Nanocomposites bio-inspired from natural seashells

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Because of severe design constraints, natural materials use alternative approaches to achieve mechanical performance. Most natural structural materials are composite materials. Nature builds these composites from the bottom up, starting from nanoscopic elements to macroscopic components. Each of the scales from nano to macro contributes to the overall performance of the material: their structure is said to be hierarchical. Moreover, these materials have been put to mechanical tests for millions of years, and through evolution their microstructure has been tailored and optimized for the type and magnitude of loading they must experience. A better understanding of how the microstructure of these materials is related to their mechanical performance has the potential to inspire new material designs.

The current project focused on nacre from molusks such as Red Abalone. Nacre is the iridescent innner layer found inside of the shell. It consists of a brick-and-mortar-like microstructure of 95% aragonite tablets ($CaCO_3$, a very brittle ceramic) and 5% soft organic compound. By the addition of this small amount of an organic phase and a well-designed microstructure, it achieves strenght and toughness that are 20 to 30 times those of pure aragonite. This toughness is key because nacre's biological function is to preserve the integrity of the shell of the outer calcite layer is damaged.

In order to identify the mechanisms involved in tablet sliding, in-situ quasi-static fracture tests were performed on wet natural nacre. A three point bending fixture was mounted on a miniature loading stage. Optical Microscopy and Atomic Force Microscopy were used to observe the involved mechanisms at different scales. Digital Image Correlation techniques were used to quantify the sliding of the tablets during the experiment.

The understanding of these mechanisms were then used to design novel high-performance composite bio-inspired materials.

This research work was published in high ranked journals such as *Nature Communication* or *Experimental Mechanics*.

Relevant publications:

* H. D. Espinosa, A. L. Juster, F. J. Latourte, O. Y. Loh, D. Grégoire, and P. D. Zavattieri, “Tablet-level origin of toughening in abalone shells and translation to synthetic composite materials.,” Nature communications, vol. 2, no. 2, p. 173, 2011.
* D. Grégoire, O. Y. Loh, A. L. Juster, and H. D. Espinosa, “In-situ AFM Experiments with Discontinuous DIC Applied to Damage Identification in Biomaterials,” Experimental Mechanics, vol. 51, no. 4, pp. 591–607, 2011.
* H. D. Espinosa, D. Grégoire, F. Latourte, and O. Loh, “Identification of Deformation Mechanism in Abalone Shells Through AFM and Digital Image Correlation,” Procedia IUTAM, vol. 4, pp. 27–39, 2012.