INTRODUCTION

Nature offers us multitude of structures in plants and animals. From the beginning the human being have been fascinating of structure and functionality of natural creatures as for example flying of birds and bats. Bio-inspired materials are becoming of increasing interest in many engineering applications. The natural structures gain the superior physical and mechanical properties by hierarchical structures. Such a materials inspired scientists and engineers. The part of the science dealing with using natural templates in engineering solutions is called biomimetics, bionics or biomimicry [1]. However, the experience in this area is that it is not possible to create a new engineering materials simply by making a direct copy of biological materials.

The paper presents the perspectives of biomimetics in materials science and engineering. The background of biomimetics and directions of development are described.

STATE OF THE ART

There is no doubt that we can learn from Nature and adopted that knowledge to our engineering solutions. In 1917 D’Arcy W. Thompson in his book “On growth and Form” [2] suggested that organic forms can be described by physical and mathematical lows.

There are some papers and books, which have been written to show the biological structures, their properties and potential as a new concept in many areas also in materials science. For example, work of J. Benyus from 1997: “Biomimicry: Innovation inspired by Nature” [3], papers and books of Vincent, Currey, Mann, Meyers, and others could be mentioned [4÷8].


How quickly biomimetics is developing in materials science and engineering is fact that new journals dedicated to this subject were appearing in many years. Almost every year there are some conferences or sessions on the conferences dedicated biomimetics, as the last one Bio-inspired Materials in March 2012 at Potsdam.

INSPIRATIONS FROM NATURE – NEW DIRECTIONS IN MATERIALS SCIENCE AND ENGINEERING

Basing on the inspirations of Nature the natural solutions can be transfer to engineering applications. As far there are some of examples of success in biomimetics solutions. The main developing directions are: 1) construction, 2) materials, 3) templates, 4) systems, 5) interfaces 6) process of forming.

From engineering point of view construction is meant as the constructions of buildings in architecture or others in civil engineering. In architecture there are some example of using natural templates. For example described at paper from 2005 of J. Godfaurd, D. Clements-Croome, and G. Jeronimidis, “Sustainable building solutions: a review of lessons from the natural world” [16]. In materials science and engineering materials construction is treated as the shape and structure of devices. Biomimetic approach requires starting from the design creating of a new materials as devices ready to use. It needs to treat construction, material and processing as not dividing procedure. This is the most difficult but extremely fascinating challenge of biomimetics.

Especially, in new biomimetic materials the composites based on natural composites are elaborated. Such an example of natural composite – shells have been considered in designing and fabrication synthetic ceramic matrix composites with improved fracture toughness. In shells as Abalone or concha (Strombus Gigas) their lamellar structure consist of mineral layer (aragonite) and organic (protein) layer is described as the brick and mortal microstructure [8]. Such a microstructure plays a crucial role in the mechanical properties as a very efficient crack deflectors. The lamellar structure based on shells has been for long time used for producing ceramic matrix composites. The crack propagation along the layers (Fig. 1) is responsible for the increase of the fracture toughness. The new obtained composites based on abalone nacre named LAST® consisted of hexagonal tiles of SiC and B4C covered by Kevlar® and linked together by also based on natural solution – Velcro®-type adhesive. This composite has been used as shock absorbing material for different type of vehicles [8].

Fig. 1 Scheme of crack propagation in layered composite

Rys. 1 Schemat propagacji pęknięcia w kompozytach warstwowych
There are many others examples of the materials with unique properties as gecko feet (strong, reusable adhesives), spider silk (high-performance, viscoelastic fibres), lotus leaves (nonfouling surfaces), sea urchin spines (optical waveguides) or peacock feathers (photonic materials) [8, 17, 18]. Some of these example have been successfully used to create a new generation of commercial materials. The popular Velcro® system of linking by loops and hooks coming from burrs [8], structural colours materials based on of the peacock feathers (Fig. 2) [8], hydrophobic surfaces and self-cleaning paints or anti-graffiti sprays works as the lotus leaves [19, 20]. Some of them still waiting for discovering and use.

