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Aging performance evaluation of vacuum insulation panel (VIP)

A R T I C L E I N F O

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A B S T R A C T

Energy efficiency solutions are being pursued as a sustainable approach to reducing energy consumption and related gas emissions across various sectors of the economy. Vacuum Insulation Panel (VIP) is an energy efficient advanced insulation system that facilitates slim but high-performance insulation, based on a porous core material evacuated and encapsulated in a barrier envelope. Although VIP has been on the market for decades now, it wasn't until recently that efforts have been initiated to propose and adopt a global standard on characterization and testing. One of the issues regarding VIP is its durability and aging due to pressure and moisture dependent increase of the initial low thermal conductivity with time; more so in building applications. In this paper, the aging performance of commercially available VIP was investigated experimentally; thermal conductivity was tested in accordance with ISO 8302 standard (guarded hot plate method) and their long-term performance was analyzed based on a non-linear pressure-humidity dependent equation based on IEA/EBC Annex 39, with the aim of evaluating durability of VIP. The center-of-panel thermal conductivity after 25 years based on initial 90% fractile with a confidence level of 90% for the thermal conductivity ($\lambda_{90/90}$) ranged from 7.3–8.2 mW/(m K) for silica core VIP. Significant differences between manufacturer-provided data and measurements of thermal conductivity and internal pressure were observed.

1. Introduction

Energy generation and use across various sectors of the economy is responsible for significant gas emissions. Measures to promote sustainable development, while ensuring environmental integrity, were the core resolution of the twenty-first Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) [1]. Energy efficiency is currently the focus of numerous stakeholders. With the recent emergence of Passive Houses, Zero-Energy Buildings, and the Green House Project, there have been concerted efforts to enable buildings to manage their energy usage independently while minimizing energy consumption. Insulation is used to minimize energy loss through the building envelope, and the insulation thickness specified in insulation standards has nearly doubled in the past few years.

Energy efficient vacuum insulation panel (VIP) is an advanced insulation system composed of an open porous evacuatable structured core material encapsulated in a sufficiently gas-tight envelope material; VIP enable slim insulation with highly efficient capabilities as compared to traditional insulation materials [2–4]. Vacuum insulation panels (VIPs) introduced as a form of high-performance thermal insulation for the construction industry, have been commercialized by several companies and increasingly used in buildings in Europe and elsewhere [5–7]. Numerous studies have focused on parametric optimization of the preparation conditions of the VIP core and envelope materials, thermophysical and mechanical properties of various VIPs, performance evaluation of VIP retrofit systems, introduction and performance of new concept VIPs, and long term durability estimation of VIPs [8–14]. While the use of VIP achieves higher insulation performance compared to traditional insulating materials, precautions must be taken against thermal bridging and the possible deterioration of durability in the long run. For instance, with time, the initial low inner pressure of the VIP increases undesirably, primarily due to residual gases left in the panel after evacuation and sealing processes, outgassing in the core material, and permeation and leaks across the polymeric seal area [15]. As such, it is important to conduct a durability evaluation of buildings to ensure the performance and durability of such products. Although international standards for performance evaluation of VIPs are being developed, some studies involving expert groups have evaluated their thermal performance and durability [16]. In addition to gas and moisture permeation effects to VIP's deterioration, recent studies have shown that long term changing of fumed silica skeleton due to increase of the interfacial area between nanosized SiO_2 particles induced by migration of physisorbed water molecules and dissolved ions containing Si and O, could be a possible third aging factor [17]; howbeit for fumed

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silica based VIPs.

The aim of this study is to evaluate the thermal performance and internal pressure of commercially available VIP products on the Korean market, based on IEA/EBC Annex 39 and to analyze their long-term performance after accelerated aging. IEA/EBC is an international energy research program in buildings and communities field under the management of the International Energy Agency. The objective of IEA/EBC Annex 39, in particular, was characterization, service life prediction and case study assessments of VIP systems and components in building applications.

