Utilization of Aerogel Materials and Systems in the Building Envelopes of Tomorrow

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ABSTRACT

Building envelopes incorporating aerogel materials may exploit miscellaneous properties of the aerogels such as a very low thermal conductivity, lightweight properties due the air-filled low-density aerogel structure, and the possibility of utilizing solar radiation as a daylight and heat source through the translucent and transparent versions of aerogel. This study presents different experimental investigations of various aerogel materials and systems intended for building envelope applications, including a new lightweight and more thermally insulating aerogel glass material, various translucent aerogel granule windows, and aerogel-incorporated concrete samples with reduced thermal conductivity. These aerogel materials and systems may become part of the future multi-functional building envelopes utilizing miscellaneous passive and active/dynamic technologies.

Keywords: aerogel, thermal conductivity, transmittance, lightweight, solar radiation.

1 INTRODUCTION

In the world of today there is a growing focus on and demand for energy-efficient materials and systems for the building envelopes being developed, e.g. exemplified through zero emission buildings and energy-producing buildings [1]. Concerning the energy-harvesting aspect, there is expected to be a large growth in application of building integrated photovoltaics (BIPV) [2-11] in the years ahead. Thermal insulation is playing a crucial role for buildings in general and for energy-efficient buildings in particular. Hence, especially high-performance thermal insulation materials and solutions are of interest, and among these ones are vacuum insulation panels (VIP) [12,13], various aerogel materials and products [14-16] and development of new superinsulation materials (SIM) like e.g. nano insulation materials (NIM) [17-27]. The aerogel material achieves its very low thermal conductivity through a highly porous and air-filled low-density silica skeleton with a typical air concentration as high as 95-99 vol%. Moreover, aerogels exhibit the unique feature of being able to be made either opaque, translucent or transparent, thus enabling a large application range.

This study is presenting miscellaneous experimental investigations of different aerogel materials and systems intended for application in building envelopes, i.e. a new lightweight aerogel glass material, translucent aerogel windows, and aerogel-incorporated concrete samples.

These aerogel materials and systems may also become part of the future multi-functional building envelopes utilizing various technologies, including both passive and active/dynamic ones, the latter comprising adaptive and controllable ones, like e.g. passive systems like super insulation materials such as nano insulation materials [17-27], adaptive technologies like phase change materials [28,29], controllable technologies like smart windows utilizing e.g. electrochromic materials [30-41], and solar cell systems like building integrated photovoltaics [2-11], which we have investigated in our laboratories.

2 INVESTIGATED AEROGEL SYSTEMS

Several aerogel materials and systems have been investigated for application in building envelopes. These ones may be summarized as the following:

- Lightweight, more thermally insulating, aerogel glass.
- Aerogel granules in translucent windows and solar walls.
  - Granule particle size and solar radiation transmittance.
  - Air convection and thermal performance.
  - Application potential and energy saving perspective.
  - Ageing issues by moisture and solar radiation exposure.
  - Various other perspectives of aerogel glazings.
- Aerogel-incorporated concrete and lowered heat transport.

In general, for all development of new building materials and components, it is crucial to perform durability investigations, e.g. by carrying out accelerated climate ageing in the laboratory [42]. Furthermore, it may also be beneficial to conduct a robustness assessment [43].

3 LIGHTWEIGHT AEROGEL GLASS

A new lightweight aerogel glass material has been made by sintering monolithic silica aerogel precursors at elevated temperatures [44]. Several important properties have been improved, which are summarized as follows: A high visible transparency ($T_{vis} \approx 91$ - 96 % at 500 nm), a low thermal conductivity ($\lambda \approx 0.17$ - 0.18 W/(mK)), a low mass density

($\rho \approx 1.60$ - 1.79 kg/dm^3) and an enhanced (compared to our earlier experiments) mechanical strength (typical elastic modulus $E_r \approx 2.0$ - 6.4 GPa and hardness $H = 0.23$ - 0.53 GPa) for our new aerogel glass material. These values may be compared to the ones for float glass which are $T_{vis} \approx 92$ % at 500 nm, $\lambda \approx 0.92$ W/(mK), $\rho \approx 2.5$ kg/dm^3, $E_r \approx 50.77$ GPa and $H = 1.64$ GPa.

The transmittance in the solar wavelength region, covering the ultraviolet (UV), visible (VIS) and near infrared (NIR) parts, is depicted in Fig.1, demonstrating a high transmittance in the visible and start of the near infrared region, whereas for longer wavelengths in the NIR region the transmittance is lower, as compared to a float glass. Thereby, a further development of this aerogel glass material may potentially be applied in transparent windows letting in as much daylight as possible and simultaneously blocking some of the near infrared solar radiation.

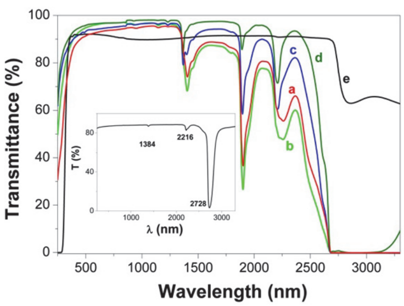

Figure 1. Transmittance spectra of as-synthesized aerogel glass materials (a-d), float glass (e) and quartz glass (inset). Graphical replot from Gao et al. [44].

4 TRANSLUCENT AEROGEL WINDOWS

Miscellaneous investigations have been carried out with translucent windows and glazing systems with aerogel granules between the glass panes [45-50].

Float glass window panes, with their cavities filled with air, large-sized aerogel granules (3-5 mm) and small-sized aerogel granules (< 0.5 mm) are shown in Fig.2 [45].

