

Application and Development Prospects of Aerogels in the Construction Field

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Abstract: Against the backdrop of the coordinated advancement of the "dual carbon" development strategy and building energy-efficiency policies, the Implementation Guide for Energy Conservation and the General Code for Energy Efficiency and Renewable Energy Utilization in Buildings have been successively promulgated and implemented, and energy-efficiency targets for new buildings in China have continued to become more stringent. China's total stock of existing buildings has reached approximately 60 billion square meters and is gradually entering a stage of large-scale energy-efficiency renovation. Traditional EPS polystyrene boards and rock wool insulation materials suffer from defects such as relatively high thermal conductivity, poor fire performance, and short service life, making it difficult for them to meet the technical requirements of ultra-low-energy buildings and deep energy-saving and carbon-reduction renovation of industrial kilns in the building materials industry. As a new type of insulation material, SiO₂ composite aerogel material is gradually demonstrating important application potential in the green building sector by virtue of its unique low thermal conductivity and lightweight characteristics. This study aims to summarize the current application status of SiO₂ composite aerogel materials in the field of building insulation and to provide an outlook on their prospects.

Keywords: SiO₂ Composite Aerogel; Dual Carbon; Building Energy Efficiency; Insulation Materials

1. Introduction

In October 2025, the Ministry of Industry and Information Technology officially released the Catalog of Technologies and Products

Encouraged for Promotion and Application in the Building Materials Industry (2025 Edition) [1], in which SiO₂ composite aerogel composite insulation products were included. In December of the same year, the Recommended Catalog of Energy-Saving and Carbon-Reduction Technologies and Equipment in the National Industrial and Information Technology Fields (2025 Edition) was released [2], in which nano-SiO₂ composite aerogel material industrial energy-saving technology was listed. By virtue of their nanoporous microstructure, SiO₂ composite aerogels possess characteristics such as ultra-low density, high porosity, extremely low thermal conductivity, and large specific surface area, demonstrating application potential in multiple fields [3,4], and represent an important research and development direction for high-performance insulation materials at the current stage. Domestic enterprises such as Nano Technology and Hongbai New Materials have achieved industrial mass production, and leading real estate enterprises such as Vanke and Country Garden have successively carried out demonstration projects for SiO₂ composite aerogel insulation buildings. However, constrained by multiple factors such as production cost, preparation technology, industry standards, and market awareness, the overall penetration rate of SiO₂ composite aerogels in the civil building insulation field is less than 5%. This study systematically reviews the industrialization status, development bottlenecks, and optimization paths of SiO₂ composite aerogel building materials, which can provide theoretical support for the promotion and application of new energy-saving building materials.

2. Characteristics of SiO₂ Composite Aerogel Materials

SiO₂ composite aerogel is a type of porous material with a three-dimensional nanostructure

composed of nanoparticles or polymer molecular chains (As shown in the Figure 1). Its porosity can range from 80% to 99.8%, and its bulk density lies within the range of 0.003–0.5 g/cm³. Its unique hollow porous structure can effectively block the heat conduction process of gases. At room temperature, its thermal conductivity is only 0.013–0.02 W/(m·K), significantly superior to conventional insulation materials such as EPS boards (thermal conductivity of 0.038–0.042 W/(m·K)) and rock wool (thermal conductivity of 0.040–0.045 W/(m·K)).

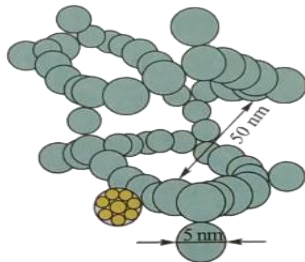


Figure 1. Nanoporous Structure of SiO₂ Composite Aerogel

The inorganic silicon-based skeleton enables the product to reach the Class A non-combustible standard, with a maximum tolerance temperature of 1200°C, no droplet phenomenon in high-temperature environments, and no release of toxic smoke (As shown in the Figure 2).



