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# Research, Development and Technology Transfer (R & D & TT) in the Field of Engineering Materials and Related Technologies

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## 1. Introduction

The proper choice of engineering material and manufacturing process appropriate for a specific industrial application is most often based on an engineer's experience and on the recommendation of product supplier. This is why the choice is mostly identical with the same material or process which has been used obviously before. But nowadays, this approach in modern life style works only rarely, because it has usually several serious drawbacks. Two engineers setting the same problem may not arrive to the same conclusion. The choices are therefore extremely dependent on individual`s knowledge and the producer can only hard show to customer the quantitative reasoning behind them. Moreover, these approaches considerably inhibit innovations – they do not systematically explore all possibilities that could deliver better results.

Real decisions on proper choice of engineering material and appropriate manufacturing process have much broader objectives, e.g. to minimize cost or the "cost per unit of function". But besides this so called "financial cost", the same principles for selection can be applied also to "environmental costs" such as energy or $CO_2$ footprint. This "eco-design" is another, at present increasingly significant, area in which only an integrated materials strategy provides benefits.

This novel approach to understanding of the world of engineering materials has been outlined recently. The method develops both an understanding of material properties and skills in selecting materials and process to meet design specifications. Nowadays this approach is strongly supported by extensive computer-based methods and tools in order to help engineering students much better understand the "world" of materials, because engineers obviously make things, and they make them of engineering materials. Materials property data are therefore essential to a wide range of people and functions in engineering enterprises – not only engineers and designers needing the right property data for engineering simulations, but also buyers aiming for optimal purchasing decisions and, of course, also managers concerned with regulatory compliance. Information on materials properties is also of fundamental interest to the materials engineers, quality assurance, testing personnel and others who generate, control and supply it (Marsden, Warde & Fairfull, 2007).

## 2. New approach to materials research and education

The research, development and education in the field of engineering materials is today still strongly affected by its more recent history, in which the physicist played a great role. The physicist's point of view leads us to concepts of atomic bonding, geometry of molecular and crystal structures, crystal defects, alloy theory and phase stability, kinetics of phase transformations, mechanisms of plasticity and fracture and so on, gradually moving up through the length-scales from the atomistic through the microstructure to the macroscopic.

This concept is the foundation on which the subject rests and for that reason there is an averseness to approach it in other ways. But it is a path that creates one serious difficulty: the most important information the engineer really needs to perform his or her role as a maker of things comes only at the end or not at all. Nevertheless, there are powerful arguments for the teaching of this scientific method, like the rigour, the ability to apply logical thought and reasoned experimentation to physical problems in the broadest sense. The subject of materials is, of course, very broad, drawing together understanding from physics, chemistry, mathematics, computer science, etc. That is why the material science is more or less an applied science, because development and applying of materials bridges these "pure" scientific disciplines.

There is an alternative approach developed over the last 20 years by Prof. Ashby and his colleagues from University of Cambridge (Ashby & Cebon, 2002). It is based on the other extreme: the satellite view of "Planet Materials" – its occupied continents and its empty oceans - giving, from the start, some ability to navigate in this new virtual world of engineering materials (Fig. 1). It is then possible to focus in progressively, exposing a gradually increasing level of detail. The main aim of this approach is by no means to reject the fundamentals underpinning of physics and chemistry, but these can be developed as the details requiring them come into focus. The essential motivation for this helpful concept is to give the engineering students tools that they can immediately start to use in their role as engineers or designers. This "thinking behind the approach" makes maximum use of computer-assisted methods that further stimulate engagement of student and support project work that can be set by the teacher or self-generated by the student.

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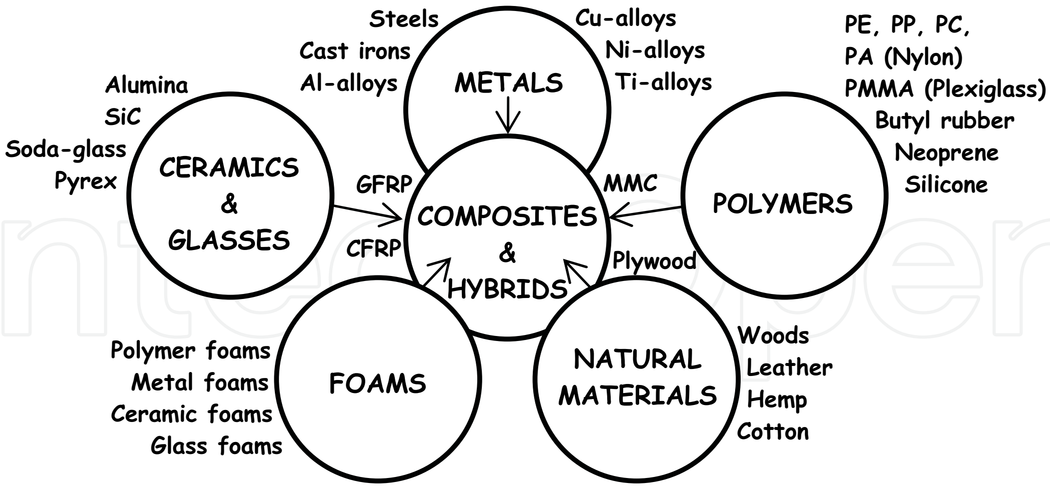

Fig. 1. The virtual world of engineering materials (Ashby & Cebon, 2002).

The "world" of engineering materials (Fig. 1) shows the "families", like: polymers, metals, ceramics, glasses, natural materials, and composites and hybrides that can be synthesised by combining these. Each family embraces classes, sub-classes and members. Every member is characterised by a set of attributes - its "property profile". This structure has the merit that it is easily understood and allows a helpful concept: that of the "material property chart", of which Figure 2 is a simple example. It is a map of one slice through material-property space. It plots stiffness, measured by Young's modulus, against weight, measured by density. It is one of a set, mapping the territory occupied by each family and the spaces in between. The bold balloons enclose the members of the families: metals, polymers, ceramics, foams and so on. Within each of them are the classes; if the resolution were sufficient, the members would come into focus.

