Abalone Inspires A Materials Revolution for Lightweight & Strong Materials

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> **"We have had the Stone Age, the Bronze Age, and the plastic age…. The future is the designed material age."**

—Shuguang Zhang, Associate Director of MIT's Center for Biomedical Engineering.

Abalone shells with mother of pearl coating have a crystalline coating, which self assembles in perfect precision and is more resilient than anything produced by humans. Mimicking abalone shells could revolutionize and inspire biologically safe hard materials that need to be lightweight but fracture resistant.

The abalone is a shellfish that is know for its delicious meat as well as for its shell that is as "hard as nails". A car could drive over an abalone shell and have no impact. It is stronger than any known ceramic, but why? It consists of an intricate crystal architecture that allows it to shrug off stress. The ceramics that are produced commercially in human systems are very strong materials, but brittle and subject to cracking. Scientists are now looking at natural designs like the abalone inner coating to determine how to reproduce that structure synthetically.

Abalone (*Haliotis* spp.) build their protective shells in seawater, at low-temperatures, using locally plentiful materials. Their shells are 3000 times stronger than their component parts that are 200% stronger than our toughest high-tech ceramics. These master builders layer elastic organic protein material (Lustrin-A protein) between rigid inorganic calcium carbonate (a crystal form called aragonite) so that the alternating layers from a nanoscale "brick and mortar" structure. The combination of hard and elastic layers gives nacre remarkable toughness and strength, allowing the material to slide under compressive force. The "bricks" of calcium carbonate are offset, and this brick-wall architecture stops cracks from propagating. Any cracks that do form in the shell diffuse in intervening protein layers rather than propagate, a flexibility that makes the shell extremely resilient to breaking.

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Several groups have mimicked nacre's structure:

Dr. Jeffrey Brinker's group at Sandia National Laboratories used a self-assembly process to create mineral/polymer layered structures that are optically clear but much tougher than glass. Unlike traditional "heat, beat, and treat" technologies, Brinker's evaporation-induced, low temperature process allows liquid building blocks to self-assemble and harden into very coatings that can toughen windshields, bodies of solar cars, airplanes or anything that needs to be lightweight but fracture-resistant. The complex nano-laminate structure of these bio-composite materials is characterized and related to their mechanical properties.

Researchers Nicholas Kotov and his colleagues at Oklahoma State University have developed a nanoscale, layered material that comes close to mother-of-pearl's (nacre's) properties such as strength and flexibility. Nicholas Kotov and his team from the University of Michigan have created a process similar to our bivalve friends that allows the creation of materials one nano-layer at a time, with impressive results. The ability to nanomanufacture artificial nacre may provide lightweight, rigid composites for aircraft parts, artificial bone and other applications. They do this by alternating layers of clay and a type of polymer called a polyelectrolyte.

Made of layers of clay nanosheets and a water-soluble polymer that shares chemistry with white glue, the material is transparent, as strong as steel, yet lighter in weight. Kotov almost dubbed it "plastic steel," but the new material isn't quite as stretchy as steel. Building materials from the bottom-up is a major engineering challenge, with possible big sustainability wins. Controlling the design and structure of the material on the molecular level allows incredible properties, without excessive use of material or energy inputs.The process is currently dependent on a robotic arm that applies the materials layer by layer, waiting for the glue to dry between layer applications. We still have a long way to go before we can create materials as sustainable and tough as a sea shell, but this proof of principle is a big step, with possible high end applications.

Materials scientist Mehmet Sarikaya has said, "We are on the brink of a materials revolution that will be on par with the Iron Age and the Industrial Revolution. We are leaping forward into a new age of materials. Within the next century I think biomimetics will significantly alter the way in which we live." Mehmet studies abalone, whose mother-of-pearl interior, is twice as tough as our high-tech ceramics, which we still make today by the heat, beat, and treat process. We heat kilns up to >2000° C when we make ceramics. The abalone shell doesn't do this, of course. So Mehmet wondered if we could make materials like this at seawater temperature using benign chemistry (that could replace some metals & ceramics – and their associated environmental impacts).

Professor Daniel Morse and his lab from the University of California Santa Barbara have been investigating the proteins involved in creating the unique structure, with the hope that we may be able to reproduce this without using expensive or damaging processes. Real breakthroughs now are coming in this area of self-assembling materials that mimic the way the abalone creates its nano-scale architecture of hard mineral and soft polymer. ***This will be the way we make products in the future. It's coming.***

The field of abalone research has developed into a rather large and international group of materials engineers and biologists. From the **Biomolecular Materials Group headed by Angela Belcher at MIT, to Marcela Bilek studying materials coating and surfaces at the University of Sydney.**

Buildings or commercial jetliners could soon get a protective coating of shatter-resistant armor similar to the material lining abalone shells. **Finnish researchers** have developed the lightweight reinforcement so that people can simply paint it on whatever structure.

Science:

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