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Preparation and characterization of aerogel/expanded perlite composite as building thermal insulation material

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ABSTRACT

Aerogel was a potential substitute for the traditional thermal insulation materials. But aerogel's fragility and high prices have negative effects on the mechanical property and cost of aerogel-based building thermal insulation materials. To solve this problem, a novel thermal insulation composite aerogel/expanded perlite (AEP) was prepared by filling the aerogel into porous structure of expanded perlite (EP). The aerogel in the pores of AEP would be protected by solid skeleton of AEP, and also reduce the thermal conductivity of AEP. The AEP was characterized by X-Ray diffraction, Fourier transformation infrared, digital microscope, scanning electron microscope, N_2 adsorption-desorption isotherms and transient hot-wire method. The results reveal that aerogel could be effectively distributed in porous structure of EP and has a positive effect on the pore structure and thermal insulation performance of EP. AEP has typical mesoporous structure and shows chemical stability and hydrophobicity. The mesoporous volumes and BET specific surface areas of AEP were about 100–280 times and 50–150 times as large as those of EP, respectively. And thermal conductivities of AEP were decreased by 14.7–31.8% than EP. All results suggested that AEP can be considered as potential building thermal insulation materials due to good thermal insulation performance and lower cost.

1. Introduction

In China, building energy consumption has reached more than 25% of total energy consumption [1–2]. And this index will reach 35% with the increase of population and the development of urbanization in China [3]. It is notable that the energy consumption caused by heat transfer of building envelope has accounted for about 8–25% of total building energy consumption [4], and has become one of the main factors influencing the building energy consumption [5]. Therefore using insulation materials in building envelope to improve the thermal insulation performance of buildings has become an important means to reduce building energy consumption. At present, the traditional thermal insulation materials mainly include organic insulation materials and inorganic insulation materials. Organic insulation materials have low thermal conductivity (~0.02–0.04 W/(m·K) [6]) and good thermal insulation performance, but have poor fire resistance and durability, such as expanded polystyrene (EPS), extruded polystyrene (XPS), polyurethane (PUR), etc. [6–9]. Inorganic insulation materials include fiber products, namely mineral wool, glass wool, as well as granular products, such as expanded perlite, vermiculite and ceramsite [6,10–11]. Most of these inorganic insulation materials have good fire resistance and durability. But inorganic insulation materials also have higher thermal conductivity and water absorption in contrast to the organic insulation materials. Just like expanded perlite (EP) and vermiculite, their thermal conductivity is about ~0.04–0.07 W/(m·K) [6,10] and the water absorption is as high as 200–800 wt% [12–13]. Because the thermal conductivity of water is close to the ~0.6 W/(m·K) [14], this will produce more adverse impact on the thermal insulation performance for these inorganic insulation materials.

The emergence of aerogel provides the possibility to solve the problems existing in the traditional thermal insulation materials. Aerogel is a kind of nanoporous material with extremely high porosity (85–99.9%) and specific surface area (500–1200 m^2/g), resulting in very low density (3–350 kg/m^3 depending on the porosity) [11]. The special nano-solid skeleton and nano-pores of aerogel efficiently limit the thermal transmission through conduction, convection and radiation, and make it have extremely low thermal conductivity (~0.003–0.02 W/(m·K) [14]), which is less than thermal conductivity of air (~0.025 W/(m·K) [11]). Aerogel is therefore become the solid material with the minimum thermal conductivity in the world. In

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addition, aerogel is also an excellent fireproof and soundproof material (sound velocities down to 40–100 m/s) [15]. These extinct properties of aerogel have attracted research interest in the field of building energy efficiency [11,14–21].

At present, aerogel-based composites applied in building energy efficiency mainly include aerogel glazing system [16], aerogel blanket [17], aerogel-filled sandwich panel (ASP) [18] and aerogel-based coating (AC) [19], etc. Nevertheless, aerogel blanket used for building envelop maybe bring a problem of durability [15]. And ASP cannot be used in irregular building's facades due to inflexibility and unable cutting. In addition, application of aerogel blanket and ASP are restricted in the residential buildings because of complicated installation and high cost. Application of AC on buildings facades can be done manually or using a plastering machine, which leads to time and cost savings. AC is suitable for different shapes of building facades, and can even fill gaps or other difficult access areas [19]. However, because of abundance of unprotected aerogel in the AC, some aerogel will be crushed when AC is plastered, which likely reduce the thermal insulation performance of AC. Furthermore, other researchers are trying to incorporate silica aerogel particles as thermal insulation aggregates into cement-based thermal insulation materials (CBTIM) [14,20–21], such as thermal insulation mortar (TIM) [20], thermal insulation concrete (TIC) [14,21], etc. But there are negative effects on the mechanical property and cost of aerogel-based CBTIM, because of aerogel's high prices (40–160 Euros/kg [14]) and poor mechanical strength (compressive strength of ~0.01–5 MPa, elasticity modulus of ~1–30 MPa [22]). For instance, Gao [14] has successfully prepared aerogel-incorporated concrete (AIC) by incorporating silica aerogel particles into concrete matrix. Although the thermal conductivity of AIC (0.26 W/(m·K)) was reduced by 86% than ordinary concrete at an aerogel content of vol.60%, the compressive strength (8.3 MPa) and flexural tensile strength (1.2 MPa) of AIC were only 13.8% and 16% of the normal concrete due to the influence of the aerogel. Moreover, the production cost of AIC will also increase by 2880 Euros/m^3 than normal concrete. It is obvious that the mechanical properties and the manufacturing cost of AIC are unacceptable in the field of construction engineering.

