Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 49
ISSUE 2
December
2011

Report on the main areas of the materials science and surface engineering own research

L.A. Dobrzański*
Director of the Institute of Engineering Materials and Biomaterials,
Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

Received 12.10.2011; published in revised form 01.12.2011

Education and research trends

ABSTRACT

Purpose: The purpose of the paper is to present the representative examples for the own scientific research in the area of the forming of the structure and properties of engineering materials including biomaterials, their properties testing and microstructure characterisation and modelling, simulation and prediction of the properties and structure of these materials after selected materials processing technologies.

Design/methodology/approach: The main areas of the scientific interests reported in this paper on the basis of the own original research include forming of structure and properties of engineering materials including biomaterials using advanced synthesis and materials processing technologies and nanotechnologies, engineering materials including biomaterials properties testing and microstructure characterisation using very advanced contemporary research methodologies including electron microscopy, modelling, simulation and prediction of properties and structure of engineering materials including biomaterials using advanced methods of computational materials science including artificial intelligence methods.

Findings: A general character of the paper concerning many aspects of material science research enabled a detailed description of research methodology and details concerning research results. Detailed information is included in many detailed cited works.

Practical implications: Presented research results can be used in practice.

Originality/value: The paper presents numerous research results which Has been made during last years generalising the achievements of the research team directed by the author.

Keywords: Materials science and engineering; Nanotechnology; Sintered tool materials; PVD and CVD coatings; Foresight of the surface treatment; Computational Materials Science; Dental engineering; Biomaterials; Composite magnetic materials; Composite materials; Nanotubes; Light metals matrix composites and alloys; Laser surface treatment; Heat and thermo-mechanical treatment; High-manganese steels; Laser micro-treatment; Photovoltaic materials

Reference to this paper should be given in the following way:
L.A. Dobrzański, Report on the main areas of the materials science and surface engineering own research, Journal of Achievements in Materials and Manufacturing Engineering 49/2 (2011) 514-549.

1. Introduction

Materials science was created in the 1950s as the fundamental branch of science and also materials engineering as the engineering knowledge applied in the industrial practice. The progress in the field of the advanced engineering materials is predicted and expected, including, among others, nanomaterials (with the particularly fine structure, ensuring the unexpected so far mechanical, as well as physical and chemical properties), biomaterials (as a group of the biomimetic materials and/or making it possible to substitute the natural human tissues and/or organs directly or designed into the purpose built devices), and infomaterials (as the most advanced group of smart- and self-organising materials), and also (functional or tool ones) gradient materials (in which properties change continuously or discretely with location because of the chemical composition, phase composition, and structure, or atomic orientation changing with the location), and light metals alloys (as materials of the particular importance, apart from the composite materials, in design and operation of the contemporary transport means), which issues decide about the development of materials engineering as one of the few areas of science and technology development most important nowadays in the contemporary World. A typical subject matter of materials science and engineering includes the description of phenomena and transformations occurring in technical materials, especially in the engineering ones, that is those manufactured in the purpose designed technological processes from raw materials available in the nature, in technological processes of manufacturing, processing, as well as forming of their structure and properties, for satisfying more and more complex practical requirements formulated by participants of the design process of products indispensable to the contemporary humans, including - among others - machines and devices.

Materials have to be manufactured on demand today, meeting the complex set of the specific demands. Manufacturing is expected of materials with properties ordered by products users. Those changes substantially the materials design methodology in general and the products materials design, as materials have to be delivered on demand of products manufacturers with the appropriately formed structure, ensuring the required set of physical and chemical properties, and not as before when the manufacturers were forced to select material closest to their expectations from the delivered materials with the offered structure and properties, yet - by assumption - not meeting them fully, which is not permitted by this design methodology. Therefore, the actual trends force classification of engineering materials based on their functional characteristics. Therefore, the type, and the chemical composition in particular, of the used materials are of less importance (to which materials engineers were used for decades, and especially the metallurgists), while its functionality is more important. This is so since the new engineering materials and manufacturing processes have been subordinated to customer needs and functional requirements of products. Manufacturing materials on demand fulfilling needs of market products manufacturers at the right time and place features a priority for new materials technologies and manufacturing processes, as the complementary base technologies (improvement of the existing solutions), alternative ones (taking advantage of synergy of various solutions), and original ones (new solutions being developed).

The main areas of the scientific interests reported in this paper on the base of the original own research are as follows:

- forming of structure and properties of engineering materials including biomaterials using advanced synthesis and materials processing technologies and nanotechnologies,
- engineering materials including biomaterials properties testing and microstructure characterisation using very advanced contemporary research methodologies including electron microscopy,
- modelling, simulation and prediction of properties and structure of engineering materials including biomaterials using advanced methods of computational materials science including artificial intelligence methods.

In this paper the examples of the detailed scientific researches made in last years with the Author's participation are presented.

2. New groups of sintered tool materials

The new group of the sintered gradient tool materials manufactured by the conventional powder metallurgy method, consisting in compacting a powder in a closed die and sintering it, is presented firstly. The materials were obtained by mixing the powders of the HS6-5-2 high-speed steel, tungsten carbide (WC), and vanadium carbide (VC). The mixes were poured one after another into the die, yielding layers with the gradually changing volume ratio of carbides within the high-speed steel matrix. Structural research by using the scanning and transmission electron microscopes, X-ray microanalysis and density, hardness and porosity tests, are performed.

Structure and hardness of selected materials after heat treatment are also investigated. On the basis of the results of the research, it is found out that it is possible to obtain gradient materials by the powder metallurgy methods, in order to ensure the required properties (Fig. 1) and structure (Fig. 2) of the designed material. The gradient tool materials reinforced with the WC carbide are characterised by a higher hardness, and a lower porosity in relation to the materials reinforced with the VC carbide. It is found out that the desired structure and properties (density, porosity and hardness) has the material containing 25% of the WC carbide in the surface layer, after sintering at the temperature 1210°C, for 30 minutes. The heat treatment application causes a significant increase of the surface layer hardness of the material. The highest surface layer hardness, equal to 71.6 HRC, shows the material austenitised at the temperature 1120°C, hardened and tempered twice at the temperature 530°C.

The sintered tool gradient materials with cobalt matrix are presented next. Those addresses issues related to research of the new group of gradient tool materials developed by means of the powder metallurgy method. In this method, the subsequent layers of mixtures of different-composition powders are passed through a closed die, and then sintered too. The materials have been obtained from the mixture of tungsten carbide and cobalt powders. The analysis involves four-layer samples, where the subsequent transient layers were formed from the surface layer to the base layer. The volume fraction of the carbide hard phase in the transient layers. The analyses of the sintered gradient tool materials include structural analysis with scanning and transmission electron microscopes; X-ray microanalysis as well as density, hardness, porosity, abrasive wear and stress level K_{IC} tests.

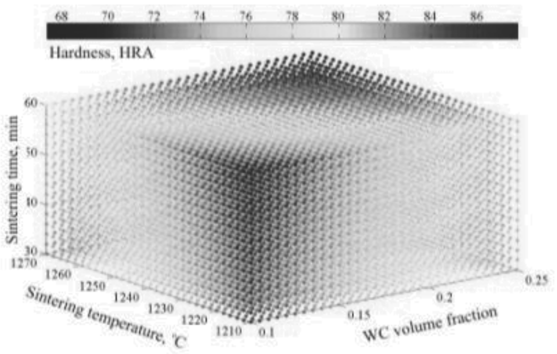


Fig. 1. The hardness of the sintered gradient tool materials on the HS6-5-2 high-speed steel matrix

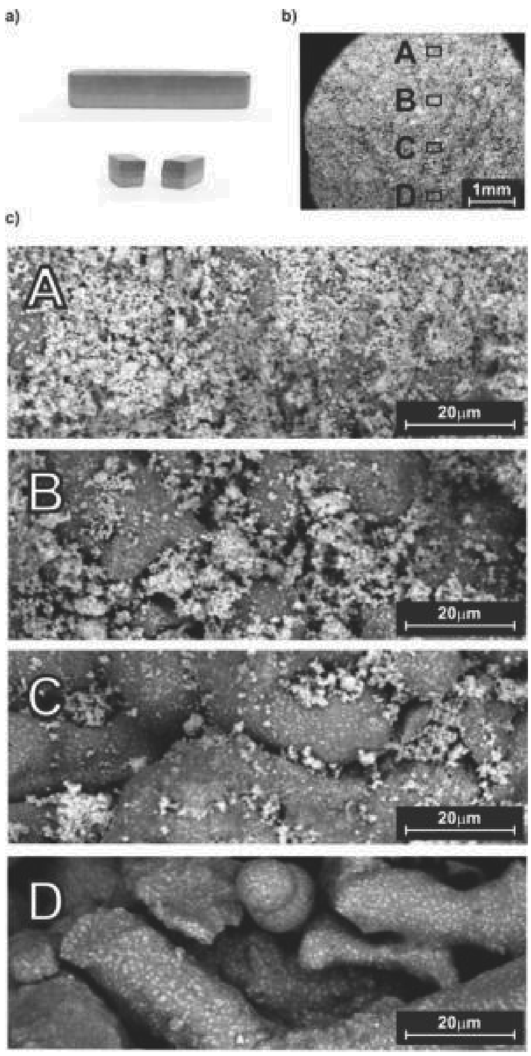


Fig. 2. The changes the structure of the sintered gradient tool materials on the HS6-5-2 high-speed steel matrix

The results of the analysis show that it is possible to obtain sintered gradient tool materials WC-Co of the desired structure and properties by means of the new powder metallurgy method. It has been established that the new sintered gradient tool materials WC-Co consist of the tungsten carbide phase WC and cobalt matrix (Fig. 3). The cobalt matrix fills the space between WC grains, often as a thin layer between the vicinal tungsten carbide grains. An observation of thin foils structures has revealed many net defects in the tungsten carbide grains, especially dislocation. It has been determined that the desired structure of material is obtained due to sintering in 1460ºC for 30 minutes [1-29].

3. PVD and CVD coatings on tool materials substrates

Nanocomposite coatings deposited by cathodic arc evaporation are presented. The development of the deposition methods and the research of new types of coatings enable to produce coatings with better performance. Nanocomposite hard coatings are widely used due to their excellent mechanical properties that make them useful in a wide variety of industrial applications. Nanocomposite coatings comprise at least two phases, a nanocrystalline phase and a matrix phase, where the matrix can be either nanocrystalline or amorphous phase. The investigated coatings have nanocomposite character with fine crystallites, while their average size fitted within the range 8-15 nm, depending on the coating type (Fig. 4). The coatings demonstrated a dense cross-sectional morphology as well as good adhesion to the substrate, the latter not only being the effect of interatomic and intermolecular interactions, but also by the transition zone between the coating and the substrate, developed as a result of diffusion and high-energy ion action that caused mixing of the elements in the interface zone and the compression stresses values. The critical load L_{C2} lies within the range 55-85 N, depending on the coating type. The coatings demonstrate high hardness (4000 HV) and corrosion resistance.

Structure and properties of the hard surface coatings depositing on sintered tool materials is the next presented research. They are presented investigations' results of the properties of the cemented carbides and cermets, both uncoated and coated with single and multiple hard surface layers in the physical (PVD) and chemical (CVD) vapour deposition processes. It was found out basing on the metallographic examinations on the SEM (Fig. 5) and on the light microscope that all the investigated single- and multi-layer coatings developed in the PVD and CVD processes were put down evenly on the substrates of the cemented carbides and tool cermets. The coatings are compact without any visible pores and cracks and adhere tightly to their substrates. Only in case of the single-layer TiN coating put down using the PVD method on the CP20 cemented carbide substrate the coating thickness unevenness was encountered (Fig. 5). In case of the multi-layer coatings of the TiCN+TiN, TiCN+TiC+Al_2O_3, Ti+TiCN+TiN, TiCN+Al_2O_3+TiN/TiC types their laminar overlap was observed. Basing on the metallographic examinations on the LM and on the SEM no total delamination of coatings was found after the scratch test even at the maximum load. Basing on the adhesion tests it was found out that all the investigated single-layer and multiple-layer coatings are characterized by very good adhesion to the substrate. One can observe, comparing the values of critical loads obtained in scratch tests that the critical load

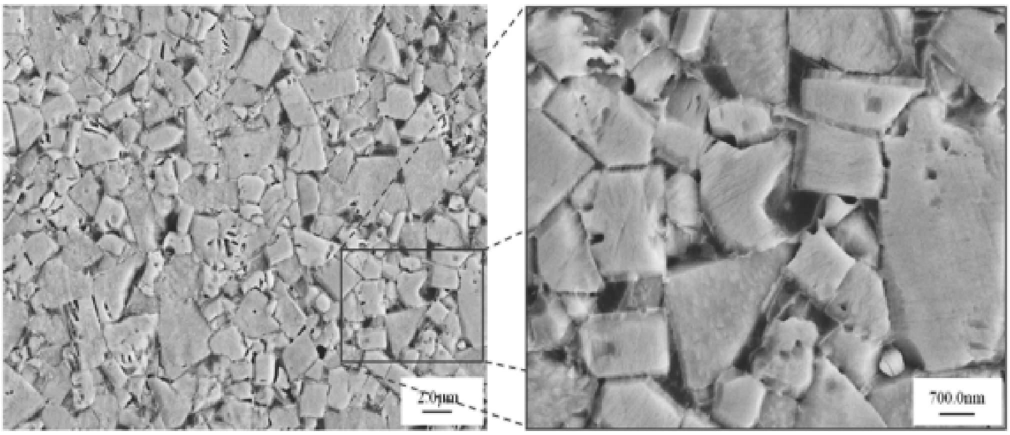


Fig. 3. Surface layer of gradient the material 3-9%Co/97-91%WC_4 sintered in a vacuum furnace at temperature T_{sp}=1430°C and subjected to hot isostatic condensation at the temperature T_{sp}=1425°C

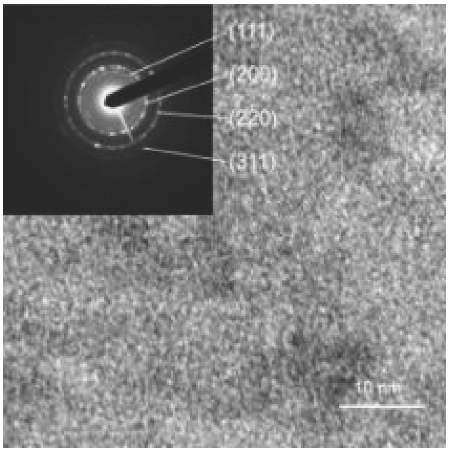


Fig. 4. TEM bright-field images and electron diffraction patterns of CrAlSiN coating

for a particular coating increases with its microhardness. The microhardness tests of the coatings revealed that the highest hardness is displayed by the PVD multiple-layer coated cermet and cemented carbide, whereas, the lowest hardness displays the cemented carbide single-coated with TiN. The highest surface quality was obtained during machining with the multi-layer coated (TiCN+TiN) cemented carbide and with the cermet with the TiN+TiC+TiN coating, whereas, the lowest quality was observed after machining with the uncoated cemented carbide and cermet.

A lot of research works carried out have been devoted to the problem of coating of tooling materials, including also the coating of tooling ceramics. PVD and CVD coating systems on oxide tool ceramics is the next solved problem. The aim of the work is the investigation of structure and properties of the Al_2O_3 based Al_2O_3+ZrO_2, Al_2O_3+TiC and Al_2O_3+$SiC_{(w)}$type based oxide tool ceramics coated with the anti-wear mono- and multilayers of the TiN, TiAIN, TiN+TiAlSiN+TiN, TiN+multiAiAlSiN+TiN and TiN+TiAlSiN+AlSiTiN types in the cathode arc evaporation CAE-PVD and with the multilayers of the TiCN+TiN and TiN+Al_2O_3 types obtained in the chemical deposition from the gas phase CVD process. The investigations were carried out on the multi-point inserts made from the Al_2O_3+ZrO_2, Al_2O_3+TiC, Al_2O_3+$SiC_{(w)}$ ceramics uncoated, coated in the PVD and CVD processes with thin coatings. Observations of the investigated coatings' structures were carried out on the transverse fractures on the scanning electron microscope. The diffraction examinations and examinations of thin foils were made on the transmission electron microscope (Fig. 6). The measurements of textures and phase composition were made. The macro-stress values were calculated. Tribological tests were carried out on the „pin-on-disk" tester. The microhardness and adhesion tests of coatings were made. Cutting ability of the investigated materials was determined basing on the technological continuous cutting tests. It has been demonstrated that the creation of the developed coatings by the use of the PVD and CVD methods on oxide ceramic tool materials causes the increase of coatings hardness and allows to improve application features of multi point cutting tools for high speed machining, tools for fine cutting coated with them and dry cutting without using the cutting fluids in comparison to the multi point cutting tools produced from the same uncoated materials. Putting down the anti-wear coatings onto the oxide ceramic tool materials is justified and the composite tool materials developed in this way may have the important application significance in the industry for cutting tools. The research studies on the PVD and CVD coatings onto sialon tool ceramics and sintered carbides show that the deposition of thin coatings on the ceramic machining cutting edges is fully grounded, since it has been demonstrated that there is a rise of cutting abilities of ceramic tools covered by the coatings obtained in the PVD and CVD processes. Both the coatings structure (Fig. 7) and mechanical properties deposited by PVD and CVD methods on sintered carbides and sialon tool ceramics substrates was an investigation. In the case of coatings containing AlN phase of the hexagonal lattice, there occur covalence bonds analogous to those in ceramic substrate, which in effect yields good adhesion of these coatings to the substrate. It means that the type of interatomic bonds presented in the material of substrate and coating has a great influence on the adhesion of the coatings to the substrate. It can be extremely helpful when selecting the coating material on ceramic

a) b)

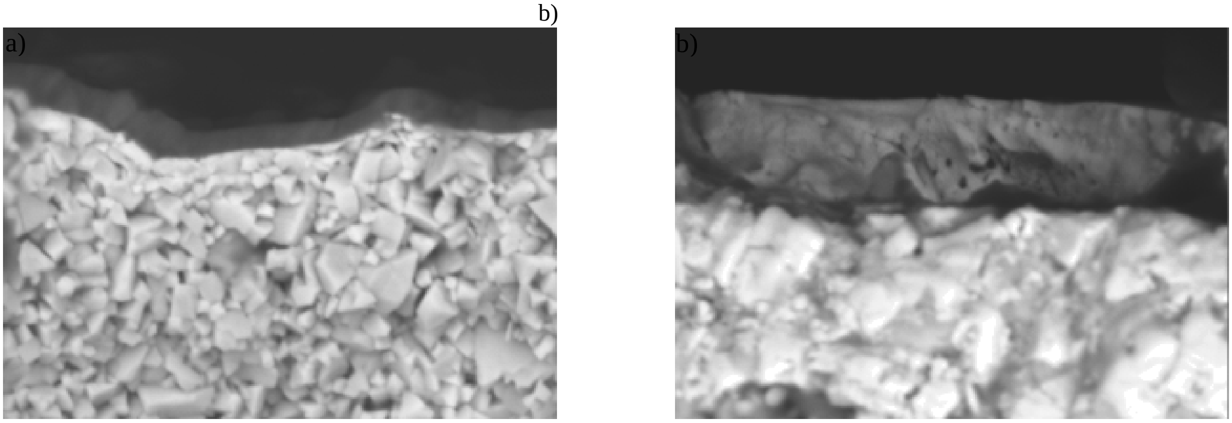


Fig. 5. Fractures of coatings deposited onto the cemented carbides sustrate: a) TiN on CP20, b) TiCN+Al_2O_3 on TP100, magnification 5000x, SEM

a) b)

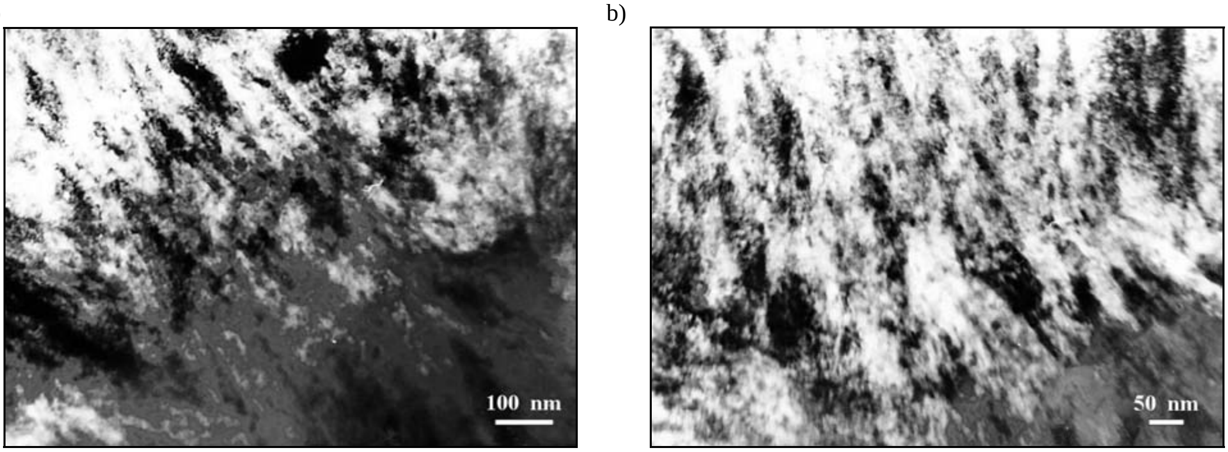


Fig. 6. a), b) TEM: Structure of TiAlN coating thin foil structure perpendicular to the layer surface at light field

cutting edges since the deposition of coatings on cutting edges in PVD processes is difficult due to their dielectric properties, because without the possibility to polarize the substrate during the deposition process it is difficult to obtain coatings which would have good adhesion to ceramic substrates. To define the influence of coating properties on the durability of cutting edges, artificial neural networks have been applied. Another relevant aspect of the research presented in the paper is the fact that the adhesion of the coatings contributes significantly to the durability of the cutting edge, whereas the microhardness of the coatings, their thickness and grain size have a slightly lower influence on the durability of the tool being coated (Fig. 8).

Gradient PVD coatings deposited onto the sintered tool materials are presented by the investigation results of properties of the sintered tool materials: cemented carbides, cermets and Al_2O_3 type oxide tool ceramics with gradient and single-layer (Ti,Al)N and Ti(C,N) coatings deposited with the cathodic arc evaporation CAE-PVD method (Fig. 9). As a result of the metallographic and spectroscopy investigations the structure as well as chemical and phase composition of investigated materials has been characterised. On the bases of XPS and AES investigations of chemical composition it was ascertained that the increase of the substrates' elements concentration in the connection zone occurs simultaneously with decrease of the coatings' elements concentration. Gradient character of the coatings was confirmed with use of Grazing Angle Incidence X-ray Scattering Geometry.

