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LONG-TERM DEVELOPMENT PERSPECTIVES OF SELECTED GROUPS OF ENGINEERING MATERIALS USED IN THE AUTOMOTIVE INDUSTRY

DŁUGOTERMINOWE PERSPEKTYWY ROZWOJU WYBRANYCH GRUP MATERIAŁÓW INŻYNIERSKICH STOSOWANYCH W PRZEMYŚLE MOTORYZACYJNYM

The purpose of the article is to present the results of comparative quantitative analysis of selected materials (steel, magnesium and aluminium alloys) and manufacturing technologies, to indicate their development outlooks and to present its application opportunities particularly in the automotive industry. Moreover in this article describes the application of the computer-integrated prediction of development for objectivised selection of a material and surface treatment technology, so that product properties can be achieved as are expected by a client. In a broad array of applications of the computer-integrated prediction of development in the field of material engineering, including materials surface engineering, experiment planning can be distinguished, usually including the selection of: a research material, surface treatment technology, construction solution and/or methods to review the final outcome achieved against the anticipated outcome. A material for the planned materials science experiments and its surface treatment technology, the application of which contributes most to meeting the high requirements set by a prospect product used, was selected in this work using a dendrological matrix of technology value. The dendrological matrix falls into to a group of contextual matrices allowing presenting graphically a quantitative assessment of the factor, phenomenon or process investigated while taking into account two analysis factors placed on the X and Y axis of the matrix. An evaluation classifying the three groups of materials analysed, i.e. casting magnesium alloys, casting aluminium alloys, constructional steels and their surface treatment technologies, to the individual quarters of the matrix was made based on the results of own materials science and heuristic experiments supported with a review of the literature.

Considering the three groups of materials subjected to an expert assessment using a dendrological matrix being inherent part of materials surface engineering development prediction methods. Aluminium cast alloys has achieved here the best position. It was further demonstrated that laser treatment is a technology with the highest potential and attractiveness in the context of applying aluminium casting alloys for surface treatment. The metallographic examinations carried out give grounds to state that the ceramic powder alloying or feeding process will be carried out successfully in case of the aluminium alloy substrate, the powder particles will be distributed uniformly in the investigated surface layer, and that the particular layers is without cracks and failures and tightly adhere to the cast aluminium material matrix.

With regard to the above, dynamic development achieved by exploitation of numerous application and development opportunities, especially strong prospects in the automotive industry, aviation industry, military sector, sport sector and in civil engineering is a recommended by appliance of long-term action strategy.

Keywords: engineering materials, surface treatment, automotive industry, dendrological matrix, heuristic investigations

Głównym założeniem artykułu jest przedstawienie wyników opracowanej ilościowej analizy porównawczej wybranych grup materiałów inżynierskich (stali, stopów magnezu i aluminium) oraz technologii ich obróbki, w celu określenia perspektyw rozwoju oraz możliwości zastosowania badanych materiałów w szczególności w przemyśle motoryzacyjnym. Ponadto w artykule opisano zastosowanie analizy komputerowej pozwalającej na prognozowanie dalszego rozwoju opisywanych grup materiałów oraz technologii ich obróbki powierzchniowej, pozwalającej na uzyskanie oczekiwanych przez klienta własności produktu. W szerokim wachlarzu zastosowań komputerowo-zintegrowanej predykcji rozwoju w dziedzinie inżynierii materiałowej, w tym inżynierii powierzchni, wyróżnić można poszczególne stadia planowania eksperymentu, obejmujące zazwyczaj dobór m.in.: materiału do badań, technologii obróbki powierzchniowej materiałów, zastosowanych rozwiązań konstrukcyjnych i/lub metody oceny wyników końcowych oraz ich porównanie z wynikami podlegającymi predykcji. Materiały do badań oraz technologie ich obróbki powierzchniowej, których zastosowanie w szerokim zakresie zaspokaja wysokie wymagania klientów odnośnie aplikacji, zostały wyselekcjonowane przy użyciu matrycy dendrologicznej uwzględniającej założone parametry technologiczne. Matryca dendrologiczna zaliczana jest do grupy macierzy kontekstowych pozwalających na graficzną prezentację oceny ilościowej danego współczynnika, zjawiska lub badanego procesu, biorąc pod uwagę dwa czynniki analizy umieszczone na osiach X i Y matrycy. Klasyfikacja trzech grup analizowanych materiałów, w tym odlewniczych stopów magnezu, stopów aluminium i stali

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konstrukcyjnych oraz technologii ich obróbki powierzchniowej, do poszczególnych ćwiartek matrycy dendrologicznej dokonano na podstawie wyników badań własnych materiałów oraz eksperymentów heurystycznych wspieranych studium literaturowym.

Na podstawie wykonanej analizy ilościowej, prezentowanej w artykule najwyżej ocenione zostały odlewnicze stopy aluminium. Stwierdzono także, że obróbka laserowa jest technologią o najwyższym potencjale i atrakcyjności w kontekście obróbki powierzchniowej odlewniczych stopów aluminium. Przeprowadzone badania metalograficzne dają podstawę do stwierdzenia, że stopowanie lub wtapianie laserowe z zastosowaniem proszków ceramicznych będzie realizowane z powodzeniem w przypadku podłoża aluminiowego, cząstki proszku będą rozprowadzane równomiernie w badanej warstwie powierzchniowej, poszczególne warstwy będą pozbawione wad i pęknięć oraz będą ściśle przylegały do osnowy aluminiowej.

Mając na uwadze powyższe przesłanki należy pamiętać, że dynamiczny rozwój w zakresie aplikacji oferowanych w szczególności przez branżę motoryzacyjną, przemysł lotniczy, sektor wojskowy, sportowy oraz sektor z zakresu inżynierii lądowej bardzo często wymaga stosowania strategii związanej z działaniem długoterminowym.

1. Introduction

Due to instrumentation and time constraints, it is infeasible to perform thorough research, especially experiments, for all the possible solutions, encompassing a full combination of materials with the expected mechanical and functional properties and the manufacturing technologies ensuring such properties. Especially steel as well as light alloys like aluminum and magnesium which have advantages like good ductility, better noise and vibration dampening characteristics than other materials excellent castability, high stability of the size and shape, low shrinkage, low density connected to high strength compared to low mass, as well recyclability, which makes it very attractive for industrial applications. The need for aluminum, magnesium alloys as well as steel materials is connected mainly to the development of automobile industry. The share of aluminum alloys in the total mass of the vehicle of reaches today about 200 kg. This material is used for example for the powertrain components (pistons, drive shafts, cylinder heads, cylinder blocks, gear boxes), bodies parts (chassis frame and vehicles bodies, truck cabins, engine bonnet, doors, seat structures, bumpers, roof cargo rails), chassis (brake systems, wheels, rear- and front axles) and others like: semi-trailers, fuel tanks or heat exchangers (Fig. 1). It should be also mentioned, that currently about 70% of castings made of magnesium alloys are produced for the automotive industry, for example for: suspension components, front- and back car axle, housing the main shaft, steering column brackets, dashboards, seat components, steering wheels, ignition system components, air filters, wheels, oil pans, transmission housing components, door and window frames, and others (Fig. 1).

An example of a relatively new application for car- and truck elements – in the above-mentioned area of constructional materials - are austenitic steels, where the high plasticity range caused by twinning, possibly assisted by a martensitic transformation, induced by cold plastic deformation allows a significant increase of the passenger passive safety of road vehicles (Fig. 1) [1, 2].

