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Novel Biological Elastomers from Marine Organisms

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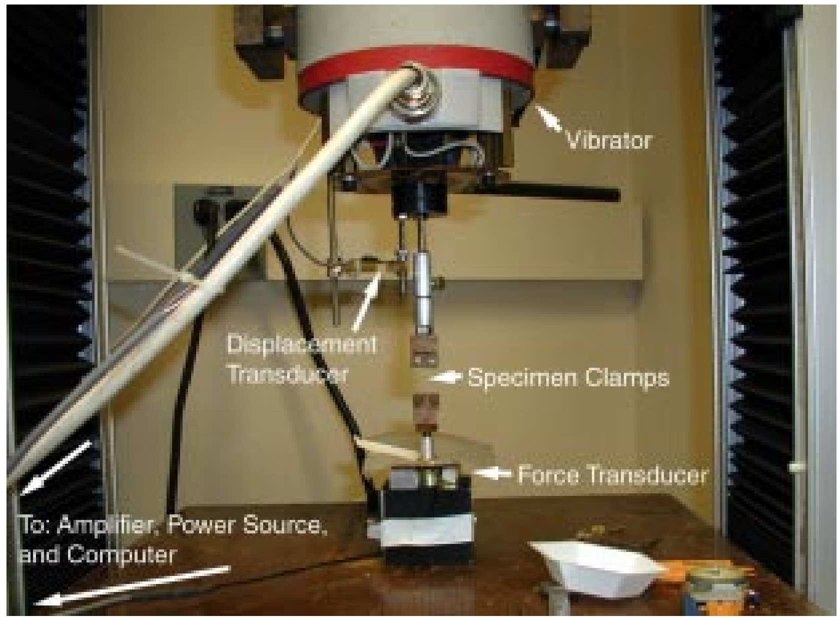
Background

Many marine snails package (technically speaking, "deposit") their eggs in special protective wrappings called egg capsules, not too unlike heavy-duty egg cartons. Female snails string these capsules into a variety of weird and wonderful shapes. Some look like candy necklaces, miniature Chinese dragons, waxy blobs, a tiny crushed trumpet, or lima beans on a string. The longest strings reach over a foot in length; most are much shorter.


Female snail laying egg capsules.



Instrumentation used to test the mechanical properties of egg capsule material.
Photos: Scripps Institution of Oceanography

Besides having unusual shapes, egg capsules are made of an intriguing material, one that is both elastic and strong. The strength and flexibility of the material ensures snail embryos remain anchored to the bottom during heavy surf and that the capsule, not the embryo, absorbs punishing wave energy.

Project

The goal of this project, led by marine biology professor Robert Shadwick of Scripps Institution of Oceanography, was to characterize basic biochemical and mechanical properties of egg capsules from several species of whelk snails, including the channeled whelk snail, *Busycon canaliculatum*, native to the East Coast, and the Kellet's whelk snail, *Kelletia kelletii*, native to the West Coast.

Tests focused on quantifying the material's response to being stretched. Of particular interest was measuring the amount of energy dissipated as the material returns to its original shape. Other tests involved stretching and relaxing the material repeatedly.

Findings

Shadwick and his graduate student, Scott Rapoport, found that capsule material was virtually identical in all seven species of snails examined, meaning the material has been highly conserved during evolution and increases snail survivorship. Shadwick speculates that the protein in the capsule material is related to proteins in human skin. Amino-acid analyses revealed an "alpha-helical conformation," a helical shape common to many animal proteins. The basic building block of the protein is a "coiled-coiled protein motif." That is, the helical proteins coil around each other, another common structure.

The mechanical properties of the material were the most intriguing. At rest, the protein polymer, which comprises 90 percent of the capsule material, is stiff like collagen. In the human body, collagen is a structural protein that gives tissues rigidity. Quasi-static tests involved stretching the capsule material and showed the material's properties change as it is stretched. When stretched five percent longer than its original length, the capsule material loses its stiffness and behaves like elastin, the protein that imparts elasticity to human skin. It took one-tenth the force to stretch the capsule material further when it was in this “stretchy” state.

To a certain degree, the capsule material shares the mechanical properties of both elastin and collagen. In the human body, collagen and elastin work together in blood vessels, tendons and ligaments, as well as in skin and other organs, to provide support and flexibility. Snails have a way to construct a single protein polymer that is both rigid and flexible. This bimodal character is somewhat common in natural materials. What makes the snail egg material unusual is that it could be stretched and re-stretched without altering its properties. Even when stretched to nearly twice its original length, the material retained its ability to return to its original size and shape.

How is the capsule material formed? A female snail produces egg capsules in her reproductive system and moulds the capsule with her foot. The process is a lot like kneading bread. The crushing, pushing and pulling of the capsule “dough” activates the cross-linking of proteins. In breadmaking, kneading forms gluten. For the snails, kneading hardens and stabilizes the egg capsule material—all the better for protecting eggs that may incubate for months in the ocean.

Applications

The idea that nature can inspire human achievement is not new. The Eiffel Tower’s design is based on the weight-displacing structure of leg bones; hull materials that deform slightly to reduce drag are modeled from the suppleness of shark and dolphin skin, while abalone produce materials that could improve hard-coatings for windshields.

Marine snails may inspire the development of novel compounds, too. A strong yet stretchy water-insoluble compound could, for example, lead to better soft-tissue transplant materials such as artificial tendons and ligaments for treating joint injuries.

Publications

Rapoport, H.S., and R.E. Shadwick. 2002. Mechanical characterization of an unusual elastic biomaterial from the egg capsules of marine snails (*Busycon* spp.) *Biomacromolecules* 3(1):42–50.

Presentations

Rapoport, H.S., and R.E. Shadwick. A keratin-like gastropod biomaterial used to clarify the mechanical models of keratin. Society for Integrative and Comparative Biology, Anaheim, California, January 2002.

Rapoport, H.S., and R.E. Shadwick. Whelk egg capsule biomaterial (*Busycon* spp): A structural and mechanical invertebrate keratin analog. Materials Research Society, San Francisco, California, April 2002.

Shadwick, R.E., and H.S. Rapoport. Development of mechanical properties in a protein elastomer from whelk egg capsules. Society for Integrative and Comparative Biology, New Orleans, Louisiana, January 2004.

Abstracts

Rapoport, H.S., and R.E. Shadwick. 2000. Investigations into the self-healing behavior of whelk egg capsule biomaterial, genus *Busycon*. *Comp. Biochem. Physiol*. 126B, Suppl. 1:S81.

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Award

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Thesis

Rapoport, Harry Scott. 2003. Biomechanics, biochemistry, and molecular biology of a molluscan scleroprotein elastomer: Whelk egg capsules.

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