INSTITUTE OF nanoTECHNOLOGY

'Bioinspired Nanotechnologies for Smarter Products'

- *Showcasing a spectrum of applications for a wide range of industries –*

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Abstracts

'Insects did it first: Biomimetic mushroom-shaped fibrillar adhesive microstructure'

S. Gorb, M. Varenberg, A. Peressadko and J. Tuma, Evolutionary Biomaterials Group, Max Planck Institute for Metals Research

To improve the adhesive properties of artificial fibrillar contact structures, the attachment systems of beetles from the family Chrysomelidae were chosen to serve as a model.
Biomimetic mushroom-shaped fibrillar adhesive microstructure inspired by these systems was characterized using a variety of measurement techniques and compared with a control flat surface made of the same material. Results revealed that pull-off force and peel strength of the structured specimens are more than twice those of the flat specimens. In contrast to the control system, the structured one is found to be very tolerant to contamination and able to recover its adhesive properties after being washed in a soap solution. Based on the combination of several geometrical principles found in biological attachment devices, the presented microstructure exhibits a considerable step towards the development of an industrial dry adhesive.

'Photonic structures in butterfly scales'

Roy Sambles, School of Physics, University of Exeter

Taking little other than material much like common cuticle, loaded with a small amount of melanin, butterflies have evolved some stunning microstructures in their wing scales. These structured surfaces, often only microns thick act as selective reflectors and polarizers as well as being sometimes very strong scatterers (white) or very strong absorbers (black) of electromagnetic radiation. They also on occasion incorporate fluorescence within these structures.
This talk will illustrate recent results on experimental studies of the wonderful structures to be found in butterflies discussing, among other aspects how high brightness iridescence arises, how black and white is produced in structures which are so thin and light and how one particular structure leads to remarkably directed fluorescence.

'Fire and Explosions in Nature – some biomimetic possibilities'

Professor Andy McIntosh, University of Leeds

In this work we will explore two areas involving fire and explosions in nature: (i) the knobcone pine and (ii) the scotch broom seed. Some possible biomimetic applications will be described of each of these. The knobcone pine has a high temperature controlled unique gas emission insulating system and the scottish broom has a mechanical, humidity controlled propulsion device for dispersing its seed. The biomimetic applications in both of these examples lie in the area of fireproofing (knobcone pine) and propulsion (for the scotch broom). The nano possibilities are considerable since insulation by gas emission is a novel concept that has not been generally considered and can have relevance to intumescence behaviour of fire-proofed polymer seating used widely in air, road and rail transport. The unique propulsion device of the broom is connected with fine tuning of drying forces and bending moments of the seed casing. Though clearly there are defence applications, the interest may well be much more in heterogeneous dispersal of nano powders for the pharmaceutical industry.

‘Information and structure as the routes of nanotechnology’

Julian Vincent, University of Bath

Whilst one of the main drivers of nanotechnology is the molecular basis of biology, we must be careful about the context in which the output of nanotechnology is applied. With all current biomimetics, the route of implementation is to abstract a concept or mechanism from its biological surroundings and re-optimise it for a technological environment. This approach is based on the exploitation of single mechanisms and could be considered adventitious or serendipitous. In a burst of dissatisfaction with such a random state of affairs, we decided on a systematic approach, using elements of the Russian TRIZ (translated as the Theory of Inventive Problem Solving) to provide an analytical description of technology. One of the most interesting approaches has been to investigate the variables which are manipulated in order to resolve a problem. The technology mindset tends to solve a problem with a direct approach, most commonly by manipulating energy (up to 70% of the time) and using materials. Biology relies very little on the manipulation of energy (no more than 5% of the time), using information embedded in the organism and its environment, and creating structures from available materials. In doing this, the similarity between solutions to problems from biology and technology is only about 12%.

A closely related difference is the available levels of hierarchy - up to 20 in biology (molecule to ecosystem); probably only 5 in technology.

Nanotechnology is currently about information at the molecular level. We should be developing the use of this information to inform interactions between levels of hierarchy, thus making structures which have hardly any reliance on energy for their synthesis. And the good news is that biology uses mostly the same manipulations as technology.

‘Biomimetics of photonic nanostructures’

Prof Andrew Parker, Department of Zoology, The Natural History Museum, London

There exists a diversity of optical devices at the nano-scale (or at least the sub-micron scale) in nature[1]. These include 1D multilayer reflectors, 2D diffraction gratings and 3D liquid crystals. In 2001 the first photonic crystal was identified as such in animals, and since then the scientific effort in this subject has accelerated. Now we know of a variety of 2D[2] and 3D[3] photonic crystals in nature, including some designs not encountered previously in physics.

