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Aerogel-enhanced blankets: state-of-the-art, market readiness, and future challenges

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ABSTRACT

Aerogel-enhanced products are often indicated as promising materials for increasing the thermal resistance of the building envelope. In particular, aerogel-enhanced blankets have already showed their effectiveness in several retrofitting projects. This paper aims to review the current state of the art regarding aerogel-enhanced blankets. In these materials, a fiber matrix bonds together the aerogel structure, compensating the low mechanical properties of the aerogels without reducing their exceptionally low thermal conductivity. This paper describes current aerogel-enhanced blankets existing worldwide and produced by different companies. Then, a new aerogel-enhanced blanket developed by the authors is presented. Thermal characterization tests confirm the superior performance of aerogel-enhanced blankets, which show a thermal conductivity as low as 0.013 W/(mK). Finally, future research challenges for aerogel-enhanced blankets are presented.

KEYWORDS

High-performance envelope, aerogel, aerogel-enhanced blanket, super-insulating materials.

INTRODUCTION

The development of innovative materials aiming to achieve energy savings is a main focus in the building technology sector. In this context, silica aerogel-enhanced products are often indicated as promising materials for increasing the thermal resistance of the building envelope. While aerogels seem to be promising but still uncommon materials, the global market for silica-based aerogels continues to grow annually at over 10%, passing from US$ 427 Million in 2016 to a forecast of US$ 1.92 billion in 2022 (GVR, 2016). Nowadays, the primary market sector for aerogel-enhanced products is represented by the oil and gas fields which mainly use aerogel-enhanced blankets. However, the building and construction aerogel-market sector is supposed to increase more than the other sectors (Berardi and Nosrati, 2018).

Silica aerogels have extraordinary small pores, which result in remarkable thermal properties, and mechanical strength. Table 1 reports the main physical properties of silica aerogels. In Table 1, it emerges that while the compression strength of the aerogel has a value around 300 kPa, their tensile strength is only 16 kPa, making aerogel extremely fragile. In order to strengthen the tensile properties of the silica aerogels to be used as an insulating material, it has been recently proposed to reinforce the aerogels with mechanically stronger materials and non-woven fiber matrixes such as glass, mineral or carbon fibers. When the fibers or fibrous matrix are added to the pre-gel mixture which contains the gel precursors, the resulting dried composite is an aerogel-enhanced blanket (Aegerter et al., 2011, Baetens et al., 2011).

Nowadays, the main reasoning for the use of aerogel-enhanced insulation is related to the possible space saved resulting from the exceptional thermal properties and fire resistance. In particular, aerogel-enhanced products during building retrofits guarantee the advantage of significant space saving and provide a high thermal resistance in thin layers (Ibrahim et al., 2014, Ghazi Wakili et al. 2014, Galliano et al., 2016). In fact, already a few years ago, the retrofit of a wall with 1 cm thick aerogel blankets on the interior side demonstrated to be economically feasible by Shukla et al. (2014), although the high material cost at that time.

Table 1. Main physical properties of silica (SiO_2) aerogels.

Property	Value
Density	3 to 350 kg/m^3 (typical 70 to 150 kg/m^3)
Pore diameter span	1 to 100 nm (~20 nm on average)
Pore particle diameter	2 to 5 nm
Average pore diameter	20 to 40 nm
Porosity	85 to 99.9 % (typical ~95%)
Thermal conductivity	0.01 to 0.02 W/mK
Primary particle diameter	2 to 4 nm
Surface area	600 to 1000 m^2/g
Tensile strength	16 kPa
Compression strength	300 kPa
Coefficient of linear expansion	2 to 4×10^{-6}

Aerogel-enhanced blankets composed of synthetic amorphous silica are a valid possibility whenever space and weight constraints exist. Several studies have investigated the use of aerogel blankets in buildings and reported about the in-situ behaviour of such products. For example, at the University of Nottingham, the energy efficient retrofit project of a 1930's house was investigated. The research aimed to understand the impact of thermal bridging on the heat loss using aerogel blankets of 20 mm thickness implemented internally with 12 mm of gypsum plaster-board. Results showed that after retrofit, the heat loss through the retrofitted wall was highly reduced, while for the separating wall, there was an increase of the heat losses due to the growing thermal bridges (Cuce et al., 2014, Cuce and Cuce, 2016). Although these preliminary experiences seem promising, a systematic evaluation of the available aerogel-enhanced blankets is still missing. This paper aims to review thermal properties of products currently on the market, to present an innovative aerogel-enhanced blanket, and to review current challenges for these highly promising insulating products.

