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ANALYSIS OF ENGINEERING MATERIALS SCIENCE FOR ADVANCES IN DESIGN FOR MANUFACTURING PROCESSES

Abstract:
This paper decribed role of materials selection for the design and manufacturing processes of new, needed products, having the highest attainable quality and performance at the optimum and reasonably set - possibly lowest cost level. The review of the long history of human civilisation indicates that the significant increase of the level of living and production is connected most often with introduction of new material groups, having their properties adjusted better and better to the real customers requirements that get more sophisticated nearly each day, and having also the technological processes relevant to them. The reasons given, make it possible to forecast that the future of the market and products on it, with the required properties, are inseparably connected with the development of Engineering Materials.

Keywords:
design, engineering materials, production process, product

INTRODUCTION

Modern products could not be often designed and manufactured without employing many materials, just as that they could not operate in required service conditions and with the required very high reliability. One has to realise that the contemporary product is composed of a host of elements made from materials varying a great deal. As an example, the average car is composed of about 15,000 elements, whereas the passenger aircraft has more than 4,000,000 elements. Many people, even today, do their work at home, without leaving it. Houses will have to be organised and furnished in a totally other way within several years' time span. Towns, transportation and telecom systems will be organised differently than nowadays. Towns and transport system will be organised in another way, including novel urban transportation systems connecting the sky-high buildings, electrically powered cars, robotized safety systems and municipal wastes utilisation systems. Health care system will be based on diagnoses made at home, non-allergic nutrition, early detection of serious illnesses and their prevention, and also on implanting of artificial organs-heart, and of a new generation of biomaterials. Future agriculture, forestry and fish industry will be based on genetic engineering achievements, mastering fanning new plants, employing other processes than photosynthesis, and also comprehensive robotisation. Mining and manufacturing industries will be based on a total robotisation of processes of industrial *recycling of water and air, on development of the ultra-microprocessor technology, and also on the high-throughput power transmission systems employing organic materials substituting copper. Earth protection systems fighting climatic effects, implementing recovery from damages caused by torrential rains, fighting droughts, and exploitation of the tropical forests, as well as decreasing the ozone layer discontinuity effects, will undergo significant changes. Systems for surveillance of oceans and seas and monitoring their contamination, and for observations of earthquakes will be developed, moreover, robots will be introduced to underwater service. Many of these materials are already available nowadays, some of them should be developed soon according to the outlined requirements.*

SELECTION OF MATERIALS FOR TECHNICAL APPLICATIONS AND PRODUCTION PROCESSES

The selection of the product manufacturing processes, closely related to the selection of materials for its parts, is a very important stage of the engineering design process. The main criterion for these selections is maximum of product quality with the simultaneous minimum of costs of its elements. The selection of a material decides often selection of feasible manufacturing processes that may be used for producing elements from the particular material. The selection of the technological process is connected with the materials performance and limited by its hardness, brittleness or plasticity, and melting temperature. Functional properties of a product are obtained only when the right material is used, manufactured in the properly selected technological process, imparting both the required shape and other geometrical features, including dimensional tolerances of particular elements, making the final assembly of the product possible, and also forming the required material structure, ensuring the expected mechanical, physical and chemical properties of the product, see Fig.1. Each production process is connected with the product shape range that may be made using this process. The general goal of the actually employed technological processes is to make the net-shaped products that make mediate assembly possible, or-in finishing-usually by machining-before installing them into the final product.

