JOURNAL OF THE MECHANICAL BEHAVIOR OF BIOMEDICAL MATERIALS 19 (2013) 1–2

ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

www.elsevier.com/locate/jmbbm

Editorial

"Science and Engineering of Natural Materials: Merging Structure and Materials"☆

It is my pleasure to introduce this special issue of JMBBM on "Science and Engineering of Natural Materials: Merging Structure and Materials". This issue is based on a special session held at the 4th International Conference on the Mechanics of Biomaterials and Tissues in December 2011 in Hawaii, and it also contains key contributions from leading researchers in this area.

Structural Engineering and Materials Science have traditionally been considered two separate engineering disciplines, with their own distinct approaches, tools, scopes and motivations. Where materials scientists concentrate on making better materials at the microscopic scales and below, examining problems such as diffusion or crystallization, structural engineers are concerned with design problems at larger scales, focusing on stress analysis, failure prediction and reliability. While there is some overlap between these two disciplines (for example, when structural engineers select a steel grade), they remain separated. In contrast, studying natural materials recently led researchers such as Markus Buehler at MIT or Marc Meyers at UCSD to observe that in nature, there is really no distinction between material and structure. In nature specific structures and mechanisms can be observed at various length scales, seamlessly from nanometers to micrometers to the size of the organ or tissue (millimeter to meters). Where material stops and structure begins is not clear, and this question is probably not relevant is terms of overall performance (which is what eventually matters). In contrast to engineers nature does not "design" at a "material" level or at a "structural level": The structures and mechanisms we observe in natural materials emerged from evolutionary processes, slow selections towards better fitness (with the environment, with other species…). The results are fascinating: exquisite microstructures organized of multiple length scales, materials with unique combinations of stiffness and toughness (seashells), materials which are stronger and tougher than steel (spider silks) or materials that can heal (bone). All of these feats are achieved by assembling small "building blocks" of relatively poor structural properties in ways which fully exploit the benefits of size effects at the nanoscale and the "property amplification" effects of structural hierarchy. Can we use the same seamless approach to develop, optimize and fabricate new materials and systems in a unified manner, merging materials science and structural engineering? This paradigm shift has already started, for example in the design and optimization of carbon fiber reinforced polymers: engineers must take integrate the orientation of the microscopic carbon fiber in the design of larger structures, ensuring that the local orientations of the fibers are optimum with respect to the geometry of the structure and the stresses it carries. This is just the beginning, and we certainly still have a lot to learn from the construction and mechanics of natural material to perfect our approach to the optimization of components at all scales.

The articles of this Special issue reflect this vision of "merging structure and materials". Chen and Pugno (pp. 1–28) start by giving an overview of the mechanics of high-performance natural materials including nacre from seashells, gecko feet, byssus threads from mussels, spider silk, lobster cuticle, armadillo and turtle shells, diatoms and plants. They observe that these materials display high toughness, strength and deformability, because of their hierarchical organization, their ability to incorporate stiff and strong minerals, and their organization over long length scales, as seen in gradients of porosity in turtle shell. Bosia et al. (pp. 29–37) follows up by systematically demonstrating how organizing the fibers of a composite into hierarchical bundles can increase their overall strength by as much as 20%. Solar and Buehler (pp. 38–44) explore how nature turns relatively brittle molecular building blocks, in this case amyloid fibrils, into strong and reliable materials. As demonstrated by this work, minute changes of properties in the structure or properties of the building blocks can have profound impacts on overall performance, with sometimes dramatic implication as seen in genetic diseases. Since natural materials are made of building blocks, the "glues" which hold these blocks together is at least equally important as the building blocks. This becomes even more evident when one appreciates that energy dissipative mechanisms and toughness are often produced at the interfaces, via for example sliding or gliding mechanisms. Rabiei et al. (pp. 45–55) measured and compared the toughness of the interfaces of three types of nacre, a high-performance natural composite found of seashell

☆This paper was presented at the Fourth International Conference on the Mechanics of Biomaterials and Tissues (ICMOBT4).

which has a "brick and mortar" structure. Their results show that the interfaces in nacre are more fragile than the mineral tablets, which is indeed a requirement for cracks to circumvent these inclusions. They also show that the toughness of the interfaces does not depend only on the intrinsic toughness of the organic "adhesives" binding them, but also on the morphology of the interface including nano-roughness. One of the challenges in modeling natural materials is to integrate a variety of complex mechanisms which occur over different time and length scales. Dhote et al. (pp. 56–69) present a nice example of such approach, with a model for engineered cartilage which incorporates a wide array of deformation mechanisms, transport phenomena and growth. Characterizing structure–properties relationships in natural materials and systems experimentally can be equally challenging, and Browning et al. (pp. 70–81) show that useful insights can be gained by studying simplified analogs of natural structures. They built models of fish scales using stiff thermoplastic plates embedded in elastomeric matrices to study the effect of scale morphology, scalation pattern, composition and material property on overall performance. Details of mechanisms such as scale rotation, scale–scale interactions and scale–matrix interactions provide invaluable insight into the mechanics of natural fish scale, and useful lessons and guidelines for future biomimetic materials. Finally Hunger et al. (pp. 82–88) demonstrate how lessons from natural material (mineral phase with highly controlled configuration and hierarchy) can be used in the design and fabrication of new high-performance engineering materials. They present an interesting new cellular material built over two length scales which outperforms traditional cellular materials by a factor of 1.5 to 4 in terms of stiffness, strength and toughness. This is a great example of how bio-inspiration can be used to expand the range of properties of engineering materials.

I would like to thank all the authors for their contributions to this special issue, which I hope will be both instructive and enjoyable.

Francois Barthelat[1]
Department of Mechanical Engineering, McGill University, Montreal, QC, Canada

1751-6161/$ - see front matter

http://dx.doi.org/10.1016/j.jmbbm.2013.02.001

[1]Guest Editor, Special Issue on "Science and Engineering of Natural Materials: Merging Structure and Materials", Journal of the Mechanical Behavior of Biomedical Materials. Organizer and Chair of the special session at the 4th International Conference on the Mechanics of Biomaterials and Tissues in December 2011 in Hawaii.