

**MECHANICAL ENGINEERING DEPARTMENT
ME/ISYE 8773-8774**

Cracking the Conch Conundrum: Tough Ceramics at the Seashore

by

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Wednesday, September 17, 2008
3:15 p.m. — Refreshments before the seminar
3:30 p.m. — Graduate Seminar
Room 1130 Mechanical Engineering

ABSTRACT — Natural composite materials are renowned for their mechanical strength and toughness; despite being highly mineralized, with the organic component constituting not more than a few percent of the composite material, the fracture toughness exceeds that of single crystals of the pure mineral by two to three orders of magnitude. The judicious placement of the organic matrix, relative to the mineral phase, and the hierarchical structural architecture extending over several distinct length scales both play crucial roles in the mechanical response of natural composites to external loads. In this talk experimental and theoretical results are first used to show that the resistance of the shell of the conch *Strombus Gigas* to catastrophic fracture can be understood quantitatively by invoking two energy-dissipating mechanisms: multiple cracking in the outer layers at low mechanical loads, and crack bridging in the shell's tougher middle layers at higher loads. Both mechanisms are intimately associated with the so-called crossed lamellar microarchitecture of the shell, which provides for tunnel cracking in the outer layers and uncracked structural features that bridge crack surfaces, thereby significantly increasing the work of fracture, and hence the toughness, of the material. Despite a high mineral content of about 99% (by volume) of aragonite, the shell of *Strombus Gigas* can thus be considered 'ceramic plywood' (albeit plywood fails in a different manner than the shell), and can guide the bioinspired design of tough, lightweight structures. The talk ends with a description of a modest attempt to mimic the crossed-lamellar structure using microelectromechanical systems fabrication techniques. The prototype beam structure, which relies on polycrystalline silicon (photoresist) to take the role of the mineralized tissue (organic matrix), was mechanically tested under displacement control using a nanoindenter. While the model structure involves only two distinct length scales, it shows graceful failure.

BIO — **Roberto Ballarini** obtained his B.E. from City College of New York (1980), and his M.S. (1981) and Ph.D. (1985) from Northwestern University, all in Civil Engineering. He is currently James L. Record Professor and Head of the Department of Civil Engineering at University of Minnesota. Professor Ballarini's research focuses on the development and application of theoretical and experimental techniques to characterize the response of materials to mechanical, thermal, and environmental loads. He is particularly interested in formulating analytical and numerical models for characterizing fatigue and fracture of materials and structures. His multidisciplinary research has involved problems arising in civil engineering, mechanical and aerospace engineering, materials science, electronics, biological tissues and prosthetic design. He has published over sixty refereed papers in the general area of fracture mechanics, and has given invited lectures at universities around the world. Several of his research projects have been featured in the popular press, including the New York Times Science Times, Science News, Business Week, Financial Times of London, Geo, and Industry Week. His current research involves the mechanical behavior of microelectromechanical systems and of nanoscale biological and synthetic tissues, and bioinspired design of composites.

Informal Faculty Luncheon: Wednesday, September 17, 2008, 12:00 noon. Meet in 1100 ME and walk to lunch with other faculty. Prof. Roberto Ballarini will be able to attend. Host: Prof. Traian Dumitrica