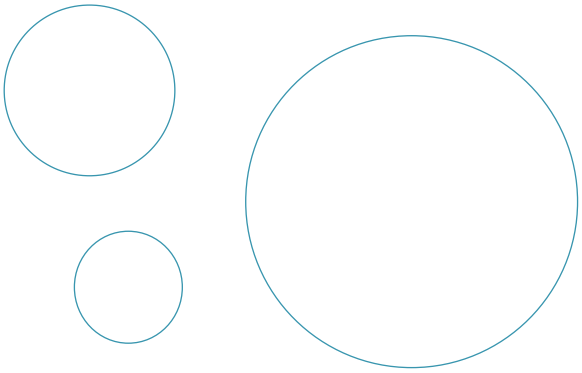
IVIS Paris 2017

13th International Vacuum Insulation Symposium

September 20-21, 2017



ABSTRACT BOOK

Edited by Daniel Quénard

In memory of Professor Ray Ogden
Chairman of IVIS 2009
School of Architecture
Oxford Brookes University - UK

CSTB
le futur en construction

Summary

Editorial

The 13th International Vacuum Insulation Symposium (IVIS 2017) is held in Paris, France from September 20 to 21st, 2017.

Organised by CSTB (Centre Scientifique et Technique du Bâtiment), the French Building Research Institute is this two-days event fosters dialogue among scientists, academics and professionals from all around the world who are related to the research, development and production of super insulating materials (SIM).

IVIS 2017 will promote the cooperation between manufacturers and researchers.

Accepted papers holding exceptional significance related to IVIS 2017 topics will be issued in "Energy and Buildings" and "Vacuum".

Contributing authors of papers selected by the scientific committee will be asked to submit a full-length manuscript to one of these journals.

Symposium Scope & Topics

IVIS 2017 encourages participation of researchers and suppliers of VIP (Vacuum Insulation Panels) and APM (Advanced Porous Materials) in building, refrigeration and cryogenic applications at a world-wide scale. Interested participants can submit papers related to the following eight topics:

1- Characterization (microstructure, thermal characteristics, internal pressure, air permeability, gas diffusion, gas adsorption)
2- Heat, Air & Moisture Transfer, from materials to building scale
3- Ageing (film, core material, panel)
4- Envelope - Films
5- Advanced Porous Materials - Core Materials (Fiber Mats, Cellular foams, Aerogel, Porous silica...)
6- Life Cycle Assessment
7- Applications: Building, Refrigeration, Transportation
8- Assessment of Performances & Standardization

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SESSION 1

IVIS Paris 2017
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SESSION 1

A combined life cycle cost and energy analysis of Vacuum insulation Panels (VIPs) in building applications

Mahmood Alam[a]
Harjit Singh[b*]

[a] Ecological Built Environment Group, Cardiff School of Art & Design, Cardiff Metropolitan University, Cardiff, CF5 2YB, UK
[b] College of Engineering, Design and Physical Sciences, Brunel University, Uxbridge UB8 3PH, UK
* Corresponding author:
harjit.singh@brunel.ac.uk

Keywords:

Vacuum Insulation Panel,
Cost and energy life cycle analysis,
Payback period,
Domestic building,
Office building.

Abstract

In this paper life cycle cost and energy analysis of a domestic and an office building that uses vacuum insulation panel (VIP) as building envelope insulation over the life span of building has been presented. Methodology used for energy and cost analysis takes into account the decrease in performance of VIP over its life time, heating efficiency over the life span of heating energy systems and fluctuating energy prices. The life cycle cost analysis show that financial payback of the VIP insulation in six storey office building in UK is between 2.5-7 years depending on the building rental value while for an average semi-detached UK house financial payback is never achieved. This demonstrates the financial viability of VIPs in non-domestic buildings located in high rental value areas.

Introduction

Vacuum Insulation Panel (VIPs) are being promoted as high thermal performance insulation material which can play a significant role in reducing energy consumption in buildings. However, VIPs are costlier compared to the conventional insulation materials [1,2]. Their use in buildings requires a comprehensive life cycle cost and energy analysis. This paper presents combined life cycle cost and energy saving assessment of VIPs when applied in a typical domestic building (3 bed semi-detached) and an office building (six storey) located in the UK. The cost analysis calculation employed is based on the net present value method. Methodology for energy and cost analysis consider the decrease in performance of VIP over its life time, heating efficiency over the life span of heating energy systems and fluctuating energy prices [3].The life cycle cost and energy analysis of applying VIPs on two different buildings has been presented in this paper.

Methodology

Life cycle cost analysis of application of insulation in building considers the cost of insulation materials, installation and space heating energy savings achieved over life time of building by applying insulation in buildings. This has been achieved by evaluating the financial payback time i.e. time period requires to offset the initial investment. For this purpose Net Present Value (NPV) method has been used which considers the time value of money and changing energy prices. Payback period of an investment is reached when NPV calculated using equation (1) [3] equals to zero.

$$NPV = -C_T + [C_E \times 1/(1+r)^n] + [C_S \times 1/(1+r)^n] \quad (1)$$

where C_T is the total insulation cost (£) including manufacturing, materials and installation costs, C_E is annual energy cost saving (£), n is the number of year, r is the annual discount rate, C_S is the annual additional rental income due to space saving (£).

$$C_E = \frac{86400 \times HDD \times \Delta L \times C_F}{H_V \times \eta(1-x)} \quad (2)$$

where HDD is the heating degree days (°C days), C_F is the cost of fuel (£m^{-3}), H_V is the calorific value of fuel (Jm^{-3}), η is the thermal efficiency of the heating system (boiler), x is the annual rate of decrease of thermal efficiency of heating boiler, ΔL is the difference of total building transmission heat loss coefficient before and after applying insulation (WK^{-1}) which takes into account the U-value of building elements.

Thermal conductivity of a VIP degrades with its life time as the pressure inside VIP rises due to infiltration of gases and moisture through envelope and any off gassing from core material. This degradation in VIP performance should be included whilst calculating the U-value of any building element comprising VIP insulation. This effect has been described in equation 3 and 4 [3].

$$U(t) = \frac{1}{R_{si}+(\sum R_e)+R_{vip}(t)+R_{sx}} \quad (3)$$

where $R_{vip}(t)$ is the time dependent thermal resistance of VIP layer in a building element and can be described as equation (4):

$$R_{vip}(t) = \frac{d_{vip}}{\lambda_{vip}(t)} \quad (4)$$

where D_{vip} is the thickness and $\lambda_{vip}(t)$ time dependent thermal conductivity of VIP.

Results and discussions

In this study a semi-detached two storey dwelling and a six storey office building have been studied whilst assuming VIPs and EPS insulation on all opaque elements. Geometric and thermal features of both buildings along with U-values before and after applying insulation on all buildings considered have been shown in table 1.

Parameter	Semi-detached house	Six Storey Office
Length (m)	7	60
Width (m)	7	15
Height of each storey (m)	2.5	3.7
Air infiltration rate (ach)	0.8	0.25
Wall existing U-value ($Wm^{-2}K^{-1}$)	0.45	0.44
Wall U-value after applying VIP insulation ($Wm^{-2}K^{-1}$)	0.27	0.30
Floor existing U-value ($Wm^{-2}K^{-1}$)	0.45	0.30
Floor U-value after applying VIP insulation ($Wm^{-2}K^{-1}$)	0.27	0.25
Roof existing U-value ($Wm^{-2}K^{-1}$)	0.25	0.37
Roof U-value after applying VIP insulation ($Wm^{-2}K^{-1}$)	0.19	0.18

By applying insulation space heating energy savings can amount to 78.8 MWh and 1395.2 MWh for semi-detached dwelling and six storey office building respectively over the 60 years of life span as shown in Fig. 1.

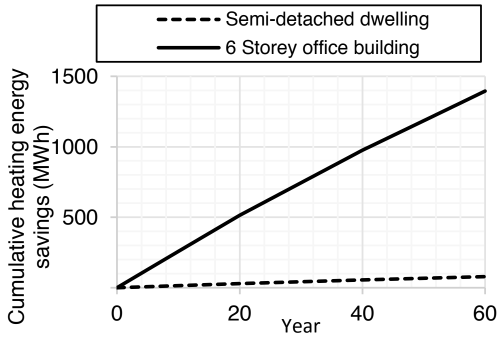

Fig. 1
Space heating energy savings

Results of the payback period using methodology described in section 2 have been shown in Fig. 2 and Fig. 3. It can be seen in Fig. 2 that in case of applying VIP in a semi-detached dwelling the cost of insulation cannot be recovered over the 60 years of life time of the dwelling.

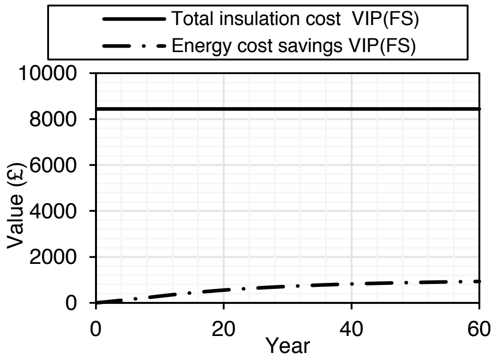

Fig. 2 Cost analysis of applying VIP insulation in a semi-detached dwelling

This is due the fact that energy cost savings achieved by applying VIP insulation cannot offset the cost of the VIP insulation. Also, there are no commercial gains associated with any space saving of applying insulation in domestic buildings. However, in case of commercial buildings, economic benefit of space savings due to small thickness of VIP insulation can be used to pay off the insulation cost of VIPs. Results of cost analysis over the life of a six storey office building (60 years) has been shown in Fig. 3. VIP is shown to have a reasonably shorter payback period of 7 years, 5 years, 3 years and 2.5 years with rental values of £400 m^{-2}, £600 m^{-2}, £800 m^{-2} and £1000 m^{-2} respectively [3].