Figure 2. Schematic Diagram of the Flame Resistance Test of SiO₂ Composite Aerogel

The service life of SiO₂ composite aerogel is 50–100 years, which can remain consistent with the service life of the main building structure. The

density of all-carbon SiO₂ composite aerogel is as low as 0.16mg/cm³. With material innovation and development, its application in the construction field will become broader and deeper [5].

3. Applications of SiO₂ Composite Aerogel Materials

3.1 Application in Building Envelope Insulation

SiO₂ composite aerogel composite insulation boards and flexible insulation rolls, by virtue of their lightweight and high-strength properties, excellent fire performance, extremely low thermal conductivity, and good insulation performance, can effectively reduce the temperature difference between the interior and exterior of buildings and improve the thermal insulation effect of buildings [6].

They are mainly used in key envelope structure parts of ultra-low-energy buildings, including exterior wall insulation systems, roof insulation layers, and bottom insulation layers of floor heating systems. At present, their penetration rate in the ordinary commercial housing market is still relatively low. However, China has an extremely large stock of old buildings, which generally suffer from problems such as poor insulation performance and high energy consumption, and urgently need energy-efficiency improvement through energy-saving renovation. In the future, with the in-depth advancement of the national "dual carbon" strategy and the continuous improvement of building energy-efficiency standards, energy-saving renovation of existing buildings will become the core incremental market for the medium- and long-term development of SiO₂ composite aerogel materials, with broad application prospects and huge market potential (As shown in the Table 1).

Table 1. Parameters of SiO₂ Composite Aerogel Insulation Felt

Insulation material	Thermal conductivity/[W/(m·K)]	Temperature range/°C	Combustion grade
Aerogel	0.013–0.038	-200–1400	A
Polyisocyanurate	0.019–0.022	-185–140	B1
Rigid phenolic	0.019–0.024	10–120	B1
Polyurethane (PU)	0.020–0.030	0–100	B2
Expanded polystyrene	0.026–0.033	Room temperature–90	B2
Glass fiber	0.034–0.040	Room temperature–250	A

3.2 Application in Energy-Saving Doors and Windows and Fireproof Components

In the field of building energy-saving doors and

windows, insulating glass filled with SiO₂ composite aerogel insulation felt as the filling medium can significantly reduce the overall window heat transfer coefficient (U-value) to

about $0.5 \text{ W}/(\text{m}^2\cdot\text{K})$, far superior to the insulation performance of conventional insulating glass, effectively reducing heat loss in winter and cooling loss in summer, thereby greatly improving the overall energy efficiency of buildings. At the same time, compared with the technical defects of vacuum glass, such as easy cracking, short sealing life, and high cost, SiO_2 composite aerogel insulating glass, while maintaining excellent thermal insulation performance, has higher safety and a longer service life, making it more suitable for large-

scale engineering applications. In addition, in terms of building fire safety, SiO_2 composite aerogel composite boards have good sound insulation and fireproof performance [7] and are widely used as fireproof door core boards and fireproof sealing materials for elevator shafts and pipe shafts. Their Class A non-combustible characteristics and low heat conduction performance can effectively delay the spread of fire and meet the stringent fire compartmentation requirements of high-rise buildings (As shown in the Table 2).

Table 2. Parameters of SiO_2 Composite Aerogel Insulation Felt (SiO_2 Composite Aerogel Roll GB/T 34336-2017 Class S) [8].

