UDC 691
IRSTI 67.15.55
REVIEW ARTICLE

THERMAL INSULATION PROPERTIES OF SILICA AEROGELS: PROSPECTS FOR USE

A.Z. Tukhtamisheva[1,*], D.A. Adilova[1], R. Bliudzius[2]

[1]International Educational Corporation, 050043, Almaty, Kazakhstan
[2] Kaunas University of Technology, LT-44249, Republic of Lithuania, Kaunas

Abstract. *Silica aerogels are unique highly porous materials with exceptionally low thermal conductivity, which opens up broad possibilities for their application in the field of thermal insulation. This article examines the main thermal insulation properties of silica aerogels, emphasizing their ability to effectively reduce heat transfer through conduction, convection, and radiation mechanisms. The physicochemical characteristics of aerogels are discussed, including porosity, density, pore size, and their influence on thermal conductivity. Special attention is given to the nanoscale structure of aerogels, which ensures their high efficiency in insulation. The study presents data on how changes in these parameters can lead to improved thermal insulation properties. The article also analyzes the prospects for using silica aerogels in construction, energy-saving technologies, and other industries where high thermal insulation efficiency is required. Potential areas of application are considered, including building insulation, the creation of energy-efficient systems, and use in specialized industrial conditions. The work discusses key factors affecting the thermal conductivity of aerogels, as well as current research and developments aimed at optimizing their properties for mass application. The conclusion emphasizes the importance of silica aerogels as materials of the future, contributing to the reduction of energy consumption and increasing the sustainability of structures.*

Keywords: *Silica aerogels, thermal insulation, heat transfer, energy efficiency, sol-gel process.*

***Corresponding author**
Ainur Tukhtamisheva, e-mail: aynurjan_kz@mail.ru

https://doi.org/10.51488/1680-080X/2024.4-09
Received 09 August 2024; Revised 16 October 2024; Accepted 06 November 2024

ӘОЖ 691
FТАМР 67.15.55
ШОЛУ МАҚАЛА

КРЕМНЕЗЕМДІ АЭРОГЕЛЬДЕРДІҢ ЖЫЛУ ОҚШАУЛАУ ҚАСИЕТТЕРІ: ПАЙДАЛАНУ ПЕРСПЕКТИВАЛАРЫ

А.З. Тухтамишева[1,*], Д.А. Адилова[1], Р. Блюджиус[2]

[1]Халықаралық білім беру корпорациясы, Алматы, 050043, Қазақстан
[2]Каунас технологиялық университеті, LT-44249, Литва Республикасы, Каунас

Аңдатпа. *Кремнеземді аэрогельдер өте төмен жылу өткізгіштігі бар бірегей жоғары кеуекті материалдар болып табылады, бұл оларды жылу оқшаулау саласында қолдануға кең мүмкіндіктер ашады. Бұл мақалада кремний аэрогельдерінің негізгі жылу оқшаулау қасиеттері қарастырылады, олардың жылу өткізгіштік, конвекция және сәулелену механизмдері арқылы жылу беруді тиімді төмендету қабілетіне назар аударылады. Аэрогельдердің кеуектілігі, тығыздығы, тері тесігінің мөлшері және олардың жылу өткізгіштікке әсері сияқты физикалық-химиялық сипаттамалары талқыланады. Аэрогельдердің наноөлшемді құрылымына ерекше назар аударылады, бұл олардың жылу оқшаулауында жоғары тиімділігін қамтамасыз етеді. Зерттеу осы параметрлердің өзгеруі жылу оқшаулау қасиеттерінің жақсаруына қалай әкелетіні туралы деректерді ұсынады. Сондай-ақ, мақалада кремнеземді аэрогельдерді құрылыста, энергияны үнемдейтін технологияларда және жылу оқшаулаудың жоғары тиімділігі қажет басқа салаларда қолдану перспективалары талданады. Ғимараттарды оқшаулауды, энергияны үнемдейтін жүйелерді құруды және мамандандырылған индустриялық жағдайларда пайдалануды қоса алғанда, әлеуетті қолдану салалары қарастырылады. Жұмыста аэрогельдердің жылу өткізгіштігіне әсер ететін негізгі факторлар талқыланады, сонымен қатар олардың қасиеттерін жаппай қолдану үшін оңтайландыруға бағытталған ағымдағы зерттеулер мен әзірлемелер қарастырылады. Қорытынды кремнеземді аэрогельдердің энергия шығынын азайтуға және құрылымдардың тұрақтылығын арттыруға ықпал ететін болашақ материалдар ретіндегі маңыздылығын көрсетеді.*

Түйін сөздер: *Кремнеземді аэрогельдер, жылу оқшаулау, жылу беру, энергия тиімділігі, күл-гель процесі.*

***Автор-корреспондент**
Айнур Тухтамишева, e-mail: aynurjan_kz@mail.ru

https://doi.org/10.51488/1680-080X/2024.4-09
Алынды 09 тамыз 2024; Қайта қаралды 16 қазан 2024; Қабылданды 06 қараша 2024