There are intensively elaborated materials and systems in micro- and nanoscale. There are called microelectromechanical systems (MEMS) and nanoelectromechanical machining (NEMS) [21]. The micro- and the nanoscale devices and nanometric materials are especially important for electronics as well as for medicine. Fabrication of such devices needs a templates with special shape and size. For this reason the natural templates are used. In the nano- and sub-microscale the biomolecules as DNA proteins, viruses, bacteria, and other cells are selected. In microscale fibers of plants, silk, skeleton of diatoms and others microorganisms.

Different shapes of viruses as rod-shaped, tubular, spherical or near-spherical, as well as variety of shape of proteins like “donuts” ferritin or “apo-horse spleen” ferritin are the templates for synthesize metal through in-situ reduction process. The metal coatings consisted of nanoparticles less than 10 nm in size, which can be deposited at both exterior and interior surfaces of virus or protein (Fig. 3) [17].

The double helix of DNA is also the template in biomorphic synthesis. The DNA has a width of about 2 nm and linear shape with a considerable length to transfer in nanowires of Pt, Au, Ni, Cu or others metals or complexes [17]. In such a way the subassemblies for variety of electronic devices can be fabricated.

The great potential is still hidden in algae-diatoms. Diatom frustules made of biosilica have a variety of shape cylinders, wheels, fans, circles, stars and many others [22]. Their morphology with nanopores and many others ornaments are important as the templates for biomorphic mineralization [13, 17, 22, 23].

Silica biomimeralization is very attractive for nanotechnology, because the nanoscale architecture of diatoms’s frustules exceeds the capabilities of present-day human engineering. Understanding the process of precisely forming the nanostructures of diatoms will give the chance to manipulation of the frustules shape according to the applications and through genetic engineering to produce of unique 3D nanomaterials with tailored structures.

There is an increasing interest in the investigation of the natural process of bioapatite mineral formation. Due to the bioapatite mineral are very close to synthetic hydroxyapatite the methods, based on natural biominalization, formation of porous hydroxyapatite scaffolds as bone replacement are developed [24, 25, 26]. The formation of CaCO₃, which built the shells is also very extensively investigated. The lamellar structure of shells as Abalone described above is responsible for high fracture toughness of these structures. Formation of the lamellar structure is initiated by the proper protein, which acts as “genetic switch” responsible of kind of crystallographic type of calcium carbonate [27]. Based on the structure of shells and natural way of its growing the new methods of synthetic materials formation are elaborated. The process of biomimeralization starts from covering of the cellulose or chitin substrate by the precursor and subsequently the homogeneous nucleation CaCO₃ films appeared. One of such a method is called polymer-induced liquid precursor (PILP) [28].

The synthesis of biomimetic materials based on the biomimeralization is embryonic however, this concept in materials science will continue to grow.

Biomimetic formation of new materials needs the knowledge of natural structures their morphogenesis and creation of new methods and instruments for producing synthetic biomimetic materials (Fig. 4) This task involves the interdisciplinary research from area of biology, chemistry, physics, materials science. Especially, molecular chemistry and molecular biomimetics is necessary. The main approach of molecular biomimetics is building atom-by-atom known as the bottom-up method [21].
The self-assembly process of the molecules are the crucial in the bottom-up methods. For this process the atomic force microscope (AFM) or scanning tunneling microscope (STM) are used. For example the dip-pen nanolithography (DPN) methods are elaborated [29].

One example of the biomolecular biomimetics is called “molecular carpet” [30]. First by the self-assembly process the support from proteins molecules is formed support, then the nanoparticles of synthetic material are located and linking with biological material (Fig. 5).

**SUMMARY**

Biomimetics has become a hot area of research. One of the main reasons for this is the fact that biological materials combined a variety of mechanical and additional functions. The development of new characterization techniques and fabrications processes as well as computer simulations methods allows for the first time to tailor new characterization techniques and fabrications processes as well as interdisciplinary. However, the success is still exception. We have to remember that not all the solutions of Nature can be translated directly into engineering materials.

The strong interdisciplinary collaboration between scientist of biology, chemistry, physics, materials scientists and engineering as well as mathematics and medicine are necessary. The most perspective direction of developing biomimetics as interdisciplinary research are presented at Figure 6.

**REFERENCES**


**Fig. 6. Perspective directions of developing biomimetic materials**

**Rys. 6. Perspektywiczne kierunki rozwoju materiałów biomimetycznych**