Seashell strength inspires stress tests

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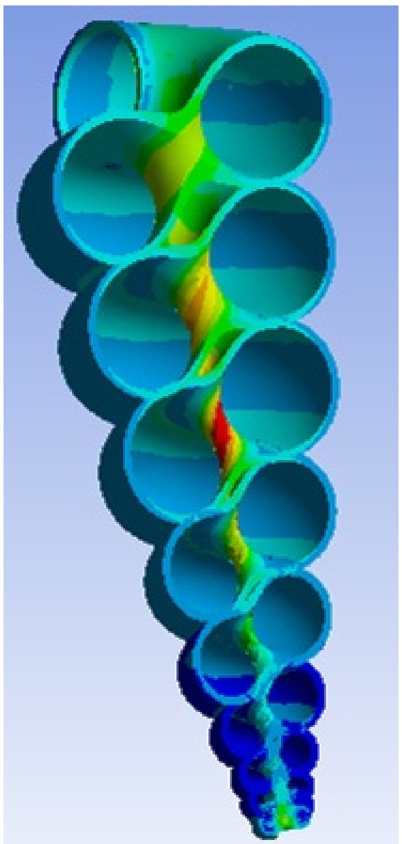


A stress map shows how a seashell redirects stress to its strongest areas - in this case, the center and widest end -- to protect the animal inside. Research at Rice University and the Indian Institute of Science showed that shells send stress to parts of the shell where inhabitants are least likely to be. Credit: Indian Institute of Science/Rice University

Mollusks got it right. They have soft innards, but their complex exteriors are engineered to protect them in harsh conditions. Engineers at the

Indian Institute of Science and Rice University are beginning to understand why.

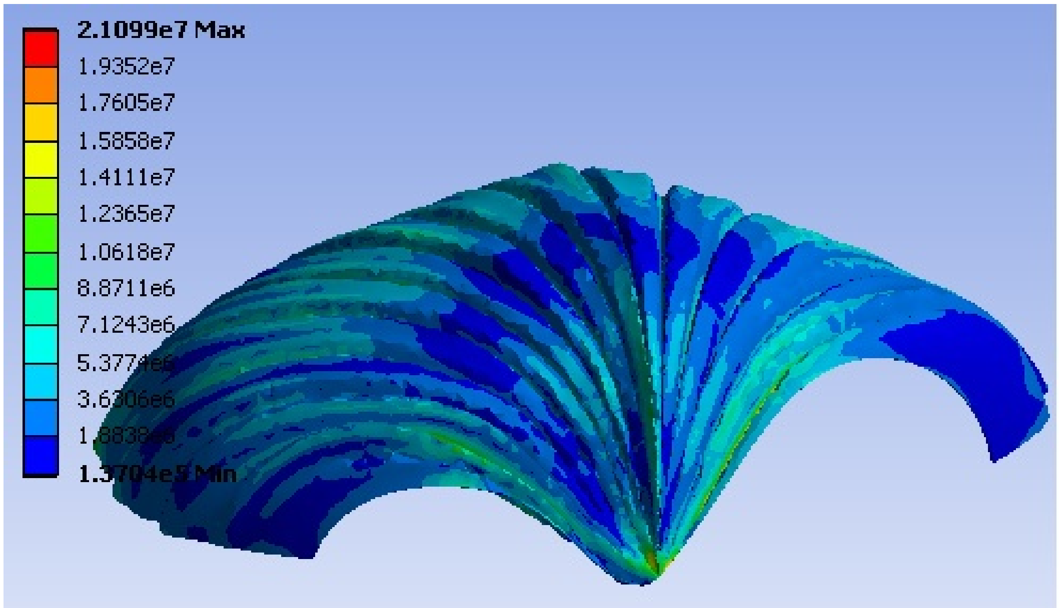
By modeling the average mollusk's mobile habitat, they are learning how shells stand up to extraordinary pressures at the bottom of the sea. The goal is to learn what drove these tough exoskeletons to evolve as they did and to see how their mechanical principles may be adapted for use in human-scale structures like vehicles and even buildings.

The team led by Chandra Sekhar Tiwary, a graduate student at the Indian Institute of Science and a visiting student at Rice, created computer simulations and printed 3-D variants of two types of shells to run stress tests alongside real shells that Tiwary collected from beaches in India.

The researchers discovered the structures that evolved over eons are not only generally effective at protecting their inhabitants, but also manage to redirect stress to locations where the soft creatures are least likely to be.

Their results appeared in a new online journal published by the American Association for the Advancement of Science, *Science Advances*.

Shells are made of nacre, also known as mother-of-pearl, a strong and resilient matrix of organic and inorganic materials recently studied by other Rice engineers as a model of strength, stiffness and toughness.



Analysis of a fan-shaped seashell by scientists at Rice University and the Indian Institute of Science shows how the shell directs stress to its strongest points, where the animal inside is least likely to be. Credit: Indian Institute of Science/Rice University

Tiwary and his colleagues took their research in a different direction to discover how seashells remain stable and redirect stress to minimize damage when failure is imminent. Their calculations showed their distinctive shapes make the shells nearly twice as good at bearing loads than nacre alone.

They examined two types of mollusk: Bivalves with two separate exoskeleton components joined at a hinge (as in clamshells) and terebridae that conceal themselves in screw-shaped shells. In the case of clamshells, the semicircular shape and curved ribs force stress to the hinge, while the screws direct the load toward the center and then the wide top.

They found such evolutionary optimization allows fractures to appear only where they're least likely to hurt the animal inside.

"Nature keeps on making things that look beautiful, but we don't really pay attention to why the shapes are what they are," said Tiwary, a member of Rice materials scientist Pulickel Ajayan's lab. Tiwary started the work with Kamanio Chattopadhyay, chair of mechanical sciences at the Indian Institute of Science, Bangalore.

The researchers noted engineers have made use of mechanical concepts from natural shapes like beak shells and shark teeth to design protective shields, automotive parts that dampen impacts and even buildings. But seashells, they wrote, represent one of the best examples of evolutionary optimization to handle varied mechanical loads.

While biologists, mathematicians and artists have contributed to the literature about seashells, materials scientists "haven't tried to think about these complex shapes because making them is not easy," Tiwary said. But the rapid development of 3-D printing has made it much easier to replicate the shapes with materials tough enough to put up a fight. "With the help of 3-D printing, these ideas can be extended to a larger reality," he said.

The researchers printed fan-shaped polymer shells, including some without their characteristic converging ribs. They also made cones that mimicked the screws but without the complexities.

They found the rib-less fans were far less effective at redirecting stress toward the base of the fan, spreading it to three separate regions across the shell. When cracks finally showed in the fans, they appeared in the same spots near the base in both the real shells and the realistic printed version.

Stress distribution in the more complex screws was "totally different," they wrote. The tough inner core of the shell took the most punishment, relieving stress from the outer surface and shunting it toward the top-most ring. In general, the researchers found the screw to be the better of the two shells at protecting its delicate contents.

"There are plenty of shapes that are even more complicated, and they may be even better than this for new structures," Tiwary said.

More information: Morphogenesis and mechanostabilization of complex natural and 3D printed shapes, *Science Advances* 15 May 2015: Vol. 1 no. 4 e1400052. DOI: 10.1126/sciadv.1400052

Provided by Rice University