

Proposal for a PhD Position

Bio-inspired functionally graded laminate layers to maximize flexibility and acting as fracture propagation traps

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Layered structures have proven to be advantageous in material design, especially for brittle materials such as ceramics. The interest in this topic, which has been extensively studied in the literature in recent decades, has its origins in the brittleness of engineering ceramic materials under tension or bending, despite their otherwise excellent thermomechanical properties [1-2]. Modern engineering materials are often used in critical applications where reliability is the most important property and thus sudden, uncontrollable fracture is therefore unacceptable. For these structures, toughness is at least as important as strength, if not more so. It is only recently that physics- and materials-based research focused on the search for materials and/or structures that simultaneously exhibit high strength and toughness. *Surprisingly, such structures are frequently found in nature.* Biological structural materials such as bone, dentin, tooth enamel, mollusk and crustacean shells and sponge silica skeletons fulfill a variety of mechanical functions, including facilitating locomotion and providing protection from predators and severe environmental conditions. The survival of an organism relies on the mechanical capabilities of structural biomaterials or biominerals. These later are composite or laminate layer materials containing an organic component and nano- or micro-scale amorphous or crystalline minerals. From a materials science perspective, organic molecules are soft, compliant and fracture resistant (tough) while inorganic crystals are hard and brittle. However, these biomineral composites combine the best of these properties and minimize the weaknesses: they are both hard and tough which explains our interest in studying them [3-5].

The proposed PhD project originates from an observational and qualitative examination conducted on both *Euplectella Aspergium* (EA) and *Monorhaphis Chuni* (MC) glass sponges (current PhD project-2022-2025). Both glass sponges live in deep sea that explains why it is important for there to resist hydrodynamic forces and be able to cope with uneven loads as the sponge moves in the ocean current. Glass is a brittle and inflexible material that is not traditionally associated with applications where bending is needed. So, how do they adapt to their environment? These animals skeleton show complex hierarchical structure from the nanometer to the macroscopic scale. However, several hypotheses have been discussed in the literature but never verified. One of the hypotheses that can be drawn is that the absorption of mechanical energy by the sponge is ensured by the macro-scale (millimetric scale), where the structure is periodic and regular, while its flexion is ensured by the internal structure of their beams, called spicules (\sim several ten of μm).

What is unique at this scale? When observing a cross-section of a EA spicule, we will notice that it is composed of glass core surrounded by a concentric cylinders glass layers with a thin biological layer sandwiched in between each one [6-7]. Many previous studies of EA and MC spicules suggest that the concentric glass layers give strength under tension to the spicule, while the biological layers act as a glue, prevent cracks propagating through the entire spicules thickness, and give them flexibility. It is suggested that the organisms drastically enhance by two to three of magnitude the toughness of brittle ceramics, like calcium carbonate or silica, by adding just a few wt.% of organic macromolecules. This hypothesis, which appears scientifically plausible, has been mentioned many times in different studies but never verified. Our study could help design model multi-layered materials inspired by the structure of the spicule and address question that remain open so far.

References:

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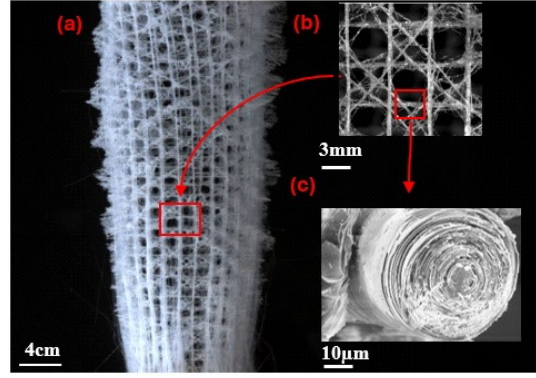


Figure 1: Euplectella aspergillum skeletal structure. (a) Photographic image of a cleaned sponge specimen showing the full skeletal structure, (b) The square-grid architecture and regular ordering of the vertical and horizontal components of the skeletal system, (c) At higher magnification, laminated organic/inorganic hybrid structure of the spicules. Copyright reserved for this image (Hassan's PhD project 2022-2025).

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