So the huge amount of needed research activity makes it necessary to perform lot of investigation. Therefore the idea presented in this paper allowing it to do in a new way, with an objectivised selection of a material for research and its surface treatment technology, what is also essential at the planning phase of a materials science experiment. A methodology of computer-integrated prediction of development [3] is dedicated to such task, enabling to perform an expert assessment and present results thereof graphically using contextual matrices being a tool of a quantitative analysis that is very desirable in engineering circles. The correctness of the newly developed methodology was reviewed with 35 examples [3-11] grouped into the following thematic units, for example: laser treatment of different substrates, vacuum technologies in surface engineering, powder metallurgy, surface technologies of polymers.

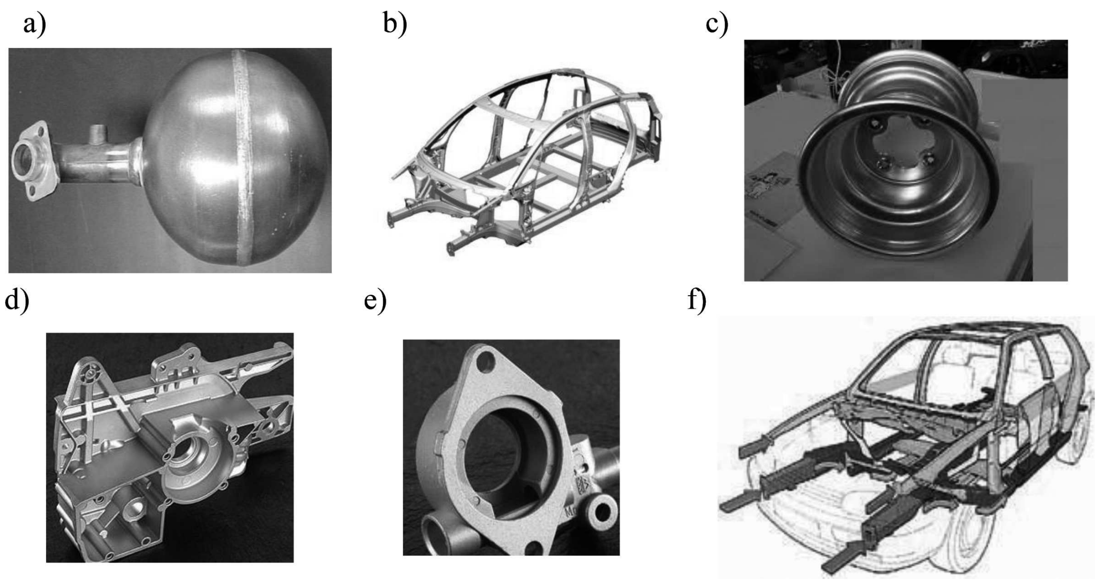

Fig. 1. Examples of parts made from aluminum alloys: a) – barometric pressure reservoir – VW Phaeton, b) – Audi A2 konstruction, c) – magnesium alloy wheel d) – crankcase casing, e) – cooling system pump casing; from austenitic steel f) – door posts A- i B; door- and roof strengthening; bumpers, seats parts, other components of complex shape

A full set of materials science investigations was carried out each time substantiating the practical fields of applications supported with studies into the literature pertaining to the case studies under consideration.

The prediction technique applied is an innovative and a very prospective research method belonging to the group of heuristic methods whereupon experts are surveyed to convert hidden implicit knowledge into explicit knowledge openly available to the public, expressed quantitatively using engineering analytical tools. The synergic interaction and cross supplementation of the materials science, computer and foresight studies is one of the most promising approaches aimed at carrying out objectivised predictions of development, as well as to appraise current and future research and deployment opportunities. Moreover, as opposed to the methods commonly used in the area of management, such as: STEEP analysis, SWOT analysis, trends extrapolation, benchmarking, econometric analyses that – out of necessity – have been implemented to date for material engineering, the method of computer-integrated prediction of development represents a very attractive option, especially developed and devoted to this area of knowledge. The approach described takes into account in particular, therefore, a specificity of materials science experiments usually requiring costly research instruments, a technological and implementation aspect and the necessity to satisfy a client's demands through the Make to Order (MTO) strategy. This article describes the application of the computer-integrated prediction of development for objectivised selection of a material for research and selection of such material's surface treatment technology so that product properties can be achieved as are expected by a client.

2. Methodology

In a broad array of applications of the computer-integrated prediction of development in the field of material engineering, including materials surface engineering, experiment planning can be distinguished, usually including the selection of: a research material, surface treatment technology, construction solution and/or methods to review the final outcome achieved against the anticipated outcome. The similar issue usually re-emerges at the stage of processing the final results of research when, due to a limited size of a publication, only certain, most essential and most representative investigations or such crucial for the overall considerations pursued should be selected for presentation from a broad spectrum of the investigations carried out. The approach proposed enjoys a widespread popularity among scientists as signified by implementations thereof in scientific works, including doctoral and habilitation dissertations [4-11]. A material for the planned materials science experiments and its surface treatment technology, the application of which contributes most to meeting the high requirements set by a prospect product used, was selected in this work using a dendrological matrix of technology value. The dendrological matrix falls into to a group of contextual matrices allowing to present graphically a quantitative assessment of the factor/phenomenon/process investigated while taking into account two analysis factors placed on the X and Y axis of the matrix. The rates placed in the contextual matrices are based on the result of a multi-criteria analysis the basis of which may be results of materials science experiments, experts' opinions and/or an outcome of a literature review. A methodological structure of the dendrological matrix refers to the portfolio methods commonly known in management sciences [12-14] serving to characterise a portfolio of products offered to a client by an enterprise. The most renowned portfolio method is the *Boston Consulting Group* – BCG matrix [15] enjoying its unique popularity due to references to simple associations and intuitive reasoning. The same applies to the dendrological matrix where the factor/phenomenon/process analysed, depending on the assessment result, is compared figuratively to various trees. A research approach proposed based on a preference analysis consists of classifying objects within a specific scale, as expressed by a precedence hierarchy of objects presented in an ordered manner by a preferential series. The weighted scores method was used, in particular, for a comparative evaluation aimed at classifying the suitability of particular elements of an analysis in the context of relationships between them. The evaluation criteria relativisation method was also used where differences are assumed in the relevance of the criteria applied and the principle of acceptability assuming the use of a selection filter classifying a given object positively or negatively. The method of weighted scores allows for a multi-criteria aggregated evaluation using a scale with intervals. A universal scale of relative states, being a single-pole positive scale without zero, where 1 is a minimum rate and 10 an extraordinarily high rate, was employed in the research undertaken.

The dendrological matrix [3] of values allows it in a relatively simple way to visualize the results of the assessment of individual groups of materials and processing technologies in terms of:

- potential, which is the real objective value of the analysed research area – the so-called hard, measurable features and,
- attractiveness, reflecting the subjective perception of the given thematic range of potential users – so-called soft property.

The potential of a given group presented on the horizontal axis is a result of a multi-criteria analysis carried out on the basis of expert opinions and extensive literature data, taking into account different potential types: creative-, application-, quality-, technical- and development potential. The vertical axis shows the importance of the attractiveness of the group, which is an average value of expert evaluation and literature data of the research area carried out on the basis of specific criteria corresponding to the economic, cultural, scientific and systematic attractiveness. Depending on the evaluation of the potential and attractiveness level, determined on the basis of expert opinion and literature study, each of the analysed materials and surface engineering technologies, was placed in one of the quarters of the dendrological matrix.

