SILICA AEROGELS

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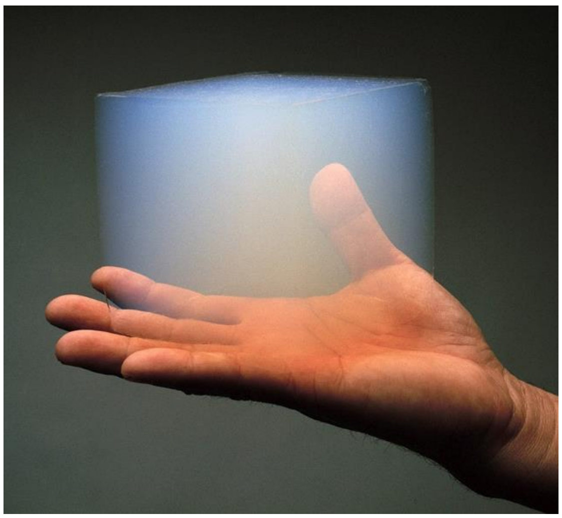
ABSTRACT

This engineering report will cover the broad family of materials known as Aerogels — with a focus on Silica Aerogels.



Aerogels are a family of synthetic materials with a complex geometric configuration that allows for ultra-low density and thermal conductivity. Silica Aerogel was synthesized from silica gel molecules, however, improved technologies in material science have allowed aerogels to be synthesized with different components such as carbon or certain metal oxides. The history of aerogels, their material properties, market outlooks, and past, present, and potential future applications will be covered in this report.

OVERVIEW

Silica Aerogel is an ultra-lightweight solid material known for its extremely low thermal conductivity. This has allowed Silica Aerogel to be used as a lighter and thinner alternative to conventional insulation methods. These space-saving and thermal-efficiency properties also make Silica Aerogel an ideal material in the aerospace industry as an alternative to traditional methods of transporting and storing fuels of energy (batteries, fuel).

The structure of Aerogel materials is that of a non-porous solid with complex interconnected polymer-like chains. Its structure is composed of 99.8 % of air giving Aerogels its low density and a light-blue “ghostly” appearance.

Despite Silica Aerogel’s favorable properties, it has been unable to make significant headway into commercial and business markets. (Disregarding the cost of manufacturing) Its material properties during manufacturing and usage – high brittleness and volumetric shrinking, as well as low strength and elasticity– have limited Silica Aerogel's viability as a commercial material.

However, as years continued and material synthesizing methods improved, the method of producing Aerogels was expanded beyond Silica. This is done by adding another material, such as a metal or polymer, during the manufacturing process. This allows the expansion of applications for the family of different Aerogel materials.

HISTORY OF AEROGELS

The invention of Aerogels is credited to Dr. Samuel Stephens Kistler, a chemical engineer, professor, and former Dean of the University of Utah's School of Engineering. Kistler first surmised the idea of replacing the liquid phase of a gel with a gas, with a minimum loss of volume. With this hypothesis, Kistler produced silica aerogels. As a professor of chemistry at the University of Illinois, Kistler was a consultant for DuPont, Rayon, and the Monsanto Company in their material sciences division.

During Dr. Kistler's time at the Monsanto Company, aerogels were commercially marketed under the name Santocel. Santocel was advertised as a low-weight, low-volume alternative to traditional insulators for gas containers, refrigeration insulation, and steam lines and pipelines to reduce losses through the pipe.

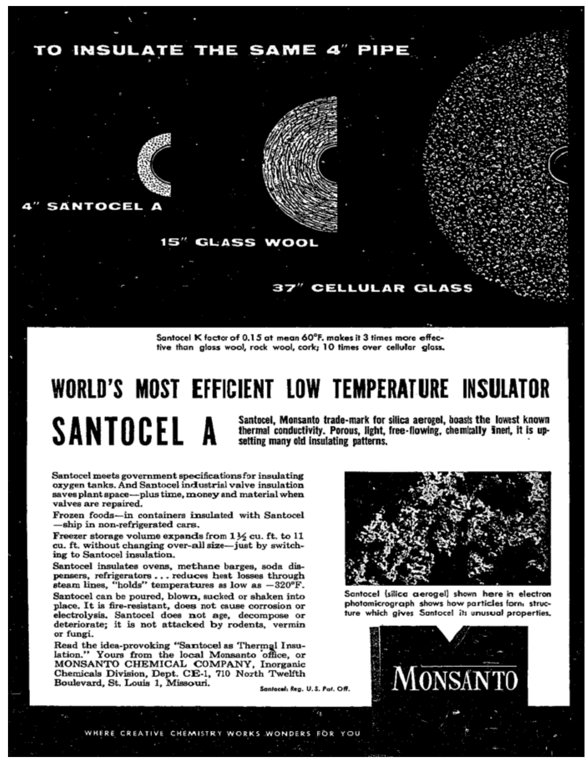


Figure 1: Advertisement for Santocel, a trademark for Silica Aerogel, under the Monsanto Company

A new method of production was developed in the late 1970s by researcher Stanislaus Teichner at Universite Claud Bernard, Lyon. Working with his graduate students, they applied the sol-gel method of synthesizing aerogels. This was more efficient and less time-consuming than the traditional solvent-swapping method developed Kistler. This allowed for innovations to be made within the field of aerogels for thermal insulation, waste management, molten metals, optics, electronic devices, capacitors, pesticides, and cosmic dust collection.