УДК 691
МРНТИ 67.15.55
ОБЗОРНАЯ СТАТЬЯ

ТЕПЛОИЗОЛЯЦИОННЫЕ СВОЙСТВА КРЕМНЕЗЕМНЫХ АЭРОГЕЛЕЙ: ПЕРСПЕКТИВЫ ИСПОЛЬЗОВАНИЯ

А.З. Тухтамишева[1]*, Д.А. Адилова[1], Р. Блюджиус[2]

[1] Международная образовательная корпорация, Алматы, 050043, Казахстан
[2] Каунасский технологический университет, LT-44249, Литовская Республика, Каунас

Аннотация. *Кремнеземные аэрогели являются уникальными высокопористыми материалами с исключительно низкой теплопроводностью, что открывает широкие возможности для их применения в области теплоизоляции. В данной статье рассматриваются основные теплоизоляционные свойства кремнеземных аэрогелей, акцентируя внимание на их способности эффективно снижать теплопередачу через механизмы теплопроводности, конвекции и излучения. Обсуждаются физико-химические характеристики аэрогелей, такие как пористость, плотность, размер пор и их влияние на теплопроводность. Особое внимание уделяется наноразмерной структуре аэрогелей, которая обеспечивает их высокую эффективность в теплоизоляции. В исследовании представлены данные о том, как изменение этих параметров может привести к улучшению теплоизоляционных свойств. Статья также анализирует перспективы использования кремнеземных аэрогелей в строительстве, энергосберегающих технологиях и других отраслях, где требуется высокая эффективность теплоизоляции. Рассматриваются потенциальные области применения, включая утепление зданий, создание энергоэффективных систем и использование в специализированных индустриальных условиях. В работе обсуждаются ключевые факторы, влияющие на теплопроводность аэрогелей, а также рассматриваются текущие исследования и разработки, направленные на оптимизацию их свойств для массового применения. Заключение подчеркивает важность кремнеземных аэрогелей как материалов будущего, способствующих снижению энергозатрат и повышению устойчивости строений.*

Ключевые слова:. *Кремнеземные аэрогели, теплоизоляция, теплопередача, энергоэффективность, золь-гель процесс.*

***Автор-корреспондент**
Айнур Тухтамишева, e-mail: aynurjan_kz@mail.ru

https://doi.org/10.51488/1680-080X/2024.4-09
Поступило 09 августа 2024; Пересмотрено 16 октября 2024; Принято 06 ноября 2024

ACKNOWLEDGEMENTS / SOURCE OF FUNDING

The study was conducted using private sources of funding.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ / ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

In the context of modern challenges related to climate change and the need to improve energy efficiency, there is an increasing demand for innovative materials that can minimize heat loss. Silica aerogels are materials with unique properties that allow for effective thermal insulation due to their nanoscale porous structure. Their ability to reduce heat transfer makes them one of the most promising materials for use in construction, industry, and energy.

However, despite their outstanding thermal insulation characteristics, there are still unresolved issues regarding the improvement of the mechanical strength and stability of aerogels under extreme operating conditions. Their high porosity, on one hand, ensures minimal thermal conductivity, but on the other hand, it reduces their structural strength, which limits their areas of application.

This article provides an overview of contemporary research aimed at enhancing the strength of silica aerogels without compromising their unique insulating properties. It also discusses the prospects of their use across a wide range of fields, from construction and building materials production to aerospace technologies, where their application could significantly reduce energy costs and improve the overall efficiency of thermal insulation systems.

Thus, the research aims to address existing gaps in the understanding of silica aerogels' properties and to develop methods for their optimization to expand practical applications in line with modern technological requirements.

2 LITERATURE REVIEW

Aerogels are solid materials with low density, predominantly mesoporous, possessing unique characteristics such as low density, high specific surface area, low dielectric constant, and extremely low thermal conductivity. Silica aerogels are distinguished by special properties, including a high specific surface area (500–1200 m^2/g), significant porosity (80–99.8%), low density (approximately 0.003 g/cm^3), high thermal insulation characteristics (0.005 W/m·K), as well as extremely low dielectric permeability (k = 1.0–2.0) and refractive index (~1.05). The structure of silica aerogel, obtained through SEM and TEM, is presented in **Figure 1 (Huang et al., 2019; F. Lou et al., 2023; Moner-Girona et al., 2003)**.

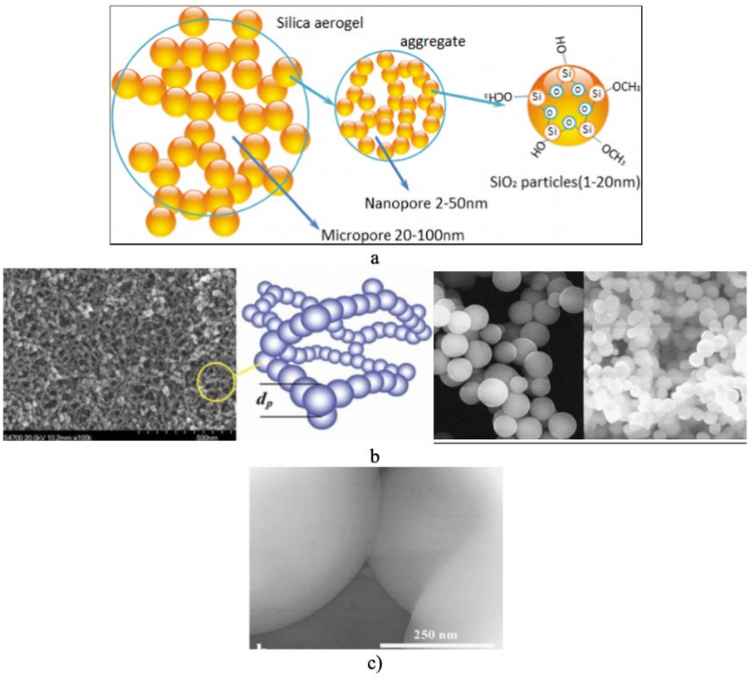

Figure 1 - Silica Aerogel: a) Structure, b) SEM Image, c) TEM Image

Table 1
Relevant Properties of Silica Aerogels (Huang et al., 2017)

