Advanced composites may borrow designs from deep-sea shrimp

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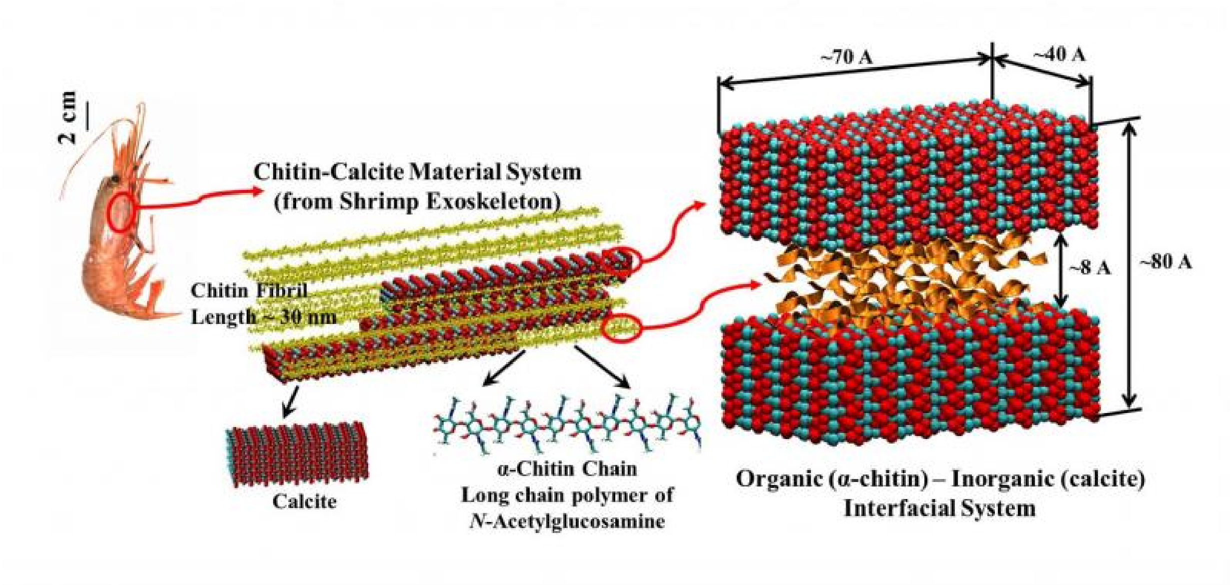

This graphic depicts the exoskeleton structure of a certain type of deep-sea shrimp able to survive the scalding hot waters of hydrothermal vents thousands of feet under water. Insights into the complex molecular behavior of the materials could have implications for the design of new synthetic armor capable of withstanding environmental extremes. Credit: Purdue University/Tao Qu

New research is revealing details about how the exoskeleton of a certain type of deep-sea shrimp allows the animal to survive scalding hot waters in hydrothermal vents thousands of feet under water.

"A biological species surviving in that kind of extreme environment is a big deal," said Vikas Tomar, an associate professor in Purdue University's School of Aeronautics and Astronautics. "And shrimp are a great test case for evolution because you can find different species all over the world living at various depths and with a range of adaptation requirements."

He and doctoral students Tao Qu, Devendra Verma, Yang Zhang and Chandra Prakash compared the exoskeletons of the deep-sea shrimp Rimicaris exoculata and the shallow-dwelling shrimp Pandalus platyceros. The deep-sea species lives 2,000 meters below the ocean surface in volcanic hydrothermal vents where temperatures can exceed 400 degrees Celsius, whereas the other species lives just below the ocean surface.

"We want to understand how evolution affects material behavior in the exoskeletons of these two shrimp species that thrive in far different conditions," Tomar said.

Insights into the complex molecular behavior of the materials could have implications for the design of new synthetic armor capable of withstanding environmental extremes.

New findings were detailed in a research paper published online July 2 and will appear in a future print issue of the journal *Acta Biomaterialia*. Two other recent papers by the same researchers focused on laboratory experiments into the shrimp exoskeletons.

The researchers probed the interface between two key components of the exoskeletons: a protein called chitin and a bone-like mineral called calcite. How these two types of materials - one organic and the other inorganic - behave at their interface is critical to determining how the exoskeleton performs.

Ten exoskeleton specimens were studied, and experimental analyses were performed using laboratory techniques including scanning electron microscopy and electron diffraction spectroscopy, revealing details about the structure and chemical composition.

The exoskeletons of both species of shrimp possess the same microstructures: the chitin, calcite and other components are arranged in a layered helicoidal structure that resembles a spiral staircase. A comparison of the two species, however, showed differences in the density of the structures, thickness of the layers and mineral content. The deep-sea shrimp's exoskeleton was found to possess a more densely packed structure.

To their surprise, the researchers found the exoskeleton of the surface shrimp is about 10 times stronger than the exoskeleton of the deep-sea shrimp.

"Mechanistically, you would expect that when it is compacted it becomes stronger, but it is actually weaker after compaction," Tomar said.

The most recent research probed what happens at the interface between the chitin and calcite and how these mechanisms affect exoskeleton performance. This interface helps to determine how the structures transfer stress.

Findings showed the deep-sea exoskeleton is softer, yet capable of withstanding temperature and pressure extremes. The surface-shrimp exoskeleton is harder and better able to protect against predators.

"Even though they have the same basic microstructure, they are completely different materials," Tomar said.

Information about the interface viscosity obtained using molecular simulations of the interacting materials allows for more accurate modeling of how polymer-ceramic composites deform due to strain. The researchers developed a "viscoplastic law," or mathematical equations for such an interface.

Conventional models for polymer-ceramic composites fall short because they key on the peak strength, whereas the materials are more likely to fail by high strain, or being stretched.

"There are failure theories that we use, but they predict the failures in terms of strength," Tomar said. "In the case of these materials it is the strain that's most important, so you cannot exceed a certain level of deformation without breaking."

Findings are shedding light on how water plays a vital role in providing strength to the molecular structure of the exoskeletons. The researchers also created an "interface database" to model how a particular composite material will perform given its composition, microstructure and type of interface.

Also an author on the Acta Biomaterialia paper was undergraduate student Milad Alucozai, who has been chosen as one of only 12 U.S. students to receive the nationally prestigious Mitchell Scholarship for graduate study in Ireland. He is Purdue's first Mitchell Scholarship recipient.

In related research, the team is working with collaborators at the Vienna University of Technology to study the interface between collagen and human bone and how bone deforms over time. The research was detailed in April in the Materials Research Society Bulletin. The findings could help to better model the behavior of medical implants.

More information: *Acta Biomaterialia*, dx.doi.org/10.1016/j.actbio.2015.06.034

Provided by Purdue University

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