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FORESIGHT OF MATERIALS SURFACE ENGINEERING AS A TOOL STIMULATING SUSTAINABLE DEVELOPMENT AND TO INCREASE THE QUALITY OF TECHNOLOGY

Technological e-foresight on the subject of ”Foresight of surface properties formation leading technologies of engineering materials and biomaterials. FORSURF” aims to identify the priority innovative technologies and strategic research trends concerning the materials surface engineering. For the purposes of conducting e-foresight, the methodology of computer aided foresight integrated researches management has been used. Conducted foresight research makes an effort to meet the market expectations and its implementation will facilitate the formulation of development strategy for small and medium-sized enterprises. The identification of leading technologies and presenting them in the form of information sheets will allow the economic representatives to be presented with those of them which have the greatest chance of contributing to the country's sustainable development. It will also provide the possibility to determine the scale of the described phenomena and select those technologies which are best for the effective implementation in the industry in respect of their advancement and "quality-price" relationship. The achievement of foresight objectives will contribute, in the long-term, to the development of knowledge-based economy, statistical increase in the quality of technologies implemented in the industry, and sustainable development.

1. INTRODUCTION

In accordance with the assumptions of the European Union development plan contained in the Lisbon Strategy, one of the key driving elements stimulating the European counties' growth is the knowledge-based economy (KBE). The fundamentals of knowledge-based economy are production, distribution, and implementation of knowledge and information, while the knowledge which constitutes the product is the major contribution to sustainable development. Sustainable development as defined by the Constitution of the Republic of Poland [1] is such a social and economic development in which the process of integrating the political, economic, and social actions occurs in order to give equal chances of access to the environment of separate societies or their citizens, both of the contemporary and future generations, while maintaining natural balance and stability of basic natural processes.

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Having in mind the economic crisis and associated distressing experience of numerous developed countries such as the United States, Island, Greece, Ireland, and taking into consideration a well-known proverb "Only a fool learns from his own mistakes; the wise man learns from the mistakes of others" it is necessary to do everything possible to make use of the available potential. Therefore, it becomes justifiable to seek scientific prediction and shape the future thus departing as far as possible from inefficient and risky trial and error method which may quickly result in wasting the achievements of previous generations. In this view, it becomes essential to orientate scientific research as a priority towards the most promising scientific domains and disciplines which may have a significant impact on a fast technological and economic development of the country, information society development, and knowledge-based economy building. Furthermore, attention should be paid to provide the possibility of using the conducted research in practice rationally and creating preferences for it in the scope of budgetary resources allotment. The achievement of such defined objectives is possible using the e-foresight methodology.

2. MATERIALS ENGINEERING AND MATERIALS SURFACE ENGINEERING VERSUS ECONOMIC TRENDS

The difficult task of classifying scientific domains and disciplines was undertaken for the first time by Auguste Compte in the positivist period. The outcome of his work has obviously lost much of its relevance as various new and more advanced domains and disciplines have been created since that time, particularly at the interdisciplinary meeting of those traditional ones. In the 50s of the last century, as a consequence of development of metal sciences and many other areas of science and technology connected with various groups of materials useful in practice, materials science was created as a basic domain and related engineering science as the engineering knowledge applied in industrial practice. It is worth noting that throughout history a substantial or often leap technological progress was determined by the availability of new technical and, later on, engineering materials, which determined the life quality improvement [2].

2.1. MATERIALS ENGINEERING SIGNIFICANCE

Materials engineering development is one of the most important science and technology development areas in the contemporary world. It is also one of the key elements of science, science and technology as well as innovative policy of Poland in the context of knowledge-based economy. According to forecasts, within next 20 years the following groups of materials will be developing at the highest pace among all advanced engineering materials [3]:

- Nanomaterials characterised by particularly fine structure which provides so far unlooked-for mechanical as well as chemical and physical properties.
- Biomaterials including biomimetic materials and/or materials allowing to replace natural tissues or human organs either directly or with the use of properly designed appliances.