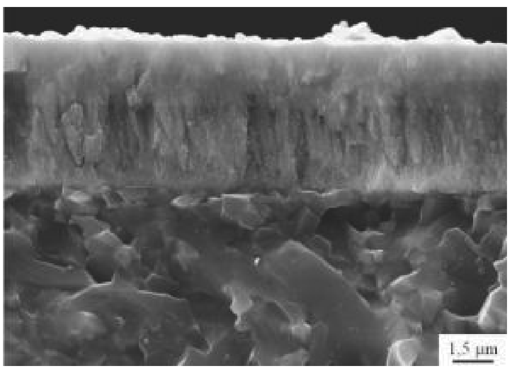


Fig. 7. Surface topography of the (Al,Cr)N coating deposited onto the sialon ceramics tools

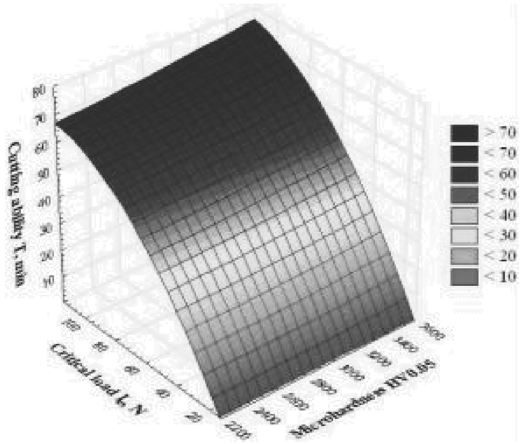


Fig. 8. Evaluation of the PVD and CVD coatings critical load and the microhardness influence of tool life T for sialon ceramics tools coated with PVD and CVD coatings determined by artificial neural networks at a fixed coating thickness 3.0 microns and particle size 8.2 nm

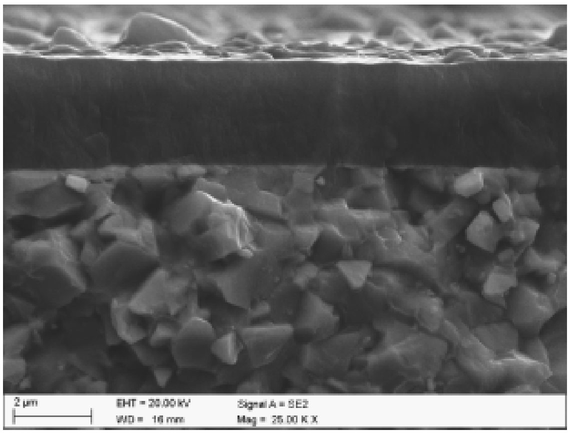


Fig. 9. Fracture surface of the gradient Ti(C,N) coating deposited onto the cemented carbides substrate

It is stated that deposition of (Ti,Al)N and Ti(C,N) gradient coatings on the investigated sintered tool materials causes the significant increase of microhardness in the surface zone. The influence of microhardness increase and good adhesion of coatings, achieved due to gradient structure of coatings, onto functional properties measured at cutting tests, was demonstrated. As a result of the functional properties it was found out that deposition of the both: single-layer and gradient (Ti,Al)N coatings onto investigated tool materials causes the tool life increase in comparison with Ti(C,N) coated tools. It is a result of high wear resistance of (Ti,Al)N coatings at elevated temperature. A better wear resistance of gradient in comparison with single-layer coatings was stated apart from the kind of substrate employed. Basing on computer simulated internal stresses of investigated coatings, verified by the experimental results, it was stated that more advantageous stress distribution of gradient coatings in comparison with corresponding single-layer coatings causes good mechanical properties of gradient coated materials. Especially stress distribution at the surface zone influence the microhardness and stress distribution at the connection zone have an effect on adhesion of coatings.

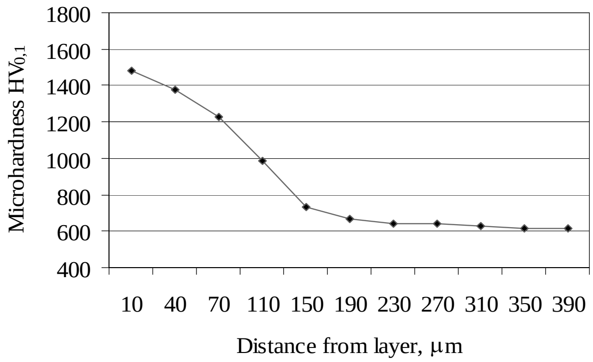


Fig. 10. Microhardness changes in the nitriding layer of the plasma nitrided hot work steel X37CrMoV5-1 type

PVD coatings are deposited also onto plasma nitrited hot work tool steels. The paper presents the results of the project focused on the investigation of the structure, mechanical and tribological properties of CrN, TiN and TiN/(Ti,Al)N PVD coatings deposited onto plasma nitrided hot work steel X37CrMoV5-1 type (Fig. 10). The structure of TiN and TiN/(Ti,Al)N coatings is columnar while of the CrN coating - fine-crystalline. What decides about the roughness of the PVD coatings deposited onto plasma nitride steel is also the topography of the coatings with heterogeneous surfaces (Fig. 11). The roughness of the investigated coatings is between R_a= 0.1-0.32 µm for the TiN/(Ti,Al)N and TiN coatings adequately. With the increase of the hardness of the PVD coatings there is the increase of the wear resistance as well. The hardness of the investigated coatings is between 2443 $HV_{0.001}$ for the CrN coatings and 3354 $HV_{0.001}$ for the TiN/(Ti,Al)N coatings. The hardness of the examined PVD coating correlates with their adhesion to the substrate material. The PVD coatings deposited onto plasma nitride steel show the adhesion (L_c=51-62 N) of the CrN and TiN to the substrate respectively. As regards all the examined PVD coatings the failures begin with the double-sided chippings on the scratch edges and flakes on their bottoms. These damages appear at different loadings depending on the type of the coating. The increased hardness and resistance of the substrate in the plasma nitride layer contributes to the limitation of the fragmentation of coatings as a result of plastic deformation of the substrate, its conformal cracking, stratification, crumbling and delamination, what finally causes the increase of the adhesion parameters as a consequence of the scratch test. A very good adhesion of the TiN/(Ti,Al)N coating to the plasma nitride steel substrate and its high hardness are connected with the good results of the pin-on-disc tribological test for this coating. The type of the damages of the coating and the substrate, arisen during the scratch test, is similar to the damages and the character of wear during the tribological test. During this test the coatings are worn in the adhesion-abrasive way, and the damage, in most cases, reaches the material substrate. It has been stated that the biggest resistance to the wear resistance at 20 and 500°C temperatures is characterized by the TiN/(Ti,Al)N coating, while the smallest resistance shows the CrN coating.

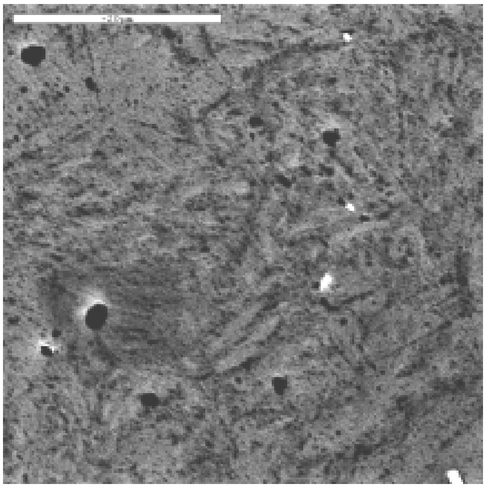


Fig. 11. Topography of the CrN coatings deposited onto plasma nitrided hot work steel X37CrMoV5-1 type

For PVD and CVD and generally surface engineering technologies development forecasting foresight methodology is applied. Foresight technology is the process concentrating scientists, engineers, industrialists, Government officials and others in order to identify areas of strategic research and the leading technologies, which in long term will contribute to the greatest economic and social benefits and sustain industrial competitiveness [30-58].

4. The foresight of the surface treatment development

The main goals of foresight technology and ways of their realisation make the triangle in Fig. 12 presented. That approach is really important in the context of the European Union's priority strategy called Europe 2020 assuming that the development of the continent should be intelligent, supportive to social inclusion and sustainable.

The main goal of realised foresight research FORSURF is to identify the priority innovative technologies and strategic research directions whose development will be crucial during the next 20 years in the scope of surface properties formation leading technologies of engineering materials and biomaterials. It is feasible to put the so-defined objectives into life using the concept of e-foresight and a custom methodology of the Computer Aided Integrated Foresight Research that organises, streamlines and modernises the actual foresight research process. The approach proposed can be implemented practically by developing an information technology including: a virtual organisation, web platform and neural networks. The key methodological assumptions of the carried out research are illustrated graphically in Fig. 13. According to the handling procedure accepted, homogenous groups should be distinguished in the first place for the technologies assessed in order to subject them to the planned research of an experimental and comparative character. The dendrological

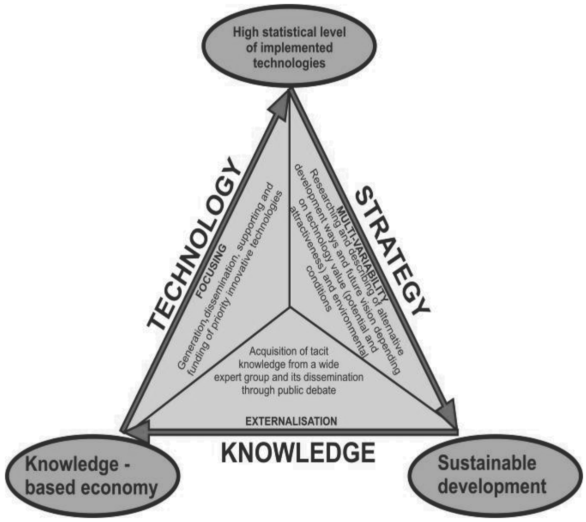


Fig. 12. Technology Foresight Triangle

matrix of technology value presents assessment results for the relevant technology groups according to the potential being the actual objective value of the specific technology and attractiveness reflecting the subjective perception of the relevant technology by potential users. Depending on the potential value and attractiveness level determined in an expert assessment, each of the analysed technologies is placed into one of the following matrix quarters: Quaking Aspen, Soaring Cypress, Rooted Dwarf Mountain Pine, Wide-stretching Oak. The meteorological matrix of environment influence illustrates graphically the results of influence of external circumstances on the relevant group of technology grouped by the difficulties with negative influence and the opportunities with positive influence on the analysed technologies. Depending on the influence degree of positive and negative environment factors determined in an expert assessment, each of the analysed technologies is placed into one of the following matrix quarters: Frosty Winter, Hot Summer, Rainy Autumn, Sunny Spring. A ten-degree universal scale of relative states was used to assess the given technology groups for their value and environment influence degree. According to this scale the smallest value 1 corresponds to a minimum level, and the highest value 10 is the level of perfection. The results of expert studies visualised with a dendrological and meteorological matrices are applied in the next stage of research works applied onto the technology strategies matrix consisting of sixteen fields corresponding to the individual variants from the set of combinations of technology types with environment types. Mathematic relationships are formulated and a computer programme based on them is created enabling to transfer the specific numerical values from the dendrological and meteorological matrix dimensioned [2x2] to the strategy matrix for technologies dimensioned [4x4]. The matrix of strategies for technologies presents graphically the place of technology including its value and environment influence degree and indicates an action strategy to be adopted with reference to the specific technology considering the factors analysed earlier. The strategic development tracks are applied onto the technology strategy matrix consisting of sixteen fields reflecting the predicted situation of the

Table 1.
The technology roadmap for manufacturing of monolayer coatings by physical vapour deposition process onto the CuZn40Pb2 brass substrate (according to A.D. Dobrzańska-Danikiewicz and K. Lukaszkowicz)

TECHNOLOGY ROADMAP	Technology name:	*Manufacturing of monolayer coatings by physical vapour deposition process onto the CuZn40Pb2 brass substrate*		Catalogue No.
	Research scope:	*PVD technologies*		*M2-12-2010/11*
When?	Time intervals	**TODAY 2010-11**	**2020**	**2030**
	All-society and economic perspectives	Creating the Critical Technologies Book	Development of priority innovation technologies	Statistically high quality of technologies implemented in industry
		Creating future events scenarios	Using chances and avoiding difficulties	Sustainable development
		Development of information society and intellectual capital	Wide education and effective intensive coopera-tion between Science and Industry representatives	Knowledge- and innovativeness-based economy
Why?	Strategy for technology Environment influence Technology value	Sunny spring Wide-stretching oak	**Strategy of an oak in string: Succeed.** To develop, strengthen, implement attractive technology of a large potential in industrial practice in order to achieve outstanding success.	
What?	**Product**	Tools and machine parts working in the conditions of higher mechanical, thermal and corrosion loads, ultrathin layers for electronics and optoelectronics, photovoltaic equipment, artificial organs in clinical and experimental medicine, photovoltaic equipment		
	Product quality at the background of foreign competitors	Quite high (7)	High (8)	Very high (9)
	Substrate	Copper and zinc alloy (also alloys of non-ferrous metals, polymer materials, ceramic materials, glass, etc.)		
	Kind of surface coatings/ layers/ processes on substrate surface	Ti/CrNx1, Ti/ZrNx1, Ti/TiAlNx1, Mo/TiAlNx1 and other with similar properties		
	Improved material properties	Increasing mechanical properties (hardness), increasing resistance to corrosion agents and unique optical and electric properties		
	Diagnostic-research equipment	Scanning electron, transmission electron, atomic force microscopes, X-ray diffractometer, GDOS, Raman, Auger, XPS spectrometer, ultramicrohardness, device for testing coating adhesion, device for corrosion tests		
How?	**Technology**	Manufacturing of monolayer coatings by physical vapour deposition process onto the CuZn40Pb2 brass substrate		
	Life cycle period	Prototype (8)	Growth (7)	Early mature (6)
	Production type	Unit and small-scale serial	Small- and medium-scale serial	Medium-scale setial
	Production organisation form	Cellular	Cellular	Cellular
	Machine park modernity	Quite high (7)	High (8)	Very high (9)
	Automation & robotisation	Moderate (6)	High (8)	Very high (9)
	Quality and reliability	Quite high (7)	High (8)	Very high (9)
	Proecology	Quite high (7)	High (8)	Very high (9)
Where?	Organisation type	R&S centres, small-and medium- sized enterprises	Small-and medium- sized enterprises,	Large-and medium-sized enterprises, microenterprises
	Represented industry	Tool, machine-building, electrical, electronic, optoelectronic, medical ones		
Who?	Staff education level	Quite high (7)	High (8)	Very high (9)
	Engagement of scientific-research staff	Very high (9)	Quite high (7)	Moderate (6)
How much?	Capital requirements	High (8)	Moderate (6)	Quite low (4)
	Production size determining profitability in enterprise	Medium (5)	Quite high (7)	High (8)
	Production size in the country	Quite low (4)	Quite high (7)	Very high (9)

LEGEND: ⟹ Cause and effect connections; ········▸ Capital connections; ······▸ Time corelations; ⟷ Two-way transfer of data and/or resources

Table 2.
The technology roadmap prepared for laser cladding of VC vanadium carbide particles in the substrate of Mg-Al-Zn casting magnesium alloys (according to A.D. Dobrzańska-Danikiewicz and T. Tański and al.)

TECHNOLOGY ROADMAP		Technology name: *Laser cladding of VC vanadium carbide particles in the substrate of Mg-Al-Zn casting magnesium alloys*		Catalogue No.
		Research scope: *Laser technologies in surface engineering*		*M1-13-2010/11*
When?	Time intervals	**TODAY 2010-11**	**2020**	**2030**
	All-society and economic perspectives	Creating the Critical Technologies Book	Development of priority innovation technologies	Statistically high quality of technologies implemented in industry
		Creating future events scenarios	Using chances and avoiding difficulties	Sustainable development
		Development of information society and intellectual capital	Wide education and effective intensive coopera-tion between Science and Industry representatives	Knowledge- and innovativeness-based economy
Why?	Strategy for technology	**Strategy of an oak in string: Succeed.** To develop, strengthen, implement attractive technology of a large potential in industrial practice in order to achieve outstanding success.		
	Environment influence	Sunny spring		
	Technology value	Wide-stretching oak		
What?	**Product**	Elements for automotive industry, which are friction, corrosive and/ or erosive worn, elements with quasi-gradient structure, MMCS composites, biomaterials, future yet unknown applications		
	Product quality at the background of foreign competitors	High (8)	Very high (9)	Excellent (10)
	Substrate	Casting magnesium alloys		
	Kind of surface coatings, layers/ processes on substrate surface	Vanadium carbide VC		
	Improved material properties	Better mechanical properties of elements (hardness), better anticorrosive properties, better 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 VC vanadium carbide particles in the substrate of Mg-Al-Zn casting magnesium alloys		
	Life cycle period	Prototype (8)	Growth (7)	Mature (5)
	Production type	Unit and small-scale serial	Small- and medium-scale serial	Small- and medium-scale serial
	Production organisation form	Cellular	Cellular	Cellular
	Machine park modernity	Excellent (10)	High (8)	High (8)
	Automation & robotisation	High (8)	Excellent (10)	Excellent (10)
	Quality and reliability	High (8)	High (8)	High (8)
	Proecology	Very high (9)	Very high (9)	Very high (9)
Where?	Organisation type	R&S centres, technological parks, large-and medium- sized enterprises	R&S centres, technological parks, large-and medium- sized enterprises	R&S centres, large-, medium-, and small- sized enterprises
	Represented industry	Medicine, automotive industry, military equipment, aviation, aeronautics		
Who?	Staff education level	Very high (9)	High (8)	Moderate (6)
	Engagement of scientific-research staff	Very high (9)	Quite high (7)	Moderate (6)
How much?	Capital requirements	Very high (9)	High (8)	Moderate (6)
	Production size determining profitability in enterprise	Medium (5)	Quite high (7)	Very high (9)
	Production size in the country	Very low (2)	Quite low (4)	Moderate (6)

LEGEND: Cause and effect connections; Capital connections; Time corelations; Two-way transfer of data and/or resources given technology if positive, neutral or negative external circumstances occur. The forecast established concerns the time intervals of 2015, 2020, 2025 and 2030 and presents a vision of future events consisting of few variants.

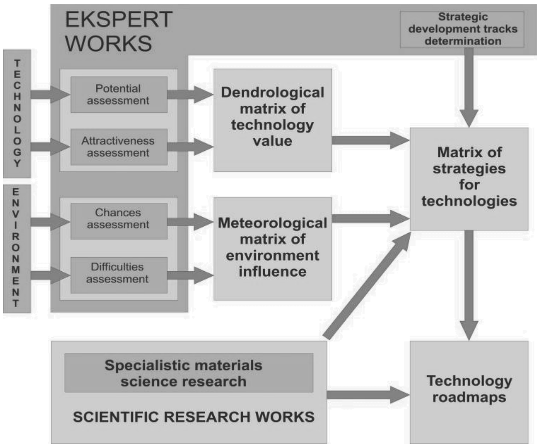


Fig. 13. Methodology of interdisciplinary foresight-materials science researches (according to A.D. Dobrzańska-Danikiewicz) [59]

The inherent part of the worked out methodology are detailed materials science experiments of surface layers structures created using the different kinds of surface treatment methods as well as research of mechanical and tribological properties and utility functions research under conditions of exploitation or similar ones. The results of these investigations relating to technologies selected through the described technology valuating methods constitute an important premise for working out and experimentally verifying the evaluations made using the set of technology foresight matrices and they are necessary for creating the technology roadmaps. A technology roadmap is a graphical comparative analysis tool for choosing the best technology group in terms of selected criteria. The set-up of the custom technology roadmap corresponds to the first quarter of the Cartesian system of coordinates. Three time intervals for the years: 2010-11, 2020 and 2030 are provided on the axis of abscissa, and the time horizon for all the results of the research applied onto the map is 20 years. Seven main layers were applied onto the axis of coordinates of the technology roadmap answering subsequently to more and more detailed questions: When? Why? What? How? Where? Who? How much? The undisputed advantage of technology roadmaps is flexibility and, if needed, additional sub-layers can be added or expanded for the maps according to the circumstances of the industry, a size of enterprise, a scale of the company's business or an entrepreneur's individual expectations.

Two demonstration roadmaps prepared for manufacturing of monolayer coatings by physical vapour deposition process onto the CuZn40Pb2 brass substrate (Table 1) and for laser cladding of VC vanadium carbide particles in the substrate of Mg-Al-Zn casting magnesium alloys (Table 2) in that work are presented. The technology roadmaps supplement the technology information sheets, which include the technical information set being a compact compendium of knowledge making easier technology practical implementation in industry, especially in small and medium enterprises. The final results of advanced foresight-material science research is the Critical Technologies Book being the set of 140 roadmaps and 140 information sheets describing critical technologies in surface materials engineering area, three alternative versions of future events scenarios of surface materials engineering development as well as public debate concerning the significance of surface engineering development for the Europe 2020 strategy realisation [60-68].

5. Application of the Computational Materials Science methods

The Finite Element Method is applied for modelling of the PVD coatings properties. On the basis of researches results, it was found out that using advanced technique of calculation among others thing the finite elements method FEM, can be exploited as tools usrd in surface engineering to characterise the coatings. This method allows to realise complex analysis proceeding during processes of coatings spread and also an analysis of phenomena occur as an effect of a final process.

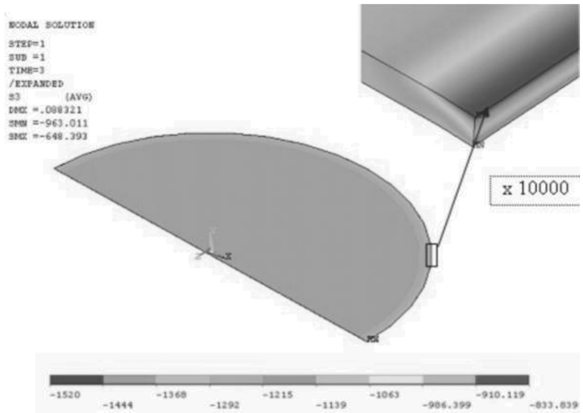


Fig. 14. Distribution of the simulated compression stresses in the TiN PVD coatings

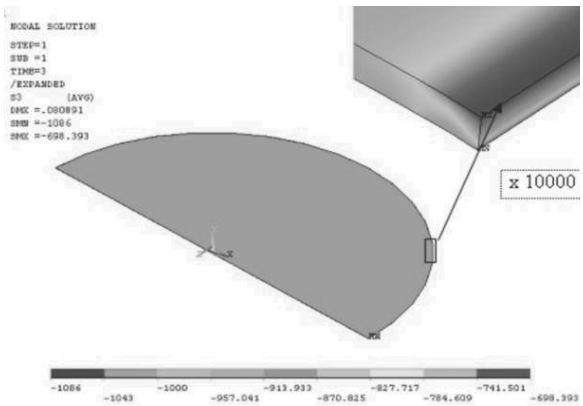


Fig. 15. Distribution of the simulated compression stresses in the TiC PVD coatings

One has to indicate that such an analysis needs knowledge of many quantities as physical and mechanical properties of substrate material and coating and also its parameters of spread. As a result of this abovementioned method allows to create a model which describes inner stresses in relation to parameters of process and also to a kind of substrate material and to coatings (Figs. 14 and 15). In addition, a developed model can eliminate the need for expensive and time-consuming experimental studies for the computer simulation to a large extent. Developing an appropriate model allows the prediction of properties of PVD coatings, which are also the criterion of their selection for specific items, based on the parameters of technological processes.

For predicting the properties of the PVD and CVD coatings the fractals as very interesting mode of the Computational Materials Science and Surface Engineering are used. The aim of the work is to establish a methodology elaboration, giving a possibility to predict properties of coatings reached in PVD and CVD processes on tool materials, based on fractal quantities describing their surface. Coatings' topography and its structure which has an impact on a shape of analysed objects' surface are characterised in a comprehensive way. Influence of a type of process and conditions of deposition over structure and shape of surface topography as well as mechanical and operational properties of the acquired coatings are determined. The coatings selection, represented in terms of types and conditions proceeding in deposition processes, types of substrates material as well as chemical and phase composition, and also a combination of applied layers provided diversity of their surface topography as well as mechanical and functional properties. Methodology for precise description of coatings topography acquired in PVD and CVD process on tool materials including using of the fractal and multi-fractal geometry on the basis of images obtained on an atomic forces microscope is elaborated and verified. A modified methodology to determine fractal parameters of surface by means of the Projective Covering Method (PCM) is applied. Dependencies between fractal and multi-fractal parameters characterising analysed PVD and CVD coatings surfaces and their mechanical and operational properties are established. Values of the fractal dimension for coatings' topography received in the magnetron PVD process are correlated with microhardness and erosion resistance, whereas the fractal dimension values of coatings' topography obtained in the high-temperature CVD process (on a substrate made of Si_3N_4 ceramics and when the outer layer was made of Al_2O_3) and in the arc PVD process is correlated with tool life increase specified in the cutting ability test. It is shown that the presented interdependencies give a possibility to predict coatings' properties received in the PVD and CVD processes on tool materials based on fractal parameters defining their surface.

