Structural Mechanics Seminar

Departments of Civil and Mechanical Engineering
Advanced Structures and Composites Center

Friday September 11, 2015, 3:10 pm
St. John Hill Auditorium, Barrows Hall

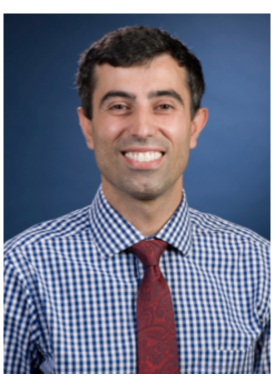
MULTISCALE TOUGHENING AND STRENGTHENING MECHANISMS: LESSONS FROM NACRE AND BAMBOO

Prof. Nima Rahbar
Worcester Polytechnic Institute

This talk focuses on the fundamental ideas arising from understanding the mechanisms behind the superior mechanical properties of biological materials through two specific examples of nacre and bamboo.

The mechanical behavior and toughening mechanisms of abalone nacre-inspired multilayered materials are explored. In nacre's structure, the organic matrix, pillars and the roughness of the aragonite platelets play important roles in its overall mechanical performance. A micromechanical model for multilayered biological materials is proposed to simulate their mechanical deformation and toughening mechanisms. The modeling results are in excellent agreement with the available experimental data for abalone nacre. The results demonstrate that the aragonite platelets, pillars and organic matrix synergistically affect the stiffness of nacre, and the pillars significantly contribute to the mechanical performance of nacre. It is also shown that the roughness induced interactions between the organic matrix and aragonite platelet, represented in the model by asperity elements, play a key role in strength and toughness of abalone nacre. The highly nonlinear behavior of the proposed multilayered material is the result of distributed deformation in the nacre-like structure due to the existence of nano-asperities and nano-pillars with near theoretical strength. Finally, tensile toughness is studied as a function of the components in the microstructure of nacre.

Bamboo, a fast-growing grass, has higher strength-to-weight ratios than steel and concrete. The unique properties of bamboo come from the natural composite structure of fibers that comprises mainly cellulose nanofibrils in a matrix of intertwined hemicellulose and lignin called lignin-carbohydrate complex (LCC). Here we have experimentally and numerically studied mechanical and fracture properties of bamboo at multiple scale. We have utilized atomistic simulations to investigate the mechanical properties and mechanisms of the interactions of these materials in the structure of bamboo fibers. With this aim, we have developed molecular models of lignin, hemicellulose and LCC structures to study the elastic moduli, glass transition temperatures and adhesion energies between LCC/cellulose nanofibril faces. Good agreement was observed between the simulation results and experimental data. It is also shown that a control hemicellulose model has better thermodynamic and mechanical properties than lignin while lignin exhibits greater tendency to adhere to cellulose nanofibril. Therefore, the role of hemicellulose found to be enhancing the mechanical properties while lignin provides the strength of bamboo fibers. The study suggests that the abundance of hydrogen bonds in hemicellulose chains is responsible for improving the mechanical behavior of LCC. The strong van der Waals forces between lignin molecules and cellulose nanofibril is responsible for higher adhesion energy between LCC/cellulose nanofibrils. We also found out that the amorphous regions of cellulose nanofibril have the weakest interface in a bamboo fiber. They ultimately determine the strength of fibers.



Dr. Rahbar joined WPI in August 2012 as an Assistant Professor. His research interests are in the area of bioinspired design of materials with an emphasis on mechanical and thermal properties across multiple scales. Dr. Rahbar has won several awards including TMS Young Leader's award in 2013, Air Force Summer Faculty Fellowship Award in 2013 and NSF CAREER award in 2012. Before joining WPI, Dr. Rahbar was a faculty member in the Civil Engineering Department at the University of Massachusetts Dartmouth from 2008-2012. He received a PhD in Civil Engineering from Princeton University in 2008.