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Vacuum insulation panels for building application Basic properties, aging mechanisms and service life

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Abstract

The vacuum insulation panel (VIP) is a high performance thermal insulation component recently introduced into building technology. Its high thermal resistivity provides new solutions for slim but still energy efficient building envelopes. One of the key issues for building application is to minimize failure in service and to ensure a service life in the order of several decades under typical stress conditions especially thermal and hygric effects. However, little experience exists up to now on the long-term properties and the durability of VIPs. This article describes aging mechanisms and reports experimental results for different temperature and humidity induced deteriorations. A functional representation of the measured data at steady state conditions is introduced. For specific VIP applications the internal pressure increase is calculated on the basis of a dynamic thermal model. End-of-life criteria and respective service life estimates are discussed as well.

Keywords: Vacuum insulation panel; High performance thermal insulation; Building envelope; Accelerated aging; Service life prediction

1. Introduction

In the last few years a novel type of a thermal insulation board for building envelope application, the so-called vacuum insulation panel (VIP), has been introduced to the construction technology [1]. Since the thermal resistivity for heat flows perpendicular to the main faces is 5–10 times higher compared to a conventional thermal insulation board a new field is opened for slim, energy efficient building envelope design. As an example, insulation of a terrace roof of an apartment building is shown in Fig. 1. A VIP is basically made of a micro-porous core structure which is evacuated and sealed in a thin, virtually gas tight envelope bag (Fig. 2). While open cell polystyrene foam has been used as core material for a long time by the refrigeration industry, fumed silica powder (SiO_2 agglomerates) has become the main core component in VIP for building application. One of the reasons is the less stringent depressurization requirement for this material. Compressed to about 200 kg/m^3 the pore size between the SiO_2 grains is well below the mean free path of atmospheric gas molecules at internal pressures below 1 mbar. Thus, the molecular collision rate is strongly reduced, and the gaseous heat transfer becomes almost negligible. Heat transfer is limited to solid conduction (2–3 mW m^{-1} K^{-1}), and thermal radiation (reduced to about 1 mW m^{-1} K^{-1} by admixture of an opacifier). Thus, the total thermal conductivity of the evacuated pyrogenic SiO_2 core is about 4 mW m^{-1} K^{-1}. It is evident that the conservation of the initial low pressure and dry state inside a VIP is the main concern when thinking of a long-term application in buildings. A service life of 30, 50 or more years is expected from a built-in component because replacement is often expensive or almost impossible. It is well known that sustainable high barriers can be achieved with metal layers having a thickness of around 10 μm or more. In fact, in the first stage of their production, VIPs were produced with laminated aluminum foils of this thickness range. However, thermal resistivity measurements and numerical calculations [2] show that the heat flow through the edge of a metal foil envelope can be even larger than the heat flow through the VIP core material. In order to optimize the opposing requirements of thermal heat loss and gas

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Fig. 1. Section of a VIP. The nano-porous fumed silica material is pressed in a PE fleece and sealed in a three-fold metallized polymer envelope under vacuum (below 1 mbar).

permeation, three-fold metallized polymer films with a thickness of 30–100 nm for each metallization are now widely used. Although better performance compared to a single metallized film can be expected, there is little knowledge if these barriers achieve the stringent requirements to ensure a service life of about 50 years. In the present study, aging is discussed in terms of an irreversible degradation of relevant performance characteristics of the VIP assembly and its components. Further the set-up and the results of hygrothermal aging experiments on VIPs are reported. Based on these an analytical acceleration function is derived. Service life estimates were made for two VIP containing building assemblies: a terrace which is the primary VIP application up to now in Switzerland, and a hypothetic wall construction due to its energy saving potential. The VIPs therein are subjected to different temperature and moisture stresses when a design reference year (DRY) for Zurich Airport (Switzerland) is applied as the outdoor boundary condition.

2. Aging mechanisms

2.1. VIP assembly

For a high performance thermal insulation component such as VIP the long-term behavior of its heat resistance is the most important issue with respect to service life. Since the thermal conductivity of the SiO_2 core is increased by a factor about 5 between low pressure (1 mbar) and standard atmospheric pressure (Fig. 3), gas permeation through the envelope is clearly the most important aging mechanism. There are many possible failure modes, starting with ‘‘childhood’’ failures caused by imperfect production. This problem frequently appeared in the beginning of VIP production. Since then the early failure rate was clearly lowered due to improved process and quality control. Another cause for short-term failure is of course mechanical damage of the rather delicate envelope during installation. This was observed on several construction sites visited by EMPA. Therefore on-site installation of unprotected VIP cannot be recommended. To avoid this problem prefabricated assemblies protecting the VIP are favorable. Normally, pressure increase in a VIP will take place due to slow permeation of atmospheric molecules through the barrier layer. Yet, there is no standardized end-of-life criterion for this continuous aging process. Based on the thermal conductivity characteristics of SiO_2 (Fig. 3), the inner pressure of 100 mbar is frequently used as a threshold value neglecting hereby the influence of moisture. For a target service life of 50 years, this would mean a maximum pressure increase of around 2 mbar per year. For three-fold metallized films (MF) on polymer substrates, oxygen transmission rates (OTR) between 0.05 and as low as $0.0005\ \mathrm{STD\ cm^3\ m^{-2}\ d^{-1}}$ at 23 °C and 50% r.H. are declared by manufacturers [3]. If the nitrogen transmission rate (NTR) is in the same order of magnitude – an often used estimation is $\mathrm{NTR} \approx \mathrm{OTR}/4$ – a pressure increase in the order of 0.01–1 mbar per year could be expected in a panel

Fig. 2. VIP insulation of a terrace with heated rooms beneath. The panels are placed on a thin polystyrene foam layer for mechanical protection.