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Synergic effects of the scientific cooperation in the field of materials and manufacturing engineering

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Education and research trends

ABSTRACT

Purpose: The paper emphasises the very significant role of materials selection for design and manufacturing processes of new needed products, having the highest attainable quality and performance at the optimum and possibly the lowest cost level.

Design/methodology/approach: The engineering design processes cannot be set apart either from the material design, being more and more often computer-aided, or the technological design of the most suitable manufacturing processes.

Findings: The attention was paid to synergic effects of the cooperation with the specialists of various branches what was a basis of the successful series of the International Scientific Conference AMME and the foundation of the World Academy of Materials and Manufacturing Engineering.

Practical implications: The paper includes also the description of the world developmental trends in that area in the first decades of the 21st century. The tasks of that field of science in priority spheres of the world development are determined.

Originality/value: Directions of activities of materials science and engineering ensuring the achievements of strategic aims of the developments of societies include materials design, computational materials science, advanced analytical methods, manufacturing and processing, nano-, smart and biomimetic materials are included. It is concluded that there is a humanistic mission which stands at the engineering circle, especially associated with materials and manufacturing engineering and its aim is to make products and consumer goods, deciding directly about the level and quality of human life.

Keywords: Development in the field of materials, manufacturing and mechanical engineering; Synergy; Engineering design; Quality of life

1. Introduction

In the 17th century a French philosopher, a creator of sociology Auguste Comte, divided science into scientific disciplines. Undoubtedly, the positive result of the specialisation of science was progress in many disciplines. The side effect is the appearance of thematic fields between developing disciplines in which many times scientific searches were even neglected.

As a result of this the interdisciplinary fields in which lately the greatest progress has been achieved are very attractive for researches. Also because of those reasons since the 1950s materials engineering created in the meeting of some traditional fundamental and engineering science, continuing mainly the physical metallurgy traditions, which was created at the beginning of industrial revolution, converted next smoothly to materials technology and in consequence to the materials science. Links were developed simultaneously between materials technology and materials engineering, and applied sciences, which can be demonstrated by many examples. Investigations of semiconductors have provided the opportunity for co-operation with solid-state physics. The development of polymer materials demonstrated the effectiveness of co-operation with polymer chemistry. There are many examples of implementing numerous models discovered by physics and chemistry for the development of materials. Many mathematical models were used, among others, for describing phase transformations, conception of *J* integral in fracture mechanics, fractal geometry for describing growth of clusters and colloidal systems, for solving the nonlinear grain boundary migration problem or Laplacian growth processes in description of the morphological phase transformations. The end of the 20th century has demonstrated that achievements of materials engineering are usually an outcome of the significant integration among various branches of science, which resulted in consequence in making the 21st century materials science an interdisciplinary area developed on the crossroad of many pure science disciplines, mostly of the solid-state physics, chemistry, mathematics, and process engineering, but also mechanics and mechanical engineering, ecology, economy, management and applied computer science, and even biology and medicine, taking advantage of achievements of those scientific disciplines to propose materials with the most advantageous set of properties and suiting higher and higher requirements posed to products and goods used by people in the best way, in conditions of the fierce market competition and with high requirements concerning quality, reliability, life, and price.

The target of materials science is an investigation of the effect of their structure in various scales (electron, crystalline, micro, and macro) on properties of materials. A great number of material brands available nowadays offer new innovative possibilities in design, manufacturing, and implementing of products. The determination of dependencies among the structure, technological process, and functional properties, as well as materials selection and technological properties forming their structure and properties for employment in complex manufacturing systems feature the core interest of materials engineering.

In the light of presented information it is clear that in order to achieve common aims the cooperation between specialists from various fields is necessary. Also as a result of this yet in 1992 the initiative of the cooperation between mechanical and materials engineering was made. The common International Scientific Conferences on Achievements in Mechanical and Materials Engineering, which series is very popular among delegates from numerous countries of the world and very successful, was initiated then. With time it turned out that the profile of the cooperation should be broaden by all issues of manufacturing and that is why in 2005 the AMME'2005 conference was organised in the framework of the Worldwide Congress on Materials and Manufacturing Engineering and Technologies COMMENT'2005, and as aresult of this the World Academy of Materials and Manufacturing Engineering as an international academy of sciences was founded and since the 14th conference it combines all issues of materials and manufacturing engineering including mechanical engineering and as it is expected that such multi-thematic cooperation will bring synergic effects which cannot be expected earlier. Manufacturing is the transformation of raw materials into products from the raw materials in various processes, using various machines and in operations organized 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 uniting 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 the engineering design of a product. The goal of manufacturing is always to satisfy the market needs of customers, according to the strategy of a company or an organisation being engaged in manufacturing, employing available possibilities and equipment.

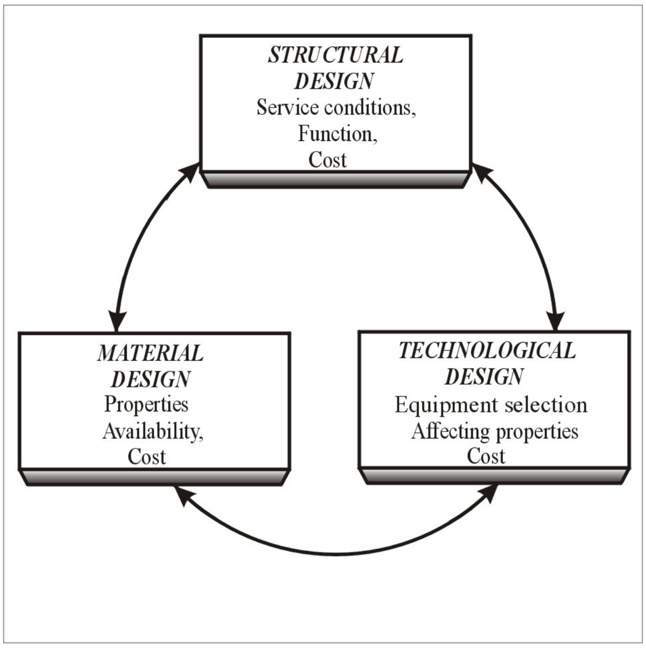

Fig. 1. Relationships between elements of engineering design i.e., structural, material and technological designs (prepared according Dieter G.E.)

