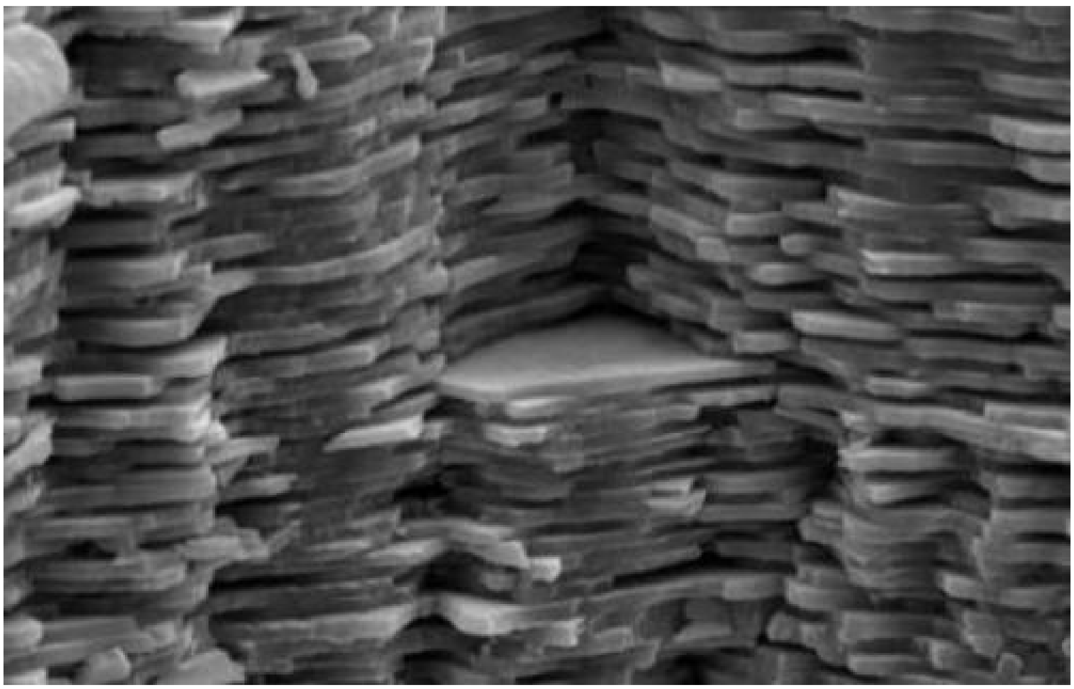
Materials theory combines strength, stiffness and toughness of composites into a single design map

March 16 2015, by Mike Williams



Nacre, also known as mother-of-pearl, is a tough, strong and light component of seashells. The microscopic structure of nacre shows platelets bound by a softer matrix to form a composite with properties materials scientists try to mimic in synthetic composites. A new formula by Rice University researchers aims to simplify the process. Credit: Wikipedia

Mother-of-pearl, the iridescent layer in the shells of some mollusks, inspired a Rice University study that will help scientists and engineers judge the ultimate strength, stiffness and toughness of composite materials for anything from nanoscale electronics to buildings.

Rice researchers Rouzbeh Shahsavari and Navid Sakhavand have created universal maps that predict the properties of natural and biomimetic platelet-matrix composites (like nacre, aka mother-of-pearl) and synthetic stacks (or heterostructures) of materials like graphene and boron nitride.

They said their computer-drawn maps are "dimensionless" and their findings will work as well for materials built with nanoscale blocks as they would for a brick wall, or bigger.

"That's the beauty of this approach: It can scale to something very large or very small," said Shahsavari, an assistant professor of civil and environmental engineering and of materials science and engineering.

The research appeared this week in *Nature Communications*.

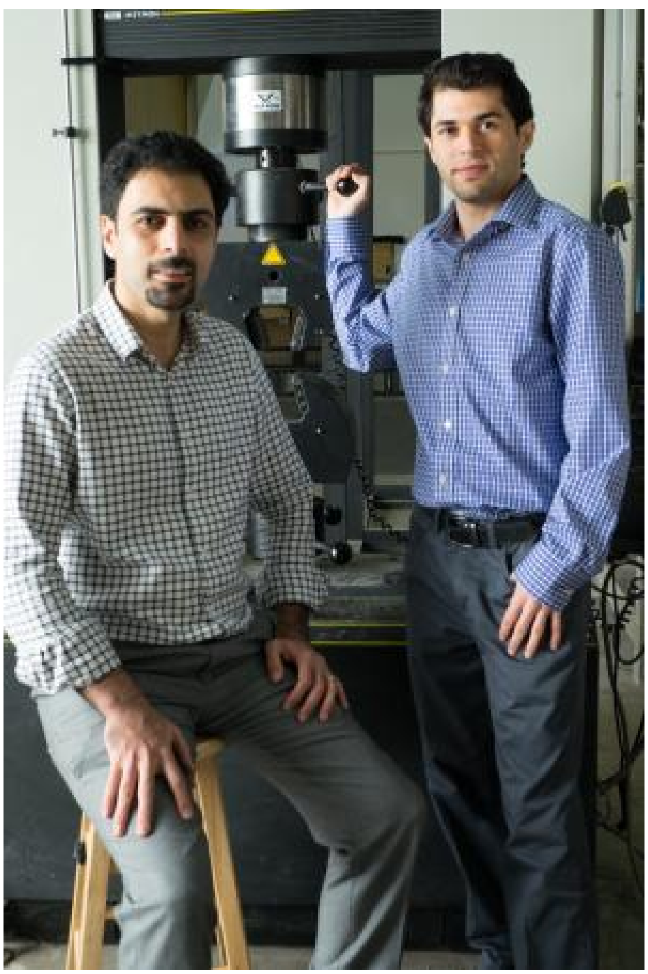
The formula relies on four characteristics of the individual materials under consideration for a composite: their length, a ratio based on their respective stiffness, their plasticity and how they overlap.

