using: (A) TiC titanium carbide, (B) WC tungsten carbide, (C) VC vanadium carbide, (D) SiC silicon carbide and (E) Al_2O_3 aluminium oxide

No.	Analysed factor		Time interval	Analysed technology				
				A	B	C	D	E
1.	All-society and economic perspectives	Trend 1	2010	Creating scenario of future events				
			2020	Development of priority innovation technologies				
			2030	Statistically high quality of technologies				
		Trend 2	2010	Creating the Book of information cards concerning future technologies				
			2020	Using chances and avoiding difficulties				
			2030	Sustainable development				
		Trend 3	2010	Development of information society and intellectual capital				
			2020	Cooperation to increase innovativeness and competitiveness of economy and intellectual capital				
			2030	Knowledge-based economy				
2.	Strategy for technology		2010	Strategy of an oak in spring	Strategy of an oak in spring	Strategy of an oak in spring	Strategy of an oak in spring	Strategy of an oak in spring
			2020	Strategy of an oak in summer	Strategy of an oak in summer	Strategy of an oak in summer	Strategy of an oak in autumn	Strategy of an oak in summer
			2030	Strategy of an oak in autumn	Strategy of an oak in autumn	Strategy of an oak in autumn	Strategy of an oak in autumn	Strategy of an oak in autumn
3.	Environment influence		2010	Sunny spring				
4.	Technology value		2010	Wide-stretching oak				
5.	Product		2010	Working parts of tools and machines, dies, punches, engine components, brake	Civil aviation, gearboxes, gear transmission components, high-speed elements	Elements for automotive industry, which are friction, corrosive and/ or erosive worn	dies, punches, engine components, gearboxes, gear transmission components	Elements corrosive worn, dies, punches, engine components,
			2020	Dies, punches, engine components, brakes, pedals, housing of equipment and machines	MMCS composites, civil aviation, elements of motorbikes and bicycles	Elements with quasi-gradient structure, MMCS composites,	MMCS composites, engine components, gearboxes, gear transmission components	MMCS composites, engine components, gearboxes, gear transmission components
			2030	Elements of vehicles, biomaterials	Elements of vehicles, future applications	Elements of vehicles, biomaterials, future applications	Elements of vehicles, future applications	Elements of vehicles, sport equipment, future applications

No.	Analysed factor	Time interval	Analysed technology				
			A	B	C	D	E
6.	Product quality at the background of foreign competitors	2010	Excellent (10)	Very high (9)	High (8)	Very high (9)	Moderate (6)
		2020	Very high (9)	Very high (9)	Very high (9)	Very high (9)	High (8)
		2030	Moderate (6)	Excellent (10)	Excellent (10)	Excellent (10)	High (8)
7.	Improved material properties	2010	Better mechanical properties of elements (hardness), better anticorrosive properties, better tribological properties				
		2020					
		2030					
8.	Diagnostic-research equipment	2010	Light, confocal laser, scanning electron, transmission electron, atomic force microscopes, X-ray diffractometer, X-ray microanalyzer, GDOES spectrometer, hardness, microhardness, scratch testers, profilometer, potentiostat				
		2020					
		2030					
9.	Life cycle period	2010	Prototype (8)	Prototype (8)	Prototype (8)	Prototype (8)	Prototype (8)
		2020	Growth (7)	Growth (7)	Growth (7)	Growth (7)	Growth (7)
		2030	Base (3)	Mature(5)	Mature(5)	Mature(5)	Base (3)
10.	Production type	2010	Unit and small-scale serial	Unit and small-scale serial	Unit and small-scale serial	Unit and small-scale serial	Unit and small-scale serial
		2020	Small- and medium-scale serial	Small- and medium-scale serial	Small- and medium-scale serial	Small- and medium-scale serial	Small- and medium-scale serial
		2030	Mass	Unit and small-scale serial	Unit and small-scale serial	Mass	Unit and small-scale serial
11.	Production organization form	2010	Cellular non-rhythmic	Cellular	Cellular	Cellular	Cellular
		2020	Linear rhythmic	Cellular rhythmic	Cellular rhythmic	Cellular rhythmic	Cellular rhythmic
		2030	Linear	Rhythmic	Cellular rhythmic	Linear	Cellular rhythmic
12.	Machine park modernity	2010	Excellent (10)	Excellent (10)	Excellent (10)	High (8)	High (8)
		2020	High (8)	High (8)	High (8)	High (8)	High (8)
		2030	Medium (5)	Medium (5)	Medium (5)	Medium (5)	Moderate (6)
13.	Automation and robotisation	2010	Excellent (10)	High (8)	High (8)	High (8)	Quite high (7)
		2020	Excellent (10)	Excellent (10)	Excellent (10)	Very high (9)	High (8)
		2030	Excellent (10)	Excellent (10)	Excellent (10)	Excellent (10)	Moderate (6)
14.	Quality and reliability	2010	High (8)	Quite high (7)	High (8)	Moderate (6)	High (8)
		2020	Very high (9)	High (8)	High (8)	High (8)	High (8)
		2030	Excellent (10)	High (8)	High (8)	Very high (9)	Very high (9)
15.	Proecology	2010	Excellent (10)	High (8)	Very high (9)	High (8)	Quite high (7)
		2020	Very high (9)	High (8)	Very high (9)	Very high (9)	Quite high (7)
		2030	Very high (9)	High (8)	Very high (9)	Very high (9)	Very high (9)