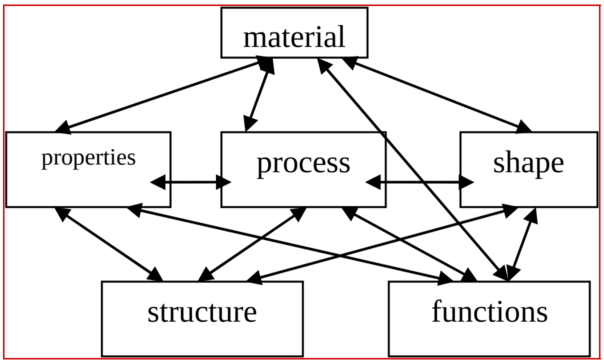

Fig. 1. Relationships among some factors connected with mate-case it is not feasible-the near-net-rial, processes and functions of aproduct [1], [3], [10]

It is possible to select the manufacturing processes of the product elements basing on the analysis of the relationship among the employed technological process, size of elements, and complexity of their shapes, see in Fig.2, [3], [4], [5], [6], [7], [8]. Variety of materials available nowadays, makes it necessary to select them properly for the constructional or functional elements, tools and eventually other products or their elements.

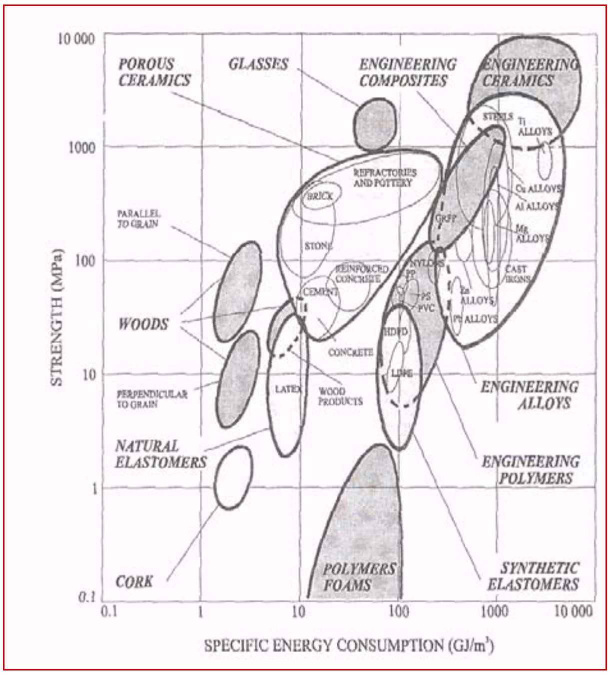

Fig. 2. Options of the product forming technological processes

This selection should be carried out basing on the multi-criterion optimalization. Functional properties of engineering materials are usually ding on its shape complexity level and weight (prepared according to [2], [9]) defined by their physical, mechanical, thermal, electrical, magnetic, and optical properties. These properties depend on structure and chemical composition of the material and on service conditions of the element. The aim of materials science is to investigate the effect of their structure in various scales (electron, crystalline, micro, and macro) on materials properties. The numerous grades of the actually available materials yield new innovative potential in implementation of products. Determining the relationships among structure, techno-logical process, and functional properties, and also the selection of materials and technological processes forming their structure and properties for use in complex manufacturing systems, feature the main focus of materials engineering. The vast majority of engineering materials are derived from raw materials obtained from the crust of the earth, raised in mines as ores and then enriched to make possible their extraction or synthesis. Figure 4 illustrates the relation of strength and the specific energy consumption of materials (defined as the product of energy required to make (he material, i.e., obtaining the raw materials, their refining, and shaping of the produced material, related to 1 kg of the material, and its density). This coefficient expresses indirectly the influence of the material manufacturing process on degradation of the environment. The specific energy consumption shows linear dependence with the material strength. The situation as it is now and current forecasts require from engineers the coordinated activities aimed at saving the available raw materials, consisting in:

- designing with the economical use of materials, mostly those hardly available and close to be depleted, with minimum of their energy consumption,
- using easier to acquire alternatives with the large margin of the half-life of their raw materials depletion and with lower energy consumption, instead of those hardly available and close to be depleted,
- making full use of the energy saving recycling for their reuse and full recovery of materials in all possible and economically justified cases.