Biomimetics is the extraction of good design from nature. Some optical biomimetic successes have resulted from the use of conventional (and constantly advancing) engineering methods to make direct analogues of the reflectors and anti-reflectors found in nature[4]. However, recent collaborations between biologists, physicists, engineers, chemists and material scientists have ventured beyond merely mimicking in the laboratory what happens in nature, leading to a thriving new area of research involving biomimetics via cell culture. Here, the nano-engineering efficiency of living cells is harnessed, and nanostructures such as diatom “shells” can be made for commercial applications via culturing the cells themselves.

1. Parker, A.R. 515 Million years of structural colour. *J. Opt. A* **2**, R15-28 (2000).
2. Parker, A.R., McPhedran, R.C., McKenzie, D.R., Botten, L.C. and Nicorovici, N.-A.P. Aphrodite’s iridescence. *Nature* **409**, 36-37 (2001).
3. Parker, A.R.,Welch, V.L., Driver, D & Martini, N. An opal analogue discovered in a weevil. *Nature* **426**: 786-787 (2003).
4. Parker, A.R., Hegedus, Z. and Watts, R.A. Solar-absorber type antireflector on the eye of an Eocene fly (45Ma) *Proc. R. Soc. Lond. B* **265**, 811-815 (1998).

‘Plant Stems as Role Models for Structurally Optimized Biomimetic Composite Profiles with Gradient Structure’

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Biomimetic means learning from nature. Three billion years of evolution and problem solving in biology can be tapped for the development of innovative technical solutions which is also of high significance for technical textiles.

Plants can be considered as evolutionary optimized composites, constructed from various tissues with different mechanical properties. Recent findings of biologists of the Plant Biomechanics Group Freiburg and the Max Planck Institute of Colloids and Interfaces (Potsdam/Golm), as to biomechanics of plants and plant tissues, give new insights into principles of the hierarchical composition of plant stems. Specifically giant reed (A*rundo donax*) and aka horsetail (*Equisetum hyemale*) have unique qualities like high specific stiffness / tenacity and high oscillation damping of strong wind-induced vibration by means of different gradients on different hierarchical levels.

The reason for high vibration damping of especially *Arundo donax* is – besides an optimised fibre architecture – a stiffness gradient between stiff fibres and less stiff parenchymatous cellular matrix, created by several parenchyma layers with centripetally decreasing Young’s modulus surrounding the fibre-bundles. The micromechanical properties and the structural basis of the gradient structure are analysed on an (ultra-)microscopical and biochemical level in ongoing joint projects of the Max Planck Institute of Colloids and Interfaces (Potsdam/Golm), the ITV Denkendorf and the Plant Biomechanics Group Freiburg. Those interface layers have in itself special micro- and nanostructures and chemical compositions. New developed test methods will help to look still deeper into the functionality of those structures.

A*rundo donax* and *Equisetum hyemale* serve as role models to develop light-weight gradient composite profiles with high specific bending stiffness, very good damping of mechanical vibrations and benign fracture behaviour. The new gradient composite profiles, produced by the cost-effective pultrusion process, can be used in many different applications like aerospace, transportation, sporting goods or building.

The Freiburg biologists and textile engineers of ITV Denkendorf co-operate together in the competence networks ‘Biomimetics’ and *BIO*KON, developing biomimetic textile solutions from biological findings.

‘Biomimetics: where has it come from and where is it going?’

Richard Bonser, University of Reading

Over the last 20 years there has been a sustained growth in interest of biomimetics as a problem-solving approach. What added value does biomimetics bring to the design process? How will this contribute to future adoption of biomimetics? These and many other questions are interesting to address if one is to gain insights into the future of biologically-inspired innovation and its uptake by industry.

Considerable research has been carried out to examine the growth of various areas of technology (for example, by exploring ‘technology trajectories’ In this talk, I present data on the growth of patenting, publishing and networking activity in recent years. Analysis of these growth patterns tells us a great deal about how biomimetics is ‘maturing’ and gives us some insights into what the future may hold.