LITERATURE REVIEW

Aerogel-enhanced blankets are flexible, highly porous, and have a remarkably high thermal resistance. In fact, they have started to be produced and commercialized by several manufactures worldwide, such as Aspen Aerogel Inc., Cabot Corporation, Svenska Aerogel AB, Acoustiblok UK Ltd., Active Space Technologies, Joda, and Airglass AB. For example, Spaceloft developed by Aspen Aerogels Inc. (MA, US) is a flexible fiber-reinforced blanket with a declared thermal conductivity of 0.013 W/(mK) at 0°C. Other common aerogel blankets are Cryogel®Z by Aspen, available in 5 mm and 10 mm thickness and suitable for industrial application, and Thermal-Wrap™, available in 5 mm and 8 mm thickness by Cabot Corporation. The thermal conductivity of these last two products is 0.014 W/(mK) and 0.023 W/(mK) respectively. Similarly, among the aerogel-based commercial blankets, Proloft by Advanced Technologies has attracted some attention as a thermal barrier strip to provide thermal bridging protection around window frames.

The advantages of aerogel-enhanced blankets are that the final panel does not show any granularity of the aerogel, since the aerogel particles are chemically attached to the fiberglass matrix. Commercially available aerogel-enhanced blankets are made with amorphous silica, and they usually suffer for dust production. However, several health organizations, including the International Occupational Safety and Health Organization, have declared aerogel blankets not hazardous for the human health. The non-toxicity combined with the excellent fire protection are promising characteristics of these blankets, which are recyclable, have minimal to no Ozone Depleting Potential and a Global Warming Potential below than 5. Table 2 reports the main properties of different aerogel-enhanced blankets available on the market.

Table 2. Main properties of the most common aerogel-enhanced blankets available on the market.

Commercial name	Manufacture	Fiber composition	Density (kg/m^3)	λ (W/mK)
Thermal Wrap	Cabot	Polyestere and PET	~70	0.023
Cryogel x201	Aspen aerogel	Polyester/fiber glass	~130	0.014
Cryogel Z	Aspen aerogel	PET / fiber glass	~160	0.014
Dow Corning HPI 1000	Dow Corning	Fiber glass	-	0.015
Pyrogel HPS	Aspen aerogel	Fiber glass	~200	0.014
Pyrogel XTE	Aspen aerogel	Fiber glass	~200	0.014
Pyrogel XTF	Aspen aerogel	Fiber glass	~200	0.014
Spaceloft	Aspen aerogel	Polyester/fiber glass	~151	0.015
Silica aerogel fiberglass blanket	Joda	Fiber glass	<300	0.016
Silica aerogel ceramic fiber blanket	Joda	Ceramic fiber	<301	0.016