Figure 2. Float glass window panes with (left) air, (middle) large-sized aerogel granulates and (right) small-sized aerogel granulates in the cavities [45].

Spectroscopical studies in the solar radiation range demonstrated that the total transmittance was very close to the diffuse transmittance for the aerogel granule windows, i.e. most of the transmitted solar radiation in these translucent aerogel window panes was diffuse and not specular [45]. It was also shown that the window pane with small aerogel granules had a much lower transmittance than the window pane with large aerogel granules, and that the transmittance decreased substantially with increasing thickness of the aerogel granule layer (Fig.3) [45].

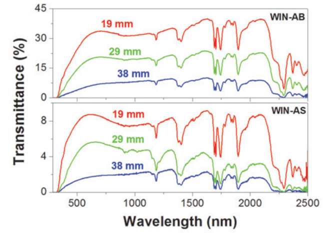

Figure 3. Total transmittance spectra of float glass window panes with (top) large-sized aerogel granules and (bottom) small-sized aerogel granules in the cavities with different aerogel granule layer thicknesses (19, 29 and 38 mm) [45].

A tiltable hot box was utilized in large-scale laboratory experiments in order to study the impact of air convection on the thermal performance of translucent aerogel granule windows [46]. The experiments showed that the convection was rather weak and thus had a negligible impact on the U-value of the window. Notwithstanding, the incorporation of aerogel granules into the window pane cavities decreased the window U-value substantially compared to reference windows with no aerogel granules in their cavities [46].

Figure 4. Inclination angles of 0° (vertical pos., left), 45° (middle photo) and 90° (horizontal pos., right) for a tiltable hot box studying impact of air convection on thermal performance of translucent aerogel granule windows [46].

The application potential of aerogel granule glazing facades has been evaluated from an energy saving perspective with simulations performed for cold (Oslo, Norway), warm (Tokyo, Japan) and hot (Singapore, Singapore) climate regions [47]. An energy saving effect was shown for aerogel glazing spandrel systems in hot and warm climates when compared to current double glazing systems used in these regions. The simulations did not show an energy saving effect for the aerogel glazing systems in a cold climate when compared to the current popular triple glazing systems in this region. Nevertheless, the results implied that the combination of aerogel glazing systems at spandrels and triple glazing systems at the visible part in a facade may gain a better energy performance.

Ageing studies have been carried out by exposing aerogel granules to moisture and solar radiation [48]. A study showed up to about 10 % higher thermal conductivity in aerogel granules during moisture ageing, whereas solar radiation exposure only moderately decreased the hydrophobicity of the aerogel surfaces. The contact angle experienced a moderate reduction during the first 100 cycles of ageing, while remained relatively constant at around 120° after that and up to 300 cycles of solar radiation ageing [48].

Various other perspectives of aerogels in energy-efficient windows have also been studied, including architectural challenges and opportunities, experimental investigations and theoretical simulations [49-50]. A feasibility study has been conducted on commercially available opaque aerogel insulation blankets, where the effect of mechanical compression and humidity on the thermal conductivity was investigated [51].

5 AEROGEL IN CONCRETE

Aerogel-incorporated concrete (AIC) samples have been made by introducing aerogel granules into the concrete matrix with the aim of reaching as low as possible thermal conductivities while still being able to maintain as high mechanical strength properties as possible, also including ultrahigh performance concrete (UHPC) recipes.

Summarized, from a long range of studies [52-56], AIC samples with compressive strengths of up to about 19 MPa were achieved with a corresponding thermal conductivity of about 0.4 W/(mK). Increasing the aerogel content and thereby fabricating more thermally insulating concrete, 70 vol% aerogel was needed and AIC samples with thermal conductivity as low as about 0.1 W/(mK) were cast.

Typically, AIC samples with mechanical strengths of up to 5 MPa could be reached when thermal conductivities of between 0.1 and 0.2 W/(mK) were desired [55] (Fig.5). The obtained results from the different experiments indicate the potential of improving AIC samples to obtain a thermal conductivity of 0.1 W/(mK) or lower with a corresponding compressive strength of 20 MPa or higher [55].

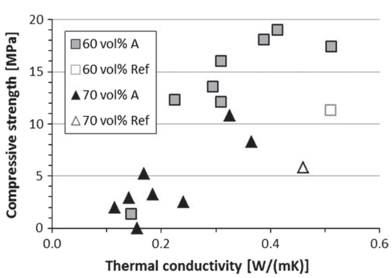

Figure 5. Thermal conductivity and compressive strength relationship for different mass densities and aerogel loadings of various AIC [55].

6 MULTI-FUNCTIONALITY

Combinations of technologies referred to in the above, with different aerogel materials and systems, may become part of multi-functional building envelopes for the future, incorporating miscellaneous materials and components with specific tailor-made properties, hence resulting in building envelopes being able to fulfil several functions and satisfy various requirements, among them dynamic building envelopes, including both controllable and adaptive ones.

The ability of producing the aerogels as either opaque, translucent or transparent materials makes them well suited in this respect. Some materials may even be able to carry out more than one single function, e.g. materials with both electrochromic and photochromic properties [57], and materials with both electrochromic and photovoltaic properties like e.g. the electrically conducting polymer poly(3-methyl thiophene) (P3MeT) [58-60], although P3MeT does not exhibit a transparent state.

7 CONCLUSIONS

Miscellaneous aerogel materials and systems have been investigated for possible utilization in the building envelopes of tomorrow, including synthesizing of a new lightweight and more thermally insulating aerogel glass material, application of aerogel granules in translucent windows and solar walls, and fabrication of aerogel-incorporated concrete with lowered thermal conductivity. Multi-functional building envelopes may be envisioned utilizing among others these different aerogel solutions.

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