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Thermal insulation property and service life of vacuum insulation panels with glass fiber chopped strand as core materials

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ABSTRACT

Thermal insulation performance and service life of vacuum insulation panels (VIPs) dramatically depend on the internal pressure of VIPs. To analyze internal pressure increase of VIPs, VIPs in various geometric sizes are manufactured from threefold metalized polymer laminate barrier envelopes and glass fiber chopped strand core materials. The gas permeation contribution to the internal gas pressure of VIPs through envelope surface area and perimeter are investigated based on theoretical calculation and experiments. The trend of calculated pressure increasing rate is consistent with experimental results. The gas permeation through barrier laminate surface area is measured by a helium leak detector while the thermal conductivity of VIPs is measured by thermal conductivity meter. The accelerated aging experiments are carried out at different temperatures and service life model is proposed based on Arrhenius law. A low cost composite adsorbent is investigated, absorption property of which for water vapor is measured at various relative humidity. As a result, it is recommended to use large square VIPs with thickness of 1.0–2.5 cm. Service life of 10–15 years or above 20 years can be achieved by adding different adsorbents for different application fields.

1. Introduction

Vacuum insulation panel (VIP) has already been widely applied in practice due to its distinguished low thermal conductivity [1,2], such as insulating refrigerators, automatic vending machines, cold storages and building envelope. It is comprised of an evacuated open porous load bearing core material which is enveloped in high gas barrier envelope to maintain vacuum. In addition, adsorbent is essential to absorb residual gases released from core material and permeated by gas barrier multilayer foil film and heat seal layer [3,4], as shown in Fig. 1. The total thermal conductivity measured is 5–10 times lower than that of the conventional thermal insulation materials [5–8]. Twenty-five percent of the energy can be saved without reducing the effective capacity of refrigerator when VIP substitutes partial polyurethane rigid foams as insulation layer [9].

In general, porous materials are used as the core materials, such as fumed silica, glass fiber, polymer foam and staggered beam structure. The thermal conductivity, as one function of internal pressure for various core materials, is shown in Fig. 2.

Nano-structured powder of fumed silica is the least sensitive material to internal gas pressure increase. The thermal conductivity of the core material is about 0.004 W/(m K) at a low gas pressure <100 Pa at room temperature. Even when the pressure increases to 10,000 Pa, the thermal conductivity increases to 0.007 W/(m K) only [10,11]. The basic properties, aging mechanism and service life of VIPs with fumed silica core materials have been investigated for building application, especially in retrofitting of considerable number of existing old buildings worldwide, where service life of several decades is required [7,10,12]. Despite of good insulation performance, it is not widely used for buildings due to high production cost and infant stage of development. Conventional insulation materials are still competitive in various applications mainly due to their low prices and long life [13]. In addition, the polystyrene (PS) foam, polyurethane (PU) foam and phenolic foam (PF) as the core materials have been investigated [9,13,14]. However, practical open-cell foam, including a fraction of closed-cell whose internal gas is not evacuated, has high solid skeleton thermal conduction and other hazardous properties, such as flammability and toxicity. Therefore, foam is hardly used as core material in practical application. Kwon et al. [15] investigated three thermal transport mechanisms of various filling materials and suggested that the fiber and staggered beam structures are promisingly proper filling materials for VIPs. The VIPs with glass fiber core material and absorbent have a thermal conductivity below 0.003 W/(m K)

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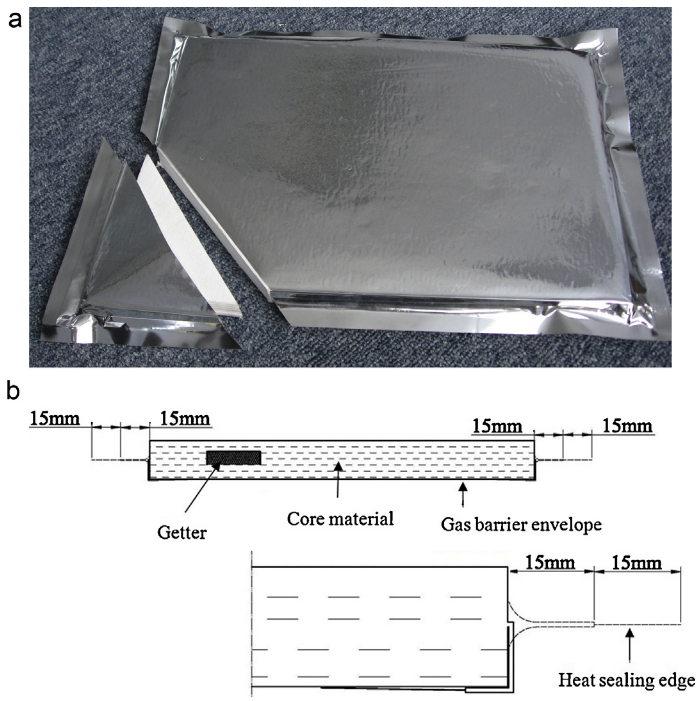

