1 Introduction on the materials surface engineering development trends

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This extensive monograph is comprised of more than ten cohesive chapters concerning technology foresight for materials surface engineering and foresight-materials science research and is currently made available to scientific workers and students in order to disseminate the methodology of this innovative approach for technology development forecasting. The chapters were previously published in 2009-2011, as research monographs, as the reference journals of the Archives of Materials Science Engineering and Journal of Achievements in Materials and Manufacturing Engineering included in the Directory of Open Access Journals.

The first part of the monograph presents the general approach to the issues analysed, with particular consideration given to the scientific and utilitarian objectives of the relevant tasks. The tasks are fulfilled as part of the research conducted and are defined for achieving milestones. Special consideration is also given to socio-economic conditions, methodological aspects and the expected indirect and final effects of the research efforts undertaken. The development state analysis is carried out separately and includes issue state assessment, technology review and a strategic analysis with integrated methods. The concept of **e-foresight**, i.e. the process of foresight research conducted by means of the Internet and information technologies embracing a virtual organisation, web platform and neural networks is also analysed separately. This approach organises, streamlines and modernises the foresight research pursued on a large scale.

The custom **computer integrated development prediction methodology** is of fundamental importance for all the issues presented. The data indispensable for performing the foresight part of the research has been gathered by surveying experts to collect the experts' explicit as well as implicit knowledge. In line with the assumptions adopted, such knowledge should be converted, through the research, into explicit knowledge. The experts were assessing the technologies and the micro- and macro-environment influencing such technologies using a universal scale of relative states being a single-pole positive scale without zero, where 1 is a minimum rate and 10 an extraordinarily high rate. According to the methodology established, a strategic position of each of the analysed critical technologies of materials surface engineering is presented graphically using the **matrix of strategies for technologies** made up of sixteen fields. The matrix presents, graphically, a position of each group of technologies according to its value and environment influence intensity together with the forecast strategic development tracks and identifies a recommended action strategy. The matrix contains the results of the expert investigations visualised with the dendrological and meteorological matrix transformed by means of software created for this purpose. The methodological structure of the both matrices is referring to the portfolio methods commonly known in management sciences, and first of all to BCG matrix enjoying its unique popularity due to a reference to simple associations and intuitive reasoning, becoming an inspiration when elaborating methodological assumptions for the both matrices. A four-field **dendrological matrix of the technology value** includes the expert assessments for the relevant technologies according to the potential being the actual objective value of the specific technology group and to attractiveness reflecting the subjective perception of the relevant technology group by its potential users. A four-field **matrix of environment influence** presents, in a graphical manner, the results of how the external positive (opportunities) and negative (difficulties) factors influence the technologies analysed. A presentation of the methodology assumptions was backed up with a theoretical example illustrating the practical application of a set of matrices with reference to laser remelting, passivation, detonation spraying and PVD multilayer coatings deposition. Classical materials science investigations into the structure of surface layers and mechanical, tribological and functional properties, performed with specialised diagnostic and research apparatuses, represent an inherent part of the materials science and foresight research conducted. The relevance and adequacy of the assessments performed according to the methodology developed is ensured by the synergic interaction of the materials science research and foresight methods. Technology roadmaps developed according to the custom setup are a tool of comparative analysis and they are technically supplemented by technology information sheets.

A series of **materials science and heuristic investigations** was carried out to verify whether the methodology developed is correct. The investigations were concerned, respectively, with the following critical groups of materials surface engineering technologies: laser alloying/cladding of carbide and oxide particles into the surface of casting magnesium alloys, laser alloying of alloy tool hot-work steels, physical vapour deposition (PVD) of coatings onto the brass substrate, physical and chemical vapour deposition (PVD/CVD) of coatings onto sintered tool materials, the selected thermochemical steel treatment technologies, texturisation of polycrystalline silicone, production of graded tool materials with the conventional powders metallurgy method, the selected modification technologies of polymeric materials surface layers. The results of detailed investigations into the structure and properties of the materials subjected to surface treatment are presented for each of the technology groups mentioned, as well as the results of foresight research including a set of foresight matrices with the recommended strategies of long-term development and strategic development tracks established for the three alternatives: optimistic, neutral and pessimistic. The results of the foresight–materials science research conducted constituted reference data serving to create technology roadmaps being a tool of a comparative analysis enabling to select technologies or a group of technologies best for the criterion chosen. The **technology roadmaps** developed with a custom concept are a very convenient tool of a comparative analysis enabling to select the technology best in terms of the specified criterion. Besides, their flexibility is their undisputed advantage, and, if needed, additional sub-layers can be added to or expanded for the maps according to the circumstances of the industry, size of an enterprise, scale of the company's business or an entrepreneur's individual expectations. **Technology information sheets,** containing technical information very helpful in implementing a specific technology in the industrial practice, especially in the SMEs lacking the capital allowing to conduct own research, are detailing and supplementing the technology roadmaps.