The dendrological matrix used for evaluating a material's suitability and, further, its surface treatment technology, is comprised of four quarters where objects are classified depending on how their attractiveness and potential is evaluated. The first quarter, referred to as a soaring cypress, is characterised by high attractiveness and a limited potential.

If an object is classified to the second quarter, a so-called wide-stretching oak, this reflects the best possible situation commensurate with the achievement of a future success. The third quarter, i.e. a quaking aspen, is least promising, with the future success being either unlikely or impossible. Those elements are classified to the fourth quarter, referred to as a rooted dwarf mountain pine, characterised by limited attractiveness and a large potential, which may ensure the achieved progress provided the right strategy is put into place. An evaluation classifying the three groups of materials analysed, i.e. casting magnesium alloys, casting aluminum alloys, constructional steels and their surface treatment technologies, to the individual quarters of the matrix was made based on the results of own materials science and heuristic experiments supported with a review of the literature.

3. Investigation results

The developed technologies focusing on hybrid surface layers, so-called quasi-composite MMCs structures (characterized by phase composition gradient, chemical composition and functional gradient) in the process of laser alloying and/or feeding with ceramic particles into the surface of the treated materials provide a complete and comprehensive solution for modeling of engineering materials. Currently, the concept of functional lightweight materials is a priority and the most investigated worldwide field of material science and engineering concerning the production and processing of new developed engineering materials. Previous studies about the effects of laser beam effect on various materials, including magnesium alloys as well as tool steels, based on the authors own long-term investigation, summarizing the experience of laser surface treatment reveal that, there are chemical composition and structure changes which are different from those occurring during conventional heat treatment [9,17-27]. This causes, that the laser treated elements shows higher hardness (especially for TaC alloyed steel surface – Fig. 2), corrosion resistance, abrasion resistance and thermal fatigue (Figs. 3) compared to the traditionally treated materials.

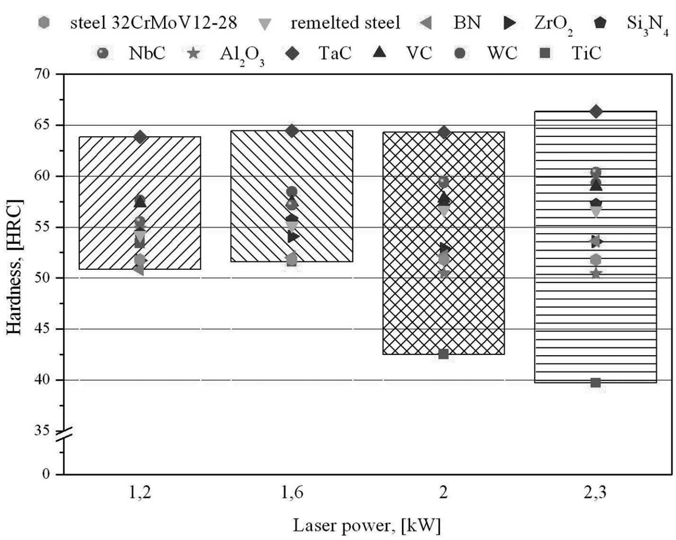

Fig. 2. Hardness measurement results of the 32CrMoV12-28 steel alloyed with ceramic powders

In general the hot work tool steel has a ferritic structure with homogeny distributed carbides in the metal matrix in the annealed state. In areas, which are between the solid and molten state dendritic structure with large dendrites can be found [17-21]. The EDS point wise analysis confirms the presence of carbide ceramic particles in the matrix in form of big conglomerates. The required hardenability for this tool steel was achieving after a suitable tempering time, which assures melting of the alloying carbides in the austenite. The structural investigations carried out using the high power diode laser allows to compare the surface layer as well as the shape and depth of the remelting area (Figs. 4-9). It was noticed that the depth of remelting area grows together with the increasing laser power [17-21].

The performed investigations of the alloyed hot work tool steel 32CrMoV12-28 show a clear effect of the applied ceramic powder used for alloying (Figs. 8, 9). It can be also clearly recognized the influence of the used laser power in the range of 1.2; 1.6; 2.0 and 2.3 kW on the shape and thickness as well as the particle distribution of the remelted material (Fig. 9). It can be seen that with the increasing laser power the distribution of the remelted metal in the steel substrate increases. Microstructure presented on Figs. 8, 9 shows a dendritic structure in the remelted area. There are also WC particles present distributed in the matrix. There is also a clear relationship between the employed laser power and the dendrite size, namely with increasing laser power the dendrites are larger [17-21].

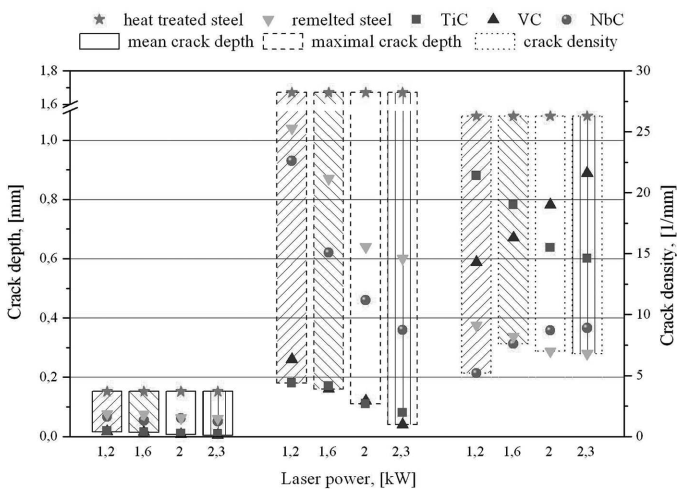

Fig. 3. Influence of laser power and the type of alloyed surface layer of the 32CrMoV12-28 steel on mean crack depth, maximal crack depth and crack density occurred during the thermal fatigue test

It was found, that in case of WC powder the difference of the remelted area thickness is about 9 times larger in case of 2.3 kW power compared to 1.2 kW laser power. Also for the same laser power (2.3 kW) the surface layer thickness increases from 1.9 mm for WC powder to 2.2 mm for TiC powder and to 2.3 mm in case of the VC powder (Fig. 10).

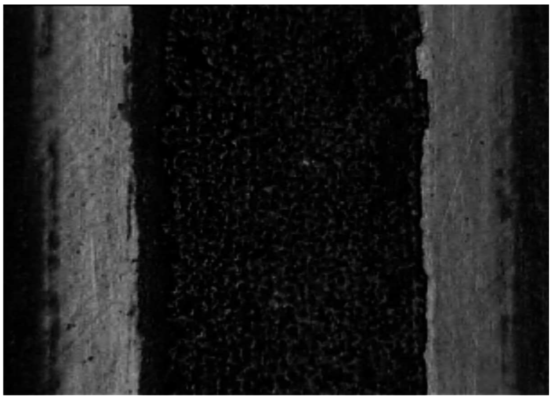
Fig. 4. 32CrMoV12-28 steel alloyed with TiC powder, laser power 1.2 kW, mag. 10x

