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PREDICTION DEVELOPMENT OF SELECTED GROUPS OF ENGINEERING MATERIALS USED IN THE AUTOMOTIVE INDUSTRY

Summary. The purpose of the article is to present the results of comparative quantitative analysis of selected materials and manufacturing technologies, to indicate their development outlooks and to present its application opportunities in the automotive industry. Concerning of the demand from the automotive sector for components and parts made of cast aluminum alloys, the development expectations of their effective manufacturing technology meeting the expected product properties, including surface laser treatment as well as physical and chemical vapour deposition, were evaluated to be very high.

PROGNOZOWANY ROZWÓJ WYBRANYCH GRUP MATERIAŁÓW INŻYNIERSKICH STOSOWANYCH W PRZEMYŚLE MOTORYZACYJNYM

Streszczenie. Celem niniejszego artykułu jest prezentacja wyników ilościowej analizy porównawczej wybranych materiałów i technologii wytwarzania, wskazanie ich perspektyw rozwojowych oraz prezentacja możliwości aplikacyjnych w przemyśle motoryzacyjnym. Zapotrzebowanie na elementy i części wykonane z odlewniczych stopów aluminium zgłaszane przez przemysł motoryzacyjny sprawia, że perspektywy rozwojowe technologii efektywnego ich wytwarzania, zapewniających oczekiwane własności produktu, do których należy powierzchniowa obróbka laserowa, oraz metody fizycznego i chemicznego osadzania powłok z fazy gazowej zostały ocenione na poziomie bardzo wysokim.

1. INTRODUCTION

Due to instrumentation and time limitations, it can be impossible 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 such as aluminium and magnesium which have advantages like good ductility, better noise and vibration damping characteristics than other materials, excellent cast ability, 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 [4, 12-17]. The need for aluminium, magnesium alloys as well as steel materials is connected mainly to the development occurred in the automobile industry. The share of aluminium 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), body 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) [4, 12-17]. It should also be mentioned, that currently about 70% of castings made of magnesium alloys are produced for the automotive industry, for example as: 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. 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).

