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NEWS RELEASE

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Note to Journalists: An electronic copy of the research paper is available from Emil Venere, (765) 494-4709, venere@purdue.edu

'Sticky nanotubes' hold key to future technologies

WEST LAFAYETTE, Ind. - Researchers at Purdue University are the first to precisely measure the forces required to peel tiny nanotubes off of other materials, opening up the possibility of creating standards for nano-manufacturing and harnessing a gecko's ability to walk up walls.

So-called "peel tests" are used extensively in manufacturing. Knowing how much force is needed to pull a material off of another material is essential for manufacturing, but no tests exist for nanoscale structures, said Arvind Raman, an associate professor of mechanical engineering at Purdue.

Researchers are trying to learn about the physics behind the "stiction," or how the tiny structures stick to other materials, to manufacture everything from nanoelectronics to composite materials, "nanotweezers" to medical devices using nanotubes, nanowires and biopolymers such as DNA and proteins, he said.

Flexible carbon nanotubes stick to surfaces differently than larger structures because of attractive forces between individual atoms called van der Waals forces.

"Operating in a nanoscale environment is sort of like having flypaper everywhere because of the attraction of van der Waals forces," Raman said. "These forces are very relevant on this size scale because a nanometer is about 10 atoms wide."

Mechanical engineering doctoral student Mark Strus made the first peeling-force measurements for nanotubes in research based at the Birck Nanotechnology Center in Purdue's Discovery Park.

Findings were detailed in a research paper published in February in the journal Nano Letters. The paper was written by Strus; materials engineering doctoral student Luis Zalamea; Raman; Byron Pipes, the John Leighton Bray Distinguished Professor of Engineering; NASA engineer Cattien Nguyen; and Eric Stach, an associate professor of materials engineering.

The energy it takes to peel a nanotube from a surface was measured in "nanonewtons," perhaps a billion times less energy than that required to lift a cup of coffee. That peeling energy is

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proportional to the nanotube's "interfacial energy," which is one measure of how sticky something is, Strus said.

"This whole idea of measuring the stickiness of something is a standard material test in industry," he said. "There are certain tests that you need to have for measuring strength, toughness and adhesion."

But until now, no such test had been completed to successfully measure and quantify these forces on the nanoscale.

Nanotubes offer promise to produce a new class of composite materials that are stronger than conventional composites for use in aircraft and vehicles.

"This is a big area of research primarily because the strength of nanotubes can be much greater than that of carbon nanofibers," Raman said.

However, properly integrating high-strength nanotubes into polymers for composite materials requires a knowledge of how the nanotubes stick to polymers and to each other.

"One of the big areas in composites, in general, and nanocomposites, in particular, is how to coat a fiber with a material that makes it stick better to the matrix," Raman said. "So it's really important to know how to judge which coatings work best for specific types of fibers. For larger fibers, industry knows which coatings work best, but such knowledge is scarce for nanoscale fibers. It's all about how to make nanotubes 'sticky' to the surrounding matrix."

Nanotubes also must be dispersed uniformly in a solution before being mixed with the polymer to make composite materials, but the tiny rods tend to clump together. Learning precisely how the tubes adhere to each other could lead to a method for dispersing them.

The findings also promise to help researchers understand how geckos are able to stick to surfaces, a trait that could translate into practical uses for industrial and military applications.

Tiny branching hairs called setae on the animal's front feet use van der Waals adhesion.

"The question is, how does it stick, and, equally important, if the adhesion force is strong enough to hold its weight onto a surface like a wall, then how does it then unstick, or peel, itself to move up a vertical surface?" Strus said.

Nanotubes also have possible medical applications, such as creating more effective bone grafts and biomolecular templates to replace damaged tissues, which requires knowing precisely how the nanotubes adhere to cells.

Yet another potential application is a "nanotweezer" that might use two nanorods to manipulate components for tiny devices and machines.

Raman and Strus plotted how much force it took to peel nanotubes from surfaces, discovering that the tubes lift off in fits and starts instead of smoothly.

"We saw these jumps in peeling forces, where the nanotubes would lift off suddenly and then snag, lift off suddenly and then snag. This behavior has a very deep physical significance and can only be appreciated by means of mathematical models," Raman said.

Pipes and Zalamea, meanwhile, had already been developing theoretical models to describe how the nanotubes would peel away from a surface and from each other. The four researchers then worked together with the others to fine tune the model, which describes the physics of why nanotubes peel off unevenly.

The nanotubes used in the research had a length of about 6 microns, or millionths of a meter, and were 40 nanometers wide, roughly 500 times thinner than a human hair.

The researchers used an atomic force microscope to measure the peeling forces. The nanotube was attached to the end of a diving-board shaped part of the microscope called a microcantilever. As the nanotube was pulled away from a surface, the cantilever bent. This bending movement was tracked with a laser, revealing the forces required to peel the nanotube.

The carbon nanotubes for the research were provided by NASA. With the assistance of Stach, the structure of the nanotubes was characterized using a transmission electron microscope. The research was funded by the National Science Foundation and the Korean Center for Nanomanufacturing and Mechatronics. Strus' work is supported in part with a Bilsland Fellowship, which he was awarded this year.

Future work may focus on making measurements that apply to nanocomposites.

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Related Web sites:
Arvind Raman: https://engineering.purdue.edu/ME/People/ptProfile?id=12884
Birck Nanotechnology Center: http://www.nano.purdue.edu

IMAGE CAPTION:

This composite image taken with an electron microscope shows a side and bottom image of a nanotube attached to a "microcantilever," a component in atomic force microscopes. Researchers at Purdue used the experimental setup to precisely measure the forces required to peel nanotubes off of other materials, opening up the possibility of creating standards for nano-manufacturing and harnessing a gecko's ability to walk up walls. The nanotube in this image has a length of about 6 microns, or millionths of a meter, and is 40 nanometers wide, roughly 500 times thinner than a human hair. This image also shows an artistic representation of how a nanotube peels away from surfaces. (Birck Nanotechnology Center, Purdue University)

A publication-quality photo is available at http://news.uns.purdue.edu/images/+2008/raman-sticky.jpg

ABSTRACT

Peeling Force Spectroscopy: Exposing the Adhesive Nanomechanics of One-Dimensional Nanostructures

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The physics of adhesion and stiction of one-dimensional nanostructures such as nanotubes, nanowires and biopolymers on different material substrates is of great interest for the study of biological adhesion and the development of nanoelectronics and nanocomposites. Here, we combine theoretical models and a new mode in the atomic force microscope to investigate quantitatively the physics of nanomechanical peeling of carbon nanotubes and nanocoils on different substrates. We demonstrate that when an initially straight nanotube is peeled from a surface, small perturbations can trigger sudden transitions between different geometric configurations of the nanotube with vastly different interfacial energies. This opens up the possibility of quantitative comparison and control of adhesion between nanotubes or nanowires on different substrates.