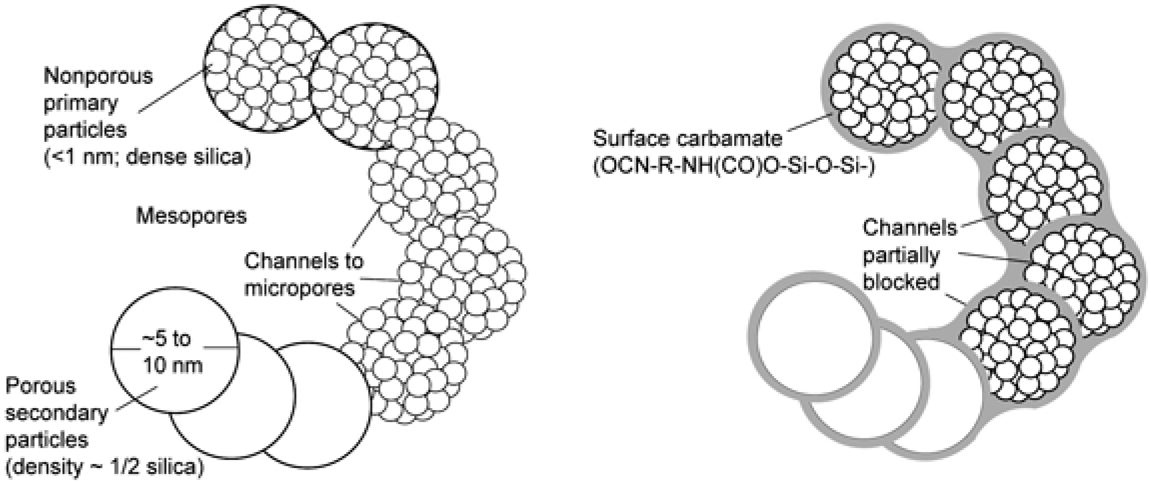
Mechanically Strong, Lightweight Porous Materials Developed (X-Aerogels)

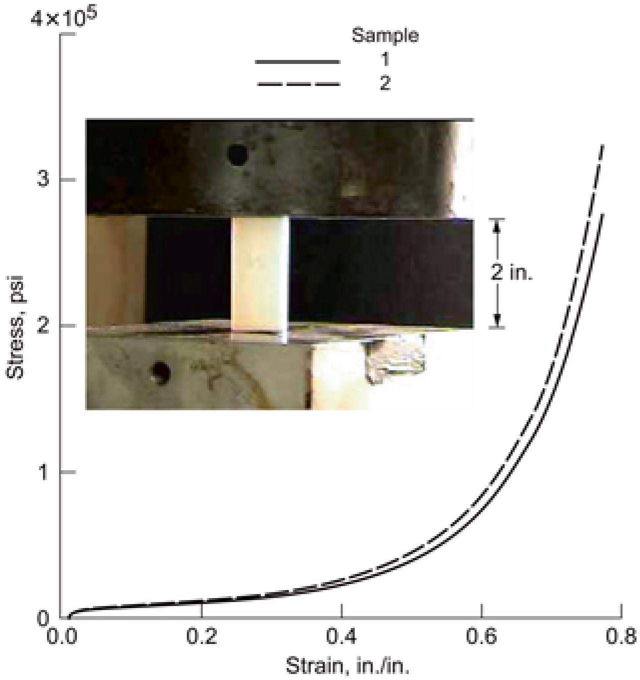
Aerogels are attractive materials for a variety of NASA missions because they are ultralightweight, have low thermal conductivity and low-dielectric constants, and can be readily doped with other materials. Potential NASA applications for these materials include lightweight insulation for spacecraft, habitats, and extravehicular activity (EVA) suits; catalyst supports for fuel cell and in situ resource utilization; and sensors for air- and water-quality monitoring for vehicles, habitats, and EVA suits. Conventional aerogels are extremely fragile and require processing via supercritical fluid extraction, which adds cost to the production of an aerogel and limits the sizes and geometries of samples that can be produced from these materials. These issues have severely hampered the application of aerogels in NASA missions.



Microstructure of a silica aerogel cross-linked with polyurethane/polyurea (X-Aerogel). Long description of figure 1. Ilustrations show nonporous primary particles (less than 1 nanometer; dense silica), mesopores, channels to micropores, porous secondary particles (about 5 to 10 nanometers; density about one-half silica), surface carbamate (OCN-R-NH(CO)O-Si-O-Si-), and partially blocked channels.

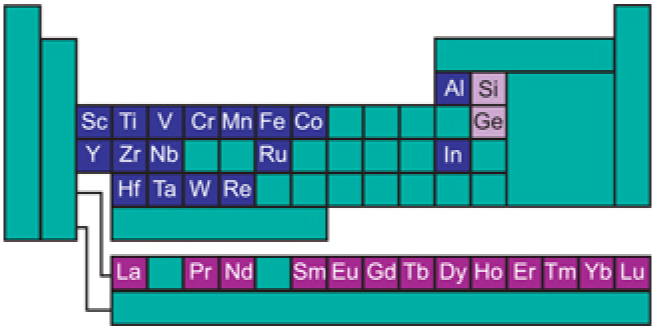
Researchers at the NASA Glenn Research Center have developed a new class of strong lightweight materials, named X-Aerogels. These materials are produced by reacting the internal (mesoporous) surfaces of porous networks of inorganic nanoparticles with polymeric crosslinking agents. The preceding illustration shows a schematic of the microstructure of a typical aerogel before and after modification with an isocyanate. Reaction of the aerogel with an isocyanate monomer results in the formation of conformal polyurethane/polyurea coating around the nanoparticles.