The selection of the proper material along with the appropriate technological process is vital, as it ensures the longest product life with the lowest costs, considering that one has to account for more than 100,000 engineering materials possible and available on the market, and yet, the average engineer has a detailed knowledge about the practical applications of some 50-100 engineering materials. Because of the significantly diversified conditions of use of various products, and also their diversified design features, collecting many detailed information is required for proper material selection. Two approaches are possible to the selection of combinations of materials and the technological process of the particular element. First, one may select either the material, which is more frequently preferred by engineers, or the techno-logical process, whose consequence is selection of the technological process or materials respectively in the second move.

GENERAL BASES OF PRODUCTS DESIGNING FOR PREPARING THEIR PRODUCTION PROCESSES

Manufacturing is the process of transforming of raw materials into products. Manufacturing consists in making products from the raw materials in various processes, using various machines and in operations organised according to the well-prepared plan. Therefore, the manufacturing process consists in a proper use of resources like: materials, energy, capital, and people. Nowadays, manufacturing is a complex activity merging people working in various professions and carrying out miscellaneous jobs using diverse machines, equipment, and tools, automated to a various extent, including computers and robots. The technical aspect of this effort pertains to the engineering design of a product. Engineering design of a product is to merge in itself three equally important and indivisible elements, Fig.3:

- structural design, whose goal is to work out the shape and geometrical features of products satisfying human needs,
- materials design for the selection the required physical and chemical, as well as technological properties, ensuring the expected life of the product or its elements, and the
- technological design making it possible to impose the required geometrical features and properties to the particular product elements, and also to ensure their correct mating after assembly, accounting for the

production volume, its automation level and computer assistance, and also with ensuring the lowest possible costs of the product.

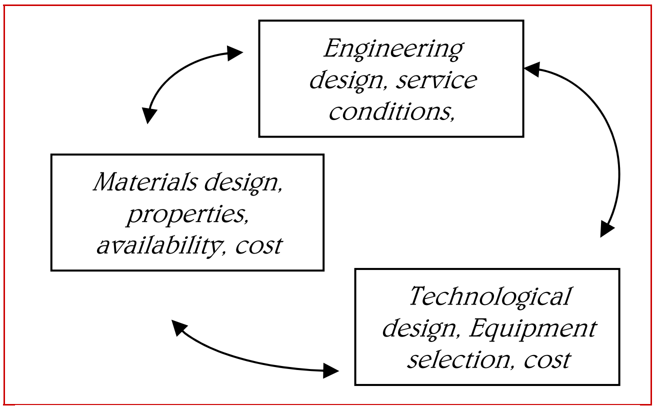

Fig.3. Engineering design of a product

Engineering design is connected with determining the shape of the product and its elements, selection of materials from which they are to be made, and the selection of the relevant technological processes. The designed product has to meet the parameters pertaining fully to its functionality, and also requirements connected with its shape and dimensional tolerances; moreover, the design has to include the list of materials used, manufacturing methods, and other necessary information. One has to account for, among other, consequences and risk of product failure, resulting from its foreseen, however probable misuse, or the imperfection of the manufacturing process. Possible consequences of product failure affect the evaluation of the significance of its assumed reliability. Economical aspects do not impose excessively demanding reliability requirements if there is no risk of injuries or incurring losses due to product failure in use, Fig.4. Each product shape version imposes some requirements pertaining to the material properties that can meet them, to which one may include the relationships between stresses resulting from the product shape and its load, and the material strength. The change of the manufacturing process may change the material properties, and some product-material combinations may be infeasible using some technological processes. Relationships between product shape requirements and material properties may be evaluated using the deterministic or stochastic methods. In the deterministic methods one uses the nominal or average stress, dimension, and strength values for calculations, moreover, the relevant factors of safety are used, whose task is to account for the expected variability of these design parameters.