A framework bridging this monograph is a presentation of the **neural networks aided future events scenarios** shown by an example of laser surface treatment. The scenarios of future events concerning the development of materials surface engineering are considered at the three levels of generality corresponding to the extent of the phenomena analysed, taking into account their number and the intensity of influence on the other phenomena. The scenarios, at a macro scale, are developed according to the three alternatives: optimistic, neutral and pessimistic. **Neural networks** were used in a novel and experimental manner to cross impacts analysis. The analysis serves to identify how the key mezofactors of surface engineering development (e.g. collaboration between science and industry, number of specialised laboratories and R&D

institutions, continuous improvement and high quality of technology, transparent and friendly legislation, international co-operation and EU funds) and the relevant thematic areas analysed (e.g. laser technologies, thermochemical technologies, nanotechnologies) may influence the occurrence of each of the macroscenarios. A data set elaborated according to the results of survey investigations was divided randomly into the three sub-groups: learning, validation and testing sub-group. The data from the learning set was used for modifying network importance in the learning process and the data from the validation set was used for network evaluation in the learning process. The remaining part of the data, as a test set, was used to determine, independently, network efficiency after completing fully the network development procedure. The following values were used as the basic indicators of model quality evaluation: an average absolute error of network forecast, a standard deviation of the network forecast error, R Pearson's correlation coefficient for the value set and for the value obtained at the neural network output. The quality evaluation indicators of artificial neural networks were calculated for each of the separated sets. The similar values of the average error, standard error deviation and correlation coefficient confirm the generalisation ability of the network, i.e. an ability to generalise the knowledge acquired in the learning process.

9 models were created altogether using artificial neural networks by adopting, as dependent (input) variables, the probabilities of the occurrence of a growth trend, stabilised trend and/or declining trend determined for the key mezo-factors conditioning the development of materials surface engineering and for the individual thematic areas for the research domain of M (Manufacturing) and P (Product). Dependent (output) variables represent the probabilities of the occurrence of each of the three macroscenarios considered. The outcomes of the simulations performed are shown in the charts created by software created for this purpose, i.e. SCENNET48 and SCENNET21. The development trends of the 14 thematic areas analysed (mezo scale) were formulated according to the results of a statistical analysis. The results were obtained based on the results of three iterations of the Delphi method and were presented as a description and as charts illustrating, in percents, to what degree the experts surveyed agree with the theses put forward. Development trends for the relevant groups of the critical materials surface engineering technologies (e.g. laser alloying) were determined at the lowest level of generality (micro scale) for which technology strategy matrices, technology roadmaps and technology information sheets were created. Development trends were also formulated for specific technologies (e.g. laser alloying of alloy tool hot-work steels using powders of titanium

carbides), subjected to the foresight and materials science research using the custom methodology described earlier in the introduction. The extensive approach proposed, pursued at the different levels of generality, is a inverse task. A synthesis consists of seeking a solution being such a combination of micro- and mezofactors which, with the greatest probability, contributes to the emergence of an optimistic or at least neutral macroscenario of future events.

By making this monograph available to the Readers I believe it will contribute to an improvement in the standard of methodological knowledge among students and scientific workers, and will encourage them to initiate their own work and research in the future in the field of technology foresight devoted to the specific areas of material engineering and production other than surface engineering. I also believe that, on the other hand, it will contribute to enhancing the skills of using the results of the foresight research performed for supporting the decision-making process for the development of an individual enterprise, industry or overall economy. A general improvement in the culture of decision-making by utilising the area of knowledge management presented in this monograph, with this area being, unfortunately, sometimes underrated by decision-makers in the field of economy and technology, may have considerable input into economic development at a an enterprise-wide, national or international scale.

I wish to express my kind appreciation to the Group of my Friends and Colleagues who have performed, together with me, the research discussed in this monograph as this multi-faceted and long-term task would not have been implemented without their assistance, involvement and very precious discussions. I would also like to thank the persons who have supported me in pursuing the set objective, including the Reviewers of the individual chapters and the Persons who have held discussions with me during many scientific conferences I have had an opportunity and was privileged to attend and during which I was able to present the outcomes of the works carried out. The discussions were encouraging me and the Group of Co-authors of this monograph cooperating with me to continue further work. Last but not least my appreciations go to the Persons who have supported me with their technical, editorial and translation assistance in preparations to publish this monograph.