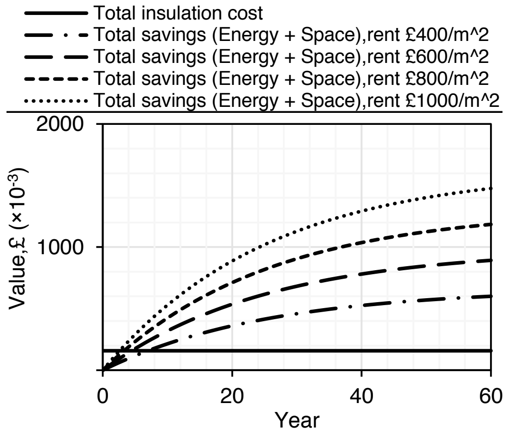

Fig. 3
Cost analysis of applying VIP insulation in a six storey office building

Conclusions

Results have shown that VIP insulation can reduce the annual space heating energy demand by approximately 78.8 MWh and 1395.2 MWh respectively for semi-detached house and six storey office building. The life cycle cost analysis has shown that financial payback of VIPs in six storey office building is between 2.5-7 years depending on the building rental value ranging from £400/m^2 to 1000/m^2. It is also shown that for an average semi-detached house financial payback will never be achieved. It is likely that at current cost, VIPs will not be widely accepted in domestic building applications. However, it is economically feasible to use VIP in office buildings despite their higher initial cost which is shown offset by the economic space gain.

References
[1] M. Alam, H. Singh and M.C. Limbachiya (2011). Vacuum Insulation Panels (VIPs) for building construction industry - Applied Energy, 88, 3592 - 3602.
[2] Kalnæs S.E. and Jelle B.P. (2014). Vacuum insulation panel products - Applied Energy, 116, 355–375.
[3] M. Alam, H. Singh S. Suresh and D.A.G. Redpath, (2017), Energy and economic analysis of Vacuum Insulation Panels (VIPs) used in non-domestic buildings, Applied Energy 188, 1-8.

Comparative investment assessment between prefabricated lightweight steel frame drywall construction insulated with VIP and massive construction with conventional materials

G.K. Semitelos[a]
D.A. Kontogeorgos[a]
I.A. Atsonios[a]*
I.D. Mandilaras[a]
M.A. Founti[a]

[a] National Technical University of Athens,
School of Mechanical Engineering, Lab.
of Heterogeneous Mixtures and Combustion
Systems, Heroon Polytechniou 9,
15780 Zografou, Greece
* Corresponding author:
Tel. +302107724002 or Fax
atsoniosgiannis@central.ntua.gr

Keywords:

Vacuum insulation panels,
Investment analysis,
Lightweight drywall construction.

Abstract

In this work an investment analysis for prefabricated lightweight steel skeleton building with drywall insulated with VIPs is presented. The analysis is compared with a massive cement-based-skeleton construction with two different brick wall configurations. Each concept is examined as a different investment project for three different European cities in order to take into account different economies and weather conditions. The investment analysis is implemented into a typical 3-storey building of 100 m^2 net floor area per storey and the comparison is made taking into account the energy performance of each construction, as well as several financial indexes, such as the net present value, the discounted payback period, the internal rate of return and the profitability index.

Introduction

Prefabricated lightweight steel frame drywall modular construction has irrefutable advantages against the typical massive cement-based-skeleton construction. Amongst them, the most important are: i) the shorter time from starting to move in (ca. 40% in time to design and build), mainly due to the simultaneous activities of prefabricated modules production and deconstruction phase of the building [1]; ii) the up to 30% savings on the overall cost and up to 75% savings on the on-site labor cost, mainly due to the better cost controlling possibilities [2]; and iii) the up to 80% reduction of the fatality rate mainly due to the fact that ~85% of the work is done off the construction site under the controlled factory environment, strict quality checks and safety controls [3]. Despite these advantages, insulating the prefab elements with VIPs could be a financial drawback. In this paper, the financial viability of prefab lightweight steel frame drywall construction with VIPs is evaluated.

Energy simulations

Two different building concepts were formulated: a massive cement structure (MCS) with two different brick external wall and a prefab lightweight steel skeleton structure (LSS) with drywall configurations. A typical 3-storey building, located in Athens, Geneva and Stockholm, was selected as the basis for the calculations. The first brick wall configuration (MCS-CN) consisted of a massive brick wall configuration used in Central/North Europe with the same U-value as the prefab external drywall system used in the LSS. The second brick wall configuration (MCS-S) consisted of a massive brick wall configuration used in South Europe with the same thickness as the prefab external drywall system used in the LSS structure. Additionally, the floor, ceiling and roof of the MCS structure were part of the building's structure (cement based). The energy performance for each structure and each city was assessed using the commercial software EnergyPlus, version 8.7 [4] (Fig. 1).

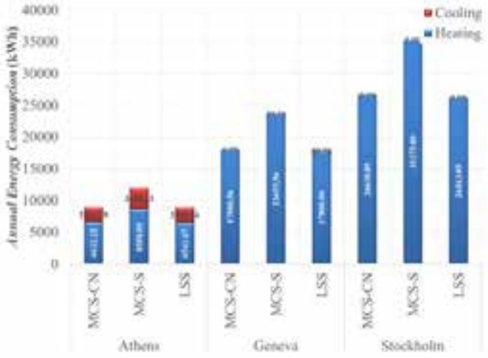

Fig. 1
Energy consumption for each city and building structure.

The MCS-CN and LSS consume quite the same energy levels (Fig. 1.). The LSS energy consumption is ~1% lower than the MCS-CN's. Both LSS and MCS-CN consume ~25% less energy than the MCS-S. In Athens, the heating consumption stands for ~73% of the overall energy consumption for all the structures.

The LSS consumes less energy for heating than the MCS-CN due to its better thermal resistance. On the contrary, the MCS-CN consumes less energy for cooling than the LSS due to its increased thermal mass. In Geneva there are insignificant cooling demands, while in Stockholm there are no cooling demands.

Financial calculations

The net present value (NPV), profitability index (PI), internal rate of return (IRR), and discounted payback period (DPP) were considered. The inflation rate was set equal to the average inflation rate of the last 20 years. The nominal interest was taken equal to the average deposit interest rate of the last 20 years. The cost for the construction of the skeleton (ground foundation and load bearing structure), the cost for the construction of the envelope components (external walls, windows, doors, roof, ceiling and floor) and the cost for the central heating system were considered. The costs were specified on the basis of information obtained from material suppliers and manufacturers in questions in Greece for the year 2016. For the other countries, it was assumed that the cost for purchasing raw materials was approximately the same as in Greece, while the labor costs were assumed to be proportional to the Greek's labor cost, based on the national average salary. Hence, the labor cost in Sweden and Switzerland was set 2.31 and 4.87 times the Greek's labor cost. The annual cash inflows (revenues) from renting the house and outflows (operating costs) for heating and cooling were considered. The life time of the investment was 50 years.

Results and discussions

In Athens, the best investment scenario is the MCS-S. The house rents and operating costs are low, and thus, the driving force that defines the potential of an investment is the initial investment cost. Here, the MCS-S scenario has the lowest initial cost. The NPV of the MCS-S is ca. 37% higher than the respective NPV of the MCS-CN (higher overall profit within the whole life time of the investment). The DPP of the MCS-S is ~14% lower than the respective DPP of the MCS-CN. The projected growth rate (IRR) of the MCS-S is 2.60%, which is 0.68 percentage units more than the projected growth of the MCS-CN. The LSS investment is not profitable (NPV<0) due to the low house rents in Athens resulting to low annual profits that cannot compensate the initial costs.

In Geneva, the best investment scenario is the MCS-S, despite the fact that the typical structure in Central Europe is the MCS-CN. The latter is associated to the relatively low prices for heating and cooling, which compensate the increased heating and cooling consumption values for the MCS-S (Fig. 1), in conjunction with the significantly reduced initial investment cost. The MCS-S NPV is 17% and 70% higher than the other NPVs. The MCS-S DPP ~29% lower than the other DPPs. Finally, the overall profit of the MCS-S accounts for 77% of the initial cost at a projected growth rate of 2.82%.

In Stockholm, the MCS-S is not profitable (NPV<0) due to the combination of its increased operating costs (low thermal resistance), and its initial expenditure (comparable to the initial costs of the other two cases). The LSS is better than the MCS-CN due to the decreased operating costs for heating/cooling and the increased rent revenues. This is owed to the LSS's better thermal resistance and larger net floor area (thinner external walls). Nevertheless, apart from the NPV, there are small differences between the LSS and the MCS-CN alternatives, which render them nearly equivalent.

