Research on New Thermal Insulation Material -Silica Aerogel

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Abstract. Energy consumption generated by buildings accounts for a large proportion of global energy consumption. As a material that can reduce building energy consumption, thermal insulation materials have an increasing impact on buildings. In China, many buildings use traditional thermal insulation materials, which have great drawbacks, not only the thermal insulation performance is general, the cost is high, but also harmful to human health. The purpose of this paper is to find a new type of thermal insulation material - silica aerogel, and analyze its properties, thermal insulation effect, and application in the field of construction. Through various comparative analysis, the most sustainable silica aerogel material type was found. The final results show that the thermal insulation properties of silica aerogel are superior to traditional thermal insulation materials, and the most sustainable one can be found in various synthetic silicone aerogel comparisons. The results can provide reference for the selection of building insulation materials.

Keywords: Thermal insulation material; silica aerogel; energy consumption; sustainability.

1. Introduction

Overall global energy consumption has changed the construction of buildings in recent years. In 2016, the global construction sector consumed about 30% of total final energy use, and CO_2-related emissions accounted for 28% of global energy consumption [1]. Therefore, building energy conservation is of great significance, and thermal insulation performance has become an important indicator for choosing building materials today. In fact, more than 95% of new buildings in China are still energy intensive, mainly because traditional insulation materials are still used. In China, traditional thermal insulation materials such as rock wool, glass wool and expanded perlite still occupy the main market. Although the price of these materials is relatively low, but the density, poor thermal insulation performance, laying thick material loss, high moisture absorption, seismic performance and environmental protection performance is poor, so the use of these thermal insulation materials is unable to meet the energy saving standards. In addition, building insulation materials such as asbestos and glass wool they contain a large number of harmful substances, which cannot meet the health requirements of human beings. The production of new foam insulation materials, such as EPS, XPS, PUF and PET, accounts for only 40% of the total thermal insulation materials in China. Compared with traditional thermal insulation materials, foam has low thermal conductivity, good thermal insulation effect, light weight, low water absorption, good chemical stability and convenient construction. However, due to the relatively high price of foam, it limits the large amount of use in China [2]. Therefore, architects should find a building material that has good insulation performance, low price and no harm to human health. Silica aerogel is a material to meet these needs. The purpose of this paper is to describe the properties of silica aerogel, its thermal insulation effect, its impact on construction after being used as a building material, and its sustainability.

2. Silica Aerogel

2.1. Properties of Silica Aerogel

Silica aerogel is a kind of solid material with high porosity and very low density [3]. These two properties will change accordingly due to different production methods. Table 1 illustrates the comparison of porosity, specific surface area, pore size, pore volume, and density of a silica aerogel sample without surface modification and with two additional surface modifications. As can be seen

from Table 1, if the surface modification is carried out in the process of making silica aerogel, its porosity will decrease and its density will increase. These changes will directly affect the thermal insulation effect and strength of the material, but overall, the density of silica aerogel is relatively low and the porosity is relatively high.

Table 1. Basic parameters of silica aerogel sample [4].

Comparison of samples before and after modification	Porosity (%)	Specific surface area (cm2/g)	Aperture (nm)	Pore volume (cm^3/g)	Density (g/ cm^3)
No surface modification	97.77	537	0.188	3.57	0.08
Modified with trimethylchlorosilane	95.88	1078	4.46	13.51	0.13
Modified with n-hexane	91.84	984	2.34	7.68	0.21

2.2. Thermal Insulation Effect of Silica Aerogel

There are essentially two categories of thermal insulation materials available today: inorganic and organic thermal insulation materials. Among these, combustible materials include organic thermal insulation materials like polystyrene foam board, which has a thermal insulation coefficient of roughly 0.035 W/ (m·K). Another type of organic thermal insulation material is polyurethane foam board, which has a combustible thermal insulation coefficient of roughly 0.02W/ (m·K). Expanded vitrified microbeads and rock wool board are two examples of inorganic thermal insulation materials. They are non-combustible and have respective thermal insulation coefficients of 0.077 W/(m·K) and 0.041 W/(m·K). Because the lower the thermal insulation factor, the better the thermal insulation effect of the material, organic materials are usually better thermal insulation but combustible, while inorganic materials are not combustible but poor thermal insulation effect. On the other hand, compared to both organic and inorganic thermal insulation materials, the thermal insulation coefficient of silica aerogel thermal insulation materials is approximately 0.02 W/(m·K). Silica aerogel-based thermal insulation materials have a class a combustion grade, which is higher than that of organic thermal insulation materials and consistent with that of inorganic thermal insulation materials. Simultaneously, the silica aerogel thermal insulation material is less dense. The thermal insulation material consisting of silica aerogel provides major advantages in the heat insulation and fire protection performance of the building envelope, as can be observed from the analytical findings above [4].