Fig. 1. (a) Cross-section through a corner of VIP with glass fiber chopped strand as core material and a three-fold aluminum-coated polymer laminate as barrier envelope; (b) the structural details of VIP.

in the evacuated state, having been widely used in the refrigerator industry with anticipated service life of about 15 years [4,16]. Glass fiber has become one of the most useful thermal insulation materials for the latest 50 years. According to different production processes, glass fiber can be classified into three categories, i.e. flame attenuation glass wool, centrifugal glass wool and glass fiber chopped strand [17]. The energy consumption of production process for glass fiber chopped strand is multiple times lower than that of flame attenuated glass wool. In addition, the chopped strand with fiber diameter >3.5 μm is harmless to health according to WHO and NIOSH criterion [18]. Therefore, glass fiber chopped strand as core materials of VIPs is investigated in this paper due to the above-mentioned advantages and low production cost.

The objective of this paper is to investigate the thermal insulation property and service life of glass fiber chopped strand as core material of VIPs and analyze the feasibility for building application. For this objective, VIPs in various geometric sizes are manufactured from threefold aluminum-coated polymer laminate barrier envelopes and glass fiber chopped strand core materials to evaluate the perimeter and surface area contribution to the internal pressure increase. The depressurization based method with an accuracy of about 30 Pa plus 5% [8] is not applicable to measure the internal gas pressure of VIPs with glass fiber core materials due to the thermal conductivity more sensitive to pressure increase. Therefore, the thermal conductivity is measured by thermal conductivity meters while the internal gas pressure is evaluated by the function shown in Fig. 2. At the same time, the internal gas pressure is calculated by theoretical models. To present the service life model based on Arrhenius law, accelerated aging experiments are carried out in different temperature chambers. A low cost composite adsorbent is investigated, absorption property of which for water vapor is measured at various relative humidity. For comparison, a common calcium oxide desiccant is also measured. Some advice is discussed in this paper to improve the thermal insulation performance and prolong service life.

2. Heat transfer theory

The total heat transfer (λ_{tot}) through porous core materials can be divided in four different heat transfer processes, i.e. heat transfer via radiation (λ_{rad}), heat transfer via conduction of the solid skeleton of the core (λ_{cd}), heat transfer via the gaseous (λ_g) inside the material and coupling conduction (λ_{cpl}) due to interaction between them. The λ_{tot} can be approximated by the sum of these different heat transfer mechanisms. The term λ_{cpl} is negligible in most literature and researches due to its complexity. Additionally, gas convection within the pores is completely suppressed [19,20].

$$\lambda_{tot} = \lambda_{cd} + \lambda_{rad} + \lambda_g \quad (1)$$

where $\lambda_{cd} + \lambda_{rad}$ is considered to be the initial thermal conductivity of VIPs in this paper, being defined as λ_{evac}.

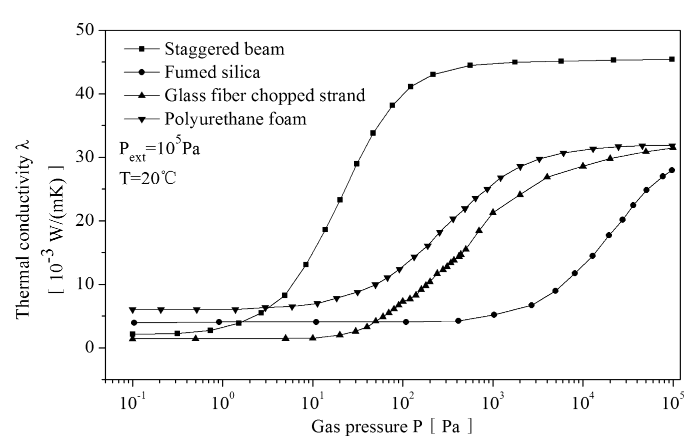

Fig. 2. Thermal conductivity of various core materials as a function of internal pressure (redrawn from [4,6]).