Graphene Aerogel is Modern and Promising Material

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Abstract. Aerogels hold 15 titles in the Guinness World Records, i.e. more than any other material. Sometimes aerogels are called “frozen smoke” and derived from aluminum, chromium, tin oxide or carbon in the process of supercritical drying. The composition of aerogels is 99.8% air, which makes it translucent. Aerogels demonstrate properties that make them the most extraordinary insulating materials known. If you have a shield made of aerogels, it will protect you from fire, as well as it will save you from cold. Using this material an insulated and worm dome could be built on the Moon. Aerogels have an incredible surface area of internal fractal structures, i.e. an aerogels cube with an edge of one inch has an internal area equivalent to a football field. The article deals with the concept of aerogels, the most common aerogels, and fields of their application.

1. Introduction

Our modern life imposes very serious requirements to the materials being developed. One of the innovative fields of development of materials science is a search for new technologies aimed to produce solid ultra-light materials. Aerogels are among these materials [1].

Aerogels demonstrate properties that make them the most extraordinary insulating materials known. They hold 15 titles in the Guinness World Records. The name “aerogel” derives from two Latin words ‘aer’ - air and ‘gelatus’ - frozen. That is why aerogels are called “frozen smoke”.

Once you take a look at the aerogel it would remind you of a frozen smoke. To say more, aerogel is an unusual gel with no liquid phase. The liquid phase is completely replaced by gaseous phase, which results in its low density and a number of other unique qualities among which are hardness, transparency, heat resistance, etc. The composition of aerogels is 99.8% air!

2. Methods and materials

The results obtained in the article are based on the analysis of literature data, as well as application of analytical methods.

3. Method description and its evaluation

Samuel Stephens Kistler was an American scientist, best known as the inventor of aerogels. He obtained the material as a by-product of crystallization of amino acids in supercritical, supersaturated fluids in the first half of the last century at the Pacific College in Stockton, California. In the course of his research the scientist replaced the liquid component with methanol in a conventional gel [2-4]. After that, the gel was heated under high pressure up to 240°C (critical temperature for methanol). At
that point, gaseous methanol left the gel; however, the dehydrated foam did not decrease in volume. As a result, a light, fine-porous material was obtained, which was later called aerogel. It was 1931 when the material appeared officially, i.e. the time when the article was published in Nature. It is still an unknown fact if it was Kistler himself who introduced the name “aerogel” or he took an advice of his colleagues. The first aerogel was obtained by the scientist from quartz. Later on, the material was made from metal oxides, organic substances, and many other initial ingredients.

The structure of aerogels is a tree network consisting of the particles of 2 to 5 nm in size, which are homogeneously grouped together (clusters) and pores filled in with the air with the size up to 100 nanometers. Externally the aerogels are similar to a transparent or translucent frozen soap sud [5]. When viewed with the naked eye, the aerogel is a continuous homogeneous substance, which distinguishes it from such porous media as foams [6]. To the touch, the aerogel also resembles frozen foam. This is rather strong material able to withstand a load 2,000 times higher than the load of its own weight. For example, a small aerogel block weighing 0.00238 kg easily resists the weight of 2.5 kg brick (Fig. 1).

Figure 1. A tiny block of transparent aerogel withstands the pressure of a brick weighing 2.5 kg

Silica aerogels are good thermal insulating materials. The process of aerogel manufacturing is complicated and time-consuming. First, the gel polymerizes under the influence of chemical reactions. This process takes several days resulting in a jelly-like product. Then, alcohol removes water from the jelly. Its complete removal is the key to the success of the entire process. The next step is supercritical drying. It takes place in an autoclave at high pressure and temperature; liquefied carbon dioxide is part of the process. Silica aerogels has started being applied as an insulating material in the 1940s of the twentieth century. A well-known company Monsanto manufactured this product under a license agreement with Kistler. However, due to the high cost of aerogel production this material had not been widely used as an insulator and in the 1970s the production was curtailed. Only at the very end of the last century aerogels started being widely used, specifically in the space industry. It was the aerogel that became the most important element of the lattice catching device with the help of which the space probe Stardust captured millions of tiny particles from the tail of the comet Wild 2 and delivered the vehicle with these samples to the ground. Incidentally, among the variety of particles trapped by the probe, traces of glycine, which is the most important amino acid for protein formation, have been found. This discovery has become an indirect evidence of the idea of the scientists who share the theory of the extraterrestrial origin of life.