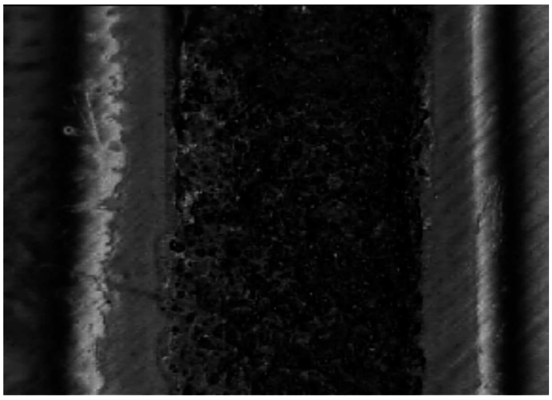
Fig. 5. 32CrMoV12-28 steel alloyed with WC powder, laser power 2.3 kW, mag. 10x

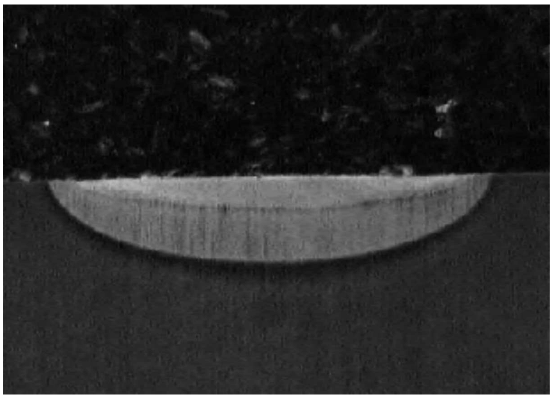
Fig. 6. 32CrMoV12-28 steel alloyed with Si_3N_4 powder, laser power 2.3 kW, mag. 10x

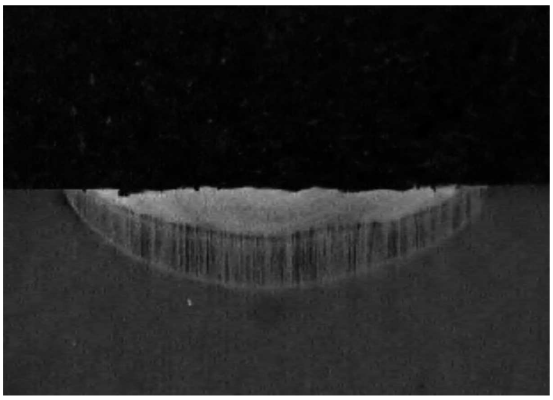
Fig. 7. 32CrMoV12-28 steel alloyed with ZrO_2 powder, laser power 2.3 kW, mag. 10x


Fig. 8. 32CrMoV12-28 steel alloyed with TiC powder, SE SEM, mag. 1000x

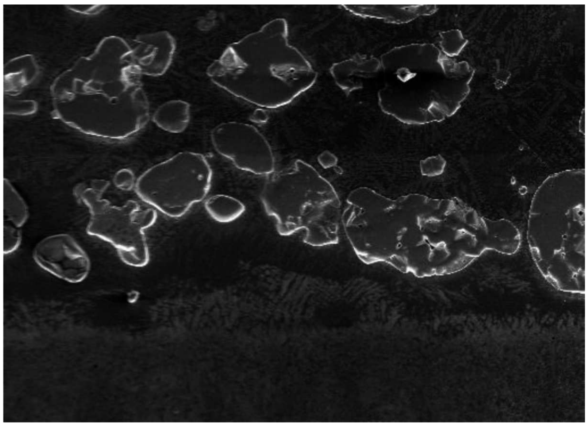
Fig. 9. 32CrMoV12-28 steel alloyed with WC powder, SE SEM, 2,3 kW, mag. 1000x

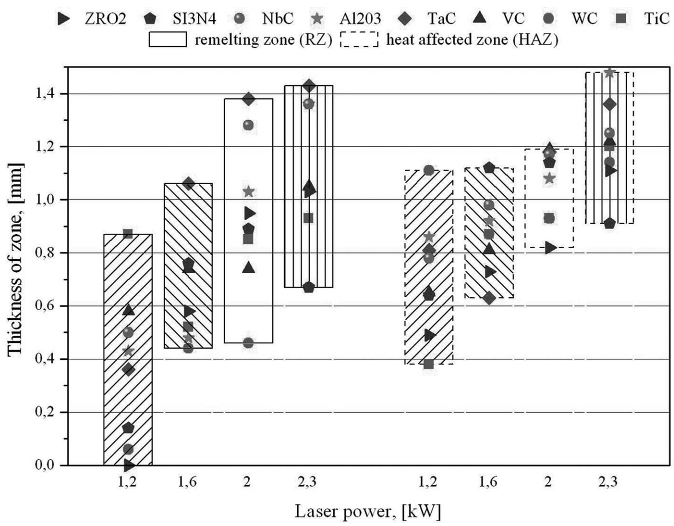

Fig. 10. Influence of laser power on thickness of the remelted zone RZ, heat affected zone HAZ and the surface layer 32CrMoV12-28 steel after laser alloyed

Similar relationships were found in case of magnesium alloy (Figs. 11-18), where the used WC, SiC and TiC powder particles are present in the laser treated magnesium surface.

After laser feeding, there was revealed - based on the performed metallographic investigations carried out on light microscope – the presence of several zones in the remelted surface layer of the cast magnesium alloys, with the thickness and the occurrence depending on the laser processing parameters and the used powder and substrate type [9, 28-32]. Starting from the top zone of the surface layer there occurs a zone rich in non-dissolved particles located on the surface of magnesium alloys, the next zone is the remelting area (RZ), the thickness and shape strictly depending on the laser power used as well the heat affected zone (HAZ) (Fig. 11).

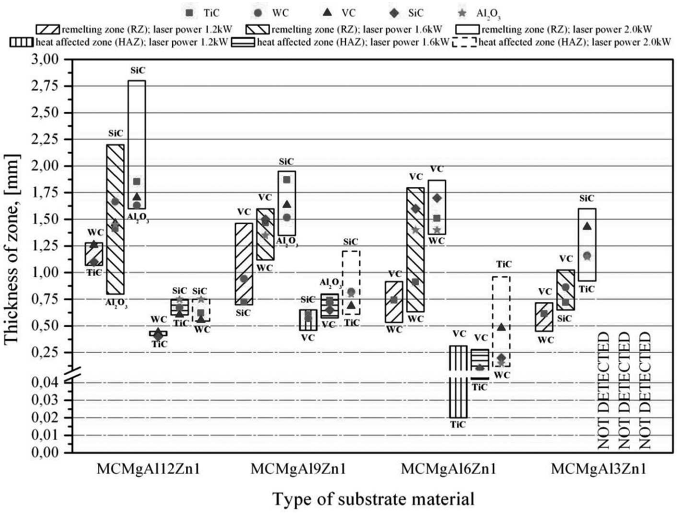

Fig. 11. Influence of laser power on thickness of the remelted zone RZ, heat affected zone HAZ and the surface layer of cast magnesium alloys after laser feeding

These zones, depending on the used laser power and the ceramic powder are of varying thickness and shape. Obtaining the effect of significant refinement of the grains is possible only thanks to fast heat transport from the remelting lake through magnesium substrate of high thermal capacity and very good thermal conductivity, which, in turn, results with the increase of grain boundaries amount representing a solid obstacle for the dislocations movement and therefore reinforcement of the material [9, 28-32] (Figs. 12-17). The structure of the solidified material after laser treatment is characterised with a zone construction with diversified morphology related to the crystallisation of magnesium alloys. Multiple change of crystal growth direction has been observed for these areas (Figs. 12-17). In the area located on the boundary between the solid and liquid phase, minor dendrites occur the main axes thereof oriented along with the heat disposal directions [9, 28-32].