The next example of the application of the Computational Materials Science and Surface Engineering is methodology of high-speed steels design using the artificial intelligence tools. The main goal of the outcarried research is to develop the design methodology for the new high-speed steels with the required properties, including hardness and crack resistance expressed by fracture toughness. The adequate models are developed first, enabling computation of high-speed steel hardness and its crack resistance solely based on chemical composition of the steel and its heat treatment parameters, i.e., austenitising and tempering temperature. The outcarried research confirmed that using the catalogue data and standards is possible, which - supplementing the set of experimental data indispensable to develop the assumed model - improve its adequacy and versatility. Methodology of the multicriteria optimisation of the high-speed steel chemical composition, using the evolutionary algorithms, is developed to design the chemical composition of the new high-speed steels, demonstrating the required hardness and fracture toughness. It was used in the own computer programme, which enables design of the chemical composition of steel with the required hardness and fracture toughness in the specified search area for the optimum high-speed steel chemical composition. Solutions presented in the work, based on using the adequate material models may feature an alternative in designing of the new materials with the required properties. The practical aspect, resulting from the developed models, which may successfully replace the above mentioned technological investigations, consisting in one time selection of the chemical composition and heat treatment parameters and experimental verification of the newly developed materials checking its properties and meeting the requirements has to be noted. It was also demonstrated that employment of computer tools enables especially efficient use of the existing materials data resources contained in publications, standards, catalogues, and data bases, and their integration in the material models form.

The Computational Materials Science and Surface Engineering methods especially the neural networks are applied among others for the prediction of continuous cooling transformation diagrams. The method of forecasting of Continuous Cooling Transformation (CCT) diagrams for steels by the use of neural networks has been presented. Input data are chemical composition and austenitising temperature.

Results of calculation of neural networks consist of temperature of the beginning and the end of transformation in the function of cooling rate, the volume fraction of ferrite, perlite, bainite, martensite with the retained austenite and the hardness of steel cooled from austenitising temperature. Presented quantities enable to draw the CCT diagram (Fig. 16). The developed neural network models make it possible to carry out computer simulation of the effect of chemical composition, austenitising temperature and/or cooling rate on a selected quantity describing austenite transformations in the CCT diagram.

The example of the Computational Materials Science and Surface Engineering methods is an analysis of alloying elements influence on the properties of the structural steels with the using of the materials science virtual laboratory. The paper introduces analysis results of selected alloying elements influence on the mechanical properties of the alloy structural steels for quenching and tempering. The investigations are performed in virtual environment with use of materials science virtual laboratory. Virtual investigations results were verified in real investigative laboratory. Materials researches performed with use of material science virtual laboratory in range of determining the mechanical properties are consistent with the results obtained during the real research in a real laboratory. For materials investigation alloyed structural steels have been selected. Material was manufactured in electric arc furnaces with devices for steel vacuum degassing (VAD). The material was supplied in the form of heat and plastic treated forged round rods. Material science virtual laboratory is, located in virtual environment, a set of simulators and trainers, which main objective is to simulate the research methodology of investigative equipment located in a real scientific laboratory. It allows for the mechanical properties prediction of non-alloy and alloy structural steels. On the basis of the input steels manufacturing conditions are possible to determine its mechanical properties without the need for real examinations (Fig. 17). Also the reversed inference is possible, namely on the basis of mechanical properties values steel's production conditions can be determined. For the description of structural steel, six mechanical properties presented in the metallurgical certificate have been selected. To describe the above properties a set of descriptors characterising steel in manufacturing process has been developed. In order to model and predict properties, material descriptors, such as chemical composition, heat treatment, plastic treatment and geometric parameters were inputted to a materials science virtual laboratory. To verify modelling correctness, results obtained during virtual examinations were compared with the results of real material investigations performed on real steel samples in a real laboratory.

Results of modelling were marked as correct, because all five types were recognised correctly. Differences among measured and predicted values of mechanical properties are very small and the values of the neural networks tolerances were not exceeded. Influence analysis was conducted to calculate how big the influence of the alloy addiction concentration on steels mechanical properties is. Dependence graphs were generated with the use of NeuroLab system among estimated mechanical properties and the concentration of chosen alloying additions. Materials researches performed in virtual environment with use of material science virtual laboratory in range of determining the mechanical properties of alloy structural steels are consistent with the results obtained during the real research in a real investigative laboratory. Results consistency was observed in the whole range of steel descriptor variation: of concentrations of chemical elements, heat and mechanical treatment conditions and mechanical properties of examined structural steels for quenching and tempering [69-98].

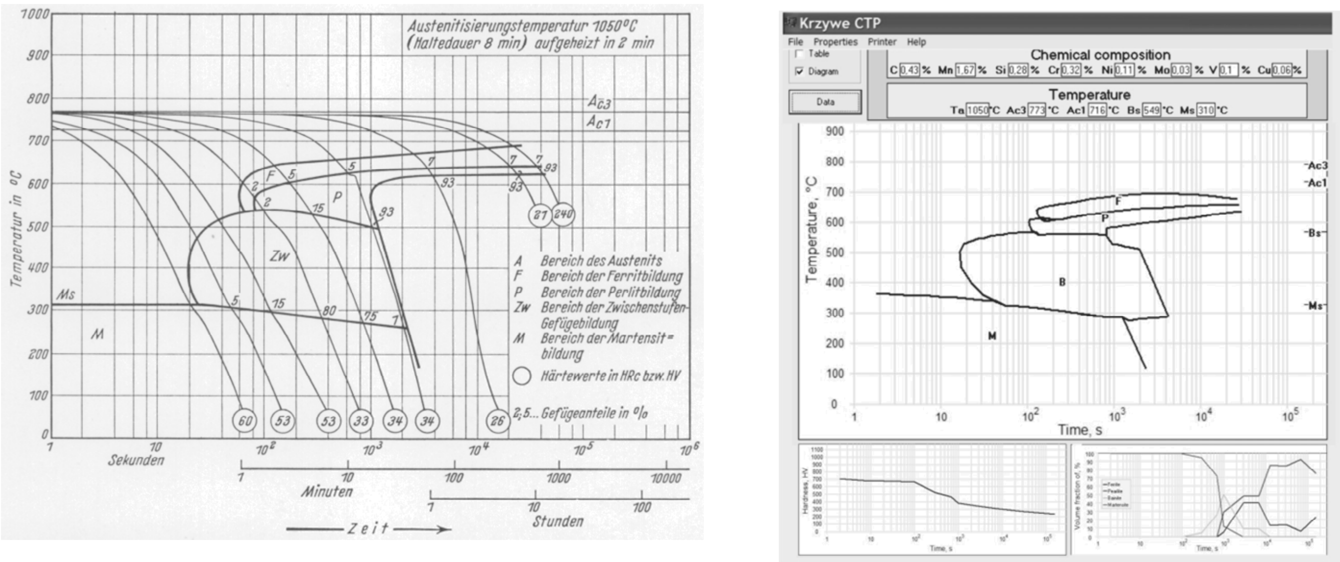


Fig. 16. CCT diagram for steel with concentrations: 0.43% C, 1.67% Mn, 0.28% Si, 0.32% Cr, 0.11% Ni, 0.03% Mo, 0.01% V, 0.06% Cu, austenitised at temperature of 1050°C: a) experimental, b) calculated by the neural network model

a) b) c)

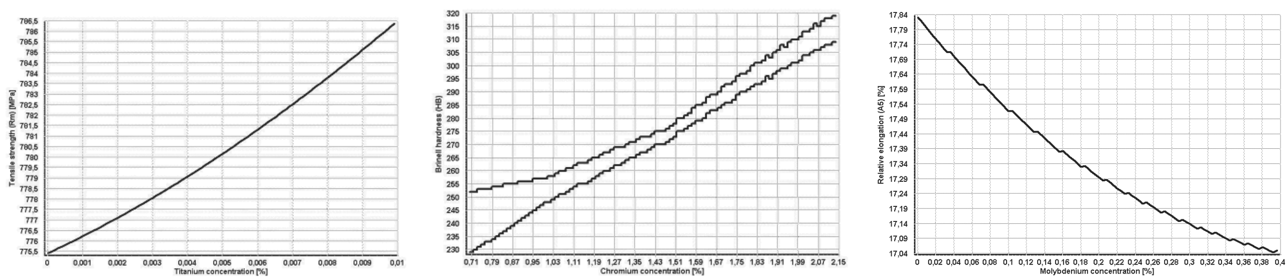


Fig. 17. Influence of: a) titanium concentration on tensile strength of 24CrMo4 steel; b) chromium concentration on Brinell hardness of 41Cr4 steel (minimum and maximum values); c) molybdenum concentration relative elongation of 30CrMo5-2 steel

6. Dental engineering and biomaterials research

In the field of dental engineering own researches directed on: structural effect occur in metallic materials, influence on useful properties like corrosion resistance and permanency of finished dentures which depends of ceramics adhesion to metallic substrate are performed. Also the study about crown and bridgeworks geometry modelling which is a criteria in tension minimalisation in constructions are provided. The last 25-30 years brought on huge development of metallic materials which are used in nowadays dentistry. An engineer may choose from hundreds materials from many world companies. Actually there is possibility to choose metallic materials using the American Dental Association classification (Fig. 18). The introduction to the alloys different additions has influence on forming metallic phases structure (Fig. 19), also affects on clinical characteristics, especially on biocompatibility and different possibility dental usage (Fig. 20).

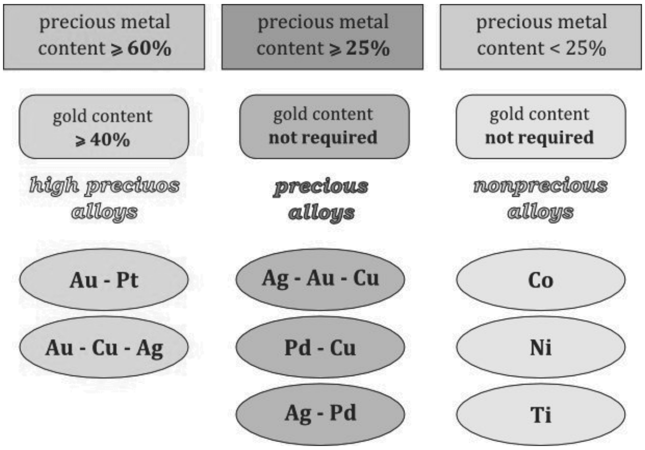


Fig. 18. Classification of the metallic materials used in dental engineering

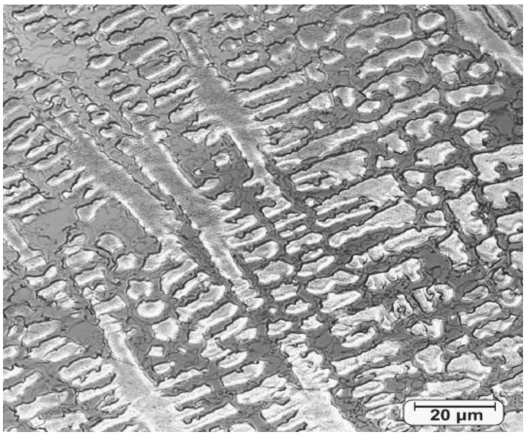


Fig. 19. Dendritic microstructure of Remanium 2000+ CoCr alloy, confocal microscope

The outworked elastic aramid-silicone composite materials for the manufacturing of the internal oesophageal prosthesis (Fig. 21) has been applied. The aim of the work is to develop the prosthesis that could replace the natural oesophagous and perform its anatomical functions. The finished prosthesis will result in cognitive, constructional and technological effects, but first of all, it will enable the increase of comfort of life of the very sick people after resection of pathologically changed oesophagus. Within the framework of this work, the construction of the mentioned prosthesis has been developed, the structure and properties of the used material have been examined. It has been established that ourworked aramid-silicone composite material is characterised with specific properties against given group of laminated materials. Resilience of analysed material will decrease the risk of bedsore inside the human body after implementation of the prosthesis. Additionally, diversified degree of inner and outer surface roughness of the developed material (low at the inner side and high at the outer one) will positively influence on easy transport of food on the one side, on the other one, on better stabilisation of the prosthesis inside the body (Fig. 22). Properly prepared surface favours the living tissue development. The technological conditions of the material itself at the first stage and the prosthesis at the second one have been determined and optimised. The well-known method of fibre with matrix winding onto previously prepared core has been chosen to prepare the prosthesis. This choice determined the necessity of a specific approach to a manufacturing process, it means, a methodological approach in the choice of the braid architecture proposed for the described prosthesis has been adopted. Present-day investigations are also of the biological character and are carried out in the Regional Blood-donor Centre - Tissue Bank. Those investigations consist on the culture and sowing of cells on the newly developed material in order to determine its influence on living organism. The application to Bioethical Committee has been also submitted, and its approval will allow the realization of planned clinical researches, which will enable the decision on further prosthesis modification. Realisation of this scientific work is enable to achieve research, constructional and technological results as well as, what is even more important, it will enable the effective help to very sick people [99-105].

7. Composite materials with magnetically controlled properties

Composite materials with controlled soft or hard magnetic properties are the next area of interesting. The search for the new soft magnetic materials has lead, among others, to the development of research on the Fe based metallic materials with the nanocrystalline structure, having the great soft magnetic properties. Bonding of powders of Fe based nanocrystalline metallic materials with the polymers and low-melting alloys enables to obtain the composite materials (Fig. 23). The range of magnetic materials application growths with improvement of their magnetic, mechanical, electrical and thermal properties. The application of magnetic composite materials allows to miniaturise magnetic elements, construction simplification and lower both manufacturing and material costs.

Fig. 20. Dental work made by metallic materials

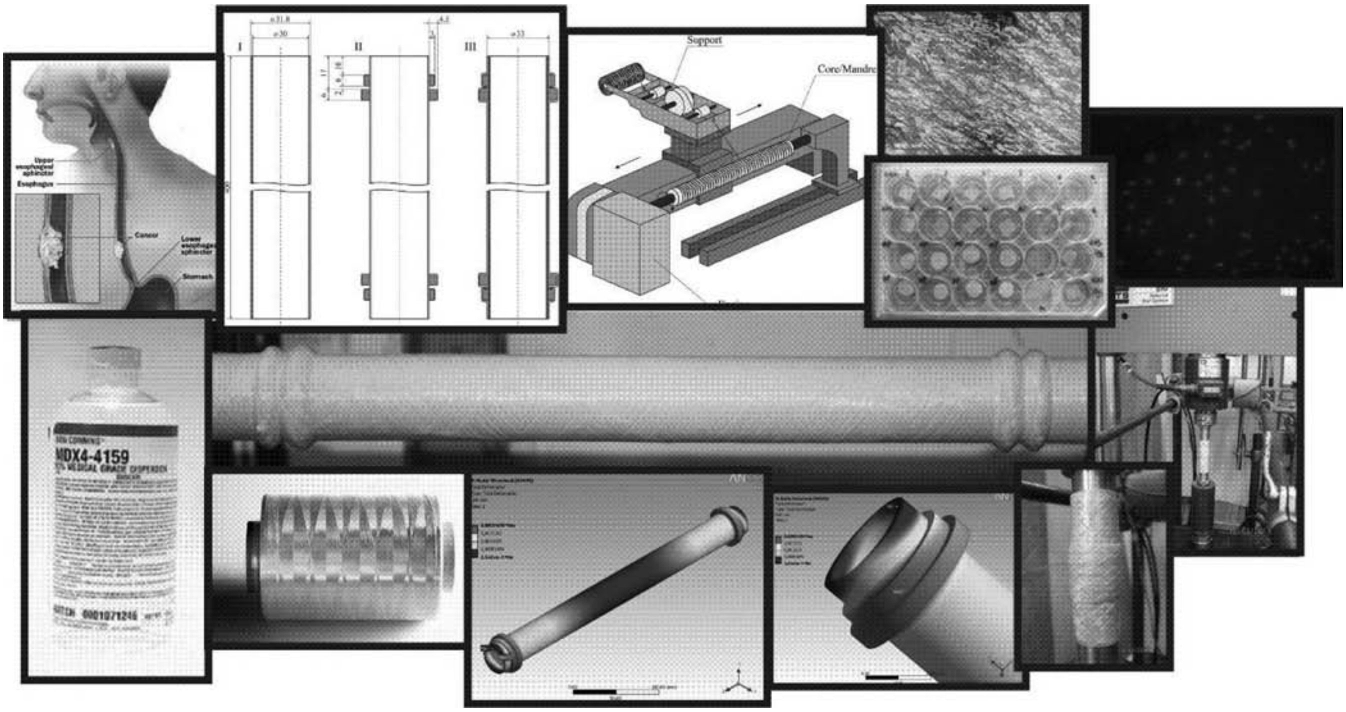


Fig. 21. The scheme of scientific activity for work out the elastic aramid-silicone composite materials for the manufacturing of the internal oesophageal prosthesis

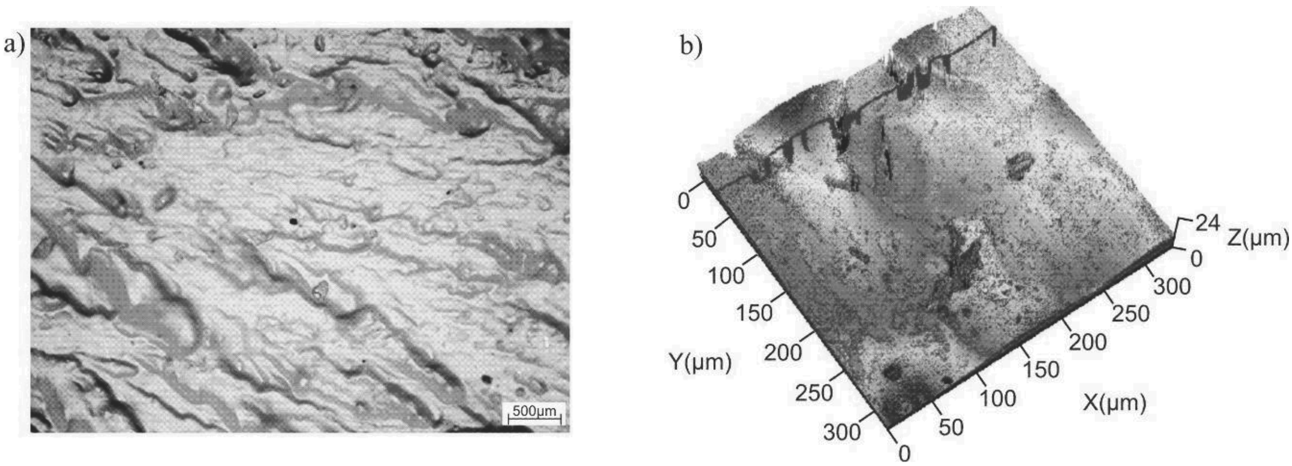
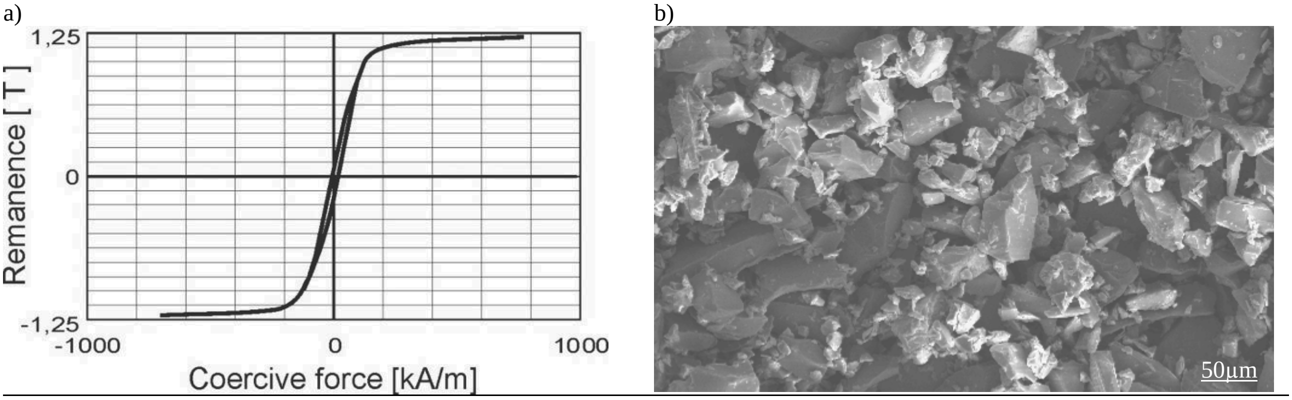


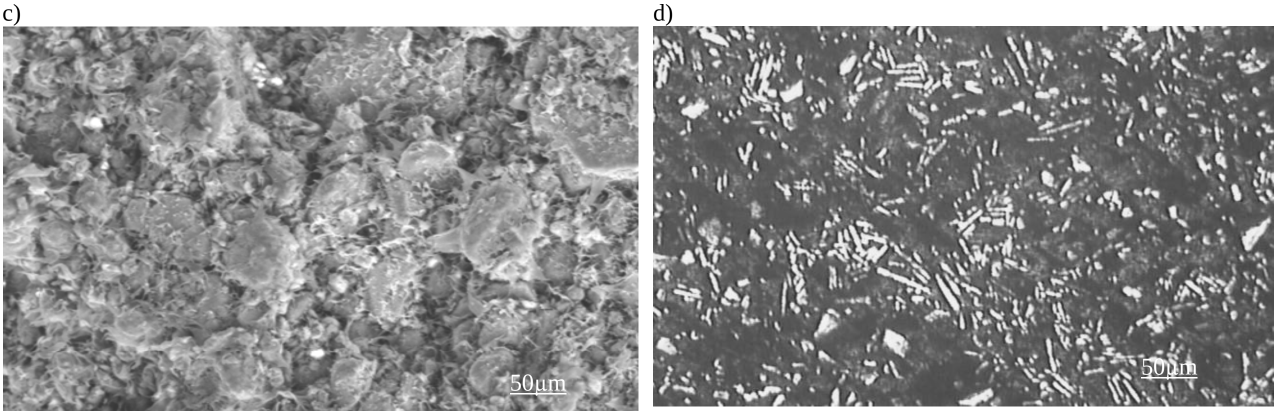
Fig. 22. The inner irregular surface of aramid-silicone material; a) MEF4A Leica Light microscope, b) LMS 5 Exciter Zeiss Confocal microscope

a) b)



H_c, kA/m	B_r, T	B_s, T	μ_{max}	Min., μm	Max., μm	Mean, μm	Stdev.
0.537	0.006	1.3	81	10.3	69.2	34.7	6.5

c) d)



e)

	R_c, MPa	A_c, %	E_c, MPa
mechanical properties	27.4	8.6	330.8

Fig. 23. FINEMET - PEHD composite material: a) hysteresis loop, b) powder $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$, c) fracture of composite material (SEM), d) structure of composite material (LM), e) mechanical properties

The work on the structure and properties of magnetically soft composite materials with the silicon matrix reinforced with the nanocrystalline powders of cobalt alloys, was dedicated to the investigation of the influence of high energy grinding process conditions on structure and magnetic properties of the soft powder material obtained from cobalt alloys and to the investigation of the effect of its heat treatment on its structure and properties. The obtained powders were consolidated and nanocomposite cores with the required properties were made from them. The examination of their magnetic properties were made on the FERROMETR-1 device; whereas, the examination of powders were carried out on the Lake Shore Cryotronics VSM vibration magnetometre and on the Moessbauer spectrometre.

Structures of the amorphous strips and those isothermally annealed, and of the obtained powder materials were examined using the JEOL JEM 200CX and TESLA BS 540 electron transmission microscopes and the DSM-940 electron scanning microscope with the Opton EDS LINK ISIS energy dispersive X-ray spectrometer. The soft magnetic powder materials are characterised by a relatively high value of coercion field (150-1200 A/m), which increased with the grinding time and magnetic saturation 0.6-0.87 T. There is a possibility to control these properties using heat treatment. Nanocomposite magnetic cores were made from the powder material obtained by high energy grinding and influence of the metallic powder fraction on soft magnetic properties were investigated along with the possibility to control these properties with the amount of powder fraction (Figs. 24 and 25). The nanocrystalline composite material with the mass fraction of metal powder to silicone polymer of 6:1 has the most advantageous magnetic properties. Composite with the mass fraction of 2:1 has the worst properties. Mass fraction of the metallic powder in the nanocomposite decides the composite's mechanical properties. The highest ultimate tensile strength UTS is characteristic for the composite with the mass fraction of the metal powder to silicone polymer of 3:1 (UTS=1.18 MPa). As the mass fraction increases, the UTS value decreases. The elongation ε dependence of the powder mass fraction is similar - linear (proportional). The highest elongation of ε=212% is characteristic for the composite with the mass fraction of metallic powder to the silicone powder of 6:2. The determined high energy grinding parameters, high treatment conditions, and the metallic powder material consolidation methods may be employed in the electronic and electrotechnical industry.

