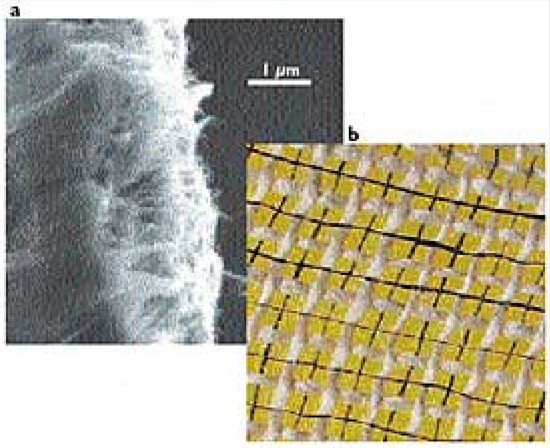
Stronger than spider silk

Toughness is a measure of the energy per unit mass needed to break a fiber, and until recently, spider dragline silk was the toughest material known—5 times as tough as steel. However, no one has learned how to produce spider silk in fiber diameters that can be woven into a superstrong material. So Kevlar, with a toughness about that of steel, has remained the toughest commercial fiber for several decades.



Surfactant-dispersed singlewalled nanotubes are injected into aqueous polyvinyl alcohol to produce nanotube gel fibers (a), which are pulled from the coagulation bath to form 100-m lengths of solid nanotube composite fiber (dark) that can be woven into textiles (light, in b). (Nanotech Institute, University of Dallas)

A collaboration between the department of chemistry and the NanoTech Institute at the University of Texas at Dallas (Richardson, TX) and the department of physics at Trinity College (Dublin, Ireland) has now yielded an artificial fiber made from single-walled carbon nanotubes (SWNTs) that tops the toughness of spider silk. The new fiber has a toughness of 570 J/g, 5 times that of silk and 25 times that of steel wire. With a diameter of 50 µm, the fibers are easily woven into fabrics (*Nature* 2003, 423, 703).

The fiber's toughness comes not just from its high strength of 1.8 GPa, equal to that of spider silk, but from an extremely high strain at failure—about 300%—which means the fibers can triple their length before breaking. Silk breaks at a strain of 30%.

To create the fibers, the research team uses detergents to put the SWNTs into solution, and then sends the liquid spinning into the center of a cylindrical pipe coated with flowing polyvinyl alcohol. When the two solutions make contact, the mixture collapses into a thick gel, which moves down the pipe and can be wound on a mandrel. "The gel is about 60% nanotubes by weight, so it shares their great strength," explains Alan B. Dalton of the NanoTech Institute. "But the polymer seems to act as a strong glue, both holding the nanotubes together and letting them slip past each other to allow for high strain." The part of the polymer in direct contact with the nanotubes is in a pseudocrystalline state, but the polymer farther from the nanotubes is amorphous, which seems to allow for strength and flexibility.

The fibers also have remarkable electrical properties, such as extremely high capacitance per unit mass—as much as 60 F/g for a single fiber. Even at low voltage, such high capacitance allows for storing considerable amounts of electrical energy, comparable to a battery on a mass-for-mass basis. In addition, when charge is injected into the fibers, they contract slightly, with a force per unit mass that is at least twice that of muscle fibers.

"Right now, we are concentrating on the mechanical properties because the electrical characteristics are limited by the low conductivity of the fibers," says Dalton. Large-scale applications will also have to wait until SWNTs become less expensive. They currently cost $500 a gram, and prices will not drop dramatically for three or more years, when new production facilities come on-line.