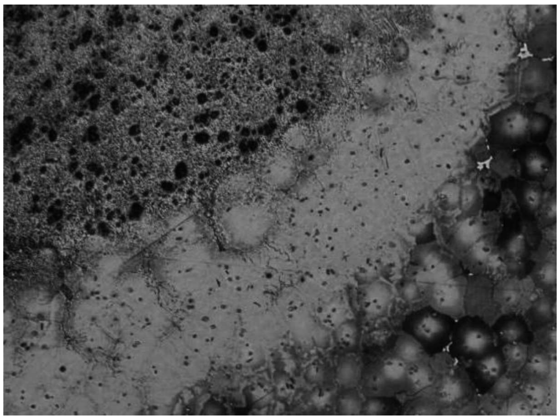

Fig. 12. Remelting path edge of the AZ121 alloyed with WC particles, scan rate: 0.75 m/min, laser power: 2.0 kW, mag. 200x

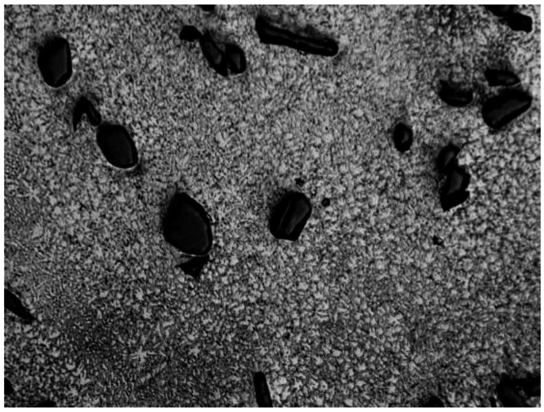

Fig. 13. Central zone of the AZ61 alloyed with SiC particles, scan rate: 0.75 m/min, laser power: 2.0 kW, mag. 500x

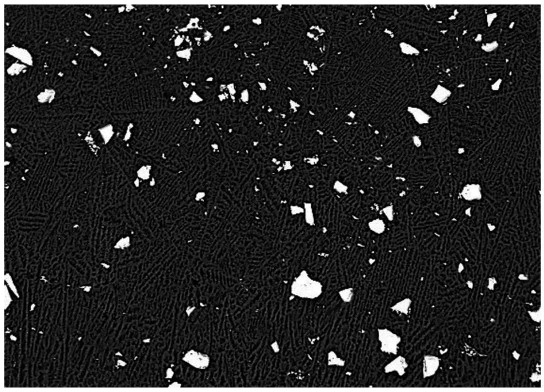

Fig. 14. Central zone of the AZ31 alloyed with TiC particles of the, scan rate: 0.75 m/min, laser power: 1.2 kW, mag. 500x

Fig. 15. Surface layer of the AZ61 alloyed with SiC particles, scan rate: 0.75 m/min, laser power: 1.6 kW, mag. 100x

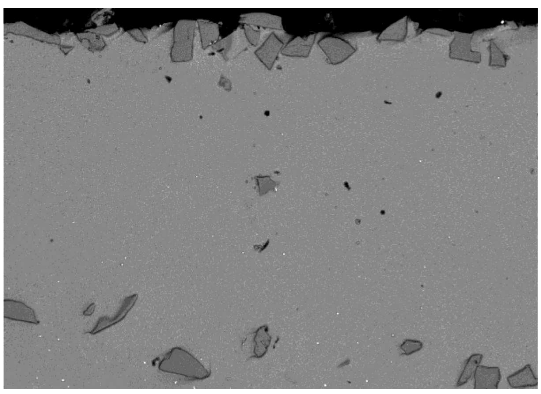

Fig. 16. Surface layer of the AZ61 alloyed with SiC particles, scan rate: 0.5 m/min, laser power: 1.5 kW, mag. 100x

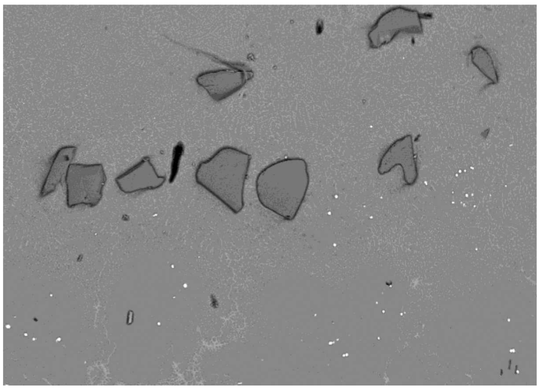

Fig. 17. Surface layer of the AZ61 alloyed with SiC particles, scan rate: 0.5 m/min, laser power: 1.5 kW, mag. 100x

Effect of laser feeding conditions, namely: laser power, feeding speed, type of the used ceramic powder and the applied substrate on hardness and hardness increase of the surface layer of the cast magnesium samples were investigated using the Rockwell hardness method. The measured hardness of the surface was obtained in the range from 32.4 to 105.1 HRF (Fig. 18). As a result of the performed investigations it was found, that the highest hardness increase was observed in case of the MCMgAl6Znl and MCMgAl3Znl cast magnesium alloys – as materials with low concentration (<6%) of aluminum, which is mainly responsible for precipitation strengthening of the studied, laser treated alloys, fed with ceramic particles [9].

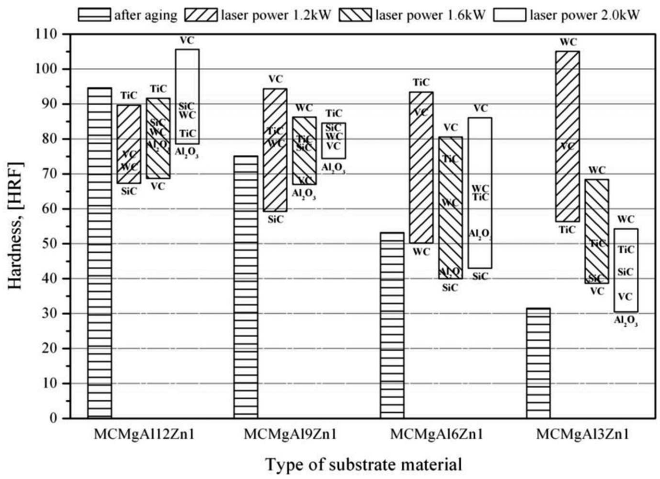

Fig. 18. Hardness measurements results of cast Mg-Al-Zn magnesium alloys samples, after aging and laser feeding

This results together with the values of preliminary investigations carried out by the team of authors is one of the most important factor to undertake this proposed research activity of laser surface treatment of aluminum alloys (Figs. 19-23). In the initial step of the planning of investigation, for selection the specific research topics, there was used an innovative science-heuristic analysis method for selection of the investigated material (substrate) and the processing technology using dendrological matrix for a complex evaluation and choosing the most promising alloy from the Al-Si-Cu material group for current and future applications [28-32].

Microstructure investigation of the aluminum alloys fed with WC, SiC and Al_2O_3 ceramic powder (Figs. 19-23) was performed. It was found out, as a result of the microstructure investigations, that there are particles of SiC (Fig. 19) and WC (Fig. 20), present in the laser treated surface layer and that there are no pores or cracks in the produced coating or any defects and failures occurs in this layer. For the WC powder the particles are partially present on the bottom of the remelted zone. In case of Al_2O_3 (Fig. 21-25) powder there is obtained a sintered surface layer confirmed by the EDS surface mapping (Fig. 23).