No.	Analysed factor	Time interval	Analysed technology				
			A	B	C	D	E
16.	Organisation type	2010	Large and medium-sized enterprises, research and scientific centres, technological parks				
		2020	Large and medium-sized enterprises, research and scientific centres, technological parks				
		2030	Small and medium-sized enterprises, research and scientific centres, technological parks				
17.	Represented industrial branches	2010	Medicine, automotive industry, sports, military equipment, aviation, aeronautics	Medicine, automotive industry, sports, military equipment, aviation, aeronautics, civil engineering	Medicine, automotive industry, military equipment, aviation, aeronautics	Automotive industry, military equipment, aviation, aeronautics	Automotive industry, aviation, civil engineering, sport
		2020	Medicine, automotive industry, sports, military equipment, aviation, aeronautics, civil engineering	Medicine, automotive industry, sports, military equipment, aviation, aeronautics	Medicine, automotive industry, military equipment, aviation	Automotive industry, sport, military equipment, aviation, aeronautics	Automotive industry, sport, aviation
		2030	Medicine, automotive industry, aviation and others	Medicine, automotive industry, aviation and others	Medicine, automotive industry and others	Automotive industry, sport, aviation and others	Automotive industry, sport, aviation and others
18.	Staff education level	2010	Excellent (10)	Very high (9)	Very high (9)	Very high (9)	Very high (9)
		2020	High (8)	Medium (5)	High (8)	Medium (5)	Medium (5)
		2030	Moderate (6)	Medium (5)	Moderate (6)	Medium (5)	Medium (5)
19.	Engagement of scientific-research staff	2010	Excellent (10)	Quite high (7)	Very high (9)	Excellent (10)	Quite high (7)
		2020	Excellent (10)	Quite high (7)	Excellent (10)	Very high (9)	Quite high (7)
		2030	High (8)	Quite high (7)	Moderate (6)	Very high (9)	Quite high (7)
20.	Capital requirements	2010	Excellent (10)	Very high (9)	Very high (9)	Very high (9)	Quite high (7)
		2020	High (8)	Very high (9)	High (8)	Quite high (7)	Quite high (7)
		2030	Medium (5)	Quite low (4)	Moderate (6)	Medium (5)	Low (3)
21.	Production size determining profitability in firm	2010	Medium (5)	Moderate (6)	Medium (5)	Moderate (6)	Medium (5)
		2020	Quite high (7)	Quite high (7)	Quite high (7)	Quite high (7)	Quite high (7)
		2030	High (8)	High (8)	Very high (9)	High (8)	High (8)
22.	Production size in the country	2010	Low (3)	Very low (2)	Very low (2)	Low (3)	Very low (2)
		2020	Medium (5)	Medium (5)	Quite low (4)	Moderate (6)	Medium (5)
		2030	High (8)	Quite high (7)	Moderate (6)	Very high (9)	Quite high (7)