Student interest is stimulated by encouragement to use these to explore the materials world. For engineering students it is very stimulating to use modern advisable software – so called Cambridge Engineering Selector (CES) to create charts with any desired combination of properties, giving the ability to zoom in on any selected part to increase resolution, and to access records for the attributes of individual materials.

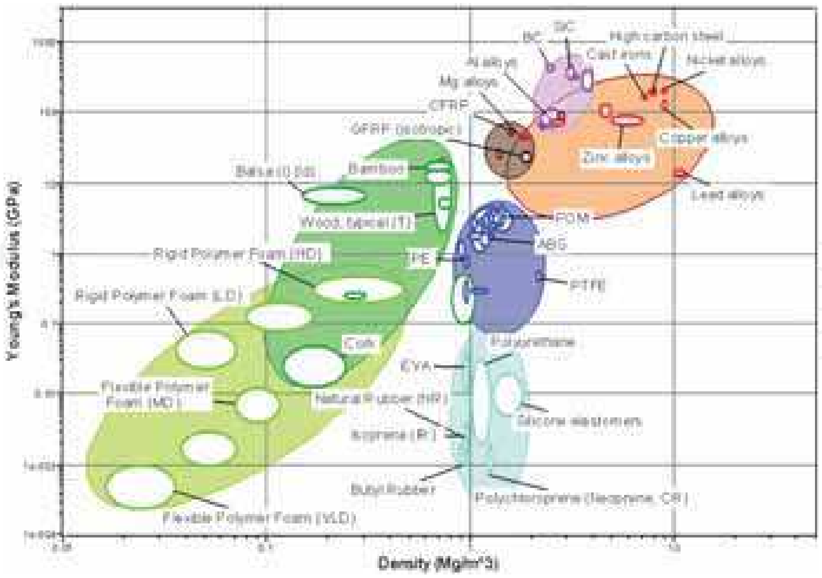

Fig. 2. The material property chart illustrated relationship between Young's modulus and Density for engineering materials created using the CES software with the Level 1 database (Ashby & Cebon, 2002).

The first level of CES software contains limited data for 80 of the most widely used engineering materials, selected from the six basic families described in Fig. 1. Each material record of CES starts with a brief description of the material illustrated with an image of a familiar product in which it is typically used, continuous by numeric data for the most basic mechanical, thermal, electrical and other physical properties and ends with a list of common material applications. Moreover, there are also manufacturing processes for shaping, joining and finishing treated in a similar, very simple way: a brief description is followed by a schematic illustrating how the process works and a brief list of attributes and industrial applications. The first level of CES allows engineering student to explore materials and processes without being overmastered by details, which are for him or her by that time fairly "non-essential". The further – second level retains this same format expanding the range of attributes for which data are listed and adding information on design, technical details and possible environmental concerns. This allows using more ambitious exercises and projects during education of expectant engineers, but still without smothering them with information. The final – third level develops this approach still further, providing a tool with which the sufficiently skilled engineers and designers are after graduation of both previous levels already familiar, but now they are capable of professional exercises and projects aimed to selection of proper engineering material and manufacturing process for real industrial application. It is possible to use at present roughly 3,700 engineering materials and 240 related processes for this purpose by means of this unique approach.

## 3. The engineering materials of nearest future

### 3.1 Developmental trends in the field of material science

The advanced technologies for utilizing energy sources with higher efficiency and for manufacturing of innovative industrial products with both higher functionality and environmentally friendly "eco-design", are based mainly on the research and development (R&D) of new engineering materials. The high-powered accumulation of results based on a long-term perspective and stable research environment is unavoidable for extensive development of material science. Thus, as one of the most important effort of each state with the ambition to be economically prosperous, it is extremely important to gain wide public understanding and achieve steady progress in this research field.

Material science, unlike culture or art, is the typical example of practical science. Its purpose is exclusively to be put to real use and therefore it has been used as a method, which is able to immobilize the framework of society based on the outworn ways of thinking. From global point of view the main mission of material science is efficient development of convenient materials desired by society in response to social needs. It has played a significant role in supplying products of steel, concrete, aluminium, polymers, semiconductors and various other engineering materials that society needs. However, there are many confirmations that besides this mission, the material science has a strong sense of being used to get a better understanding of the principles of natural phenomena.

The material science is at present steadily more or less the practical science, not to make the framework of society more rigid, but to appeal its existence to each other in various separated scientific fields. A lot of attention is being given nowadays to advanced material technologies with high potential to be applied soon in the industrial praxis and mainly to material science fields that have high productivity. The fact of this matter is that human being is always pushing ahead with R&D that is narrow, deep, separate and especially so short-termed as possible (Shinohara, 2008).

But unfortunately, it seems the time is coming when mankind becomes aware that present environmental and energy problems are inseparable part of the growth of material science. The approaches to practical material science should then be also revised. We need even now to return to basics – to pursuit the principles of natural phenomena, rebuild material science in an inter-connected manner, discover the best solutions of problems and establish a new kind of modern material science that is not captive to specific fields of materials or practical science.

Some of the most perspective fields of future material science are therefore shortly introduced in several next chapters.

### 3.2 Metallic glasses

Offering some of the highest specific strength and resilience values known among bulk materials, the amorphous metallic materials, more commonly termed metallic glasses, have the large potential to revolutionize the field of material science and engineering. The next decades will surely bring exciting advantages of this material class, as just now is the humankind on the threshold of exploiting new opportunities for their microstructural design, opening up much broader application of the fascinating materials formed from metallic glasses.

