IOWA STATE UNIVERSITY
Department of Mechanical Engineering

Mechanics of Biological Materials and Biomimetic Design

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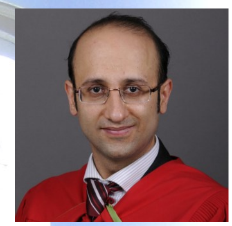

Abstract

Part 1: In contrast to man-made materials, nature designs materials (from relatively weak constituents) with excellent functional properties through combining high stiffness, low weight, high strength and remarkable toughness. Such materials can be considered as patterns for designing composites with novel microstructural elements and remarkable mechanical properties. Such properties are the result of nature's hierarchical design patterns as well as unique structural and material functional gradients employed at multiple scales. The elytron of beetles is a unique example of biological materials which is of significant interest due to its multifunctional properties, such as supporting the animal's weight and resisting predator attacks and environmental damage while enabling locomotion. The core region inside the exoskeletons is composed of chitin fibrils arranged in a helicoidal stacking. Elytra distinguish beetles from all other insect orders and are widely acknowledged as a key biomechanical trait. Cross-species comparisons, and the study of mechanical properties of biological composites have traditionally pertained to the separate realms of biology and engineering, respectively, despite the ostensible links that bind mechanical performance to biological functionality. In an attempt to bridge the aforementioned fields, we present integral comparisons encompassing the macro-, micro- and nanostructure of four beetle species from the same taxonomical subfamily to understand the adaptation of the elytra *bauplan* to changes in body size spanning three orders of magnitude. The results reveal the workings of a natural strategy combining both invariant and scalable features to synergistically accommodate size changes while maintaining functionality. Despite the substantial differences in size, the integration of size-dependent and size-independent strategies manages to endow each beetle with similar specific mechanical performance (stiffness, strength, and energy absorption capabilities) together with an array of toughening mechanisms to ensure biomechanical functionality pertaining to protection and flight. The results promise to elucidate additional biological design rules that could be leveraged in the design of scalable synthetic composites.

Part 2: Biological tissues demonstrate an array of hierarchical arrangements across length scales that are deemed essential to mechanical properties emerging from tissue building blocks. Such hierarchical arrangements evolved to reach overall properties that confer arteries with functional elasticity while preserving mechanical integrity. In the second part of this talk, we show that while the mechanical stiffness of single collagen fibrils in the layers of human aorta are on the order of a few megapascals, the hierarchical entanglements of such fibrils with other extracellular matrix components, leads to tissue level mechanical stiffness of the order of kilopascals. Such tissue stiffness enables necessary deformations while smoothening the highly pulsatile nature of the blood flow in the aorta (i.e., Windkessel effect). This microstructural and nano-mechanical quantification methodology can serve as protocols to interrogate ultrastructural changes resulting from various diseases, e.g., atherosclerosis, wherein fibrillar geometry and stiffness changes within extracellular matrix may help predict plaque rupture.

Biography

Meisam Asgari is currently a research associate of mechanical engineering at McGill University working with Professor Marco Amabili. He has a B.Sc. with distinction in Mechanical Engineering (2007) and an M.Sc. in Applied Solid Mechanics (2011) from Isfahan University of Technology, and a PhD in Mechanical Engineering from McGill University, Canada (Nov. 2015). Upon graduation, he completed a postdoctoral training in the Laboratory of Architectured Materials at McGill University (2016-2018). He then joined the Micro and Nano Mechanics Laboratory at Northwestern University as an NSERC Fellow (2018-2020). He has won several awards such as NSERC PDF grant, FRQNT PDF scholarship, McGill outstanding TA award, McGill Graduate Research Mobility Award and McGill Graduate Excellence Fellowship. His research lies in the area of micro- and nano- mechanics, multi-scale characterization of biological materials and soft tissues, toughening mechanisms in natural composites, and bio-inspired design of advanced materials. His current research at McGill University involves ultrastructural and nano-mechanical characterization of human aorta as a result of extracellular matrix remodeling associated with cardiovascular diseases.

This seminar counts towards the ME 600 seminar requirement for Mechanical Engineering graduate students.

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