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A Study on the Architectural Application of Aerogel

Young Cheol Kwon

School of Architecture, Halla University, Gangwon 220-712, Korea

Abstract: As the building energy saving is more and more important, high-performing insulation like aerogel will be required in buildings to improve their thermal environment and to save building energy. This study conducted the literature survey on the aerogel blanket and presents the architectural application considering its high-insulating property. If aerogel is applied to a building as an envelope insulation, its thickness could be reduced to as half as that of existing insulation such as polystyrene foam board or glassfiber. Currently, aerogel is largely used as a thermal breaker in thermal bridges in buildings. It is still too expensive to be used as a main insulation of whole building envelopes. Thanks to the advantages of aerogel blanket such as low thermal conductivity, broad temperature range for use, excellent water repellent property and fire resistance, easiness of moving and applying, it has much possibility in the respect of its building application.

Key words: Insulation, aerogel, thermal conductivity, aerogel blanket.

1. Introduction

The depletion of energy resources and the problem of global warming require people sustainable development. Sustainability covers many issues, but none is as important as energy. More than any other factor, the energy consumption of buildings is destroying the planet. Buildings use about 40% of all the energy consumed. This energy is mostly derived from fossil sources that produce the carbon dioxide that is the main cause of global warming. People must replace these polluting sources with clean, renewable energy sources such as wind, solar energy and biomass, or people must increase the efficiency of their building stock so that it uses less energy, or people must do both. Of course, people need to do both, but decreasing the energy consumption of buildings is both quicker and less expensive [1].

To fight global warming, people must understand what their energy options are. By far the most important option is efficiency, which is the easiest, quickest and least expensive way to fight global warming. The most efficient way to decrease the energy consumption of buildings is to increase the insulation of thermal envelopes such as the roof and exterior walls.

Aerogel has largely been used as insulation for the spacecraft and industrial facilities. As the building energy saving is more and more important, high-performing insulation like aerogel will be required in buildings to improve their thermal environment and to save building energy.

This paper aims to show the possibility of aerogel as a building insulation.

2. The General Properties of Aerogel

2.1 Aerogel Materials Derived from Polymers Other than Silica

Essentially, any liquid can be gelled when a continuous solid lattice structure is formed within the liquid phase, entraining the solvent within open pores.

The key to making a nanoporous aerogel involves developing a balance between polymer chain growth and interchain cross-linking that will net the desired pore structure and high surface area. The modulus (stiffness) of the resulting gels must be high enough to resist the capillary forces generated during solvent

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Corresponding author: Young Cheol Kwon, Dr., professor, research fields: building energy saving and insulation. E-mail: yckwon@halla.ac.kr.

removal. This property is strongly influenced by the number of links between neighboring chains per unit volume of gel. Many materials can be incorporated into the silica- or other metal oxide-matrix at the sol stage, including organic polymers that uniquely modify the aerogel physical properties. Many highly cross-linked polymer systems can also be induced to create gels in organic solvents, such as resorcinol-formaldehyde, melamine-formaldehyde, polyimides, polyurethanes, polyisocyanurates and various unsaturated hydrocarbon materials.

2.2 Aerogels Have Extreme Structures and Extreme Physical Properties

The highly porous nature of an aerogel structure provides a huge amount of surface area per unit weight. For instance, a silica aerogel material with a density of about 100 kg/m^3 (or about 1/10th that of water) can have surface areas of around 800 m^2/g to 1,500 m^2/g depending on the precursors and process utilized to produce it. That is equivalent to roughly 3 to 5 football fields per gram of solid material—showing that an extraordinary amount of surface is folded in on itself within the aerogel structure.

The percentage of open space within an aerogel structure is about 94% for a gel with a density of 100 kg/m^3.

2.3 Development of Aerogel Blanket

Aerogel blanket was developed in 1999 by an American company of Aspen Aerogel. The production procedure of aerogel blanket is shown in Fig. 1.