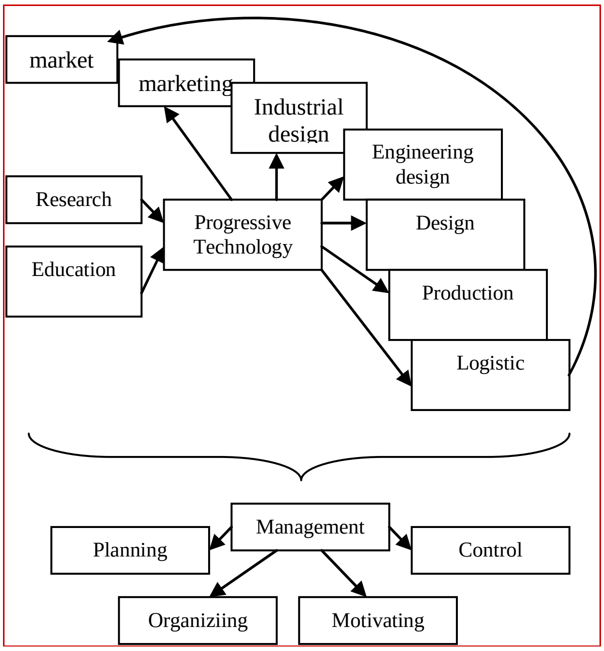

Fig.4. Design of the product is located between its marketing and manufacturing in the process of its introducing into the market

The reasons of some 90% failures caused by material fatigue in service are connected with the faulty design and manufacturing faults, and only 10% result from material faults, its improper chemical composition or heat treatment errors. Even the seemingly insignificant reasons may result in serious consequences. In one case, for instance, the fatigue damage of the aircraft in flight was caused by the inspection stamp that was imprinted too heavily on one of its elements. The failure modes that might directly endanger life or limb or else damage or destroy products or their elements should not be allowed. The experimental verification enables to check the computer simulation in various scales and using the artificial intelligence methods, for employing the new materials and their manufacturing processes. The Computer Aided Materials Selection Systems (CAMS) and the Computer Aided Materials Design ones (CAMD) have found their right position within the framework of the Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) systems. Progress in this area is particularly important as the computer systems made available eliminate the gross errors made not infrequently using the traditional methods, and also feature the indispensable elements of *the computer aided design/ manufacturing/ material selection systems – CA-X.*

STRATEGIC DIRECTIONS OF ACTIVITIES OF THE FUTURE IN THE AREA OF MATERIALS SCIENCE AND ENGINEERING AS THE BASIS OF DESIGN AND MANUFACTURING OF THE NEW DEVELOPED PRODUCTS

The process of implementing the new materials is connected with improving the existing materials or with taking into account the contemporary achievements connected with working out of the new compounds, structure, and ensuring the new properties. The fundamental feature is the possibility of designing the new materials focused on their small scale, inclusive the nanometric one, the optimisation of their applications, and also the optimisation of their manufacturing, including modelling of properties and processes. The modern theory of materials science and modelling specific for the computational materials science, are used for development of new materials. Introduction of new materials and improvement of the properties of materials manufactured to date call also for working out and implementing the new synthesis and processing methods. One should estimate, in particular, that the further progress of civilisation connected with introducing new products with the required high functional properties, will be-to a great extent-dependent on development of the engineering materials, making it possible to use them in engineering design of many new products expected on the market, encompassing, among others:

- *development of modelling the relationships among chemical composition, structure, parameters of the technological processes, and service conditions of the engineering materials,*
- *development of the pro-ecological manufacturing technologies with the possible lowest harmful environmental impact and/or influencing the environment and atmosphere,*
- *development of surface engineering and related technologies in order to increase significantly the competitiveness of products and technological processes,*
- *development and deployment of the industrial applications of the „smart" materials and automatically supervised technological processes,*
- *development of manufacturing technologies making it possible employing the existing high-temperature superconductors in market products,*
- *introduction of the new heat resistant and high-temperature creep resisting materials for service at elevated and high temperatures, especially for the space,*
- *development of the composite materials and others obtained using other non-conventional technologies,*
- *introduction of new generations of biomaterials and biomimetic materials that will render it possible to extend the range of possible medical interventions and implanting the artificial organs and limbs to improve the level of treatment of diseases and injuries.*