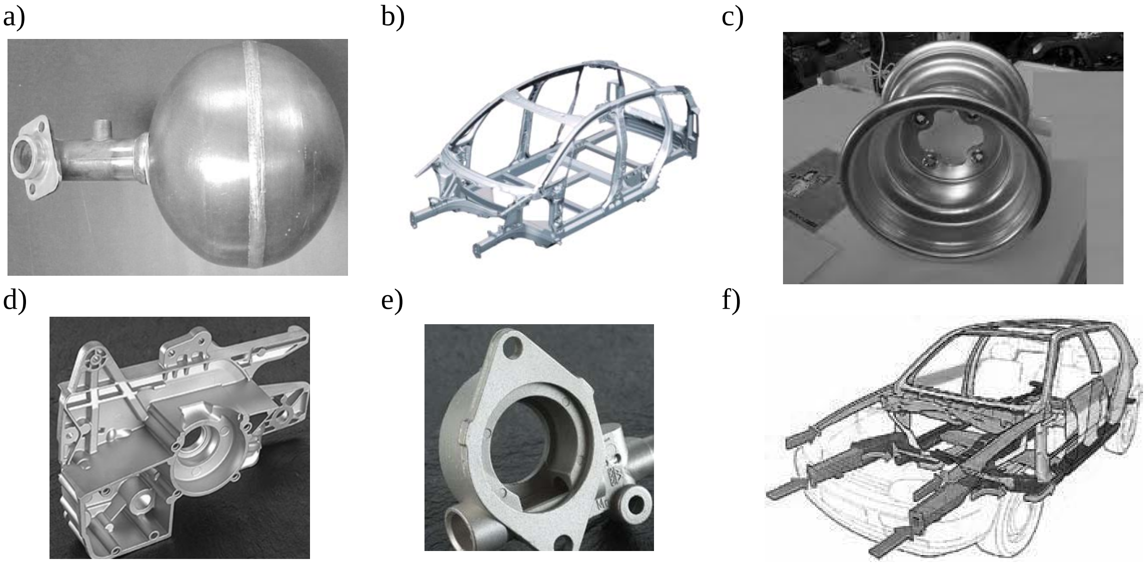

Fig. 1. Examples of parts made from aluminum alloys: a) barometric pressure reservoir – VW Phaeton, b) Audi A2 body frame, c) magnesium alloy wheel d) crankcase casing, e) cooling system pump casing; from austenitic steel f) door posts A i B; door and roof strengthening; bumpers, seats parts, other components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

Rys. 1. Przykładowe elementy wytworzone ze stopów aluminium: a) zbiornik ciśnienia atmosferycznego – VW Phaeton, b) ramownica nadwozia Audi A2, c) koło wykonane ze stopu magnezu, d) korpus skrzyni korbowej, e) układ obudowy chłodzenia pompy ze stali austenitycznej, f) słupki drzwiowe A i B, drzwi i wzmocnienie dachu, zderzaki, części foteli, pozostałe elementy o złożonym kształcie

So the huge amount of needed research activity makes it necessary to perform a lot of investigations. Therefore the idea presented in this paper is to do it 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 materials science experiment. A methodology of computer-integrated prediction of development [1] is dedicated to such task, which enable it to perform an expert assessment and present results graphically using contextual matrices as a tool of quantitative analysis, which is very desirable in the engineering environment. The correctness of the newly developed methodology was reviewed with 36 examples [1-8]. 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 applied prediction technique 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 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. This article describes the application of the computer-integrated prediction of development for objectivised selection of an appropriate material for research and selection of especially material's surface treatment technology, which enables it to obtain product properties, which can be achieved according to the expectation of the customer.

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 in 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 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 meets a widespread popularity among scientists as signified by implementations thereof in scientific works, including doctoral theses and habilitation dissertations [2-4]. 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 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 [5-7] serving to characterise a portfolio of products offered to the customer. The most renowned portfolio method is the *Boston Consulting Group* – BCG matrix [8] 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 range, as expressed by a precedence hierarchy of objects presented in an ordered manner by 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 these elements. The method of relative evaluation criteria was also used there, where differences are assumed in the relevance of the applied criteria 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 [1] of values allows it in a relatively simple way to visualize the results of the assessment of individual material groups and processing technologies in terms of: potential, which is the real objective value of the analysed research area - the so-called hard, measurable features as well as attractiveness, reflecting the subjective perception of the given thematic range of potential users – the so-called soft properties. 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 data study, each of the analysed materials and surface engineering technologies, was placed in one of the four quarters of the dendrological matrix.

The dendrological matrix used for evaluating a material suitability and, further, its surface treatment technology, is linked to one 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 group 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 entirely 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 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.

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 worldwide investigated fields of material science and engineering concerning the production and processing of new developed engineering materials. Previous studies about the effects of laser beam effect on various materials, including magnesium alloys as well as tool steels, based on the authors own long-term investigation, summarizing the experience of laser surface treatment reveal that, there are chemical composition and structure changes which are different from those occurring during conventional heat treatment. This causes, that the laser treated elements shows higher hardness (especially for TaC alloyed steel surface), corrosion resistance, abrasion resistance and thermal fatigue compared to the traditionally treated materials.

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 there can be found dendritic structure with large dendrites. 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 achieved 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. 2-5). It was noticed that the depth of remelting area grows together with the increasing laser power.

The performed investigations of the alloyed hot work tool steel 32CrMoV12-28 shows a clear effect of the applied ceramic powder used for alloying (Figs. 4-5) [9-11]. 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.5). 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. 4-5 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.

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.

Similar relationships were found in case of magnesium alloy (Figs. 6-11), where the used WC, SiC and TiC powder particles are present in the laser treated magnesium surface.

