# Nano research fit for a king: Scientists test strength of composite bonds one nanotube at a time

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(PhysOrg.com) -- Arthur pulled a sword from a stone, proving to a kingdom that right beats might. Researchers at Rice University are making the same point in the nanoscale realm.

In this case, the sword is a multiwalled carbon nanotube and the stone is a bead of epoxy.

Knowing precisely how much strength is needed to pull the nanotube from the bead is essential to materials scientists' advancing the art of making stronger, lighter composites for everything from sporting goods to spacecraft.

A team led by Jun Lou, an assistant professor of mechanical engineering and materials science at Rice, and first author Yogeeswaran Ganesan, who recently earned his doctorate in Lou's lab, has published a paper in the American Chemical Society journal Applied Materials and Interfaces describing its work to measure the interface toughness of carbon nanotube-reinforced epoxy composites.

Lou, Ganesan and their colleagues have a second new paper in *ACS Nano* on using the same technique to measure the effect of nitrogen doping on the mechanical properties of carbon nanotubes.

Nanotubes are finding their way into products as manufacturers bank on their reputation for strength and lightness. One can buy baseball bats, tennis rackets and high-priced bicycles reinforced with nanotubes.

"Carbon nanotubes are so small (a strand of hair is 50,000 times wider) that in order to use them on the human scale, you have to do something to make them bigger," Lou said.

One such way is to mix them into composites, an imperfect science that involves much trial and error since the possible strength of the interface between every type of nanotube and every type of base material is not well understood. Lou and his team intend to eliminate the guesswork with a way to measure important properties of a composite before the first batch is mixed.

"You don't want to spend a lot of time and money on a fancy chemical treatment without knowing what's happening at the critical interface," Lou said.

Single-fiber pullout tests have been used since the early days of composite manufacturing to measure not only the strength of a bond but when, why and how it will break. That's hard on the nanoscale. Others have used atomic force microscopes as part of the pulling mechanism, but the method has its limitations, Lou said.

The Rice team has built a better device: a spring-loaded, push-pull micromechanical assembly on a silicon chip that allows researchers to string a multiwalled nanotube to a blanket of epoxy on one side while the other is held firmly in place with a platinum anchor. Pressing down on the spring applies equal force to both sides, allowing researchers to see just how much is needed to pull the tube from the epoxy.

The team reported in the first paper that forces binding multiwalled nanotubes to a general-purpose epoxy called Epon 828 were actually weaker than they expected. "We have started to understand that adding nanotubes to bulk material doesn't always give you better properties," Lou said. "You have to be very careful about how you add them in and what kind interface they form."

Because batches of nanotubes tend to stick together, some manufacturers functionalize their surfaces to disperse them before mixing into a material. "But that can disrupt the outer wall, and that's a bad thing," Lou said. "If you do something to make nanotubes easily dispersible but decrease their intrinsic strength, you're shooting yourself in the foot."

On the other hand, he said, "If manufacturers need a tough material that absorbs energy without breaking, a weaker interface may not be a bad thing. During this pullout process, there's a lot of friction at the interface of the nanotube and the matrix, and friction is effectively a way to dissipate energy."

Sometimes the end product is better if the nanotube stretches before it breaks. In the ACS Nano paper, the team compared the tensile strength of pristine versus nitrogen-doped multiwalled carbon nanotubes. They found the pristine tubes tend to snap in a brittle fashion, while nitrogen-doped tubes exhibit signs of plasticity -- "necking" before they break.

That may be desirable for certain materials, Lou said. "You don't build a bridge out of ceramic. You build it out of steel because of its plasticity.

"If we can develop a nanotube composite with room-temperature plasticity, it's going to be fantastic," he said. "It will find many, many uses."

Lou said Rice's versatile technique for carrying out nanomechanical experiments is poised to find many long-sought answers. "Developing an ability to engineering nanocomposites with mechanical properties tailored for specific applications is the proverbial holy grail of all structural nanocomposite research," Ganesan said. "The technique essentially takes us one step closer to achieving this goal."

Provided by Rice University

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