Engineering design of a product is not a separated activity, as it influences all other phases of that process, on which it is simultaneously dependent. Engineering design of a product is to merge in itself three equally important and indivisible elements, i.e. Figure 1:

- structural design, whose goal is to work out the shape and geometrical features of products satisfying human needs,
- material design for the selection of the required physical and chemical, as well as technological properties, ensuring the expected life of the product or its elements, and

- 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.

Design of the product is located between its marketing and manufacturing in the process of its introducing into the market (Fig. 2) and it is not a separated activity, as it influences all other phases of this process, on which it is simultaneously dependent. The first product design phase pertains industrial design, connected with the general description of the product's functions and with working out of its general conception, comprising only its outer shape, colour, and eventually, some general assumptions referring to linking its main elements. The succeeding phases include the engineering design and next production preparation.

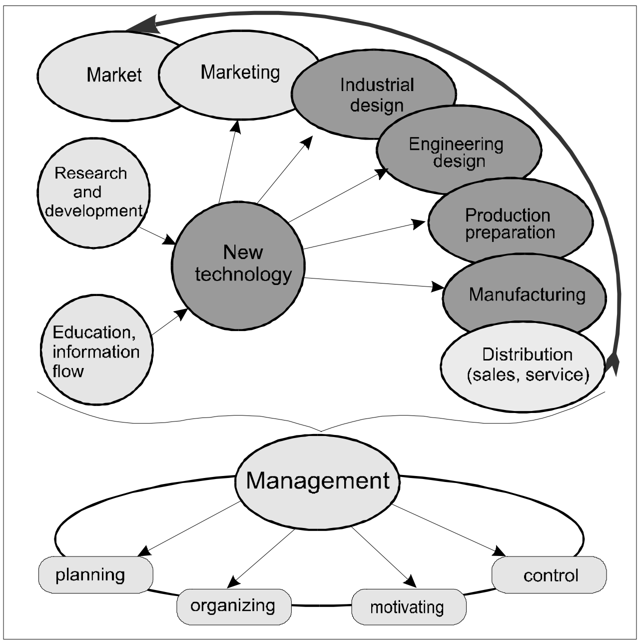

Fig. 2. Relations between factor connected with introducing a product to market

The first engineering design stage consists in conception development, connected with general specification of the available materials and processes. In the succeeding general project design stage, the shapes and approximate sizes of its elements are determined using the engineering analysis methods. The designer decides at this stage the general class of the materials to be used and type of the manufacturing process, e.g., selecting plastic forming or casting to make an element from the nonferrous metal alloys. Material properties should be defined more precisely at this time. At the detailed project design stage, material and the technological process are finally selected. One, appropriate material is chosen and only several variants of the technological process at the very most. It is connected simultaneously with making a decision pertaining dimensional tolerances, stress state optimisation, and with selection of the best manufacturing process, employing the quality engineering methodology and costs simulation. The designer should be well versed in detailed materials' properties, depending on the significance of the designed element.

The goal of that paper is to explain the very important role of materials selection in 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. In that context the future development of materials science and engineering is presented, as a very significant element connected with advanced design and manufacturing processes of those new products. My attitude on that subject matter was presented by me many times, as invited lectures on numerous world conferences and a few times was published in the form of papers and also as chapters in general books concerning materials science and engineering, however the creation of the World Academy of Materials and Manufacturing Engineering seems to be an appropriate occasion to recall those considerations as a conception important for the programme development of that new academy of sciences. That premise was fundamental for the presentation of such subject matter in that volume of that Journal[1].

2. Significance of materials design in the engineering design of products

Engineering design is connected with determining the shape of the product and its elements, the 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. 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. A change of a manufacturing process may change material properties, and some product-material combinations may be infeasible using some technological processes. Each manufacturing process is connected with the product shape range that may be made using that process. Shape is closely connected with the manufactured product, and its

[1] The full text of the Author's paper on that subject matter was published in the Journal of Materials Proccessing Technology, Vol. 174, 2006

Table 1.
Manufacturing processes used for various materials

Process	Material												
	Cast iron	Carbon steel	Alloy steel	Corrosion resistant steel	Al and Al alloys	Cu and Cu alloys	Zn and Zn alloys	Mg and Mg alloys	Ti and Ti alloys	Ni and Ni alloys	Refractories	Thermoplastics	Hardening plastics
Casting / shaping													
Sand casting	○	○	○	○	○	○	◑	○	◑	○	◑	●	●
Investment casting	◑	○	○	○	○	○	◑	◑	◑	○	◑	●	●
Pressure die casting	●	●	●	●	○	◑	○	○	●	●	●	●	●
Injection casting	●	●	●	●	●	●	●	●	●	●	●	○	◑
Engineering foams forming	●	●	●	●	●	●	●	●	●	●	●	○	●
Blow moulding	●	●	●	●	●	●	●	●	●	●	●	○	●
Injection moulding	●	●	●	●	●	●	●	●	●	●	●	○	●
Rotary swaging	●	●	●	●	●	●	●	●	●	●	●	○	●
Forging / forming of bars													
Blow extrusion	●	○	○	◑	○	○	○	◑	●	●	●	●	●
Cold upset forging	●	○	○	○	○	○	◑	◑	●	◑	●	●	●
Closed-die forging	●	○	○	○	○	○	●	○	○	◑	◑	●	●
Press moulding and sintering	●	○	○	○	○	○	●	○	◑	○	○	●	●
Hot extrusion	●	○	◑	◑	○	○	●	○	◑	◑	◑	●	●
Rotary swaging	●	○	○	○	○	◑	◑	○	●	○	○	●	●
Machining													
Machining from the semi-finished steel	○	○	○	○	○	○	○	○	◑	◑	◑	◑	◑
ECM – Electro-chemical machining	○	○	○	○	◑	◑	◑	◑	○	○	◑	●	●
Electromachining	●	○	○	○	○	○	◑	◑	◑	○	◑	●	●
Wire EDM – wire electrodischarge machining	●	○	○	○	○	○	◑	◑	◑	○	◑	○	●
Forming													
Sheet – metal forming	●	○	○	○	○	○	◑	◑	◑	◑	●	●	●
Thermoforming	●	●	●	●	●	●	●	●	●	●	●	○	●
Spinning	●	○	◑	○	○	○	○	◑	◑	◑	◑	●	●