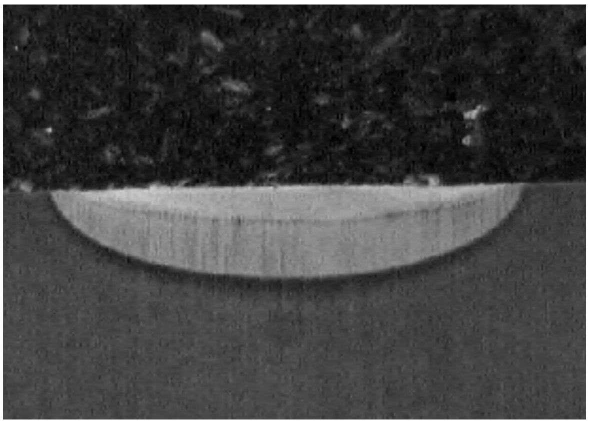

Fig. 2. 32CrMoV12-28 steel alloyed with Si_3N_4 powder, laser power 2.3 kW, mag. 10x
Rys. 2. Stal 32CrMoV12-28 stopowana proszkiem Si_3N_4, moc lasera 2,3 kW, powiększenie 10x

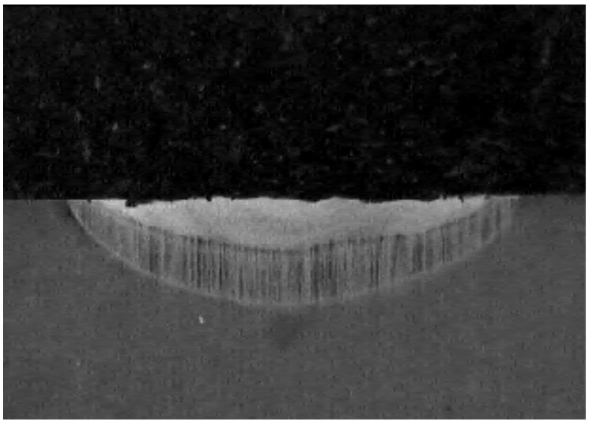

Fig. 3. 32CrMoV12-28 steel alloyed with ZrO_2 powder, laser power 2.3 kW, mag. 10x
Rys. 3. Stal 32CrMoV12-28 stopowana proszkiem ZrO_2, moc lasera 2,3 kW, powiększenie 10x

Fig. 4. 32CrMoV12-28 steel alloyed with TiC powder, SE SEM, mag. 1000x
Rys. 4. Stal 32CrMoV12-28 stopowana proszkiem TiC moc lasera, SE SEM, powiększenie 1000x

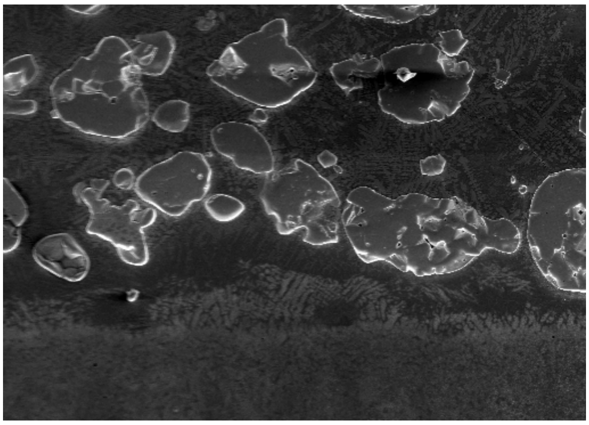

Fig. 5. 32CrMoV12-28 steel alloyed with WC powder, SE SEM, 2,3 kW, mag. 1000x
Rys. 5. Stal 32CrMoV12-28 stopowana proszkiem WC, moc lasera 2,3 kW, powiększenie 1000x

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 shape depending on the laser processing parameters as well as the used ceramic powder as well as the substrate type. 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). 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 (Figs. 6-11).