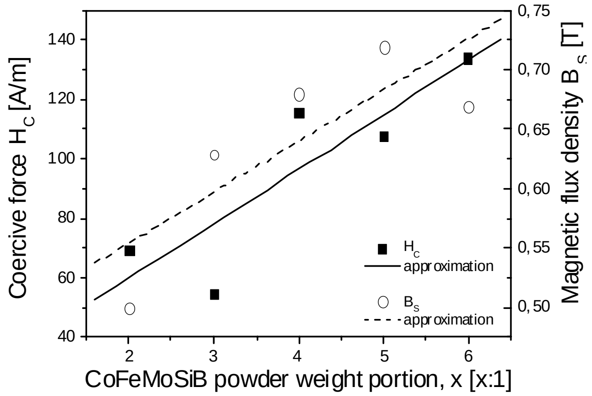


Fig. 24. Magnetic properties of the nanocomposite magnetic soft materials with the various metallic powder to polymer matrix weight ratios

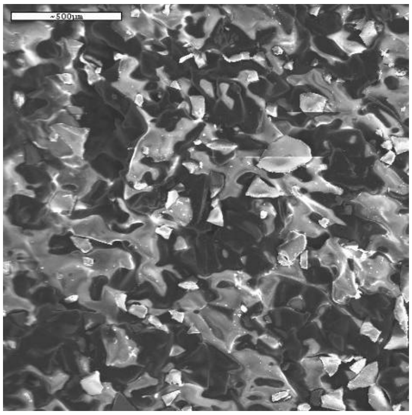


Fig. 25. Structure of the nanocrystalline composite material with the silicone matrix reinforced with the $Co_{68}Fe_4Mo_1Si_{13.5}B_{13.5}$ alloy powder, powder to silicone in the composite weight ratio 3:1; SEM

Structure and properties of composite materials with polymer matrix reinforced Nd-Fe-B hard magnetic nanostructured particles were also investigated. The experiments were made with the polymer matrix hard magnetic composite materials reinforced with nanostructured particles of the powdered rapid quenched Nd-Fe-B strip MQP-B type made by Magnequench ($Nd_{14.8}Fe_{76}Co_{4.95}B_{4.25}$). Powders of metals and their alloys: iron, aluminium, CuSn10 casting alloy of copper with tin, and of the X2CrNiMo17-12-2 high-alloy steel (5, 10, 15% wt.) were added to the composite material. The heat-hardening epoxy resin was used as the matrix (2.5% wt.). The following compacting process parameters were used: unilateral uniaxial compaction, room temperature, pressure 800-900 MPa. The polymer matrix of the composite materials was cured at the temperature of 180°C for 2 hours after compacting (Fig. 26).

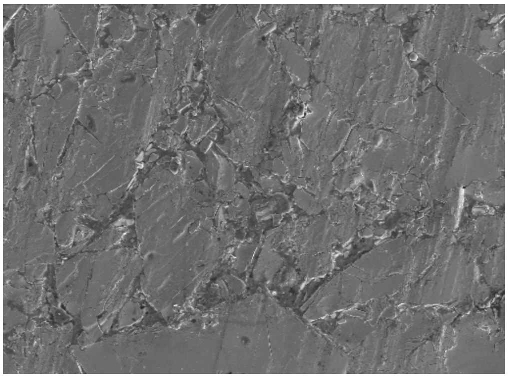


Fig. 26. Microstructure of composite material without addition powders

It is shown that additions of metal powders and their alloys to polymer matrix hard magnetic composite materials cause improvement not only of mechanical properties (Fig. 27) but also the application properties, including mainly corrosion resistance. Composite materials with no additions are characterised with good magnetic properties. Additions of metallic powders to those composite materials causes decrease of magnetic properties, but improves mechanical properties of magnets. The highest influence on the increase of ultimate compression strength has iron powder, although the most advantageous influence on hardness increase has X2CrNiMo17-12-2 high-alloy steel powder. Corrosion resistance of composite materials increases thanks to additions of metallic powders. Materials including additions of aluminium powders are characterised with the greatest resistance, whereas including additions of iron provide the lowest one. The developed neural network model, verified experimentally, allows computer simulation of influence of metallic powder additions and/or the test duration on corrosive wear of magnets in corrosion environments assumed.

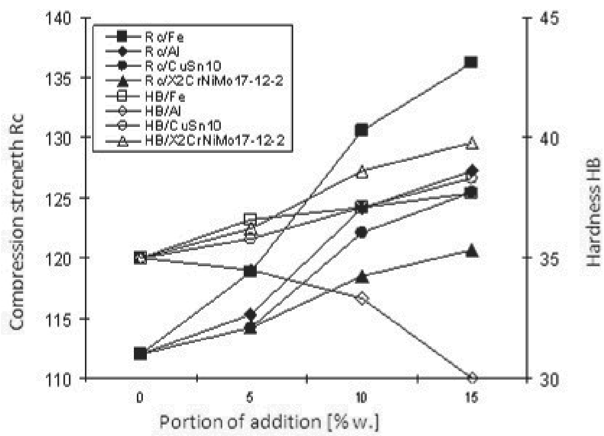


Fig. 27. Comparison of the hardness and compressive strenght of composite materials

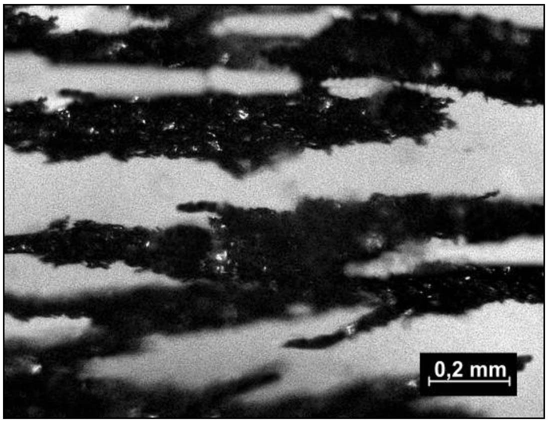


Fig. 28. Microstructure of composite materials with 10% volume fraction of $Tb_{0.3}Dy_{0.7}Fe_{1.9}$ with aligning the particles in polymer matrix; 100x

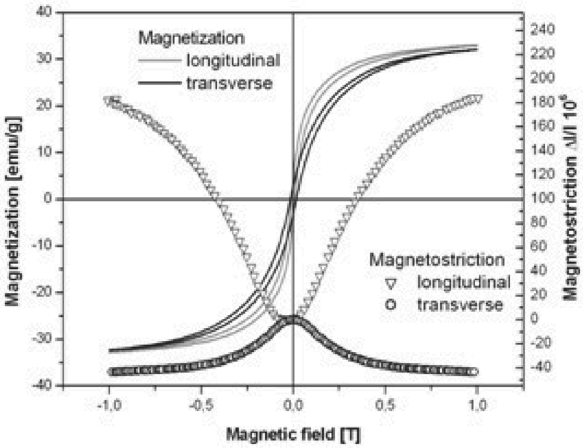


Fig. 29. Magnetic field dependence of magnetization and magnetostriction the external applied field longitudinal and transverse to the internal bias field for oriented composite materials with 10% volume fraction of $Tb_{0.3}Dy_{0.7}Fe_{1.9}$

Intelligent polymer matrix composite materials reinforced by $Tb_{0.3}Dy_{0.7}Fe_{1.9}$ magnetostrictive particles were investigated. The $Td_{0.3}Dy_{0.7}Fe_{1.9}$ alloy exhibits giant magnetostriction (800-1200 ppm) in a considerably low magnetic field (50-200 kA/m) at the room temperature. Unfortunately some factors - such as the development of eddy currents in high frequency applications, brittleness in tension, large magnetic fields required to induce strain and high price have limited its use. For potential applications in technological devices, such as sensors and actuators, it is desirable to form a composite system by combining magnetostrictive phases with passive matrix in order to have giant magnetostrictive effect and, at the same time, to reduce disadvantages of monolithic material. In this work the relationships among the manufacturing technology conditions of composite materials, their microstructure, as well as their magnetic properties were evaluated as function of both bias field and frequency. It was shown that anisotropy of composite materials - arising from $Tb_{0.3}Dy_{0.7}Fe_{1.9}$ particles magnetic alignment during curing of polymer matrix (Fig. 28) – causes low values of transverse magnetostriction but at the same time - the greater longitudinal response (Fig. 29) in comparison to non-oriented one. The obtained results show the possibility of manufacturing the magnetostrictive composite materials based on the $Td_{0.3}Dy_{0.7}Fe_{1.9}$ particles with desired microstructure and magnetic properties, being a cheaper alternative for conventional giant magnetostrictive materials GMM [106-123].

8. Composite materials with nanotubes

The work on in-mould manipulation of injection moulded polymer nanocomposites investigates the structure development of polymer based nanocomposites. Nanofiller strongly influenced on mechanical behaviour and morphology of polymer composites. Polypropylene (matrix material) was blended with the organo-modified montmorillonite nanoclay in ratio of 97/3 wt% (polymer or polymer composite/nanofiller). After blending in rotational drum, materials were injection moulded into cavity in special mould. Processing consists of two steps, where first one was traditional injection moulding process and second one started just after filling the cavity inside mould, where melt was manipulated by reciprocation movements, inducing multilayer zone and outer skin, and containing simultaneously small, spherullitic core. Diversified settings of the operative processing parameters were used according to the moulding set-up, basing on the design of experiments. Three main parameters (melt temperature, stroke time and number) were changeable during processing and their mutual combination brought series of interesting results. Mechanical tests were performed on universal testing machine on notched specimens and sharpened with razor blade, by 3-point bending test with crosshead speed 10 mm/min (according to the ASTM E399 standard) under constant room condition (23ºC and 50% of humidity). This mechanical characterization was prepared for comparison of the synergetic effects of polymer-polymer composites and processing conditions on the fracture behaviour. The best improvement of energy value has been obtained for pure polymer matrix reinforced by nanoparticles. Polymer nano-composites as a new and interesting class of polymer composites derived from nano-scale particles are investigated worldwide, demonstrating a broad scope of material composition possibilities. A high aspect ratio of homogenously dispersed particles, which dimension ranges from 1 to 1000 nm improve mechanical, thermal and barrier properties. Enriching composites by nanoparticles varies and is dictated by cost of nanofillers, generally reaching 5 and even 10 wt%. Production of polymer nanocomposites by compounding the nanofiller with polymer matrix (e.g. PC or PP) by melt mixing, in situ polymerization and other processes is widely and challenging investigating area. Nanoparticles inside polymer composites are disposed in two forms: intercalated and exfoliated ones. In reality both of these types are mixed simultaneously, unless special control during processing has been satisfied. The difference between these systems is the stacking - intercalated system contains stacked silicate galleries, while exfoliated system has fully separated particles, stochastically dispersed inside a polymer matrix. Good dispersion rises to enhance the properties (Fig. 30).

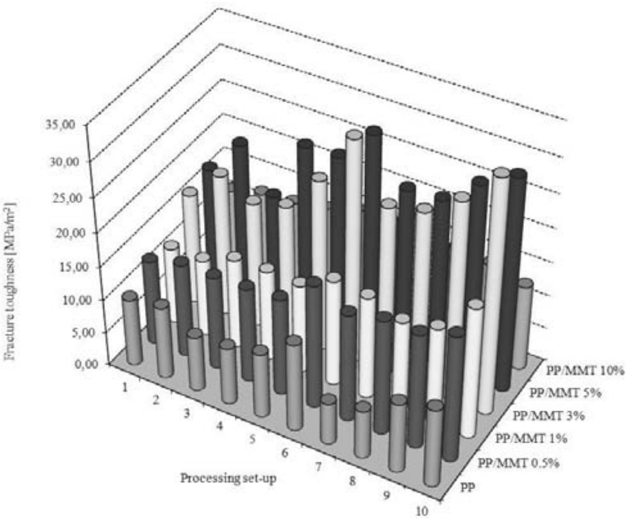


Fig. 30. Comparison of fracture toughness K_{IC} of all nano-composites performed by advanced injection moulding technique with different processing set-up of changeable parameters

The purpose of the work on synthesis and characterisation of carbon nanotubes (CNTs) decorated with platinum nanoparticles is to obtain Pt/CNT composites. Platinum are widely used in many applications, especially as a catalyst for CO oxidation in catalytic converters and for fuel cell technology. It can also be used as a stable electrode material. Since Pt is particularly expensive, there is a real incentive to reduce the amount of Pt required in applied processes. With this end of view a lot of efforts is put to reduce the size of used Pt particles what additionally can significantly increase its specific surface area. Carbon nanotubes become the one of the mostly researched nanomaterial in the last decades because of their promising applications in any aspect of nanotechnology, result mainly from theirs high surface area, mechanical strength, chemical and thermal stability. Due to the possibility to combine the unique physical and chemical properties of CNT with innovative properties of noble (including Pt) metal nanoparticles in one discrete structure there is a great deal of interest in attaching nanoparticles to nanotube surface. The controlled coating without aggregation would be crucial for this issue and it was the main aim of the research.

To improve metal deposition onto CNTs in the experiments the purification procedure with a mixture of reduction reagents was applied. Carbon nanotubes decorated with platinum nanoparticles were synthesised by organic colloidal process as an example of direct formation of nanoparticles onto CNTs. Chemical composition and crystallographic structure of the obtained Pt/CNT composites were determined by energy dispersive X-ray spectroscopy (EDS) and by X-ray diffraction (XRD) measurements, while transmission (TEM) and scanning (SEM) electron microscopy were used for characterisation of the morphology of composite as well as the distribution of nanocrystals on the CNTs surfaces. High efficiency of proposed method was confirmed as well as possibility of the coating of Pt nanoparticles onto CNTs, without aggregation of these particles. Fabricated material is homogenous and contained mainly carbon nanotubes. The Pt phase appearance is convincingly confirmed by energy dispersive X-ray spectrometry. The side walls of CNTs with diameter of 10-50 nm are evenly decorated with Pt nanoparticles. The density of attached nanocrystals are high. Observed platinum particles appear to have a narrow size distribution and they are durably attached to the nanotubes (Fig. 31). The diffraction peaks in XRD pattern indicating a good crystallinity of the supported nanoparticles. The average crystallite size of Pt calculated using the Debye-Scherrer formula was determined as about 4 nm, consistent with SEM and TEM observations. Obtained material can be employed in constructing various electrochemical sensors. As a result of increasing of the surface area of Pt caused by the reduction of the size of used particles, fabricated sensor are expected to be more sensitive.

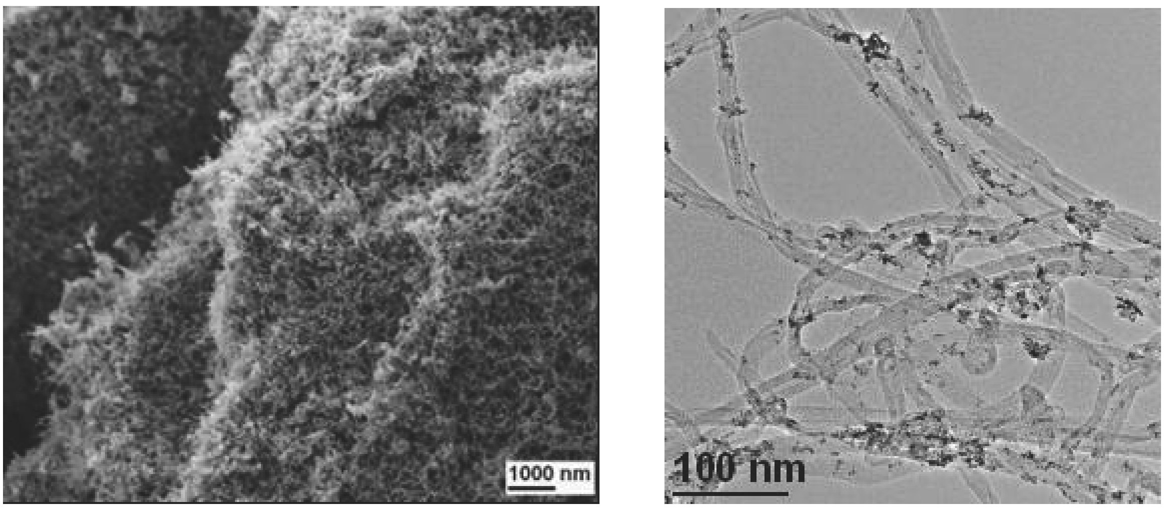


Fig. 31. SEM (left) and TEM (right) images of obtained Pt/CNTs composite

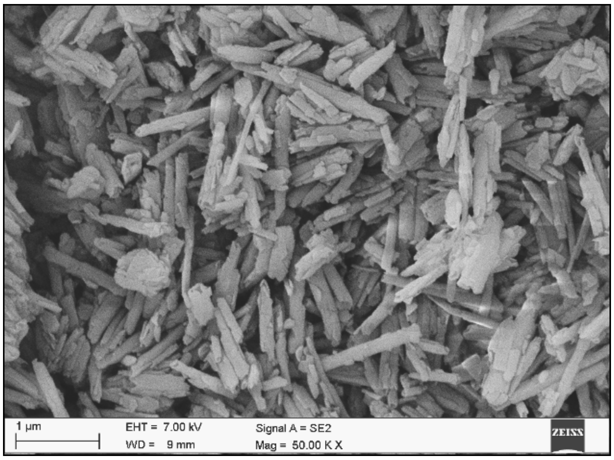


Fig. 32. Morphology of as received halloysite nanotubes, SEM

Fig. 33. Microstructure of extruded EN AW6061 with 15% addition of halloysite nanotubes

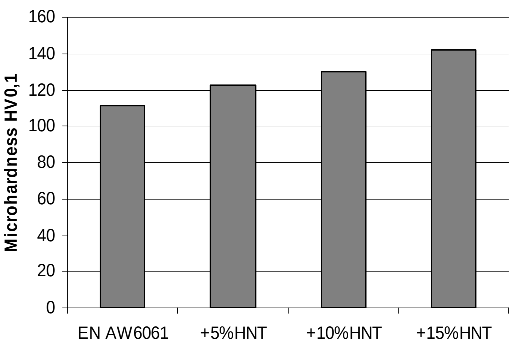


Fig. 34. Microhardness measurements results for obtained composites

The goal of the work on aluminium matrix composites reinforced by halloysite nanotubes consists in the elaboration of these composite materials, manufactured with the use of powder metallurgy technologies, including mechanical alloying and hot extrusion and in determining the influence of the share of halloysite - as the reinforcing phase on the structure and mechanical properties of fabricated composites. Halloysite being a clayey mineral of volcanic origin is built from flat surface plates, partially curled, or they are shaped like tubes made from curled plates (Fig. 32). Composite powders of EN AW6061 aluminium matrix reinforced with 5-15wt.% of halloysite nanotubes were produced by high energy ball milling using an centrifugal mill. The obtained powders were cold pressed in the cylindrical matrix with 300 MPa pressure and then extruded at 480°C without caning and degassing. Obtained composite material was examined by hardness Vickers test in the parallel plane related to the extrusion direction. Microstructure observations were made by optical and scanning electron microscopy. It has been proven that the application of mechanical alloying method, which enables to fabricate nanostructural structure of the composite material, it is possible to regulate the size of the strengthening phase particles and to ensure its uniform distribution, which results in the rise of mechanical properties (Fig. 33). The presence of halloysite reinforcements particles accelerates the mechanical alloying process. It has been confirmed that halloysite nanotubes can be applied as effective reinforcement in the aluminium matrix composites (Fig. 34) [124-133].

9. Light metals matrix composites and alloys

Composite materials with the EN AW-AlCu4Mg1(A) alloy matrix (AlMMC) reinforced with Al_2O_3 and Ti(C,N) ceramic particles are a group of materials which due to their properties (high specific elasticity modulus, high stiffness) are more and more frequently used in modern engineering constructions. Composites reinforced with ceramic particles (Al_2O_3 and Ti(C,N), and also SiC and BN) are gradually being implemented into production in automotive, electronic or aircraft industries, first and foremost due to high resistance to friction wear. Basing on the outcarried structural examinations of the composite materials with the EN AW-AlCu4Mg1(A) aluminium alloy matrix reinforced with the Al_2O_3 and Ti(C,N) particles the homogeneity of their distribution in the matrix was revealed, as well as the fact that during their extrusion the directed structure oriented according to the extrusion direction is developed. The employed heat treatment makes it possible to reduce significantly the sizes of the intermetallic phases' precipitations and results in a more homogeneous matrix structure (Fig. 35).

The influence of the heat treatment carried out on the corrosion resistance of the investigated composite materials was observed. Introducing the Al_2O_3 reinforcing particles into the matrix causes improvement of the corrosion resistance of the investigated materials. At the 5% and 10% portions of the reinforcing particles this resistance is better, and at their 15% portion a slight deterioration of the corrosion resistance occurs, compared with the matrix material. In case of the composite materials reinforced with the Ti(C,N) particles, also at the 5% portion the corrosion resistance compared to the matrix material corrosion resistance improves; whereas, at the 10% and 15% portions this resistance gets slightly worse.

a)
b)

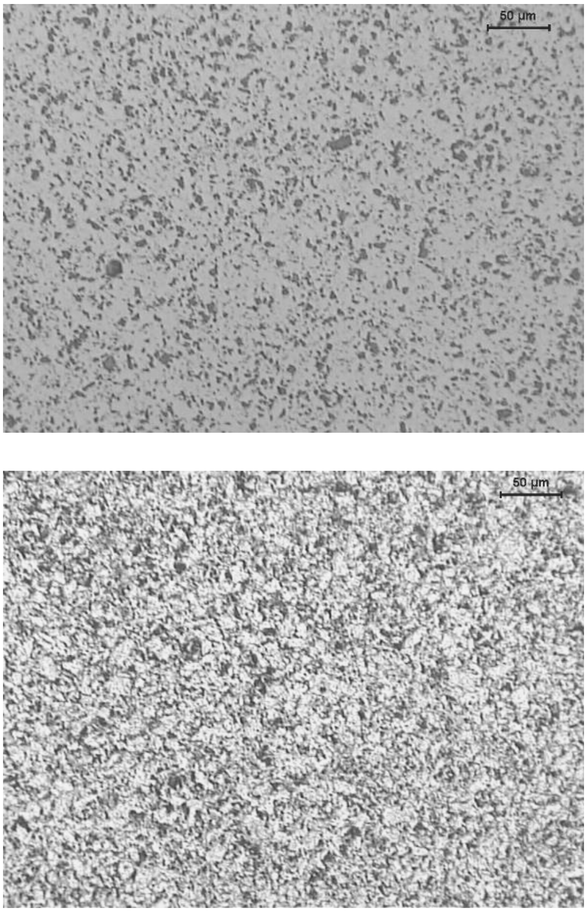


Fig. 35. Section of etched aluminium alloy matrix composite materials with particles: a) Ti(C,N), b) Al_2O_3, cross section

Thermal analysis of aluminium, magnesium and zinc alloys as a technique is used to evaluate the melt quality of these metals and their alloys. By this method, some characteristic values are extracted from a cooling curve and/or its derivative, and then a regression relationship is built up between the characteristics and quality indexes as for example grain size, eutectic structure and silicon morphology. The researchers shown that the thermal analysis carried out on UMSA Technology Platform is an efficient tool for collect and calculate thermal parameters. The formation temperatures of various thermal parameters, mechanical properties (hardness and ultimate compressive strength) and grain size are shifting with an increasing cooling rate (Figs. 36 and 37). For the improvement of the mechanical properties of the cast alloys, despite the heat treatment also modification of the alloy is applied, which causes change of the morphology and decrease of the inter-phase distance of the α+ β eutectic, as well as microstructure refinement. For this reason different kinds of modification additive are used. Improvement of the outcarried chemical modification and appliance of a proper cooling of the casts leads to the improvement of the mechanical properties of the produced casts. Therefore it is very important to have the knowledge about the microstructure modification of the casts according to the cooling rate or chemical composition change by addition of modifiers to the liquid metal.

