BIONICS AND NANOTECHNOLOGY

Pavel KEJZLAR a,b, Lukáš VOLESKÝ a, Zuzana ANDRŠOVÁ a, Dora KROISOVÁ a,b,

a Department of Material Science; Faculty of Mechanical Engineering; Technical University of Liberec, Liberec (Czech Republic), E-mail: pavel.kejzlar@tul.cz

b Laboratory of Analytical Methods; Centre for Nanomaterial, Advanced Technologies and Innovations; Technical University of Liberec, Liberec (Czech Republic).

Abstract

The study of natural materials and creating of their similarities from the construction-, structure- and material point of view is relatively new and a perspective field, connecting results of scientific research in biology, chemistry, physics, material engineering, construction and design. At present time, a lot of these results are transferred into the industry applications. As we can see - natural materials could become a source of inspiration on field of materials, technologies and construction as well as on field of nanotechnologies.

Keywords: bionics, nanotechnology, scanning electron microscopy

1. GENERAL INTRODUCTION

The bionics is a scientific discipline which studies natural materials and creates their analogies. The word of „bionics“ has been used for the first time about fifty years ago. It is composed by two parts of two words – biology and technics. The bionics is studying biological structures and processes with purpose to use acquired knowledge as models for development of synthetic systems.

Of course, the purpose of bionics is not only imitation but mainly the utilization of the nature´s creative potential and the inspiration for constructions and technologies.

The life on Earth originated about 3.85 to 3.5 billion years ago. During this time living organisms achieved almost perfect solutions in construction, remodelation processes and self-repairing [see e.g. 1, 2].

Observation of the nature and using of aquired knowledge practically accompanies the mankind from the beginning. As one of the first scientist in bionics could be highlighted e.g. Leonardo da Vinci. This brilliant perceptive observer overtook his period by hundreds of years. He made a lot of detailed studies of bird flight and construction plans of several flying machines, which were simulating the anatomy of bird- and bat wings.

During last ten years this scientific branch has been going through the huge expansion. Partially it is caused by the fact with help of a scanning electron microscopy and/or other advanced imaging techniques we can realize a view into the enchanting world of weird structures and shapes where processes and technologies are coded in genetic information and raw materials are not processed in the blast furnace but have a natural origin and are biodegradable.

The current spectrum of materials around us is outstandingly diverse and it changes corresponding to the type of community. People living in advanced developed and industrial countries mostly use synthetic materials. At the other hand people coming from developing countries are closely connected to the nature and prefer natural materials.

To solve the question of: „which materials (synthetic or natural) are better?“, we should try to look closely at some natural materials as results of a million-year evolution.

Several examples of plant- and animal kingdom were selected to illustrate some special functional structures that could become an inspiration for the nanomaterial science.
2. NATURAL MATERIALS

2.1 Shark Skin

Shark is one of the most feared predators living in the water world. The whole body is designed to hunt and kill his prey. His hydrodynamic body shape, aerobic muscle mass and the skin are covered with placoid scales to reduce friction during swimming, give it the ability to reach spectacular speed of 74 km/h and to move with great agility [3, 4]. What is remarkable is the special shape and arrangement of shark’s scales providing easy tearing-off of water streamlines and reducing of the turbulent flow [5] (Fig. 1).

The shark skin structure has inspired the Speedo company to develop technology called FAST SKIN®. This technology is used in the manufacturing of swimwear in order to minimise the water resistance [6].

The shark skin was also an inspiration for a research led by the Frauenhofer Institute, where a special substance has been developed [7]. This substance decreases the air and/or water resistance after application onto the surface of a plain or a boat. The substance is based on nanoparticles which resist to UV radiation, temperature changes and mechanical load. Very interesting is the way how the substance is applied on the surface – it is carried out using a template which imitates the structure of the shark skin.