	Color	Translucent
	Density (g cm^{-3})	0.16×10^{-3}
	Thermal conductivity (W m^{-1}·K)	0.022 18
Silica aerogel	Pore diameter (nm)	21.85
	BET (m^2 g^{-1})	715.57
	Pore volume (cm^3 g^{-1})	3.82
	Initial Melting point (°C)	—

Silica aerogels are primarily synthesized using the chemical sol-gel process. This method consists of two key stages: 1) gel formation under high humidity conditions and 2) drying of the resulting gel with an intermediate aging stage. In the first stage, the hydrolysis of silicon alkoxides occurs with the addition of appropriate solvents, catalysts, and water, resulting in a homogeneous solution. As a result, a colloidal dispersion of particles forms, which over time organizes into a three-dimensional network structure composed of solid and liquid phases. This process is called gelation, which is part of the sol-gel method, as shown in **Figure 2 (Gesser & Goswami, 1989)**.

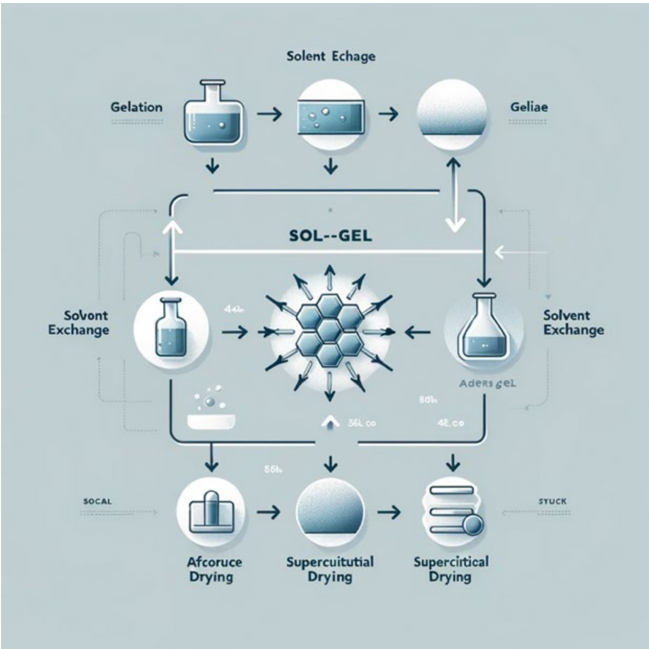

Figure 2 - Sol-Gel Process (Gesser & Goswami, 1989).

The forming gel can take the shape of a polymer chain or colloidal gel, depending on the pH value of the medium used during synthesis. The solvent is then distilled, leaving a viscous liquid that is re-dissolved in an alcohol-containing liquid, such as ethanol. To completely remove the residual solvent and water, the re-dissolution process in alcohol is carried out in several cycles. The second stage involves drying, which is a key moment in the production of aerogel, as previously noted, pressure and temperature significantly influence the properties of the material. During this stage, the remaining liquid is removed from the pores while preventing the destruction of the gel structure. **Figure 3** presents the main stages of aerogel production. The aging process can be considered an intermediate stage between gelation and drying (Lee et al., 1995).

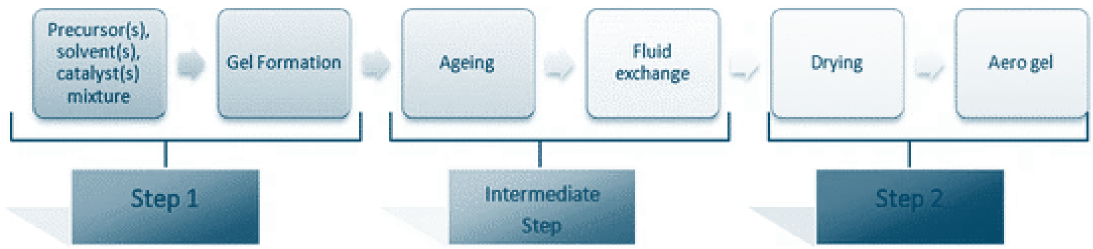

Figure 3 - Overview of Key Processes in Aerogel Production **(Sachithanada et al., 2016)**.