The term "glass" means in scientific terminology any material that can be cooled from a liquid to a solid without crystallizing. Most metals do crystallize as they cool, arranging their atoms into a highly regular spatial pattern called a lattice. But if crystallization does not occur and the atoms settle into a nearly random arrangement, the final form is a metallic glass. Through effectively probing the fundamental mechanism responsible for deformation in metallic glasses nanoindentation has the potential to provide the answers necessary for their industrial applications.

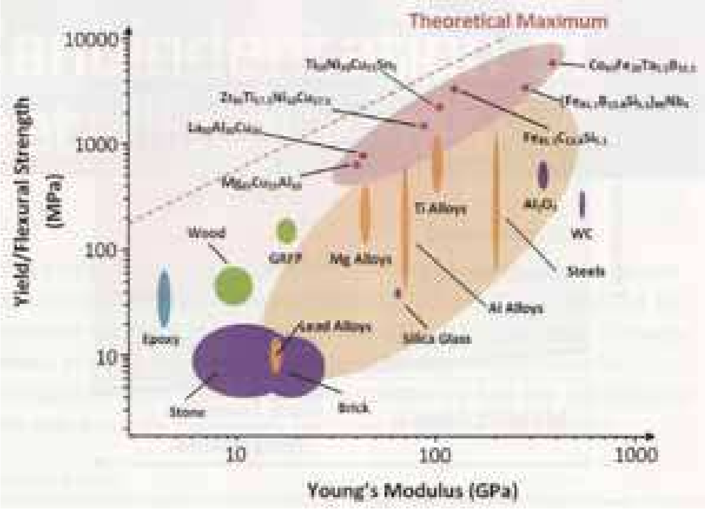

Fig. 3. The yield (metals, composites and polymers) or flexural strength (ceramics) as a function of Young`s modulus. Diagram shows strength of metallic glasses (light red) over conventional crystalline metals (light orange) (Ashby & Greer, 2006).

Metallic glasses exhibit mechanical and physical properties representative of a completely new paradigm in material science, because their structure lacks the dislocations and grain boundaries, which are inherent in crystalline materials. The elastic strain may regularly approach about 2% without of premature deformation of slip, thereby facilitating strength and hardness values which are far beyond those of crystalline metals (Fig. 3). In the work representing the highest strength, specific strength and specific Young`s modulus of any bulk metal, it has been found (Inoue et al., 2003) a fracture strength of 5 085 GPa and Young`s modulus of 268 GPa for $Co_{43}Fe_{20}Ta_{5.5}B_{31.5}$ alloy. Besides these extremely advisable mechanical properties, metallic glasses exhibit extremely high values of toughness, low mechanical damping, good corrosion resistance and high magnetic permeability coupled with low coercivity to give superior soft magnetic properties. However, recently discovered advances have allowed more amenable geometries needed for generating various novel metallic glass products. The particularly intriguing possibilities of relatively low temperature superplastic forming operations are up to now insufficiently exploited. Tensile specimens following superplastic forming in the supercooled liquid region are able to withstand the elongation of 1 600% at $Zr_{41.25}Ti_{13.75}Cu_{12.5}Ni_{10}Be_{22.5}$ alloy (Wang et al. 2005 – Fig. 4) and even over 20 000% at $La_{55}Al_{25}Ni_{20}$ one (Nieh et al., 2006). The high-quality golf club heads, baseball bats and tennis racquets have benefited from significantly enhanced elasticity, while high strength and hardness can be utilized for production of medical and aerospace coating applications. The absence of crystallization during casting process in conjunction with high melt density ensure low casting shape fidelity which is the not only advisable factor for any thermomechanical forming operation but in particular relevance in the production of various micro electromechanical systems.

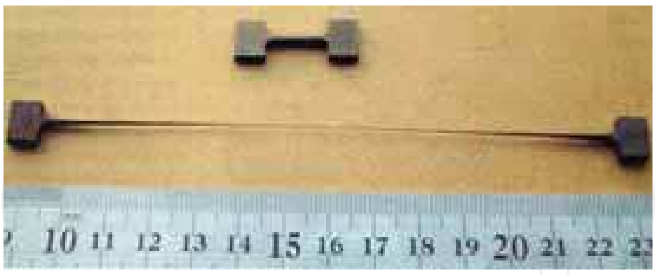

Fig. 4. Tensile specimen made of Zr41.25Ti13.75Cu12.5Ni10Be22.5 alloy following superplastic forming in the supercooled liquid region (Wang et al., 2005).

Recent observations has emphasized that densest packing which is the typical for monatomic metallic glasses is a key factor governing their structure and properties. But dense packing, even when non-crystalline, is certainly not random. The chemical interactions between the elements in alloys are very important. Glass-forming ability is enhanced when the elements of an alloy have a negative heat of reaction (i.e. in a system such as nickel-boron, Ni-B bonds are preferred in comparison with Ni-Ni or B-B bonds). The relevance of such chemical effects emerged in many structural studies of metallic glasses such as $Ni_{81}B_{19}$ that there are no B-B nearest neighbours.

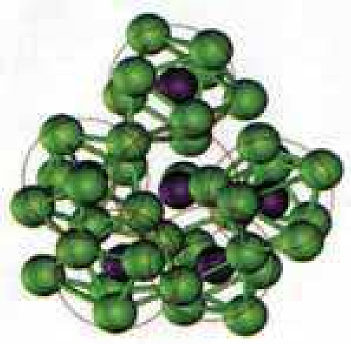

Fig. 5. Structure of $Ni_{81}B_{19}$ metallic glass showing quasi-equivalent solute-centered clusters (Greer, 2009).