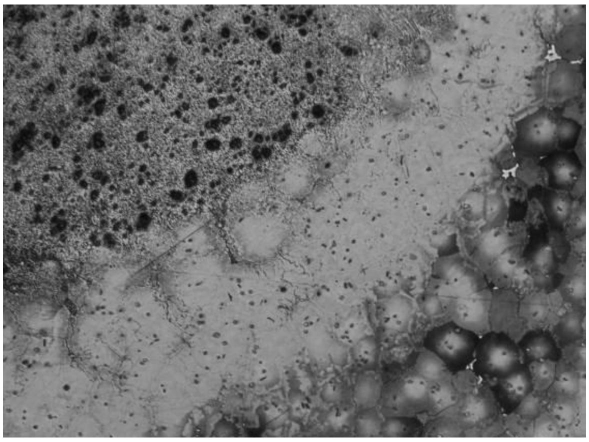

Fig. 6. Remelting path edge of the AZ121 alloyed with WC particles, scan rate: 0.75 m/min, laser power: 2.0 kW, mag. 200x

Rys. 6. Brzeg ścieżki przetopienia AZ121 stopowanego cząsteczkami WC, szybkość skanowania: 0,75 m/min, moc lasera 2,0 kW, powiększenie 200x

Fig. 7. Central zone of the AZ61 alloyed with SiC particles, scan rate: 0.75 m/min, laser power: 2.0 kW, mag. 500x

Rys. 7. Centralny obszar stopu AZ61 stopowanego cząsteczkami SiC, szybkość skanowania: 0,75 m/min, moc lasera 2,0 kW, powiększenie 500x

The structure of the solidified material after laser treatment is characterised with a zone-like construction with diversified morphology related to the crystallisation of magnesium alloys. Multiple change of crystal growth direction has been observed in these areas. In the area located on the boundary between the solid and liquid phase, minor dendrites occur where the main dendrite axes are oriented along the heat transfer directions.

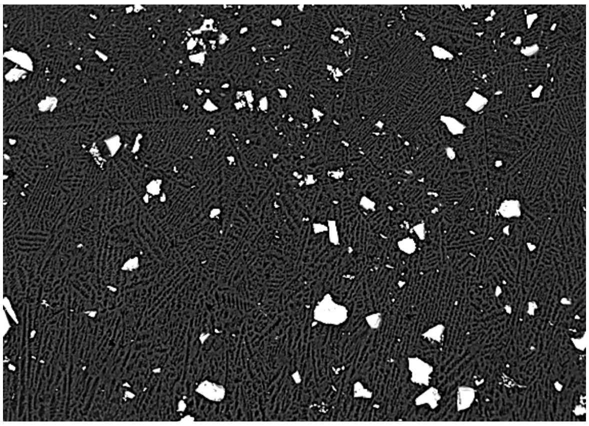

Fig. 8. Central zone of the AZ31 alloyed with TiC particles of the, scan rate: 0.75 m/min, laser power: 1.2 kW, mag. 500x

Rys. 8. Centralny obszar AZ31 stopowanego cząsteczkami TiC, szybkość skanowania: 0,75 m/min, moc lasera 1,2 kW, powiększenie 500x

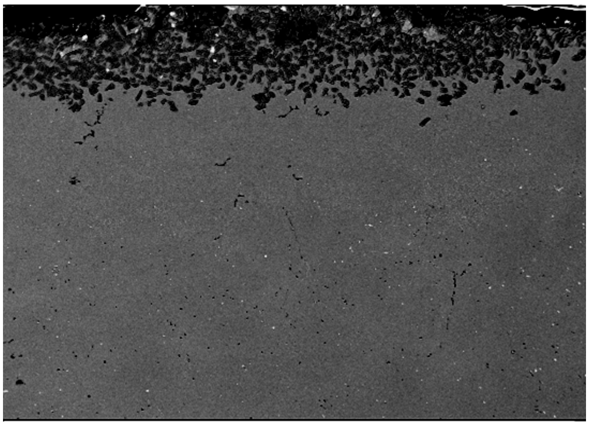

Fig. 9. Surface layer of the AZ61 alloyed with SiC particles, scan rate: 0.75 m/min, laser power: 1.6 kW, mag. 100x