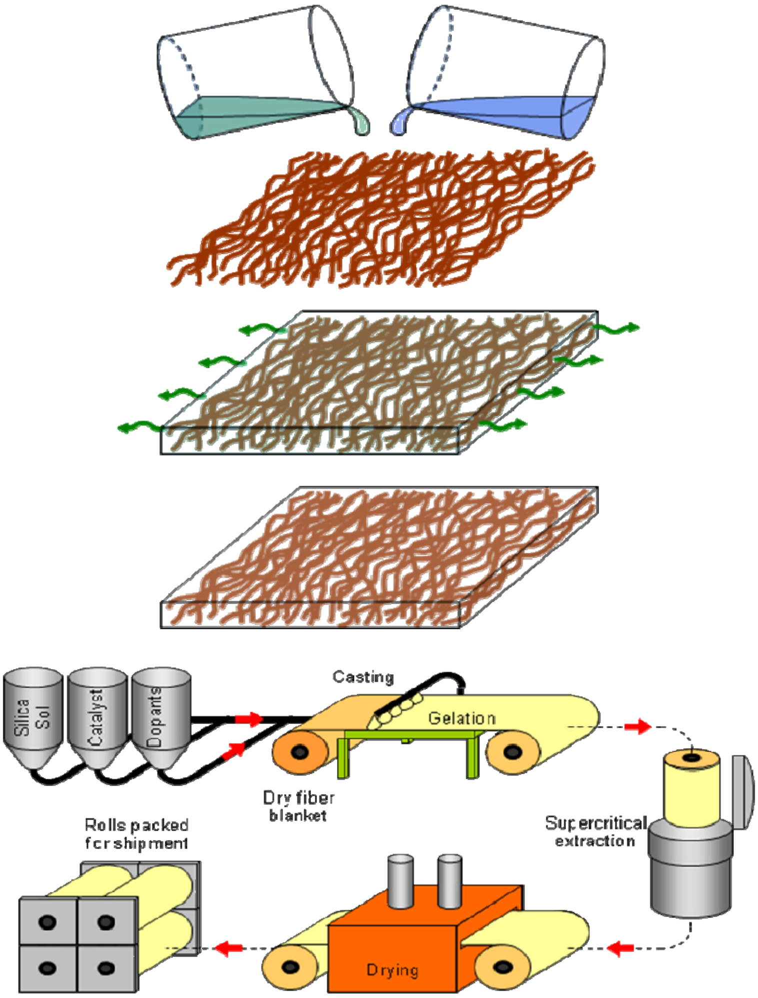


Fig. 1 Production procedure of aerogel blanket.

Aerogel production has remained a costly affair mainly due to high prices of raw materials and relatively lower production volumes. Traditionally, aerogel synthesis involves the following three steps [2, 3]:

2.3.1 Sol-Gel Preparation

The gel is prepared using silicon precursors, such as tetramethyl orthosilicate (TMOS), tetraethylortho–silicate (TEOS), polyethoxydisiloxane (PEDS), methyltriethoxysilane (MTES), silicon alkaoxide, etc..

2.3.2 Gel Aging

The gel prepared in step 1 is aged in a solvent for long periods of time to improve the mechanical and permeability properties of the gel network. The concentration, aging time, temperature, pH and polarity have a strong influence on the strength and porosity of the aerogel.

In laboratory settings, a batch process is adopted for the aging step, which is inherently a slow process. When scaling to production phase, the batch processing step may increase product cost due to increased process line downtime and frequent stopping/starting of the production line. A continuous process is desirable because it helps to increase output. However, as with any multi-step process, the individual step only adds time to the overall process if it is the bottleneck. Since aging is not the capital intensive part of the process, larger aging vessels can be used to reduce the process time for this step.

