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AEROGEL-A Future Material for Aircraft Structure

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ABSTRACT

Aerogel is a synthetic porous material derived from a gel, in which the liquid component of the gel has been replaced with a gas. The result is a solid with extremely low density and thermal conductivity. It is nick named frozen smoke, solid smoke, solid air or blue smoke owing to its translucent nature and the way light scatters in the material; however, it feels like expanded polystyrene (Styrofoam) to the touch. Aerogel is an engineering marvel which used a process that started with adding sodium silicate to sulfuric acid that was then aged for several hours where it turned into a gel, to a much more innovative cheaper process created because of companies such as BASF, Thermolux, Aerojet, Airglass and Aspen Aerogels. AeroGel is an insulation that out ways all other general insulations used today and therefore will be a material that in the future might just change the way we live our lives.Silica aerogel is the most common type of aerogel and the most extensively studied and used. It is a silica-based substance, derived from silica gel. The lowest-density aerogel is silica nanofoam at 1 mg/cm^3 which is the evacuated version of the record-aerogel of 1.9 mg/cm^3. The density of air is 1.2mg/cm^3 (at 20°C and1atm). Only the recently manufactured metallic microlattices have a lower density at 0.9 mg/cm^3. Silica aerogel strongly absorbs infrared radiation. It allows the construction of materials that let light into buildings but trap heat for solar heating.This can be used for the manufacturing of the structure of the aeroplane so that it can have low weight and high thermal resistance so that it can gain high lift with less fuel consumption and can has high endurance.

INTRODUCTION

Aerogel is a synthetic porous material derived from a gel, in which the liquid component of the gel has been replaced with a gas. The result is a solid with extremely low density and thermal conductivity. It is nicknamed frozen smoke, solid smoke, solid air or blue smoke owing to its translucent nature and the way light scatters in the material; however, it feels like expanded polystyrene (Styrofoam) to the touch.

Aerogel was first created by Samuel Stephens Kistler in 1931, as a result of a bet with Charles Learned over who could replace the liquid in "jellies" with gas without causing shrinkage.

Aerogels are produced by extracting the liquid component of a gel through supercritical drying. This allows the liquid to be slowly drawn off without causing the solid matrix in the gel to collapse from capillary action, as would happen with conventional evaporation. The first aerogels were produced from silica gels. Kistler's later work involved aerogels based on alumina, chromia and tin oxide. Carbon aerogels were first developed in the late 1980s.

PRODUCTION

Production of aerogels is done by the sol-gel process. First a gel is created in solution and then the liquid is carefully removed to leave the aerogel intact.

The first step is the creation of a colloidal suspension of solid particles known as a “sol”. Silica aerogel is made by the creation of colloidal silica. The process starts with a liquid alcohol such as ethanol which is mixed with a silicon alkoxide precursor, for example tetramethyl ort hosilicate (TMOS)or tetraethyl orthosilicate(TEOS). A hydrolysis reaction forms particles of silicon dioxide forming a sol solution. The oxide suspension begins to

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undergo condensation reactions which result in the creation of metal oxide bridges (either M-O-M, “oxo” bridges or M-OH-M, “old” bridges) linking the dispersed colloidal particles.When this interlinking has stopped the flow of liquid within the material, this is known as a gel. This process is known as gelation. These reactions generally have moderately slow reaction rates, and as a result either acidic or basic catalysts are used to improve the processing speed. Basic catalysts tend to produce more transparent aerogels with less shrinkage.

The removal of the liquid from a true aerogel involves special processing. Gels where the liquid is allowed to evaporate normally are known as xerogels. As the liquid evaporates, forces caused by surface of the liquid-solid interfaces are enough to destroy the fragile gel network. As a result xerogels cannot achieve the high porosities and instead peak at lower porosities and exhibit large amounts of shrinkage after drying.
In 1931, to develop the first aerogels, Kistler used a process known as supercritical drying. By increasing the temperature and pressure he forced the liquid into a supercritical fluid state where by dropping the pressure he could instantly gasify and remove the liquid inside the aerogel, avoiding damage to the delicate three-dimensional network. While this can be done with ethanol, the high temperatures and pressures lead to dangerous processing conditions. A safer, lower temperature and pressure method involves a solvent exchange. This is typically done by exchanging the ethanol for liquid acetone, allowing a better miscibility gradient, and then onto liquid carbon dioxide and then bringing the carbon dioxide above its critical point. A variant on this process involves the direct injection of supercritical carbon dioxide into the pressure vessel containing the aerogel. The end result of either process removes all liquid from the gel and replaces it with gas, without allowing the gel structure to collapse or lose volume.

