Super Fibers

Carbon nanotubes could be the key to spinning the future's hottest threads.

By Christen Brownlee

Imagine you're a soldier of the future. As you scan the horizon for possible threats to your platoon, the day heats up, but you stay cool. Tiny air conditioners placed strategically within your shirt turn up the juice before sweat makes its first appearance.

But that's just the start of the laundry list of things your new standard-issue attire might do.

For example, sensors integrated into the fabric could take minute-by-minute health readings to make sure you're fit, calm, and well hydrated. Radios woven right into the cloth might communicate your position and status back to the home base. Your camouflage could instantly morph to hide you in any background, not just the usual forest greens or desert browns. All of these powerful applications might be fueled by light-weight capacitors, or batteries, twisted right into the threads. To top it all off, your shirts and pants might stop projectiles on their own, without the help of extra bullet proof materials.

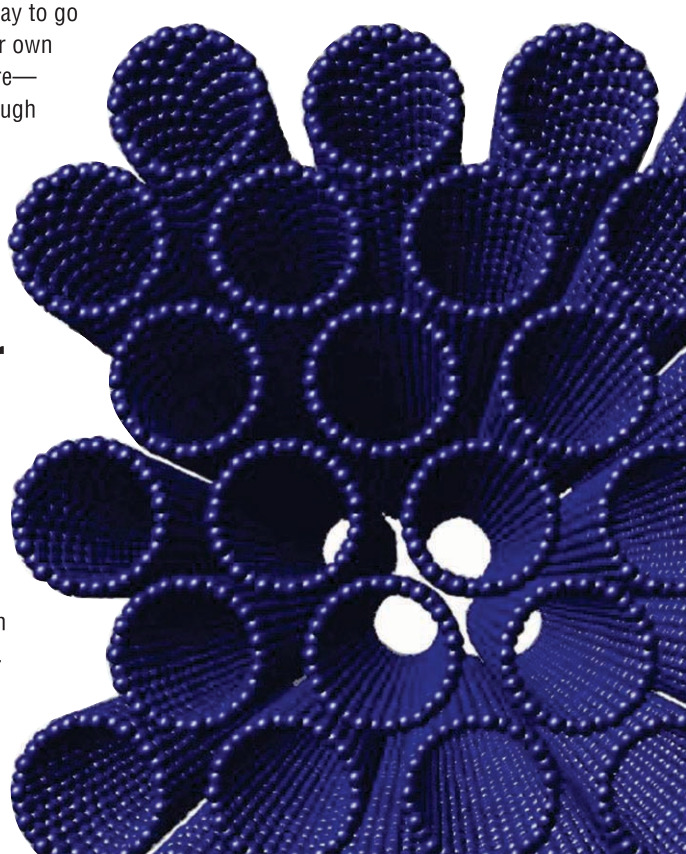
Think these revolutionary duds are "mission impossible"? Think again. Scientists are currently working on developing super fibers made of powerful carbon nanotubes. These ultra-thin threads can be less than one-ten thousandth the width of a human hair, and they come with a bevy of interesting chemical properties such as super strength, and super electrical and thermal conductivity. Woven into a fabric, these fibers could turn any article of clothing into extraordinary wired attire.

The research still has a long way to go before you'll be able to pick up your own super shirt at the army surplus store—chemists need to work out some tough kinks in manufacturing the right kind of nanotubes at the right length for these applications. But with the science marching swiftly ahead, an army of super-tailored soldiers won't be long behind.

Strong character

Despite scientists' long-range scheming over possible applications, carbon nanotubes are still a relatively new technology. They were discovered by chance in 1991 by researcher Sumio Iijima at Japan-based NEC Laboratories while he was examining other carbon structures for unrelated applications.

Iijima and his colleagues knew they had something special. They immediately saw how the structure of the tubes, which look like rolled-up chicken wire at the molecular level, gives them unique chemical features that scientists haven't seen in any other material.