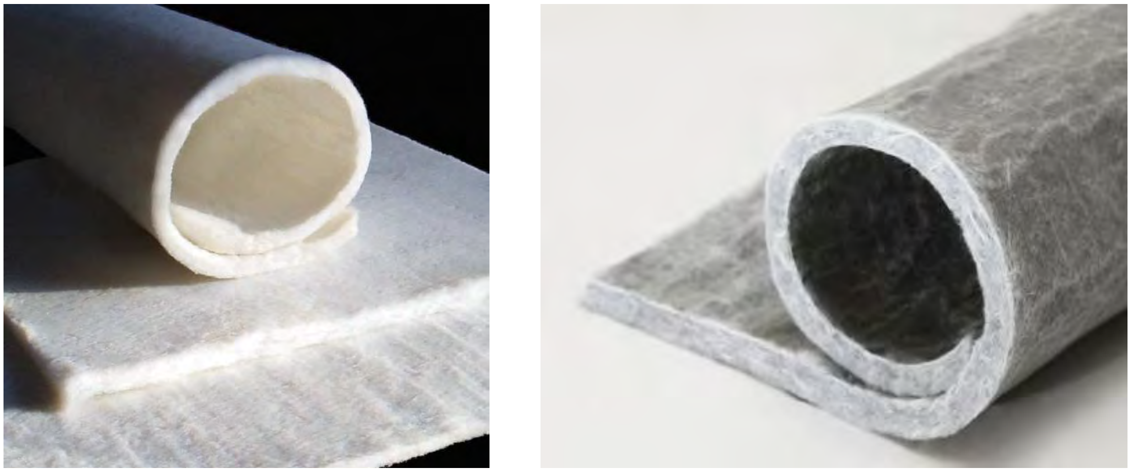

Figure 1. Aerogel blankets Cryogelx201 (left) and Dow Corning HPI 1000 (right).

Lakatos (2017) and Nosrati and Berardi (2018) assessed how the thermal conductivity of aerogel-blankets increases as a function of the moisture content. In particular, Lakatos (2017) studied the application of the aerogel-blanket to a brick-based wall. Firstly, sorption isotherms were investigated to understand the temperature sensitivity of moisture uptake. Each aerogel slab was tested after wetting the dried samples for 0, 4, 8, 12, 16, 20 hours at 293 K and 93% relative humidity, showing significant higher thermal conductivity in the wetting stage.

A comprehensive investigation of the thermal conductivity of the aerogel-enhanced Cryogel by Aspen Aerogel and Thermal Wrap by Cabot blankets in humid conditions at transient and steady-state regimes was made by Hoseini et al. (2017). The moisture build-up in the two aerogel blanket samples was measured as a function of the relative humidity and temperature. Transient plane source tests revealed that the thermal conductivity increased by up to approximately 15% as the ambient relative humidity increased from 0% to 90%. However, when the aerogel blankets were placed in a humid environment, it took hours for the moisture to diffuse towards the material core.

EXPERIMENTAL STUDIES

Comparison of existing products

Figure 2 shows the thermal conductivity values declared by the manufacturer for different aerogel blankets currently on the market. The results are particularly promising, especially at the temperature typically incurred in the building sector.

To help comparing several products, the authors performed hygrothermal tests in the Building Science Lab at Ryerson University. In particular, after exposing the different blankets to the same hygrothermal conditions, the thermal conductivity values for different aerogel blankets were measured using the heat flow meter apparatus HFM 436 Lambda. The temperature difference between the hot and cold plates was set to 20 ºC, while the temperatures ranged from -20 ºC to +50 ºC. Figure 3 reports the results for four aerogel-enhanced blankets.