Aerogel composites have been made using a variety of continuous and discontinuous reinforcements. The high aspect ratio of fibers such as fiberglass has been used to reinforce aerogel composites with significantly improved mechanical properties.Resorcinol-formald hyde aerogel (RF aerogel) is made in a way similar to production of silica aerogel.Carbon aerogel is made from a resorcinol-formald ehyde aerogel by its pyrolysis in inert gas atmosphere, leavin g a matrix of carbon. It is commercially available as solid shapes, powders, or composite paper.
Safety

Aerogel safety depends on the material, from which the aerogel is made, i.e., it will be carcinogenic or toxic if the solid component has such characteristics. Silica-based aerogels are not known to be carcinogenic or toxic. However, they are a mechanical irritant to the eyes, skin, respiratory tract, and digestive system. They also can induce dryness of the skin, eyes, and mucous membranes. Therefore, it is recommended that protective gear including gloves and eye goggles be worn whenever handling aerogels.

PROPERTIES

Fig 1: A flower is on a piece of aerogel which is suspended over a Bunsen burner. Aerogel has excellent insulating properties, and the flower is protected from the flame.

Despite their name, aerogels are rigid, dry materials and do not resemble a gel in their physical properties; the name comes from the fact that they are derived from gels. Pressing softly on an aerogel typically does not leave a mark; pressing more firmly will leave a permanent depression. Pressing firmly enough will

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cause a catastrophic breakdown in the sparse structure, causing it to shatter like glass-a property known as friability; although more modern variations do not suffer from this. Despite the fact that it is prone to shattering, it is very strong structurally. Its impressive load bearing abilities are due to the dendrit ic microstructure, in which spherical particles of average size 2–5 nm are fused together into clusters. These clusters form a three-dimensional highly porous structure of almost fractal chains, with pores just under 100 nm. The average size and density of the pores can be controlled during the manufacturing process.

Aerogels are good thermal insulators because they almost nullify the three methods of heat transfer (convection, conduction, and radiation). They are good conductive insulators because they are composed almost entirely from a gas, and gases are very poor heat conductors. Silica aerogel is especially good because silica is also a poor conductor of heat (a metallic aerogel, on the other hand, would be less effective). They are good convective inhibitors because air cannot circulate through the lattice. Carbon aerogel is a good radiative insulator because carbon absorbs the infrared radiation that transfers heat at standard temperatures.

Owing to its hygroscopic nature, aerogel feels dry and acts as a strong desiccant. Persons handling aerogel for extended periods should wear gloves to prevent the appearance of dry brittle spots on their skin.

The slight color it does have is due to Rayleigh scattering of the shorter wavelengths of visible light by the nanosized dendritic structure. This causes it to appear smoky blue against dark backgrounds and yellowish against bright backgrounds.

Aerogels by themselves are hydrophilic, but chemical treatment can make them hydrophobic. If they absorb moisture they usually suffer a structural change, such as contraction, and deteriorate, but degradation can be prevented by making them hydrophobic.

Aerogels with hydrophobic interiors are less susceptible to degradation than aerogels with only an outer hydrophobic layer, even if a crack penetrates the surface. Hydrophobic treatment facilitates processing because it allows the use of a water jet cutter.

Types

Silica

Fig2: Peter Tsou with a sample of aerogel atJet Propulsion Laboratory, California Institute of Technology

Silica aerogel is the most common type of aerogel and the most extensively studied and used. It is a silica-based substance, derived from silica gel. The lowest-density aerogel is silica nanofoam at 1 mg/cm^3, which is the evacuated version of the record-aerogel of 1.9 mg/cm^3. The density of air is 1.2 mg/cm^3 (at 20 °C and 1 atm). Only the recently manufactured metallic microlattices have a lower density at 0.9 mg/cm^3.