- Infomaterials which are the most advanced group of intelligent and self-organizing materials.
- Light metal alloys which are of particular significance next to composite materials for the modern means of transport design and operation.
- Functionally and tool graded materials in which the chemical constitution, phase composition, and structure or arrangement of atoms changes gradually along with their position (in a continuous or discrete manner).

Among the basic European Union's programmes and initiatives implemented within the framework of international cooperation for the achievement of the mentioned condition, the one which is most important is the European Community's 7th Framework Programme 2007 to 2013 (FP7) for research, technological development and implementations. The scope of the detailed programme *CAPACITIES* in FP7 is of considerable significance for the European Union's competitiveness and maintenance of productive potential, essential enhancement of industrial research, and implementation of new solutions to improve the current productive potential. The detailed programme *IDEAS* in FP7 intends to support the most creative, interdisciplinary scientific frontier research. The drivers behind new technologies development, specified by the European Commission, include pressure on developing new technologies, intensifying demand for new materials and manufacturing processes, and implementing the sustainable development principles. Innovative effects and associated competitiveness of product manufacturers on the international markets are obviously dependent on integration of different advanced domains of science and technology and achievement of synergistic effects in the development of new technologies, including materials technologies and these connected with the engineering materials surface structure and properties formation. The area concerning the substance of research specified in FP7 related to the main line of development of materials engineering and production methods is covered by the subject *"Nanosciences, nanotechnologies, materials and new production technologies"* of the detailed programme *COOPERATION* in FP7 and it fits well into the European policy of building competitive Europe.

The results of research conducted as part of the Europe's technological Foresight in the 5th and 6th European Community Framework Programme and announced in the reports on implementation of the projects *The Future of Manufacturing in Europe (FutMan)* and *Manufacturing Visions The Futures Project (ManVis*) have been used in order to define the detailed assumptions of FP7 in the scope of materials and production methods. The generalisation of the results of European Foresight research on different new materials and different technologies is to anticipate the production of materials with properties demanded by product users [4].

The most important of the selected future trends include: development of new engineering materials for expected applications, simplification of engineering materials production processes, and alternative opportunities for new production processes development in respect of new engineering materials. Among the methods of accomplishing the anticipated trends one can distinguish:

- specialisation which means improving current materials technologies by acquiring one of their basic functions,

- convergence which means obtaining the intended functional properties by associating different types of engineering materials,
- integration which means producing multi-function materials using knowledge of multiple scientific and technological domains in order to meet the users' and materials producers' requirements.

One of the most important tendencies observed recently in relation to engineering materials and biomaterials is the necessity of producing them on demand, which arises more and more often, in order to meet the complex set of specific requirements defined by the customer. In other words, the materials with properties demanded by the customer are produced. It changes the method of materials designing in general and the product material designing. At present, materials with properly formed structure guaranteeing the required set of physical and chemical properties have to be provided on demand of product manufacturers. This approach replaces traditional choice-making [5],[6] based on the supplied materials with the offered structure and properties, choice of material which is closest to the expectations, however, which does not meet them whatsoever, thus being the choice of a lesser evil. The current tendencies force therefore the classification of engineering materials in respect of their functional characteristics. In this view, the type, and especially the chemical constitution of the material used, is of a minor importance (which the materials engineers, and especially metallurgists, were used to for tens of years), while **product functionality gains greater importance**. At present, the materials engineers participate in the product designing process, and the product manufacturers have to meet the imposed requirements as the effect of multi-criteria optimization of structure, properties, mass, product manufacturing and use costs, as well as ecological compatibility with natural environment, etc. It is therefore fundamental to make a change in the assessment of engineering materials role as they can no longer be perceived as the materials in themselves of sought applications, and the new engineering materials market can no longer be the manufacturer's market. Offering materials which are currently in stock regardless the users' needs is out of question now. The manufacturers' market has ended irretrievably. The new engineering materials and production processes are subjected to the customer's needs and product functional features. The production of materials which satisfy the needs of market product manufacturers in due time and place is the priority of new materials technologies and production processes as they are:

- complementary base technologies used to improve the existing solutions,
- alternative technologies applying synergy of various solutions,
- original technologies aiming at developing new solutions.