Appearance	Flexible roll, mainly white, color customizable	
Thickness	$10\pm 1\text{mm}$, $15\pm 1\text{mm}$, $20\pm 1\text{mm}$	
Width	1500 mm	
Thermal conductivity	$\leq 0.017 \text{ W}/(\text{m}\cdot\text{K}) @ 25^\circ\text{C}$	GB/T 10295
Volume density	$160 \text{ kg}/\text{m}^3$	GB/T 5480-2017
Hydrophobic rate	99.5%	GB/T 10299-2011
Volume water absorption	0.20% (fully immersed 25mm, 2 h)	GB/T 5480-2017
Combustion grade Class	A	GB 8624-2025
Compressive strength	35 kPa @10%	GB/T 13480
Compressive rebound rate	99%	GB/T 34336
Vibration mass loss	$\leq 0.5\%$	
Service life	>20 years	
Packaging	Overall stretch film ; customized	

3.3 Application in Industrial Thermal Pipeline Insulation

In high-energy-consumption industrial fields such as cement manufacturing, coal chemical industry, and petrochemical industry, energy loss during heat transmission has long existed. Traditional insulation materials such as aluminum silicate fiber and rock wool generally suffer from disadvantages such as relatively high thermal conductivity, easy moisture absorption and aging, and complex construction, making it difficult for them to meet modern industry's demand for efficient energy saving and long-term stable operation. (As shown in the Figure 3). In recent years, SiO_2 composite aerogel prefabricated pipe shells, by virtue of their extremely low thermal conductivity (as low as $0.015 \text{ W}/(\text{m}\cdot\text{K})$ at room temperature), excellent high-temperature resistance (long-term service temperature can reach above 650°C), and good hydrophobicity and structural stability, are gradually replacing traditional insulation materials and becoming the preferred solution for energy-saving renovation of industrial thermal pipeline systems. At present, such products have been successfully applied in

multiple large-scale industrial projects, not only significantly reducing pipeline heat loss but also reducing maintenance frequency and energy consumption, providing key material support for high-energy-consumption industries to achieve green and low-carbon transformation and better guiding the industry toward low-carbon goals [9].

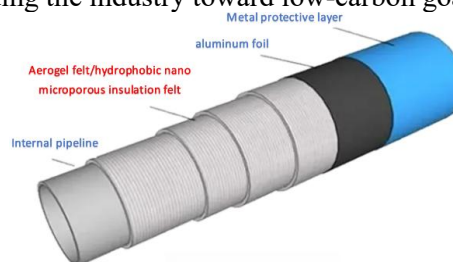


Figure 3. Schematic Diagram of SiO_2 Composite Aerogel Used in Industrial Pipelines

4. Problems Existing in the Application of SiO_2 Composite Aerogel Materials and Solutions

4.1 Problems Existing in the Application of SiO_2 Composite Aerogel Materials

(1) Relatively high overall product cost

The production process system of SiO_2 composite aerogel is highly complex. Its

production process requires precision equipment and strict control of production processes and process parameters. The technical barrier to production is relatively high, which directly leads to a relatively high product production cost. The high cost not only makes it difficult for aerogel products to achieve large-scale popularization and limits the comprehensive expansion of the civil market, but also restricts the mass production and standardization development of the industry. It is the core economic bottleneck hindering industrialization. (As shown in the Table 3).

Table 3. Reference for Core Performance and Market Price

Material category	Thermal conductivity (W/m·K)	Market unit price (yuan/m ³)
EPS polystyrene board	0.030–0.040	800–1500
XPS extruded board	0.030–0.040	800–1500
Rock wool/mineral wool	0.035–0.045	500–1000
Polyurethane	0.026–0.030	2000–3000
Glass wool	0.035–0.045	500–1000
SiO ₂ composite aerogel products	0.018–0.023	8000–12000

(2) Insufficient overall market awareness

As a new type of functional material, SiO₂ composite aerogel is still in the initial stage of market popularization [10]. At present, the government, market end users, and the general public have limited understanding of the material characteristics, application advantages, and use value of aerogels. This cognitive barrier directly hinders the market promotion of SiO₂ composite aerogel products. Many downstream traditional industries still rely on traditional insulation materials, resulting in a relatively slow market substitution process for aerogel materials and making it difficult to rapidly develop the entire market. (As shown in the Figure 4).