Silica aerogel strongly absorbs infrared radiation. It allows the construction of materials that let light into buildings but trap heat for solar heating.

It has remarkable thermal insulative properties, having an extremely low thermal conductivity: from 0.03 W/m·K down to 0.004 W/m·K, which correspond to R-values of 14 to 105 for 3.5 inch thickness. For comparison, typical wall insulation is 13 for 3.5 inch thickness. Its melting point is 1,473 K (1,200 °C or 2,192 °F).By 2011, silica aerogel held 15 entries in Guinness World Records for material properties, including best insulator and lowest-density solid.

Carbon

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Carbon aerogels are composed of particles with sizes in the nanometer range covalently bonded together. They have very high porosity (over 50%, with pore diameter under 100 nm) and surface areas ranging between 400–1,000 m^2/g. They are often manufactured as composite paper: non-woven paper made of carbon fibers,impregnated with resorcinol formaldehyde aero gel, and pyrolyzed. Depending on the density, carbon aerogels may be electrically conductive, making composite aerogel paper useful for electrodes in capacitors or deionization electrodes. Due to their extremely high surface area, carbon aerogels are used to create super capacitors, with values ranging up to thousands of farads based on a capacitance of 104 F/g and 77 F/cm^3. Carbon aerogels are also extremely "black" in the infrared spectrum, reflecting only 0.3% of radiation between 250 nm and 14.3 µm, making them efficient for solar energy collectors.

The term "aerogel" has been incorrectly used to describe airy masses of carbon nanotubes produced through certain chemical vapor deposition techniqu es—such materials can be spun into fibers with strength greater than Kevlar, and unique electrical properties. These materials are not aerogels, however, since they do not have a monolithic internal structure and do not have the regular pore structure characteristic of aerogels.

Alumina

Aerogels made with aluminum oxide are known as alumina aerogels. These aerogels are used as catalysts, especially when "metal-doped" with another metal. Nickel-alumina aerogel is the most common combination. Alumina aerogels are also being considered by NASA for capturing of hypervelocity particles; a formulation doped with gadolinium and terbium could fluoresce at the particle impact site, with amount of fluorescence dependent on impact energy.

Other

SEA gel is a material similar to organic aerogel, made of agar.Chalcogels are a type of aerogel made of chalcogens (the column of elements on the periodic table beginning with oxygen) such as sulfur, selenium, and other elements. Research is ongoing, and metals less expensive than platinum have also been used in its creation.Aerogels made of cadmium selenide quantum dots in a porous 3-D network have recently been developed for use in the semiconductor industry.

Applications

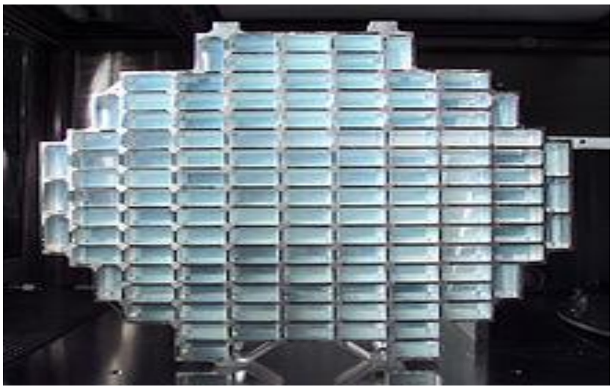

Fig3: The Stardust dust collector with aerogel blocks. (NASA)

There is a variety of applications for which aerogels are used.

- Commercially, aerogels have been used in granular form to add insulation to skylights.
- Transparent silica aerogel would be very suitable as a thermal insulation material for windows, significantly limiting thermal losses of buildings. One research team has shown that producing aerogel in a weightless enviro nment can produce particles with a more uniform size and reduce the Rayleigh scattering effect in silica aerogel, thus making the aerogel less blue and more transparent.
- Its high surface area leads to many applications, such as a chemical absorber for cleaning up spills (see adsorption). This feature also gives it great potential as a catalyst or a catalyst carrier.
- Aerogel particles are also used as thickening agents in some paints and cosmetics.
- Aerogels are being tested for use in targets for the National Ignition Facility.

