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Nature Publishes Secret of Abalone Shell Strength

Researchers have cracked the mystery of the abalone shell's toughness and fracture resistance, according to the June 24 issue of the journal Nature.

It's all in the stretch, according to the discovery made at the UC Santa Barbara, by a team of physicists, molecular biologists and chemists.

The discovery suggests a new kind of biological "rubber" and helps explain the exceptional strength of the plywood-like structure of the abalone shell.

"Now that we've elucidated some of nature's secrets, we can begin to mimic these design patterns," said Bettye L. Smith, research associate in the Department of Physics, and lead author, who is working toward designing and synthesizing strong and tough fibers based on nature's design.

The abalone shell is roughly 3,000 times more fracture resistant than a single crystal of calcium carbonate, the mineral that makes up most of its bulk. The UC Santa Barbara experiments show that the mechanism behind the fracture resistance is in the polymer adhesive that holds the crystal tablets together.

The researchers were able to reveal the properties of the adhesive in single-molecule pulling experiments using the Atomic Force Microscope (AFM) to measure the elasticity and strength of individual protein molecules. This work was done under the direction of Paul K. Hansma, professor of physics, by his laboratory group.

(Hansma is a major developer of new techniques using the AFM.)

"By grabbing a single molecule and pulling on it as if it were a rubber band, you can measure the strength of a single molecular fiber," said Smith.

"Using this technique our team discovered that the tiny crystal plates of mineral that make up the abalone shell are held together with many molecules of a protein that have a truly enormous capacity to absorb shock without breaking," said Dan Morse, professor of molecular genetics and biochemistry and chairman of the Marine Biotechnology Center, and a co-director of the work.

"From studies in our lab in which we cloned the gene that codes for this protein, we're able to see a unique 'modular' structure that makes the protein look like a series of springs or shock absorbers linked together," said Morse.

The experiments revealed that these springs are uncoiled when the molecule is stressed, letting go one at a time, said Smith. "Remarkably, when the stress is relaxed, they coil back, recovering their original structure."

These "sacrificial" links break in response to stress before the whole molecule breaks, thus protecting the whole molecule. And these "sacrificial" links can reform when the stress is gone, explained Hansma.

Fibers produced synthetically are either very strong like Kevlar - used in bulletproof vests - or tough and elastic like silicon rubber, but very few combine both properties.

"These findings are nature's secret of how to build fibers that are simultaneously strong and elastically tough at the same time," said Smith. "We hope that by applying the secret to the synthesis of new materials we'll be able to produce inexpensive fibers that are tailored to tough and strong high performance applications."

Possible applications of such fibers include usage in textiles, ropes, construction materials, aeronautics, camping gear, and biomedical applications such as implant materials and prosthetics.

Authors of the Nature article, "Molecular Mechanistic Origin of the Toughness of Natural Adhesives, Fibers, and Composites," are Bettye L. Smith, research associate, Department of Physics, UCSB; Tilman E. Schaffer, assistant professor, Department of Molecular Biology, Max-Planck-Institute for Biophysical Chemistry, Germany (and former graduate student, Department of Physics, UCSB); Mario Viani, graduate student, Department of Physics, UCSB; James B. Thompson, graduate student, Department of Physics, UCSB; Neil A Frederick, undergraduate, Department of Physics, UCSB; Johannes Kindt, graduate student, Department of Physics, UCSB; Angela Belcher, assistant professor, Department of Chemistry, University of Texas, (and former graduate student, Department of Chemistry, UCSB); Galen D. Stucky, professor of chemistry and materials, UCSB; Daniel E. Morse, professor of molecular genetics and biochemistry, and chairman, Marine Biotechnology Center, UCSB; and Paul K. Hansma, professor of physics, UCSB.

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