CONCLUSIONS

Materials connected issues play surely an important role in carrying out these tasks of the engineers' circles, deciding thus directly the development potential of their societies. Integration of the advanced design and manufacturing processes of the state-of-the-art products and consumer goods features an important determinant of this development, encompassing the progress in the area of the design methodology and new designs created using the computer assisted technique methods (CAD). One should add to that development of new technologies and manufacturing processes, of the technological design methodology of modem manufacturing organization and operational management along with the computer assisted manufacturing (CAM), and also development of the materials design methodology, working out the completely new engineering materials with the required - better and better-functional properties, with the pro-ecological features and minimised energy consumption, along with the development of the computerised materials science and the computer assisted materials design methodology (CAMD). This integration is expressed best in the computer integrated manufacturing (CIM).

Among the all main development trends of the advanced design and manufacturing processes of the novel advanced products in the forthcoming decades of the 21^st century, one can *single out the importance of materials science and engineering, boiling down to materials design connected with adjusting the materials, starting from their chemical composition, constituent phases and micro-structure, to the set of properties required to use them in the final products, computational materials science as the indispensable materials' properties and manufacturing processes affecting them prediction tool, advanced analytical techniques employed in investigation and synthesis of materials to their nanocrystalline and atomic scales inclusive, techniques of the future for manufacturing the engineering materials composed of atoms and molecules, and development of nanomaterials, smart materials and the biomimetic ones. The essential challenges facing the academic circles in the area of the advanced design and manufacturing processes of the novel advanced products and consumer goods call for convincing the world of industry, management, and politics about the need of investing in science for acquiring the contemporary technological progress. It is important that the time span between the scientific discoveries and their practical applications is made as short as possible, and that the societies are convinced that there exist links between the current fundamental research and future welfare.*

REFERENCES

[1] ASHBY, M.F.: Materials Selection in Mechanical Design, Pergamon Press, Oxford - New York - Seoul-Tokyo, 1992

[2] DIETER, G.E.: ASM Handbook - Materials Selection and Design, ASM International, Vol. 20, Metals Park, 1997

[3] DOBRZARISKI, L.A.: Fundamentals of Materials Science and Physical Metallurgy. Engineering Materials and Fundamentals of Materials Design, WNT, Gliwice - Warszawa, 2002

[4] JURKO, J.-GAJDOŠ, M.: Zvyšovanie produktivity pri obrábaní v reálnych podmienkach firmy. In: Proceedings of conference „Management of manufacturing systems, Prešov, 2008, pp.225-228

[5] JURKO, J.: Vŕtanie austenitických nehrdzavejúcich ocelí. Prešov, D.A.H. Prešov, 2005, 101 p.

[6] JURKO, J.-LUKOVICS, I.: Vŕtanie-Technologická metóda výroby dier. 1. vyd., Zlín : UTB, 2007. 191 p.

[7] JURKO, J.-LUKOVICS, I.: Obrábateľnosť materiálov. 1. vyd., Zlín : Univerzita Tomáše Bati, 2008. 144 p.

[8] JURKO, J.-PANDA, A.: Výrobný proces - montáž a demontáž v strojárstve. 1. vyd - Prešov : FVT TU, 2008. - 140 p.

[9] PANDA, A.-JURKO, J.-PANDOVÁ, I.: Vývoj, výroba a overenie nových výrobkov pre automobilový priemysel. 3. časť, 1.vyd., Prešov : FVT TU, 2009. 79 p.

[10] RUHLE, M.-DOSCH, H.-MITTEMEIJER,E.J.-Van de VOORDE,M.H.: European White Book on Fundamental Research in Materials Science. Max-Planck-Institute fuer Metallforschung, Stuttgart, 2001

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