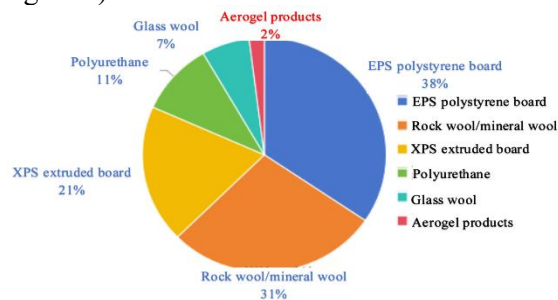


Figure 4. Market Share of Various Materials in 2025

(3) Lagging industry development and weak market foundation

Compared with overseas markets, China's SiO₂

composite aerogel industry started significantly later. In the early stage of industry development, the domestic market was completely dependent on foreign aerogel products, and the local industry was in a blank state. At the same time, the market price of early SiO₂ composite aerogel products remained high, industry market promotion efforts were insufficient, and the public and downstream enterprises had extremely low awareness of aerogel materials, resulting in limited market acceptance and popularization. This laid hidden foundation problems for subsequent industrialization and large-scale development, and the overall market cultivation process was slow.

(4) Imperfect production technology and product system

The process system of China's SiO₂ composite aerogel industry has still not reached a fully mature state. The formulations and production processes of products produced by enterprises are lacking in stability and maturity, and the industry has not yet formed unified and standardized production process specifications. This situation has led to uneven quality of domestic aerogel products, and product stability is difficult to effectively guarantee. The overall production process level lags behind mature overseas markets such as Europe and cannot meet the supply demand for high-quality products required by large-scale industrialization and marketization.

(5) Insufficient expansion of application fields and single market structure

At present, the downstream application scenarios of domestic SiO₂ composite aerogels are highly concentrated, mainly relying on two major fields: building materials and military aerospace [11]. In 2018, the combined demand from these two fields accounted for more than 80%. However, many civil emerging fields such as petrochemicals, rail transit, and special clothing are currently only in the stage of small-scale trial use and have not yet formed a mature market scale. Overall, the coverage of aerogel application scenarios is relatively narrow, the market structure is single, the growth points of industrial development are limited, and market potential has not yet been fully released.

(6) Imperfect industrial supporting mechanisms and immature industrialization system

China's SiO₂ composite aerogel industry is still in the initial stage of start-up and growth. The overall development mechanism of the industry

needs improvement, and there is a lack of mature industry norms, industrial supporting systems, and market adaptation mechanisms [12]. At the same time, the connection between the research end and the industrial end is not close enough, some research and development achievements are difficult to efficiently transform into actual productivity, and a collaborative development model of industry, universities, and research institutes has not yet been fully established, making it difficult to support the industry in achieving high-speed, high-quality industrialization.

The superposition of the above multiple factors jointly restricts the large-scale promotion and sinking application of SiO₂ composite aerogel insulation materials in the building market and delays their popularization from high-end demonstration projects to ordinary residential and commercial projects.

4.2 Solutions

(1) The guiding role of government energy-saving and environmental protection policies

The guiding role of policies and regulations in industry development is unquestionable. By virtue of their unique structural and performance advantages, SiO₂ composite aerogel materials demonstrate significant application value in the field of energy conservation and environmental protection. They can not only help achieve the goal of "green development" and promote the resolution of prominent environmental problems, but also provide strong support for the construction of "Beautiful China." Therefore, it is necessary to further strengthen the guiding function of government energy-saving and environmental protection policies and effectively promote the development of the aerogel industry through measures such as implementing various supporting energy-saving and environmental protection policies, increasing investment in various science and technology plans and small and medium-sized enterprise energy-saving and environmental protection innovation funds, and improving government procurement mechanisms.