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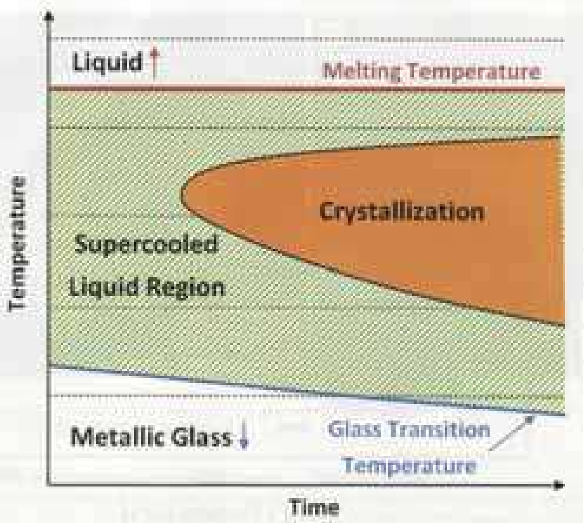

Fig. 6. Schematic time – temperature transformation diagram for metallic glasses. Crystallization rate is determined by the competing effects of undercooling and reaction kinetics. The supercooled liquid region exists between the melting and glass transition temperatures over time periods not exceeding that required for crystal nucleation. (Burgess & Ferry, 2009).

Many criteria have been proposed for selection of alloy compositions that would favour glass formation, but none of them shows universal advisability. The crystallization of melt during cooling becomes thermodynamically possible below the liquidus temperature $T_l$ and is kinetically hindered below the glass-transition temperature $T_g$ (Fig. 6). Glass formation is most likely when the gap between $T_l$ and $T_g$ is minimized and is indicated by a high value of the reduced glass-transition temperature $T_{rg}= T_g / T_l$. The higher values of $T_{rg}$ are associated with lower critical cooling rates for glass formation. As $T_g$ appears to be independent on composition, high values of $T_{rg}$ are indicated by depressions of $T_l$ and indeed glass-forming ability is particularly good at deep eutectics which are more likely to be found in multicomponent systems. As the critical cooling rate for glass formation is reduced, an amorphous structure can be made in thicker sections, commonly represented by the maximum diameter of cylinder that can be cast into a fully glassy form. The compositions for which the critical diameter exceeds 10 mm are considered to form so called bulk metallic glasses (BMGs). The history of their recent development is shown in the Table 1.

From technological point of view it is extremely important that metallic glasses show viscous flow at elevated temperatures. The ability to use various hot-forming processes obviously used for conventional glasses and for thermoplastic polymers is very advantageous, especially when combined with the high strengths obtained on cooling. Most BMGs are in liquid state too strong for good thermoplastic properties, but strategies are beginning to emerge to design alloys that can be easily cast into glasses, yet are comparatively fragile and therefore easily shaped (e.g. BMG with the composition $Zr_{35}Ti_{30}Cu_{8.25}Be_{26.75}$ thanks to a record large interval of 159 K between the glass-transition and the crystallization temperature shows exceptionally good thermoplastic workability).

The first demonstration that glass formation could be achieved for metallic liquid was made in 1959 in laboratory of California Institute of Technology (CalTech) by Prof. Pol Duwez and up to now, this institute is leading force in the research, development and commercialization of metallic glasses. Their so called Liquidmetal® Technologies controls the intellectual property rights with more than 20 patents on the composition, processing and usage of technology related to these high performance materials and products revolutionizing the materials world.

The first material revolution occurred in the 1800's, when Sir Henry Bessemer of England invented a process to mass-produce steel inexpensively. Cheaper steel was crucial to the modern industrial revolution. Construction of factories, automobiles, railroads, bridges and high-rise buildings was made possible by the availability of steel. During the 1900's, chemists invented thermo-plastics, which dramatically reduced the cost of manufacturing by using one mold for thousands of parts and thereby revolutionized industrial production for the second time. In this 21st century, scientists at Caltech develop a unique Liquidmetal® Technologies described in this chapter. While the Bessemer Process and thermo-plastics technology dramatically improved the cost paradigm of their day, BMGs with the trademark Liquidmetal® are in the nearest feature able to redefine the cost and performance paradigm simultaneously. Their superior properties are obtained by recent revolutionary scientific and technological innovations.

| **Base metal** | **Composition (atomic %)** | **Critical diameter (mm)** | **Year** |
|---|---|---|---|
| Pd | $Pd_{40}Ni_{40}P_{20}$ | 10 | 1984 |
| | $Pd_{40}Cu_{30}Ni_{10}P_{20}$ | 72 | 1997 |
| Zr | $Zr_{65}Al_{7.5}Ni_{10}Cu1_{7.5}$ | 16 | 1993 |
| | $Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5}$ | 25 | 1996 |
| Cu | $Cu_{46}Zr_{42}Al_7Y_5$ | 10 | 2004 |
| | $Cu_{49}Hf_{42}Al_9$ | 10 | 2006 |
| rare earth | $Y_{36}Sc_{20}Al_{24}Co_{20}$ | 25 | 2003 |
| | $La_{62}Al_{15.7}Cu_{11.15}Ni_{11.15}$ | 11 | 2003 |
| Mg | $Mg_{54}Cu_{26.5}Ag_{8.5}Gd_{11}$ | 25 | 2005 |
| | $Mg_{65}Cu_{7.5}Ni_{7.5}Zn_5Ag_5Y_5Gd_5$ | 14 | 2005 |
| Fe | $Fe_{48}Cr_{15}Mo_{14}Er_2C_{15}B_6$ | 12 | 2004 |
| | $(Fe_{44.3}Cr_5Co_5Mo_{12.8}Mn_{11.2}C_{15.8}B_{5.9})_{98.5}Y_{1.5}$ | 12 | 2004 |
| | $Fe_{41}Co_7Cr_{15}Mo_{14}C_{15}B_6Y_2$ | 16 | 2005 |
| Co | $Co_{48}Cr_{15}Mo_{14}Er_2C_{15}B_6$ | 10 | 2006 |
| Ti | $Ti_{40}Zr_{25}Cu_{12}Ni_3Be_{20}$ | 14 | 2005 |
| Ca | $Ca_{65}Mg_{15}Zn_{20}$ | 15 | 2004 |
| Pt | $Pt_{42.5}Cu_{27}Ni_{9.5}P_{21}$ | 20 | 2004 |

Table 1. Representative bulk metallic glass composition with the critical largest diameter of cylinders that can be cast fully glassy and the year of first report (Greer, 2009).