Occasionally occurred discontinuity of the layer can be seen as a product of the heat transfer process and may be neutralised by properly adjusted powder quality and powder feed rate. The thickens of the powder feed depth can be determined in the range up to 150 μm (Fig. 21) in case of Al_2O_3 powder fed with laser power of 1.5 kW and 1.5 mm for laser power of 2.0 kW (Fig. 22). It was also found that the examined layers consists of three subzones – the remelted zone, the heat influence zone with a dendritic structure and the substrate material (Fig. 25) [26-27]. Further investigations should revealed the exact morphology and nature of these sublayers after alloying with different ceramic powders, different process parameters. Moreover there can be recognised, that the obtained surface are characterised by a well formed structure without any breaks or defects, they are uniformly horizontally deposited in the substrate surface.

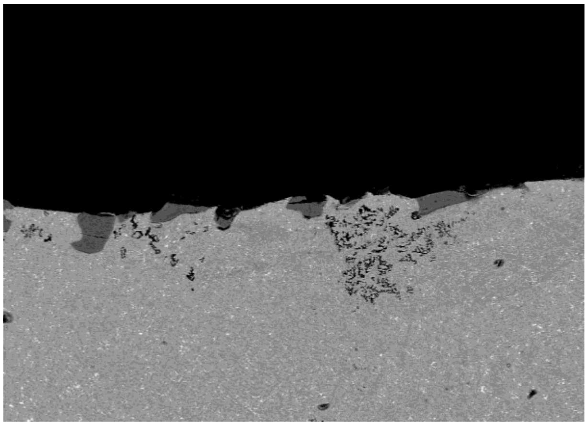

Fig. 19. Surface layer of the AlSi9Cu alloyed with SiC particles, scan rate: 0.25 m/min, power 2.0 kW, feed rate 2.0 g/min, mag. 100x

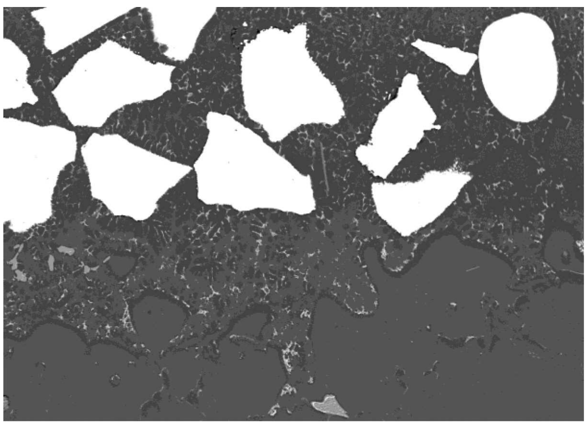

Fig. 20. Surface layer of the AlSi9Cu4 alloyed with WC particles, scan rate: 0.25 m/min, power 2.0 kW, feed rate 3.0 g/min, mag. 500x

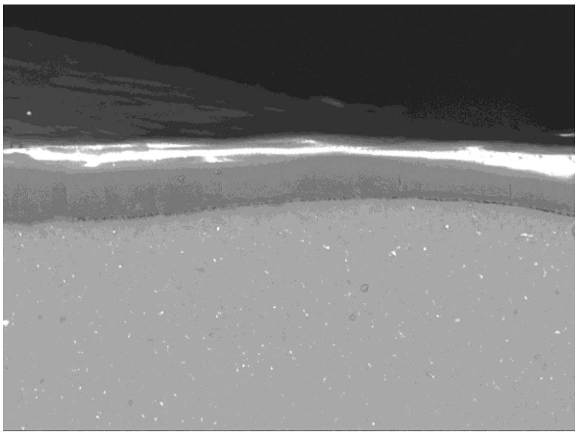
Fig. 21. Surface layer of the AlSi9Cu alloyed with Al_2O_3 scan rate: 0.25 m/min, power: 1.5 kW, powder feed rate 1.5 g/min, mag. 200x

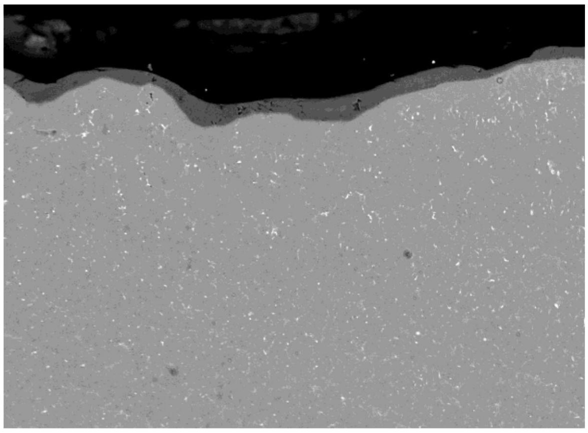
Fig. 22. Surface layer of the AlSi9Cu alloyed with Al_2O_3 scan rate: 0.25 m/min, power: 2.0 kW, powder feed rate 1.5 g/min, mag. 100x