City	Structure	NPV (€)	PI (-)	IRR (%)	DPP (yr.)
Athens	MCS-CN	45061	1.39	1.92	34.7
	MCS-S	61927	1.60	2.60	29.8
	LSS	-3362	0.98	0.38	>50
Geneva	MCS-CN	166689	1.57	2.22	31.2
	MCS-S	195332	1.77	2.82	27.5
	LSS	97812	1.26	1.20	39.3
Stockholm	MCS-CN	3018	1.02	1.55	48.8
	MCS-S	-1804	0.99	1.42	>50
	LSS	4978	1.03	1.59	48.1

Tab. 1
Results from all the investment evaluation methodst

Conclusions and outlook

The potential of using VIPs for insulation in modular construction was examined for 3 different cities. Results indicated that this concept is financial viable in cities with cold weather conditions, such as Stockholm. On the contrary, in cities with mild or not so cold weather conditions, the conventional cement construction with brick walls is more financial viable. Despite this, taking into account the economics of scale, the standardization activities and the mass production of the prefab elements it is expected that the initial costs will be significantly reduced, transforming the modular construction to a financial viable even in mild weather conditions.

Acknowledgements

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References
[1] R.E. Smith, Prefab architecture: a guide to modular design and construction, New Jersey: John Wiley & Sons Inc; 2011.
[2] C.T. Haas, W.R. Fagerlund, Preliminary research on prefabrication, pre-assembly, modularization and off-site fabrication in construction. Report, Austin, Texas: The Construction Industry Institute, The University of Texas at Austin; 2002.
[3] Lawson RM, Ogden RG, Bergin R. Application of modular construction in highrise buildings. J Archit Eng 2012;18(2):148–54.
[4] EnergyPlus™, version 8.7, Engineering Reference, U.S. Department of Energy, September 30, 2016.

Implications of Embodied Energy Data for Optimally Specified Low Carbon VIP Building Envelopes

S. Resalati[a]*
R. G. Ogden[b]
C. Kendrick[c]

[a] Senior Lecturer, School of Architecture, Oxford Brookes University, Oxford, UK
[b] Associate Dean, Faculty of Technology, Design & Environment, Oxford Brookes University, Oxford, UK
[c] Senior Lecturer, School of Architecture, Oxford Brookes University, Oxford, UK
* Corresponding author:
Tel. +44 1865 484190
sresalati@brookes.ac.uk

Keywords:

Vacuum insulation panels,
embodied energy,
recycling,
low carbon.

Abstract

Low carbon buildings have historically been characterised as requiring relatively little energy for heating and cooling. The embodied energy associated with the materials used to construct these buildings has largely been ignored. Whilst this approach was useful when operational energy was around ten times greater than embodied energy, it is no longer valid. Where buildings are constructed to good thermal standards, and particularly where service lives are less than 60 years, operational and embodied energy can now be equivalent, meaning that it is imperative that embodied energy is considered when determining optimal insulation strategies. The normal thicknesses of many conventional insulation materials, including mineral wool and PUR/PIR foams, cannot be significantly increased without incurring total carbon disbenefits i.e. more energy being invested to produce the additional thickness of insulation than saved during the anticipated service life. It has been demonstrated that vacuum insulation can justify far lower U values than can be justified by conventional insulation materials, on the basis of potentially lower embodied energy. Two issues require consideration however: The first is the discrepancies that exist in the embodied energy figures cited for fumed Silica core materials, and the second are the assumptions that should be made for recycled content. This paper reviews the ranges of figures currently in circulation and the very considerable implications that the differences have in terms of justifying the use of VIPs in the context of future highly insulated envelopes.

Introduction

This paper draws on a 4 year research project carried out at Oxford Brookes University which is now informing the EU funded INNOVIP project aimed at producing more viable forms of VIPs, including products with reduced embodied energy.

Regulations in developed economies that have significant building heating requirements increasingly demand good standards of thermal building envelope performance. The main focus however has been on reducing operational energy (Yan 2011, Anastaselos 2009, Ramesh 2010). Relatively little attention has thus far been given to embodied energy.
True low carbon building specifications must take account of both operational and embodied energy, particularly in relation to insulation materials. It is entirely possible to invest more embodied energy into the production of insulation materials than the amount of operational energy saved during building service lives. The paper (Ogden et al, 2012) 'A Combined Operational and Embodied CO_2 Approach: The limits of Conventional Insulation Materials and Case for High Performance Vacuum Technology' presented by the authors at the 12th IVIS conference illustrated this phenomenon and set out a quantified carbon based case supporting the selection of vacuum insulation in relation to very low U value envelopes. This work reflected the fact that the embodied energy of vacuum panels can be less than that of conventional insulation materials when compared on the basis of equivalent thermal insulation values.

Sensitivity of Life Cycle Data

The original work used calculated values for the embodied energy of fumed Silica cores but as research progressed it was noted that significant discrepancies exist in the values cited by manufacturers of vacuum panels, and also between these and the values assumed in academic analyses. There is evidence that certain figures once cited in literature have been withdrawn. Currently available figures for the embodied energy of vacuum panels range from 6.05kgCO_2/kg to 10.78 kg CO_2/kg expressed on a Cradle to Gate basis i.e. a partial product life cycle from resource extraction (cradle) to the factory gate. This alone is sufficient to make a significant difference to ideal combined operational and embodied energy specifications. Perhaps more critically however there is increasing debate as to the correct recycling assumptions that should be used in cradle to cradle analyses. Cradle to cradle is arguably a far more appropriate measure of carbon requirements (representing whole life carbon implications) and in the case of vacuum panels acknowledging recycling.

Table 1 illustrates the variation and the effect that these variations have on ideal building envelope U values for a semi-detached residential building in the UK calculated using cradle to gate embodied energy data. The critical U value represents the theoretical point beyond which incorporating further vacuum insulation begins to increase total carbon during the service life of the building, rather than to reduce it as is the objective. It is based on building specific combined analysis of the type described in Ogden et al 2012, which determines the combined 'Minimum Carbon' figure.

	Embodied Carbon ($kgCO_2/kg$)	**Minimum Carbon ($kgCO_2/m^2/yr$)**	**U-value (W/m^2K)**
Supplier A	9.37	7.29	0.19
Supplier B	10.78	7.6	0.23
Research A	9.14	7.43	0.19

Tab. 1
Cradle to Gate Minima

Whilst these critical U-values vary significantly as a consequence of variations in the cradle to gate figures, far greater variations exist if analyses are made on a cradle to cradle basis.

	100% recycled silica	
	Min. carbon ($kgCO_2/m^2/yr$)	**U-value (W/m^2K)**
Supplier A	4.61	0.057
Supplier B	4.69	0.057
Research A	5.36	0.08
	70% recycled silica	
	Min. carbon	**U-value**
Supplier A	5.76	0.12
Supplier B	6.05	0.12
Research A	6.19	0.12
	30% recycled silica	
	Min. carbon	**U-value**
Supplier A	6.75	0.15
Supplier B	7.07	0.19
Research A	6.98	0.19

Tab. 2
Cradle to Cradle Minima

A key factor for vacuum insulation panels is the assumed level of recycling of core materials as this accounts for a large part of the assumed embodied energy. Table 2 summarises the differences in optimal U values if the cited embodied energy figures are combined with a range of assumptions regarding the recycled content of vacuum panels, in this case ranging from 30 to 100%. As would be expected, panels with 100% recycled content can justify far lower U value building envelopes than those with lesser recycled content. Perhaps less predictably however is the degree of variation. The best case U value based on 100% recycled content is 0.057 W/m^2K, whilst 30% recycled content only allows justification of 0.15 W/m^2K.

Fig. 1
Typical cradle to cradle analysis: supplier A: 100% recycled core material (aggregation of operational CO_2 and insulation embodied CO_2

Conclusions

These figures, which comprise only a small part of a far larger area of ongoing research, illustrate that whilst vacuum insulation panels can uniquely justify very low U value building envelopes (as assessed using combined operational and embodied carbon analyses), there is a high level of sensitivity concerning cradle to gate embodied energy figures and a far greater sensitivity still to the percentage of recycled content. This implies that recycling of vacuum panel core materials may have far greater future significance than has hitherto been appreciated.

References
[1] Q. Yan and C. Zheng, Energy Procedia 11, (2011) 2489-2496.
[2] D. Anastaselos et al, Energy and Buildings 41 (2008) 1165-1171.
[3] T. Ramesh et al, Energy and Buildings 42, (2010) 1592-1600.
[4] R. Ogden et al. 12th IVIS conference. (2015) NUAA China.

SESSION 2

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13th International
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September 20-21, 2017

A Comprehensive Study on the Production Process and Properties of Composite Core Materials for Vacuum Insulation Panels for Construction Applications

Chuanwei Zhai[a*]
Zhuangxian Li[a]
Yi He[a]
Ting Liu[a]
Miaotian Sun[a]
Jianbo Liu[a]

[a] Qingdao Kerui New Environmental Materials Group Co.,LTD, Qingdao 266000, PR China
* Corresponding author:
Tel. +86(532)85011721
zhaichuanwei@cncreek.net

Keywords:

Vacuum insulation panels,
aerogel,
glass fiber,
core materials.

Abstract

In this study, a kind of vacuum insulation panel (VIP) has been produced for heat preservation in construction applications with composite core materials of silica aerogel and glass fiber. It has been proved that, in the vacuum condition, the composite approach has great impacts on the thermal conductivity of the VIPs, namely, the core material produced through the sol-gel method shows better properties than those produced through the casting moulding process. Comparing to the single-fiber-typed core materials, the composite core materials show less deformation, higher structural stability and lower thermal conductivity, which demonstrate a high potential to be applied as thermal insulation materials in construction applications.

