Materials

Strong, Lightweight, Porous Materials

These materials, derived from silica aerogels, can be tailored to have superior properties.

John H. Glenn Research Center, Cleveland, Ohio

A new class of strong, lightweight, porous materials has been invented as an outgrowth of an effort to develop reinforced silica aerogels. The new material, called X-Aerogel is less hygroscopic, but no less porous and of similar density to the corresponding unmodified aerogels. However, the property that sets X-Aerogels apart is their mechanical strength, which can be as much as two and a half orders of magnitude stronger that the unmodified aerogels. X-Aerogels are envisioned to be useful for making extremely lightweight, thermally insulating, structural components, but they may also have applications as electrical insulators, components of laminates, catalyst supports, templates for electrode materials, fuel-cell components, and filter membranes.

In broad terms, X-Aerogels are formed by chemical reaction of a cross-linking agent with the surfaces of the nanoporous network of the native aerogel. The cross-linking agent may be a monomeric or an oligomeric precursor of a polymer that forms a conformal coating on the nanoparticles, reinforcing the underlying structure while preserving the mesoporosity. The nanoporous network itself may consist of silica, alumina, titania, vanadia, or other metal oxide aerogels. Research with various other oxide nanoparticle skeletal frameworks has led to X-Aerogels based on approximately 35 different metals from the Periodic Table.

The nanoparticles that comprise the aerogels can be cross-linked in their native form through the hydroxyl groups, which are found naturally on their surface. Thus, the first class of X-Aerogels utilizes isocyanates for cross-linking, which react both with the surface hydroxyl groups and any water adsorbed on the surfaces of the nanoparticles. This limits polymer accumulation only on the internal surfaces of the aerogel, leaving the mesopores empty. The result is a greatly reinforced structure at a minimal increase in density.

While the isocyanate cross-linked aerogels show great improvements in properties, relying on the native hydroxyl group functionally of aerogels for cross-linking limits the variety of possible precursors that can react with the mesoporous surfaces. This issue has been addressed by chemical modification of the aerogel itself. The mesoporous surface of silica has been modified with amines and olefins, and the resulting particles have been cross-linked with epoxides and with polystyrene. Many other combinations of surface functional groups and cross linkers can be envisioned, which would impart additional desired properties to the X-Aerogels.

This work was done by Nicholas Leventis, Mary Ann B. Meador, and James C. Johnston of Glenn Research Center and Eve F. Fabrizio and Ulvi Ilhan of Ohio Aerospace Institute. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17685-1.

Nanowicks

Fiber geometries could be tailored for pumping, filtering, mixing, separating, and other effects.

NASA's Jet Propulsion Laboratory, Pasadena, California

Nanowicks are dense mats of nanoscale fibers that are expected to enable the development of a variety of novel capillary pumps, filters, and fluidic control devices. Nanowicks make it possible obtain a variety of novel effects, including capillary pressures orders of magnitude greater than those afforded by microscale and conventional macroscale wicks. While wicking serves the key purpose of transporting fluid, the nanofiber geometry of a nanowick makes it possible to exploit additional effects — most notably, efficient nanoscale mixing, fluidic effects for logic or control, and ultrafiltration (in which mats of nanofibers act as biomolecular sieves).

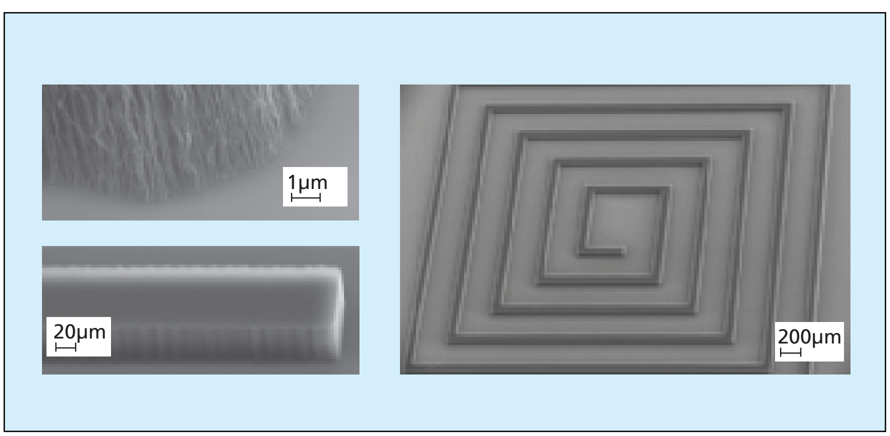

Figure 1. This **Scanning Electron Micrograph** depicts a nanowick in the form of a mat of carbon nanotubes, which can be grown in a tailorable pattern as shown on the right.