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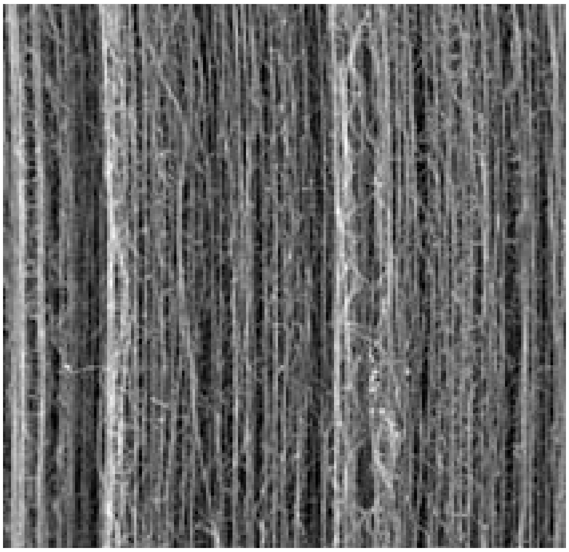

COURTESY OF NASA SEM IMAGE OF CARBON NANOTUBE FIBERS

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Carbon nanotube fibers are 4 times stronger than spider silk and 17 times stronger than the Kevlar used in bullet-proof vests.

According to Matteo Pasquali, a chemical engineer at Rice University in Houston, TX, like every covalent network solid, every atom in a carbon nanotube shares electrons with its neighbors. Sometimes, this property gives them the ability to conduct electricity extremely efficiently. The tubes' honeycomb lattice and cylindrical structure also allow them to channel heat effectively and retain their shape.

Carbon nanotubes conduct heat better than any known material and are many times stronger than any known fiber. Plus, they are extremely lightweight, making them perfect for adding these special qualities to other materials without adding extra pounds.

"To some extent," says Pasquali, "they're the Holy Grail of fibers." But much like the original Holy Grail, he adds, good carbon nanotubes are extremely tricky to find.

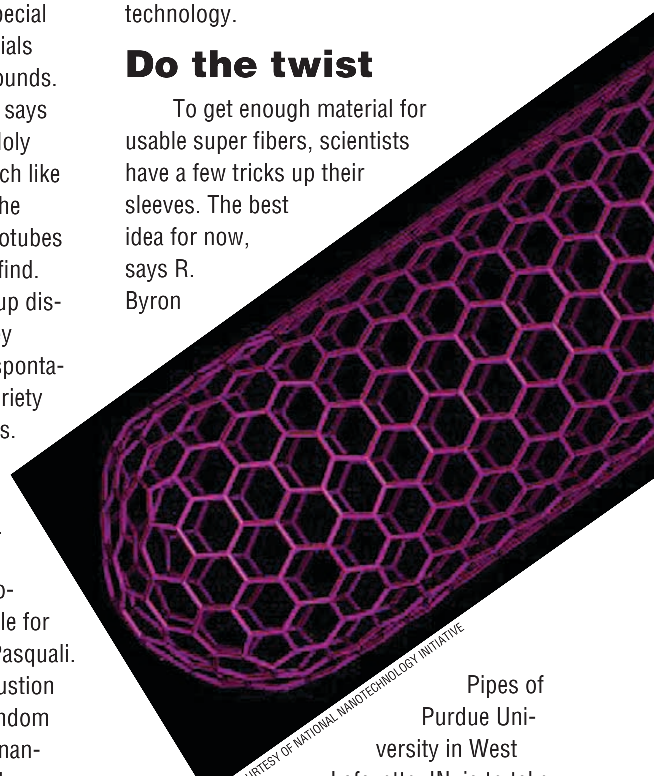
When Iijima's group discovered nanotubes, they noticed that the tubes spontaneously arise from a variety of combustion reactions. For example, nanotubes emerge every time you light a candle. But this run-of-the-mill production makes nanotubes that aren't suitable for anything useful, says Pasquali.