2.3.3 Gel Drying

In this step, the liquid inside the gel network is removed using a liquid to gas phase change process. However, due to the surface tension of the liquid in contact with the solid, the liquid changing phase tends to pull the gel network along with it. This causes the gel network to shrink and collapse. To retain the integrity of the gel structure during the drying process, the aged gel is brought to supercritical conditions. Under the supercritical conditions, surface tension vanishes as there is no distinct liquid-vapor phase boundary. The supercritical conditions may be realized either at low or high temperatures depending on the liquid (CO_2, ethanol, etc.), but high pressures are always required.

As-produced aerogels are fragile and unsuitable for use in any practical application unless they are reinforced with glass fiber, mineral fiber, carbon fiber etc. or cross-linked with polymers [4]. Although the reinforcement process provides mechanical strength and flexibility to the aerogel, it may result in an undesirable increase in the thermal conductivity and density of the resulting aerogel composite [5, 6]. If the mechanical requirements for the aerogel application permit, the thermal conductivity increase might be minimized by using lower volume fractions of inferior thermal conductivity fibers. Infrared opacifiers, such as carbon black, titanium oxide and iron oxide, with suitable fiber diameters may also be added during the sol-gel process to reduce the radiative part of the thermal conductivity [7]. The radiative contribution can be further reduced by using IR opacified fibers, such as PET fibers coated with carbon black.

Aerogel blanket is used world-widely especially for the insulation of spaceships and industrial facilities thanks to its low thermal conductivity and wide range of applicable temperature.

Fig. 2 shows the shape of blanket-type aerogel.

2.4 Physical Properties of Aerogel Blanket

The thermal conductivity of aerogel blanket is 0.011-0.015 W/m·K, which is half of that of polyurethane and air [8].

Fig. 2 Aerogel blanket.

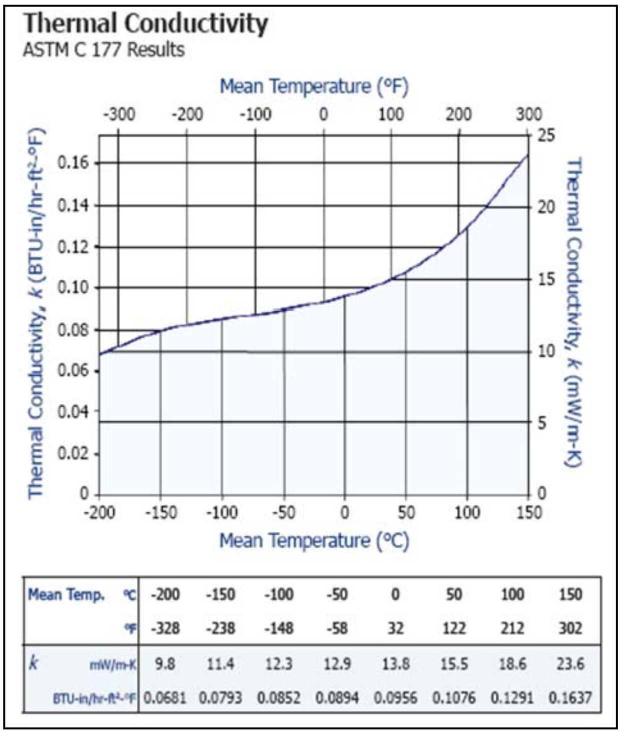
Fig. 3 shows the thermal conductivity of aerogel blanket according to the mean temperature.

Fig. 4 shows the thermal conductivities of various insulations.

The range of applicable temperature of aerogel blanket is from -200 °C to 650 °C, so it could be used as a special insulation to meet the needs of both keeping cold and keeping hot from extreme cold environment to extreme hot temperature. Fig. 5 shows the applicable temperature ranges of various insulations.

Fig. 6 shows it also has the high fire resistance which can be resistant for the flame of 1,200 °C. Fig. 7 shows it has high hydrophobility that prevents water to be passed but allows air penetration. Aerogel has the flexibility which allows an easy installation and has high strength which could be used under the floor heating pipes like in Fig. 8.