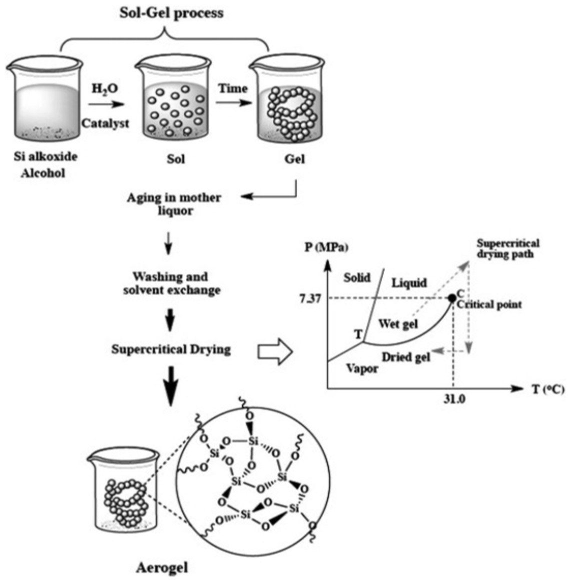

Figure 4 - Schematic Representation of a Typical Sol-Gel Synthesis Procedure for Obtaining Aerogels **(Maleki et al., 2014)**.

3 MATERIALS AND METHODS

3.1 Heat Transfer Analysis through the Material

The industrial success of silica aerogels is primarily attributed to their use as highly effective thermal insulation materials. The thermal conductivity of silica-based aerogels can reach a minimum value of 0.012 W/(m·K), which is explained by their high porosity and complex particle network structure that limits the thermal conductivity of the solid phase. Additionally, the small pore sizes, smaller than the mean free path of gas molecules, reduce the thermal conductivity of the gas phase due to the Knudsen effect. This ultra-low thermal conductivity, which is twice lower than that of conventional air and traditional insulation materials, has led to the creation of a rapidly growing market estimated to be worth hundreds of millions of dollars. The overall thermal conductivity of the material significantly correlates with its density, as illustrated in **Figure 5**.

For standard insulation materials, an important factor is heat transfer due to radiation, and as pore sizes increase, air convection also becomes significant. As the density of materials increases, the thermal conductivity due to radiation decreases, while the thermal conductivity of the solid phase increases. These opposing effects create a U-shaped relationship between thermal conductivity and density. For aerogels, these effects also play a significant role, but there is an additional notable reduction in the thermal conductivity of the gas phase. This is because the pore sizes in aerogels are smaller than the mean free path of air molecules, which reduces the frequency of their collisions and decreases the heat transfer of the gas. As a result, the minimum overall thermal conductivity shifts to higher densities, achieving significant reductions in thermal conductivity values.

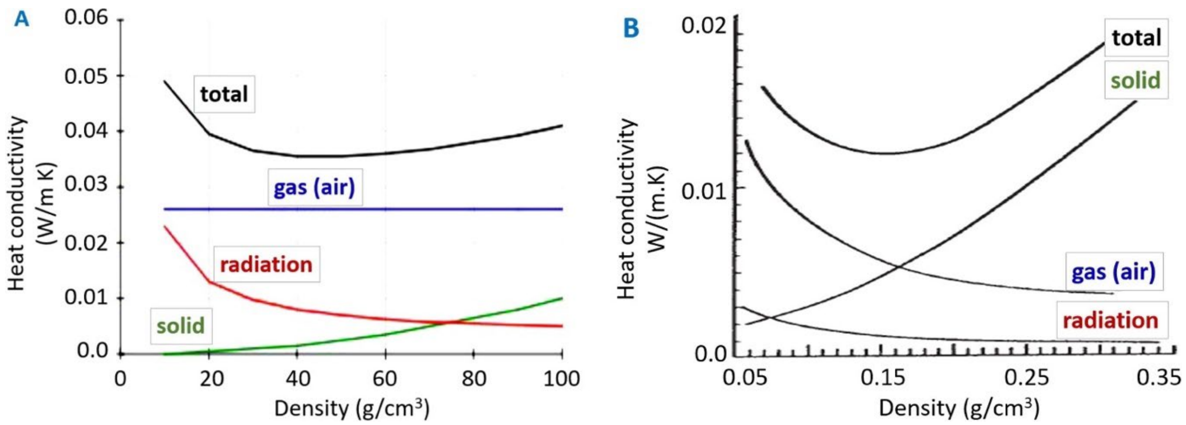

Figure 5 - A) Thermal Conductivity of Conventional Insulation **(Simmler et al., 2005)**, and B) Aerogel Materials **(Hüsing & Schubert, 1998)**.

Aerogels demonstrate outstanding thermal insulation characteristics, making them one of the most effective insulating materials known today. Their exceptional ability to prevent heat transfer is due to their nanoscale porous structure, which significantly reduces heat transfer through conduction, convection, and radiation. In particular, silica-based aerogels are characterized by extremely low thermal conductivity, even at high temperatures, with values around 0.012–0.015 W/(m·K) **(Koebel et al., 2012)**.

3.2 Analysis of Standards for Determining the Thermal Properties of Materials and Practical Laboratory Measurements

The optical characteristics of the glazing sample in the wavelength range of 300–2500 nm were evaluated using an infrared spectrophotometer operating in the ultraviolet range. The tests were conducted in accordance with the international standard ISO 9050:2003 "Glass in Building - Determination of Light Transmission, Solar Heat Gain Coefficient, Total Solar Energy Transmittance, Ultraviolet Transmission, and Related Parameters of Glazing." Thermal conductivity was measured using a flat thermal conductivity meter according to the standard GB/T10294-2008 "Thermal Insulation - Determination of Steady-State Thermal Resistance and Related Properties - Method for Protected Heating Device."