First, many combustion reactions produce a random mishmash of different nanotube structures—the hexagons in the tubes' chicken-wire structure may be rolled up at different angles, for example, giving them different properties. This slipshod production also spews out various assortments of nanotube types. Single-walled nanotubes, the hose-like structures that seem to have the most benefits, are often mixed in with multiwall nanotubes, which look like tubes rolled up within tubes. To get the most reliable properties, scientists need to work with a uniform batch of tubes that perfectly match each other.

Second, the manufacturing techniques available today—such as knocking carbon off of a surface with a laser, for example, or discharging bits of carbon by zapping carbon rods with electricity—can only produce nanotubes that are usually only a few micrometers long. "If you interrupt the nanotube, then you interrupt their properties," says Ray Baughman of the University of Texas at Dallas. The most bang for chemists' buck lies in learning how to manufacture individual, extra-long nanotubes. However, many scientists agree that it will be a big stretch to produce single nanotubes much longer than the current limits with today's technology.

Do the twist

To get enough material for usable super fibers, scientists have a few tricks up their sleeves. The best idea for now, says R. Byron Pipes of Purdue University in West Lafayette, IN, is to take many short nanotubes and bundle them into yarns. Although the resulting yarn has less than 1% of the theoretical strength, heat conductivity, and electrical conductivity, the end product still has some intriguing possibilities.



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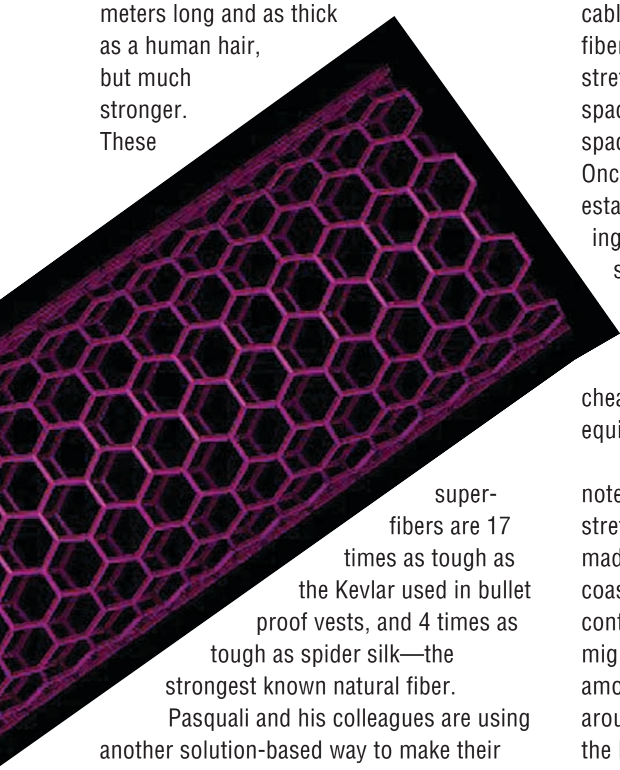
"For many centuries, man had only discontinuous fibers at his disposal, like flax and cotton. But we've made yarn, rope, and cloth, twisting fibers so they become strong," says Pipes. "Most people think that if the elements aren't continuous then it's not strong, but that's not true."

For example, Baughman and his coworkers have manufactured carbon nanotube yarns by distributing billions of nanotubes into a detergent solution. The scientists keep the tubes from bunching together by blasting the solution with high-frequency sound waves. Feeding a thin stream of the solution into a whirling bath, the scientists have twisted yarns up to 200 meters long and as thick as a human hair, but much stronger. These superfibers are 17 times as tough as the Kevlar used in bullet proof vests, and 4 times as tough as spider silk—the strongest known natural fiber.