Introduction

Aerogels are porous materials with high specific surface area, low density and high porosity, which makes it a super insulation material. [1] However, although it possesses excellent insulation property, the high cost and low mechanical strength limited its application. One method to enhance the strength of the aerogels is to produce hybrids with aerogel and supporting fiber materials. [2]

In this study, aerogel-fiber glass was produced by two low-cost methods. One method is to soak glass fiber mat in the sol, and to dry the gel under ambient temperature; another method is to produce aerogel particles first and mix them with binder and surfactant, then to pour the mixture into the pores of the glass fiber mat, in the end to dry under ambient temperature.

In recent years, many publications have been released on VIP composite core materials produced by fumed silica, glass fibers, open-cell foams, inorganic powders and fibers. [3] However, core materials of aerogel-fiber composite materials are rarely reported. The aim of this work is to produce a kind of novel composite core material for VIPs with high stability and good insulation performance, meanwhile, to further explore the application fieldsof aerogels.

Material and methods

Preparation of aerogel-glass fiber mat

Sol-gel method: Sodium silicate, ethanol and water with a volume ratio of 1:1:2 were added into a container. A piece of glass fiber mat with thickness of 10 mm was placed in to the mixture. After the gel has been formed, solvent exchange was done with ethanol and other reagents. The aerogel-glass fiber mat was dried.

Casting moulding method: A certain amount of aerogel particles was added into a mixture of emulsion adhesive and surfactant to produce a slurry. The glass fiber mat (10 mm) was pre-dried in oven at 160°C for 30 min and cooled down to room temperature. The aerogel slurry was added onto the glass fiber mat through a porous mold. By pressing and drying at 80°C for 4 hrs, the aerogel-glass fiber mat was produced.

Preparation of VIPs

The produced aerogel-glass fiber mats were cut into squares with length of 300 mm, and were further dried in oven at 180°C for 90 min. The composite core materials were then placed into the multi-layer barrier film bags. The film bags with core materials were then vacuumed and heat sealed (vacuum degree: 0.1-0.01 Pa). The produced VIP was then flattened with rolling rods (fig. 1).

Property tests

Property tests of aerogels: the samples were analyzed with the ASAP 2020 chemisorption analyzer from Micromeritics. The samples were pretreated at 300°C, 1.333 x 10-3 Pa for 3-7 hrs, and was analyzed by N2 adsorption under liquid nitrogen atmosphere (77 K).

Thermal conductivity λ: The qualified samples were analyzed by HFM 436 heat flow meter from NETZSCH.

Rebound ratio: The VIPs were perforated by needles, and rebounds under ambient pressure.

Fig. 1
VIP with the composite core material of aerogel-glass fiber mat produced by sol-gel method

Results and discussions

Structure and properties of aerogel and composite core materials

The specific area of the aerogel produced through sol-gel method was around 800 m²/g, with density of 40-60 kg/m³, pore diameter around 20 nm and porosity above 90 %.Although the aerogel applied in the casting moulding method were grinded, the inner structure was not destroyed and possess similar properties as the former.

As shown in table 1, the thermal conductivity of the product from the sol-gel method is lower than that of the casting moulding method by 2 mW/m K. This indicate that during the processing, the aerogel slurry was unevenly spread on the glass fiber mat, which causes the partially high thermal conductivity of the adhesives and other additives, therefore a higher conductivity of the composite mat.

Sample type		Measured total thermal conductivity (W/m·K)
Core material	Glass fiber	0.030
	Products from Sol-gel method	0.018
	Products from casting moulding	0.020
VIP	Glass fiber	0.0035
	Products from Sol-gel method	0.0043
	Products from casting moulding	0.0055

Tab. 1
Thermal conductivities of core materials and VIPs

Properties of VIPs

As shown in table 1, since the composite mat produced by sol-gel method has a lower thermal conductivity than that of casting moulding, the VIP with such core material has as well as a lower conductivity by 1.2 mW/m K. Although compared to the VIPs with glass fiber as core material, the thermal conductivity of the VIPs with aerogel-glass fiber is higher by 0.8-2 mW/m K, the rebound ratio of the VIPs was reduced significantly.

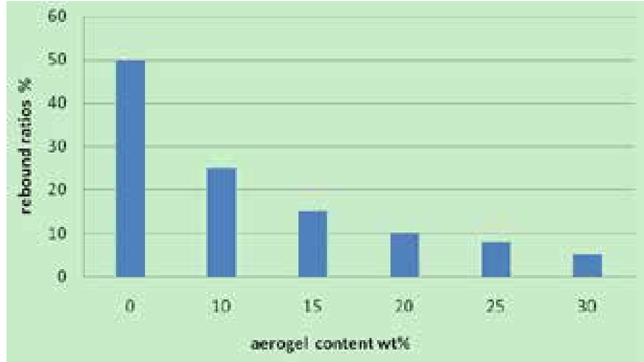

Fig. 2
The rebound ratio of VIPs with core material of composite glass fiber produced by sol-gel method with increasing aerogel content.

According to figure 2, the rebound ratio of VIPs deceases from 49.5% to 6.1% with increasing content of aerogel. The decease of rebound ratio indicates the improving safety of using VIP for insulation in buildings. Based on the test results of the insulation performance and rebound ratio, the VIPs produced with aerogel content of 20-30% are suitable to be applied in construction applications.

Conclusions and outlook

In this work, VIPs with composite core materials of aerogel-glass fiber were produced through low cost methods. The results have shown: (1) The properties of the core material produced by so-gel method is better than those by casting moulding method. (2) The composition of aerogel and glass fiber hybrids reduces the rebound ratio of VIPs significantly, which improves the safety of applying VIPs in construction.

Acknowledgements

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References
[1] M.A. Aegerter et al.Aerogel Handbook, 2011.
[2] H. Maleki et al. J. Non. Cryst. Solids 385 (2014)55–74.
[3]X. Di et al.Vacuum 97 (2013) 55–59.

A New Sub-Micron Size Polystyrene Foam as Core Material for Vacuum Insulations

F. A. Almeida[a*]
N. Dodamani[a]
H. Beyrichen[a]
R. Caps[a]
A. Müller[b]
R. Oberhoffer[b]

[a] va-Q-tec AG, Karl-Ferdinand-Braun-Str., 7, Würzburg D-97080, Germany
[b] SUMTEQ GmbH, Luxemburger Str. 90, 50939 Köln, Germany
* Corresponding author:
Tel. +49 931 359422985
Flavia.Almeida@va-q-tec.com

Keywords:

Vacuum insulation panels,
sub micron pore size,
polystyrene foams,
Knudsen effect,
thermal conductivity.

Abstract

New polystyrene (PS) foams with submicron pore sizes and open pore structure are introduced as potential cores for vacuum insulation panels (VIPs). Measurements of the thermal conductivity λ of the air-filled and evacuated new PS foams, the influence of temperature T, opacifiers as well as gas pressure p on the thermal conductivity λ are presented. First results of the foam microstructures, as visualized in electron microscope, confirm that pore sizes smaller than 1 μm can be achieved. Thermal conductivity values of advanced samples in vacuum of about 7 mW/(m·K) were measured, with a great potential to achieve even lower values.

Introduction

A main topic of current basic research in vacuum insulation panels (VIPs) is the development of new materials with improved properties and cost effectiveness. We currently are testing a new kind of polystyrene (PS) foam with sub-micron pores ("SUMFOAM"). The material is produced by SUMTEQ using an innovative technology that allows a scalable and economical production of such foams for the first time [1]. In the present work, the thermal conductivity results of the first and second generations of SUMFOAM are presented. The ultimate objective of the product development is to achieve a true costeffective core with fine pores rendering long service life time and light-weight vacuum insulation panels.

Thermal conductivity analysis

The 1st and 2nd generations of SUMFOAM cores for VIP are based on PS granules, without and with opacifier, respectively (hereon called "white" and "black"). Disc samples of ø100 × 15 mm were produced by pre-compacting the granules to different core densities. Fig. 1 shows examples of the two tested foam types and a VIP made from such foams.

Using a heat flow meter apparatus, thermal conductivities λ of the new foams were measured in air and in vacuum, as well as at different mean temperatures and internal gas pressures.

Fig. 1
(left) 1st and 2nd generation disc samples; (right) SUMFOAM VIP.

Results and discussions

Fig. 2 shows that the overall thermal conductivity of the first generation "white" samples in air and in vacuum has a nearly linear relationship with core density ρ due to the increasing solid conduction λs.

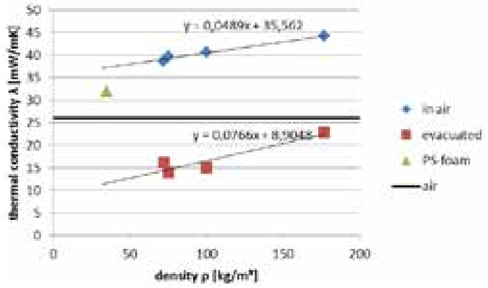

Fig. 2
Overall thermal conductivity values of "white" PS foam in air and at p < 1 mbar as function of core density ρ.

In air, thermal conductivities are in the range of 40-45 mW/(m·K) (a commercial, opacified PS foam has λ ~ 32 mW/(m·K)) and decrease to values around 15 to 20 mW/(m·K) when in vacuum.