The measured thermal conductivity of the sample with silica aerogel was approximately 0.13 W/(m²·K). The calculated U-value for this sample was about 2.8 W/(m²·K). For the reference glazing sample, the thermal conductivity was measured as 0.15 W/(m²·K), and the U-value, according to calculations, was about 3.2 W/(m²·K). Thus, the thermal insulation properties of the glazing sample with silica aerogel significantly exceed the characteristics of a conventional double-glazing system **(Huang et al., 2015)**.

For the thermal conductivity determination of aerogel samples, the most widely applied methods are the Guarded Hot Plate (GHP), in the steady-state case, and the Transient Plane Source (TPS) method, for the transient methodologies. The apparatus and testing procedure for the GHP method are described in different standards, ASTM C177, European Standard EN 12667 and International Standard ISO 8302. Even though this method has been extensively used, the technique presents some drawbacks, such as the necessity of relatively large testing samples and usually long waiting time. The TPS method, especially the "Hot Disk ®" variants, has been adopted for fast characterization of thermal properties. The ASTM D7984 and the ISO 22007-2 define the devices and procedures for this methodology. The TPS method is reportedly capable of measuring thermal conductivities from 0.005 to 500 $mW\cdot m^{-1}\cdot K^{-1}$, in a large temperature range (cryogenic temperatures to 500 K). However, the two sample pieces needed must be similar and feature one entirely planar side, which can be sometimes challenging for aerogel samples **(Lamy-Mendes et al., 2021)**.

For acoustic measurements of sound absorption coefficients, two methods are most commonly used: the impedance tube method and reverberation chamber methods. The impedance tube, described in the standards ISO 10534-1 and ISO 10534-2, is used to assess sound absorption on small samples. In turn, reverberation chamber methods, as specified in standard ISO 354, are applied for measuring acoustic characteristics in larger samples. To evaluate sound insulation or sound transmission loss through air systems made from various materials, different approaches are employed depending on the sample size. The impedance tube is used for small samples, while methods outlined in the ISO 10140 series (Parts 1-5) are applied for larger samples, such as building materials or their cladding **(Mazrouei-Sebdani et al., 2021)**.

3.3 Analysis of Material Use in Building Projects.

Key Properties of Silica Aerogel for Application in Buildings **(Lamy-Mendes et al., 2021)**:

1. Pore structure and density - Silica aerogels are materials composed by ultrafine particles, linked in a pearl necklace 3D arrangement, and air-filled pores that usually contribute to 85–99.8% of the total aerogel volume. Therefore, when incorporated in composites, they lead to a reduction of their overall density and, thus, the weight of the building envelope, as well as an increase in the thermal resistance due to their low thermal conductivity.

2. Thermal conductivity - The thermal energy is transferred through silica aerogels by three mechanisms: solid conduction (λs), gaseous conduction (λg), and radiative (infrared) transmission (λr).

3. Optical properties - Silica aerogels show optical properties between transparent and translucent, depending on their internal structure.

4. Acoustic properties - Besides thermal insulation performance and the light transmission properties, the acoustic insulation in building envelope materials is very important, regarding both noise insulation and sound absorption. Among the unique properties of aerogels, their high porosity leads to low sound velocity, allowing them to be also applied as noise insulators and sound absorbing materials.

5. Other properties - Silica aerogels also show other advantageous properties, as non-flammability, non-toxicity and easy disposal when compared with other insulation products in the market. The commercial products containing silica aerogels are also considered as having the same properties.

Silica aerogels are the most common and widely studied type of aerogels. They are typically derived from silicon alkoxide precursors such as TMOS or TEOS using the sol-gel process. Silica aerogels are known for their excellent thermal insulation properties, low density, and high porosity. They can also transmit light with minimal scattering or absorption, making them transparent to visible light. These attributes make silica aerogels suitable for a variety of construction applications, including thermal insulation, energy-efficient glazing, and solar thermal collectors. They demonstrated that materials infused with aerogels are increasingly being designed and assessed for construction purposes, including applications like panels, blankets, cement, mortars, plasters, renders, concrete, glazing systems, and solar collector covers **Figure 6 (Gu & Ling, 2024)**.

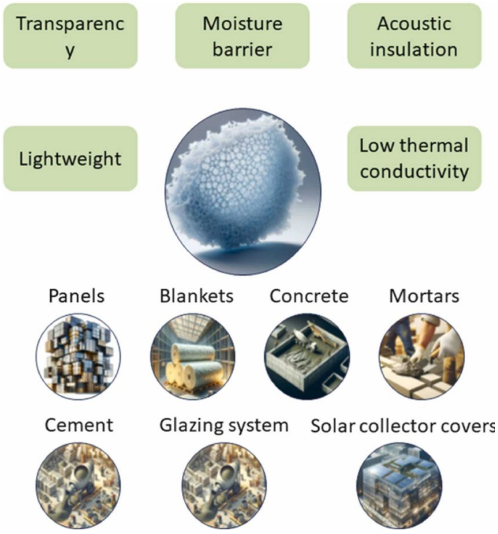

Figure 6 - Materials Containing Silica Aerogel for Use in Construction **(Gu & Ling, 2024)**

Window made of silica aerogel, characterized by high optical transparency and a refractive index of ≈1.52 **(Wang & Petit, 2020)**.