Rys. 9. Warstwa powierzchniowa AZ61stopowanego cząsteczkami SiC, szybkość skanowania: 0,75 m/min, moc lasera 1,6 kW, powiększenie 100x

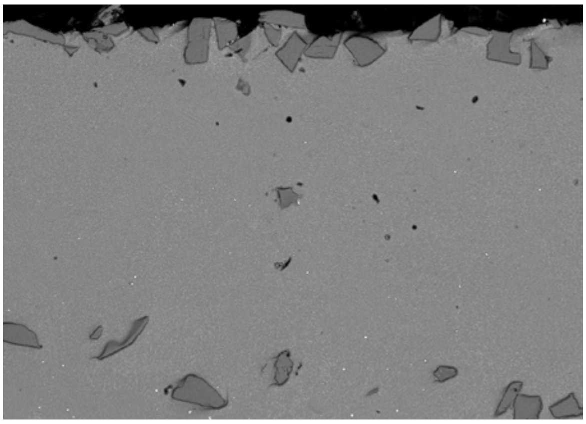

Fig. 10. Surface layer of the AZ61 alloyed with SiC particles, scan rate: 0.5 m/min, laser power: 1.5 kW, mag. 100x
Rys. 10. Warstwa powierzchniowa AZ61stopowanego cząsteczkami SiC, szybkość skanowania: 0,5 m/min, moc lasera 1,5 kW, powiększenie 100x

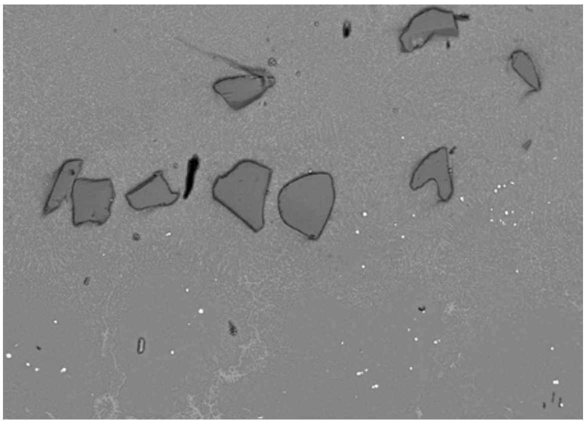

Fig. 11. Surface layer of the AZ61 alloyed with SiC particles, scan rate: 0.5 m/min, laser power: 1.5 kW, mag. 100x
Rys. 11. Warstwa powierzchniowa AZ61 stopowanego cząsteczkami SiC, szybkość skanowania: 0,5 m/min, moc lasera 1,5 kW, powiększenie 100x

Effect of laser feeding conditions, namely: laser power, feeding rate, 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. 12). 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 aluminium concentration (<6%), which is mainly responsible for precipitation strengthening of the investigated, laser treated alloys, fed with ceramic particles.

