Three examples of segmented structures in nature and how they inspire better flexible armor, tougher glass and new morphing materials

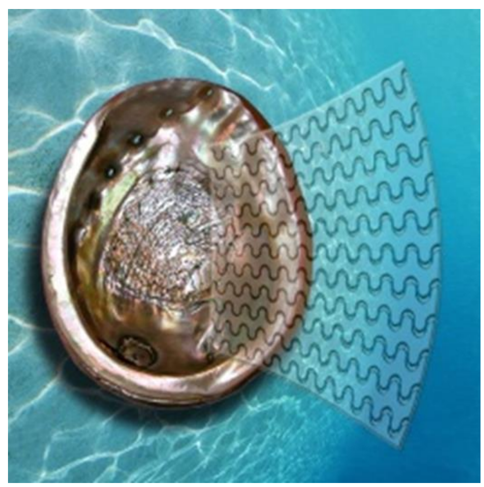
Francois Barthelat

Department of Mechanical Engineering

University of Colorado Boulder

Abstract

Segmentation and repetition of structural motifs is a “Universal” rule of construction in biology: Nature abound in examples of segmented materials and structures including spines segmented into vertebrae, tessellated turtle shells, annelid worms, articulated arthropod shells. Compared to monolithic materials and structures, segmented materials have a richer architecture that involves size, morphology and arrangement of individual structural units. These additional structural parameters and features lead to intriguing mechanisms and to combinations of mechanical properties that surpass monolithic materials. The properties are the most impressive when the building blocks are very stiff, and when these blocks interact through much softer materials or even only friction. These general principles lead to building blocks which can slide, rotate, separate or interlock collectively, providing a wealth of tunable mechanisms, precise structural properties and functionalities. In this talk I will discuss three specific examples of segmented biological materials: The scaled skin of fish, nacre from mollusk shells, and fish fins. Each of these systems display unique and powerful mechanisms which we have been exploring using combinations of experiments, modeling and 3D printing. The scaled skin of fish provides unique combinations of flexible armored protection from finely tuned scale-scale and scale-substrate interactions. Nacre from mollusk shells is a bioceramics that displays quasi-ductile behavior and outstanding toughness from the collective “sliding” of the mineral tablets of which it is made. Fish can change the camber of individual fin rays using muscles at the base of the fin, yet fins are also stiff enough to sustain large hydrodynamic forces without collapsing – a unique morphing performance which we explained by the segmented architecture of the rays. We are now using these bioinspired concepts and micro-architectures to develop flexible protective gloves covered with hard elements, nacre-like laminated glasses with superior impact resistance, and new morphing materials for applications in aerospace and robotics.



Bio

Francois Barthelat is Professor of Mechanical Engineering at the University of Colorado Boulder. He obtained his PhD from Northwestern University in 2006, and was a Professor in Mechanical Engineering at McGill University (Montreal, Canada) from 2006 to 2019. Francois Barthelat founded the Laboratory for Advanced Materials and Bioinspiration to explore key structures and mechanisms in natural materials, and to develop new bioinspired, high-performance materials. Dr. Barthelat and his students have discovered new deformation and fracture mechanisms in bone, in mollusk shells and in fish scales. They have also pioneered new bioinspired materials and systems which they are now implementing in engineering applications. The new bioinspired strategy he and his students developed to toughen glass was selected among the top ten scientific discoveries in Quebec by the magazine *Quebec Science* in 2014. He is also the recipient of the Hetényi Award for best research paper in *Experimental Mechanics*, of a Discovery Accelerator Supplement from NSERC, and of a Department of National Defence /NSERC Discovery Grant Supplement. Barthelat serves on the editorial board of *Scientific Reports*, *Bioinspiration and Biomimetics*, the *Journal of the Mechanical Behavior of Biomedical Materials* and *Mechanics of Materials.*