Variable-Amplitude Fatigue: An Exciting Bridge to Cross Between Research and Engineering Application

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Most research in metal fatigue continues to be stuck with constant amplitude loading. Without exception, practical engineering problems involve a variable-amplitude load environment. Fatigue crack growth under variable-amplitude offers exciting opportunities for research of fundamental and the same time, interdisciplinary nature that promise results of practical importance. This talk attempts to 'sell' metal fatigue as an ever-young area, and one, where Nature is willing to reveal new secrets provided one is willing to design imaginative experiments and models that embody a persistent spirit of enquiry. Secrets, that industry could benefit from.

Crack Localization in Soft Materials

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Traditional hyperelastic models are developed to describe the mechanical response of intact materials. So, these models satisfy the material stability requirement. Strong ellipticity condition, Baker-Ericksen inequalities, polyconvexity are different forms of material stability requirement. However, all materials fail. Therefore, it is necessary to predict the onset of crack localization— a precursor to catastrophic failure, in order to ensure the safety of the structures. No real material can accumulate energy beyond a critical value— critical failure energy. We introduce this energy limiter in the constitutive model and predict the onset of material instability via the loss of strong ellipticity of the associated incremental initial boundary value problem. Loss of strong ellipticity corresponds to the onset of vanishing wave speed of the superimposed plane wave. This work concerns soft materials which usually resist volumetric changes much more than shape distortions. This leads us to enforcing the incompressibility constraint in the analysis of failure of soft materials. Enforcement of the incompressibility constraint, rules out longitudinal waves. Hence, we consider the propagation of transverse waves superimposed on the homogeneous deformation states.

This work particularly addresses two interesting problems. First, we find the direction of crack localization in rubber bearings under combined compression and shear. Our study shows that cracks localize in horizontal direction, parallel to the shear. We also find that compression delays the onset of crack localization. Second, we examine the damage localization in a sheet of aneurysm material subjected to equi-biaxial tension. We find that the aneurysm sheet exhibits infinitely many possible directions of damage localization under equi-biaxial tension.

Flagellum-inspired Soft Underwater Propulsor Exploiting Passive Elasticity

Dr Costanza Armanini

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Among the numerous themes in which soft robotic technologies have quickly branched, underwater robotics stands out, on one hand, for its added complexity and, on the other hand, for offering an especially suitable context to test these new kinds of machines. Within the context of aquatic organisms, major sources of inspiration have been drawn from fish and cephalopods, but equally compelling to design bioinspired aquatic vehicles is the study of flagellated bacteria. These prokaryotic microorganisms sport a vast repertoire of swimming strategies mediated by subtle differences in the structure and kinematics of the flagellum, which ultimately enable efficient propulsion. A limited range of flagellum-inspired prototypes exists, characterized by a stiff structure and ranging in size in the micrometre scale. However, flagella are an interesting case study in soft robotics because they closely resemble, from a morphological and dynamics perspective, some of the archetypal continuum manipulators. This, along with the simplicity of their actuation and the richness of their dynamics makes them a valuable source of inspiration to design continuum, self-propelled underwater robots. In this presentation, we introduce the design, model and testing of a macro-scale aquatic soft robot inspired by flagellated prokaryotic bacteria which exploits the compliance of its own body to passively attain a range of geometrical configurations from the interaction with the surrounding fluid. The spontaneous formation of stable helical waves along the length of the flagellum is responsible for the generation of positive net thrust. We investigate the relationship between actuation frequency and material elasticity in determining the steady-state configuration of the system and its thrust output. This is ultimately used to perform a parameter identification procedure of an elasto-dynamic model aimed at investigating the scaling laws in the propulsion of flagellated robots.

Unraveling the connection between architecture and toughness in layered biological ceramic composites

Dr Max Monn

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Layered architectures can drastically increase the fracture toughness of some stiff biological composites, like bone and shell. The connection between layer geometry and toughness enhancement, however, is not fully understood. Understanding how variations in the geometry of a layered architecture affect toughness is critical for designing bio-inspired composites and avoiding the pitfalls of naive biomimicry.

We used the silica fibers, known as spicules, produced by the marine sponge Euplectella aspergillum as a model system for investigating this structure-property connection. Several research groups have previously speculated that the spicule's cylindrical layered architecture provides substantial toughness enhancement. However, the current work contains the first measurements of the spicule's fracture toughness.

By performing notched flexural tests on these spicules, we show that the spicule's cylindrical layers do not provide the dramatic toughness enhancements observed in biological composites containing flat layers. We explore the cause of this reduced toughness enhancement using a computational model. The model shows that the curvature of the spicule's layers bypasses some critical toughness enhancing mechanisms that would otherwise be activated by the layered architecture (like in nacre or bone).

Finally, we discuss this finding in the context of the mechanical function the spicule provides to the sponge and explore alternative hypotheses for the existence of this intricate architecture.

Design, Fabrication and Mechanics of Tough Transparent Bio-inspired Architectured Materials

Dr Zhen Yin

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Glass receives sustained demand in mechanical, biomedical, electronic and photovoltaic applications because of its outstanding optical properties, hardness and chemical stability. The brittleness of glass leads to poor reliability and low damage tolerance in these applications. The low deformability of glass also limits its applications on flexible electronics and wearable devices. Tempered glass increases strength of glass, but they suffer catastrophic failure even by slightest damage. Laminated glass improv safety of glass by using polymer interlayers to hold the glass fragments together, but it does not change the brittle behavior of glass. Interestingly many hard biological materials such as tooth enamel and mollusk shells are made of brittle minerals but have toughness thousands of times higher than their weak constituents. Their microstructures provide templates for us to design tough structures and materials using brittle materials. However, it has been a major challenging to duplicate the structures and mechanisms of biological materials despite of decades of research efforts. In this work, we use three-dimensional laser engraving to carve highly controlled structures in glass and develop a series of transparent bio-inspired architectured glasses. Although made of more than 90 wt% glass, the bio-inspired architectured glasses are highly deformable and tough with decent stiffness and strength. Fracture toughness of the bio-inspired architectured glass can go up to two orders of magnitudes higher than plain laminated glass, and their impact resistance is more than twice higher than tempered glass and plain laminated glass.

How Supertough Gels Break

Dr Itamar Kolvin

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Soft materials may stretch far before they break. Fracture in these materials is challenging to our current understanding of how things break, which is based on small-strain linear elasticity. This problem is most conspicuous in a novel class of materials— tough gels. These soft materials owe 2–3 orders of magnitude increase in toughness to a combination of two or more types of polymer networks or cross-linkers.

I will show how we directly visualized rupture of tough double-network gels at $> 50\%$ strain. During fracture, crack tip shapes obey a $x \sim y^{1.6}$ power law, in contrast to the parabolic profile observed in low-strain cracks. A new length scale emerges from the power law that scales directly with the stored elastic energy and diverges when the crack velocity approaches the shear wave speed. Our results show that double-network gels undergo brittle fracture and provide a testing ground for large-strain fracture mechanics.

Fatigue and fracture of orthopedic polymers

Prof Lisa Pruitt

University of California, Berkeley

I will speak broadly about our research into the characterization of fatigue and fracture behavior of clinical polymers used in load-bearing orthopedic applications. I will also speak broadly to the importance of diversity in faculty hiring and student mentoring. Moreover I will speak to the benefits of creating inclusive classrooms and a culture of belonging in engineering and science.