The most striking feature of these novel aerogels is that, for a nominal increase (no more than threefold) in density, their mechanical strength can be increased by up to 300 times that of the unmodified, conventional aerogel. In addition, the specific compressive strength of these materials is ~10 times that of steel. The following graph shows the stress-strain curve of a typical X-Aerogel monolith under a compressive load. Under compression, these aerogels fail at a load of about 30,000 psi, where the sample has been compressed to ~80 percent of its original length with no bucking and only a minimal "swelling" (~20 percent). This occurs mostly during the last stages of compression. The thermal conductivity of these new aerogels is in the range of only 20 to 40 mW/mK, about 3 to 6 times that of a conventional aerogel. Ongoing research with these materials is focused on reducing their density and thermal conductivity while maintaining acceptable mechanical properties.



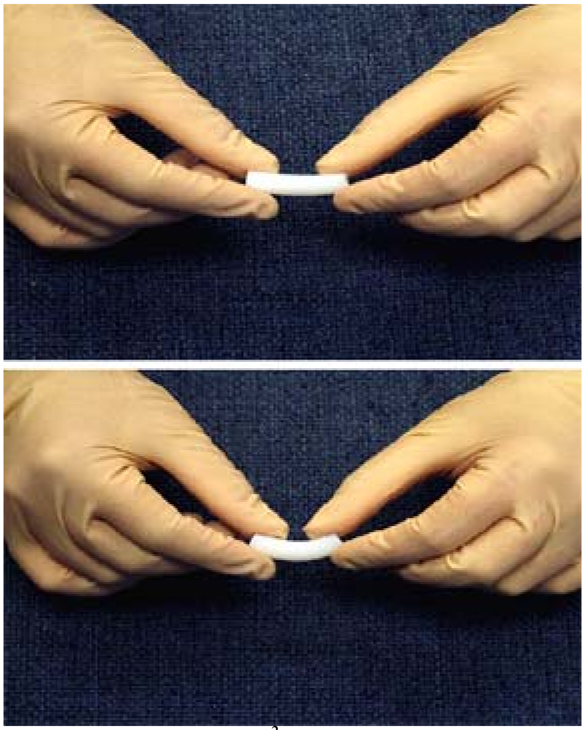
Stress-strain curves from a compressive strength test of an isocyanate cross-linked X-Aerogel monolith (~0.45 g/cm^3, 0.7 in. diam, 1.5 in. long). (Data obtained by Prof. Samit Roy of Oklahoma State University).

Other Glenn research is focused on extending this approach to the development of other aerogel materials. Two parallel approaches are being explored--(1) developing aerogels from other inorganic materials besides silica and (2) utilizing other polymer cross-linkers besides diisocyanates. Along these lines, this chemistry has been successfully demonstrated with more than 35 different metal and semimetal oxide aerogels utilizing isocyanates as the cross-linking agent (see the periodic table). Many of these new aerogel materials may have unique optical, magnetic, or electrical properties.



Periodic table showing elements that have been made into X-Aerogels and have been successfully cross-linked into X-Aerogels.

In addition, the surfaces of the silica aerogels have been modified with (1) amines that have then been cross-linked with epoxies and (2) olefins, such as polystyrene. Polystyrene, because of its high hydrogen content, has been shown to be an effective radiation shielding material. The radiation shielding capabilities of polystyrene cross-linked aerogels are currently under investigation. It may be possible that these new aerogels could afford both radiation protection and thermal insulation to astronauts on future exploration missions. Silica-based X-Aerogel chemistry has also been modified to produce flexible systems (see the photographs). These new aerogel compositions could be used as EVA suit insulation, where conventional aerogels cannot be used because they are too rigid and fragile.



Flexible, low-density (~50 mg/cm^3) isocyanate cross-linked X-Aerogel.

In addition to the NASA mission applications discussed above, X-Aerogels could find use in a variety of nonaerospace applications, including catalyst supports for automotive and industrial applications, thermal and acoustic insulation materials for construction, optoelectronic devices, and packaging of sensitive electronic devices.

Bibliography

Zhang, Guohui., et al.: Isocyanate CrossLinked Silica Aerogel Monoliths: Preparation and Characterization. J. Non-Cryst. Solids, vol. 350, 2004, pp. 152-164.

Bertino, M.F., et al.: Room Temperature Synthesis of Noble Metal Clusters in the Mesopores of Mechanically Strong Silica-Polymer Aerogel Composites. J. Sol-Gel Sci. Tech., vol. 30, no. 1, 2004, pp. 43-48.

Leventis, Nicholas, et al.: Synthesis and Characterization of Ru(II) Tris(1,10-Phenanthroline)-Electron Acceptor Dyads Incorporating the 4-Benzoyl-N-Methylpyridinium Cation or N-Benzyl-N´-Methyl-Viologen. Improving the Dynamic Range, Sensitivity, and Response Time of Sol-Gel-Based Optical Oxygen Sensors. Chem. Mater., vol. 16, 2004, pp. 1493-1506.

Bertino, M.F., et al.: High Resolution Patterning of Silica Aerogels. J. Non-Cryst. Solids, vol. 333, 2004, pp. 108-110.

Zhang, G., et al.: Isocyanate Cross-Linked Silica: Structurally Strong Aerogels. Polymer Preprints, vol. 44, no. 1, 2003, pp. 35-36.

Find out more about NASA Glenn:
http://www.nasa.gov/centers/glenn/home/index.html

Glenn contact: Dr. Nicholas Leventis, 216-433-3202, Nicholas.Leventis-1@nasa.gov
Author: Dr. Nicholas Leventis
Headquarters program office: Aeronautics Research
Programs/Projects: IR&D