2.2. MATERIALS SURFACE ENGINEERING SIGNIFICANCE

It is hard to undermine the significance of engineering materials development, which constitutes at present one of the most important elements of science, science and technology, and innovative policy of Poland within the framework of knowledge-based economy. When considering this issue it should be noted that the functional properties

of many products and their elements depend not only on the possibility of transferring the mechanical load through the entire cross section of the element made of applied material or on its physical and chemical properties. These properties very often depend also, or mainly, on the surface layer structure and properties. As a result of proper selection of element's material together with its structure and properties formation processes as well as surface layer type and technology, which guarantee required functional properties, it is possible to put together the manufactured element's core and surface layer properties in the most favourable manner. Materials surface engineering constitutes thereby an extremely important element of the materials engineering in a broad sense, and as such it deserves to be analysed separately and thoroughly.

It is worth noting that materials surface engineering, including surface treatment and coating, is one of the most dynamically developing economic sectors in many technologically advanced countries. As an example, according to reference data of 2008, 8-10% of German economy was accomplished in this very industrial sector. Thus, an assumption can be made that an analogous phenomenon will soon occur in a rapidly developing Polish economy. Surface treatment and coating in its wide context are carried out in almost each manufacturing sectors of industry including the automotive, machine building, tool construction, mechatronic, metallurgical, electrotechnical, electronic, plastics, aircraft, medical equipment, sanitary devices, jewellery, precision, construction, and other industries. Engineering materials and biomaterials surface engineering is undoubtedly one of those domains which are promising to the future and its development can be a key contribution to the country's economic growth.

In a long time horizon, the Polish enterprises, following the example of the countries operating within the so-called old European Union, should put pressure on constant development of advanced manufacturing technologies and search for innovative solutions in order to achieve production which will respond in a flexible manner to continuous change in the customers' preferences. The level of technological novelties implementation and increased quality of applied technologies within this scope is definitely unsatisfactory, especially of small and medium-sized enterprises (SMEs). The SMEs' expenditures on development are inconsiderable thus a need arises to chart the course of action for them, which will positively contribute to their market success. This development should be based on the achievements of the research and development spheres, whose fundamental research direction should be coincident with the development directions of companies, resulting from the opportunities created by environment. It becomes therefore necessary to achieve statistical increase in the quality of technologies implemented in the Polish industry. Examined issue does not concern solely the cutting edge technologies applied by model enterprises which are often referred to when discussing new technologies. It is much more important to focus on the critical need of increasing the technology implementation average level by statistical majority of manufacturers. It is crucial for the quality and stability of a statistical majority of products launched into the market and it substantially determines competitiveness of the country's economy. In the view of the quoted arguments it should be concluded that the problem under discussion is of a great economic significance.

3. FORSURF PROJECT

The response to a strong interest of the national and foreign scientific, industrial, and public administration environments in the extremely important and promising issues of materials surface engineering in its broad context is the project on the subject of ”Foresight of surface properties formation leading technologies of engineering materials and biomaterials FORSURF”. The interest in this subject has been confirmed by the fact that the project has been awarded the European Union funding from financial resources of European Regional Development Fund (85%) and the Polish Ministry of Science and Higher Education (15%). The FORSURF project assumptions are based on the Innovative Economy Operational Programme 2007-2013 (IE OP), and are mainly treated in *Sub-action 1.1.1. Research projects using the foresight method* which is part of the *Action 1.1. Support for scientific research for establishment of a knowledge-based economy*, which in turn is a component of *Priority axis 1. Research and development of modern technologies*. **The main objective of the FORSURF project** is to identify the priority innovative technologies and strategic research trends in the scope of engineering materials and biomaterials surface structure and properties formations methods whose development in the country will beof key importance within next 20 years. The achievement of the project main objective will contribute to the achievement of **general objective**, which is to increase innovation and competitiveness of the Polish economy through a closer cooperation between the research and development (R&D) spheres and economy, and in particular through the adaptation of the research work subject matter to the current and actual demand of industrial enterprises and increasing the involvement of national enterprises in pro-innovative activities which will contribute to the increase in receptivity to innovation and absorption of pro-innovative activities funding in economy [7].