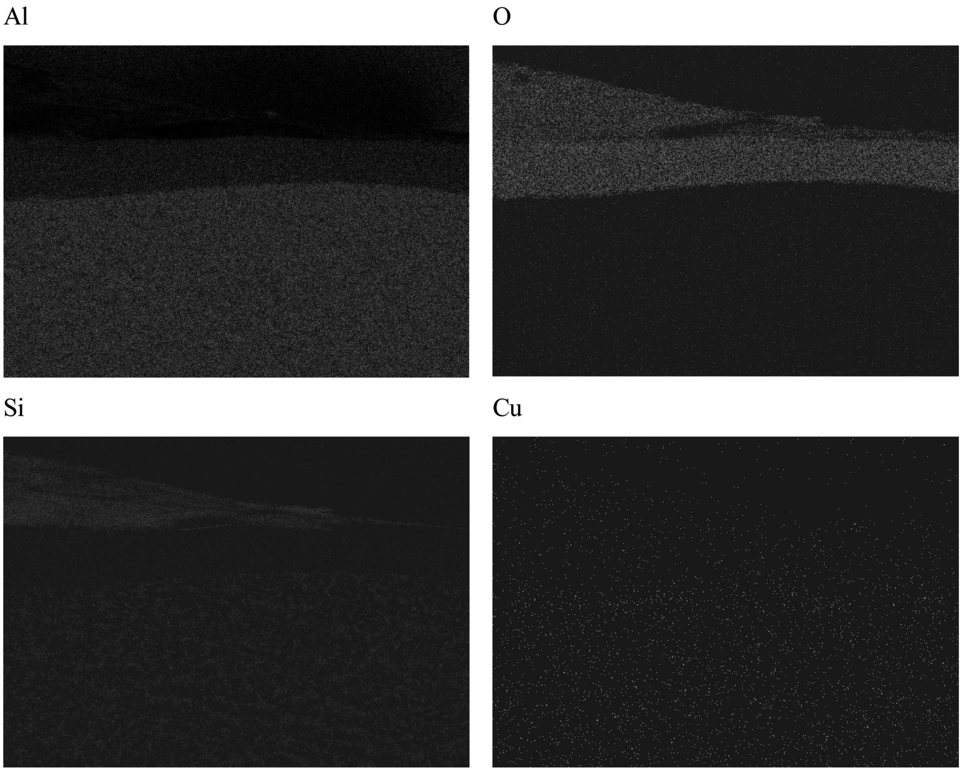

Fig. 23. EDS microanalysis odf the area in fig. 21, invloving Al, O, Si and Cu

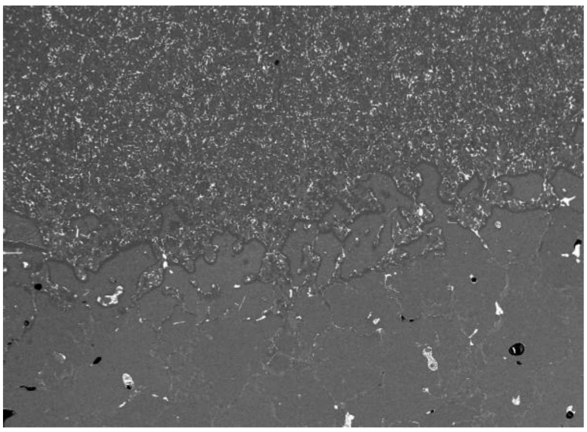
Fig. 24. Heat influence zone and transition zone over the substrate material of the AlSi9Cu alloyed with Al_2O_3 scan rate: 0.25 m/min, power: 1.5 kW, powder feed rate 1.5 g/min, mag. 500x

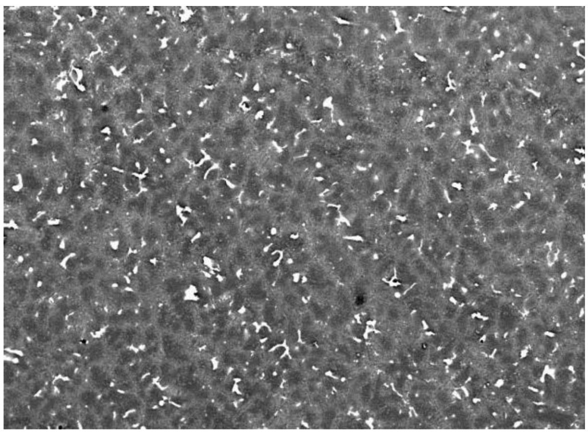
Fig. 25. Dendrites in the heat influence zone of the AlSi9Cu alloyed with Al_2O_3 scan rate: 0.25 m/min, power: 1.5 kW, powder feed rate 1.5 g/min, mag. 500x

TABLE 1

Detailed criteria for the assessment of the potential and attractiveness of the investigated materials groups chosen for the material engineering and heuristic investigations

No:	Potential	Importance
Criterion 1	High heat conductivity of the material	**0.3**
Criterion 2	Low material density	**0.2**
Criterion 3	Radiation and light absorption for high ageing resistance	**0.1**
Criterion 4	High corrosion resistance	**0.2**
Criterion 5	High strength of the material	**0.2**
No:	**Attractiveness**	**Importance**
Criterion 1	Recycling susceptibility	**0.3**
Criterion 2	Simplicity of forming and modelling technologies	**0.2**
Criterion 3	Susceptibility for surface pre-treatment technologies (anodising, sandblasting, etching, polishing)	**0.2**
Criterion 4	Demand on the world markets	**0.2**
Criterion 5	Positive effect of the material on the human bodies	**0.1**

TABLE 2

Results of the multi-criteria analysis of material groups used for the material engineering and heuristic investigations

Symbol	Group of materials	Potential						Attractiveness					
		Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Average value	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Average value
M_1	Aluminum alloys	3.0	0.8	0.9	1.6	1.0	7.3	3.0	1.2	1.8	1.0	0.2	7.2
M_2	Magnesium alloys	2.7	1.0	0.8	1.0	0.8	6.3	2.4	1.0	1.4	0.8	1.0	6.6
M_3	Steels	2.1	0.6	0.7	0.8	2.0	6.2	0.9	1.4	0.4	1.2	0.4	4.3

TABLE 3

Detailed criteria for the assessment of the potential and attractiveness of the investigated technology groups chosen for the material engineering and heuristic investigations

No:	Potential	Importance
Criterion 1	The possibility for obtaining of complex properties and surface structures (multi-compound, multi-layer, multi-phase, gradient, composite, metastable, nanocrystalline)	**0.3**
Criterion 2	Wide possibilities of surface material choice - wide range of surface properties	**0.2**
Criterion 3	The possibility for obtaining hard-surface layers with special protective properties (corrosion, tribological)	**0.2**
Criterion 4	Obtaining of surface layers with good adhesion to the substrate material	**0.2**
Criterion 5	Possibility to obtain in one manufacturing process of gradient surface layers of any chemical composition or structure	**0.1**
No:	**Attractiveness**	**Importance**
Criterion 1	Environmental friendly process of surface treatment (no harmful by-products of chemical reactions and the need for their utilisation)	**0.2**
Criterion 2	Possibility for creation of surface layers with properties, which are not possible to obtain using other methods	**0.3**
Criterion 3	Wide range of possibilities for further development of the technology	**0.2**
Criterion 4	The possibility of full automation and robotics of the surface treatment process	**0.1**
Criterion 5	Necessity for high precision in the surface treatment processes	**0.2**

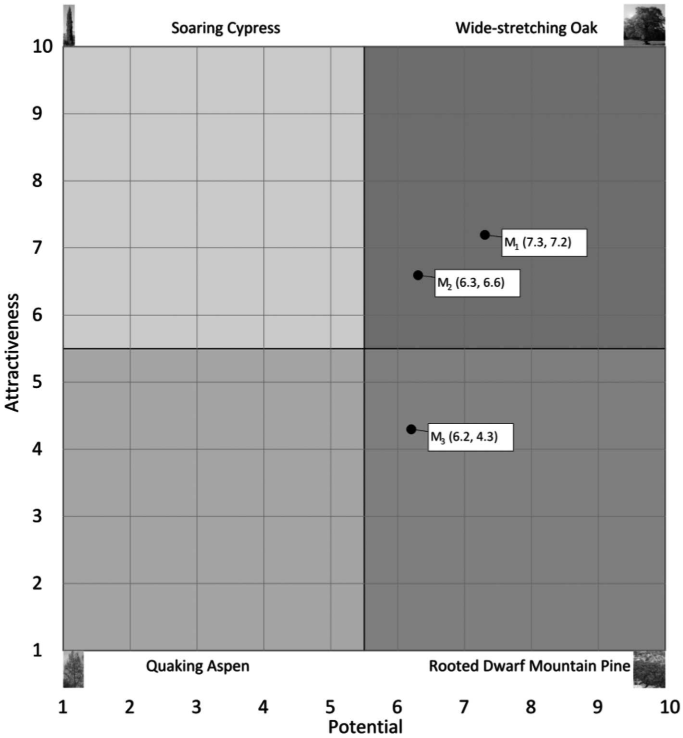

Fig. 26. Dendrological evaluation matrix presenting the positions of the diverse material groups used in carried out investigations

The individual groups of engineering materials were evaluated by key experts according to the considered specific criteria (Tab. 1) using the ten-point universal scale of relative states. A weighted average for the specific criteria considered, distinguished for attractiveness and potential, was calculated using a multi-criteria analysis (Tab. 2) and the results obtained for the individual groups of the materials were entered into the dendrological matrix (Fig. 24). The casting aluminum M_1 and magnesium alloys M_2 were classified, as a result of the analysis, to the most promising quarter called a wide-stretching oak permitting to foresee their dynamic future development. A noticeable predomination of aluminum alloys above magnesium alloys should be noted though, mainly influenced by better heat conductivity and better anticorrosive properties of the material and also an attractiveness factor consisting of improved recyclability of aluminum alloys. Constructional steels, being least attractive, were assigned to a quarter called a rooted dwarf mountain pine characterising well-known materials with promising prospects provided an appropriate strategy is implemented of seeking new markets and client groups while maintaining a high potential.