Designation: ○ - standard practice ◑ - rarely used ● - N/A

complexity decides the feasible manufacturing process type. Increasing the product shape complexity limits the scope of processes that may be employed and increases costs. The main design principle is to ensure the simplest shape possible. One can back out that principle if a more complex shape makes it possible to join several elements or if it lets us eliminate even one stage in the manufacturing process only. The general goal of the actually employed technological processes is to make the net-shaped products that make immediate assembly possible, or - in case it is not feasible - the near-net-shape products requiring limited finishing - usually by machining - before installing them into the final product. It is not possible to make any element exactly, according to the dimensions assumed.

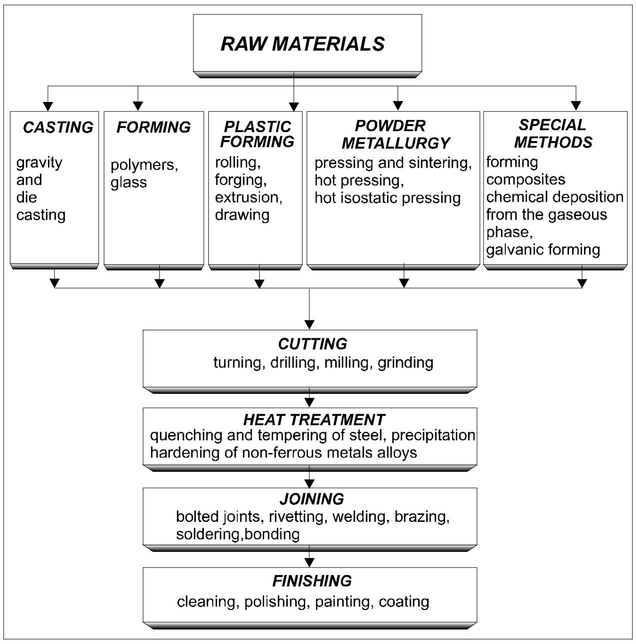

Fig. 3. Schematic diagram of manufacturing processes (prepared according to M.F. Ashby)

Selection of the product manufacturing processes, closely related to selection of materials for its elements, is a very important stage of the engineering design process. The main criterion for these selections is maximization of product quality with the simultaneous minimization of costs of its elements. Manufacturing processes may be grouped in nine classes (Fig. 3). The first row contains the initial forming processes, whereas the manufacturing processes put into the vertical column include the secondary forming processes and finishing. Designing the technological processes mostly at the development stage, and general engineering design stages, accounts for the main primary factors:

- material factors,
- shape factors,
- technological factors.

Selection of a material decides often selection of feasible manufacturing processes that may be used to make elements from the particular material. Various technological processes are given in table 1, used most often for various product groups.

Engineering design is a complex activity requiring taking into consideration many diversified elements (Fig. 4). Interrelations between the tasks that have to be accounted for are shown schematically in Figure 5.

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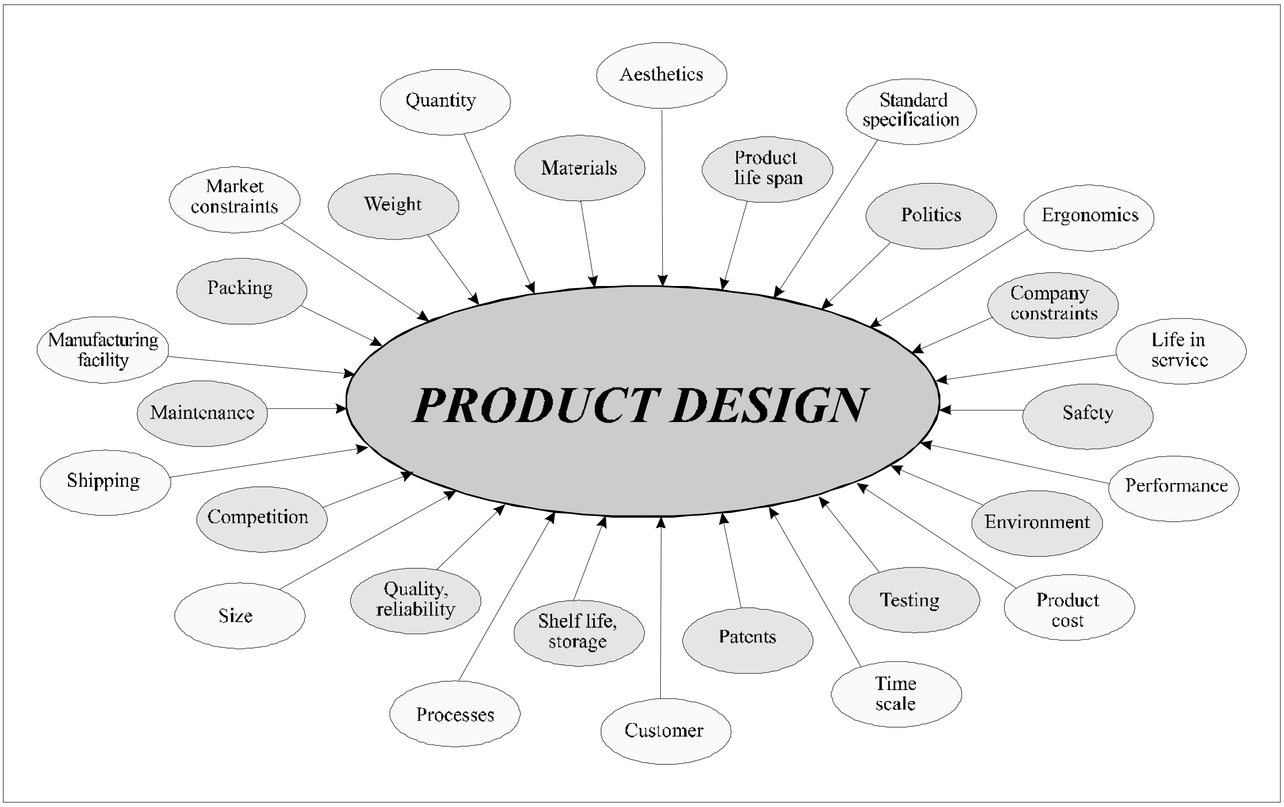

