Biologically inspired materials.

Biomimetic design and assembly

Summer school

Organized by
Materials Science and Engineering (MSE)
at Virginia Tech, USA and
EXPERTISSUES

June, 9-15, 2008

Virginia Tech European Campus

Villa Maderni, 6826 Riva San Vitale, Switzerland

The biological materials are superior to man-made synthetic materials with regard to combination of mechanical properties such as stiffness and impact strength yet exhibiting very light weight. They are also highly anisotropic and self-repairing. They are produced without the use of solvents and with low energy consumption. In biological systems, advanced micro-architecture is assembled with precise control of size and structures. This course will provide basic principles of Biomimetic design of future materials. This includes understanding of structure-property relationship and requires use of advanced material characterization methods which can be applied in wet state and will provide information at all length scales. This course will teach about structure and unique properties of selected biological materials such as bone, wood, cartilage, jelly-fish, shells, spider silk and gecko lizard. The visco-elastic behaviour and fracture mechanics will be taught. Then the principle of biomimetic design for preparation of new materials using renewable building blocks will be brought. The course will also give brief introduction to biological fabrication which includes use of enzymes, cells and coordination of system biology. The introduction to tissue engineering and regenerative medicine will be given. The course is suitable for graduate engineering students but will be open for highly motivated undergraduate students. The students from other schools will be welcome to apply. This is one of the Materials Science and Engineering at Virginia Tech efforts to enhance international collaboration and mobility. The course will bring together students from Virginia Tech and other leading Academic institution in USA, Europe and Asia. The classes will be given by international experts in each field of expertise. The guide to Advanced Biomaterial Characterization (abc) at ICTAS Nanoscale Characterization and Fabrication Laboratory (ncfl) at Virginia Tech will be provided by distance learning.

For information contact:

Prof . Paul Gatenholm

VirginiaTech
Invent the Future

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Preliminary program

Students are invited to prepare posters describing their own research. The poster presentation will take place the first day. The best poster will get award.

Monday, June 9,

13-16	Registration
16-17	Welcome and Get together
17-19	Student Poster Session
19-20	Dinner
20-22	Poster Session

Tuesday, June 10,

8-9	Breakfast
9-12	Introduction to material science and engineering of biological materials, Prof. Paul Gatenholm
12-13	Lunch
13-16	Workshop
16-18	Introduction to macromolecular materials, Biomimetic synthesis and assembly, Prof. Tim Long
19-20	Dinner

Wednesday, June 11,

8-9	Breakfast
9-10	Molecular characterization of materials, Prof. Tim Long
10-12	Viscoelastic properties of biological materials, Prof. Claudio Migliaresi,
12-13	Lunch

13-16 Collecting Biological Materials
17-18 Composites and Biocomposites, Prof Claudio Migliaresi,
19-20 Dinner

Thursday, June 12,
8-9 Breakfast
9-11 Biofabrication. Biogenesis, enzymes and cells at work, Prof. Antonella Motta
11-12 Polysaccharides, Non-saccharidic plant components, Prof. Wolfgang Glasser
12-13 Lunch
13-15 Think Tank by Lugano Lake
15-18 Hierarchical structure of plant materials, Molecular interactions in plant composites, Plant biomimetics, Prof. Wolfgang Glasser
19-20 Dinner

Friday, June 13,
8-9 Breakfast
9-12 Proteins, synthesis, protein based materials, spider silk, Prof. David Kaplan
12-13 Lunch
13-15 Brain Storming Session
15-18 Bioceramics: Shells, bone, biomineralization, Prof. Patricia Dove
19-20 Dinner

Saturday, June 14,
8-9 Breakfast
9-12 Mechanical properties and fracture mechanics of biological materials, Prof. Paul Gatenholm
12-13 Lunch
15-18 Biomimetic and Biological Inspired Control, protein as active component of sensors, actuators and micromuscles, phospholipids as material building blocks, Prof. Donald Leo
19-20 Dinner

Sunday, June 15,
8-9 Breakfast
9-12 Biomimetic support for replacement of human organs, Prof. Aaron Goldstein
12-13 Lunch
13-14 Course evaluation

Course content:

Introduction to material science and engineering of biological materials, Prof. Paul Gatenholm

Biomimetic design of future advanced materials requires understanding of structure-property relationship of biological materials. This can partly be achieved by advanced characterization of biological materials in wet state at all length scale but it also requires basic knowledge of materials science and engineering. This lecture will give an introduction to basic components of the discipline of materials science and engineering; processing, structure, properties and performance and their correlations. The lecture will also provide introduction to atomic structure and interatomic bonding and crystalline and amorphous structure of soft materials. The role of water in structure and properties of biological materials will be exemplified.