### 3.3 Lightweight structural materials

The main role of structural materials is to have the ability to support a large load safety. The resistance to plastic deformation is the yield stress and the one to fracture is the tensile strength. As the yield stress and the tensile strength increase, a load that a material can support increases. Therefore, if materials show a constant yield stress, the weight of the structural components that support a given load can be decreased when the density of material is small. This index (yield stress/density) is referred as specific strength.

Metallic materials that have a lower density than steel, which is the most highly used structural material, are generally called light metals or lightweight structural materials.
Table 2 shows the physical properties of most frequently used structural metals. The density and the Young`s modulus are properties that depend only on the chemical composition. However, the yield stress and the tensile strength are the structural sensitive properties, which depend also on the metallic crystal microstructure.

| **Metal** | **Density (1000 · kg/m$^3$)** | **Young`s Modulus (GPa)** | **Melting point (°C)** |
|---|---|---|---|
| Iron (Fe) | 7.87 | 210 | 1536 |
| Titanium (Ti) | 4.54 | 115 | 1666 |
| Aluminium (Al) | 2.69 | 70 | 660 |
| Magnesium (Mg) | 1.74 | 45 | 650 |

Table 2. Physical properties of structural metals (Tsuzaki, 2008).

The yield stress of steel can be increased by control of microstructure even up to over 800 MPa. Table 3 shows mechanical properties of structural metals, which includes steels with a yield stress over 1400 MPa and aluminium (A7075) over 500 MPa. These materials exceed the specific strength of 150 MNm/kg and they can be therefore both classified as a lightweight structural materials that are more than 10-times lighter than industrial pure iron with the specific strength of only 12 MNm/kg.

| **Material** | **Yield stress (MPa)** | **Elongation (%)** |
|---|---|---|
| Iron – industrial pure | 98 | 60 |
| High tensile strength steel (HT80) | 834 | 26 |
| Ni-Cr-Mo steel (SNCM439) | 1471 | 8 |
| Ti – industrial pure | 170 | 27 |
| Ti-6Al-4V alloy | 920 | 14 |
| Al – industrial pure | 15 | 30 |
| Al-Cu-Mg alloy (Duralumin) | 195 | 15 |
| Al-Zn-Mg alloy (Extra Super Duralumin) | 505 | 11 |
| Cast Mg alloy | 70 | 7 |
| Wrought Mg alloy | 160 | 6 |

Table 3. Mechanical properties of structural metals (Tsuzaki, 2008).

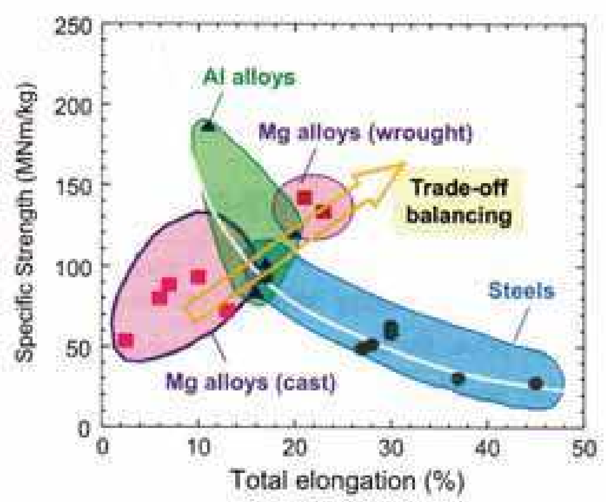

Fig. 7. Relationship between total elongation and specific strength (Tsuzaki, 2008).

The main application potential of lightweight structural materials is mainly in industries such as automotive, aircraft and space industries, shipbuilding, etc., where they are utilized with the aim to reduce the weight of vehicles. But numerous material related problems arise when we intend to save the weight by employing the lightweight materials with high specific strength. The first problem area is of course the cost. Titanium alloys are typical lightweight metals with superior characteristics, but seldom to be applied in vehicles because of their high cost. The expensive titanium alloys are even in the aircraft field employed mainly to military planes. The second problem is deterioration of formability. The elongation decreases as the yield stress or the specific strength increases. Various lightweight components are produced using a plastic deformation called press forming and therefore the increasing of elongation is being demanded despite their high strength. As shown in Fig. 7., this is a challenging issue to be overcome. The control of microstructure using nanotechnology is being carried out for this type of scientific encounter. Nevertheless, for the processing of lightweight high strength materials many other problems remain in such areas, e.g. machinability or weldability.

### 3.4 Nanostructural materials for energy and environment sectors

The current nanotechnology science investigates new materials and substances with a strong sense of scale, from the molecular and atomic level to sizes on the nanometer order. The search for various nanostructure-controlled materials is being conducted and many developments are being made in this scientific field. Various studies performed with the purpose of having new developments in material science made through nanotechnology play useful roles in solving essential problems in the fields of environment and energy such as saving energy, reducing negative impacts on the environment and finding alternatives for scarce natural resources.