The density of aerogel blanket is 0.10-0.17 g/cm^3. The general properties of aerogel blanket can be summarized as Table 1 [9].



Mean Temp.									
	°C	-200	-150	-100	-50	0	50	100	150
	°F	-328	-238	-148	-58	32	122	212	302
k	mW/m-K	9.8	11.4	12.3	12.9	13.8	15.5	18.6	23.6
	BTU-in/hr-ft²-°F	0.0681	0.0793	0.0852	0.0894	0.0956	0.1076	0.1291	0.1637

Fig. 3 Thermal conductivity of aerogel according to its temperature [9].

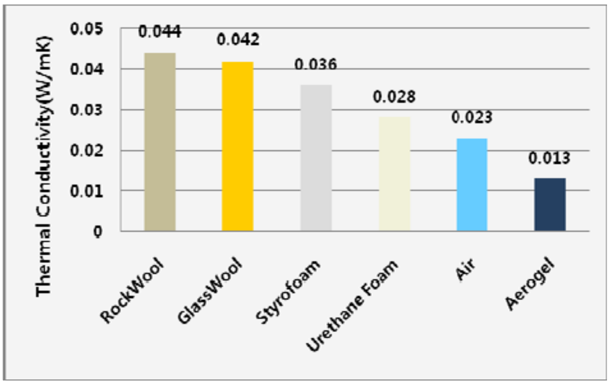


Fig. 4 Thermal conductivity of insulations

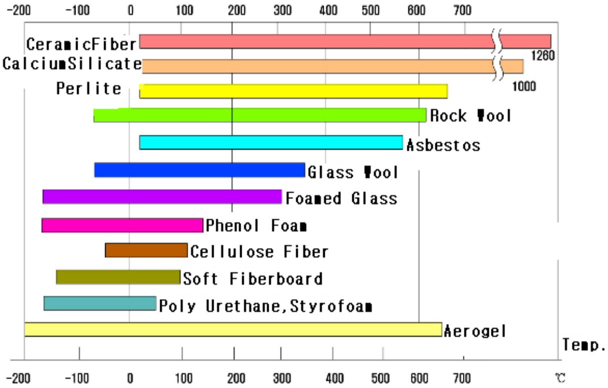


Fig. 5 Applicable temperature ranges of insulations.

Fig. 6 Fire resistance of aerogel blanket.

Size of a molecule of a vapor: 0.25 nm
Size of an aerogel airspace: 10-50 nm
Size of a water particle: above 100 nm

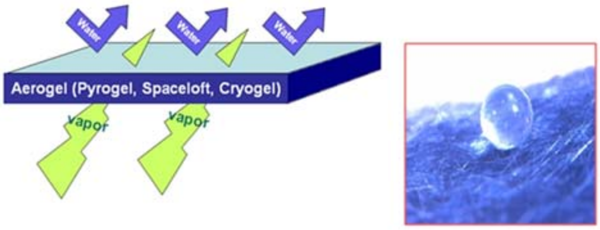


Fig. 7 Hydrophobicity of aerogel blanket.

Fig. 8 Aerogel blanket used under heating pipe.

3. Architectural Applications of Aerogel Blanket

Up to now, aerogel blanket has usually been used for the insulation of spaceships or industrial facilities. However, as the building energy saving is highly required, it could be effectively used as a building insulation.

Figs. 9-11 show some architectural applications [10]. Fig. 9 shows it can be used as an effective thermal breaker on the framing. Fig. 10 shows its roofing application. Aerogel blanket is used as an insulation of envelopes of mobile homes like in Fig. 11.

Aerogel was once introduced as a material to protect the earth in the future of 2050 through its high effective insulating performance for building energy saving through a documentary program of “Eco Polis”.

It was reported that “If aerogel is used as building insulation, the green house gas could be reduced as much as 29%”.

