Introduction on the importance of the materials structure and properties forming processes for contemporary industrial production

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Many new and contemporary science branches and disciplines, especially at the interdisciplinary areas of the traditional ones, have emerged since a positivist – Auguste Comte had categorised them. As a consequence of the development of physical metallurgy and many other fields of science and technology connected with a various group of materials useful in practice, 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. It is worth noting that just rendering accessible newer and newer technical materials, and with time also engineering ones within the compass of history, decided – as a rule – the significant, and quantum leap at times technical progress, determining improvement of the quality of life. Not unlike it is today. Therefore 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 development of materials engineering as one of the few areas of science and technology development most important nowadays in the contemporary World. Of course, the development of all other groups of engineering materials and process technology materials, traditionally considered to be less avant-garde today is constantly noticeable and still awaited. The development of materials engineering and materials science features also one of the most essential elements of the scientific-, scientific and technical-, and innovative policy of Poland within the framework of the knowledge based economy, consisting in knowledge generation, treated as production, and in distribution and practical use of knowledge and information.

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. This 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 materials used are of less importance (to which materials engineers were used for decades, and especially the metallurgists), while its functionality is more important. Currently, materials engineers participate (and have to do so) in the products design processes and materials manufacturers have to face the requirements, as the effect of the multicriteria optimisation of, e.g., structure, properties, mass, product manufacturing and service costs, as well as of their ecological compatibility with the natural environment. Therefore, a change in the engineering materials role assessment is important, as they cannot be perceived any more as goods in themselves, with their applications sought for, and the market of the new engineering materials cannot remain the manufacturer’s market any more. There is no way to offer materials which, by chance, are offered by their manufacturers, regardless of the users’ needs. The market of materials manufacturers is never to return. 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).

It was decided that the results of various works made in the Institute of Engineering Materials and Biomaterials of the Silesian University of Technology in Gliwice, Poland, concerning advanced engineering materials and materials processing technologies will be published in the form of monographs. First of them, concerning chosen aspects of the effect of casting, forming and surface technologies on the structure and properties of the selected engineering materials beginning the cycle of those studies will be prepared both in English and Polish. In the given issue five detailed studies were presented. First of them presents an influence of Al concentration and cooling rate on structure and mechanical properties of magnesium alloys. Also the work presents a methodology to predict crystallisation temperatures obtained during crystallisation process using UMSA platform, based on cooling rate and chemical composition and mechanical properties and grain size based on characteristic temperatures. The next study consists in investigation of newly elaborated high-manganese austenitic steels with Nb and Ti microadditions in variable conditions of hot-working. The hot-deformation resistance and microstructure evolution in various conditions of hot-working for the new-developed high-manganese austenitic steels were investigated. The main objective of the third presented work is to elaborate the fabrication technology of novel sintered tool gradient materials on the basis of hard tungsten carbide phase with cobalt binding phase, and to carry out research studies on the structure and properties of the newly elaborated sintered tool gradient materials. The main objective of the fourth work is to investigate the structure and properties of multilayer gradient coatings produced in PVD and CVD processes on sintered carbides and on sialon ceramics, and to define the influence of the properties of the coatings such as microhardness, adhesion, thickness and size of grains on the applicable properties of cutting edges covered by such coatings. In the fifth work the investigation of the structure and properties of sintered tool materials, including cemented carbides, cermets and oxide ceramics deposited with single-layer and gradient coatings (Ti,Al)N and Ti(C,N) are included and the determination of the dependence between the substrate type, coating material or linear variation of chemical composition and the structure and properties of the obtained tool material were also investigated.

The presented researches are a fragment of many-year works made in the Institute of Engineering Materials and Biomaterials of the Silesian University of Technology in Gliwice, Poland, enabling further works to improve many materials design methodology activities changed because of changes of expectations and contemporary requirements of manufacturing of materials having required structure and utility properties. At present modelling, simulation and prediction of both the technological processes of manufacturing, processing, and forming their structure and properties, and especially of the service and use properties of materials, including those after long time service in the complex conditions, the development of safe materials and products technologies, the standardisation of materials testing procedures, the development of the prediction methodology of the new materials behaviour in service is necessary. One should note that many classic calculation models developed to date, employed in materials science, e.g., Avrami equation used for processes being a function of time and temperature, Fick's laws for diffusion processes, Hall-Petch equation describing dependence of mechanical properties and grain size, Huber-von Mises yield criterion for determining the material loading condition in the complex strain state, equations of the classic mechanics of solids, equations of classic fracture mechanics, models developed using FEM and BEM as well as the related numerical methods, parametric equations and empirical equations, and others, do not fulfil the refined expectations of the designers, especially related to materials – in case of many contemporary material groups or structural phenomena occurring in them, because of the insufficient adequacy of models, and also often because of superposition or superimposition of processes – oftentimes opposing processes, and also due to difficulties in the simultaneous modelling of phenomena occurring at the same time in various scales – from nanometric to metric inclusive, lack of generality of the statistic and parametric equations because of the limited function domain (range) encompassing selectively only some material grades or types, so these factors decide the limited usability or simply impossibility to use those models to fulfil all expectations. Moreover, the trial-and-error method is often the ground of the classically used modelling methods and practical verification of the calculation of obtained is needed nearly each time, because of the significantly excessive mass of the employed materials (and, therefore, also of the products), and the need to employ the high values of the safety factors in product design, because of the insufficient dependability of the used models. Absence of the relevant analytical models is frequently the reason for stopping the progress of the products materials and technological design processes. This stops also the R&D projects in many materials engineering areas, forcing the classic trial-and-error method approach with the extensive experimental investigations plan, even if those experiments are statistically planned.

All this causes also the unjustified increase of costs of such investigations and essential extension of the lead time needed to solve the scientific problem of the significant importance for the implementation practice.

In general, methodology of carrying out each of those scientific tasks consists in completing the entire set of the contemporary materials science examinations using methods and state-of-the-art scientific and research equipment at the unrestricted disposal of the Institute of Engineering Materials and Biomaterials of the Silesian University of Technology, in Gliwice, Poland, including structure examinations also on the transmission and scanning electron microscopes, on the light microscope and the laser confocal one, quantitative and qualitative diffraction analyses with X-ray methods, but also using EBSD, spectral analyses, including also WDS, EDS, and GDOES, and also the required mechanical tests, also in the nanoscale, examinations of the physical and chemical properties, and other dedicated and specialist tests depending on the task topic, after various necessary fabrication processes of the investigated materials and their processing and forming of their structure and properties expected in products for which they are going to be used, to set up the relevant databases and knowledge bases containing results of these investigations related to various groups of the contemporary engineering materials for development and verification of the relevant models, including those for the inverse analysis (specifying at the beginning the material type and its chemical composition, as well as conditions of the technological processes ensuring obtaining properties required and assumed at the beginning by the product designer) and for prediction (assuming the properties used by the product designer in the design process, also including properties after the long time service for the analysed contemporary engineering material type and its chemical composition, as well as conditions of the technological processes).