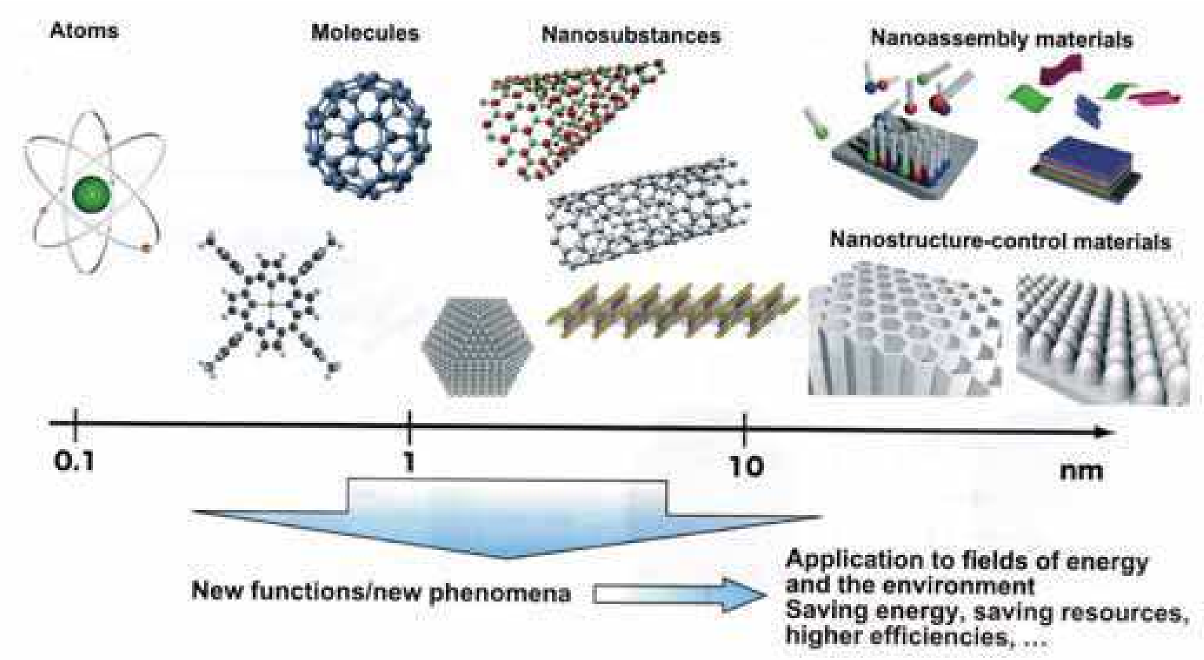

Fig. 8. Illustration of recent developments in material science through nanotechnology (Sasaki, 2008).

The development of nanotechnology-driven materials for the application in the fields of saving energy and reducing of environmental impacts is at present organized into four approaches:

a) *Investigation of new phenomena and functions on the atomic and molecular level*

Thanks to rapid progress in technologies that permits single electrons or molecules to be individually manipulated typified by the scanning probe microscope, it is now possible to approach phenomena and properties of materials that had been impossible up to now. Recent developments in this field are particularly proceeding on phase change memory, magneto-resistance memory, resistive random access memory, atomic switches and other modern devices that have reached the extremes of miniaturization. Each such nanometer-scaled switch is the non-volatile programmable solid-electrolyte device, so it has properties invisible in ordinary semiconductor devices. This atomic switch achieves the switched-on state by means of a metal filament, so it is characterized by having a smaller resistance in the switched-on state than the other devices. It is suitable for the application in low power consumption and high-speed signal transmission circuits. It is possible to shrink the surface area of a switching circuit to 1/30 of a conventional circuit when an atomic switch is used, what allows to incorporate many switches into a single chip. This makes possible to develop devices that can achieve many types of functions on a single chip. The operation of the atomic switch was initially confirmed using a sulphide system as the ion conductor, but recently its operation has also been confirmed in a metal oxide system that can be more easily embedded into semiconductor devices. However, as operation principle of atomic switches differs from that of semiconductor devices, it is even not known whether or not the same evaluation techniques can be used as in case of semiconductor devices.

b) *Development of new functions for nanoscale substances*

The discovery and synthesis of nanotubes, nanorods, nanosheets, nanoparticles and many other new substances that have various size and dimensionalities (Fig. 8) stimulate the investigation of new functions derived from the size effects and unique shapes. For example, high efficiency of electron emissions and hydrogen storage are possible using nanotubes, while superior electronic and magnetic functions are achieved with nanosheets. The exploration of wide range of applications is therefore unavoidable.

In the field of energy and environment, applied research is mainly focused to creation of nanoordered functional and structural materials with advanced physical properties for energy savings, which contribute to environmental improvement and conservation. There are many possibilities on the creation of functional nanostructural materials for high-energy savings and new environmentally friendly systems such as solar batteries, fuel cells, hydrogen storage nanotubes and self-cleaning $TiO_2$ nanocoatings. The recent developments in the field of self-assembled nanostructural materials are aimed to removing of hazardous chemical substances selectively, as well as to creation of new nanoporous materials which possess a selective catalytic function. In the field of oxide nanomaterials, recent progress in nanofabrication techniques has lead to the creation of advanced electronic materials and various interesting properties have been explored by control of nanostructures and nanospaces in glasses (amorphous semiconductors), cement constituents ($12CaO \cdot 7Al_2O_3$) and other commonplace materials.

c) *Fabrication of new materials by nanoassembly technologies*

Through the development of techniques for the integration and creation of arrays of organic-inorganic nanomodules, a wide variety of materials can now be designed in the sense of assembling them from parts and as a result, it is now possible to develop advanced functions that would be difficult to achieve with a single substance. Various industrial applications of highly efficient energy conversion elements are expected.