The difference of thermal conductivity of samples in air λ_{air} and in vacuum λ_{evac} is somewhat lower than the conductivity of still air (26 mW/(m·K)). This may already be an indication of the Knudsen effect due to small pore sizes. The gas conduction λg inside the pores depends on gas pressure p as:

$$\lambda_g = \lambda_{g0} / (1 + p_{1/2} / p) \qquad (1)$$

where λ_{g0} is the thermal conductivity of free air and $p_{1/2}$ is the typical pressure for gas conduction in the pores. $p_{1/2}$ is material-specific and depends on the effective pore diameter dp of the insulation material [2]. For air, this dependence is:

$$p_{1/2}\ [mbar] = (230/d_p\ [\mu m]) \qquad (2)$$

By applying both equations (1, 2) on the above experimental data, an estimation of the pore structure of the core is possible. The estimated $p_{1/2}$ values for the different foam densities vary in between 100-200 mbar, which is in the middle range compared to common VIP core materials (600 mbar for fumed silica and 5 mbar for glass fiber [3]). The corresponding pore diameters d_p being in the range of 1.2 – 2.3 µm reveal that the larger the density ρ the smaller are the pores.

Fig. 3 presents the results of λ as function of gas pressure p for the highest density sample. The best fit of the data values is possible when two distinct pore sizes are considered. Here, 75% pores have $p_{1/2}$ = 600 mbar and 25% pores have a $p_{1/2}$ = 2 mbar, corresponding to pore sizes of d_p = 0.4 µm and d_p = 120 µm, respectively.

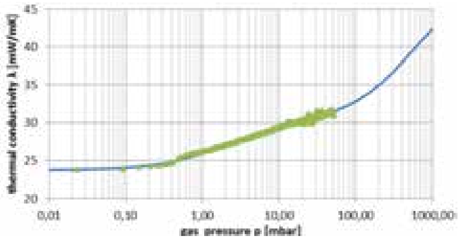

Fig. 3
Thermal conductivity as function of gas pressure p for the "white" foam with ρ = 175 kg/m³

These very first results on pore sizes and typical gas pressures were very promising ones. However, the overall λ still is very high for a VIP core. The contributions of solid (λ_s) and radiative (λ_r) conduction play an important role in the overall λ values. The radiative conduction was calculated by measuring λ at different mean temperatures (Fig. 4), from where the solid conduction λ_s could also be estimated. The following relation was considered:

$$\lambda_{evac}(T^3) = \lambda_s + (16/3)\sigma T^3/E \qquad (3)$$

where σ = 5,67×10⁻⁸ Wm⁻²K⁻⁴; E: radiation extinction coefficient and T: temperature in K.

For the 75 kg/m³ sample, values of λ_s = 6.7 mW/(m·K) and λ_r(10°C) = 7.2 mW/(m·K) were calculated, showing that about half of the total λ value of the white foam is due to radiation. The specific radiation extinction e (taken from e = E/ρ) is 12.6 m²/kg and has an inverse relationship with core density ρ. This value is very low in comparison with the ones of conventional PS (~40-50 m²/kg [4]). So the addition of an opacifier material to the new foam is essential. Fig. 5a and Fig. 5b show the result of the thermal conductivity of a 2nd generation, opacified ("black") core as function of cubic mean temperature T³ and gas pressure p, respectively. It is clear that the opacification of the core has a significant influence on the total thermal conductivity values, able to decrease it to about one half (λ = 7-8 mW/(m·K), Fig. 5a) of the values of the "white" PS foams. For this "black" foam, the calculated specific extinction e = 43 m²/kg is now in the range of commercial PS. The low solid conduction λ_s = 3.6 mW/(m·K) of the "black" foam suggests that its microstructure may also has been changed due to the added opacifier. In fact, by fitting the thermal conductivity λ as function of gas pressure p (Fig. 5b) with eqs. (1) and (2), the resulting pore size dp of ~3.5 µm is larger than the minimum one of the "white" PS foam, but with a unimodal distribution. Such values are in good agreement with the observed pore dimensions in SEM pictures, as can be seen in Fig. 6a,b for the "white" and "black" foams, respectively.

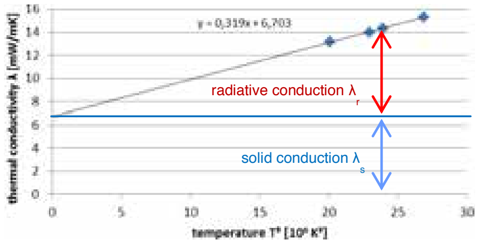

Fig. 4
Thermal conductivity λ of "white" foam (core ρ = 75 kg/m³) as function of cube of temperature T³

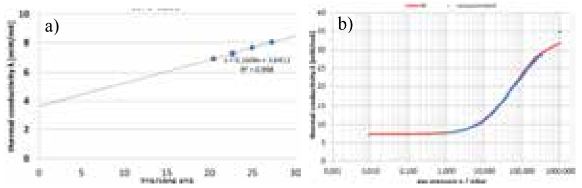

Fig. 5 a) λ vs. temperature T³; b) λ as function of gas pressure p for an opacified "black" core with ρ = 44 kg/m³

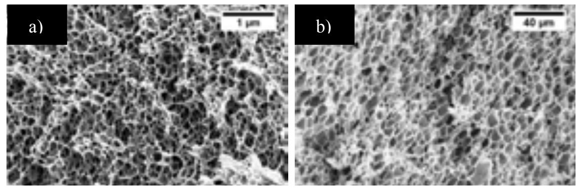

Fig. 6
SEM micrographs of a) "white" and b) "black" foam.
(Note: Fig. 6a has a 40x higher magnification than 6b)

Conclusions and outlook

The 1st and 2nd generation new PS foams achieved good evacuation ability, in contrast to conventional PS foams. The new foams present fine pore structures (some of them well below 1 µm), able to reduce considerably the gas conduction lower than that of free air at atmospheric pressure. The preliminary results show that the radiative conduction has a huge influence on the overall thermal conductivity. So, opacifier materials are needed. SUMTEQ is now working on the match of good material properties and microstructure, and more interesting results are to come in the near future.

Acknowledgements

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References
[1] R. Strey et. al. WO002015071463A2 (2015)
[2] T. Beikircher et al. J Heat Trans-T ASME 135 (2013) 051301-1 - 051301-11.
[3] M. Tenpierik, PhD thesis, Technische Universität Delft, The Netherlands, 2009.
[4] M. Arduini-Schuster Int. J. Therm Sci (2015) 156-164.

The Quest for Nano Insulation Materials Applying Hollow Silica Nanospheres

Bjørn Petter Jelle[ab*]
Sohrab Alex Mofid[a]
Tao Gao[a]
Mathieu Grandcolas[c]
Ole Martin Løvvik[cd]
Rolf André Bohne[a]
Serina Ng[b]
Espen Sagvolden[c]

[a] Norwegian University of Science and Technology (NTNU), Department of Civil and Environmental Engineering, NO-7491 Trondheim, Norway
[b] SINTEF Building and Infrastructure, Department of Materials and Structures, NO-7465 Trondheim, Norway
[c] SINTEF Materials and Chemistry, Department of Materials and Nanotechnology, NO-0314 Oslo, Norway
[d] University of Oslo (UiO), Department of Physics, NO-0316 Oslo, Norway
* Corresponding author:
Tel. +47-73593377
bjorn.petter.jelle@sintef.no

Keywords:
Nano insulation material,
NIM,
Hollow silica nanosphere,
HSNS,
Super insulation material,
SIM,
Thermal conductivity.

Abstract

High-performance thermal insulation materials with substantially lowered thermal conductivity are being developed in the on-going quest to obtain energy-efficient and zero emission buildings. Depending on the exact definition, e.g. with respect to vacuum-, gas- or air-based porous core materials, these materials may be termed superinsulation materials (SIM) when they reach a thermal conductivity value below e.g. 15 mW/(mK), 20 mW/(mK) or the stagnant air value of 26 mW/(mK), respectively. A very low thermal conductivity will enable the use of normal or thin wall thicknesses in energy-efficient buildings. Very thick building envelopes are not desirable due to several reasons, e.g. space issues with respect to both economy, floor area, transport volumes, architectural restrictions and other limitations, material usage and existing building techniques. A promising pathway to achieve SIMs is to exploit the Knudsen effect for substantially decreasing the gas conduction and the gas interaction with the solid state pore walls, thus making a porous material with the pores in the nano range, i.e. nano insulation materials (NIM). This study presents the current laboratory investigations attempting to manufacture NIMs by the fabrication of hollow silica nanospheres (HSNS) through a sacrificial template method.

Introduction

Energy-efficiency has for the last decades been gaining widespread attention, also within the building sector. In this respect the development of high-performance thermal insulation materials with substantially lowered thermal conductivity may play an increasingly important role. Thermal insulation with vacuum-, gas- or air-based porous core materials, may be termed superinsulation materials (SIM) when they reach a thermal conductivity value below e.g. 15 mW/(mK), 20 mW/(mK) or the stagnant air value of 26 mW/(mK), respectively. These SIMs can then be applied in energy-efficient buildings with normal or thin wall thicknesses. Very thick building envelopes are not desired due to several reasons like e.g. space issues with respect to both economy, floor area, transport volumes, architectural restrictions and other limitations, material usage and existing building techniques. Decreasing the pore size of a porous thermal insulation material down to the nano range makes it possible to utilize the Knudsen effect in order to achieve a very low thermal conductivity [1-3], hence the term nano insulation material (NIM). In this study we are presenting our laboratory investigations attempting to fabricate NIMs by the synthesis of hollow silica nanospheres (HSNS) through a sacrificial template method.