3.1. PRAGMATIC SIGNIFICANCE OF FORSURF PROJECT

The FORSURF project makes an effort to meet the market expectations. The achievement of its objectives will facilitate the formulation of development strategy for small entities operating in an increasingly competitive and globalised economy. The project objectives will also guarantee the achievement of a high technological level by manufacturers and high research funding effectiveness in the discussed scope. Information about surface structure and properties formation technologies of separate engineering materials groups and their desirable development as well as the categories of products for which the state of the art technologies should be applied will be useful for decisions making regarding the research funding and development of innovative solutions within this area. The identification of leading technologies and presenting them in the form of information sheets will allow the economic representatives to be presented with those of them which have the greatest chance of contributing to the country’s sustainable development. It will also provide the possibility to determine the scale of the described phenomena and select those technologies which are best for the effective implementation in the industry in respect of their advancement and “quality-price” relationship. The realisation of the project will

contribute to directing the scientific research as a priority towards the scientific domains and disciplines which may significantly influence a fast development of the country's civilization and economy and building the knowledge-based economy, as well as to rational use of research in practice and creating preferences for it in the scope of budgetary resources allotment which gains particular significance in the crisis conditions. Scientific prediction and shaping of the future will allow the existing potential to be used properly and effectively, departing as far as possible from inefficient and risky trial and error method which may quickly result in wasting the achievements of previous generations as it took place in recent years in such countries as the United States, Island, Greece, or Ireland.

The identification of priority innovative technologies concerning the engineering materials and biomaterials surface structure and properties formation will allow directing the increase in the Polish production enterprises' innovation and contribute to the country's sustainable development. Charting the strategic research trends in the scope of foresight will allow increasing the significance of the Polish science in the economy and will positively influence the competitiveness level of the Polish research in the scope of technical science in the EU and in the world. Pro-innovative direction of the national scientific research and Polish enterprises activities will be a key contribution to increasing the percentage of innovative products in the national economy, thus providing the possibility of creating numerous new, permanent jobs connected with the knowledge-based economy building. Conducted foresight will be an important source of diagnosis for the key scientific, technological, economic, and ecological problems and will be a tool for the forecasts and decisions taken by the state authorities for science, business environment, and public administration institutions.

One of the FORSURF project results is the public debate concerning priority innovative technologies of materials surface engineering and strategic research trends of key significance for the country within next 20 years in the scope of the analysed research field. Subjecting the FORSURF project results to public consultations allows making better use of the process and facilitates indicating the scenarios of future events responding to the existing needs in the best way. Public consultations are to create the feeling of participation and involvement of participants, maximize the decision-making process effectiveness and accuracy, as well as win social approval for decisions resulting from the project implementation. All of the opinions provided during online public consultations will be taken into account upon formulation of the final project results. The initiated and stimulated public debate aiming at disseminating the project results across environments interested in the taken up e-foresight FORSURF subject matter is to contribute to yet closer cooperation between the research and scientific spheres and economy and stimulation of personnel flow between those groups, which also constitutes the pragmatic consequence of activities carried out within the framework of the project, resulting in the improvement of competitive situation of economy and Polish science compared to other European and world countries.

3.2. FORSURF PROJECT SUBJECT AREAS

Two **research fields** have been distinguished within the framework of the FORSURF project, which have been divided into smaller subject areas. The first research field of **M**

symbol (MANUFACTURING) reflects the manufacturer's point of view and encompasses the manufacturing processes determined by the state of knowledge and machinery park productive capacities. The following detailed subject areas have been distinguished within the research field (M):

- M1. Laser technologies in surface engineering.
- M2. PVD/CVD technologies.
- M3. Thermochemical technologies.
- M4. Other technologies in surface engineering.
- M5. Polymers surface treatment.
- M6. Modelling and computer adding in surface engineering.
- M7. The impact of wear conditions on engineering materials surface properties.