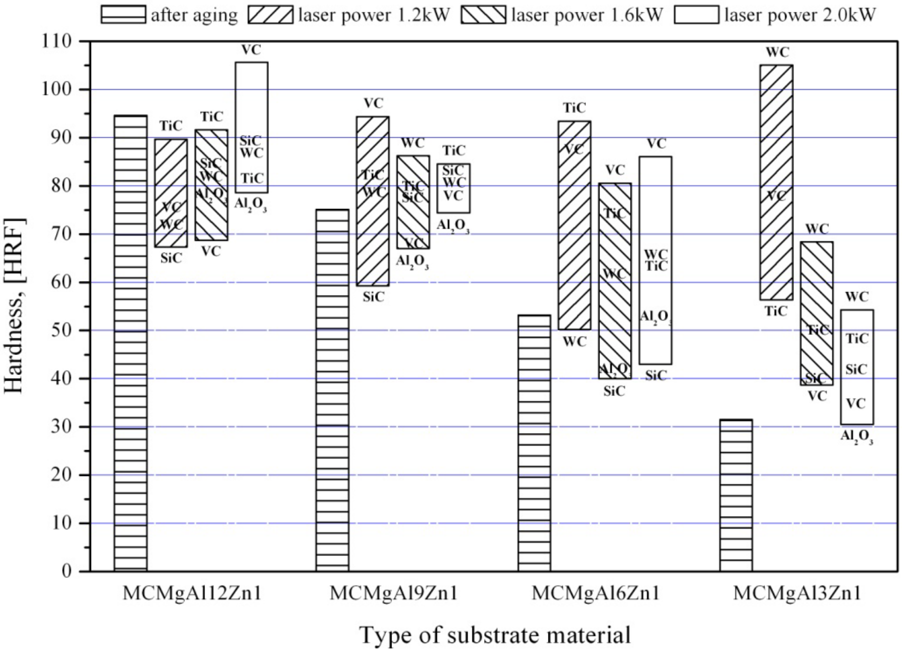

Fig. 12. Hardness measurements results of cast Mg-Al-Zn magnesium alloys samples, after aging and laser feeding
Rys. 12. Wyniki pomiarów twardości próbek odlewniczych stopów magnezu Mg-Al-Zn po starzeniu i wtapianiu laserowym

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. In the initial step of the planning investigation, for selection of the specific research topics, there was used an innovative scientific-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 used for current and possible future applications. Microstructure investigations of the aluminium alloys fed with WC, SiC and Al_2O_3 ceramic powder were performed, where it was found, as a result of the microstructure investigations, that there are present particles of SiC and WC, in the laser treated surface layer as well as, that there are no pores or cracks in the obtained coating or any other defects and failures occurred in this surface layer. For the WC powder the particles are partially present on the bottom of the remelted zone. In case of Al_2O_3 powder there is obtained a sintered surface layer confirmed by the EDS surface mapping.

Occasionally occurred discontinuity of the obtained 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 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. 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. Further investigations should reveal the exact morphology and nature of these sublayers after alloying with different ceramic powders and 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.

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 body	0.1

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 are obtained for the individual groups of the materials were put in into the dendrological matrix (Fig. 13). The cast aluminium 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 aluminium 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 aluminium alloys. Constructional steels, which are 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.

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	Aluminium 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

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 listed criteria are assigned with specific weights, and weighted values as well as their sum, creating 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. 14).

The carried preference analysis reveals that, assuming the used criteria, 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 cast aluminium alloys properties and structure modelling 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 analysed technologies, i.e. anodisation processes (T_5), galvanic technologies (T_6), painting layer deposition (T_8) and discharge nitriding (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.

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

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	Aver. value	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Aver. value
T_1	PVD techniques, incl. 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, incl. 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 incl. 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

Symbol	Technology group	Potential						Attractiveness					
		Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Aver. value	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Aver. value
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