Experimental

Miscellaneous experimental paths for synthesizing HSNS have been described in our earlier studies [4-9]. This work is still ongoing with many experimental pathways and parameters to be explored. The HSNS synthesis is based on a sacrificial template approach, where e.g. polyacrylic acid (PAA) and polystyrene (PS) have been used as template materials. Our initial starting point was based on the work by Du et al. [10], who used the method to prepare antireflection coatings, and the study by Wan and Yu [11].

Results and discussions

A part of a succesful HSNS synthesis is to make the sacrificial templates. Scanning electron microscope (SEM) images of PS templates with diameters 80 nm and 195 nm are given in Fig. 1. To make PS monodisperse spheres with diameters below 100 nm is a rather hard challenge, thus the 80 nm PS spheres in Fig. 1 represent a hard-gained feat in itself.

The next step in the sacrificial template method is to cover the PS spheres with a thin silica coating, and thereafter to dispose of the PS templates by a heating process where the PS template material is evaporated and diffused through the silica shell. Hence, the removal of the templates results in the formation of silica shells around spherical voids, i.e. HSNS.

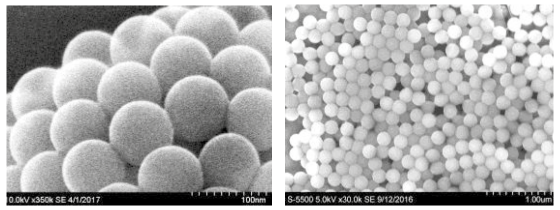

Fig. 1 SEM images of PS templates with diameters 80 nm (left) and 195 nm (right)

Selected examples of HSNS are depicted in Fig. 2 and Fig. 3 by their SEM, scanning transmission electron microscope (STEM) and transmission electron microscope (TEM) images, with inner diameters being 80, 90, 140 and 190 nm. In general, the corresponding shell thicknesses are typically varying between 10 to 50 nm. The silica shell is constituted of small, spherical silica particles, where their primary particle size is a major factor in determining the surface roughness of the HSNS.

The choice of silica precursor, e.g. tetraethyl orthosilicate (TEOS) or water glass (Na_2SiO_3), is also influencing the HSNS surface roughness [12].

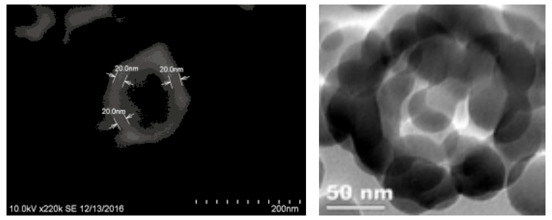

Fig. 2 Dark-field STEM and TEM images of HSNS with inner diameters 80 nm (left) and 90 nm (right)

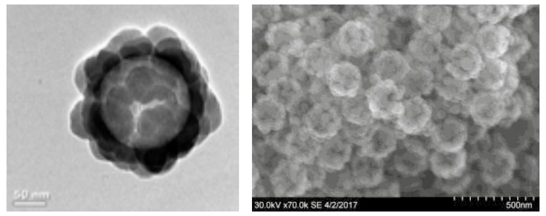

Fig. 3 TEM and SEM images of HSNS with inner diameters 140 nm (left) and 190 nm (right)

The thermal conductivity values of the HSNS powder samples are typically in the range 20 to 90 mW/(mK), though some uncertainties in the Hot Disk apparatus measurement method have to be further clarified.

Conclusions

Various hollow silica nanospheres have been synthesized by several different sacrificial template approaches, which represent a possible stepping-stone toward the goal of manufacturing nano insulation materials and superinsulation materials.

Acknowledgements

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References

[1] M. G. Kaganer, "Thermal insulation in cryogenic engineering", IPST Press, 1969 (Russian version 1966).
[2] B. P. Jelle, A. Gustavsen and R. Baetens, "The path to the high performance thermal building insulation materials and solutions of tomorrow", Journal of Building Physics, 34, 99-123, 2010.
[3] B. P. Jelle, "Traditional, state-of-the-art and future thermal building insulation materials and solutions - Properties, requirements and possibilities", Energy and Buildings, 43, 2549-2563, 2011.
[4] B. P. Jelle, B. G. Tilset, S. Jahren, T. Gao and A. Gustavsen, "Vacuum and nanotechnologies for the thermal insulation materials of beyond tomorrow - From concept to experimental investigations", Proceedings of the 10th International Vacuum Insulation Symposium (IVIS 2011), pp. 171-178, Ottawa, Canada, 15-16 September, 2011.
[5] T. Gao, B. P. Jelle, L. I. C. Sandberg and A. Gustavsen, "Monodisperse hollow silica nanospheres for nano insulation materials: Synthesis, characterization, and life cycle assessment", ACS Applied Materials and Interfaces, 5, 761-767, 2013.
[6] L. I. C. Sandberg, T. Gao, B. P. Jelle and A. Gustavsen, "Synthesis of hollow silica nanospheres by sacrificial polystyrene templates for thermal insulation applications", Advances in Materials Science and Engineering, 2013, 6 pages, Article ID 483651, 2013.
[7] T. Gao, L. I. C. Sandberg and B. P. Jelle, "Nano insulation materials: Synthesis and life cycle assessment", Procedia CIRP, 15, 490-495, 2014.
[8] B. P. Jelle, T. Gao, L. I. C. Sandberg, B. G. Tilset, M. Grandcolas and A. Gustavsen, "Thermal superinsulation for building applications - From concepts to experimental investigations", International Journal of Structural Analysis and Design, 1, 43-50, 2014.
[9] T. Gao, B. P. Jelle, L. I. C. Sandberg and A. Gustavsen, "Thermal conductivity of monodisperse silica nanospheres", Journal of Porous Media, 18, 941-947, 2015.
[10] Y. Du, L. E. Luna, W. S. Tan, M. F. Rubner and R. E. Cohen, "Hollow silica nanoparticles in UV-visible antireflection coatings for poly(methyl methacrylate) substrates", ACS Nano, 4, 4308-4316, 2010.
[11] Y. Wan and S.-H. Yu, "Polyelectrolyte controlled large-scale synthesis of hollow silica spheres with tunable sizes and wall thicknesses", Journal of Physical Chemistry C, 112, 3641-3647, 2008.
[12] B. P. Jelle, T. Gao, S. A. Mofid, S. Ng, B. G. Tilset and M. Grandcolas, "Hollow silica nanospheres as a stepping-stone toward thermal superinsulation materials", Proceedings of the 12th International Vacuum Insulation Symposium (IVIS 2015), pp. 254-256, Nanjing, China, 19-21 September, 2015.

High temperature insulation based on zirconia aerogels

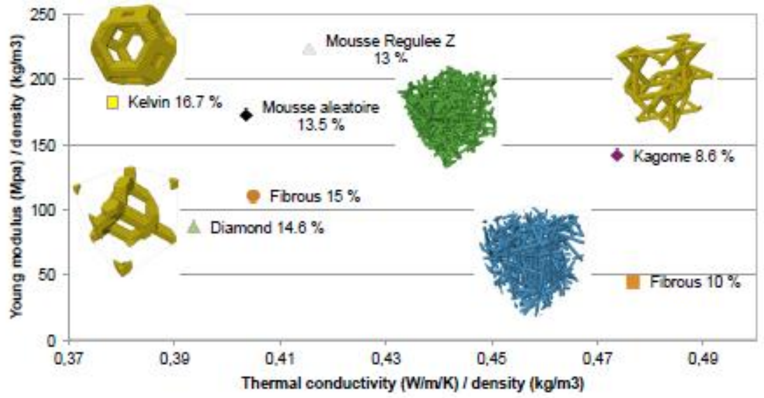
C. Ambard
A. Dieraert
Y. Carre
S. Chupin
D. Rochais
Ph. Belleville

High temperature insulation is a major subject of concern for aerospace, energy or automotive fields. Aerogels are known for their properties of superinsulation. Beds of aerogel granulate or powder are frequently used for thermal insulation for example in space applications [1]. Most of works deal with silica aerogels ; nevertheless silica is not applicable for high temperature (about 1200K).

These works focus on yttria stabilized zirconia aerogels. Different routes of synthesis were investigated using alkoxy and chlorides precursors. Different drying processes were also tested such as supercritical CO_2 drying.

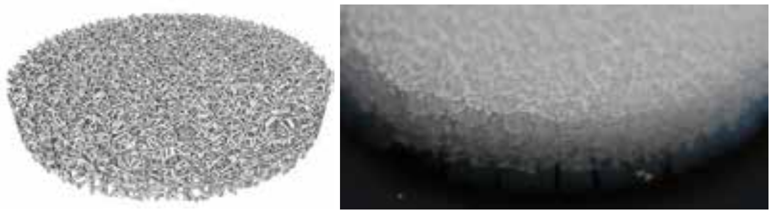
a) YSZ aerogels: a) supercritical dried

The aerogels obtained are fragile materials. Mechanical reinforcement is therefore required for the elaboration of thermal insulation. We propose an innovative approach based on numeric materials to design structures with good thermo-mechanical compromise.