Fig. 4. Elements for consideration in a product design specification (prepared according to C. Nevay and G. Weaver)

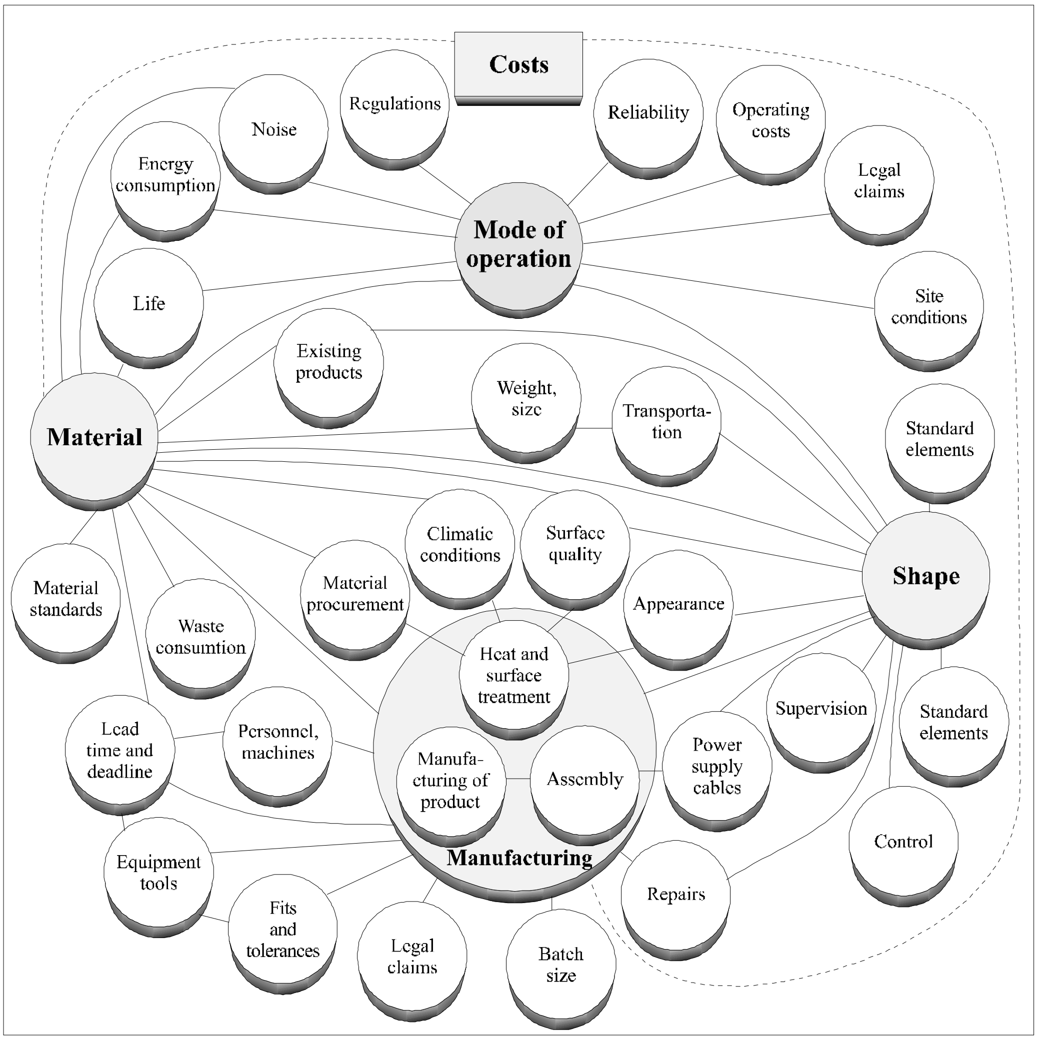

Fig. 5. Set up of tasks accounted for in engineering design and their interrelations

criterion for those selections is a maximisation of product quality with the simultaneous minimisation 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 material's performance and limited by its hardness, brittleness or plasticity, and melting temperature. Some materials are too brittle to be plastic formed; others are inapt to casting processes due to their excessive reactivity or low melting temperature. The possibility of using plastic forming is defined by loads required during forging or rolling, depending on plasticity. As cutting forces and temperatures of the machined material and tool during machining depend on hardness of the machined material, that feature decides the possibility of using machining in the manufacturing process. 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 Figure 6.

