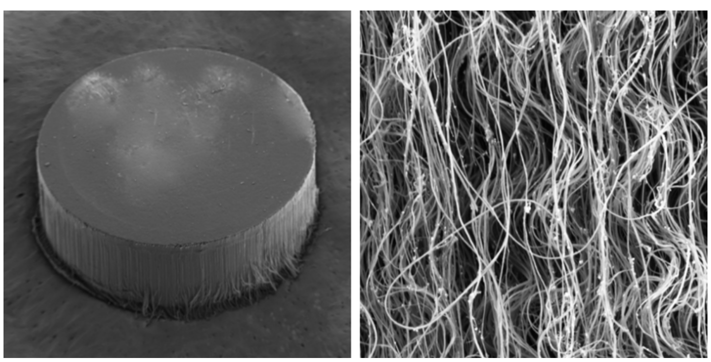
Nanotube Material Has Perfect Memory

A carbon nanotube foam springs back to its initial state, regardless of the speed of the compression, a property that could lead to a new type of shock absorber.

By **Michael Schirber**

Spongy materials can spring back following compression, but they don't return exactly to their original shape. New experiments show that a foam made with carbon nanotubes snaps back to its initial shape, implying a perfect mechanical "memory" [**1**]. The material is also uniquely insensitive to deformation rate, behaving the same under fast and slow compressions. The researchers found that this combination of memory and rate-independence leads to an unusual property: The material's response to mechanical shocks can be adjusted by appropriately compressing it before the shock. They imagine using this foam in "smart" helmets that reduce injury risk by controlling the propagation of impact energy.



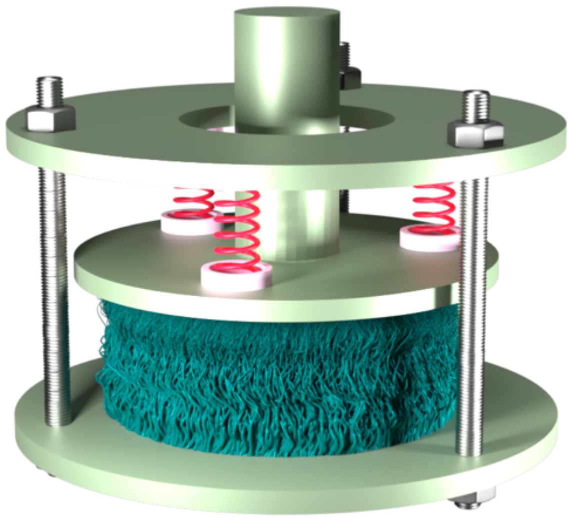
Perfect padding. Vertically aligned carbon nanotube (VACNT) foam can be synthesized into cushion-like cylinders that are roughly 5 mm wide (left). Microscope images of the foam reveal a "forest" of fibers, each of which consists of multiple carbon nanotubes (right).
Credit: A. Gupta *et al.* [**1**]

Polymer foams—like the ones in some mattresses—can spring back, but viscosity effects cause irreversible changes to the internal structure, preventing the material from returning to its initial state. With repeated cycles of compression and release, the material drifts further from its original condition. "People refer to this as fading memory," says Ramathasan Thevamaran from the University of Wisconsin–Madison. He and his colleagues have found a material that isn't so forgetful.

The material is a highly structured foam containing "forests" of multiwalled nanoscale fibers. This so-called vertically aligned carbon nanotube (VACNT) foam is finding applications in electromagnetic shielding and heat management. But the foam is also an impressive shock absorber, with the ability to absorb 20 times more impact energy than the top-of-the-line helmet materials [**2**]. Thevamaran and his colleagues were studying that absorption when they noticed something strange: The foams were insensitive to the rate of squeezing. "Whether we did very slow compression or very fast compression, it didn't matter. The foam behaved the same way," Thevamaran says.

In follow-up tests, the researchers applied a deformation (or strain) on the foam and measured the response force (or stress) exerted by the material. As the strain was repeatedly increased and decreased, the stress and strain data generated a so-called hysteresis loop, as commonly observed in magnetic materials exposed to a magnetic field cycling between high and low values. The team found that the VACNT foam retraced the same loop in cycle after cycle, exhibiting a memory that—unlike other foams—never faded.

The researchers developed a model that incorporated the



Total recoil. Researchers tested the stress response of VACNT foams when a compressive strain is applied. The results show that the material retains a mechanical memory that doesn't fade.
Credit: A. Gupta *et al.* [**1**]

memory effect with the foam's insensitivity to deformation rate. Using this model, they explored the material's response to a rapid compression, or mechanical shock. They found that the foam should be stiff against weak shocks, while being relatively soft against strong shocks. To verify this trend, the team fabricated a narrow waveguide in which several foam disks were stacked horizontally, like a roll of coins, with metal spacers separating the disks. Projectiles impacted one end of this assembly, and vibrational waves were recorded at the other end. Harder impacts generated slower waves, in agreement with the model's prediction of softening with increasing shock.

Thevamaran and colleagues also found that the foam was tunable: Precompressing the waveguide increased the speed at which vibrations traveled. To investigate how this wave control might be used, the team formed a "multichannel" array by placing a dozen waveguides in parallel to one another—like pencils in a box. By varying the amount of precompression in each waveguide, the researchers could slow some vibrations relative to others. This programmed delay could diffuse the energy of a high-velocity impact, potentially preventing a brain injury if this type of structure were used in a helmet.
Beyond shock absorption, such an array could potentially be used as an analog computing device, according to the team. Acoustic waves, for example, could be manipulated by sending them through specially tuned waveguides, similar to the way that optical waves can be manipulated in photonic devices. Thevamaran says that this setup might be useful in an ultrasound detector, where VACNT foams might enhance the imaging or optimize the processing. The advantage is that the signal would remain analog (as opposed to digitized), which could reduce energy consumption.

"We know of many materials with mechanical memory," says mechanical physics expert Joseph Paulsen from St. Olaf College in Minnesota. Examples such as polymer networks and amorphous solids can encode information in deformations. "But one of the striking aspects of these VACNT foams is that they appear to be protected from degradation: They don't age or accumulate damage," Paulsen says. The foams also respond in the same way to fast and to slow mechanical oscillations. "While that physics is intriguing in its own right," he says, "the researchers show how this bulk response could be leveraged to engineer useful acoustic materials."

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REFERENCES

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