4 RESULTS AND DISCUSSION

Aerogels can be used in energy-efficient window constructions due to their unique properties. Transparent silica aerogels, which possess high thermal insulation and light transmittance, represent a promising solution for window glazing, providing significant energy savings. Silica-based aerogels, thanks to their transparency and exceptionally low thermal conductivity, can reduce energy losses for heating and cooling residential buildings by 25% due to decreased heat transfer through windows. The widespread use of monolithic silica aerogels in window systems can substantially lower energy costs. However, despite these advantages, aerogels exhibit insufficient optical transparency compared to ordinary glass due to light scattering and often have surface defects, which limits their appeal for window constructions.

To address these issues, several approaches have been proposed **Figure 7**. These include improvements in the technological process to enhance visible light transmittance, innovative mold designs to produce homogeneous aerogels, the use of thinner monoliths in window systems, and the application of artistic effects such as paints and laser engraving. The latter allows for the transformation of visible surface defects into elements of aesthetic design, similar to mosaics or stained glass **(Carroll et al., 2022)**.

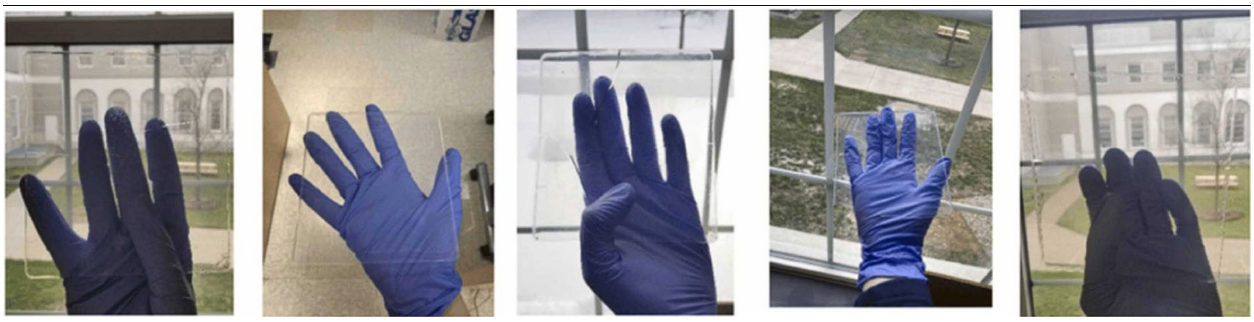

Figure 7 - Images of Monoliths Made of Silica Aerogel Measuring 13 × 12.5 × 0.5 cm, Manufactured Using Various Recipes **(Carroll et al., 2022)**.

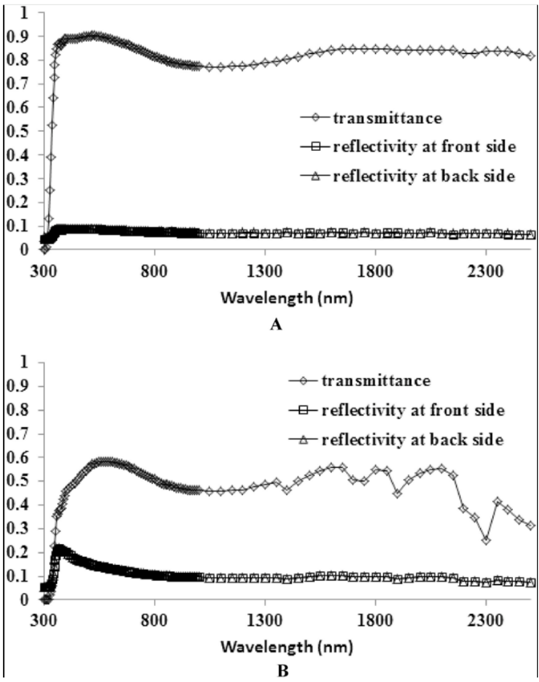

Figure 8 - Results of Optical Characteristics Testing. A. Control Window Sample; B. Silica Aerogel Window Glass Sample **(Huang & Niu, 2015)**.

To evaluate the optical characteristics, it is necessary to measure three key parameters: transmittance, front reflectance, and back reflectance. For these measurements, a reference glazing sample was prepared, which allowed for a clear assessment of the impact of the silica aerogel filler on the optical properties of glass constructions. The control glazing sample was identical to the sample containing silica aerogel, except that there was no aerogel filler between the two layers of glass in the control sample.

Figure 8 shows the optical characteristics of both samples. The results indicate that the addition of silica aerogel filler significantly reduces the light transmittance across the wavelength range. Before filling the sample with silica aerogel, the glass transmittance was approximately 0.8, whereas after introducing the silica aerogel, this value decreased to about 0.45. A slight increase in reflectance was also observed **(Huang & Niu, 2015)**.

In the context of the pressing issues of climate change and the necessity for energy conservation, the role of building insulation becomes particularly important. Aerogels, especially silica aerogels, represent one of the most effective materials for insulation due to their outstanding thermal insulation properties. These materials possess exceptionally low thermal conductivity even at high temperatures, attributed to their high porosity and nanostructured network, which hinders heat transfer through convection, conduction, and radiation.