The vast majority of engineering materials are derived from raw materials obtained from the crust of the earth, raised in mines such as ores and then enriched to make possible their extraction or synthesis. Figure 7 illustrates the relation of strength and the specific energy consumption of materials (defined as the product of energy required to make the material, i.e., obtaining the raw materials, their refining, and shaping of the produced material, related to 1 kg of material, and its density). That coefficient expresses indirectly the influence of the material manufacturing process on degradation of the environment. The specific energy consumption shows linear dependence on material strength. The present situation 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 minimisation 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 a full use of energy saving recycling for their reuse and full recovery of materials in all possible and economically justified cases.

Figure 8 presents a general perspective on the life-cycle of engineering materials: a short manufacturing cycle links into a very long geological one within the Earth. Notice that the recycling of waste products offers a short-cut in the cycle.

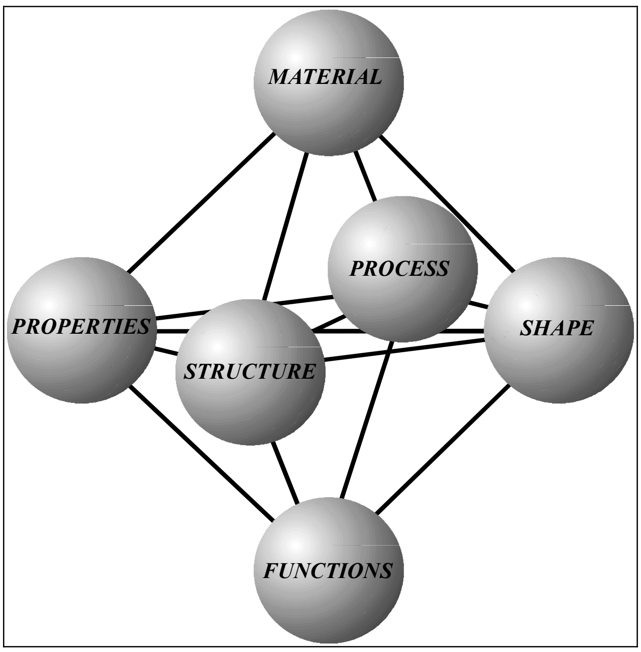

Fig. 6. Relationships among some factors connected with material, processes and functions of a product.

The character of ductility and fracture toughness changes for various groups of engineering materials (measured by the stress intensity factor) differ from changes of their strength Figure 9. That value is in a broad range from 0.01 to 100 MPa·m$^{1/2}$. The highest ductility is demonstrated by metals and their alloys. It seems that their common use is owed to the compromising merging of the highest possible ductility with the very high strength. Composite materials demonstrate similar properties. However, the definite brittleness of the engineering ceramics features a serious limitation for its use. Wood and polymers demonstrate the comparable brittleness. Ductility of the porous ceramics is up to 10 times lower.

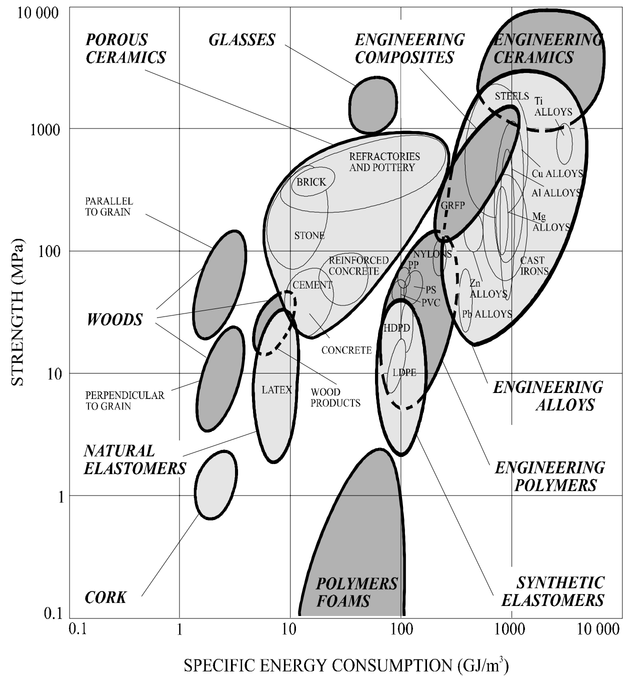

Fig. 7. Strength and specific energy consumption of various materials (prepared according to M.F. Ashby)

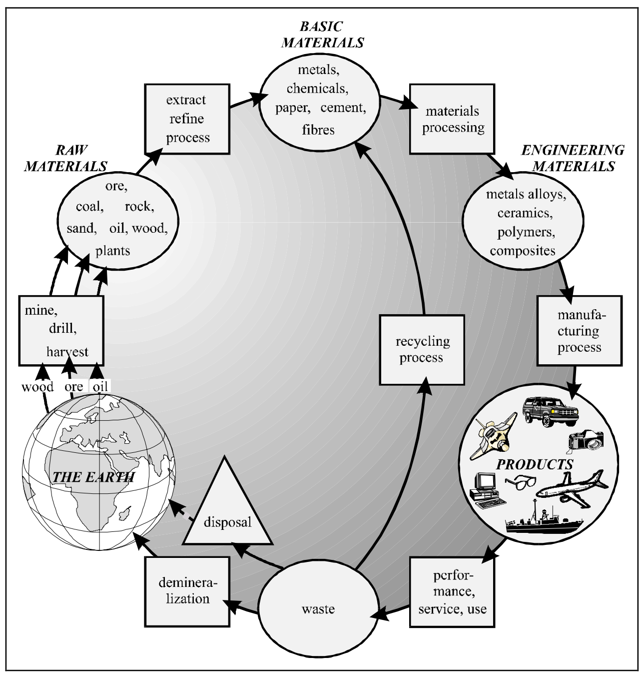

Fig. 8. Diagram of a technical life-cycle of the enginering materials (prepared according to C. Newey and E. Weaver)

All engineering materials are equivalent from the engineering design point of view, all that can guarantee the required products' properties and the multi-criterion optimisation features the basis for the materials selection with the best functional and technological properties, and with the lowest possible manufacturing, processing, and operation costs of the material and product. So, the problem posed is: „what can the product of interest to the customer on the market be made from?” and not: „what can be made from the material we have at hand or which we know?”