While passive house has largely the thickness of insulation of 25-40 cm for its high insulating performance, aerogel can meet the same insulating property with thickness of 9-15 cm [11]. Fig. 12 shows the overall thermal transmittance of thermal envelopes of a passive house and required thickness of insulation.

In spite of the incomparable physical performance of aerogel blanket, the only handicap in its architectural applications could be its high price.

Table 1 General properties of aerogel blanket.

Thermal conductivity	0.011-0.013 W/m-K at 38 ºC (100 ºF) and 760 torr. Conductivity decreases to 0.004 W/m-K at 10 torr.
Constant use temperatures	-273 °C/-459 °F to 650 °C/1,200 °F
Density	Currently available in densities from 0.10 to 0.12 g/cm^3 (6 pcf to 8 pcf)
Pore size	Open celled structure (2-50 nm pores) with an average pore size approximately 10 nm
Flexibility	Conformable at 0.25 inch thickness, drapeable at 0.125 inch thickness
Compressive strength	Aerogels typically have excellent compressive strength compared to microcellular foams and fibrous insulations
Hydrophobicity	Unencapsulated materials will float on pure water indefinitely and resist liquid water infiltration
Acoustic properties	At 100 m/s, aerogels have an extremely slow speed of internal sound propagation, sound transmission through aerogel is significantly retarded with fiber reinforcement
Toxicity	Aerogels are based on amorphous silica gel, which is considered safe and non-toxic, in typical handling, unencapsulated materials will generate nuisance dust

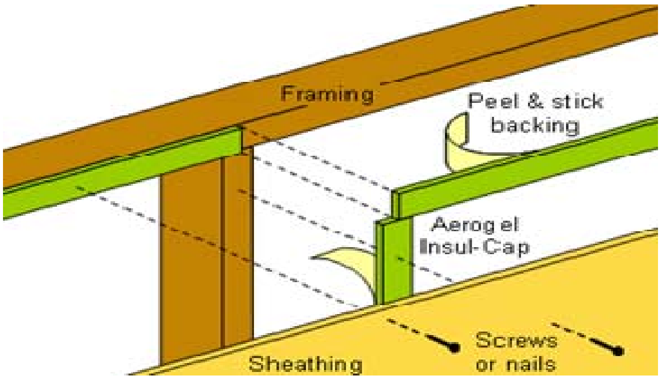


Fig. 9 Aerogel blanket used for breaking thermal bridge through framing.

Fig. 10 Aerogel blanket used in roofing applications.

Fig. 11 Aerogel blanket used in mobile homes.

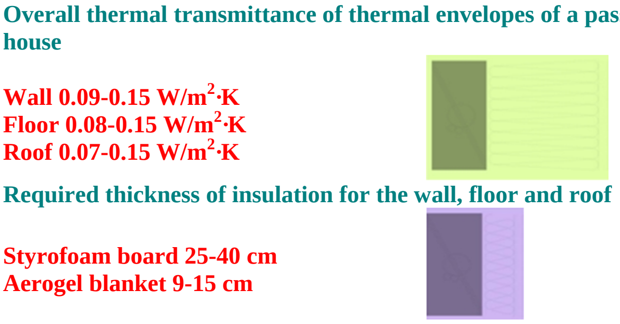


Fig. 12 Overall thermal transmittance of thermal envelopes of a passive house and required thickness of insulation.

4. Conclusions

Thanks to the advantages of aerogel blanket such as low thermal conductivity, broad temperature range for use, excellent water repellent property and fire resistance, easiness of moving and applying, it has much possibility in the respect of its building application. However, because of its high price, it has reluctance in the building use.

Therefore, the strategy to establish its priority in price competition is necessary. Price reduction of the product and development of complex insulation system using aerogel blanket are recommended.

Complex insulation system with reflective insulation could be one of the solutions to secure its price competition for building application.

It is also recommended to develop a new not-too-expensive aerogel insulation which has normal applicable temperature range about from -50-50 °C.

Acknowledgments

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