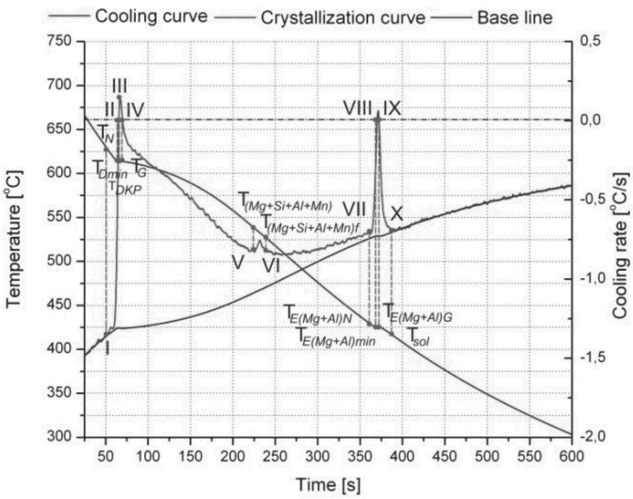


Fig. 36. Representative cooling, crystallization and calorimetric curves with characteristics points of crystallization process of MC MgAl6Zn1 alloy cooled at 0.6°C/s

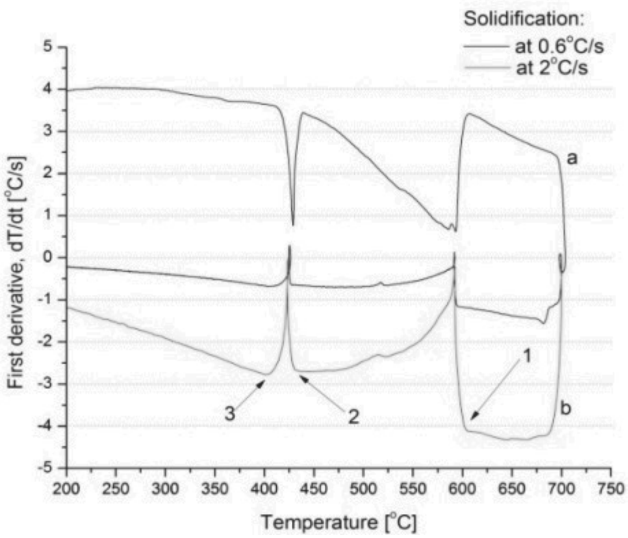


Fig. 37. First derivative (heating/cooling rate) vs. temperature curves of the test samples recorded during melting and solidification at 0.6°C/s (blue line) and 2°C/s (red line)

The purpose of the work on heat treatment of casting aluminium alloys is to present influence of heat treatment on the microstructure of aluminium-silicon-copper casting alloys. Their chemical composition is not-standardised and contains approximately 7 and 9% silicon weight concentration and 1, 2 and 4% copper, respectively. The used heat treatment process is composed of solution treatment, quenching and artificial ageing. The samples are solution treated at temperature of 490°C for 2 hours, next quenched and artificially aged in various temperatures

(130°C – 250°C) and times (1 h – 16 h). The microstructure of as-cast AlSi9Cu4 alloy is shown in Fig. 38. Most likely the dark grey plates are silicon phases while α matrix is light grey. Microstructure observed after precipitation hardening process is more dispersive, particles and intermetallic phases are spaced more evenly. Chemical composition of the samples has an influence on hardness of the as-cast material as well as at the parameters of the ageing process. In as-cast state copper content has bigger influence on hardness than silicon. Hardness of the samples changes from approximately 78 HRF (1% cooper weight concentration) to 88 HRF (4% cooper weight concentration). Hardness investigations after heat treatment shows that higher Si and Cu weight concentration results in higher hardness, for example AlSi7Cu4 has 95 HRF while AlSi9Cu4 - 98 HRF (ageing at 160°C for 4 h).

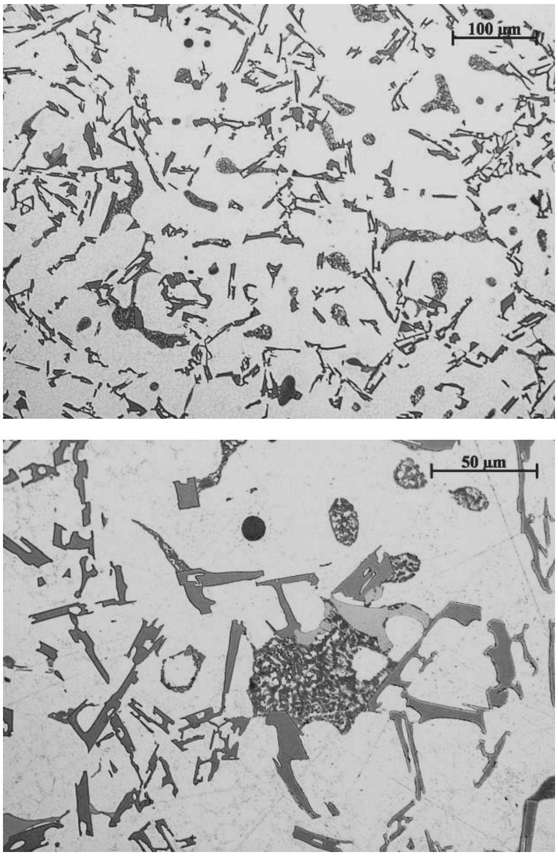


Fig. 38. Microstructure of as-cast AlSi9Cu4

Optimisation is very important for precipitation hardening process because dissolution of the all alloying elements is crucial during the solution treatment process. If time is too short and/or temperature too low than too little amount of alloying elements will be dissolved, while too long time and/or too high temperature may cause melting of the multi-component eutectic areas. Importance of these two factors during ageing process is great as well. Too long time and/or too high temperature will cause overageing of the alloy and in result mechanical properties would be much lower than expect.

Scientific aims of this work and the achieved results concerns the influence of phase transformation and precipitation processes of cast magnesium alloys. The magnesium alloys are one of the basic groups of metal alloys, which allows the realisation of the tasks mostly based on innovative constructional solutions as well as modern materials, which directly influence on mass, performances and fuel consumption of the contemporary cars. The most often pioneer solutions in this field there are applied light, strength materials with big projecting potentials in the dynamic development of the automotive industry.

The investigations are made on the cast magnesium alloys MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 with different concentration of alloying additives, particularly aluminium in the concentration range of 3 to 12% (in 3% steps) for achieving of desirable structure in the cast state and after heat treatment and its influence on the structure, mechanical properties, as well as the corrosion resistance. The selection of optimal heat treatment conditions that is temperature and heating time during solution treatment and ageing as well the cooling rate after solution treatment, is performed using criterion of maximal hardness calculated after the whole heat treatment process – solution treatment and ageing. For comparison of the achieved results on the basis of the performed investigations a computer neural network model was used for analysis of the aluminium content and heat treatment parameters influence on the properties of the worked out cast magnesium alloys. Based on the hardness measurement and modelling using neural networks can be stated that the optimal heat treatment type is solution treatment at a temperature of 430°C for 10 hours with water cooling and ageing in temperature at 190°C for 15 hours with air cooling (Fig. 39). Ageing with air cooling after solution treatment in water causes a precipitation of homogeny distributed $Mg_{17}Al_{12}$ phase in the matrix, which shows a following relationship with the matrix:

$$(1\bar{1}01)\ \alpha\text{-Mg} \parallel (10\bar{1})\ Mg_{17}Al_{12}$$
$$[11\bar{2}0]\ \alpha\text{-Mg} \parallel [111]\ Mg_{17}Al_{12}$$

γ – $Mg_{17}Al_{12}$ phase precipitation have mostly a shape of rods and plates, a prevailing growing direction are the directions from the <110> family of the α-Mg phase (Figs. 40 and 41).Precipitation hardening has influence on mechanical properties. The highest hardness increase, strength, yield point and the average mass loss value in tribologic investigations after ageing was found for the MCMgAl12Zn1 alloy. Corrosion resistance decrease of the investigated alloys occurs according to the increase of the phase content in magnesium matrix. The highest corrosion resistance has after the test in 3% water sodium chloride solution in as-cast material as well after heat treatment has the MCMgAl3Zn1 alloy.

The aim of the work on the effect of the laser surface melting microstructure and properties of the magnesium alloys is to achieve a quasi-composite MMCs structure onto the surface of elements produced from the magnesium alloys Mg-Al-Zn by appliance of high power diode laser (HPDL) remelting and alloying with carbide particles or ceramic particles like: TiC, WC, VC, SiC, NbC, Al_2O_3. The aim is also to investigate the phase transformations and precipitations processes occurred after the laser alloying and remelting by properly chosen process parameters: laser power in the range between 0.5 to 2.2 kW, alloying/remelting rate in the range of 0.1 to 1 m/min as well as

a) b)

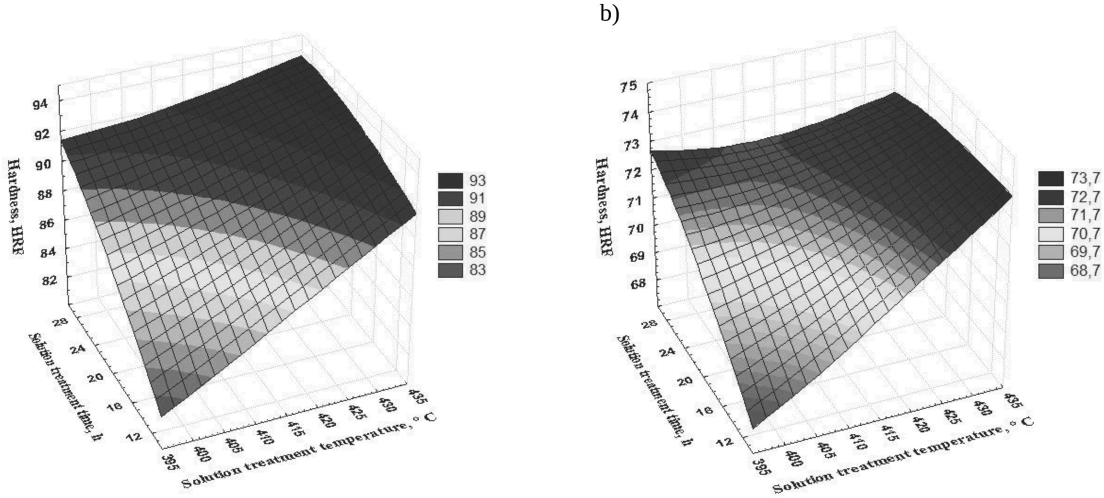


Fig. 39. Simulation of the temperature and solution heat treatment time influence on hardness of the: a) MCMgAl12Zn1, b) MCMgAl9Zn1 cast magnesium alloys by selected ageing temperature and time – 190°C and 15 hours, the results are achieved using a computer neural network simulation

a) b)

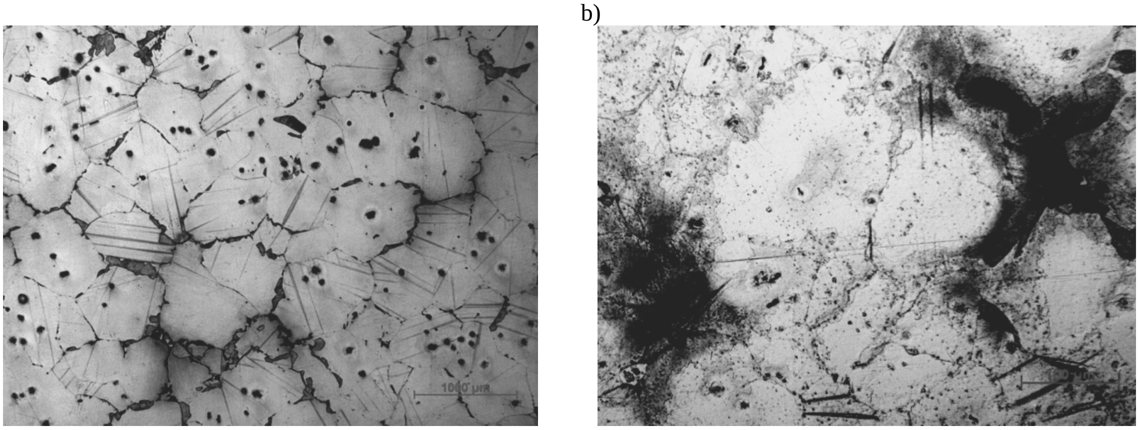


Fig. 40. Microstructures of a) MCMgAl9Zn1, b) MCMgAl6Zn1 alloys after aging treatment

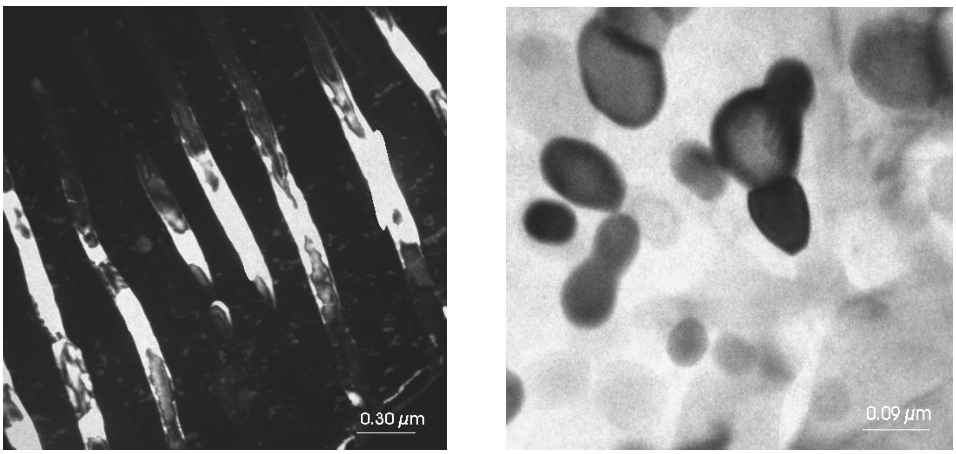


Fig. 41. TEM image examples of the intermetallic secondary phase γ – $Mg_{17}Al_{12}$ in the form of needle precipitations from the MCMgAl9Zn1 alloy after aging treatment

the type shielding gas. Investigations of the outcarried surface layers confirm that alloying of the surface layer of the Mg-Al-Zn casting magnesium alloys is feasible using the HPDL high power diode laser ensuring better properties compared to alloys properties after the regular heat treatment after employing the relevant process parameters. The structure of the remelted zone is mainly dendritic of primary magnesium with eutectic of phase α-Mg and intermetallic phase γ-$Mg_{17}Al_{12}$ (Figs. 42 and 43).

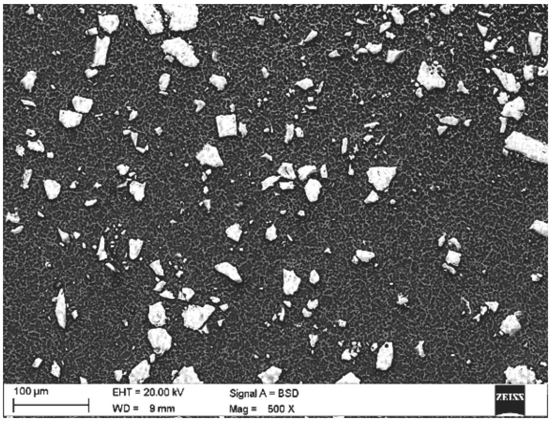


Fig. 42. Scanning electron microscope micrograph of laser modified surface of MCMgAl9Zn1 alloy with TiC particles of the central modified zone, scan rate: 0.75 m/min, laser power: 1.6 kW

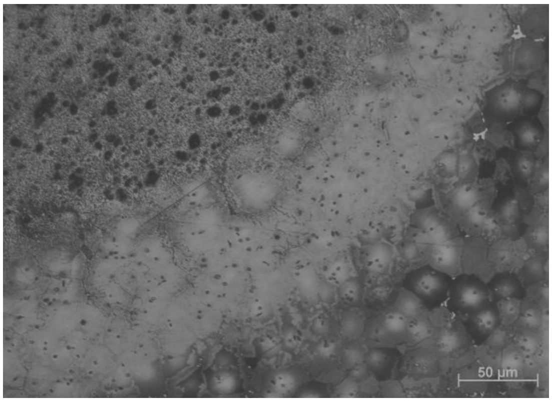


Fig. 43. Boundary between the RZ, HIZ and substrate of the MCMgAl12Zn1 alloy after alloying with WC powder, laser power 2.0 kW, scan rate 0.75 m/min

Magnesium alloys with aluminium concentration 9 and 12 wt. % reveal a heat affected zone in opposition to alloys with aluminium concentration 3 and 6 wt. %. Surface layers fabricated by alloying with VC, TiC, WC, SiC and Al_2O_3 the casting magnesium alloys (MCMgAl12Zn1 and MCMgAl9Zn1) demonstrate the clear effect of the alloyed material, parameters of the alloying process, and especially of the laser beam power and type of the ceramic particles on structure of the surface layers (Figs. 42 and 43). Due to laser alloying structure develops with the clear refinement of grains containing mostly the dispersive particles of the carbide and oxide distributed in the casting magnesium alloy matrix [134-168].

10. Laser surface treatment of alloyed steels

The purpose of the work on structure and properties of laser alloyed hot-work tool steels is focused on the X40CrMoV5-1, 32CrMoV12-28, 55NiCrMoV7, X38CrMoV5-3 hot work tool steels surface layers improvement properties using HPDL laser. Investigations indicate the influence of the alloying carbides on the structure and properties of the surface layer of investigated steels depending on the kind of alloying carbides and power implemented laser (HPDL). Laser alloying of surface layer of investigated steels without introducing alloying additions into liquid molten metal pool, in the whole range of used laser power, causes size reduction of dendritic microstructure with the direction of crystallization consistent with the direction of heat carrying away from the zone of impact of laser beam (Fig. 44). In the effect of laser alloying with powders of carbides WC, NbC, VC, TiC or TaC size reduction of microstructure as well as dispersion hardening through fused in but partially dissolved carbides and consolidation through enrichment of surface layer in alloying additions coming from dissolving carbides occurs. Introduced particles of carbides and in part remain undissolved, creating conglomerates being a result of fusion of undissolved powder grains into molten metal base. In effect of convection movements of material in the liquid state, conglomerates of carbides arrange themselves in the characteristic of swirl. Remelting of the steel without introducing into liquid molten pool the alloying additions in the form of carbide powders, causes slight increase of properties of surface layer of investigated steel in comparison to its analogical properties obtained through conventional heat treatment, depending on the laser beam power implemented for remelting (Fig. 45).

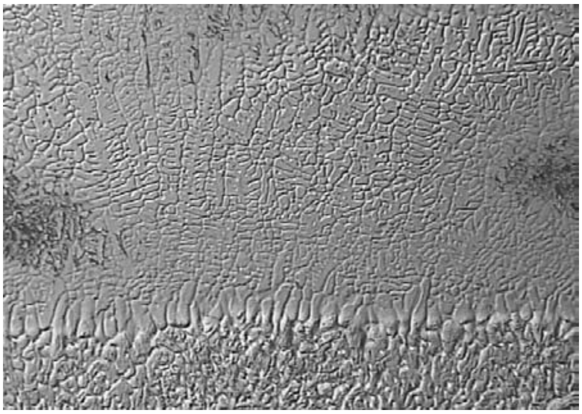


Fig. 44. Boundary of the remelted steel surface layer after alloying with parameters: scanning rate – 0.5 m/min, beam power – 1.5 kW, WC coating thickness – 0.11 mm

The increase of hardness of surface layer obtained throughout remelting and alloying with carbides by high power diode laser is accompanied by increase of tribological properties, when comparing to the steel processed with conventional heat treatment.

The artificial neural networks were used to determine the effect of the technological effect of laser alloying on hardness and resistance wear abrasion of the hot work tool steels. The outcome of the research is an investigation and proving the structural mechanisms accompanying laser remelting and alloying. It has the important cognitive significance and gives grounds to the practical employment of these technologies for forming the surfaces of new tools and regeneration of the used ones.

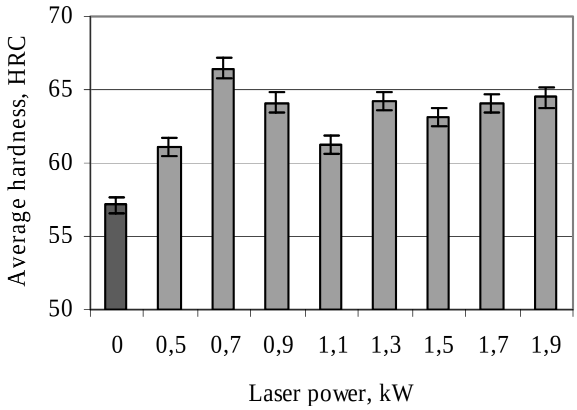


Fig. 45. Change of the average X40CrMoV5-1 steel surface layer hardness after alloying with the tungsten carbide of the 0.11 mm layer thickness with the variable power laser

The purpose of work on laser surface remelting and alloying of sintered austenitic stainless steels deal with the microstructure and properties of laser remelted surface of wrought and sintered austenitic stainless steels type 316L. The laser treatment was performed with the use of high power diode laser (HPDL) and the influence of beam power of 0.7-2.1 kW on the properties of the surface layer was evaluated. The remelting process influences the microstructure refinement and formation of cellular-dendritic crystals with the microsegregation at the solidified cell boundaries in microstructure of stainless steel. The microsegregation of chromium at cell walls was not sufficiently high to form delta ferrite phase, as confirmed by performed X-ray analysis. The increase of laser beam power of LSR process resulted in the increase of hardness of sintered stainless steel due to strain hardening of refined microstructure and porosity reduction. In case of the wrought material the remelting results in remarkable decrease of roughness while in case of sintered material it slightly increases with the laser beam power. The corrosion resistance of remelted surface increased for sintered material when remelted at 2.1 kW. The wrought stainless steel revealed impairment of pitting corrosion when remelted at lower beam power and also comparing to the initial state. Taking into account the obtained results, the additional surface finishing treatment is indispensable to ensure the proper corrosion resistance of remelted surfaces. The studies of the effect of laser surface alloying with Cr on the microstructural changes and properties of vacuum sintered 316L have been also performed. The influence of laser alloying conditions, both laser beam power and powder feed rate (1.0-4.5 g/min) at constant scanning rate of 0.5 m/min on the width of alloyed surface layer, penetration depth, microstructure evaluated by LOM, SEM, X-ray analysis, surface roughness and microhardness are performed. The microstructures of Cr laser alloyed surface consist of different zones, starting from the superficial zone rich in alloying powder particles embedded in the surface; these particles protrude from the surface and thus considerably increase surface roughness. The next one is alloyed zone enriched in alloying elements where both ferrite and austenite simultaneously occur. The following transient zone is located between properly alloyed material and the base metal and can be considered as a very narrow HAZ zone.