2.3. The Strength of Silica Aerogel

Due to the need to apply silica aerogel to building materials, its mechanical properties and strength need to be properly considered. Although the thermal insulation effect of silica aerogel is good, its extremely low density and high porosity also make it fragile. Therefore, their use in load-bearing applications poses challenges [5]. In order to make silica aerogel suitable for building materials, it is necessary to study the method of increasing its strength or making high strength silica aerogel.

The first method is to change the silicon source of silica aerogel and the proportion of silicon source. Using Methyltrimethoxysilane (MTMS) as silicon source, high strength silica aerogel can be prepared. The aerogels density pairs prepared by different MTMS mass fractions are shown in Table2

Table 2. The density of aerogels prepared with different MTMS mass fraction [6].

Mass fraction of MTMS (wt%)	Density (g/cm^3)
54	0.312
48	0.281
42	0.260
37	0.253

It can be seen from Table 2 that the larger the proportion of MTMS in the aerogel, the higher its density will be. Among them, the aerogel with MTMS mass fraction of 54wt % has the best

mechanical properties, compressive strength of 6.4 MPa, and maximum deformation of 58%, which is significantly higher than that of traditional silica aerogel [6].

In addition to the above methods of increasing the strength of silica aerogel, there are also methods such as the introduction of a second reinforcing phase and the introduction of an organic silicon source precursor. The method of introducing the second phase reinforced silica aerogels is to prepare silica aerogels composite materials by adding fiber, graphene, carbon nanotubes and porous materials. When the silicone aerogel is prepared by the organosilane precursor system, the space between the secondary colloidal particles is increased due to the introduction of non-hydrolyzed organic groups (alkyl, amine, vinyl, etc.), and then a certain elastic deformation can be generated within a certain pressure range, so that the silica aerogel has a certain flexibility [7].

2.4. Application Case of Silica Aerogel

As an excellent thermal insulation material, silica aerogel has many application examples. There are also many applications in construction, such as silica aerogel energy-saving glass. The excellent light transmission, heat insulation and noise reduction capabilities of silica aerogel make it have obvious advantages in the field of construction, especially in the application of architectural glass. Glass curtain wall due to the characteristics of heat absorption and reflection, but also cause the building energy consumption is too high. However, if aerogel is added to the glass curtain wall, the thermal insulation capacity of the building can be increased without affecting the original lighting and aesthetic conditions of the glass, and the energy consumption of the glass curtain wall building can be reduced. There are silica aerogel coatings, coatings have huge applications in many fields, and the use of building materials is increasing. With the improvement of the performance requirements of coatings, silica aerogel as a functional filler for coatings has attracted the attention of many researchers. As early as 2010 Shanghai World Expo Zero carbon Pavilion and Vanke Laboratory building have been put into use, the energy saving effect is outstanding. In addition, silica aerogel plate is also an application embodiment, is the pure aerogel and fiber, particles, mortar, metal, organic polymer and other materials through secondary forming composite rigid plate. In the field of external wall insulation, Guangdong Eliseng High-tech Co., Ltd. and Zhejiang Nano Technology Co., Ltd. have commercial SiO2 aerogel insulation panels, and their thermal conductivity is basically below 0.020 W /m·K; There are also manufacturers combined with the production technology of vacuum insulation board to prepare an aerogel vacuum insulation board with a thermal conductivity less than 0. 020 W /m·K. These have good thermal insulation performance, but also flame retardant effect, the latter can even be used in low temperature environment, well meet the requirements of the northern cold area building energy conservation design standards. Silica aerogel can also be added to concrete. Although there are technical problems, the application of silica aerogel to concrete and mortar is of great significance, and the field is also heavily studied today. China Academy of Building Science and Shanghai Jianke Building Energy Saving Technology Co., Ltd. and other units have carried out the development and research of silica aerogel/vitrified microbeads composite insulation materials and insulation systems, and have solved the basic technical problems such as good adhesion and compatibility of hydrophobic silica aerogel fragments and particles with inorganic materials such as cement and water glass [8].

3. Sustainability of Silica Aerogel

If silica aerogel is used as thermal insulation material, then the material will be used in large quantities. Therefore, its sustainability, economic and environmental impact will not be ignored. First, it is necessary to find the most economical and environmentally friendly one among the different manufacturing methods of silica aerogel. Subcritical drying is a more cost-effective and secure method of generating silica aerogel than supercritical aerogel. Three distinct artificial subcritical silica aerogels will be compared for their effects on the environment and the economy in this paper.

3.1. Environmental Effects of Subcritical Production

Inorganic aerogel hybrid aerogel in powder form (HYB-A) and hybrid aerogel in monolithic form (HYB–C) are the three subcritically produced silica aerogels. The selection of the environmental impact category and the method for the environmental impact assessment must coincide. The intermediate markers of the eventual environmental impact of the three silica aerogels mentioned above will be examined in this paper. Abiotic Depletion Potential (ADP), Photochemical Ozone Creation Potential (POCP), Eutrophication Potential (EP), Ozone Depletion Potential (ODP), Global Warming Potential (GWP), and Acidification Potential (AP) are a few of these indicators.