Typical examples of molecular assembly have included the manufacture of single-molecule films and molecular wires. For example, the development of organic electronics had previously been concerned with its applications to lightweight and thin devices, but more recently, there has been a focus on the environment and energy problems, and accordingly they have attracted attention as eco-materials and alternative materials as substitutes for rare materials. For example, while silicon is mainly used as the material for solar cells and thin-film transistors, demand for such is expected to increase in the future. The value of organic materials as an alternative material for silicon is at present also often reviewed. For example, the conventional amorphous silicon thin films are deposited by plasma CVD process which consumes large energy amounts, they may be replaced by organic thin films that could be produced by printing methods or other low-temperature, less energy-intensive processes (Wakayama, 2008).

d) *Fine control of nanostructures*

By achieving fine control of the types of atoms and their arrangement within inorganic crystal lattice, the control of materials and substances that take advantage of nanoscaled porous structures and the control of the degree of dispersion of nanoparticles and clusters dispersion becomes possible along with an extremely wide range of other new technologies.

Porous ceramics comprising nanopores connected to each other are widely used as catalyst carriers or filters. A wide-spread technique is the method of manufacture of porous glass that utilizes the phase-separation phenomena of borosilicate glass. Glass that was heat-treated and phase-separated in the phase-separation temperature range is subjected to acid etching treatment to elute the phase with boron oxide as the primary component, thereby obtaining porous silica glass with pores of several nanometers in diameter. When the phase-separation treatment and acid etching is performed after being spun into hollow glass fiber, a heat-resistant hollow-yarn membrane of an inorganic oxide is formed. This can be used in industrial applications, e.g. for water purification and various filters.

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### 3.5 Nature-guided material processing

Natural materials are remarkably efficient, because they fulfill the complex requirements posed by the way plants and animals function and that they do so using as small amount of material as possible. Many of these requirements are mechanical in nature: the need to support static and dynamic loads created by the mass of the organism, by blood pressure, etc. The same is true for plants: they must support themselves, tolerate wind and snow loading. Some of them are thermal or electrical: the need to insulate, transpire, sense, and actuate. And most natural materials are sustainable, recyclable, and — when disposal is necessary — biodegradable.

Almost all natural materials are composites and consist of a relatively small number of polymeric and ceramic components or structural building blocks, which often are composites themselves. Wood, bamboo and palm consist of cellulose fibers in a lignin/hemicellulose matrix, shaped to hollow prismatic cells. Collagen is the basic structural element of soft tissues like tendon, ligament, skin, blood vessels, muscle and cartilage. Mineralized tissues – antler, bone, dentine and enamel for instance – are composed mainly of hydroxyapatite with varying degrees of residual collagen. Hair, hooves, horn, wool, and reptilian scales are made of keratin. Insect cuticle contains chitin in a matrix of protein. From a mechanical point of view, there is nothing very special about the structural building blocks. It is the structure and arrangement of the components that give rise to the striking efficiency of natural materials (Ashby, 2008).

A number of advanced bio-materials have been developed recently to allow repair or replacement of tissue. They are bio-compatible and, in some cases, even able to stimulate cell growth. They resist attack by body fluids or, if attacked, it must be in a way that allows the body to absorb the corrosion products benignly. All these bio-materials are also able to carry the cyclic loads imposed on them by the normal functioning of the body, and to do so for many years. Among polymers, polyolefins, consisting only of carbon and hydrogen, are the least toxic. They have properties that more closely match those of tissue than do the properties of metals. Principal among them is ultra-high molecular weight polyethylene, UHMWPE. Acrylics find use both as contact lenses and as cements for bone hip and other joint replacements. Silicone elastomers are used for cosmetic implants.

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Learning from and attempting to come closer to duplicating the wonders of nature has continued to be an age old challenge for material scientists and engineers. With the widespread use of processing tools at present due to the advancements in nanotechnology, in many fields, it is becoming increasingly possible to make breakthroughs that come close to the truly complex mechanism of nature rather than simply simulate the pattern as in the past. A lot of research has come to recognize the importance of learning from nature and living organisms. Professor Hideki Ishida from Tohoku University (Japan) proposed a completely new approach to manufacturing and lifestyle by scientifically looking at “Nature`s Cycle” which is a product of the endless repetition of verification and selection throughout Earth`s history and by redesigning what are essential for the human ecosystem among them (Fig. 9). This approach is called “Nature Tech”. Until now, the concept of “Learning from Nature and Living Things” has been associated with refined simplicity and beauty, or conversely, mind-boggling complexity and detail. However, we need to learn much more from nature in which moderation is used to obtain essential structures and functions, using only a minimum of non-hazardous natural elements to create objects with a minimum amount of energy. We need to have the sense and observation skills to re-design as well as techniques to imitate so that we can go beyond just admiring nature.

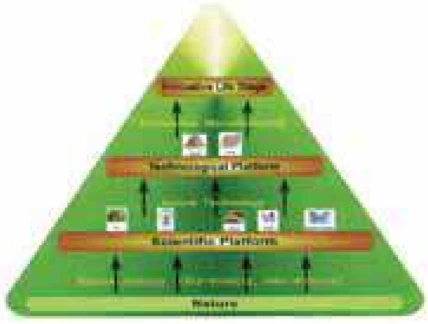


Fig. 9. Concept of “Nature Tech” (Kakisawa, 2008).