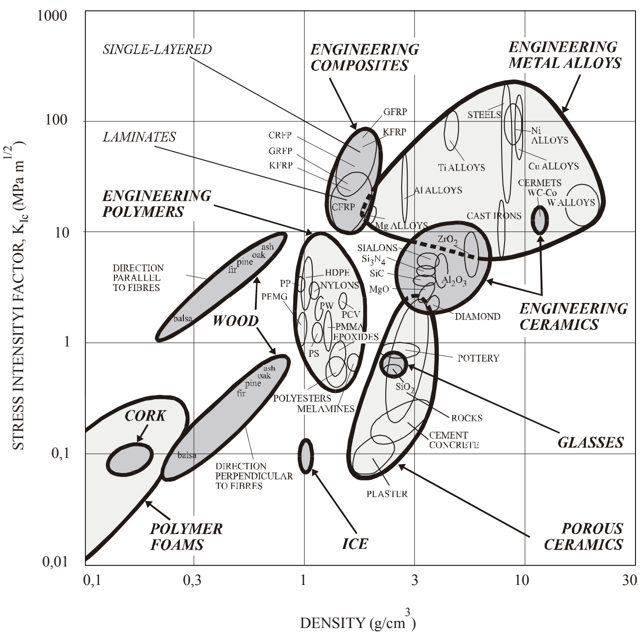

Fig. 9. Stress intensity factor and density of various materials (prepared according to M.F. Ashby)

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 50-100 engineering materials. Because of the significantly diversified conditions of a use of various products, and also their diversified design features, collecting many detailed information is required for proper material selection (tab. 2).

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 consists of more than 4,000,000 elements. As modern materials are worked out and deployed, they also become the substitutes for the ones being employed until now. As an example, materials developed and introduced for the space or aerospace technology may be mentioned, that are very often employed in other areas, including sport. Among many reasons for that attitude one may name the simplification of the design, extending the life and increasing reliability, making assembly and engineering easier, along with decreasing the material, manufacturing and operation costs.

Analysing the contemporary development trends of various material groups one can find out, which is evident, that the mass portion of the ultramodern products (like the aircraft and space technology products or even biomedical materials) in the total volume of products manufactured by people, albeit growing, is not big. Gaining widespread presence by polymers in our environment (which only seem to be ubiquitous) is neither possible so far, because of their relatively low abrasion resistance and other types of wear, and also because of their limited operation temperature range, which does not exceed 300÷400°C. Porous ceramics belongs to the building industry domain, albeit glass finds numerous applications in household and also in car production. Some brands of ceramics, especially of the glass type, are used even in machine design. Metals and their alloys are the main materials in machine design, automobile industry and shipbuilding, in machine-building, household consumer goods industry, tool industry and in many other ones, but they are also important in building industry, albeit in many cases engineering ceramics and also some composites compete with those materials.

The vision of the future and evaluate the development trends of various fields of activity and manufacturing processes basing on visions proposed by eminent bodies consisting of scientists and futurologists is connected with forecasts pertaining the development of various engineering materials. Nearly all of the forecasted projects will require the relevant manufacturing technologies and above all - relevant materials. Many of those materials are already available nowadays, some of them should be developed soon according to the outlined requirements. It is good to realise that many venturous projects will be made possible if those new materials are made. The future successes connected with the introduction of better and better products into the market, satisfying the needs of the steadily growing requirements of the societies, are connected closely with development and the implementation of new generations of the engineering materials which can be used for manufacturing those new expected 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 the outworking of the new compounds, structure, and ensuring the new properties.

3. Significance of contemporary development of materials science and engineering for of life’s conditions improvement

Contemporary interests of materials science and engineering may be reduced to issues presented in Table 3, taking into account lots of interdisciplinary factors. Knowledge and further investigation of many phenomena, among others, electrical,

Table 2.
Characteristics of materials

PHYSICAL PROPERTIES	MECHANICAL PROPERTIES	13. Ultimate tensile strength
1. Crystalline structure	1. Hardness	14. Vibration coefficient
2. Density	2. Modulus of elasticity	15. Friction properties
3. Melting temperature	• *Tension*	• *Friction corrosion*
		• *Abrasion*
4. Vapour pressure	• *Compression*	• *Erosion*
5. Viscosity	3. Poisson's ratio	16. Cavitation
6. Porosity	4. Stres strain curve	CHEMICAL PROPERTIES
7. Permeability	• *Tension*	1. Position in the elektrochemical series
8. Transparency	• *Compression*	2. Corrosion and degradation
9. Optical properties	• *Shear*	• *Atmosphere*
10. Dimensional stability	5. Strength	• *Sea water*
ELECTRICAL PROPERTIES	• *Tension*	• *Acids*
1. Conductivity	• *Compression*	• *Emission*
2. Specific inductive capacity	• *Bearing element*	• *Ultraviolet radiation*
3. Coercive force	6. Fatigue properties	3. Oxidation
4. Hysteresis	• *Roughness*	4. Thermal stability
NUCLEAR PROPERTIES	• *Notch*	5. Biological stability
1. Half-life period	• *Corrosion fatigue*	6. Stress corossion
2. Transverse section	• *Contact stresses*	7. Hydrogen embrittlement
3. Stability	• *Fretting corrosion*	8. Hydraulic resistance
THERMAL PROPERTIES	7. Chipping	TECHNOLOGICAL PROPERTIES
1. Conductivity	8. Ballistic action	1. Castability
2. Specific heat	9. Brittle fracture appearance transition temperature	2. Heat treatability
3. Coeficient of expansion	10. Fracture toughness (K_K)	3. Hardenability
4. Absorbtion coefficient	11. High-temperature behaviour	4. Deformability
5. Ablation coefficient	12. Creep	5. Machinability
6. Refractoriness		6. Weldability