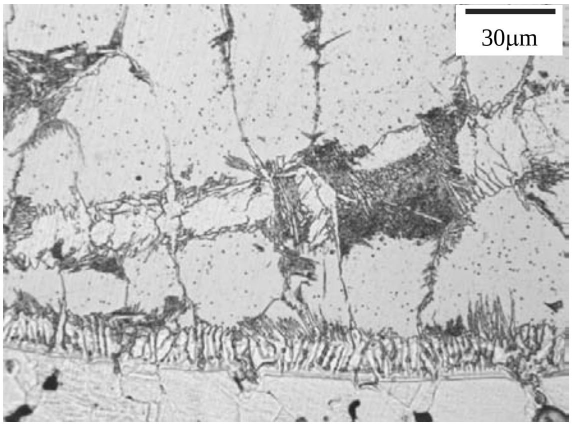


Fig. 46. The central zone of 316L laser alloyed with Cr at laser beam power 2.0 kW and powder feed rate of 4.5 g/min

The optimal microstructure homogeneity of Cr alloyed austenitic stainless steel was obtained for powder feed rate of 2.0 and 4.5 g/min and laser beam power of 1.4 kW and 2 kW. Obtained results are very promising in respect of possible application of HPDL laser in surface alloying for sintered stainless steels. Despite of lower thermal conductivity of sintered steel comparing to wrought one they are still easy to process by laser treatment. Produced alloyed layers are uniform and flat without any visible undercuts or superficial cracks. The high surface roughness requires the application of final surface finish treatment but obtained penetration depth is sufficient to perform it. The microstructure of alloyed layer is composed of austenite and maximally 38% of ferrite with variable Cr content between 22-29%. The alloying process influenced the microstructure refinement and formation of cellular-dendritic crystals with the Cr microsegregation at the solidified cell boundaries. The fully alloyed Cr zone also consists of massive ferritic grains with the needle-like austenite precipitations on the grain boundaries (Fig. 46). Laser surface alloying can be an efficient method of surface layer modification of sintered stainless steel and by this way the surface chromium enrichment can produce microstructural changes affecting both mechanical and corrosion properties. Application of high power diode laser can guarantee uniform heating of treated surface, thus uniform thermal cycle across treated area and uniform penetration depth of chromium alloyed surface layer [169-191].

11. Heat and thermo-mechanical treatment of high-manganese steels

Austenitic steels, mainly high-manganese austenitic TWIP, TRIP and TRIPLEX steels, are the objects of interest in respect of application among others in the automotive industry. The aim of the work is to determine the high-manganese austenite propensity to twinning induced by the cold working and its effect on structure and mechanical properties, and especially on the strain energy per unit volume of ten new-developed high-manganese Fe – Mn – (Al, Si) investigated steels, including six selected high-manganese austenitic TWIP steels containing 25-27.5% Mn, 1-4% Si, 2-3% Al, two high-manganese TRIP steels containing 17-18% Mn, about 1% Si, about 3% Al and two selected high-manganese TRIPLEX steels containing 24% Mn and about 11% Al and some of that steels with Nb and Ti microadditions, with various structures after their heat- and thermo-mechanical treatments. New-developed steels achieve profitable connection of mechanical properties, i.e. (ultimate tensile strength) UTS~800-1000 MPa, (yield strength) $YS_{0.2}$ = 250-450 MPa, and plastic (uniform elongation) UEl = 35-90%, and moreover, particularly strong formability and strain hardening occurring during forming. The new-developed high-manganese Fe – Mn – (Al, Si) steels provide an extensive potential for automotive industries through exhibiting the twinning induced plasticity (TWIP) and transformation induced plasticity (TRIP) mechanisms for the fracture counteraction. TWIP steels not only show excellent strength, but also have excellent formability due to twinning, thereby leading to excellent combination of strength, ductility, and formability over conventional dual phase steels or transformation induced plasticity TRIP steels. In order to develop automotive steels with excellent properties for CO_2 reduction into the environment and increased efficiency, thus, researches on identifying and under-standing these mechanisms are highly required. The micro-structure evolution in successive stages of deformation was determined in metallographic investigations using light, scanning

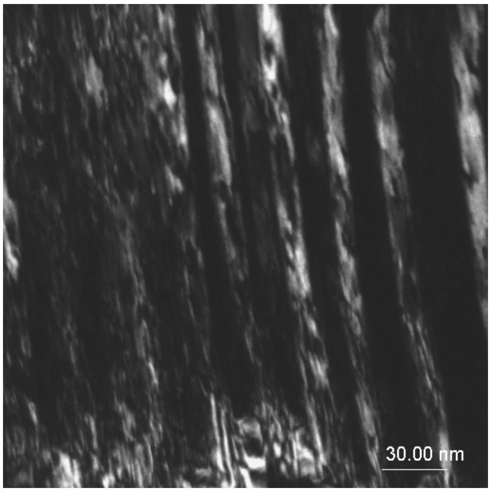


Fig. 48. Austenitic structures with mechanical twins obtained after hot-rolling with a true strain 0.29 and after static tensile test

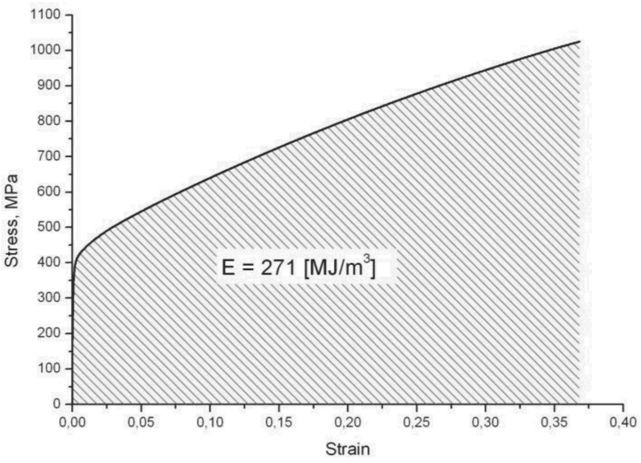


Fig. 47. Mechanism of twinning by the cold working of the high-manganese austenitic steels results in growth of the strain energy per unit volume

and electron microscopes as well as X-ray diffractometre. Results obtained for new-developed high-manganese austenitic steels with the properly formed structure and properties in the heat treatment- or thermo-mechanical processes indicate the possibility and purposefulness of their employment for constructional elements of vehicles, especially of the passenger cars to take advantage of the significant growth about 25% of their strain energy per unit volume (Fig. 47) which guarantee reserve of plasticity in the zones of controlled energy absorption during possible collision resulting from activation of twinning for TWIP steels (Fig. 48), supported with martensitic transformation for TRIP steels, induced cold working which may result in significant growth of the passive safety of these vehicles' passengers [192-201].

12. Laser micro-treatment of photovoltaic materials

The wide area of interests is photovoltaic materials and technologies. In laser technology it is possible to apply for texturisation of polycrystalline silicon surface for solar cells. Laser texturing constitutes an attractive alternative for other conventional texturing methods. The material used for experiments was commercially available boron doped p-type polycrystalline silicon wafers obtained from the ingot by wire sawing of thickness ~330 μm, area 5 cm x 5 cm and resistivity 1 Ωcm.

To minimise reflection losses from the front surface texturisation of wafers by means of ALLPRINT DN50A Q switched Nd:YAG laser was performed. Successive grooves were scribed with constant spacing within consecutive scanning the wafer surface by laser beam in the opposite directions. Many trials for different values of laser parameters were carried out. It seems that presented laser texturing method may be successfully incorporated into production line of high-tech polycrystalline silicon solar cells. Solar cells (Fig. 49a) require good reflection control to minimise the amount of light lost at the front surface. This is typically achieved with combination of antireflection coating and surface texturing. Most conventional methods used for texturisation of monocrystalline silicon are ineffective when applied for texturing polycrystalline silicon. This is consequence of diversified susceptibility of regions of different crystalographic orientation to surface texturisation. As a result texture obtained by means of these methods is not uniform. Texturing of polycrystalline silicon surface using Nd:YAG laser makes it possible to increase absorption of the incident solar radiation. Moreover, the additional technological operation consisting in etching in 20 % KOH solution at temperature 80°C allows for significant improvement in their electrical performance compared to cells produced from the non-textured wafers after saw damage removal as well as wafers textured by etching in 40 % KOH:IPA:DIH_2O solution. With the appropriate selection of the laser processing conditions the uniform texture corresponding to parallel grooves and criss-cross grooves can be produced (Figs. 49b and 49c). Solar cells produced from laser-textured polycrystalline silicon wafers demonstrate worse electrical performance than cells manufactured from the non-textured wafers after saw damage removal as well as wafers textured by etching in alkaline solutions. Those results from the laser induced defects introduced into the laser-processed layer that reduce electrical quality of textured silicon surface limiting performance of the cells. Etching of textured surface in 20% KOH solution at temperature 80°C subsequent to laser processing shows to have a greatly increased impact on electrical performance of solar cells. However, continued etching to remove laser induced defects caused the texture to flatten out reducing its optical effectiveness.

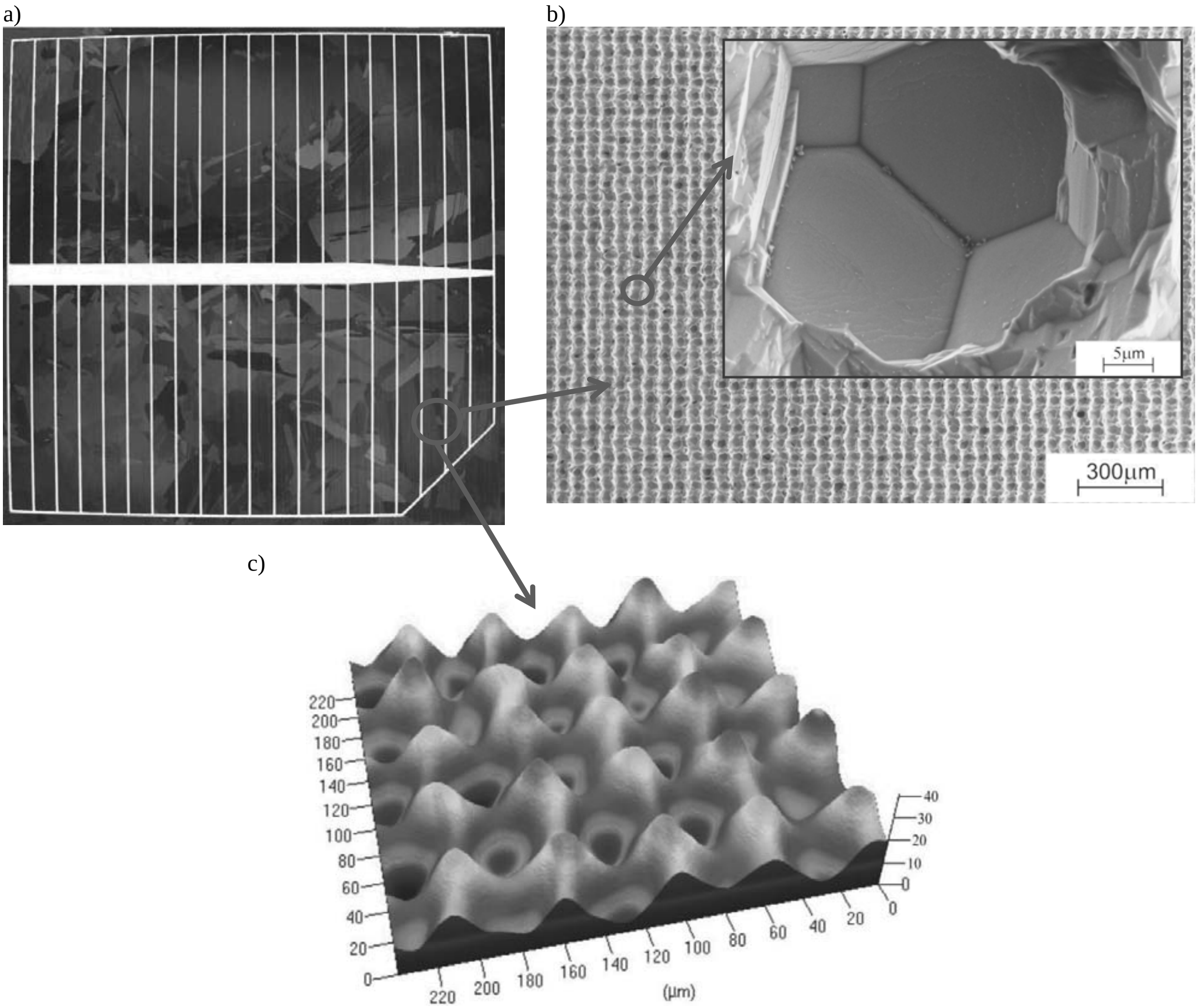


Fig. 49. a) Polycrystalline silicon solar cells, b) SEM micrograph of texture corresponding to grid of grooves after removal of distorted layer of thickness 40 µm, c) 3D confocal laser scanning microscope topography of texture corresponding to grid of grooves after removal of distorted layer of thickness 40 µm

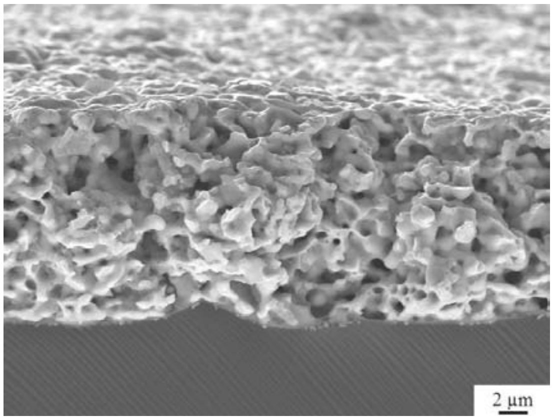
The work on laser application in monocrystalline silicon solar cell fabrication shows that laser micro-machining of silicon elements of solar cells from different morphology monocrystalline silicon including selective laser sintering of the front contact to its surface using CO_2 laser influences the quality improvement by minimisation of the resistance of a joint between the contact and substrate. The influence of therefore obtained front contact on electrical properties of solar cells was estimated. This work investigates the front contacts formation using silver pastes (based on nano powder). Front metallisation is one of the process operations for the production of solar cells. Currently in the world different metal contacts fabrications methods in order to improve the electrical properties of contacts fingers are analysed. Selective laser sintering (SLS) is a manufacturing method that uses a high-heat laser to melt powder into a given before into a programme shape. The investigations were done on monocrystalline silicon wafers. In the Table 3 the material properties of silicon used in this work are presented. A special test structure to evaluate the contact resistance of the metal-semiconductor junction is prepared. Front contacts are formed on the surface with different morphology. Both surface topography using SEM (Fig. 50a) and CLSM (Fig. 50b) microscope and cross section of front electrodes using SEM microscope are investigated. The phase composition analyses of chosen front electrodes are done using the XRD method. The medium size of the pyramids was measured using the atomic force microscope (AFM). Resistance of front electrodes is investigated using Transmission Line Model (TLM). The following technological recommendations of the laser micro-machining technology such as optimal paste composition, the power and scanning speed of the laser beam, morphology of the silicon substrate, to manufacture the front electrode of silicon solar cells are experimentally selected in order to obtain uniformly melted structure well adhered to substrate, of a small front electrode substrate joint resistance value [202-216].

Table 3.
The properties of silicon

Type	p
Doped	boron
Thickness	200 ± 30 μm
Area	5 cm x 5 cm
Resistivity	1-3 Ω·cm

The work on studying of thin films of organic compounds in photovoltaic applications presents the examined effect of the parameters of vacuum evaporation and chemical composition on the optical properties and surface morphology of the thin films of blends phthalocyanine - perylene derivative. These layers determine a bulk p-n junction which can significantly increase the efficiency of organic solar cells. The major aim of this work is to develop the technical conditions of fabrication bulk p-n junction in thin films using the thermal evaporation techniques. Thin films of organic mixtures composed of perylene-3,4,9,10-tetracarboxylic-dianhydride (PTCDA) and titanyl - phthalocyanine (TiO-Pc) or nickel -phthalocyanine (Ni-Pc) were deposited by vacuum thermal evaporation under vacuum of 10^{-5}hPa on glass substrate at room temperature (Fig. 51).

a)



b)

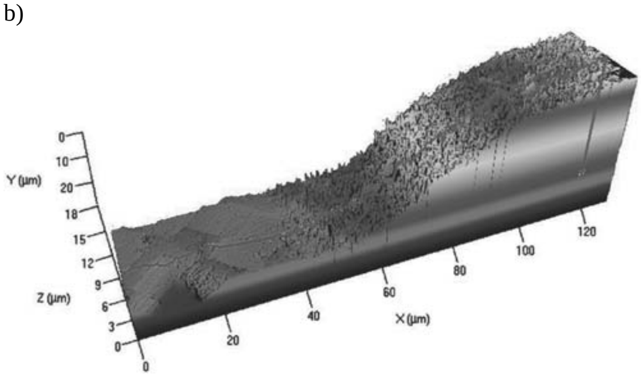


Fig. 50. a) SEM fracture image and b) CLSM three-dimensional surface topography of front electrode performed from standard PV 145 paste on the surface without texture and with ARC layer, co - fired in the furnace in 920°C temperature (chosen example)

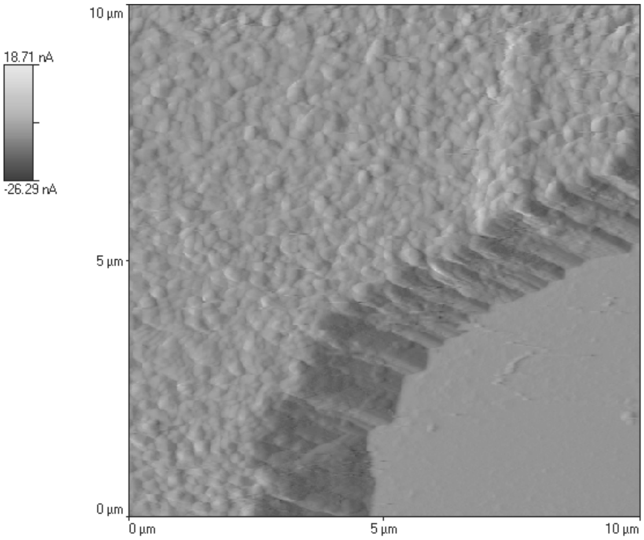


Fig. 51. AFM image of thin film composed of PTCDA/ TiO-Pc mixture

Deposition technologies use evaporation from single and double sources. These mixtures of different proportions were evaporated using different temperatures. Obtained results indicate that surface topography and optical properties of layers obtained depend largely on the composition of the mixture derivative perylene - phthalocyanine, phthalocyanine type used and the evaporation rate. Research is led to the obtain of optimal parameters of evaporation process to obtain layers with the highest quality. The development of this technology also allows for material savings and minimising the cost of the process. To further study the organic layer blends composed of PTCDA and TiO-Pc or Ni-Pc that reveal the most promising properties of the surface topography and optical will be inserted between the anode (ITO composition of PEDOT-PSS layer) and aluminium cathode in order to evaluate their photovoltaic properties [217-221].

13. Final remarks

Concluding this paper it is necessary to remark that the presented examples are representative for the own scientific research in the area of the forming of the structure and properties of engineering materials including biomaterials, their properties testing and microstructure characterisation and modelling, simulation and prediction of the properties and structure of these materials after selected materials processing technologies. The Author would like to thank the closest co-operators: Profs. Grajcar A., Kwaśny W., Sitek W., Weszka J., Drs: Bilewicz M., Bonek M., Borek W., Brytan Z., Dobrzańska-Danikiewicz A., Dołżańska B., Domagała-Dubiel J., Drygała A., Dziekońska M., Gołombek K., Jonda E., Kloc-Ptaszna A., Konieczny J., Król M., Krupińska B., Krupiński M., Labisz K., Lukaszkowicz K., Malara Sz., Matula G., Mikuła J., Musztyfaga M., Pawlyta M., Polok-Rubiniec M., Staszuk M., Śliwa A., Tański T., Trzaska J., Włodarczyk-Fligier A., Ziębowicz B., Żukowska L.W. and PhD Students: Hajduczek J., Jarka P., Nowak A., Reimann Ł., Tomiczek A., Tomiczek B. for co-operation and help in the scientific research and in the preparation of this paper. The paper was presented as invited key-note lecture in the International Scientific and Technical Conference «4th Ukrainian-Polish Scientific Dialogue» on 11th-14th October 2011 in Jaremche, Ukraine chaired by Prof. Y.I. Shalapko. The paper was also published as chapter in the book: Y.I. Shalapko & L.A. Dobrzański (eds.) “Scientific basis of modern technologies: experience and prospects”, Khmelnitsky National University, Khmelnitsky-Jaremche, 2011.

References

[1] A. Kloc, L.A. Dobrzański, G. Matula, J.M. Torralba, Effect of manufacturing methods on structure and properties of the gradient tool materials with the non-alloy steel matrix reinforced with the HS6-5-2 type high-speed steel, Materials Science Forum 539-543 (2007) 2749-2754.

[2] L.A. Dobrzański, A. Kloc-Ptaszna, G. Matula, Gradient tool WC/HS6-5-2 materials produced using the powder metallurgy method, Archives of Materials Science and Engineering 31/1 (2008) 9-12.

[3] L.A. Dobrzański, A. Kloc-Ptaszna, G. Matula, J.M. Torralba, Structure of the gradient carbide steels of HS6-5-2 high-speed steel matrix, Archives of Materials Science and Engineering 28/10 (2007) 589-592.

[4] L.A. Dobrzański, A. Kloc-Ptaszna, G. Matula, J.M. Torralba, Structure and properties of the gradient tool materials of unalloyed steel matrix reinforced with HS6-5-2 high-speed steel, Archives of Materials Science and Engineering 28/4 (2007) 197-202.

[5] L.A. Dobrzański, A. Kloc-Ptaszna, Structure and properties of the gradient tool materials based on a high-speed steel HS6-5-2 reinforced with WC or VC carbides, Journal of Achievements in Materials and Manufacturing Engineering 37/2 (2009) 213-237.

[6] L.A. Dobrzański, J. Hajduczek, A. Kloc-Ptaszna, Effect of sintering parameters on structure of the gradient tool materials, Journal of Achievements in Materials and Manufacturing Engineering 36/1 (2009) 33-40.

[7] L.A. Dobrzański, A. Kloc-Ptaszna, G. Matula, J.M. Torralba, Structure and properties of gradient tool materials with the high-speed steel matrix, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 47-50.

[8] L.A. Dobrzański, A. Kloc-Ptaszna, A. Dybowska, G. Matula, E. Gordo, J.M. Torralba, Effect of WC concentration on structure and properties of the gradient tool materials, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 91-94.

[9] L.A. Dobrzański, A. Kloc-Ptaszna, G. Matula, J.M. Torralba, Characteristics of structure and properties of a sintered graded tool materials, Materials Engineering 28/3-4 (2007) 138-142.

[10] L.A. Dobrzański, G. Matula, G. Herranz, A. Várez, B. Levenfeld, J.M. Torralba, Metal injection moulding of HS12-1-5-5 high-speed steel using a PW-HDPE based binder, Journal of Materials Processing Technology 175/1-3 (2006) 173-178.

[11] G. Matula, L.A. Dobrzański, A. Várez, B. Levenfeld, J.M. Torralba, Comparison of structure and properties of the HS12-1-5-5 type high-speed steel fabricated using the pressureless forming and PIM methods, Journal of Materials Processing Technology 162-163 (2005) 230-235.

[12] A. Várez, B. Levenfeld, J.M. Torralba, G. Matula, L.A. Dobrzański, Sintering in different atmospheres of T15 and M2 high speed steels produced by modified metal injection moulding process, Materials Science and Engineering A 366/2 (2004) 318-324.

[13] L.A. Dobrzański, G. Matula, A. Várez, B. Levenfeld, J.M. Torralba, Structure and mechanical properties of HSS HS6-5-2- and HS12-1-5-5-type steel produced by modified powder injection moulding process, Journal of Materials Processing Technology 157-158 (2004) 658-668.

[14] L.A. Dobrzański, G. Matula, A. Várez, B. Levenfeld, J.M. Torralba, Fabrication methods and heat treatment conditions effect on tribological properties of high speed steels, Journal of Materials Processing Technology 157-158 (2004) 324-330.