Introduction to macromolecular materials, Biomimetic synthesis and assembly, Prof. Tim Long

Non-covalent interactions enable the development of novel supramolecular structures from functional polymeric precursors. Both ionic interactions and hydrogen bonding provide important routes to self assembly and tailored adhesion. Ionic interactions result from strong electrostatic attractions, which persist to elevated temperatures and lead to the formation of ionic aggregates in the solid state. In contrast, hydrogen bonding interactions exhibit greater thermoreversibility and specificity, allowing reversible attachment of guest molecules. Due to the thermal integrity of ionic aggregates, processing of ionic polymers requires high energy input. Current research efforts involve combining hydrogen bonding interactions with ionic interactions to benefit from the advantages of both association modes. Our strategy involves the introduction of ionic hydrogen bonding guest molecules to reversibly attach ionic guests to the hydrogen bonding elastomeric triblock copolymers. Potential applications include elastomers and multifunctional adhesives, as well as ion-conducting materials for fuel cells.

Molecular characterization of materials, Prof. Tim Long

This lecture provides guide to basic tools for molecular characterization of macromolecules. The lecture covers basic use of IR, NMR, MS for determination of molecular composition, thermal methods such as DSC and various methods for determination of the size of macromolecules (SEC, MALDI-TOF)

Viscoelastic properties of biological materials, Prof. Claudio Migliaresi

The lecture will give the introduction to viscoelastic properties of polymeric materials explaining creep and stress relaxation phenomena. The lecture will also discuss the properties of biological origin materials as governed by their viscoelastic behavior. Characterization methods will be illustrated and specific behavior examples will be presented.

Composites and Biocomposites, Prof. Claudio Migliaresi

A world of composite materials! Most biological materials are made by composites. Examples are wood or animal tissues such as bone or skin. Nature made composites to combine functional and structural properties of different materials, then assembled them in hierarchical dynamical structures that are the living organisms. As for man made composites, properties of biological composites can be modeled and predicted on the basis of quite simple equations and parameters. These aspects will be discussed with reference to a possible design of "biological composites resembling" man made composites.

Biofabrication. Biogenesis, enzymes and cells at work, Prof. Antonella Motta

This lecture will provide brief introduction into biology as a tool for fabrication of materials and structures. The lecture will cover composition of plant cell and simple animal or human cell, cellular fate processes, how the enzymes produce polymers, intracellular and extracellular production

Proteins, synthesis, protein based materials, spider silk, Prof. David Kaplan

Polysaccharides, Non-saccharidic plant components, Prof. Wolfgang Glasser

The introduction to polysaccharides, the monomer structure of sugar units, their bonds, stereoisometry, examples of the most important polysaccharides; cellulose, starch (amylose and amylopectin), hemicelluloses, chitin. The solid structure of cellulose and chitin, Solubility and regeneration of cellulose and other polysaccharides, other plant polysaccharides and Non-saccharidic plant components

Hierarchical structure of plant materials, Molecular interactions in plant composites, Plant biomimetics, Prof. Wolfgang Glasser

Wood is a biocomposite of principally three polymeric entities that serve complementary purposes. A highly crystalline linear polysaccharide (cellulose) provides (tensile) strength; a group of para-crystalline heteropolysaccharides adds ductility (plasticity) and interfacial compatibility to an epoxy-like polyaromatic component (lignin). This composite is created in a "bottom-up" fashion following self-assembly principles. The understanding of the molecular make-up of wood may serve as guide for the ("bio-inspired" or "biomimetic") design of novel man-made nano-composites.

Biological Mineralization: Biomaterials design for the last 500 million years, Prof. Patricia M. Dove

With time on her side, Nature has developed the ability to produce minerals and biomaterials with exquisite designs through processes broadly known as biomineralization. Using strict spatial and chemical controls, organisms direct the nucleation and growth of carbonates, phosphates, oxides, silicates, and other inorganic materials through templates and selective introduction of macromolecules into specialized microenvironments. By modifying the interfacial energies and kinetic barriers that determine the pathways of nucleation, rates of step motion, surface morphology, and facet stability, organisms produce nanophase materials, topologically complex single-crystals, and multi-layer biocomposites. The ‘products’ have diverse biological functions such as structural support, filtration, grinding and cutting, light harvesting, gravity sensing, and magnetic guidance. This presentation will introduce biomineralization concepts through examples that show the compositional and morphological capabilities of biomaterials that can be formed. Of particular interest are the strategies that Nature uses to optimize properties that confer functional advantages for the organism.