magnetic, optical, mechanical, thermal, taking into account the mutual interactions among the external factors, material structure, and theory pertaining to the fundamentals of those phenomena, after using modern mathematical modelling methods, and also with using the artificial intelligence tools and other computer assistance methods along with the advanced analytical techniques and testing methods explaining materials' behaviour, especially in their nanometric and atomic scales, and in the exceptionally short time periods of femtoseconds (10^{-15} s) make it possible to adjust properties of materials, including nanomaterials, biomaterials and biomimetic materials to requirements posed by their practical use.

The introduction of the new generations of materials and the propagation of products with the expected properties that can be made from those materials, calls for coming to know the materials behaviour, as substances for manufacturing the new products, from their atomic/nanostructure scale, through their microstructure, up to the macroscopic one, using the advanced analytical methods and computer modelling. That strategy calls for the improvement of the conventional materials manufactured and used on a large scale, like steel or the non-ferrous metals alloys, and also of the new functional materials used in smaller and smaller smart devices.

Employing the fundamental principles of physics and chemistry pertaining to the state and properties of the condensed matter, the theory of materials is used for modelling the structure and properties of the functional real materials, and for designing and forecasting the new materials and devices with the improved practical usability. The modern theory of materials science and modelling specific for the computational materials science, are used for the development of new materials. The introduction of new materials and the improvement of the properties of materials manufactured to date call also for working out and implementing the new synthesis and processing methods.

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.

Therefore, materials science and engineering play a key role in establishing and upgrading the economical conditions of quality of living, especially in the spheres chosen as priority ones in the world development for the forthcoming decades of the 21st century Table 4. The main directions of activities assumed or continued in the area of materials science and engineering, which results, as it is judged now, will have the most important effect on reaching the goals connected with the development of societies in the coming decades of the 21st century are given in Table 5. 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 -

Table 3.
Area of interest of materials science and materials engineering (according to Ruehle, M., Dosch, H., Mittemeijer, E.J., Van de Voorde, M.H.)

Range of topic	Goals to pursue and methods of action
Synthesis and processing of materials	The arrangement of atoms and constituents in a bigger scale in materials into systems with the required configuration
Chemical composition and microstructure of materials	The assessment of the chemical composition effect and microstructure on materials' behaviour
Phenomena and properties of materials	The investigation of mechanisms active in materials during the technological processes and operation for explaining the phenomena and their effect on materials' properties
Behaviour of materials in operating conditions	The assessment of the usefulness of materials for various applications
Materials design and prediction their durability and/or life	Predictionthe chemical composition, properties, and durability of materials in their working conditions using the theoretical methods and with computer assistance, including the artificial intelligence methods

Table 4.
Tasks of materials science and engineering in priority spheres of the world development in the next decades (according to Ruehle, M., Dosch, H., Mittemeijer, E.J., Van de Voorde, M.H.)

Priority development sphere	Strategic goal	Role of materials science and engineering
Improvement of conditions of living	More efficient use of materials and energy sources is required urgently because of hazards to the environment.	The participation in the development of new energy generation technologies, more energy-efficient devices and less toxic materials and better suited to recycling.
Health care system	The development of novel diagnostic and therapeutic methods, as well as new devices, apparatus and drugs is required, because of the need to overcome and prevent diseases, to limit the scope and consequences of disability and because of the concern for the improvement of the health state in the whole world.	The development and the introduction of novel materials, including those for the development of artificial bones, implants, and artificial organs, safe administration of drugs, water filtration systems, as well as of the therapeutic and diagnostic equipment.
Communication and information transmission	The development of new generations of tele-communication and IT devices, as well as fully miniaturised computers along with all peripheral devices, due to the need of increasing the speed and reliability of connection network in the world.	Determining the progress in the IT and computer revolution, as well as introducing the new electronic, optic, and magnetic materials.
Consumer goods	Intensive efforts to obtain the expected state are required because of the customers' expectation for the fast delivery of consumer goods with the very high quality and reliability, at the possibly lowest, justified, and acceptable prices, delivered regardless of the manufacturing location in the world, and also of the high quality and effective services.	The development and the introduction of materials that will make it possible to improve the quality and usefulness of products, as well as ways of their delivery (e.g., packing) which will result in speeding and facilitating of their manufacturing, and cutting short delivery of consumer goods with the best properties.
Transport	Co-ordinated actions are needed, connected with increasing the speed, safety, and comfort of transport means, because of the need to improve travel conditions in connection with business projects, rest, and the Earth and the space exploration.	The development and the introduction, among others, of the lightweight car bodies and accessories made from, e.g., aluminium and magnesium alloys, as well as from composite materials, brake systems for the high-speed trains, airplanes emitting much less noise, insulation coatings for space shuttles, and many other technical solutions guaranteeing reaching the assumed goals.

dependent on the development of the engineering materials, making it possible to use them in engineering design of many new products expected on the market.