The other research field of **P** symbol (PRODUCT) is determined by expected functional properties resulting from the customer's needs, and it focuses on the product and the material it was made of. The following detailed subject areas have been distinguished within the research field (P):

- P1. Surface engineering of biomaterials.
- P2. Surface engineering of structural metallic materials.
- P3. Surface engineering of structural non-metallic materials.
- P4. Surface engineering of tool materials.
- P5. Surface engineering of functional materials.
- P6. Surface engineering of nanomaterials.
- P7. Surface engineering of polymeric materials.

Generally, within the FORSURF project framework, 14 subject areas are analysed. Around 500 technologies have been analysed at the initial stage of research, 150 of which have been qualified for detailed analysis. Three survey iterations will be conducted within the framework of the project which will be addressed to top-class experts selected from the scientific, business, and public administration environments. It has been planned that 210 filled in surveys will be obtained in each of three foresight research iterations – 630 in total. With such a large assumed scale of the conducted research it has become justifiable to search for the methods which would streamline the process of carrying it out. The necessity has therefore arisen to develop methodology and information technology which would arrange, streamline, and modernize the conducted foresight research. **This is how the e-foresight idea emerged.**

4. E-FORESIGHT

Both literature study [8-10] and everyday observation of contemporary world, possible thanks to commonly available modern information technologies, allowed distinguishing leading trends which significantly determine the way in which the contemporary world works:

- aspirations to computerize and automate the increasing number of domains of life,

- aspirations for continuous improvement which is manifested in the form of higher and higher quality in various domains of social and economic life as well as the growing number of innovations implemented in the economy,
- aspirations to develop information society which has access to and is able to make use of knowledge, information, and information structure for the purpose of efficient and economically justified achievement of collective and individual goals,
- aspirations for higher and higher emphasis on natural environment supported by the sustainable development idea understood as a process of integrating political, economic, and social activities while maintaining natural balance and stability of basic natural processes,
- aspirations for scientific prediction and shaping of the future in order to build knowledge-based economy and make appropriate use of currently available potential, having in mind the economic crisis and associated experience of many countries such as the United States, Island, Greece, Ireland, which distinctly shows how easy it is to waste the achievements of previous generations.

The results of literature study as well as the observations and individual experience gained when conducting the foresight research on the subject of materials surface engineering have become the contribution to the development of an original methodology of Computer Aided Foresight Integrated Researches Management (CA FIRM). The developed methodology is an integrated approach which allows gaining explicit and tacit knowledge from the top-class experts selected from the scientific, business, and public administration environments during the performance of three survey iterations. The proposed approach uses the synergy effect and eliminates unfavourable psycho-social phenomenon called by the author of the article as the "show-off effect". The **show-off effect** is manifested during direct meeting of people which serves to exchange views on a specific subject and consists in the fact that people are orientated to show themselves to their best advantage and promote themselves instead of sharing their knowledge.

In relation to already known and commonly used concepts [11],[12]: e-management, e-business, e-commerce, e-banking, e-logistics, e-sevices, e-administration, e-education, which always refer to the performance of particular activities using the computer networks, especially the Internet, the author of this work suggests to introduce the concept of e-foresight on an analogical basis**. E-foresight** means conducting the foresight research using the Internet [13]. E-foresight is orientated to support the activities of two beneficiaries. The first group consists of foresight researchers, who can perform their work at any time and in any location, which combined with *teleworking* contributes to giving equal opportunities on the labour market as it allows the persons working from home, including mothers raising small children and disabled persons, to join the team of project researchers The other group of beneficiaries are the domain experts, who are direct participants of the conducted survey and can work according to the principle: *"I participate with my laptop in the foresight research at the time and place which are most convenient to me"*, thus contributing to a quicker and more effective acquiring of indirect and final research results.