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- Aerogel performance may be augmented for a specific application by the addition of dopants, reinforcing structures, and hybridizing compounds. Using this approach, the breadth of applications for the material class may be greatly increased.
- Commercial manufacture of aerogel 'blankets' began around the year 2000. An aerogel blanket is a composite of silica aerogel and fibrous reinforcement that turns the brittle aerogel into a durable, flexible material. The mechanical and thermal properties of the product may be varied based upon the choice of reinforcing fibers, the aerogel matrix, and opacification additives included in the composite. In 2000 was testing the first Aerogel jacket for Sport in South Pole.
- NASA used aerogel to trap space dust particles aboard the Stardust spacecraft. The particles vaporize on impact with solids and pass through gases, but can be trapped in aerogels. NASA also used aerogel for thermal insulation of the Mars Rover and space suits
- The US Navy is evaluating aerogel undergarments as passive thermal protection for divers.
- Aerogels are also used in particle physics as radiators in Cherenkov effect detectors. ACC system of the Belle detector, used in the Belle Experiment at KEKB, is a recent example of such use. The suitability of aerogels is determined by their low index of refraction, filling the gap between gases and liquids, and their transparency and solid state, making them easier to use than cryogenic liquids or compressed gases. Their low mass is also advantageous for space missions.
- Resorcinol-formaldehyde aerogels (polymers chemically similar to phenol formaldehyde resins) are mostly used as precursors for manufacture of carbon aerogels, or when an organic insulator with large surface is desired. They come as high-density material, with surface area about 600 m^2/g.
- The first residential use of aerogel as an insulator is in the Georgia Institute of Technology's Solar Decathlon House where it is used as an insulator in the semi-transparent roof.
- Metal-aerogel nano composites can be prepared by impregnating the hydrogel with solution containing ions of the suitable nob le or transition metals. The impregnated hyd rogel is then irradiated with gamma, leadin g to precipitation of nanoparticles of the metal. Such composites can be used as catalysts, sensors, electromagnetic shielding, and in waste disposal. A prospective use of platinum-on-carbon catalysts is in fuel cells.
- Aerogel can be used as a drug delivery system owing to its biocompatibility. Due to its high surface area and porous structure, drugs can be adsorbed from supercritical CO_2. The release rate of the drugs can be tailored based on the properties of aerogel.
- Carbon aerogels are used in the construction of small electrochemical double layer super capacitors. Due to the high surface area of the aerogel, these capacitors can be 1/2000th to 1/5000th the size of similarly rated electrolytic capacitors. Aerogel super capacitors can have a very low impedance compared to normal super capacitors and can absorb or produce very high peak currents. At present, such capacitors are polarity-sensitive and need to be wired in series if a working voltage of greater than about 2.75 V is needed.
- Dunlop has recently incorporated aerogel into the mold of its new series of tennis racquets, and has previously used it in squash racquets.
- Chalcogels have shown promise in absorbing the heavy metal pollutants mercury, lead, and cadmium from water.
- Aerogel can introduce disorder into superfluid helium-3.
- Arms control experts speculate it is used to transform radiation into pressure in multistage nuclear weapons.

- Grado Zero Espace, a company specialized in innovation products on demand, in 2001 in collaboration before with NASA and then with European Space Agency Transfer Technology Programme, introduced to the market the first range of extreme sport equipments, with the brand "Aerogel Design System" an optimized system to integrate aerogel in sport clothing.
- Shiver Shield, a brand of cold weather garments that is insulated with encapsulated aerogel, was recently introduced to the market in 2011.

Conclusion:

Comparisons between Aluminum, Titanium and Silica Aerogel:

	Aluminum	Silica Aerogel
Melting Point	933.47K	1473K
Density	2.70g/ cm^3	0.003g/cm^3
Thermal Conductivity	237W/(mK)	0.03W(mK)
Electrical Resistivity	28.2 nΩ·m	10^4 nΩ·m

Aerogel can be used for the manufacture of the aircraft structure which will increase the specific fuel consumption, range, endurance and performance of the aircraft.

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