Thermo-mechanical ratio of numeric materials

Associate to additive manufacturing such as stereolithography laser, this approach allows designing new insulation materials which can be combined with aerogels.



a) Virtual mechanical reinforcement structure
b) Printed material impregnated with aerogel

References

[1] Fesmire, J.E., Aerogels insulation systems for launch applications, Cryogenic, 2006, 46, 111-117

Mechanical study of highly nanoporous silica powder for vacuum insulation panels cores (VIP)

Belynda Benane[ab*]
Sylvain Meille[a]
Bernard Yrieix[b]
Christian Olagnon[a]
Geneviève Foray[a]

[a] Univ Lyon, INSA Lyon, CNRS, MATEIS UMR-5510, F-69621, Villeurbanne, France
[b] EDF R&D les Renardières, 77818, Moret-sur-Loing, France
* Corresponding author: belynda.benane@insa-lyon.fr

Abstract

VIP cores are commonly made of stacks of highly porous silica nanopowders (> 90% porosity), slightly densified by uniaxial compression. Fumed silica (FS) particles are mainly used for the fabrication of VIP core, due to their ability to reach the target compression strength (0.1 MPa) for a density of 160 kg/m^3 against 200 kg/m^3 using precipitated silica (PS) powders. This difference in density ensures a better thermal insulation for the VIP made with FS core as compared with PS core. The aim of this study is to understand the differences in the mechanical behavior of compacted FS and PS powders, by using œdometric compression test, combined to a fine characterization of the samples' microstructure.

Keywords:

Silica, powder,
compression,
VIP,
microstructure.

Introduction

Silica powders are made of elementary nanometre-sized particles, organised at a larger scale into aggregates and agglomerates. Silica aggregates consist of strongly bounded elementary silica particles. The connection of aggregates by weak forces leads to bigger structures called agglomerates of 100 nm typical size. Amorphous silica powders are characterised by their small elementary particles diameter (< 20 nm) and pore size after compaction (< 200 nm) which limit thermal convection through the solid route and inhibit convective transfer through the gas route [1], [2]. A wide range of thermal insulated systems based on nanostructured silica has emerged in recent years from aerogels to vacuum insulating panels (VIP), made of a compacted silica core in a sealed envelope[1], [3]. However, the relatively high price of VIP limits their development. Since 2007, studies are carried out to develop new VIP core formulations at a reduced cost by replacing the expensive FS powders currently used in commercial VIP by PS powders [4]. However, core formulation based on PS powders usually lead to decrease mechanical properties of the compacted bead. Thus, they are more densified which finally increase their thermal conductivity.

This work aims at understanding the differences in mechanical behavior between PS and FS powders under compression stresses to develop in a next future efficient VIP cores at a reduced cost. To reach this objective, two types of silica powders are studied in this work. First, a fumed silica powder (FS), synthesized by pyrolysis in a flame up to 1200°C, considered as a reference material. Second, two precipitated silica powders (PS); both obtained by aqueous hydrolysis and processed after drying either by milling (hereafter referred as PS1) or by micronization (hereafter referred as PS2).

The powders' mechanical behavior was tested under œdometric compression. This test is actually like the manufacture process of VIP cores before sealing. Mechanical tests were completed by characterization of samples microstructure by mercury porosimetry, laser granulometry, N2 adsorption and TEM observations.

Materials and methods

Nanostructured powders

PS powders are commercial products. Their elementary particle size is around 20 to 25 nm. This synthesis route confers them a hydrophilic surface with a hydroxyl (Si-OH) density on the surface of 4.6 OH/nm². FS powder is also a commercial product.
Its particle size is about 8 to 10 nm and the surface is less hydrophilic with a silanol rate at approximately 1 OH/nm².
The specific surfaces (S_{BET}), intrinsic density (ρ_S) and average size distribution measured in water (D50) of all three powders are given in Table 1.

Powders	***FS***	***PS1***	***PS2***
S_{BET} (m²/g)	190	200	170
ρ_s (g/cm^3)	1.9 - 2.2	1.8 –1.9	1.8 -1.9
D50 (µm)	70	10	6

Tab. 1 Experimental powders' physical characteristic

Experiments

Edometric compression were performed using a custom designed cell under a universal testing machine with a load cell of 500N.

The œdometric compression test comprised three steps. First, a filling step by gravity flow of 200mg of silica powder. Then, a loading phase up to a given load, followed by an unloading phase. Tests were carried out at a controlled crosshead speed (5 mm/min). For all three silica tested, the maximum load applied was 400 N for the same initial powder weight. Cylindrical samples were about 20 mm diameter and 2 mm ±0.2 mm height after compaction. All tests were repeated three times, at ambient temperature and relative humidity (23°C and 44% RH). Thus, three samples were obtained for each powder in the same processing conditions. Experiments were also carried out to determine the evolution of mechanical properties with storage time of the powder and the influence of adsorbed water (tested by storing the powders at different relative humidities, typically 44% and 100% RH).

Results and discussion

Compression stress vs. density curves during œdometric compression are shown in Figure 1. It appears that FS powder shows a limited tendency to compact at a given load as compared to the two PS powders, as illustrated by a smaller sample density. The two PS powders show a similar behaviour under œdometric compression.

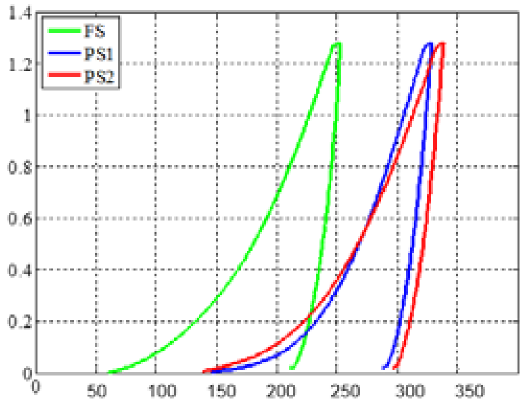


Fig. 1 Stress versus compacts' densities

The œdometric modulus (E_{oed}), calculated at the beginning of the unloading step, is larger for FS samples as compared to PS samples (Table 2).

	FS	**PS2**	**PS1**
Densities (kg/m^3)	210±2	300±2	290±2
E_{oed} (MPa)	10	6.1	6.2
Relative std dev (%)	2	1	1

Tab. 2 Calculated œdometric modulus

The œdometric modulus of the tested powders are nearly identical for PS ones for approximatively the same pellets' densities. FS pellets œdometric modulus is higher for a lower density .Thus, FS leads to a higher relative compacts' stiffness. Œdometric compression tests confirm previous knowledge on the mechanical properties of VIP cores, with a higher specific strength for core based on FS powders as compared to PS ones [4].

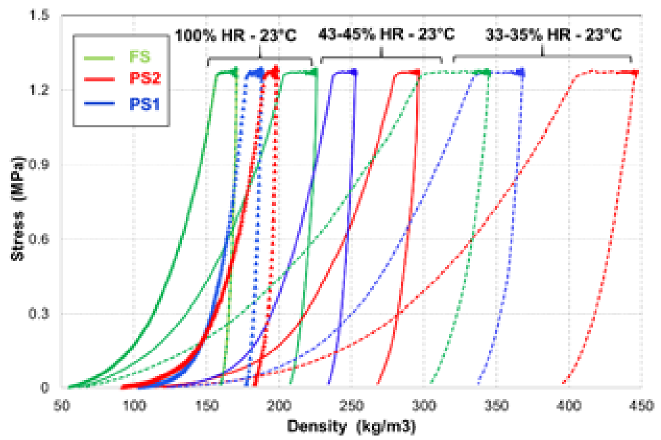


Fig. 2 Moisture effect on Compacts' density

Figure 2 shows a clear evolution of compacts' densities according to moisture conditions of powders storage. Results show that increasing the RH during powder storage increases the amount of adsorbed water and leads to reduced sample density after compaction (Figure 2). It is also shown that increasing the RH storage reduces the differences between FS and PS powders' modulus and between final densities after compaction. Physisorbed water on the silica surface is supposed to modify interactions between agglomerates. In particular, a high relative humidity seems to increase agglomerates cohesion, thus interaction forces. FS and PS powders show different surface properties, as well as specific area and particles / aggregate / agglomerates size distribution. All these parameters affect the interaction forces between particles, aggregates and agglomerates of silica. Different interparticular forces (Van der Walls, capillary forces, mechanical anchoring) govern the aggregates and agglomerates formation as well as the global cohesion of the material during compression. These interparticular forces are controlled by primary particle size, chemical functions at their surface, shape and roughness [5]-[7]. They seem to be largely different between FS and PS powders (see Table 1).

Conclusions

This work confirms the differences between PS and FS compacts under oedometric solicitation. In addition to these tests, spherical indentation and biaxial bending tests of the compacted samples will be carried out to determine their mechanical properties (hardness, fracture strength). SAXS measurements will help to characterize the structure of compacted silica at different length scales [8][9]. The whole work will permit to understand why FS powders show better mechanical properties than PS ones.

Acknowledgements

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References
[1] M. Davraz and al, Sci. Eng. Compos. Mater., 21 (2014) 521–527
[2] M. Alam and al," Appl. Energy, 88 (2011), 3592–3602
[3] R. Baetens and al.," Energy Build., 42 (2010), 147–172
[4] D. P. Solano, ," Liège (Belgique), 2009.
[5] W. Yao and al , "Powder Technol.", 124 (2002), 152–159
[6] L. F. Hakim and al, "Powder Technol.", 160 (2005), 149–160
[7] A. K. Müller and al , Eur. J. Pharm. Sci., 34 (2008),303–308
[8] G. Baeza, "Nanocomposites industriels simplifiées: analyse structurale et propriétés mécaniques", Thesis 2013.
[9] J. B. Madeline and al, Langmuir, 23 (2007), 1645–1658.