6. Conclusions

Materials science and foresight researches described in this paper are a part of own wider actions aiming to isolate, investigate, characterise and define strategic perspectives of developmental priority innovative technologies of surface engineering of engineering materials in the process of technological e-foresight. In this paper, the scope of research and analysis was limited only to laser surface treatment of selected Mg-Al-Zn casting magnesium alloys. The paper presents the results of experimental and comparative interdisciplinary researches located mainly in the area of materials surface engineering and technological foresight, and to a lesser extent, artificial intelligence, statistics, information technology, machine building and operation and strategic and operational management. The main goal of outcarried researches was to determine the value of laser treatment technology of casting magnesium alloys in the background environment with recommended procedure strategies, the strategic development tracks including the influence of this treatment on quality, microstructure and properties of surface layers obtained by cladding and remelting casting magnesium alloys. The final result closing the whole experimental and competitive works was the creation of a series of roadmaps of the analysed groups of technologies. The outworking and the use of this tool allowed to present various factors characterising directly and indirectly examined groups of technologies taking into consideration forecasts and perspectives of their development in different time intervals of taken time horizon in a uniform transparent format. As it was shown in the discussed example, roadmaps of technology are very convenient and practical tool for comparative analysis, making easier to choose technologies in terms of selected criteria, and complemented by technological cards including precise technical details which allow to implement technology in industrial practice. A very important advantage of a roadmap of technology is its flexibility, which allows to complement and expand with additional sublayers, depending on emerging needs.

Analyzing the achieved results it is clear that it will be possible to use tested Mg-Al-Zn alloys and technologies of their treatment, and alternative surface layers to ensure the best possible properties of a "quasi-gradient" on the cross-section of products, in industrial practice, especially in aerospace and automotive industries where low weight products, increased abrasion resistance, high mechanical properties as well as repair parts of ready-made components are required. The requirement to reduce the weight of car components as a result of legislation limiting emission created renewed interest in magnesium [103]. Recent research and development studies of magnesium and magnesium alloys have focused on weight reduction, energy saving and limiting environmental impact. Together with mass decreasing the driving parameters improve, this is connected mainly to the dynamic behaviour of the vehicles. A need for reduction of the transportation vehicle mass is very important, because more and more transportation vehicles is equipped with additive accessories (like airbags, safety belts, raising and lowering system for car windows, etc.) which increases mass and have influence not only on safety, but also on usable attractiveness of these vehicles [57, 90, 94, 95, 99, 100, 102-104, 108, 109]. Volkswagen was the first to apply magnesium in the automotive industry on its Beetle model, which used 22 kg magnesium in each car of this model [103]. General Motors in their big cars (Savana & Express) use 26.3 kg of casting magnesium alloys, and in smaller cars (Safari, Astro) – 16.5 kg, Ford F – 150 – 14.5 kg, VW Passat and Audi A4 and A6 from 13.6 to 14.5 kg, Alfa Romeo – 9.3 kg. The engine weight of Audi V8 Quattro model was reduced 5 kg comparing to other Audi eight-cylinder by using magnesium components. The instrument panel for the GMH-van vehicle is made of magnesium alloy which weights 12 kg as opposed to the 18 kg in steel [99, 102, 103]. Magnesium substitution in the automotive industry has steadily increased over the last decade, in parts such as valve covers, instrument panels, steering wheels, steering wheel armatures, cylinder block heads, transmission cases, clutch housings, lower crank cases, intake manifolds, brake and gas pedals and seat bodies [94, 99, 100, 102, 103]. A steering wheel is the component that has received the greatest worldwide acceptance which made of Mg alloy. Assuming 20 kg of magnesium alloy components will be used instead of alternatives on 25% of the 40 million cars produced, one calculates that the car manufacturing industry requires 200,000 tons of magnesium alloys [103]. The strategy regarding the use of Mg in vehicles to achieve a "second Mg age" is based on the applications for cast components; here further development of Mg properties (e.g. improved creep resistance) will be helpful. Mg components in body, sheet and extrusion applications will follow in niche and premium vehicles supported by new Mg alloys with improved ductility and energy absorption. Significant research is still needed on magnesium processing, alloy development, joining, surface treatment, corrosion resistance, and mechanical properties improvement [94, 99, 100, 102, 103]. Different coating methods are used to increase the properties of surface layer of magnesium alloys (corrosion resistance, lubricity, high frictional-resistance, non-wetting properties, hardness, decorative and etc.), e.g. galvanic coating, anodisation, coating using the PVD method, laser cladding/ remelting.