In order to achieve the objectives of technological e-foresight, which come down to the identification of priority, innovative strategic research technologies and trends in respect of the analysed research field, with the use of computer aided foresight integrated researches

management CA FIRM, it is necessary to develop the concept of functioning within the virtual organisation's cyberspace. The **Virtual Organisation** for Foresight Integrated Researches Management (**VO FIRM)** is set up to accomplish a long-term all-society objective which is a closer relation between science and economy and development of information society, thus increasing the importance of knowledge-based economy (KBE), seeking sustainable development and improvement in the quality of life. The computer tool which enables the achievement of such defined objectives and aims from the technical aspect is the **WebPlatform** for Foresight Integrated Researches Management (**WP FIRM)** allowing the management of virtual organisation in cyberspace.

5. METHODOLOGY OF CA FIRM

By implementing the methodology of computer aided foresight integrated researches management, the foresight project Head will be able to provide answer to the key question which is:

> *Which of the technologies applied in a particular research field belong to the set of priority innovative technologies and the development of which strategic research trends in a particular research field will be of key importance for the country within next 20 years?*

In order to answer the above research question it is necessary to execute the following **steps** of the computer aided foresight integrated researches management (CA FIRM):

- Division of wide research fields covered by the foresight subject into detailed subject areas.
- Carrying out three survey iterations addresses to the top-class experts selected from scientific, business, and public administration environments.
- Construction of technology value dendrological matrix presenting in a graphic form the separate technologies' potential and attraction value [14].
- Construction of methodological matrix for the environmental influence on particular technologies presenting in a graphic form the difficulties and opportunities created by environment for separate technologies [14].
- Construction of the matrix of strategies for technologies presenting in a graphic form the recommended strategies for behaviour in relation to particular technologies while taking into consideration the technology value (internal factors) and environmental impact (external factors) [14].
- Prediction of strategic research trends of key importance for the country within next 20 years within the area of the analysed research field using the artificial intelligence methods – self-learning neural networks, which constitutes a novel approach to the analysed problem, not used in the country.
- Construction of future scenario matrix presenting in a graphic form the expected visions of the future in respect of the analysed research field.
- Creation of technology information sheet Book containing the information sheets arranged according to ranking list and containing detailed description of each

technology classified into the priority innovative technologies group of a particular research field subjected to foresight research.

- Scientific compilation of research results using statistical methods (selected measures of location and measures of variability), allowing the analysed phenomena to be expresses in terms of numbers, which is possible by ensuring an appropriate scale of the conducted research (210 filled in surveys in each of three iterations – 630 in total).
- Objectification of the analysed research by introducing respondent credibility heuristic scoring assessment which allows to differentiate the answer weight of particular respondents, taking into account their professional competences (validation questions, cross-questions, particular group membership).
- Scoring assessment of satisfaction of domain experts participating in the computer aided foresight integrated researches conducted in the last (third) survey iteration in respect of similar research carried out in a traditional manner.

Separate steps of the computer aided foresight integrated researches management CA FIRM are arranged on a serial and parallel basis and allow the technological foresight process to be carried out in an organised, efficient, and modern way.

6. CONCLUSIONS

The development of materials engineering and engineering materials and biomaterials surface engineering is currently one of the key elements of science, science and technology, and innovative policy of Poland aiming at creation of information society, knowledge-based economy, and sustainable development. Similarly, the achievement of statistical increase in the quality of technologies implemented in the Polish industry is one of the important objectives which are to improve the quality and statistical stability of products launched into the market which consequently determine significantly the national economy competitiveness. The realisation of e-foresight described in this article is used for the purposes of scientific prediction and shaping of the future using modern information technologies: virtual organisation VO FIRM, WebPlatform WP FIRM, databases and neural networks. Implementation of the described e-foresight results in the economic reality aims at enhancing the cooperation between scientific and business environments in order to increase the Polish economy innovation and competitiveness. Conducted research will also serve for the future development of selected priority innovation technologies as well as taking advantage of opportunities and avoiding threats in accordance with the forecasts included in the constructed future events scenarios.

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