Those are the inputs, said Sakhavand, a graduate student in Shahsavari's lab. "If you know them, you can predict the stiffness, strength and toughness of the final composite. We call this a universal map because all of those input parameters are relevant to all composites and their structural properties."

To materials scientists and engineers, stiffness, toughness and strength are distinct, important mechanical properties. Strength is the ability of a material to stay together when stretched or compressed. Stiffness is how well a material resists deformation. Toughness is the ability of a material to absorb energy before failure.

The researchers' design maps show how materials rate in all three categories and where they overlap. Their goal is to help engineers calculate the ultimate qualities of a material and cut down on trial and error.

The study began when Shahsavari took a close look at the architecture of nacre, which maximizes both strength and toughness, which as typically mutually exclusive properties in engineered materials. Under a microscope, nacre looks like a well-built brick wall with overlapping platelets of different lengths held together by thin layers of an elastic biopolymer.

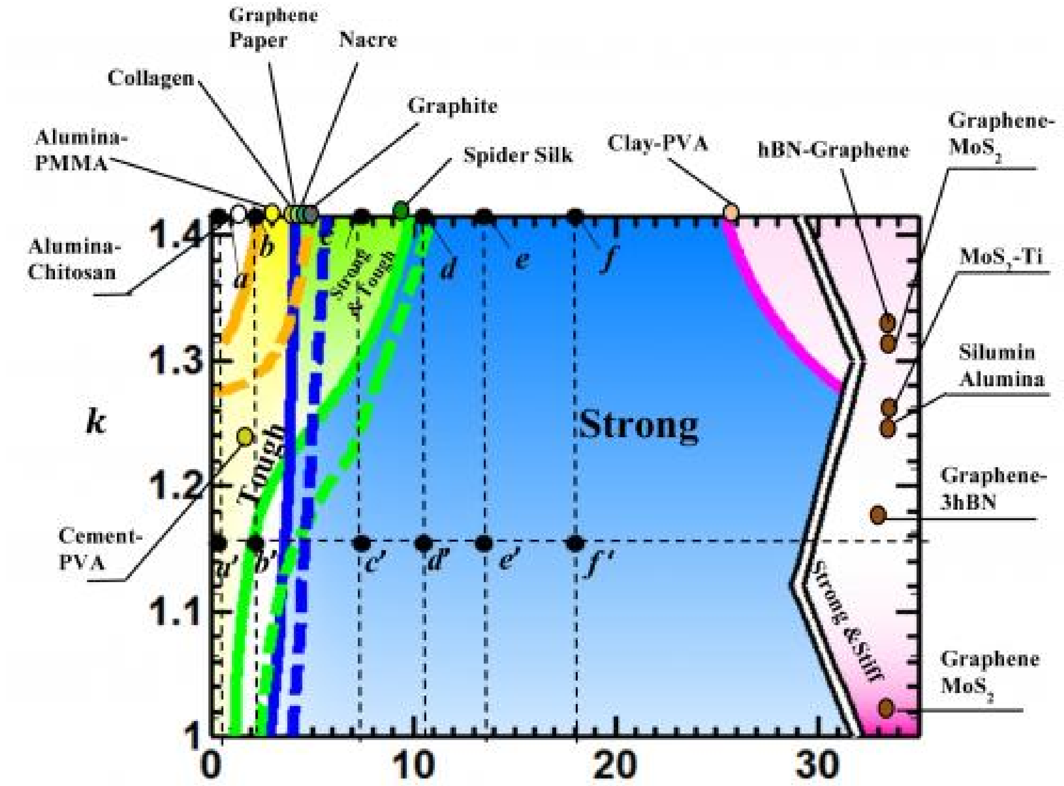


Rice researchers Rouzbeh Shahsavari, left, and Navid Sakhavand have created universal maps that predict the properties of natural and biomimetic platelet-matrix composites and synthetic stacks of materials like graphene and boron nitride. Credit: Jeff Fitlow/Rice University

"It has a very particular structure and property: It optimizes different mechanical properties at the same time." Sakhavand said.

However, engineering nacre-like composites has been difficult so far, "mainly because of the lack of a design map that can reveal the various links between the structure, materials and properties of nacre-like materials," Shahsavari said.

He said the work is an important milestone toward a better ability to decode and replicate nacre's architecture for lightweight, high-performance composites. These could benefit the aerospace, auto and construction industries, he said.



An illustration produced by Rice University scientists compares the properties of composite structures based on their calculations. The researchers have created a design map that predicts the strength, stiffness and toughness of composites regardless of size. Credit: Shahsavari Group/Rice University

The Rice researchers' work spanned three years of calculation and experimentation that involved mapping the properties of natural composites like collagen and spider silk as well as synthetic stacks like hexagonal boron-nitride/graphene and silumin/alumina. They also tested their theory on macro-scale, 3-D printed composites of hard plastic and soft rubber that mimicked the properties they observed in nacre.

A map of 15 of the materials they tested shows natural ones like nacre tend to be strong and tough while synthetics lean toward strong and stiff. Shahsavari said he hopes materials scientists will use the design maps to give their composites the best possible combination of all three properties.

More information: *Nature Communications*, www.nature.com/ncomms/2015/150 … full/ncomms7523.html

Provided by Rice University