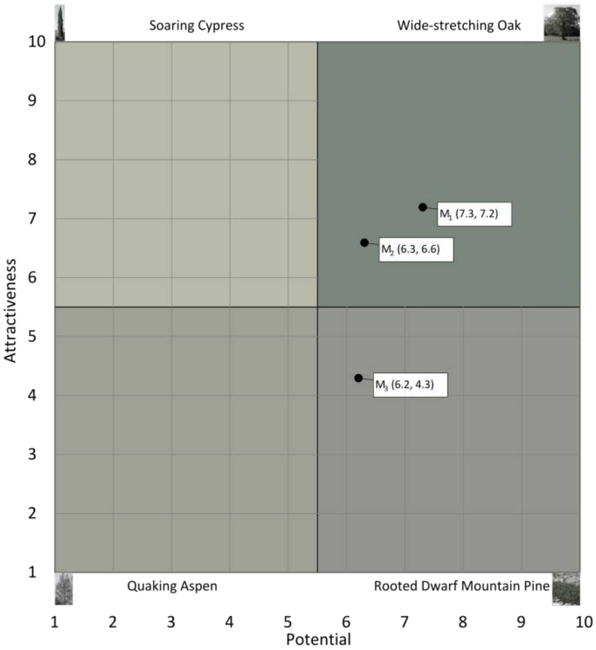

Fig. 13. Dendrological evaluation matrix presenting the positions of the diverse material groups used in carried out investigations

Rys. 13. Dendrologiczna macierz wartości otoczenia obrazująca umiejscowienie różnych grup technologii badanych w danej pracy

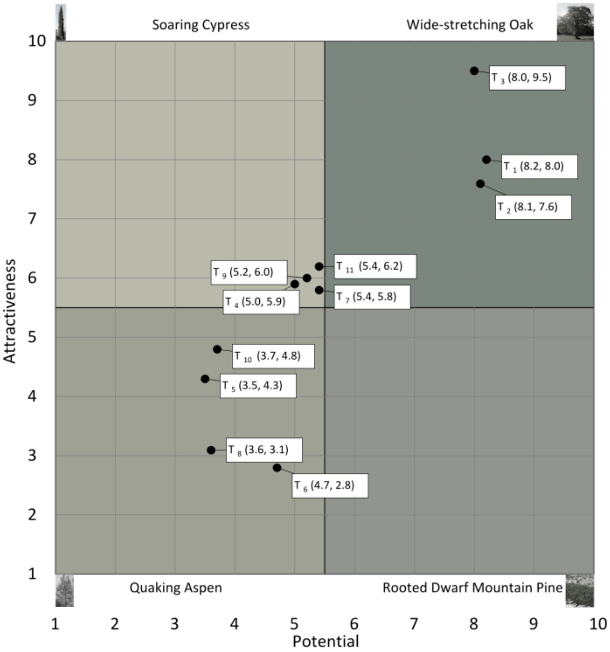

Fig. 14. Dendrological evaluation matrix presenting the positions of the diverse technology groups used in carried out investigations

Rys. 14. Dendrologiczna macierz wartości otoczenia obrazująca umiejscowienie różnych grup technologii badanych w danej pracy

The analysis made reveals it is reasonable to develop laser treatment technologies (T_3) and PVD (T_1) and CVD (T_2) methods for the casting aluminium alloys most promising for the criteria considered. Note that the indicated research areas represents a most avant-garde and development-prone areas of material surface engineering.

4. SUMMARY

Considering the three groups of materials subjected to the expert assessment using a dendrological matrix being inherent part of materials surface engineering development prediction methods, aluminium 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 aluminium cast alloys for surface treatment. The carried out metallographic investigations give grounds to state, that the ceramic powder alloying or feeding process will be carried out successfully in case of the aluminium alloy substrate, the powder particles will be distributed uniformly in the investigated surface layer, and that the particular layers is without cracks and failures and tightly adhere to the cast aluminium material matrix. In general the following should be pointed out: (1) the surface layer are without cracks and of a maximal thickness in the range of 2 mm; (2) the surface layers consists of three zones: the remelting zone the heat influence zone and substrate material as well as sometime of an additional intermediate zone; (3) the laser surface treatment process gives good 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 aluminium 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 investigating numerous opportunities from the environment, especially strong demands in the automotive industry, aviation industry, military sector, sports equipment sector and in civil engineering is a recommended long-term action strategy. Magnesium, aluminium and steel are the most commonly used constructional materials for laser surface treatment, moreover there are suitable for applications as components in the automotive industry.

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