[15] L.A. Dobrzański, G. Matula, A. Várez, B. Levenfeld, J.M. Torralba, Structure and Properties of the Heat-Treated

High-Speed Steel HS6-5-2 and HS12-1-5-5 Produced by Powder Injection Molding Process, Materials Science Forum 437-438 (2003) 133-136.
[16] G. Matula, L.A. Dobrzański, G. Herranz, A. Várez, B. Levenfeld, J.M. Torralba, Influence of Binders on the Structure and Properties of High Speed-Steel HS6-5-2 Type Fabricated Using Pressureless Forming and PIM Methods, Materials Science Forum 534-536 (2007) 693-696.
[17] K. Gołombek, G. Matula, J. Mikuła, L.A. Dobrzański, Influence of binder composition on the properties of feedstock for cemented carbides, Archives of Materials Science and Engineering 51/2 (2011) 116-124.
[18] G. Matula, K. Gołombek, J. Mikuła, L.A. Dobrzański, Structure of sintered gradient tool materials, Journal of Achievements in Materials and Manufacturing Engineering 32/1 (2009) 23-28.
[19] G. Matula, L.A. Dobrzański, A. Várez, B. Levenfeld, Development of a feedstock formulation based on PP for MIM of carbides reinforced M2, Journal of Achievements in Materials and Manufacturing Engineering 27/2 (2008) 195-198.
[20] G. Matula, L.A. Dobrzański, G. Herranz, A. Várez, B. Levenfeld, J.M. Torralba, Structure and properties of HS6-5-2 type HSS manufactured by different P/M methods, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 71-74.
[21] G. Matula, L.A. Dobrzański, B. Dołżańska, Influence of cobalt portion on structure and properties of FGHM, International Journal of Materials and Product Technology 33/3 (2008) 280-290.
[22] L.A. Dobrzański, B. Dołżańska, K. Gołombek, G. Matula, Characteristics of structure and properties of a sintered graded tool materials with cobalt matrix, Archives of Materials Science and Engineering 47/2 (2011) 69-76.
[23] L.A. Dobrzański, B. Dołżańska, Hardness to toughness relationship on WC-Co tool gradient materials evaluated by Palmqvist method, Archives of Materials Science and Engineering 43/2 (2010) 87-93.
[24] L.A. Dobrzański, B. Dołżańska, G. Matula, Influence of carbide (W, Ti)C on the structure and properties of tool gradient materials, Archives of Materials Science and Engineering 28/10 (2007) 617-620.
[25] L.A. Dobrzański, B. Dołżańska, Structure and properties of sintered tool gradient materials, Journal of Achievements in Materials and Manufacturing Engineering 43/2 (2010) 711-733.
[26] L.A. Dobrzański, B. Dołżańska, G. Matula, Structure and properties of tool gradient materials reinforced with the WC carbides, Journal of Achievements in Materials and Manufacturing Engineering 28/1 (2008) 35-38.
[27] L.A. Dobrzański, B. Dołżańska, G. Matula, Influence of hard ceramic particles on structure and properties of TGM, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 95-98.
[28] G. Matula, L.A. Dobrzański, B. Dołżańska, Structure and properties of TGM manufactured on the basis of cobalt, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 151-154.
[29] L.A. Dobrzański, B. Dołżańska, G. Matula, Structure and properties of gradient cermets reinforcer with the (W, Ti)C carbides, Vìsnik Tehnologìchnogo Unìversitetu Podìlla 4/2 (2007) 15-20.
[30] L.A. Dobrzański, K. Gołombek, E. Hajduczek, Structure of the nanocrystalline coatings obtained on the CAE process on the sintered tool materials, Journal of Materials Processing Technology 175/1-3 (2006) 157-162.
[31] K. Lukaszkowicz, L.A. Dobrzański, W. Kwaśny, K. Labisz, M. Pancielejko, Microstructure and mechanical properties of nanocomposite coatings deposited by cathodic arc evaporation, Journal of Achievements in Materials and Manufacturing Engineering 42 (2010) 156-163.
[32] L.A. Dobrzański, K. Gołombek, Characterisation of the gradient coatings TiN+(Ti,Al,Si)N+TiN type deposited on sintered tool materials, Metallurgia Italiana 98/4 (2006) 29-34.
[33] W. Kwaśny, L.A. Dobrzański, Structure, physical properties and fractal character of surface topography of the Ti+TiC coatings on sintered high speed steel, Journal of Materials Processing Technology 164-165 (2005) 1519-1523.
[34] W. Kwaśny, L.A. Dobrzański, S. Bugliosi, Ti+TiN, Ti+Ti(CxN1-x), Ti+TiC PVD coatings on the ASP 30 sintered high-speed steel, Journal of Materials Processing Technology 157-158 (2004) 370-379.
[35] L.A. Dobrzański, M. Staszuk, K. Gołombek, A. Śliwa, M. Pancielejko, Structure and properties PVD and CVD coatings deposited onto edges of sintered cutting tools, Archives of Metallurgy and Materials 55/1 (2010) 187-193.
[36] L.A. Dobrzański, M. Polok-Rubiniec, M. Adamiak, PVD coatings deposited onto plasma nitrided X37CrMoV5-1 type steel, International Journal of Materials and Product Technology 33/3 (2008) 226-239.
[37] M. Adamiak, L.A. Dobrzański, Microstructure and selected properties of hot-work tool steel with PVD coatings after laser surface treatment, Applied Surface Science 254/15 (2008) 4552-4556.
[38] L.A. Dobrzański, L.W. Żukowska, J. Mikuła, K. Gołombek, D. Pakuła, M. Pancielejko, Structure and mechanical properties of gradient PVD coatings, Journal of Materials Processing Technology 201/1-3 (2008) 310-314.
[39] K. Lukaszkowicz, L.A. Dobrzański, Structure and mechanical properties of gradient coatings deposited by PVD technology onto the X40CrMoV5-1 steel substrate, Journal of Materials Science 43/10 (2008) 3400-3407.
[40] L.A. Dobrzański, D. Pakuła, A. Křiž, M. Soković, J. Kopač, Tribological properties of the PVD and CVD coatings deposited onto the nitride tool ceramics, Journal of Materials Processing Technology 175/1-3 (2006) 179-185.
[41] L.A. Dobrzański, L.W. Żukowska, Structure and properties of gradient PVD coatings deposited on the sintered tool materials, Journal of Achievements in Materials and Manufacturing Engineering 44/1 (2011) 115-139.
[42] M. Soković, J. Mikuła, L.A. Dobrzański, J. Kopač, L. Kosec, P. Panjan, J. Madejski, A. Piech, Cutting properties of the Al_2O_3 + $SiC_{(w)}$ based tool ceramic reinforced with the PVD and CVD wear resistant coatings, Journal of Materials Processing Technology 164-165 (2005) 924-929.
[43] L.A. Dobrzański, M. Polok, M. Adamiak, Structure and properties of wear resistance PVD coatings deposited onto

X37CrMoV5-1 type hot work steel, Journal of Materials Processing Technology 164-165 (2005) 843-849.
[44] M. Polok-Rubiniec, L.A. Dobrzański, M. Adamiak, Comparison of the PVD coatings deposited onto plasma nitrited steel, Journal of Achievements in Materials and Manufacturing Engineering 42 (2010) 172-179.
[45] L.A. Dobrzański, D. Pakuła, Comparison of the structure and properties of the PVD and CVD coatings deposited on nitride tool ceramics, Journal of Materials Processing Technology 164-165 (2005) 832-842.
[46] L.A. Dobrzański, K. Lukaszkowicz, A. Zarychta, L. Cunha, Corrosion resistance of multilayer coatings deposited by PVD techniques onto the brass substrate, Journal of Materials Processing Technology 164-165 (2005) 816-821.
[47] L.A. Dobrzański, M. Staszuk, PVD and CVD gradient coatings on sintered carbides and sialon tool ceramics, Journal of Achievements in Materials and Manufacturing Engineering 43/2 (2010) 552-576.
[48] L.A. Dobrzański, K. Gołombek, Structure and properties of the cutting tools made from cemented carbides and cermets with the TiN + mono-, gradient- or multi(Ti,Al,Si)N + TiN nanocrystalline coatings, Journal of Materials Processing Technology 164-165 (2005) 805-815.
[49] K. Lukaszkowicz, L.A. Dobrzański, A. Zarychta, Structure, chemical and phase compositions of coatings deposited with the reactive magnetron sputtering onto the brass substrate, Journal of Materials Processing Technology 157-158 (2004) 380-387.
[50] L.A. Dobrzański, M. Staszuk, M. Pawlyta, J. Konieczny, The investigations of (Ti,Al)N and (Al,Ti)N coatings obtained by PVD process onto sintered cutting tools, Journal of Achievements in Materials and Manufacturing Engineering 42 (2010) 148-155.
[51] M. Polok-Rubiniec, K. Lukaszkowicz, L.A. Dobrzański, Comparison of nanostructure and duplex PVD coatings deposited onto hot work tool steel substrate, Journal of Achievements in Materials and Manufacturing Engineering 41 (2010) 187-194.
[52] L.A. Dobrzański, M. Staszuk, K. Gołombek, M. Pancielejko, Properties of Ti(B,N) coatings deposited onto cemented carbides and sialon tool ceramics, Journal of Achievements in Materials and Manufacturing Engineering 41 (2010) 66-73.
[53] L.A. Dobrzański, M. Staszuk, A. Křiž, K. Lukaszkowicz, Structure and mechanical properties of PVD gradient coatings deposited onto tool steels and sialon tool ceramics, Journal of Achievements in Materials and Manufacturing Engineering 37/1 (2009) 36-43.
[54] L.A. Dobrzański, M. Staszuk, M. Pawlyta, W. Kwaśny, M. Pancielejko, Characteristic of Ti(C,N) and (Ti,Zr)N gradient PVD coatings deposited onto sintered tool materials, Journal of Achievements in Materials and Manufacturing Engineering 31/2 (2008) 629-634.
[55] K. Gołombek, J. Mikuła, D. Pakuła, L. Żukowska, L.A. Dobrzański, Sintered tool materials with multicomponent PVD gradient coatings, Journal of Achievements in Materials and Manufacturing Engineering 31/1 (2008) 15-22.
[56] G. Matula, M. Bonek, L.A. Dobrzański, Comparison of Structure and Properties of Hard Coatings on Commercial Tool Materials Manufactured with the Pressureless Forming Method or Laser Treatment, Materials Science Forum 638-642 (2010) 1830-1835.
[57] L.A. Dobrzański, D. Pakuła, J. Mikuła, K. Gołombek, Investigation of the structure and properties of coatings deposited on ceramic tool materials, International Journal of Surface Science and Engineering 1/1 (2007) 111-124.
[58] K. Lukaszkowicz, J. Mikuła K. Gołombek, L.A. Dobrzański, J. Szewczenko, M. Pancielejko, Structure and mechanical properties of nanocomposite coatings deposited by PVD process onto tool steel substrates, Materials Engineering 29/6 (2008) 732-737.
[59] A.D. Dobrzańska-Danikiewicz, E. Hajduczek, M. Polok-Rubiniec, M. Przybył, K. Adamaszek, Evaluation of selected steel thermochemical treatment technologies using foresight methods, Journal of Achievements in Materials and Manufacturing Engineering 46/2 (2011) 115-146.
[60] A.D. Dobrzańska-Danikiewicz, E-foresight of materials sur¬face engineering, Archives of Materials Science Engineering 44/1 (2010) 43-50.
[61] A.D. Dobrzańska-Danikiewicz, Foresight methods for tech¬nology validation, road¬mapping and development in the surface engineering area, Archives of Materials Science Engi¬neering 44/2 (2010) 69-86.
[62] A. Dobrzańska-Danikiewicz, Foresight of material surface engineering as a tool building a knowledge-based economy, Materials Science Forum (2012) (in print).
[63] A. Dobrzańska-Danikiewicz, Foresight of materials surface engineering as a tool stimulating sustainable development and to increase the quality of technology, Journal of Machine Engineering 10/3 (2010) 48-59.
[64] A. Dobrzańska-Danikiewicz, Practical application of foresight research methodology to selected surface engineering technologies, Proceedings of the 8th International Conference "Industrial Tools and Mechanical Processing Technologies", Ljubljana, Slovenia,2011, 217-220.
[65] L.A. Dobrzański, A.D. Dobrzańska-Danikiewicz, Engineering materials surface treatment, Open Access Library 5 (2011) 1-480 (in Polish).
[66] A.D. Dobrzańska-Danikiewicz (ed.), Materials surface engineering development trends, Open Access Library 6 (2011) 1-594.
[67] A. Dobrzańska-Danikiewicz, Main assumptions of the foresight of surface properties formation leading technologies of engineering materials and biomaterials, Journal of Achievements in Materials and Manufacturing Engineering 34/2 (2009) 165-171.
[68] A. Dobrzańska-Danikiewicz, The methodological fundaments of development state analysis of surface engineering technologies, Journal of Achievements in Materials and Manufacturing Engineering 40/2 (2010) 203-210.
[69] L.A. Dobrzański, A. Śliwa, W. Kwaśny, Employment of the finite element method for deter¬mining stresses in coatings obtained on high-speed steel with the PVD process, Journal of Materials Processing Technology 164-165 (2005) 1192-1196.
[70] L.A. Dobrzański, A. Śliwa, W. Sitek, W. Kwaśny, The computer simulation of critical compressive stresses on the PVD coatings, International Journal of Computational Materials Science and Surface Engineering 1/1 (2007) 28-39.

[71] A. Śliwa, L.A. Dobrzański, W. Kwaśny, M. Staszuk, Simulation of the microhardness and internal stresses measurement of PVD coatings by use of FEM, Journal of Achievements in Materials and Manufacturing Engineering 43/2 (2010) 684-691.
[72] A. Śliwa, M. Matula, L.A. Dobrzański, Finite Element Method application for structure determining of powder injection moulding samples, Archives of Computational Materials Science and Surface Engineering 2/3 (2010) 157-164.
[73] L.A. Dobrzański, M. Kremzer, J. Trzaska, A. Nagel, Examination and simulation of composite materials $Al\text{-}Al_2O_3$ tribological properties, Archives of Computational Materials Science and Surface Engineering 1/4 (2009) 205-209.
[74] L.A. Dobrzański, S. Malara, J. Trzaska, Project of neural network for steel grade selection with the assumed CCT diagram, Journal of Achievements in Materials and Manufacturing Engineering 27/2 (2008) 155-158.
[75] L.A. Dobrzański, T. Tański, J. Trzaska, L. Čížek, Modelling of hardness prediction of magnesium alloys using artificial neural networks applications, Journal of Achievements in Materials and Manufacturing Engineering 26/2 (2008) 187-190.
[76] J. Trzaska, A. Jagiełło, L.A. Dobrzański, The calculation of CCT diagrams for engineering steels, Archives of Materials Science and Engineering 39/1 (2009) 13-20.
[77] L.A. Dobrzański, M. Kremzer, J. Trzaska, A. Włodarczyk-Fligier, Neural network application in simulations of composites $Al\text{-}Al_2O_3$ tribological properties, Archives of Materials Science and Engineering 30/1 (2008) 37-40.
[78] L.A. Dobrzański, M. Kowalski, J. Madejski, Methodology of the mechanical properties prediction for the metallurgical products from the engineering steels using the Artificial Intelligence methods, Journal of Materials Processing Technology 164-165 (2005) 1500-1509.
[79] W. Sitek, L.A. Dobrzański, Application of genetic methods in materials' design, Journal of Materials Processing Technology 164-165 (2005) 1607-1611.
[80] L.A. Dobrzański, W. Sitek, M. Krupiński, J. Dobrzański, Computer aided method for evaluation of failure class of materials working in creep conditions, Journal of Materials Processing Technology 157-158 (2004) 102-106.
[81] W. Sitek, J. Trzaska, L.A. Dobrzański, Evaluation of chemical composition effect on materials properties using AI methods, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 379-382.
[82] A. Śliwa, L.A. Dobrzański, W. Kwaśny, W. Sitek, The computer simulation of internal stresses on the PVD coatings, Archives of Computational Materials Science and Surface Engineering 1/3 (2009) 183-188.
[83] L.A. Dobrzański, A. Jagiełło, R. Honysz, Virtual tensile test machine as an example of Material Science Virtual Laboratory post, Journal of Achievements in Materials and Manufacturing Engineering 27/2 (2008) 207-210.
[84] J. Trzaska, L.A. Dobrzański, A. Jagiełło, Computer program for prediction steel parameters after heat treatment, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 171-174.
[85] L.A. Dobrzański, R. Honysz, Artificial intelligence and virtual environment application for materials design methodology, Archives of Materials Science and Engineering 45/2 (2010) 69-94.
[86] L.A. Dobrzański, R. Honysz, The idea of material science virtual laboratory, Journal of Achievements in Materials and Manufacturing Engineering 42 (2010) 196-203.
[87] L.A. Dobrzański, M. Drak, J. Trzaska, Computer simulation of hard magnetic composite materials Nd-Fe-B properties, Journal of Materials Processing Technology 192-193 (2007) 595-601.
[88] J. Trzaska, L.A. Dobrzański, Modelling of CCT diagrams for engineering and constructional steels, Journal of Materials Processing Technology 192-193 (2007) 504-510.
[89] L.A. Dobrzański, T. Tański, J. Trzaska, Optimization of heat treatment conditions of magnesium cast alloys, Materials Science Forum 638-642 (2010) 1488-1493.
[90] W. Sitek, J. Trzaska, L.A. Dobrzański, Modified Tartagli method for calculation of Jominy hardenability curve, Materials Science Forum 575-578 (2008) 892-897.
[91] A. Śliwa, J. Mikuła, L.A. Dobrzański, FEM application for modelling of PVD coatings properties, Journal of Achievements in Materials and Manufacturing Engineering 41 (2010) 164-171.
[92] A. Śliwa, M. Matula, L.A. Dobrzański, Finite Element Method application for determining feedstock distribution during powder injection moulding, Journal of Achievements in Materials and Manufacturing Engineering 37/2 (2009) 584-591.
[93] A. Śliwa, L.A. Dobrzański, W. Kwaśny, W. Sitek, Finite Element Method application for modeling of PVD coatings properties, Journal of Achievements in Materials and Manufacturing Engineering 27/2 (2008) 171-174.
[94] W. Kwaśny, W. Sitek, L.A. Dobrzański, Modelling of properties of the PVD coatings using neural networks, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 163-166.
[95] L.A. Dobrzański, A. Śliwa, W. Kwaśny, The computer simulation of stresses in the $Ti+Ti(C_xN_{1-x})$ coatings obtained in the PVD process, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 155-158.
[96] L.A. Dobrzański, S. Malara, J. Trzaska, Project of computer program for designing the steel with the assumed CCT diagram, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 351-354.
[97] L.A. Dobrzański, A. Pusz, A.J. Nowak, M. Górniak, Application of FEM for solving various issues in material engineering, Journal of Achievements in Materials and Manufacturing Engineering 42 (2010) 134-141.
[98] J. Konieczny, L.A. Dobrzański, B. Tomiczek, J. Trzaska, Application of the artificial neural networks for prediction of magnetic saturation of metallic amorphous alloys, Archives of Materials Science and Engineering 30/2 (2008) 105-108.
[99] L.A. Dobrzański, A. Pusz, A.J. Nowak, M. Górniak, Constructional model of internal oesophageal prosthesis, Archives of Materials Science and Engineering 42/2 (2010) 69-76.
[100] L.A. Dobrzański, A.J. Nowak, W. Błażejewski, R. Rybczyński, The concept of preparation of oesophageal prosthesis

based on long-fibre composite material, Journal of Achievements in Materials and Manufacturing Engineering 46/1 (2011) 18-24.

[101] L.A. Dobrzański, A. Pusz, A.J. Nowak, The effect of micropores on output properties of laminate materials with assumed medical implantation, Journal of Achievements in Materials and Manufacturing Engineering 37/2 (2009) 408-415.

[102] L.A. Dobrzański, A. Pusz, A.J. Nowak, The elimination of micropores and surface defects in aramid-silicon laminated materials with special properties, Journal of Achievements in Materials and Manufacturing Engineering 35/2 (2009) 121-128.

[103] L.A. Dobrzański, A. Pusz, A.J. Nowak, Aramid-silicon laminated materials with special properties – new perspective of its usage, Journal of Achievements in Materials and Manufacturing Engineering 28/1 (2008) 7-14.

[104] L.A. Dobrzański, A.J. Nowak, A. Pusz, M. Górniak, The preparation of aramid fibres in silicone based composite materials, Journal of Achievements in Materials and Manufacturing Engineering 45/2 (2011) 125-131.

[105] L.A. Dobrzański, A.J. Nowak, W. Błażejewski, R. Rybczyński, Non-standard test methods for long-fibrous reinforced composite materials, Archives of Materials Science and Engineering 47/1 (2011) 5-10.

[106] L.A. Dobrzański, B. Ziębowicz, M. Drak, Magnetic nanocomposite materials: structure and mechanical properties, International Journal of Materials and Product Technology 33/3 (2008) 240-251.

[107] L.A. Dobrzański, R. Nowosielski, J. Konieczny, A. Przybył, J. Wysłocki, Structure and properties of nanocrystalline soft magnetic composite materials with silicon polymer matrix, Journal of Magnetism and Magnetic Materials 290-291 Part 2 (2005) 1510-1512.

[108] L.A. Dobrzański, M. Drak, Hard magnetic composite materials Nd-Fe-B with additions of iron and X2CrNiMo-17-12-2 steel, Journal of Alloys and Compounds 449/1-2 (2008) 88-92.

[109] L.A. Dobrzański, A. Tomiczek, A Nabiałek, Z. Stokłosa, Magnetic properties of magnetostrictive $Tb_{0.3}Dy_{0.7}Fe_{1.9}$ / polyurethane composite materials, Archives of Materials Science and Engineering 51/2 (2011) 97-102.

[110] L.A. Dobrzański, M. Drak, B. Ziębowicz, New possibilities of composite materials application – Materials of specific magnetic properties, Journal of Materials Processing Technology 191/1-3 (2007) 352-355.

[111] L.A. Dobrzański, A. Wydrzyńska, O. Iesenchuk, R. Żuberek, Magnetostrictive properties of epoxy-bonded $Tb_{0,3}Dy_{0,7}Fe_{1,9}$ composites, Advanced Materials Research 89-91 (2010) 633-638.

[112] L.A. Dobrzański, M. Drak, Properties of composite materials with polymer matrix reinforced with Nd-Fe-B hard magnetic particles, Journal of Materials Processing Technology 175/1-3 (2006) 149-156.

[113] M. Drak, L.A. Dobrzański, Corrosion resistance of hard magnetic materials Nd-Fe-B in acid environment, Vìsnik Tehnologìchnogo Unìversitetu Podìlla 4/2 (2007) 25-28.

[114] L.A. Dobrzański, R. Nowosielski, J. Wysłocki, A. Przybył, J. Konieczny, Softmagnetic nanocomposite with silicon polymer matrix and powdered $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$, Journal of Metastable and Nanocrystalline Materials 23 (2005) 91-94.

[115] L.A. Dobrzański, A. Tomiczek, A. Nabiałek, R. Żuberek, Structure and magnetic properties of magnetostrictive $Td_{0.3}Dy_{0.7}Fe_{1.9}$ / polyurethane composite materials, Journal of Achievements in Materials and Manufacturing Engineering 43/2 (2010) 527-532.

[116] M. Drak, B. Ziębowicz, L.A. Dobrzański, Manufacturing of hard magnetic composite materials Nd-Fe-B, Journal of Achievements in Materials and Manufacturing Engineering 31/1 (2008) 91-96.

[117] J. Konieczny, L.A. Dobrzański, J.E. Frąckowiak, Structure and magnetic properties of powder HITPERM material, Archives of Materials Science and Engineering 28/3 (2007) 156-164.

[118] B. Ziębowicz, L.A. Dobrzański, Application of nanostructural materials in manufacturing of soft magnetic composite materials $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ – PEHD type, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 91-94.

[119] M. Drak, L.A. Dobrzański, Hard magnetic materials Nd-Fe-B/Fe with epoxy resin matrix, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 63-66.

[120] L.A. Dobrzański, A. Wydrzyńska, O. Iesenchuk, Intelligent epoxy matrix composite materials consisting of $Tb_{0.3}Dy_{0.7}Fe_{1.9}$ magnetostrictive particulates, Archives of Materials Science and Engineering 35/1 (2009) 33-38.