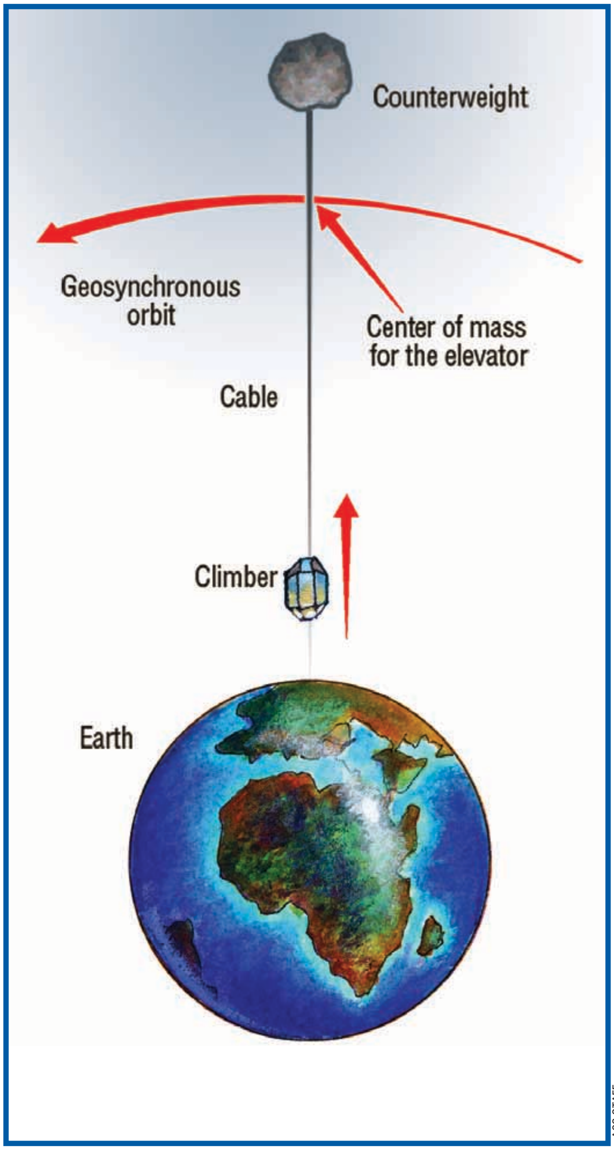
Pasquali and his colleagues are using another solution-based way to make their own nanotube yarns. Dumping their individual nanotubes into sulfuric acid, the researchers found that electrical charges within the acid distributed the tubes evenly without the high-frequency sound waves. Pasquali's team simply pressed the nanotube solution through a syringe into a coagulating bath, pushing out meters of super-strong nanotube cables.

Next big thing

Researchers are now testing the new fibers to see exactly what kind of physical properties they possess. If they can tweak the properties of these yarns to even one-tenth of an individual nanotube, then scientists will be in business for a number of opportunities.

Clothes for a futuristic soldier will be only the tip of the iceberg, says Baughman. They could play a major part in building stronger vests for police officers and artificial muscles that twitch with electricity. These are two super fiber possibilities that he and his team are talking about.

Many scientists are dreaming much bigger; for example, some researchers believe that an extra-long cable spun of carbon super fibers might someday stretch all of the way to space, tethering an orbiting spacecraft to the earth. Once the initial thin cord is established, a small climbing machine could strengthen and thicken the line, eventually creating a space elevator that could cheaply carry people and equipment into space.



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On a more practical note, Pasquali thinks that stretching electrical cables made of super fibers from coast to coast—or even continent to continent—might save an enormous amount of electricity around the world. "One of the big problems with power is that, for the most part, you can't store it," says Pasquali. "You continuously have to produce the power that's needed."

Right now, loads of electricity are wasted as power plants churn away through the night, supplying electricity for just a few night owls. But at night in one part of the world, it's daytime in another. If scientists could move electricity instantly from one half of the world to another, energy production's efficiency would dramatically improve.

Traditional cables won't work for such an expansive application—right now, they lose about 50% of the energy that's produced through resistance while just moving it around. However, a cable woven of carbon super fibers could be a perfect fit for the job, notes Pasquali.

Although the phenomenon has been only demonstrated over a distance of a micrometer, it's an exciting result. He estimates that some of the applications of carbon super fibers could be here in a mere 10 to 20 years.

In the meantime, he and other carbon nanotube chemists will keep spinning longer and longer superfibers, weaving their dreams toward reality.

Christen Brownlee is a contributing editor to *ChemMatters*. Her article "Flaking Away" also appears in this issue.