PROPERTIES OF AEROGELS

Applying enough pressure on Silica Aerogels causes a catastrophic breakdown in the sparse structure, causing it to shatter like glass—a property known as friability.

Silica Aerogel's load-bearing capabilities are due to its microstructure of interconnected, dendrite-like chains. In the microstructure, spherical particles of average size 2-5 nanometers (nm) are fused together into clusters that form the three-dimensional, highly porous structure of chains, with pores smaller than 100 nm

Aerogel's extreme thermal insulation properties are a result of its geometric structure. This happens because air cannot circulate efficiently in the lattice of chains, thus limiting heat transfer by nullifying conduction.

Strength, T_s, (kPa)	14-16
Density, ρ (g/cm^3)	0.08–0.10
Young's Modulus, E (MPA)	0.1 - 10
Specific Heat Capacity, λ (W/m-K)	0.01 – 0.04
Thermal Conductivity, c_p (J/g-K)	0.7–1.15
Melting Point, M_p (°C)	1700
Boiling Point, Bp (°C)	2230

Chart 1: Material Properties for Silica Aerogel (Sachithanadam, Joshi)

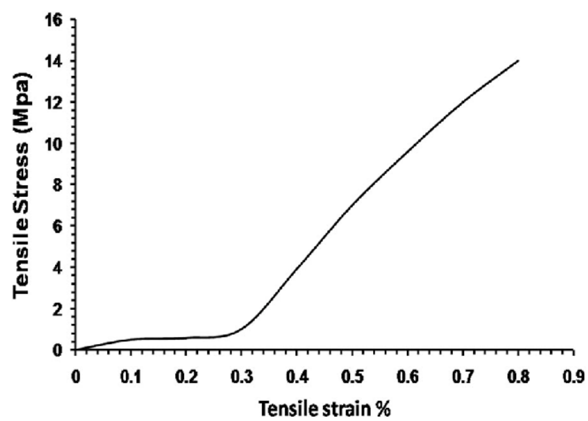


Image 2: A stress–strain curve for silica aerogel – polyester composite (UPSA – B).

PRODUCTION

SOL-GEL production method:

Two steps: 1) formation of the wet gel and 2) drying of the gel with an intermediate aging process.

The first step involves hydrolysis of silicon alkoxide, and suitable methanol solvent stirred in a solution. Under the process of gelation, the solution forms to create "alcogels." The second step involves drying the developed alcogels under supercritical condition which then produces silica aerogels.

Gelation is the process whereby a free-flowing sol (liquid) is converted into a 3D solid network enclosing the sol. A gel is a semisolid dense with liquid. Gelation is identified by rise in viscosity and elasticity under stress. For aerogels, the gelation is induced through a change in the pH level of the solution. The mechanical state of the gel depends on the cross-links in the network – the greater the degree of cross-linking in the microstructure, the more rigid the structure formed.

Once the gel network is synthesized, the process of aging is carried out. Aging refers to the strengthening of the gel network through condensation, dissolution, or supercritical drying. This results in a porous, but rigid solid in which the solvent is trapped.

AEROGELS TODAY

NASA prominently uses aerogels for its outer space purposes. Polymer-enhanced Aerogels have been developed by NASA for its low density and thermal conductivity. “These polymer-enhanced aerogels offer the same insulation properties as typical aerogels and can be translucent. They share the same positive attributes of silica aerogels and are much less fragile.” NASA also used aerogel for thermal insulation of space suits and the Mars Rover.

The Lawrence Livermore National Laboratory has developed a method of a Capacitive Deionization process that purifies salt water (salt content between 800 ppm-1200ppm) between two carbon aerogel electrodes. This method uses up to 10 times less energy than conventional electrolysis methods.

Kistler Aerogel Jackets – by SUPIELD. A Kickstarter uses a thin insulating layer of aerogel fabric to provide resistance from cold temperatures. The Kickstarter claims to resist temperatures as low as 200 °C. Unfortunately, reviews on the product page on its Kickstarter page are mostly negative due to the company's poor customer service and long, usually inaccurate shipping service.

CONCLUSION

Initially synthesized in 1936, Aerogels are a relatively new material that has seen its production methods and commercial applications shift in the 80 years since their discovery. Innovation in replacing silica with carbon-metal alloys and in variation of structure have seen the vast improvement of its material properties. Despite these innovations, aerogels have not found a consistent market outside of the aerospace industry. Chemical modification methods and ambient pressure drying aim to reduce the cost of production and make aerogels more competitive with other materials.

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