Continuous Freeze-Casting for Thermally Insulating Anisotropic Aerogels

Kit-Ying Chan (kit-y.chan@polyu.edu.hk), Xi Shen (xi.shen@polyu.edu.hk)

Department of Aeronautical and Aviation Engineering, The Hong Kong Polytechnic University, Hong Kong SAR, China

Abstract

Thermal management materials for building envelopes are vital to energy-efficient and sustainable buildings, easing the pressure on achieving carbon neutrality. Recent developments of thermally super-insulating aerogels having a thermal conductivity lower than air (24 mW/m K) are promising to isolate the heat for more energy-efficient cooling [1-3]. In addition to low thermal conductivity, aerogel envelopes should also have a low solar absorption to mitigate the solar heat gain under direct sunlight. However, most aerogels tend to absorb the sunlight for undesirable solar heat gain, and it is demanding to scale up the anisotropic aerogel fabrication while maintaining consistent properties [1, 4]. Here, a large-scale thermally super-insulating, solar-reflective anisotropic aerogel containing in-plane aligned pores is developed by a novel additive freeze-casting technique, as shown in Fig. 1. The freezing dynamics are controlled by using a moving cold source to maintain aerogel panels having uniform in-plane pore alignments with decimeter length. The pore walls are further engineered using boron nitride nanosheets (BNNS) to leverage their unique anisotropic thermo-optical properties. The coupling between BNNS and in-plane pore channels delivers an ultralow out-of-plane thermal conductivity of 16.9 mW/m K and an outstanding solar reflectance of 97%, minimizing both parasitic and solar heat gains. The as-fabricated aerogel panel achieved an up to 8 °C lower interior temperature than commercial silica aerogels when used as cooling panels under direct sunlight. This work demonstrates the facile bottom-up fabrication of scalable anisotropic aerogels towards practical energy-efficient cooling applications.

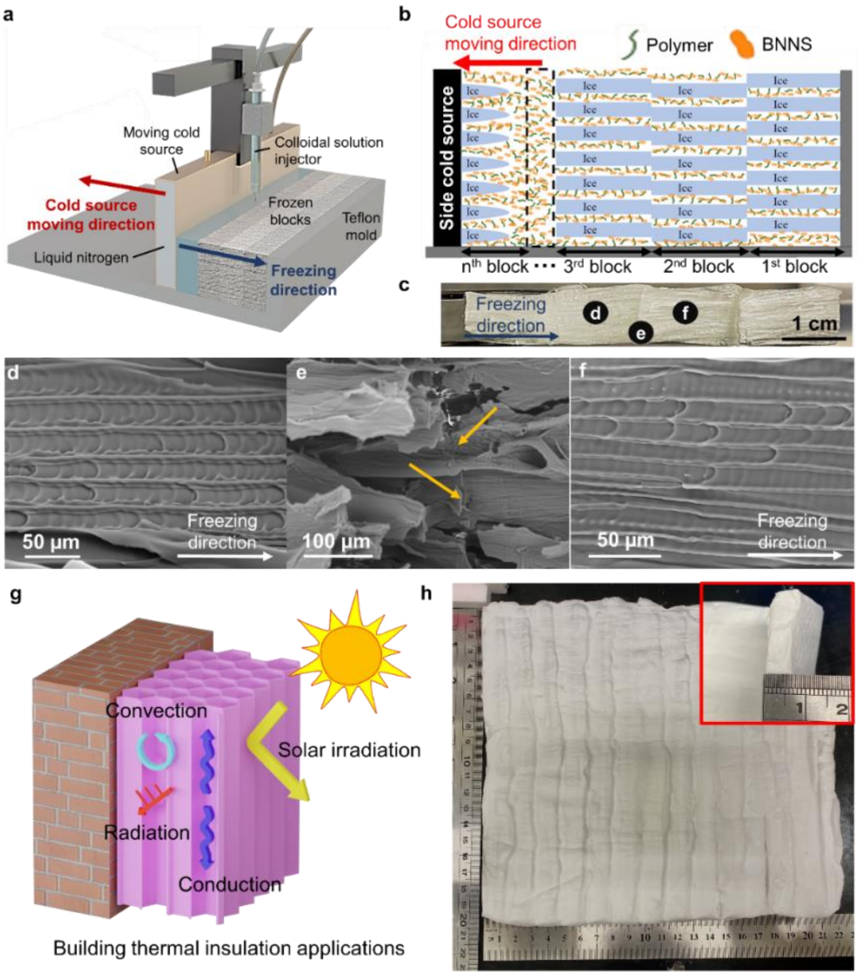

Fig. 1 Design and continuous freeze-casting of thermally insulating anisotropic aerogels. (a) Schematics of the set-up and (b) mechanism of the additive freeze-casting for the fabrication of large-scale anisotropic aerogel. (c) Photograph and (d-f) scanning electron microscope (SEM) images showing the uniform pore alignment and structural integrity of the aerogel. The SEM images were taken from the different positions in the pore alignment direction, showing the consistent pore diameters along the freezing direction and the seamless connection between adjacent blocks as indicated by orange arrows. (g) Anisotropic aerogel panel with ultralow k and high solar reflectance for energy-efficient building applications. (h) Photograph of anisotropic aerogel panels with lateral dimension of 20 × 20 cm^2 and thickness of less than 1 cm, fabricated using the continuous freeze-casting.

Acknowledgements

This project was financially supported by the Research Grants Council (16200720) of Hong Kong SAR and start-up fund for new recruits of PolyU (P0038855, P0038858).

References

1. Wicklein, B., et al., *Thermally insulating and fire-retardant lightweight anisotropic foams based on nanocellulose and graphene oxide.* Nature nanotechnology, 2015. **10**(3): p. 277-283.
2. Li, T., et al., *Anisotropic, lightweight, strong, and super thermally insulating nanowood with naturally aligned nanocellulose.* Science advances, 2018. **4**(3): p. eaar3724.

3. Yang, J., et al., *Superinsulating BNNS/PVA Composite Aerogels with High Solar Reflectance for Energy-Efficient Buildings.* Nano-micro letters, 2022. **14**(1): p. 1-16.
4. Waschkies, T., R. Oberacker, and M.J. Hoffmann, *Control of lamellae spacing during freeze casting of ceramics using double-side cooling as a novel processing route.* Journal of the American Ceramic Society, 2009. **92**: p. S79-S84.