A Cache of Nature’s Secrets: Principles of Mineral Nucleation, Growth, and Demineralization, Prof. Patricia M. Dove

Until recently, the study of biomineralization was primarily a descriptive science, with insights into mechanisms and stereochemical relationships deduced primarily from studies of structural biology and macroscopic lab-based growth experiments. Little process quantification or rigorous analysis within the well-established formalism of crystal nucleation and growth had been pursued. This presentation will establish basic principles governing crystal nucleation and growth, then examine how the last decade of nanoscale studies have significantly advanced classical views of crystallization. We will examine underlying mechanisms to show how modifications in energetic factors and stereochemical relationships enable biomineralization to proceed. A key emerging issue is how biomolecules, from simple residues to full proteins, modulate mineralization through perturbations in local solvent structure. Along the way, the presentation will show how methods in scanned probe microscopy, molecular modeling, and compositional analysis on well-defined model systems bring quantification and rigor to this fast-moving field.

Frontiers: Nonclassical mineralization from amorphous precursors and template-directed growth, Prof. Patricia M. Dove

With recent advances in high resolution cryo-tem and in situ methods, studies are showing that echinoderms, mollusks, and possibly many other organisms produce biominerals by first accumulating amorphous precursor phases into a localized area. These precursors are held until such time that chemical trigger(s) initiate the transformation into fully crystalline materials. It is believed this process, in conjunction with using organic matrices as templates, makes possible the 'shaping' of biominerals into complex morphologies. That is, the template is generally assumed to control mineral orientation and possibly stabilize and/or initiate phase transformation. While the existence of this nonclassical mineralization process appears evident, the nature of the accumulation and transformation processes is poorly understood. This presentation will summarize our emergent understanding of these processes and opportunities for future advances in biomaterials design and synthesis.

Mechanical properties and fracture mechanics of biological materials, Prof. Paul Gatenholm

The design of a material or product require from the engineer to minimize the risk of failure. This lecture will first cover basics of mechanical evaluation of man-made materials and compare them with testing of biological materials. Focus will be on understanding fracture behavior and particularly understand how biological system design materials to improve toughness using water as plasticizer, developing hierarchical organization and preventing stress concentration. Self-healing behavior of biological systems will be also discussed.

Biomimetic and Biological Inspired Control, protein as active component of sensors, actuators and micromuscles, phospholipids as material building blocks, Prof. Donald Leo

Biological systems exhibit a vast array of functionalities that provide inspiration for engineering systems. In this topic we will overview fundamental models of transport in biological systems and understand how transport can be used to develop engineering materials and systems with biomimetic properties. Examples will be provided from topics in the development of artificial muscles, protein-based transducers, and new results in cell mimics.

Biomimetic support for replacement of human organs, Prof. Aaron Goldstein

Tissue Engineering is an emerging discipline in which biomaterial scaffolds provide biochemical and mechanical signals that regulate cell morphology, direct cell proliferation and deposition of an extracellular matrix, and guide the assembly of cells into tissue structures. Key challenges is this field, therefore, are 1) to engineer the mechanical properties of the biomaterial to match those of the target tissue, 2) to develop biomaterial processing strategies that achieve surface topographies at the micron scale to guide cell alignment and porous architectures at the 100 micron scale to permit assembly of neo-tissues, and 3) incorporate both bioactive and/or bioinert (i.e., stealth) moieties at cell biomaterial interface where they can influence cell behavior through receptor-mediated signaling pathways.

Finally, the biomimetic scaffolds must be mechanically robust and capable of withstanding cyclic stresses that will be encountered both in vitro within a bioreactor and in vivo at the implant site.

Project work

At the end of course students will select biological materials such as spider silk, bone, wood, shell etc to study their structure-property relationships. U.S. students will be able to gain European Research Experience by visiting research facilities at Chalmers in Sweden (Gothenburg), University of Trento, Italy and University of Minho, Portugal. European students together with U.S. students are welcome to use advanced biomaterial characterization facility at ICTAS/NCFL at Virginia Tech. Students will take practical training of ESEM, bio-AFM and confocal microscopy to study morphology of biological materials. Our intention is to team up 4-5 students, hopefully different disciplines, for example, chemist, mechanical engineer, material scientist. The students will use then biomimetic principle to design new material. We will also provide additional lectures in early Fall about biomimetic design, Biorecyling, Renewable-feed stocks and life cycle analyses to compute the environmental aspects of biomimetic design. The lectures will be available for European students by distance learning. The course will end with short project report and student presentations. The expected student presentations are in middle of October. We will provide distance learning facilities. The course will give 3 credits (USA) or 4.5 EST credits (Bologna System).