Now let us consider the most ultralight of aerogels and possible areas of their application.
In 2011, aerogels based on multilayer carbon nanotubes (MCNT), also known as frozen smoke, were obtained with a density of 4 mg/cm$^3$. However, it soon gave way to a micro-lattice aerogel with the density amounting to 0.9 mg/cm$^3$. Later, it was replaced by aerographite (0.18 mg/cm$^3$). However, the material preserved an interest for quite a short period of time. Aerographite is black (nontransparent within visible range), electrically conductive, chemically stable, hydrophobic, plastic material with a density of less than 0.2 mg/cm$^3$, which is 4 times less compared to nickel microlattice. Such specific properties of aerographite are formed in the course of the material production. First, the zinc oxide pellets with porous structure are manufactured. They serve as a template for the process of chemical vapor deposition. Then, these pellets are placed in the reactor at a temperature of 760°C into which a gaseous mixture consisting of argon and toluene is fed. Hydrogen is also fed in the reactor, reacting with zinc oxide after which gaseous zinc and water vapor are formed. As a result a graphite network of porous tubes is obtained.

Nowadays, the world’s lightest material is graphene aerogel which is a porous substance consisting of graphene and carbon nanotubes obtained as a result of freeze-drying of their solution (Fig. 2). Its density is 0.16 mg/cm$^3$. This is twice as much as the density of hydrogen and 7.5 times less than the density of air.

![Graphene aerogel](image)

This material is known globally and there exist multiple areas of its application [7].

The oil industry is one of the areas that cause significant damage to the environment [8-14]. One of the disasters is the oil spills. Over 40 major oil spills were registered for the period of 2010 - 2018. The total amount of spilled substance was more than 800,000 tons which caused serious harm to the seas and oceans. This problem is successfully solved with the help of aerogels based on graphene. This material is extremely durable and resilient. It has the ability to quickly take its original form after being compressed, as well as it may absorb and retain a significant volume of insoluble substances, i.e. 900 times more of its own weight. Due to its hydrophobicity 3.5 kg of this aerogel can absorb about 1 ton of oil which is 10 times more compared to the capacity of commercial absorbent. Due to such property as elasticity both aerogel and the collected oil can be recycled.

As a unique thermal insulating material, aerogel is planned to be used in space suits designed for the exploration and development of Mars. Besides, aerogels can be used as thermal shields for new types of shuttles. Aerogel application is very promising in the field of microelectronics [15]. It is worth mentioning that aerogels have the lowest dielectric constants. The use of aerogels as insulation material in multi-layer printed circuit boards will significantly improve the speed of electronics. In 2007, American chemists presented the aerogel which can serve as a filter for cleaning water from harmful impurities such as mercury, lead and other toxic heavy metals. The production of these
materials is rather limited due to their high price as filters include platinum; however, when such pricy material as platinum is replaced by its cheaper analogue, the water reservoirs of the planet will be cleaned from the heavy metals. In addition, new aerogels exhibit the properties of semiconductors and, therefore, can be used in photocells and other optoelectronic devices.

Silica aerogel is a unique thermal insulating material [16]. It can withstand temperatures up to 500°C; a layer of 2.5 cm thick can protect the human hand from a direct impact of soldering lamp. There are varieties of aerogels with a melting point up to 1,200°C. The properties of aerogels depend on the initial material they are made from. There are alumina aerogels (with aluminum oxide), silica, as well as tin and chromium oxide aerogels. Moreover, aerogels can be used as catalysts. At present, aluminum oxide aerogels containing rare elements, i.e. gadolinium and terbium are being tested. These aerogels are used as high-speed collision detectors. Some transparent aerogels are considered by scientists as a replacement for the window glass. After all, the refractive index of aerogels is much lower than that of glass (1.05 vs. 1.5). The issue of fragility of this promising material has been overcome. Now the aerogels are more elastic and flexible. Currently, the issue of cost effectiveness of aerogel production is being solved for the material to be used on a large scale.

4. Conclusions

Thus, ultralight materials have a wide range of applications and their further development and global implementation is an urgent task. Currently, aerogels are produced only by those who managed to achieve the best performance of this material. Aerogels are made to order only by the Siberian Branch of the Russian Academy of Sciences and the Japanese company Matsushita. Other research laboratories produce aerogels for their own needs. The production of aerogels is very expensive and its application is limited to the scientific research. The cost of a monolithic homogeneous block with the volume of only 0.002 m$^3$ is about 6 thousand Euros. Aerogels are often called the material of the XI$^{st}$ century.

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