The presented results of materials science researches show a beneficial improvement of the mechanical properties of material. Laser cladding and remelting of all mentioned carbide and oxide powders affect the fragmentation of the structure throughout the range of laser power and the diversity of grain size in different zones of the surface layer of the examined alloys. The surface layers are divided into two zones: remelting (SP) and the heat affected ones (HAZ), whose characteristic size (layer thickness) is dependent on the applied laser power and used alloying material. The thickness of the achieved surface layer of casting magnesium alloys increases with the increase of laser power from 1.2 to 2.0 kW and ranges from tenths of a mm to about 4 mm (in the MCMgAl12Zn1 alloy alloyed with SiC). The structure of the material solidifying after laser remelting is characterized by a diverse morphology and consists of a dispersive particles of used carbide: TiC, WC, VC, SiC or aluminium oxide Al_2O_3, with the dendrites of lamellar eutectic and $Mg_{17}Al_{12}$ and Mg in inter-eutectic areas, whose main axes are oriented along the lines of heat abstraction and the precipitates containing Mg and Si, as well as phases of high concentrations of Mn and Al. In addition, the morphology of the composite structure of alloyed area was achieved due to the change of the alloy from hypoeutectic into hypereutectic, depending on the arrangement of alloyed elements and change of the process parameters of laser surface treatment. The applied laser processing parameters also affect the surface roughness of casting magnesium alloys after laser treatment. With invariable speed of scanning and intensity of powder feed together with the increase of laser power surface roughness is reduced. Measured surface roughness is in the range from 4.0 μm to 42.5 μm. In Mg-Al-Zn casting magnesium alloys which underwent cladding and remelting by carbides and oxides, resulting in fragmentation of the grains and the presence of hard particles of used powders, maximum hardness of about 103 HRF was obtained for the MCMgAl12Zn1 alloy alloyed with titanium carbide with a laser power of 1.2 kW and the alloying speed of 0.5 m/min. One may think that such manufactured materials may be used in mass production of items of equipment and vehicle construction in the automotive and aviation industry.

Generally, this paper, which is a practical application of methodology of foresight and materials science researches to a given technology having practical industrial meaning, indicates that it is intentional, reasonable and useful to use the methodology presented theoretically in previous works [40, 41] to analyze the value, strategic development tracks and the outworking of technology roadmaps of forming structure and surface properties of engineering materials. This methodology will therefore be used for other technologies and in relation to other engineering materials in their further own researches and presented in subsequent publications. It is intentional also to use not only the evaluations made by key experts, but also to analyse the results of surveys carried out by a broad group of industry experts in which the possibilities of e-foresight, theoretically worked out in the own work will be fully applied [41].

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