Research into the treatment technologies of the alloys used were narrowed down to the area of surface engineering only, as an extensive range of the available types of coatings and engineering materials surface layer properties and structure formation methods allows to design, accurately and comprehensively, the most advantageously compiled properties of the core and surface layer of an element produced. The detailed assessment criteria of attractiveness and potential of the considered materials surface treatment technologies are shown in Table 3. The criteria listed are assigned specific weights, and weighted values and their sum, forming a basis of a comparative analysis, are next calculated as shown in Table 4. The multi-aspect results were then visualised with a dendrological matrix of technology value (Fig. 25).

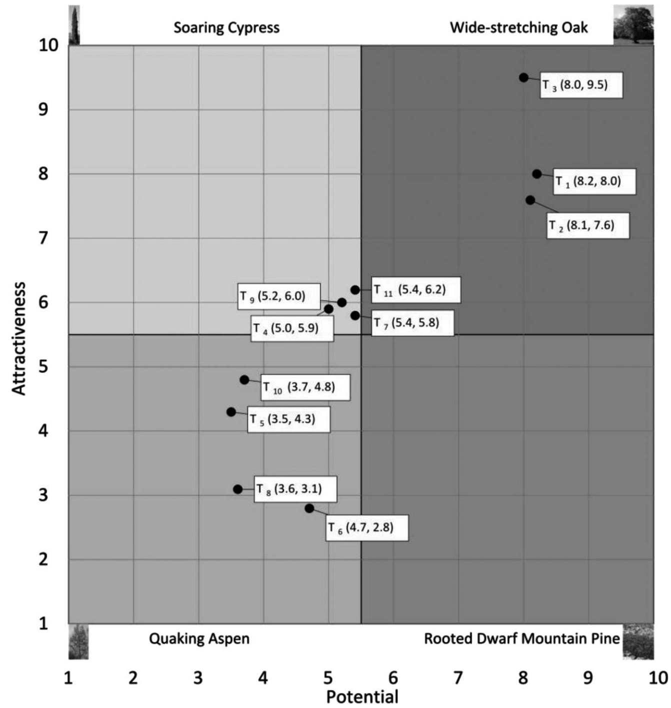

Fig. 27. Dendrological evaluation matrix presenting the positions of the diverse technology groups used in carried out investigations

The preference analysis made reveals that, assuming the criteria used, the laser surface treatment technologies T_1 which, similar to physical (T_2) and chemical (T_3) vapour deposition were placed in the most promising quarter of the matrix, i.e. wide stretching oak, are most attractive. Such technologies' dominance derives from a wide range of their current and future applications and the high precision of laser treatment enabling to fabricate commodities with high accuracy unfeasible with other methods. The values of the T_1,T_2 and T_3 technology's potential are similar, thus ensuring their certain position among the most promising casting aluminum alloys properties and structure formation technologies. The thermal spraying (T_4), pulse laser deposition (T_7), ion implantation (T_9) and hybrid technologies (T_{11}) were assigned to the quarter called a soaring cypress evidencing their high attractiveness with a limited potential making it necessary to conduct further research to strengthen the technologies and ensure their competitive advantage. The other technologies analysed, i.e. anodisation processes (T_5), galvanic technologies (T_6), painting layer deposition (T_8) and discharge nitridig (T_{10}) were found in the least promising quarter (quaking aspen) indicating their limited potential and attractiveness, no success should therefore be expected in case of implementation for light metal alloys. The position of traditional painting techniques should be highlighted in the dendrological matrix, which – as opposed to the majority of materials – due to an uncomplicated layers deposition mechanism and a low application cost were found in the rooted dwarf mountain pine field with a high potential and limited attractiveness, but the scope of their future applications for the considered group of materials is found to be very limited, hence their position in the least promising matrix quarter called quaking aspen. The analysis made reveals it is

TABLE 4

Results of the multi-criteria analysis of technology groups used for the material engineering and heuristic investigations

Symbol	Technology group	Potential						Attractiveness					
		Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Average value	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Average value
T_1	PVD techniques, including also Cathodic Arc Deposition	2.7	1.6	1.8	1.2	0.9	8.2	1.8	2.7	1.6	0.9	1.0	8.0
T_2	CVD techniques, including also Plasma Assisted CVD	2.7	1.6	1.8	1.2	0.8	8.1	1.4	2.7	1.6	0.9	1.0	7.6
T_3	Laser techniques including alloying\remelting\feeding	2.7	1.0	1.8	2.0	0.5	8.0	1.8	2.7	2.0	1.0	2.0	9.5
T_4	Thermal spaying	1.5	1.0	1.4	0.6	0.5	5.0	1.2	1.8	0.6	0.9	1.4	5.9
T_5	Anodisation processes	0.6	0.2	1.2	1.2	0.3	3.5	1.2	1.5	0.2	0.4	1.0	4.3
T_6	Galvanic technologies	0.9	1.0	1.2	1.4	0.2	4.7	0.4	0.9	0.2	0.9	0.4	2.8
T_7	Laser ablation -PLD	1.5	1.0	1.0	1.4	0.5	5.4	1.6	1.2	1.2	0.6	1.2	5.8
T_8	Painting layer deposition	0.3	0.8	1.0	1.4	0.1	3.6	0.6	0.6	0.2	0.9	0.8	3.1
T_9	Ion implantation	1.5	1.0	1.0	1.2	0.5	5.2	1.4	1.8	1.2	0.6	1.0	6.0
T_{10}	Discharge nitrating	0.6	0.4	1.2	1.2	0.3	3.7	0.8	1.8	0.6	0.8	0.8	4.8
T_{11}	Hybrid technologies (multiplex)	1.5	1.0	1.2	1.2	0.5	5.4	1.0	2.7	1.2	0.5	0.8	6.2

reasonable to develop laser treatment technologies (T_3) and PVD (T_1) and CVD (T_2) methods for the casting aluminum alloys most promising for the criteria considered. Note that the indicated research areas represent ones most avant-garde and development-prone areas of material surface engineering.

4. Summary

Considering the three groups of materials subjected to an expert assessment using a dendrological matrix being inherent part of materials surface engineering development prediction methods, aluminum casting alloys has achieved the best position. It was further demonstrated that laser treatment is a technology with the highest potential and attractiveness in the context of applying aluminum casting alloys for surface treatment. The metallographic examinations carried out give grounds to state that the ceramic powder alloying or feeding process will be carried out successfully in case of the aluminum alloy substrate, the powder particles will be distributed uniformly in the investigated surface layer, and that the particular layers is without cracks and failures and tightly adhere to the cast aluminum material matrix. In general the following should be pointed out:

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

In general it can be recognised, that the obtained layers on the aluminum alloyed surface are characterised by a structure without any defects, the next step is to achieve uniformly deposited ceramic particles in the substrate. With regard to the above, dynamic development by exploiting numerous opportunities from the environment, especially strong prospects in the automotive industry, aviation industry, military sector, sports equipment sector and in civil engineering is a recommended long-term action strategy. Magnesium, aluminum and steel are the most commonly used constructional materials after laser surface treatment, moreover there are suitable in applications as components in the automotive industry.

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