‘Mechanically Functional Amyloid Fibrils in Natural Adhesives as a Target for biomimicry’

Anika S. Mostaert & Suzanne P. Jarvis
Centre for Research on Adaptive Nanostructures and Nanodevices Trinity College Dublin

Using atomic force microscopy (AFM), we have been able to provide an explanation into the mechanical design for natural adhesive strength at the molecular level.
AFM data from an algal adhesive (Prasiola linearis), exhibited repetitive ‘sawtooth’ responses, characteristic of material with high mechanical strength due to the presence of ‘sacrificial bonds’ and ‘hidden length’ within adhesive molecules. We proposed the mechanism for adhesive tensile strength was based on the existence of protein in the form of amyloid fibrils, and concluded that our AFM data was the result of mechanically manipulating β-sheets within the highly ordered amyloid structures.

We have found evidence for the presence of amyloid in other natural adhesives, including that from a parasitic worm (Entobdella solae). Amyloid fibrils are normally associated with neurodegenerative diseases, however we consider this quaternary protein structure in natural adhesives to be ‘mechanically functional amyloid’. So far our results have shown differences in mechanical strength between different types of amyloid fibrils. Elucidating the mechanisms behind such differences are necessary in order to reap the full benefit of amyloid in natural materials and to explore their potential for biomimicry.

Recent related publications:
•Mostaert, A. S. & Jarvis, S. P. (2007). Nanotechnology 18: 044010 •Mostaert, A. S., Higgins, M. J., Fukuma, T., Rindi, F. & Jarvis, S. P. (2006).
Journal of Biological Physics DOI 10.1007/s10867-006-9023-y •Fukuma, T., Mostaert, A. S. & Jarvis, S. P. (2006). Tribology Letters 22:
233-237

‘Structural coloration does not necessarily imply a fancy, iridescent or metallic, appearance’

Prof Jean-Pol Vigneron, BioPhot project, University of Namur

Colours from structural (rather than pigmentary) origin are often first detected by the naked eye or by optical microscopy because they lead to a metallic shine or an easily perceivable iridescence. In these cases, the colour is changing, sometimes over a broad range, along with the angle of incidence and the angle of emergence, an effect which is often undesirable for utility objects. Nature tells us how to produce structural colours that emphasize iridescence, but it also teaches us how to avoid it. This talk will develop natural examples where iridescence has been broken in some clever way. The use of a chirped photonic crystal which produces a broadband mirror, as in the case of the golden beetle *Chrysina resplendens*, is one of the clever way of avoiding iridescence, but not metallicity. More subtle, the interplay of a short-range order with a long-range disorder in the form of a photonic polycrystal has been met in at least two insects: the Brazilian butterfly *Cyanophrys remus* and the tropical weevil *Pachyrrhynchus congestus pavonius.* These examples will be examined and the physical interpretation of the coloration will be developed. In both cases, the iridescence is shown to be broken by orientation disorder.

‘Lotus-Effect®: Biomimetic superhydrophobic surfaces and their application’

Boris F. Striffler, Zdenek Cerman, and Wilhelm Barthlott, Nees Institute for Biodiversity of Plants

Understanding processes creating water repellent surfaces in nature and applying the derived knowledge to technical surfaces has been a long time quest, not only in material sciences. Water repellent surfaces in nature are seldom completely smooth but have a certain roughness. The majority of plants have distinctly microstructured leaves; some are additionally covered with nanoscale wax crystals. This combination of a twofold structure together with hydrophobic properties of these waxes creates an outstanding phenomenon: water forming spherical droplets. Such droplets have contact angles exceeding 140 degrees and roll off angles of less than 10 degrees. Commonly, surfaces having these properties are termed superhydrophobic.

Not only water cannot adhere properly to superhydrophobic surfaces even dirt, whether it is hydrophilic or even hydrophobic, is removed easily by running water. This is due to the reduced contact area of surface and particle, which results in the drop laying on the surface like a fakir on a bed of nails. Further information: www.lotus-effect.com

After the discovery and the analysis of the self-cleaning effect, the mechanism was applied to first technical prototypes. The technical conversion was patented and the trade mark Lotus-Effect® was introduced. In the mid-1990s a large cooperation project with industrial partners started. Since then several Lotus-Effect® products have been marketed: a facade paint and a rendering by Sto AG, a coating for glass surfaces by Ferro, a spray and a nano-particle powder (Aeroxide LE®) for multipurpose applications by Degussa.

Recently a different aspect of water repellent surfaces was investigated: underwater superhydrophobicity. Within this project aquatic floating plants and semiaquatic animals were examined in respect of surfaces holding an air film when submerged. Successfully transferred from its natural models textile prototypes proved to retain an air film for about 4 days. Aim of the underwater superhydrophobicity project is to develop technical surfaces for long time application in ships and pipelines, as an air film between surface and liquid produces high drag reductions and thus savings of fuel and energy.