Hybrid Dual Porosity CNTs Function as Sliding Electrical Contacts

D.N. Futaba and co-workers from the National Institute of Advanced Industrial Science and Technology of Japan, together with S. Sasaki from the Tokyo University of Science have demonstrated the first known hybrid dual-porosity carbon nanotube (CNT) material composed of a section of highly porous and a section of much less porous assemblies of aligned nanotubes seamlessly connected by locally collapsing the initially sparse CNT material using the capillary forces of liquids. The researchers demonstrated the potential of this hybrid material as a low wear tribological material, useful as a sliding electrical contact, in the September 9 issue of *Nano Letters* (DOI: 10.1021/nl901581t; p. 3302).

The researchers grew millimeter-tall single-walled nanotubes (SWNTs) with a porosity of ~97% by chemical vapor deposition on Si substrates with an oxidized layer 600-nm thick and covered with a thin catalytic Al_2O_3(40 nm)/Fe(1 nm) metal layer. They used ethylene (99.999%) as the carbon source flowing at 50–100 cm^3 STP per minute. Water vapor (100–200 ppm) was used as a catalyst preserver and enhancer. The water vapor was supplied by flowing the helium (99.9999%) and hydrogen (99.99999%) carrier gas through a water bubbler.

In a first demonstration of the concept, the researchers delivered a controlled amount of liquid (a mixture of water and alcohol) to a precise location on the CNT structure using drop delivery from toothpicks. In the location where the liquid was applied, the CNT volume collapsed, greatly reducing the porosity of the section. The researchers were thus able to transform the uniformly porous CNT forest into a hybrid dual porosity material where a forest (high porosity, ~97%) and a solid (low porosity, ~50%) were seamlessly and smoothly connected similar to a whisk broom. The researchers said that the forest section possessed interesting mechanical properties, such as elastic recovery, dry adhesion, and field emission, while the solid section showed excellent mechanical robustness and strength. By controlling the contact point of liquids, the researchers created different structures such as "mushroom" type structures, "tepee" structures with an abrupt change in porosity along the cylinder length, and high density "shell" structures with a metallic luster surrounding the sparse interior. The researchers were able to demonstrate other structures using application of liquid thin films, bubbles, vapors, and superink-jet printing, such as beds of needles and porcupine-like structures.

The researchers demonstrated the functionality of this hybrid material as a tribomaterial by making a brush by fixing the solid part of the hybrid structures to parallel leaf springs while the highly porous and flexible part remained at the free end, making contact with the counter surfaces. The researchers observed that friction of the SWNT brushes was more stable than that of other standard tribological materials, and they did not damage the counter surfaces, exhibiting low removal of material through surface contact (wear), and with no generation of CNT graphitic debris. All this translated in longer component lifetime and holds promise for application of these structures as electrical contact materials.

In a last experiment, the researchers assembled four wide brush-hybrids into a "clover" configuration with the low porosity section connected to a copper wire, and the highly porous section forming a uniform circular exterior. They then used this assembly as a sliding electrical contact by installing it into a dc motor, achieving rotation in excess of 300 rpm with a current of ~0.1 A. The researchers said that the assembly might be useful in vibrator motors for cell phones where the lifetime is limited by oxidization of the metal contacts.

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