2. VIP for buildings

2.1. VIP overview

VIP is a high-performance insulating material, with an internal pressure of less than 1 mbar and a thermal conductivity below 4.5 mW/m K for a freshly fabricated VIP. Compared to existing insulating materials for buildings, VIPs have an insulation performance that is theoretically ten times superior. They have been mostly developed for use in appliances such as freezers and refrigerators, and their use is being expanded to buildings in response to policies aimed at improving energy efficiency through zero-energy buildings. In order to apply VIPs to buildings, the various factors that require consideration include thermal resistance, thermal conductivity, internal pressure, exterior surface characteristics and dimensions (length, width, area, and flatness), thickness, fire resistance, and others (dimensional stability, deformation, compressive strength, etc.). Since VIPs must maintain a high performance during building life (period of use), their durability is highly important. The rise in internal pressure and accumulation of moisture in the core material are typical factors affecting the long-term thermal resistance and service life of VIPs. Accumulation of moisture in the core material can be detected by precise weight measurements, but there is no standard method of measuring the internal pressure in VIPs. ZAE-Bayern (Bavarian Centre for Applied Energy Research, Germany), EMPA (Swiss Federal Laboratories for Materials Science and Testing, Switzerland), and NRC (National Research Council, Canada) successfully measured the internal pressure in VIP by inserting samples in a vacuum chamber and continuously lowering the surrounding pressure of VIP in the chamber; termed pressure compensation method or lift-off method.

2.2. VIP performance

VIP is a heterogeneous material with an envelope having a relatively higher thermal conductivity than the core material. Consequently, a thermal bridge is created at the edge. Due to this thermal bridge, the effective or total thermal conductivity is higher than the thermal conductivity in the central area. Thus the thermal conductivity of VIP must be evaluated differently from that of existing insulating materials, which are often homogeneous. The effective thermal conductivity of VIP is influenced not only by the product itself, but also by thermal bridge factors resulting from the edge of adjoining VIP elements. The effective thermal conductivity of VIP can be expressed by the following equation [16]:

$$\lambda_{eff} = \lambda_{cop} + \psi_{VIP} \cdot d \cdot p / A \tag{1}$$

where λ_{cop} is center-of-panel thermal conductivity (W/m K), d is thickness of VIP in the heat flux direction (m), A is surface of VIP perpendicular to the heat flux direction (m^2), p is perimeter of the surface A (m), and ψ_{VIP} is linear thermal transmittance (W/m K). In addition, the linear thermal transmittance is a factor of the panel thickness, center-of-panel thermal conductivity, thickness of the barrier film, and thermal conductivity of the film. As such, the thermal resistance and thermal conductivity of VIP must be measured using the guarded hot plate method and a thermal conductivity evaluation should include the thermal bridge (see Fig. 1).

Changes in the thermal conductivity of VIP depend on the pressure and moisture content within the panel. The higher the internal pressure and moisture content, the higher the resultant thermal conductivity. The durability of VIP can be evaluated through changes in the thermal conductivity arising from aging, and this is considered an important indicator of performance. For aging tests of VIPs in [16], three VIPs were stored for at least six months at 23 °C/50% RH, and thermal conductivity and internal pressure (weight) were measured every three months. The long-term performance (endurance period) was derived from changes in internal pressure and weight of the VIPs over time. The measurements were also used to estimate the thermal conductivity in 25 years' time. The accelerated aging test can be used to evaluate changes in thermal conductivity, which is dependent on the increase in internal air pressure. The initial test conditions follow the specifications of EN 12667 and ISO 8302, and the initial internal pressure was tested with the pressure compensation method.

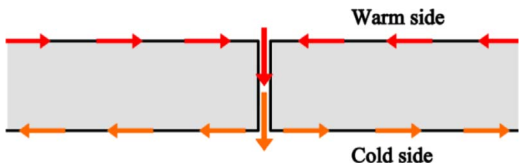

Fig. 1. Schematic representation of a thermal bridge between two VIPs.