New discoveries show that the structure of a shark skin could find an usage in medicine. Scientific team of Anthony Brennan from the Office of Naval Research has discovered a new material called Sharklet™ [8]. Sharklet™ is the world’s first technology which allows inhibiting a bacterial growth through the pattern alone. The antimicrobial Sharklet surface is comprised by millions of small diamonds, arranged in a distinct pattern that mimics the microbe-resistant properties of shark skin. Sharklet Technologies puts the pattern into the adhesive-backed films and manufactures the pattern into medical devices and consumer goods to prevent bacterial growth.

2.2 Beetle Wing Case

Wing case of the carabid beetle (Carabus arcensis) is a remarkable example of extraordinary composite material. It is very light and simultaneously provides an effective mechanical protection.

The wing case is composed of long chitin fibres (Fig. 2a) which cross in layers one above the other in angle of 90°. The square fibre cross-section (Fig. 2b) allows faultless filling the space between the fibres by a bonding agent – a protein matrix. Individual fibres are also interlinked by thin fibres which further enhance the coherence of individual layers. The number of layers corresponds with the level of the stress in different places of the wing case.

The synergic effect between fibres and a protein matrix causes the extraordinary mechanical properties – the excellent torsion rigidity and the shear strength. The beetle wing case excels in its high resistance to the
long-term dynamic stress. Peaks of potential cracks are split and expanded into large areas along many fibres and layers. It causes substantial drop in energy at the forefront of crack and stops its further growth.

Fig. 2: A) Long chitin fibres cross in layers one above the other in angle of 90°; B) The fibre cross-section is square shape. Individual fibres are interlinked by thin fibres to further enhance the coherence of individual layers.

Fig. 3: A) Canals on the wing case surface; B) The wing case fine structure surface resembles to roof tiles.

The outer layer of wing case is chemically stabilized to be resistant to the damaging effects of UV radiation and a humidity. Water droplets caught on the surface of the wing case are being collected and drained by thin canals which are visible in Fig. 3a. In Fig. 3b we can see the fine structure of the wing case surface which is similar to roof tiles.

2.3 Hydrophobic plant surfaces

As we can observe, surfaces of leaves and/or petals of many plants are cleaned completely from dust pollutions by a simple rain shower. Such leaves are called hydrophobic. That means that water droplets are
forming into the spheres (Fig. 4) with very little adhesion to the surface and roll off very quickly even at small inclinations.

Fig. 4: Small water droplets formed on the hydrophobic surfaces. A) White Clover; B) Snowberry; C) Rose flower.

This phenomenon, so called Lotus-effect, was studied and described in many publications [9-13]. The Lotus-effect is usually related to the nanopatterns occurring on the surfaces of leaves. The main condition of hydrophobic surfaces is a roughness on the micro- and nanometer scales. This is a reason why contact area for water and pollution is extremely reduced. The basic connections between surface roughness and water repellence were worked out by Cassie and Baxter as well as by Wenzel [14, 15]. Hydrophobicity in nature could be achieved in different ways as illustrated in Fig. 5a-d. In Fig. 5a is the detail of the leaf of Lemon Bottlebrush (Callistemon citrinus) surface. This surface is covered with long thin trichomes (tiny hairs) which are in addition used to reflect radiation and lower plant temperature. They also provide defence against insects. The surface of white clover leaf is covered by submicron wax platelets seen in Fig. 5b. The water-repellent properties of snowberry leaves are caused by a submicron specific structure resembles “small fingers” (Fig. 5c). Their diameter is lower than 200 nm. In Fig. 5d is a rugged surface structure of rose petal.
CONCLUSION

Contemporary scientists struggle to invent and develop many new technologies to satisfy the demands of industrial progress. A desired solution can be often founded seemingly “ordinary things” around us. What we all have to do is to see and understand them. Nature is always giving very valuable lessons to the innovation. Functional structures observable in the nature have been evolving and improving over many years and provide a surprisingly advanced and sophisticated solutions designed to satisfy the most demanding requirements of the environment. This is the reason why we should thoroughly examine, study and imitate our surroundings. The idea is to copy the function things from nature and apply them to our technology. Using this way we can work without unbalancing the nature.

ACKNOWLEDGEMENTS

This work was supported by the SGS project “Innovations in material engineering” and by the project CxI CZ.1.05/2.1.00/01.0005.

LITERATURE