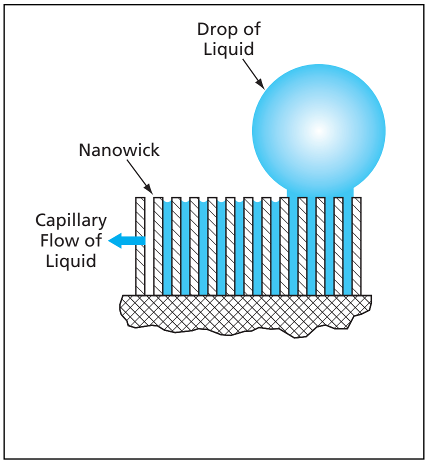

Figure 2. A **Drop of Liquid** would be placed on a nanowick. The liquid would be absorbed into the wick and transported by capillary action.

A nanowick (see Figure 1) typically consists of carbon nanotubes grown normal to a substrate in a tailorable pattern. The liquid of interest is constrained to flow in the interstices between the fibers. (In practice, the liquid must include a surfactant because carbon nanotubes are hydrophobic.) By suitable control of the growth process, the interfiber distance and/or the fiber length can be made to range from nanometers to millimeters and to vary with position (in one or two dimensions) on the substrate. Similarly, the fiber diameter can be made to vary with position. The spatial variation in spacing and/or diameter can be chosen to obtain such effects as prescribed spatial variations in wicking speed or prescribed degrees of separation among different biomolecules.

The following are examples of potential applications and potential variations in designs of nanowicks:

- Somewhat analogously to strips of litmus paper, wicking chips could be made as disposable devices for rapid testing of liquids. To start a test, a drop of liquid would be placed on top of the array of nanofibers on a wicking chip (see Figure 2). After absorption of the drop and transport of the liquid by wicking, the liquid could be filtered and analyzed (for viscosity, for example) in a very simple manner, without need for any complicated pumping mechanism.
- A liquid could be made to flow continuously, as in a capillary-pumped loop. The liquid would enter a nanowick at one end, would flow through the mat of fibers by capillary action, and would be made to evaporate at the other end. The evaporation would sustain the pumping action in the same manner in which evaporation of water from leaves sustains capillary pumping in living plants.
- A nanowick could serve as both a filter and a pump: While a liquid was flowing through a nanowick, the fibers could trap particles and large molecules (for example, protein and deoxyribonucleic acid molecules).
- The pattern of nanofibers could be tailored to exploit a combination of diffusion and extensional flow to promote nanoscale mixing of two liquids.
- Nanowicks could be patterned to act as various fluidic logic devices, including ones that exert fluidic effects analogous to the electrical effects of transistors and diodes. Unlike macroscale and microscale fluidic devices, the nanowick-based fluidic devices could, conceivably, be designed and built without channels and could operate without mechanical pumps.
- It might be possible to construct nanowicks in which selective wicking could be controlled electrically.
- Although capillary forces would suffice to contain a liquid within a nanowick, without need to place the wick in a channel, the nanowick could be capped, if desired, to prevent evaporation.
- Nanowicks could be used to transport liquids through interstitial spaces into which tubes could not inserted.

This work was done by Flavio Noca, Michael Bronikowski, Elijah Sansom, Jijie Zhou, and Morteza Gharib of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Lightweight Thermal Protection System for Atmospheric Entry

The material withstands up to 1,970 K to protect wing leading edges and nose caps on hypersonic vehicles.

Ames Research Center, Moffett Field, California

TUFROC (Toughened Uni-piece Fibrous Reinforced Oxidation-resistant Composite) has been developed as a new thermal protection system (TPS) material for wing leading edge and nose cap applications. The composite withstands temperatures up to 1,970 K, and consists of a toughened, high-temperature surface cap and a low-thermal-conductivity base, and is applicable to both sharp and blunt leading edge vehicles. This extends the possible application of fibrous insulation to the wing leading edge and/or nose cap on a hypersonic vehicle.

The lightweight system comprises a treated carbonaceous cap composed of ROCCI (Refractory Oxidation-resistant Ceramic Carbon Insulation), which provides dimensional stability to the outer mold line, while the fibrous base material provides maximum thermal insulation for the vehicle structure. The composite has graded surface treatments applied by impregnation to both the cap and base. These treatments enable it to survive in an aero-convectively heated environment of high-speed planetary entry. The exact cap and base materials are chosen in combination with the surface treatments, taking into account the duration of exposure and expected surface temperatures for the particular application.

Current leading edge TPS systems weigh approximately 1.6 g/cm^3, while the TUFROC version weighs 0.4 g/cm^3. The RCC system used on the orbiter operates at heat fluxes below 70 W/cm^2 during Earth re-entry. Not only are systems like this heavier than TUFROC, they are far more expensive with RCC costing approximately 100 times more than TUFROC components of equivalent size. Furthermore, RCC requires significantly longer fabrication lead times — 12 rather than the