Aerogel insulation materials can be used for finishing walls, roofs, and floors, significantly reducing heat transfer and enhancing the energy efficiency of buildings. The market offers aerogel coatings, panels, and slabs that simplify the installation process. Furthermore, due to their lightweight nature, aerogels contribute to reducing the overall weight of structures, which is an important aspect in construction **(Gu & Ling, 2024)**.

The exceptional thermal insulation properties of aerogels make them key components for enhancing energy efficiency in the construction sector. Modern buildings consume more than one-third of the world's energy resources, with a significant portion of this energy lost due to heat transfer through walls, windows, ceilings, and other enclosing structures **(Lamy-Mendes et al., 2021; Dou et al., 2023; Han et al., 2023)**.

The use of aerogel coatings, panels, or granulated aerogels in the enclosing structures of buildings significantly reduces thermal flow, leading to a decrease in energy demand for heating and cooling. Currently, commercial products such as Spaceloft aerogel insulation are available, which have an outstanding thermal conductivity of 15 mW/m·K and are designed for finishing walls, attics, and window inserts. Experimental data show that replacing traditional insulation materials with aerogels can reduce the thermal transmittance coefficient (U-value) by more than 50%. These exceptional performance characteristics, combined with the material's thinness and lightness, make aerogels particularly promising for the creation of zero-energy buildings **(Gu & Ling, 2024)**.

The acoustic properties of a building significantly affect the comfort and functionality of the interior space. Aerogels, due to their high porosity and complex internal structure, can effectively absorb sound waves, making them excellent sound insulators. These sound-absorbing properties are beneficial for various construction applications, from residential buildings requiring improved sound insulation to specialized spaces like recording studios and concert halls, where acoustic control is critically important. Silica aerogels exhibit unique acoustic properties, including particularly low sound speeds in the range of 100 to 300 m/s at densities from 0.07 to 0.3 g/m^3. These values are significantly lower than sound speeds in air (343 m/s) and in quartz glass (≈5000 m/s) **(Gronauer et al., 1986)**.

A coating based on insulating materials, such as silica aerogels, has been developed **Figure 9 (Achard et al., 2011)**. This lightweight building mortar is designed for application on the external surfaces of buildings to create an effective thermal insulation coating. The composition of the mortar includes mineral and/or organic hydraulic binders, an insulating filler containing hydrophobic silica aerogel granules (or powder from this material), as well as a structuring filler and optional additives.

The building mortar is made using aerogel grains, which replace the sand typically used in traditional building mortars. It is produced industrially in the form of a dry mixture, consisting of carefully blended components. This mixture is packaged in bags and delivered to the construction site. On-site, the dry mixture is combined with water to form a paste with the necessary viscosity for application, for example, by spraying on the external surfaces of the building. The thickness of the coating is determined by the ease of its application, thanks to specially developed technologies.

Figure 9 - Coating based on silica aerogel **(Ibrahim et al., 2014)**.

5 CONCLUSIONS

Silica aerogel is characterized by a wide range of properties, which expands its wide range of applications. One of the main properties that silica aerogel is valued for is its pore structure and density, silica aerogels are composed of ultra-fine particles connected by 3D pearl necklaces and air-filled pores that typically make up 85-99.8% of the total aerogel volume. Therefore, when incorporated into composites, their overall density is reduced, and thus the weight of building envelopes, as well as thermal resistance is increased due to low thermal conductivity, which greatly expands the use of silica aerogel in various composites to support the properties of these composites.

Climate change and energy conservation are major issues in the modern world, so the role of building insulation has never been more important. The thermal conductivity of silica aerogels is extremely low, even at high temperatures, which is related to the high porosity and nanostructured network that inhibits heat transfer by conduction, convection, or radiation. Therefore, insulating materials based on silica aerogels can be used very widely, starting with roof insulation, wall insulation, and ending with floor insulation. This significantly reduces heat transfer, increases the energy efficiency of the building. In addition, the lightweight nature of silica aerogels reduces the overall weight of the structure, which is a critical consideration in construction.

In addition to the unique properties of aerogels, their high porosity leads to low sound speeds, which allows them to be used as noise insulators and sound absorbing materials, which further expands the application possibilities of these materials. Silica aerogels are also characterized by non-flammability, non-toxicity and easy removal compared to other insulating products on the market.

