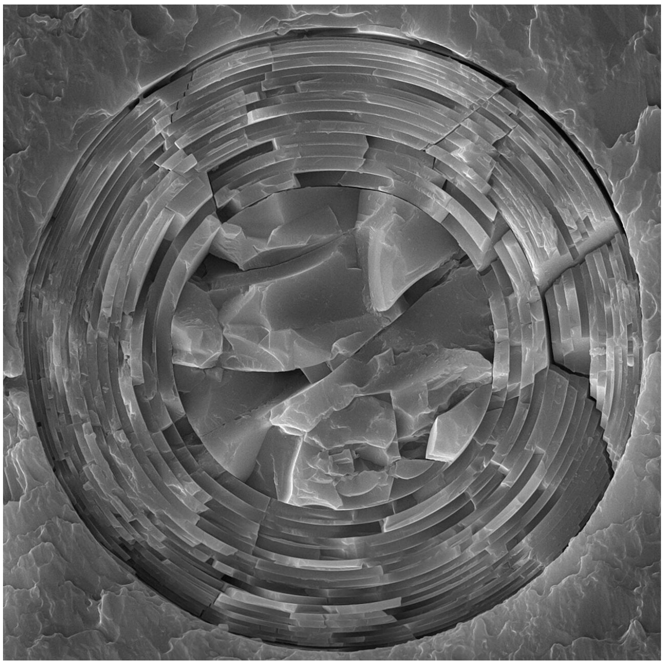
Not all of nature's layered structures are tough as animal shells and antlers, study finds

17 January 2020, by Kevin Stacey



The anchor spicules that hold the sponge species Euplectella aspergillum to the ocean floor have an intricately layered internal structure. Similar layered structures are known to increase the toughness of materials like bone and nacre. But this new research finds that the layering in the spicules does little to enhance toughness. The research could help to avoid "naive biomimicry," the researchers say. Credit: Kesari Lab/Brown University

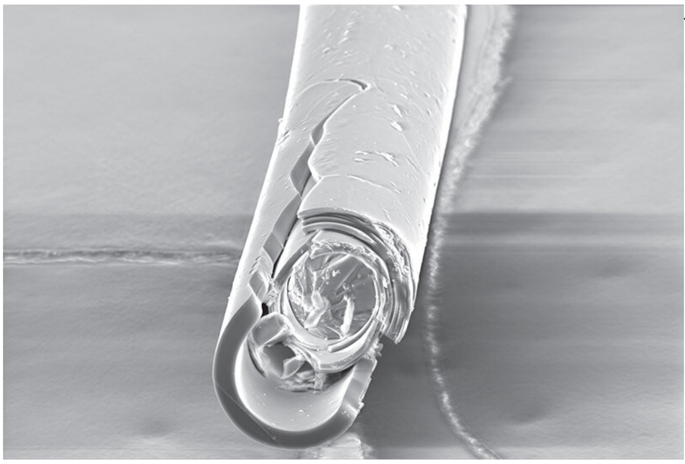
Nacre—the iridescent part of mollusk shells—is a poster child for biologically inspired design. Despite being made of brittle chalk, the intricately layered microstructure of nacre gives it a remarkable ability to resist the spread of cracks, a material property known as toughness.

Engineers looking to design tougher materials have long sought to mimic this kind of natural layering, which is also found in conch shells, deer antlers and elsewhere. But a new study by Brown University researchers serves as a caution: Not all layered structures are so tough.

The study, published in *Nature Communications*, tested another layered microstructure renowned for its physical properties—the anchor spicules of a sea sponge called Euplectella aspergillum. The spicules are tiny filaments of layered glass that hold the sponges to the sea floor. The layered structure of the spicules is often compared to that of nacre, the researchers say, and it's been assumed that the spicule structure similarly enhances toughness. This new study finds otherwise.

"Despite the similarities between the architectures of nacre and Euplectella spicules, we found that the spicule's architecture does relatively little in terms of enhancing its toughness, contrary to a long-held assumption," said Max Monn, a recently graduated Ph.D. student at Brown and a study coauthor.

For the study, the researchers compared the toughness of Euplectella spicules to those of another sponge species, Tethya aurantia. Tethya spicules have a similar chemical composition to Euplectella spicules but lack the layered structure. To test toughness, the team put tiny notches in the spicules and then bent them. By measuring the energy consumed when cracks propagated from the notches under bending strain, the researchers could quantify the toughness of both types of spicules.



The researchers found that when layered architecture is curved, cracks can propagate from layer to layer. That negates the toughness enhancement normally associated with layering in stiff biological materials. Credit: Kesari Lab / Brown University

The experiments showed very little difference in toughness between the two spicules, which suggests that Euplectella's layering doesn't provide much of a toughness enhancement. Using computer modeling, the researchers were able to look deeper into why layering enhances toughness in some materials and not others. The models showed that the curvature of the layering in cylindrical spicules seems to turn off the toughness enhancement of layered structures. Flat layers, like those found in nacre, seem to prevent cracks from spreading from one layer to the next, the researchers say. But in materials with curved layers like the Euplectella spicules, cracks are able to jump from layer to layer rather than being stopped between the layers.

The findings reveal a previously unknown relationship between curvature and toughness in layered materials and have implications for the design of bio-inspired composite materials, says Haneesh Kesari, an assistant professor in Brown's School of Engineering and the paper's senior author.

"Specifically, it shows that if you adopt a layered architecture in order to enhance the toughness of a material, you should be careful of areas that require the layers to be curved," Kesari said. "Our measurements of the spicules and results from our computational model show that curved layers don't provide the same magnitude of toughness enhancements as when layers are flat."

The findings don't mean that the layered structure of Euplectella spicules isn't interesting. Previous work from Kesari's lab has shown that the layered structure seems to vastly increase the spicules' bending strength—to withstand large bending curvatures before failing. But bending strength and toughness are very different mechanical properties, and helping to dispel the idea that layering always enhances toughness is a useful insight for bio-inspired design in general, the researchers say.

"Our study indicates that not all layered architectures provide significant toughness enhancement," said Sayaka Kochiyama, a Brown graduate student and study coauthor. "That better understanding of structure-property relationship is necessary to avoid naive biomimicry."

More information: Michael A. Monn et al, Lamellar architectures in stiff biomaterials may not always be templates for enhancing toughness in composites, *Nature Communications* (2020). DOI: 10.1038/s41467-019-14128-8

Provided by Brown University

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