[121] L.A. Dobrzański, M. Drak, B. Ziębowicz, Manufacturing, properties and application of composite materials with specific magnetic properties, Archives of Materials Science 29/4 (2008) 159-167.

[122] L.A. Dobrzański, A. Tomiczek, B. Tomiczek, A. Ślawska-Waniewska, O. Iesenchuk, Polymer matrix composite materials reinforced by $Tb_{0.3}Dy_{0.7}Fe_{1.9}$ magnetostrictive particles, Journal of Achievements in Materials and Manufacturing Engineering 37/1 (2009) 16-23.

[123] B. Ziębowicz, L.A. Dobrzański, M. Drak, A. Wydrzyńska, Corrosion resistance of composite materials $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ – PE type in acid environment, Archives of Materials Science and Engineering 30/2 (2008) 89-92.

[124] L.A. Dobrzański, B. Tomiczek, M. Adamiak, Manufacturing of EN AW6061 matrix composites reinforced by halloysite nanotubes, Journal of Achievements in Materials and Manufacturing Engineering 49/1 (2011) 82-89.

[125] L.A. Dobrzański, M. Pawlyta, A. Krztoń, B. Liszka, K. Labisz, Synthesis and characterization of carbon nanotubes decorated with platinum nanoparticles, Journal of Achievements in Materials and Manufacturing Engineering 39/2 (2010) 184-189.

[126] L.A. Dobrzański, M. Pawlyta, A. Krzton, B. Liszka, C.W. Tai, W. Kwaśny, Synthesis and characterization of carbon nanotubes decorated with gold nanoparticles, Acta Physica Polonica A 118/3 (2010) 483-486.

[127] L.A. Dobrzański, M. Bilewicz, J.C. Viana, Mechanical approach of PP/MMT polymer nanocomposite, Archives of Materials Science and Engineering 43/2 (2010) 94-100.

[128] B. Ziębowicz, D. Szewieczek, L.A. Dobrzański, J.J. Wysłocki, A. Przybył, Structure and properties of the composite materials consisting of the nanocrystalline $Fe_{73,5}Cu_1Nb_3Si_{13,5}B_9$ alloy powders and polyethylene, Journal of Materials Processing Technology 162-163 (2005) 149-155.
[129] L.A. Dobrzański, M. Bilewicz, J.C. Viana, A. Cunha, Non-conventionally obtained polymer nanocomposites with different nano-clay ratios, Journal of Achievements in Materials and Manufacturing Engineering 31/2 (2008) 212-217.
[130] B. Ziębowicz, M. Drak, L.A. Dobrzański, Corrosion resistance of the composite materials: nanocrystalline powder – polymer type in acid environment, Journal of Achievements in Materials and Manufacturing Engineering 36/2 (2009) 126-133.
[131] M. Bilewicz, J.C. Viana, L.A. Dobrzański, Development of microstructure affected by in-mould manipulation in polymer composites and nanocomposites, Journal of Achievements in Materials and Manufacturing Engineering 31/1 (2008) 71-76.
[132] B. Ziębowicz, D. Szewieczek, L.A. Dobrzański, Manufacturing technology of the composite materials: nano-crystalline material – polymer type, Journal of Achievements in Materials and Manufacturing Engineering 14 (2006) 37-42.
[133] M. Bilewicz, J.C. Viana, A.M. Cunha, L.A. Dobrzański, Morphology diversity and mechanical response of injection moulded polymer nanocomposites and polymer-polymer composites, Journal of Achievements in Materials and Manufacturing Engineering 15 (2006) 159-165.
[134] L.A. Dobrzański, M. Kremzer, K. Gołombek, Structure and Properties of Aluminum Matrix Composites Reinforced by Al_2O_3 Particles, Materials Science Forum 591-593 (2008) 188-192.
[135] L.A. Dobrzański, M. Król, Thermal and mechanical characteristics of cast Mg-Al-Zn alloy, Archives of Foundry Engineering 10/1 (2010) 27-30.
[136] L.A. Dobrzański, T. Tański, S. Malara, M. Król, Structure and properties investigation of a magnesium alloy processed by heat treatment and laser surface treatment, Materials Science Forum 674 (2011) 11-18.
[137] M. Krupiński, K. Labisz, L.A. Dobrzański, Z.M. Rdzawski, Derivative thermo-analysis application to assess the cooling rate influence on the microstructure of Al-Si alloy cast, Journal of Achievements in Materials and Manufacturing Engineering 38/2 (2010) 115-122.
[138] L.A. Dobrzański, M. Kremzer, W. Sitek, The application of statistical models in wear resistance simulations of Al-Al_2O_3 composites, Archives of Materials Science and Engineering 43/1 (2010) 5-12.
[139] L.A. Dobrzański, M. Król, T. Tański, R. Maniara, Thermal analysis of the MCMgAl9Zn1 magnesium alloy, Archives of Materials Science and Engineering 34/2 (2008) 113-116.
[140] M. Krupiński, K. Labisz, L.A. Dobrzański, Structure investigation of the Al-Si-Cu alloy using derivative thermo analysis, Journal of Achievements in Materials and Manufacturing Engineering 34/1 (2009) 47-54.
[141] T. Tański, L.A. Dobrzański, R. Maniara, Microstructures of Mg-Al-Zn and Al-Si-Cu cast alloys, Journal of Achievements in Materials and Manufacturing Engineering 38/1 (2010) 64-71.
[142] L.A. Dobrzański, M. Kremzer, A.J. Nowak, A. Nagel, Aluminium matrix composites fabricated by infiltration method, Archives of Materials Science and Engineering 36/1 (2009) 5-11.
[143] L.A. Dobrzański, M. Krupiński, K. Labisz, Derivative thermo analysis of the near eutectic Al-Si-Cu alloy, Archives of Foundry Engineering 8/4 (2008) 37-40.
[144] A. Włodarczyk-Fligier, L.A. Dobrzański, M. Kremzer, M. Adamiak, Manufacturing of aluminium matrix composite materials reinforced by Al_2O_3 particles, Journal of Achievements in Materials and Manufacturing Engineering 27/1 (2008) 99-102.
[145] M. Krupiński, K. Labisz, L.A. Dobrzański, Z. Rdzawski, Derivative thermo analysis of the Al-Si cast alloy with addition of rare earths metals, Archives of Foundry Engineering 10/1 (2010) 79-82.
[146] L.A. Dobrzański, M. Król, T. Tański, Application a neural networks in crystallization process of Mg-Al-Zn alloys, Archives of Computational Materials Science and Surface Engineering 2/3 (2010) 149-156.
[147] L.A. Dobrzański, M. Kremzer, A. Nagel, Aluminium EN AC-AlSi12 alloy matrix composite materials reinforced by Al_2O_3 porous preforms, Archives of Materials Science and Engineering 28/10 (2007) 593-596.
[148] L.A. Dobrzański, M. Król, T. Tański, Influence of cooling rate on crystallization, structure and mechanical properties of MCMgAl6Zn1 alloy, Archives of Foundry Engineering 10/3 (2010) 105-110.
[149] T. Tański, L.A. Dobrzański, L. Cížek, Influence of heat treatment on structure and properties of the cast magnesium alloys, Advanced Materials Research 15-17 (2007) 491-496.
[150] M. Krupiński, L.A. Dobrzański, J.H. Sokolowski, Micro-structure analysis of the automotive Al-Si-Cu casting, Archives of Foundry Engineering 8/1 (2008) 71-74.
[151] L.A. Dobrzański, M. Kremzer, J. Konieczny, The influence of Ni-P layer deposited onto Al_2O_3 on structure and properties of Al-Al_2O_3 composite materials, Journal of Achievements in Materials and Manufacturing Engineering 46/2 (2011) 147-153.
[152] L.A. Dobrzański, M. Król, Thermal and structure analysis of the MA MgAl6Zn3 magnesium alloy, Journal of Achievements in Materials and Manufacturing Engineering 46/2 (2011) 189-195.
[153] L.A. Dobrzański, R. Maniara, J. Sokolowski, W. Kasprzak, M. Krupiński, Z. Brytan, Applications of the artificial intelligence methods for modeling of the ACAlSi7Cu alloy crystallization process, Journal of Materials Processing Technology 192-193 (2007) 582-587.
[154] L.A. Dobrzański, M. Kremzer, M. Adamiak, The influence of reinforcement shape on wear behaviour of aluminium matrix composite materials, Journal of Achievements in Materials and Manufacturing Engineering 42 (2010) 26-32.
[155] L.A. Dobrzański, M. Król, T. Tański, Thermal analysis, structure and mechanical properties of the MC MgAl3Zn1

cast alloy, Journal of Achievements in Materials and Manufacturing Engineering 40/2 (2010) 167-174.
[156] L.A. Dobrzański, T. Tański, L. Čížek, Z. Brytan, Structure and properties of magnesium cast alloys, Journal of Materials Processing Technology 192-193 (2007) 567-574.
[157] L.A. Dobrzański, M. Krupiński, K. Labisz, Z. Rdzawski, Influence of thermo-derivative analysis conditions on microstructure of the Al-Si-Cu alloy, Archives of Foundry Engineering 11/2 (2011) 19-22.
[158] L.A. Dobrzański, M. Kremzer, A. Nagel, Structure and properties of ceramic preforms based on Al_2O_3 particles, Journal of Achievements in Materials and Manufacturing Engineering 35/1 (2009) 7-13.
[159] L.A. Dobrzański, M. Król, T. Tański, Effect of cooling rate and aluminum contents on the Mg-Al-Zn alloys' structure and mechanical properties, Journal of Achievements in Materials and Manufacturing Engineering 43/2 (2010) 613-633.
[160] L.A. Dobrzański, R. Maniara, J. Sokolowski, W. Kasprzak, Effect of cooling rate on the solidification behavior of AC AlSi7Cu2 alloy, Journal of Materials Processing Technology 191/1-3 (2007) 317-320.
[161] K. Labisz, M. Krupiński, L.A. Dobrzański, Phases morphology and distribution of the Al-Si-Cu alloy, Journal of Achievements in Materials and Manufacturing Engineering 37/2 (2009) 309-316.
[162] L.A. Dobrzański, M. Król, T. Tański, R. Maniara, Effect of cooling rate on the solidification behaviour of MC MgAl6Zn1 alloy, Journal of Achievements in Materials and Manufacturing Engineering 37/1 (2009) 65-69.
[163] M. Krupiński, K. Labisz, L.A. Dobrzański, Z. Rdzawski, Image analysis used for aluminium alloy microstructure investigation, Journal of Achievements in Materials and Manufacturing Engineering 42 (2010) 58-65.
[164] L.A. Dobrzański, R. Maniara, J.H. Sokolowski, The effect of cooling rate on microstructure and mechanical properties of AC AlSi9Cu alloy, Archives of Materials Science and Engineering 28/2 (2007) 105-112.
[165] L.A. Dobrzański, T. Tański, Influence of aluminium content on behaviour of magnesium cast alloys in bentonite sand mould, Solid State Phenomena 147-149 (2009) 764-769.
[166] L.A. Dobrzański, M. Król, T. Tański, R. Maniara, Effect of cooling rate on the solidification behavior of magnesium alloys, Archives of Computational Materials Science and Surface Engineering 1/1 (2009) 21-24.
[167] R. Maniara, L.A. Dobrzański, J.H. Sokolowski, W. Kasprzak, W.T. Kierkus, Influence of cooling rate on the size of the precipitates and thermal characteristic of Al-Si cast alloys, Advanced Materials Research 15-17 (2007) 59-64.
[168] L.A. Dobrzański, T. Tański, L. Čížek, J. Madejski, The influence of the heat treatment on the microstructure and properties of Mg-Al-Zn based alloys, Archives of Materials Science and Engineering 36/1 (2009) 48-54.
[169] L.A. Dobrzański, E. Jonda, K. Labisz, The influence of laser modification on the structure and properties of the X40CrMoV5-1 and 32CrMoV12-28 hot work tool steels, Archives of Materials Science and Engineering 41/2 (2010) 104-111.
[170] M. Bonek, L.A. Dobrzański, E. Hajduczek, A. Klimpel, Structure and properties of laser alloyed surface layers on the hot-work tool steel, Journal of Materials Processing Technology 175/1-3 (2006) 45-54.
[171] L.A. Dobrzański, E. Jonda, A. Klimpel, Laser surface treatment of the hot work tool steel alloyed with TaC and VC carbide powders, Archives of Materials Science and Engineering 37/1 (2009) 53-60.
[172] L.A. Dobrzański, M. Bonek, E. Hajduczek, A. Klimpel, Effect of Diode Laser Surface Alloying of Hot-Work Tool Steel, Metallurgia Italiana 98/4 (2006) 41-46.
[173] L.A. Dobrzański, K. Labisz, M. Piec, A. Klimpel, Mechanical properties of the surface layer of the laser alloyed 32CrMoV12-28 steel, Archives of Materials Science and Engineering 29/1 (2008) 57-60.
[174] L.A. Dobrzański, K. Labisz, A. Klimpel, Comparison of Mechanical Properties of the 32CrMoV12-28 Hot Work Tool Steels Alloyed with WC, VC and TaC Powder Using HPDL Laser, Key Engineering Materials 324-325 (2006) 1233-1236.
[175] L.A. Dobrzański, K. Labisz, E. Jonda, Laser treatment of the surface layer of 32CrMoV12-28 and X40CrMoV5-1 steels, Journal of Achievements in Materials and Manufacturing Engineering 29/1 (2008) 63-70.
[176] L.A. Dobrzański, M. Bonek, E. Hajduczek, A. Klimpel, A. Lisiecki, Comparison of the structures of the hot-work tool steels laser modified surface layers, Journal of Materials Processing Technology 164-165 (2005) 1014-1024.
[177] L.A. Dobrzański, K. Labisz, M. Bonek, A. Klimpel, Comparison of 32CrMoV12-28 steel alloyed with WC, VC and TaC powder using HPDL laser, Journal of Achievements in Materials and Manufacturing Engineering 30/2 (2008) 187-192.
[178] L.A. Dobrzański, M. Bonek, E. Hajduczek, A. Klimpel, Alloying the X40CrMoV5-1 steel surface layer with tungsten carbide by the use of a high power diode laser, Applied Surface Science 247/1-4 (2005) 328-332.
[179] L.A. Dobrzański, E. Jonda, K. Labisz, M. Bonek, A. Klimpel, The comparision of tribological properties of the surface layer of the hot work tool steels obtained by laser alloying, Journal of Achievements in Materials and Manufacturing Engineering 42 (2010) 142-147.
[180] L.A. Dobrzański, M. Bonek, E. Hajduczek, A. Klimpel, A. Lisiecki, Application of high power diode laser (HPDL) for alloying of X40CrMoV5-1 steel surface layer by tungsten carbides, Journal of Materials Processing Technology 155-156 (2004) 1956-1963.
[181] K. Labisz, L.A. Dobrzański, E. Jonda, J. Lelątko, Comparison of surface laser alloying of chosen tool steel using Al_2O_3 and ZrO_2 powder, Journal of Achievements in Materials and Manufacturing Engineering 39/1 (2010) 87-94.
[182] M. Bonek, G. Matula, L.A. Dobrzański, Effect of laser surface melting on structure and properties of a high speed tool steel, Advanced Materials Research 291-294 (2011) 1365-1368.
[183] L.A. Dobrzański, E. Jonda, A. Križ, K. Lukaszkowicz, Mechanical and tribological properties of the surface layer of the hot work tool steel obtained by laser alloying,

Archives of Materials Science and Engineering 28/7 (2007) 389-396.
[184] M. Bonek, L.A. Dobrzański, Characterization performance of laser melted commercial tool steels, Materials Science Forum 654-656 (2010) 1848-1851.
[185] L.A. Dobrzański, K. Labisz, A. Klimpel, Structure and properties of the laser alloyed 32CrMoV12-28 with ceramic powder, Journal of Achievements in Materials and Manufacturing Engineering 32/1 (2009) 53-60.
[186] M. Piec, L.A. Dobrzański, K. Labisz, E. Jonda, A. Klimpel, Laser Alloying with WC Ceramic Powder in Hot Work Tool Steel Using a High Power Diode Laser (HPDL), Advanced Materials Research 15-17 (2007) 193-198.
[187] M. Bonek, M. Piec, L.A. Dobrzański, The study of properties of laser modified hot-work tool steel surface layer, Journal of Achievements in Materials and Manufacturing Engineering 28/1 (2008) 75-78.
[188] L.A. Dobrzański, M. Bonek, M. Piec, E. Jonda, Diode Laser Modification of Surface Gradient Layer Properties of a Hot-work Tool Steel, Materials Science Forum 532-533 (2006) 657-660.
[189] L.A. Dobrzański, K. Labisz, M. Piec, J. Lelątko, A. Klimpel, Structure and Properties of the 32CrMoV12-28 Steel Alloyed with WC Powder using HPDL Laser, Materials Science Forum 530-531 (2006) 334-339.
[190] L.A. Dobrzański, E. Jonda, K. Labisz, Structure and properties of surface layer of hot-work tool steels alloyed using high power diode laser, Journal of Achievements in Materials and Manufacturing Engineering 37/2 (2009) 617-621.
[191] L.A. Dobrzański, M. Bonek, E. Hajduczek, K. Labisz, M. Piec, E. Jonda, A. Polok, Structure and properties laser alloyed gradient surface layers of the hot-work tool steels, Journal of Achievements in Materials and Manufacturing Engineering 31/2 (2008) 148-169.
[192] L.A. Dobrzański, W. Borek, Hot-Working Behaviour of Advanced High-Manganese C-Mn-Si-Al Steels, Materials Science Forum 654-656 (2010) 266-269.
[193] L.A. Dobrzański, A. Grajcar, W. Borek, Microstructure evolution of high-manganese steel during the thermomechanical processing, Archives of Materials Science and Engineering 37/2 (2009) 69-76.
[194] L.A. Dobrzański, W Borek, Hot deformation and recrystallization of advanced high-manganese austenitic TWIP steels, Journal of Achievements in Materials and Manufacturing Engineering 46/1 (2011) 71-78.
[195] L.A. Dobrzański, W. Borek, Hot-working of advanced high-manganese austenitic steels, Journal of Achievements in Materials and Manufacturing Engineering 43/2 (2010) 507-526.
[196] L.A. Dobrzański, W. Borek, Microstructure forming processes of the 26Mn-3Si-3Al-Nb-Ti steel during hot-working conditions, Journal of Achievements in Materials and Manufacturing Engineering 40/1 (2010) 25-32.
[197] L.A. Dobrzański, W. Borek, Processes forming the microstructure evolution of high-manganese austenitic steel in hot-working conditions, Journal of Achievements in Materials and Manufacturing Engineering 37/2 (2009) 397-407.
[198] L.A. Dobrzański, A. Grajcar, W. Borek, Microstructure evolution and phase composition of high-manganese austenitic steels, Journal of Achievements in Materials and Manufacturing Engineering 31/2 (2008) 218-225.
[199] L.A. Dobrzański, A. Grajcar, W. Borek, Hot-working behaviour of high-manganese austenitic steels, Journal of Achievements in Materials and Manufacturing Engineering 31/1 (2008) 7-14.
[200] L.A. Dobrzański, A. Grajcar, W. Borek, Influence of hot-working conditions on a structure of high-manganese austenitic steels, Journal of Achievements in Materials and Manufacturing Engineering 29/2 (2008) 139-142.
[201] L.A. Dobrzański, A. Grajcar, W. Borek, Microstructure evolution of C-Mn-Si-Al-Nb high-manganese steel during the thermomechanical processing, Materials Science Forum 638-642 (2010) 3224-3229.
[202] L.A. Dobrzański, A. Drygała, K. Gołombek, P. Panek, E. Bielańska, P. Zięba, Laser surface treatment of multicrystalline silicon for enhancing optical properties, Journal of Materials Processing Technology 201/1-3 (2008) 291-296.
[203] L.A. Dobrzański, A. Drygała, P. Panek, M. Lipiński, P. Zięba, Development of the laser method of multi-crystalline silicon surface texturization, Archives of Materials Science and Engineering 38/1 (2009) 5-11.
[204] L.A. Dobrzański, M. Musztyfaga, A. Drygała, W. Kwaśny, P. Panek, Structure and electrical properties of screen printed contacts on silicon solar cells, Journal of Achievements in Materials and Manufacturing Engineering 45/2 (2011) 141-147.
[205] A. Drygała, L.A. Dobrzański, Photovoltaic cells with a laser-textured surface, Scientific Papers of Rzeszow University of Technology - Civil and Environmental Engineering 57/4 (2010) 133-138 (in Polish).
[206] L.A. Dobrzański, A. Drygała, Processing of silicon surface by Nd:YAG laser, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 321-324.
[207] L.A. Dobrzański, A. Drygała, Laser processing of multi-crystalline silicon for texturization of solar cells, Journal of Materials Processing Technology 191/1-3 (2007) 228-231.
[208] L.A. Dobrzański, M. Musztyfaga, A. Drygała, Selective laser sintering method of manufacturing front electrode of silicon solar cell, Journal of Achievements in Materials and Manufacturing Engineering 42 (2010) 111-119.
[209] L.A. Dobrzański, A. Drygała, Influence of laser treatment on the topography of the polycrystalline silicon, Electronics - constructions, technologies, applications 52/4 (2011) 53-54 (in Polish).
[210] L.A. Dobrzański, M. Musztyfaga, Effect of the front electrode metallisation process on electrical parameters of a silicon solar cell, Journal of Achievements in Materials and Manufacturing Engineering 48/2 (2011) 115-144.
[211] L.A. Dobrzański, A. Drygała, A. Januszka, Formation of photovoltaic modules based on polycrystalline solar cells, Journal of Achievements in Materials and Manufacturing Engineering 37/2 (2009) 607-616.
[212] L.A. Dobrzański, A. Drygała, J. Konieczny, J. Lelątko, Structure of laser treated multicrystalline silicon wafers, Journal of Achievements in Materials and Manufacturing Engineering 21/2 (2007) 69-72.

[213] L.A. Dobrzański, A. Drygała, Surface texturing of multicrystalline silicon solar cells, Journal of Achievements in Materials and Manufacturing Engineering 31/1 (2008) 77-82.
[214] L.A. Dobrzański, A. Drygała, Laser texturisation of polycrystalline silicon surface, Electronics - constructions, technologies, applications 5/2010 (2010) 57-59 (in Polish).
[215] L.A. Dobrzański, A. Drygała, Laser texturisation in technology of multicrystalline silicon solar cells, Journal of Achievements in Materials and Manufacturing Engineering 29/1 (2008) 7-14.
[216] L.A. Dobrzański, A. Drygała, P. Panek, M. Lipiński, P. Zięba, Application of laser in multicrystalline silicon surface processing, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 179-182.
[217] J.P. Weszka, P. Jarka, D. Pakuła, L.A. Dobrzański, M. Domański, J. Jurusik, Studying of kinetic growth of organic thin films, Journal of Achievements in Materials and Manufacturing Engineering 35/1 (2009) 29-36.
[218] J. Weszka, B. Hajduk, M. Domański, M. Chwastek, J. Jurusik, B. Jarząbek, H. Bednarski, P. Jarka, Tailoring electronic structure of polyazomethines thin films, Journal of Achievements in Materials and Manufacturing Engineering 42/1-2 (2010) 180-187.
[219] B. Hajduk, P. Jarka, J. Weszka, M. Bruma, J. Jurusik, M. Chwastek, D. Mańkowski, Studying of polyoxadiazole with Si atom in the backbone, Archives of Materials Science and Engineering 42/2 (2010) 77-84.
[220] J. Weszka, L.A. Dobrzański, P. Jarka, J. Jurusik, B. Hajduk, M. Bruma, J. Konieczny, D. Mańkowski, Studying of spin-coated oxad-Si properties, Journal of Achievements in Materials and Manufacturing Engineering 37/2 (2009) 505-511.
[221] M. Chwastek, J. Weszka, J. Jurusik, B. Hajduk, P. Jarka, Influence of technological conditions on optical properties and morphology of spin-coated PPI thin films, Archives of Materials Science and Engineering 48/2 (2011) 69-76.