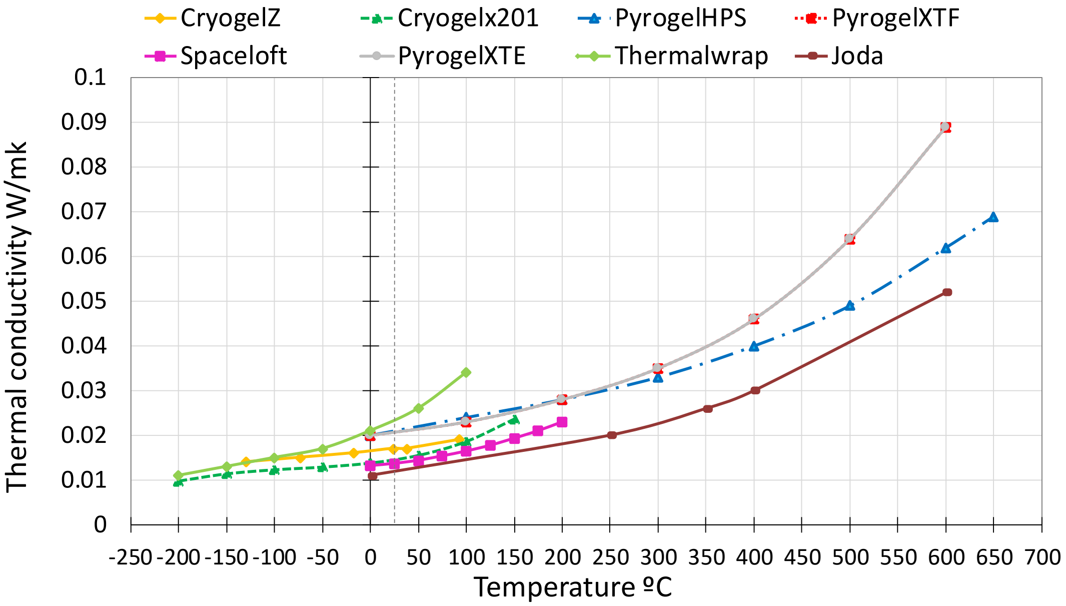

Figure 2. Thermal conductivity values across the temperature for different aerogel blankets (this figure was drawn using the values declared by the manufactures).

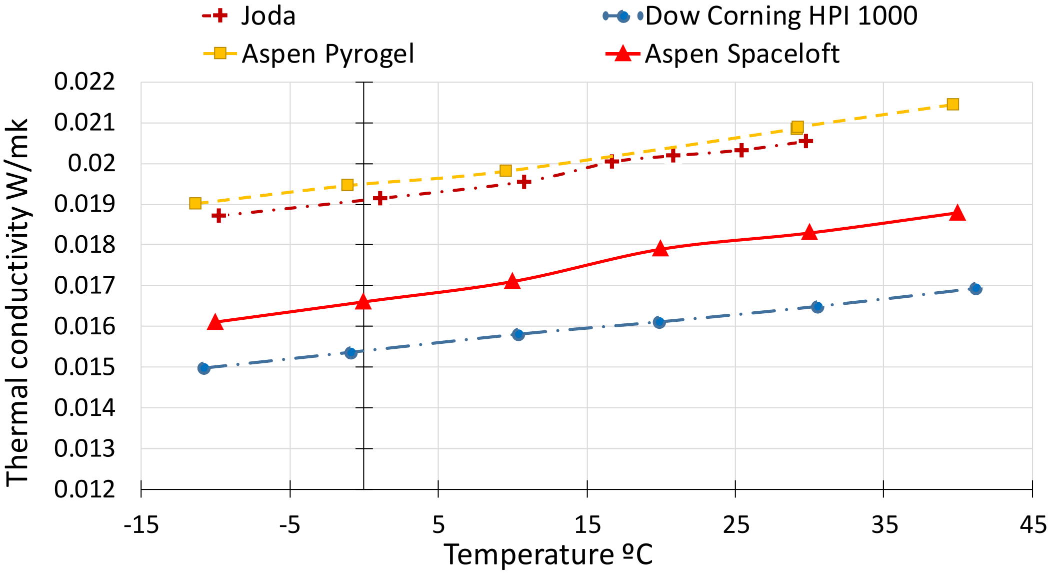

Figure 3. Thermal conductivity values across temperature for different aerogel blankets (these values were measured by the authors after having normalized the hygrothermal conditions).

Development of a new aerogel-enhanced blanket

The synthesis of silica aerogels is typically carried out in three phases: gel preparation, aging, and drying. In particular, three methods for drying the aerogels can be used: supercritical drying (SCD), ambient pressure drying (APD) and the freezing drying. SCD reduces capillary tension but comports higher costs. On the other hand, APD is more cost-effective but involves increased capillary tension which can lead to shrinking and possible fractures, therefore SCD is generally used for silica aerogels. The cost of the SCD process represents a limiting factor to obtain a competitive price for the aerogel. To lower the price of the blankets by avoiding to perform a SCD, the authors have obtained aerogels and aerogel-enhanced blankets drying the materials in a vacuum oven for 24 hours (Fig. 4).