The appropriate selection of material for the particular application, based on the multi-criterion optimisation taking into account its chemical composition, manufacturing conditions,

Table 5.
Main directions of activities in materials science and engineering for achieving the strategic aims of the development of societies (according to Ruehle, M., Dosch, H., Mittemeijer, E.J., Van de Voorde, M.H)

Main directions of activity	Evaluation of the current situation and plans for future
Materials design	The subject of the contemporary materials science and engineering is adjustment of materials, beginning from their chemical composition, constituent phases and microstructure, up to the set of properties required for the particular application. The traditional empirical methods of introducing the new materials will be supplemented to a growing extent by the theoretical predictions in the not so distant future. Computer simulation is employed in certain cases in the commercial scale, and the development of computer tools is expected for the evaluation of materials properties in their virtual environment. It will make it possible to improve those properties, as well as their prediction - even before manufacturing of materials, with the significant reduction of expenditures and time required for their investigation and implementation.
Computational materials science	A significant progress has been made in the last decade in the area of simulation of properties and the processing of engineering materials; however, computer modelling will become the indispensable tool in materials science and engineering soon. The computer strategy provides the description of materials from the chemical and physical points of view in a broad scale of both dimension and time, and the multi-scale modelling makes using the consistent simulation structure possible within the entire range of those scales or in their prevailing parts.
Advanced analytical techniques	The development of new engineering materials in future and thediscovery of new phenomena deciding their properties call for the development, the introduction, and the dissemination of the new and more efficient research techniques making examination of materials possible in the atomic scale, like the high resolution transmission electron microscopy, scanning probe microscopy, X-ray and neutron diffraction, as well as various types of spectroscopy, integrated with the more powerful computers, making the fast visualisation possible and the comparison with computer models, including also their use in the manufacturing (synthesis) processes, where they can be employed for control and manipulating the materials in the atomic and nanocrystalline scales, as well as in the atomic force microscopy.
Synthesis and processing	The goal of the manufacturing and processing techniques of the future is to design the engineering materials from the complex arrangements of atoms and particles, with the same accuracy and control as is currently used to the semiconductor materials, and including, e.g., the chemical conversion from the simple precursor units, fast prototyping of the ceramic and metal components using the streaming technique, microwave sintering, deposition methods from gas phases (CVD, PVD) to form the thin films, infiltration of composites, to the most promising techniques.
Nanomaterials	The capacity to control, synthesise and design materials in the nanometric scale (10^{-9} m) features one of the main progress directions to use those materials for the development of their new applications, scrap and waste reduction, as well as for optimisation of properties in all main engineering material groups , including, e.g., high-precision drug administration systems, nanorobots, in micro-manufacturing, nanoelectronics, ultra-selective molecular screens, and nanocomposites for employment in airplanes and other vehicles.
Smart materials	Smart materials, different from other materials are designed in such a way that they react to the external stimuli and improve their properties, adapting themselves to the environmental conditions, increasing their life, saving energy, or modifying the conditions to improve human comfort, and also autonomously multiplicating themselves, repairing or damaging - as needed, reducing waste and increasing efficiency; all work in that area is considered especially vanguard in its character.
Biomimetic materials	Thanks to a better understanding of the development of minerals and composites by the live organisms, biomimetic materials become the fast developing area of materials engineering, enabling to copy the biological processes and materials, both organic and inorganic ones (e.g. synthetic spider's thread, DNA chips, crystal growth within the virus crates) and are manufactured more and more accurately and efficiently, due to which their usefulness improves and new possibilities of their use become apparent (e.g., self-repair feature, ultra-hard and ultra-light composites for airplanes), which calls for the new chemical strategy Bering the self-organisation with their capability to from the hierarchically built materials.

synthesis conditions, operating conditions, and the material waste disposal method in its after-service phase, as well as the price-dependant issues connected with obtaining the material, its transforming into a product, the product itself, and also costs of the disposal of the industrial waste and scrap, as well as the modelling of all processes and properties connected with materials, feature the fundamentals of the dynamically developing computational materials science. Various models are employed in computational materials science, depending on scale and also possibilities of using the engineering materials modelling, their synthesis, structure, properties, and phenomena. 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. An essential determinant of the manufacturing processes' development, giving consideration to economical and ecological conditions, at the threshold of the 21st century, is an integration in the area of advanced design and manufacturing of the up-to-date products and consumer goods, deciding the improvement of the quality of life and welfare of societies, which encompasses the development of design methodology and connected with it newer and newer designs developed using the computer aided design methods (CAD), the development of new technologies and manufacturing processes, of technology design methodology, contemporary production organisation, operational management and quality driven management along with the computer aided manufacturing (CAM), and also the development of materials engineering methodology, the development of entirely new engineering materials with the required better and better functional properties, with the pro-ecological values and minimised energy consumption along with the development of the computer based materials science and methodology of computer aided materials design (CAMD).

4. Conclusions

Giving people access to products and consumer goods deciding directly the level and the quality of living, the information interchange, the education level, the quality and the potential of health service and many other aspects of the environment in which we live, features the profoundly humanistic mission awaiting the engineers' circles, in which the materials issues play an important role and thus decide directly possibilities of the development of societies.

The strategic importance of engineering materials for the future development of civilisation poses essential requirements in that area, and the cooperation with the specialists of other branches in order to achieve synergic effects and the short half-obsolescence period of knowledge in materials science, materials engineering and materials processing technology areas call for methodical and dynamical studies as well as research and development activities, along with the coordinated and systematic efforts for upgrading the general knowledge level of the engineering cadres of various special fields for fast transfer of that knowledge to the product engineering design practice and their spheres of their manufacturing and use. One can indicate to the basic determinants connected with those areas of science and technology, indispensable for attaining the expected improvement of life quality of the contemporary societies.

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