REFERENCES

1. **Huang, D., Shen, Y., Yuan, Q., Wang, C., Shi, L.** (2019). Preparation and characterization of silica aerogel/polytetrafluoroethylene composites. Materials Research Express, 6 (11), 115021 http://dx.doi.org/10.1088/2053-1591/ab454e
2. **Lou, F., Dong, S., Zhu, K., Chen, X., Ma, Y.** (2023). Thermal insulation performance of aerogel nano-porous materials: characterization and test methods. Gels, 9 (3), 220 https://doi.org/10.3390/gels9030220
3. **Moner-Girona, M., Roig, A., Molins, E., Llibre, J.** (2003). Sol-gel route to direct formation of silica aerogel microparticles using supercritical solvents. Journal of Sol-Gel Science and Technology, 26, 645-649 http://dx.doi.org/10.1023/A:1020748727348
4. **Huang, D. M., Guo, C. N., Zhang, M. Z. and Shi, L.** (2017). Characteristics of nanoporous silica aerogel under high temperature from 950 °C to 1200 °C. Mater Design, 129, 82–90 https://doi.org/10.1016/j.matdes.2017.05.024
5. **Gesser, H.D. & Goswami, P.C.** (1989). Aerogels and related porous materials. Chemical Reviews, 89 (4), 765–788. https://doi.org/10.1021/cr00094a003
6. **Lee, K.-H., Kim, S.-Y. and Yoo, K.-P.** (1995). Low-density, hydrophobic aerogels. Journal of Non-Crystalline Solids, 186, 18–22 https://doi.org/10.1016/0022-3093(95)00066-6
7. **Mahesh, S., Sunil, C. J.** (2016). Silica aerogel composites. Novel fabrication methods, Springer Singapore, 149 http://dx.doi.org/10.1007/978-981-10-0440-7
8. **Maleki, H., Durães, L., Portugal, A.** (2014). An overview on silica aerogels synthesis and different mechanical reinforcing strategies. Journal of Non-Crystalline Solids, 385, 55-74 https://doi.org/10.1016/j.jnoncrysol.2013.10.017
9. **Simmler, H., Brunner, S., Heinemann, U., Schwab, H., Kumaran, K., Mukhopadhyaya, P., Quénard, D., Sallée, H., Noller, K., Kücükpinar-Niarchos, E., Stramm, C., Tenpierik, M.J., Cauberg, J.J.M., Erb, M.** (2005). Vacuum Insulation Panels-Study on VIP-components and panels for service life prediction of VIP in building applications (Subtask A) http://surl.li/trnxwg
10. **Hüsing, N., Schubert, U.** (1998). Aerogels—airy materials: chemistry, structure, and properties. Angewandte Chemie International Edition, 37 (1–2), 22-45 httpыs://doi.org/10.1002/(SICI)1521-3773(19980202)37:1/2<22::AID-ANIE22>3.0.CO;2-I
11. **Koebel, M., Rigacci, A., Achard, P.** (2012). Aerogel-based thermal superinsulation: an overview. Journal of Sol-Gel Science and Technology, 63, 315-339 https://doi.org/10.1007/s10971-012-2792-9
12. **Lamy-Mendes, A., Pontinha, A.D.R., Alves, P., Santos, P., Durães, L.** (2021). Progress in silica aerogel-containing materials for buildings' thermal insulation. Construction and Building Materials, 286, 122815. https://doi.org/10.1016/j.conbuildmat.2021.122815
13. **Mazrouei-Sebdani, Z., Begum, H., Schoenwald, S., Horoshenkov, K.V., Malfait, W. J.**

(2021). A review on silica aerogel-based materials for acoustic applications. Journal of Non-Crystalline Solids, 562, 120770 https://doi.org/10.1016/j.jnoncrysol.2021.120770

14. **Gu, X., Ling, Y.** (2024). Research progress of aerogel materials in the field of construction. Alexandria Engineering Journal, 91, 620-631 https://doi.org/10.1016/j.aej.2024.02.039
15. **Wang, J., Petit, D., Ren, S.** (2020). Transparent thermal insulation silica aerogels. Nanoscale Advances, 12, 5504-5515 https://doi.org/10.1039/D0NA00655F
16. **Carroll, M.K., Anderson, A.M., Mangu, S.T., Hajjaj, Z., Capron, M.** (2022). Aesthetic aerogel window design for sustainable buildings. Sustainability, 14 (5), 2887 https://doi.org/10.3390/su14052887
17. **Huang, Y. & Niu, J.L.** (2015). Application of super-insulating translucent silica aerogel glazing system on commercial building envelope of humid subtropical climates – Impact on space cooling load. Energy, 83, 316-325 https://doi.org/10.1016/j.energy.2015.02.027
18. **Dou, L., Han, H., Yang, B., Lin, C., Pan, S., Li, Q., Yan, P., Zhao, D., Chang, X., Li, J.** (2023). Rapid determination of quercetin and caffeic acid in honeysuckle tea by high efficiency electrochemical sensor. Journal of Food Measurement and Characterization, 17, 5821-5827 http://dx.doi.org/10.1007/s11694-023-02095-0
19. **Han, J.** (2023). Preparation of a highly sensitive graphene-based sensor to investigate the effect of exercise on electrolytes in sweat in hot and humid environment. Carbon Letters, 33, 1959-1966 http://dx.doi.org/10.1007/s42823-023-00542-y
20. **Gronauer, M., Kadur, A., Fricke, J.** (1986). Mechanical and Acoustic Properties of Silica Aerogel. J. Fricke (Ed.), Aerogels, Springer Berlin Heidelberg, Berlin, Heidelberg, 167-173 https://doi.org/10.1007/978-3-642-93313-4_22
21. **Ibrahim, M., Henry, P.B., Wurtz, E., Achard, P.** (2014). A study on the thermal performance of exterior walls covered with a recently patented silica-aerogel-based insulating coating, Building and Environment, 81, 112-122 https://doi.org/10.1016/j.buildenv.2014.06.017