

Synthetic materials that behave like mollusk shells

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Nacre, commonly known as mother-of-pearl, is the iridescent material lining many mollusk shells. It is part of a two-layer armor system that protects the animal from predators. The brittle outer layer of the shell absorbs the initial impact, but is prone to cracking. To prevent these cracks from catastrophically propagating through the shell to the animal itself, the nacreous layer is surprisingly strong and tough, with outstanding crack arresting properties. Thus it acts as a lining to maintain the integrity of the shell in the event of cracking of the outer layer.

"What makes this [natural material](#) unique is that it is composed of relatively weak constituents," said Owen Loh, a graduate student at Northwestern University. At the microscale, brittle calcite tablets are stacked in a brick-and-mortar-like structure with thin layers of biopolymer lining the interfaces between tablets. This results in a material that well outperforms its individual constituents. For example, the toughness of nacre is orders of magnitude greater than that of the tablet material itself. In addition, nacre is at once strong and tough, a combination that is generally mutually exclusive in engineering materials.

As a result, nacre has been the object of significant interest within the materials community and serves as a model after which numerous man-made [composite materials](#) are designed. This includes composites for light-weight armor systems and structural elements in transportation and aerospace applications.

Nacre's outstanding performance has long been attributed to its brick-and-mortar microstructure. However, the specific attributes of this hierarchical structure, which contribute to the toughness of nacre, have been the subject of debate. As a result, efforts to translate deformation mechanisms observed in nacre into man-made composite materials have been widespread but mostly unsuccessful.

In a paper published online in the journal *Nature Communications*, Horacio Espinosa, the James N. and Nancy J. Farley Professor in Manufacturing and Entrepreneurship at the McCormick School of Engineering and Applied Science at Northwestern, Loh and colleagues report the identification of specific characteristics of the material microstructure that enable its outstanding performance. By performing detailed fracture experiments within an atomic force microscope, the group was able to directly visualize and quantify the way the tablets slid relative to each other as the material is deformed.

The group previously found that the tablets are not perfectly flat but instead have an inherent waviness in their surfaces. As a result, they tend to interlock as they slide relative to each other, spreading damage and dissipating energy over large areas. "We published these results before but it took atomic scales experiments to confirm our hypothesis on the origin of toughness in these biomaterials," Espinosa said.

The group then applied the findings to the design of artificial composites. "We took what we learned from natural nacre and designed a scaled-up artificial composite material with an interlocking tablet structure," said Pablo Zavattieri, a co-author of the paper and assistant professor of civil engineering at Purdue University. "By applying nacre's highly effective toughening mechanism to this material, we were able to achieve a remarkable improvement in energy dissipation."

The findings have important implications for future design of high-

performance composite materials. "We believe these findings may hold a key to realizing the outstanding potential of nanocomposites," Espinosa said. "While carbon nanotubes and other nanoscale reinforcements utilized in these materials have unprecedented properties, their performance has yet to be translated to bulk composites. By implementing toughening mechanisms such as those we found in natural nacre, we may be able to achieve this."

Provided by Northwestern University

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