(2) Enhance enterprise production efficiency

The production process of SiO₂ composite aerogel is relatively complex, requiring strict control of a large amount of equipment and precise adjustment of process parameters. Therefore, the SiO₂ composite aerogel industry is a high-technology industry. After decades of development, SiO₂ composite aerogel materials

and their production technology have made significant progress. However, in the face of rapidly growing market demand, production enterprises still need to strengthen technical reserves, such as improving the maturity and stability of product formulations and production processes and promoting standardization of production processes. These measures will help enterprises achieve stable production, reduce costs, ensure product quality, improve production capacity, and thereby enhance their viability and market competitiveness.

(3) Strengthen the research and development of new materials and the transformation of achievements

The core of the national development strategy, "enhancing independent innovation capability and building an innovative country," has become a consensus among all parties in industry, universities, research institutes, government, and capital. SiO₂ composite aerogel-related enterprises and scientific research institutes should uphold the concept of innovation-driven development, accurately grasp the development trends of the industry, technology, and products, continuously overcome key scientific and technological difficulties, and enhance the core competitiveness of enterprises. They should not only conduct in-depth development of existing technologies and products, but also increase investment in innovative research and development and continuously cultivate new growth points for the industry, promoting high-quality development of enterprises and the industry [13,14]. At the same time, the transformation of scientific and technological achievements depends on a high degree of matching between scientific research directions and market demand as well as sufficient financial support. It is necessary to build a benign interaction mechanism between the innovation end and the industrial end, enhance cooperation and trust between scientific research institutes and enterprises, balance the interests of all parties, and achieve win-win cooperation.

(4) Improve the publicity of aerogel materials

At present, most people still lack awareness of the concept and material characteristics of SiO₂ composite aerogel. SiO₂ composite aerogel materials still belong to the "emerging" category, and this situation largely restricts the sales of aerogel products and the development of the industry [15]. Therefore, the industry, enterprises, and relevant units and personnel

need to attach great importance to the publicity, promotion, and packaging of aerogel materials, popularize basic knowledge of aerogels to the general public and users through diverse channels, emphasize their notable characteristics and advantages, and shape product and enterprise images. These measures will certainly effectively promote product sales and promote industry development.

(5) Broaden the scope of market applications

The production cost of SiO₂ composite aerogel materials is relatively high, so they are more competitive in high-end and high-value-added markets. Enterprises should conduct in-depth research on these fields, accurately grasp users' application needs to advance new product research and development, continuously expand the market space for aerogel products, and create a new situation for industry development.

(6) Enhance the integration process of traditional materials and aerogels

Traditional materials have mature production processes, sales channels, and application markets. By integrating SiO₂ composite aerogels with traditional materials through methods such as compounding, mixing, and partial substitution, it is possible to promote the rapid entry of aerogel materials into the market while fully leveraging the respective characteristics of both, achieving complementary advantages, thereby improving product performance and expanding application fields.

5. Development Prospects of SiO₂ Aerogels in the Construction Field

With the continuous advancement of China's "dual carbon" strategy and the continuous upgrading of building energy-efficiency standards, the demand for high-performance insulation materials in the construction field is growing rapidly. As a material with excellent thermal insulation performance and lightweight characteristics, SiO₂ composite aerogel, with its relatively low thermal conductivity, shows significant advantages in improving building energy efficiency and reducing carbon emissions. This material naturally conforms to the development direction requirements of the building energy-saving field for lightweight, high-performance, green, and safe materials. In the future, with the continuous iterative maturation of preparation processes, the gradual control and reduction of production costs, and the continuous improvement and perfection of

industry standard systems, SiO₂ composite aerogels will gradually break through the limitations of current application scenarios: they will not only further expand their application scale in fields such as high-energy-consumption industrial renovation and high-end public buildings, but will also gradually sink into broader markets such as ordinary civil residences and energy-saving renovation of existing old buildings, becoming a key new material for promoting energy conservation and carbon reduction in the construction industry and realizing green and low-carbon transformation, and providing important material support for China's construction sector to implement the "dual carbon" strategic goals.

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