Hidden gems: New composites are stiffer than diamond

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Using a unique combination of barium titanate and tin, University of Wisconsin-Madison researchers have made the first known material that's stiffer than diamond. The group published its results in the Feb. 2 issue of *Science*.

Aside from its value as a gemstone, diamond has the highest thermal conductivity and is the stiffest, hardest material around. Yet despite its benefits, diamond is too expensive to consider in such structural applications as bridges, buildings, airplanes or golf clubs.

While diamond achieves its rock-solid stability via dense, directional, extremely tight atomic bonds, the UW-Madison researchers created their stiff composite from ordinary materials held together in an extraordinary way, says Roderic Lakes, a professor of engineering physics. "We're using a material now that's chosen for having the ability to change volume during phase transformation," he says. "The material we chose-barium titanate-goes from one solid to another solid."

Barium titanate is a well researched crystalline material previously used in such applications as microphones or cell phone speakers. Embed bits of it in a tin matrix, and the phase transformation, or shift in the arrangement of atoms, is held back, creating stored energy. "Imagine water getting into cracks in the road and freezing," says Lakes. "It can't expand because it's held in place."

The blocked phase transformation creates negative stiffness, or instability, within the barium titanate, while the tin has positive stiffness, or stability. "We've finally showed that in the lab, you can make a composite that's stiffer than either constituent, which nobody thought was possible before, because in all of the previous composites both constituents are in a minimum energy state," he says. "There's no stored energy, and both stiffness values are positive."

In laboratory experiments, Lakes and his collaborators showed that if they embed the barium titanate within the tin, the resulting composite material achieves stiffness approaching 10 times that of diamond. "You'd think that if you'd add positive and negative, you'd get zero," says Lakes. "Actually, that's exactly how you get the extreme stiffness, because you're adding compliances."

For example, he says, steel is very stiff; rubber is very compliant. A positive compliance is the inverse of a stiffness and a negative compliance is the inverse of a stiffness. Add positive compliance and negative compliance and the sum is close to zero-which corresponds to very high stiffness.

Like the phase transformation of water to ice at 0 degrees Celsius, the barium titanate phase transformation also is governed by temperature, so the current composite exhibits extreme stiffness within a temperature range of less than 10 degrees. "The temperature at which this material works is like a hot day in Libya," says Lakes. "So it's like 65 degrees Celsius, and a hot day in New York is 40 Celsius. It's a higher temperature than is convenient. We think we can tune that, but that's the future."

Source: University of Wisconsin-Madison, by Renee Meiller