Fig. 1 shows a comparison of the environmental impacts of the three silica aerogels at all stages from raw material production to packaging. According to Fig. 1, inorganic aerogels have the largest environmental impact in the ADP, GWP, POCP, PE-NRe, and PE-Re categories, while HYB-A aerogels have the least impact in all other categories. HYB-C aerogels have the largest impact in the remaining categories. The reason for this variation is the raw ingredients that were utilized to create each aerogel.

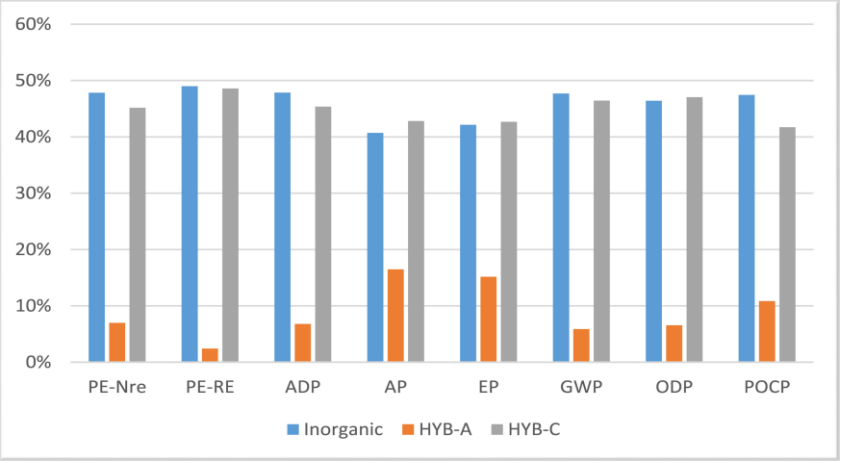

Fig 1. Comparison of the environmental impacts of all stages for inorganic aerogel, HYB-A and HYB-C (per kg of finished product) [9].

3.2. Economic Evaluation of Subcritical Dry Silica based Aerogel Production

This section presents an economic analysis of the three distinct synthesized silica aerogels that were previously discussed. The expenses of the several phases of the aerogel life cycle are shown in Table 3, with HYB-C aerogel being by far the most costly. The primary distinction is the raw material purchase cost.

Table 3. Costs at different stages of the aerogel life cycle (€/kg) [10].

Different stages	Raw materials	Production	Dosing, bagging and carrying	Total
IA	436.39	12.56	0.14	449.10
HYB-A	640.00	3.16	0.14	643.30
HYB-C	716.39	12.56	0.14	729.10

Regarding the energy consumption of all aerogels, the drying phase of the production process is the most significant synthetic step. The energy used per kilogram of aerogel at each stage of manufacture (synthesis) is displayed in Table 4.

Table 4. Energy consumption of aerogel at the production (synthesis) stage (kWh/kg) [10].

Different stages	Mixing	Heating and stirring (Hydrolysis)	Condensation	Aging	Washing	Drying	Total
IA	0.0	2.1	0.0	0.0	0.0	99.3	101.4
HYB-A	0.0	2.1	0.0	0.0	0.0	24.2	26.3
HYB-C	0.0	2.1	0.0	0.0	0.0	99.3	101.4

Thus, in terms of economic relevance, the step of raw material procurement applies to all types of aerogels. The primary distinction at the synthetic stage is that, although hybrid HYB-A aerogels may be manufactured in just 4 days, at a cost of about 0.49%, inorganic and hybrid HYB-C aerogels require approximately 20 days to fully dry.

In summary, compared with inorganic and hybrid HYB-C aerogels, although the material cost of hybrid HYB-A aerogels is higher than that of non-polar aerogels, the production cost is lower, and the environmental impact of hybrid HYB-A aerogels is significantly lower than that of the other two aerogels. Therefore, hybrid HYB-A aerogel is the best choice among subcritical silica aerogels, considering economy and environmental protection.

4. Conclusion

In this paper, the new building material silica aerogel is studied. The main conclusions are as follows:

(1) Silica aerogel is a material with low density and high porosity, and these two properties will be slightly changed due to different production methods. The thermal insulation properties of silica aerogel are better than those of other traditional thermal insulation materials and are non-combustible materials. The mechanical properties of silica aerogel can be changed. The material has various applications in the field of construction.

(2) Hybrid HYB-A aerogel is one of the most sustainable silica aerogels prepared by different synthetic methods. It is economical and has little impact on the environment.

(3) Although there are many examples of the application of silica aerogel in the field of construction, it is not extensive enough. The thermal insulation materials used in most Chinese buildings are still too traditional, with not good performance and poor economy. It is hoped that new thermal insulation materials with high thermal insulation effect and sustainability, similar to silica aerogel, can be widely used in China's construction field in the future.

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