In this work, in order to solve the problems related to the aerogel applied in building thermal insulation materials and promote the commercial development of the aerogel, a new method have been proposed. As mention earlier, EP is a kind of inorganic insulation material with superior fireproof and soundproof performance. Because of economical cost (~15 Euros/m^3), this white granular porous materials had been widely used in building thermal insulation materials such as thermal insulation board (TIB) [23], TIM [24] and TIC [25]. Meanwhile, because EP also shows the characteristic of chemical inertness and high adsorption for liquid phase materials, it had been usually regarded as good carrier material, and applied in synthesis and preparation for phase change materials (PCM) [26–27], photocatalytic materials [28–29], etc. Therefore, based on these special properties and low cost for EP, we will try to fill the aerogel into open pores of EP as the carrier to synthesize a novel composite thermal insulation material: aerogel/EP (AEP). Schematic diagram of the synthesis of AEP was shown in Fig. 1. Because the thermal conductivity of aerogel is lower than air, it is expected that the AEP, whose pores have been filled with aerogel, has a lower thermal conductivity than that of EP. If it does, then the thermal insulation materials prepared by AEP would have better thermal insulation performance. Like the EP, the AEP can be directly applied in TIB, and as thermal insulation aggregates used in TIM or TIC. In addition, the aerogel in the pores of AEP will be protected by solid skeleton of AEP, which reduce aerogel cracked risks to avoid the negative impact on mechanical properties of those aerogel-based composites. Because EP as a carrier material is with low cost and easy to be obtained, AEP and its thermal insulation composites also have a more reasonable manufacturing cost, which is more desirable for the economical requirements of the building materials.

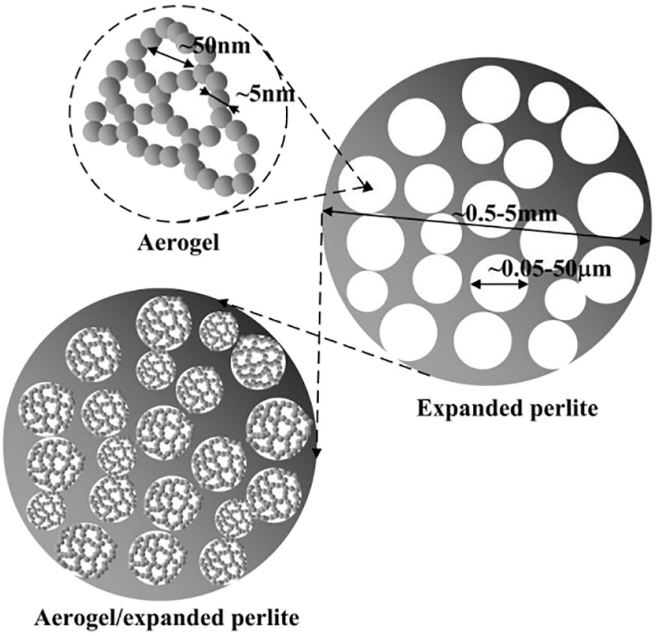

Fig. 1. Schematic diagram of the synthesis of AEP.

In our early work [13], a composite EP/A (EP filling with aerogel) had been synthesized through filling the pores of EP with aerogel. Although EP/A showed hydrophobic property compared to EP, the thermal conductivity of EP/A had no obviously decrease than EP due to the high thermal conductivity of aerogel (0.034–0.037 W/(m·K)) that prepared by using water glass as precursor and nitric acid as catalyst. This result does not satisfy our objective, i.e. thermal conductivity of EP is reduced by filling with aerogel. Additionally, the chemical compatibility between EP and aerogel and microstructure of EP/A had not been detail researched. Therefore, in this work, a new composite AEP was prepared by using new synthesis process aiming at obtaining aerogel with lower thermal conductivity and reducing the thermal conductivity of EP. And the chemical compatibility between EP and aerogel were tested by X-Ray diffraction (XRD) and Fourier transformation infrared (FT-IR). The microstructure of aerogel, EP and AEP were characterized by transmission electron microscopy (TEM), scanning electron micro-scope (SEM) and N_2 adsorption-desorption isotherms. The heat transfer mechanism of AEP was also analyzed by comparing the thermal conductivity of aerogel, EP and AEP.

2. Materials and methods

2.1. Materials

EP was obtained from Xinyang Kemei New Building Materials co. Ltd., China. Chemical components of EP were presented in Table 1. The EP was sieved by square-opening sieve to obtain three particle sizes: 5–10 mesh (1.7–4 mm), 10–20 mesh (0.83–1.7 mm), 20–30 mesh (0.55–0.83 mm). Before usage, the EP particles were dried in an oven at 105 °C until constant weight.

Table 1
Chemical components of EP.

Components	Weights ratio (%)
SiO_2	71.0–74.0
Al_2O_3	10.0–18.0
K_2O	4.0–6.0
Na_2O	3.0–4.0
Fe_2O_3	0.5–1.5
CaO	0.5–0.8
MgO	0.2–0.5