## 4. Networking of institutions fostering by R&D&TT of engineering materials

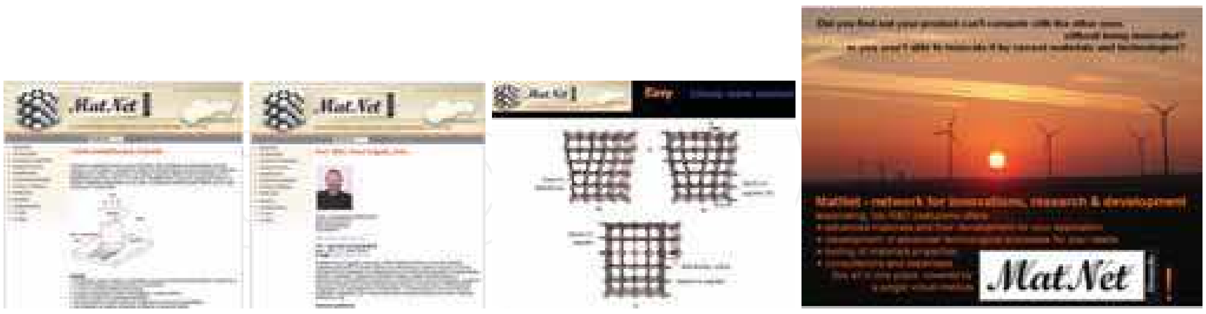
The experience from countries with high economic level shows at present the great necessity to create conditions for faster and more efficient transfer of knowledge on recently developed materials and technological processes into the industrial practice. Establishment of excellently equipped research centres for technological transfer, which serve mainly to the purposes of small and medium size enterprises, is an essential prerequisite to raise the level of manufacturing possibilities, and thereby these ones support the further technological progress.

The creation of the networks linking the institutions and experts working in the field of material research and development of related technologies is the reliable practice in many countries with advanced industrialized economy. There are many examples of similar virtual networks organizing these activities very successfully. One of the most advanced European network in this field is Materials Valley e.V. (www.materials-valley-rheinmain.de) established in 2002 in the German region of Rhein-Main, which links about 750 industrial companies and 120 high educational and research institutions. The similar network CORONET - Thermoplastic Composites Infrastructure Cooperation Network (www.coronet.eu.com) links 18 institutions from 9 European Union countries working in the field of thermoplastic composites.

The region of Central Europe is nowadays a region of materials science with tradition. Favourable tax laws, sustainable economic growth and directions accommodating investors ensure above-average growth of direct foreign investments in this region. Large industrial companies such as VW, Peugeot, KIA or Siemens already profit of the economic advantages of this region. The volume of procurement of eleven companies manufacturing products and components exclusively for automotive industry within the radius of 300 km around

Bratislava – the capital of Slovakia - increased to more than EUR 40 billion in the year 2008. That is why the professional research and education in connection with the state-of-the-art infrastructure is of the highest importance. The virtual network for R&D in the field of engineering materials and related technologies was recently established for this purpose in Slovakia and represents a valuable contribution from this point of view. The virtual network for technological innovations MatNet which links Slovak scientific, academic and industrial institutions dealing with research and development in the field of engineering materials and accompanying technologies has been created in order to enable more efficient transfer of knowledge on modern materials and advanced manufacturing processes of their production, pretreatment and joining from the academic community into the Slovak industrial companies. One of the network objectives is to establish the centre that organizes educational courses not only for developers and designers, but also for university teachers, scientific workers and doctoral students. The aim of these courses is the training in new complex principles of structural and functional components creation, on the basis of proper material selection with regard to functionality, type of operation loading and cost of product or construction and synchronized optimization of component outline and appropriate production process. During the courses, the participants have an opportunity to work on one's own with real databases containing properties of nearly all current engineering materials, as well as parameters of modern manufacturing processes and to learn the use of these databases in proposals of optimum design of components and structures for various industrial applications (Jerz & Košút, 2008).

The main communication platform of the network is the web portal MatNet - Slovakia (www.matnet.sav.sk), gathering and depositing useful information about materials and processes via various Slovak and international sources. The ambition of recently established Slovak network for innovations - MatNet is to enable developers from Slovak industrial companies (working e.g. in automotive, electrical, mechanical, building, aircraft, chemical, food and other industrial sectors) more effectively cooperate with scientists and experts from the academic community in order significantly to enhance the quality of their products.



A B C D

Fig. 10. Records of the web portal MatNet - Slovakia (examples) describing: A - technology of friction stir welding, B - expert of the network MatNet., C - e-learning lesson: "Metals - Theory of Dislocations". D – Home page of web portal MatNet.

## 5. Conclusion

The activities supporting innovations in the field of engineering materials and accompanying technologies should enable a more efficient linking of scientists and experts from the academic community to the industry, effective transfer of knowledge and more rational purchase of equipment, realisation of complex projects, etc.

Further enlargement of networking activities is therefore essential. The process of involving local companies into the research activities for large industrial producers and suppliers will be speeded up through activities aimed to establishment of research driven clusters with participation of governmental institutions, both regional and local research stakeholders, local enterprises and large multinational producers. This is the main approach how to eliminate the consequences of ominous crease in economic grow. The importance of these activities is crucial because of enormous potential of huge capital investments as the consequence of future extensive industrial expansion.

## 6. Acknowledgment

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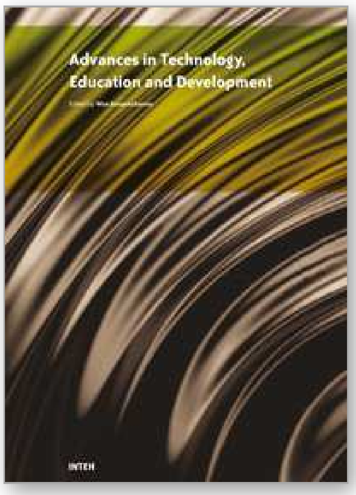

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From 3rd to 5th March 2008 the International Association of Technology, Education and Development organised its International Technology, Education and Development Conference in Valencia, Spain. Over a hundred papers were presented by participants from a great variety of countries. Summarising, this book provides a kaleidoscopic view of work that is done, all over the world in (higher) education, characterised by the key words ‘Education” and ‘Development’. I wish the reader an enlightening experience.

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