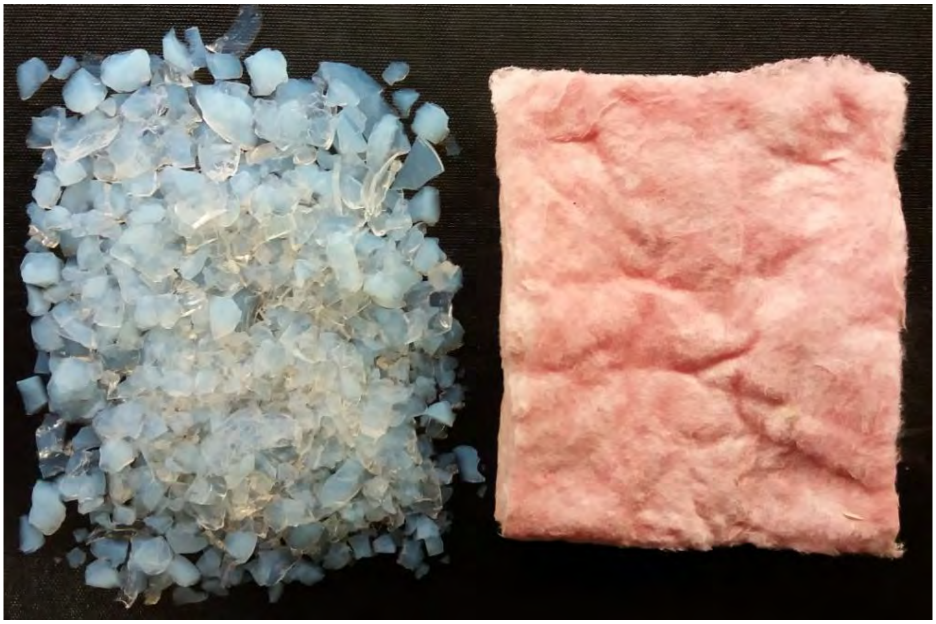

Figure 4. Authors' produced aerogel granules (left) and aerogel-enhanced blankets obtained embedding a fiberglass panel with precursor aerogel before the drying process (right).

The silica aerogels were prepared using the 2-step Stöber process, as adapted from Shlyakhtina et al. (2007), using reagents purchased from Sigma Aldrich. Firstly, 120 ml of isopropanol was added to 123.2 ml of tetraethylorthosilicate in a graduated cylinder. The contents were then transferred to a beaker with a stir bar, set to stir for 30 minutes, and sealed with paraffin to prevent evaporation. Next, 29 ml of 0.1 M HCl was added dropwise, and set to stir for an additional hour until the mixture was completely hydrolyzed into silicic acid. A timer was started, and 28 ml of 0.15 M NH4OH was added dropwise to initiate the polymerization. The solution was transferred into a cellophane-lined rectangular mould. Pre-cut and pre-weighed fiberglass samples 2 cm thick were dipped into the solution, and then the excess solution was squeezed out. Afterwards, the samples were set to cure, and were transferred to a heated vacuum furnace for 24 hours, similarly to the work of Padmanabhan et al. (2016). The samples were taken out and weighed to determine their final mass and that of aerogel, by subtracting from their initial mass. The thermal conductivity of the aerogel-enhanced blanket shown in Fig.4, tested using the same apparatus and conditions described previously, resulted to be 0.029 W/(mK) at 0 ºC and 0.031 W/(mK) at 20 ºC, generally above that of commercial aerogel-enhanced blankets, although the price of this bat would be extremely competitive and its manufacturing process would not require expensive equipment. In fact, the costs of the aerogel and of the aerogel-enhanced blankets were below \$4/gram and \$30/m^2 respectively.

CONCLUSIONS

This paper has presented ongoing research activities leading to the manufacture of aerogel-enhanced blankets. An overview of products available on the market has been reported. Meanwhile, a new aerogel-enhanced blanket has been presented. The hope is that soon APD processes could be improved to realize cheap aerogel-blankets with a thermal conductivity of 0.010 W/(mK), a target that would make these products preferable over traditional insulating ones.

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