SESSION 3

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Overall thermal performance of VIP – Comparison of Hot-Plate Measurements (GHP and HFM), Hot-Box Measurements and numerical simulation

C. Sprengard[a*]
L. Berger[a]

[a] Forschungsinstitut für Wärmeschutz e.V. München – FIW München – (Research Institute for Thermal Insulation) Lochhamer Schlag 4; 82166 Gräfelfing, Germany
* Corresponding author:
Tel. +49 89 8580058
Sprengard@fiw-muenchen.de

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Vacuum insulation panels,
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linear thermal transmittance,
overall thermal conductivity,
effective thermal conductivity,
overall thermal performance.

Abstract

The determination of the linear thermal transmittance ψ at the edges of VIPs and for joints in constructions containing VIPs is usually done by numerical simulation. The thermal bridging effects can be measured in hot-plate apparatuses (GHP and HFM) and Hot-Boxes as well, if the measurement method takes the non-uniform temperature distribution on the surface of the panels is taken into account.

Introduction

The thermal performance of all insulation materials is described by their thermal resistance or thermal conductivity. Usually thermal conductivity is used as it is similar or equal for all thicknesses of products sold by a manufacturer. In the case of VIP the declared thermal conductivity needs to consider the value determined in the center of panel (COP) and the additional thermal bridging effects at the panel edges. The different effects on the edge heat losses of VIPs with and without cover layers have been subject to many publications, e.g. [1][2]. If VIPs are applied additional thermal bridging effects occur depending on the material in the joint between the VIP panels, (air space or gasket strip), due to additional materials in the construction (e.g. plaster layers) and due to fasteners used [3],[4],[5].

The aim of the study is to determine the ψ-value of various VIP assemblies by different measurement methods (e.g. GHP, HFM and Hot-Box) and numerical simulations, in order to determine subsequently the overall thermal performance and compare the individual methods to each other.

Materials and methods

For the test series, glass fiber panels in the dimensions of 40 x 80 cm and 40 x 120 cm in the thicknesses 2 and 3 cm, as well as fumed silica panels in the same dimensions with thicknesses of 2 and 4 cm are used. The joint assembly of the glass fiber panels has a multilayered edge design in the metering area for hot-plate measurements whereas the joint assembly of the fumed silica panels has a single layered edge design. For the determination of the ψ-values Hot-Plate measures are used as well as Hot-Box measurements. The method of determining the ψ-value in the HFM and the GHP is described more accurately in [6]. Hot-Box measurements enable the determination of the U-value of complex or inhomogeneous samples such as VIPs. They meter the effective U-value of a VIP already including thermal bridging effects at all different stages according to ISO 8990. It is important to pay attention to uniform measuring setups in order to ensure reproducibility of the results. Especially in the case of Hot-Box measurement, test set-up consists not only of one panel pair, but of a setup containing several VIPs. Fig. 1 shows schematically the arrangement of the panels and the terminal diagram of the thermocouples.

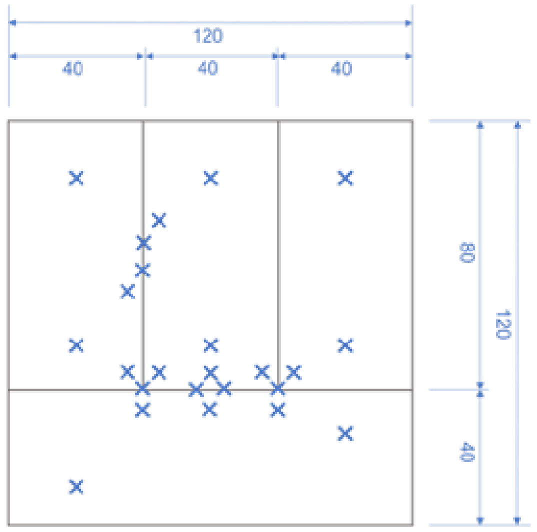

Fig. 1 Schematical arrangement of the panels and position of the thermocouples (x)

Due to thermal bridging effects (e.g. linear joints and T-joints) there is no homogeneous temperature distribution on the surface of the VIP set-up. So the thermocouples record the temperatures in three different temperature areas: There are TCs directly on the joints, (area strongly affected by thermal bridging), elements near the joint (slightly affected) and in the undisturbed COP-area. To disable airflows through the joints, they are masked with an adhesive tape (see Fig. 2).

Fig. 2 Installation in the Hot-Box

The determination of the thermal bridging effects is normally performed by numerical simulations according to ISO 10211. Since the thermal conductivity of the involved layers in a VIP differs very strongly (several orders of magnitude) and the dimensions are often very different (components: centimeters and meters, foils: nanometer and micrometer), the FD-method proves to be more robust [5]. The simulation of the thermal bridge effects by means of numerical simulations has some advantages. The influence of various envelopes, core materials, edge designs, joint-filler material, cover layer, etc., can be determined more quickly and sensitivity studies can be performed easily.

The multilayered edges are modelled with an air space between panel and flab (0.5 to 1 mm), because it is not possible to fix the flab on the VIP without any air space during measurements.

Results and discussions

Table 1 shows measured and calculated ψ-values of the fumed silica panels with a metallized foil and a single layered edge design and glass fiber panels with an aluminum foil and a multilayered edge design. There is a good correlation between GHP measurements and FDM results. HFM values are significantly lower. Further measurements are under way and will be presented at the conference in Paris together with possible reasons for the deviations.

	Linear thermal transmittance ψ in W/(m·K) obtained from…			
VIP Thickness	HFM	GHP	Numer. FDM	Hot-Box
20 mm (MF)	0.0049 ± 0.000392	0.0070 ± 0.00056	0.0070	-
40 mm (MF)	0.0027 ± 0.000216	0.0035 ± 0.00028	0.0040	to be presented in Paris
20 mm (AF)	0.095 ± 0.0076	to be presented in Paris	0.147	-
30 mm (AF)	0.079 ± 0.00632	to be presented in Paris	0.112	to be presented in Paris

Tab. 1 Comparison of results for ψ obtained from simulations and measurements

Conclusions and outlook

The complicated measurement and the high vulnerability of errors during the measurement setup (e.g. positioning of the thermocouples and thickness measuring) are two disadvantages of the metrological determination of the linear thermal transmittance. Therefore, simulations are usually used on the basis of FD-method to determine thermal bridging effects.

References

[1] K. Ghazi-Wakili, R. Bundi, and B. Binder: Effective thermal conductivity of vacuum insulation panels. Building Research & Information 32(4), 2004, :293.

[2] H. Simmler, S. Brunner: Vacuum insulation panels for building application - Basic properties, aging mechanisms and service life, Energy and Buildings 37, 2005, 1122–1131

[3] . Sprengard, M.H. Spitzner: Investigations into ageing and thermal bridging invacuum insulation panels (VIP) for construction applications, Bauphysik 33 (4), 2011 (German Journal for Building Physics)

[4] C. Sprengard, S. Treml, et al: Vakuum-Isolations-Paneele (VIP) in der Bauanwendung: vom Dämmstoff zum Dämmsystem (in German only)

[5] Sprengard, C.; Holm, A.H.: "Numerical examination of thermal bridging effects at the edges of VIPs in various constructions". in: Energy and Buildings, Elsevier (2014)

[6] Sprengard, C., Holm, A.: Determination of Linear Thermal Transmittance of Vacuum Insulation Panels by Measurement in a Guarded Hot Plate (GHP) or a Heat-Flow-Meter (HFM) Apparatus, Proceedings of the 12th Vacuum Insulation Symposium, Nanjing, 2015, P. 292-295.

Superinsulation material ageing, characterized by combined sorption analysis and thermal measurements

B. Chal[a*]
B.Yrieix[b]
G. Foray[a]
L. Roiban[a]
J-M. Chenal[a]
K. Masenelli-Varlot[a]

[a] Université de Lyon - INSA Lyon - Université Claude Bernard Lyon1, CNRS UMR 5510, MATEIS, 7, Avenue Jean Capelle, 69621 Villeurbanne Cedex, France - MATeB
[b] EDF R&D, MMC, Avenue des Renardières Ecuelles, 77818 Moret sur Loing Cedex, France - MATeB
* Corresponding author:
Tel. 04 72 43 63 98
bruno.chal@insa-lyon.fr

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pyrogenic silica,
silica aerogel,
microstructure,
hydrophilicity,
conductivity.

Abstract

Some commercial products, silica powders (both precipitated and pyrogenic) and aerogels, were aged in conditions ranging from 50 °C to 70 °C and from 70%RH to 90%RH during 24 to 384 days. Microstructural characterizations (nitrogen and water sorption) were performed to track any evolution in the structure as any modification of hydrophilicity. In complements, some thermal measurements were performed to rely to thermal conductivity.
As expected, severe conditions produce ageing (coarsening of pore size, lowering of the specific surface area, and change in the water adsorbed quantity) and provide first steps to understand mechanisms. In the next future, those data will be used as input in modeling tools providing conductivity results for less severe applications.
As products achieving adequate microstructure and surface properties exhibit durable thermal properties, new routes for superinsulation material should therefore focus on such material architecture.

Introduction

Superinsulation materials are of growing concern to achieve the target lowering of CO_2 emissions. Up to now, nanostructured silica based products failed to become widespread in building renovation field due to their high market price and decades of durability required. There is a common agreement on literature on the fact that silica pyrogenic and precipitated undergo microstructural ageing according to work done by Bonsack [1], Morel et al. [2–4] or Collins et al. [5]. Balard et al. [6] and Hamdi et al. [7,8] focused more precisely on pyrogenic silica. The aim of this study is to observe amorphous silica ageing, both in powder and aerogels. Several commercial products with different synthesis process (pyrogenic, precipitated), hydrophobic treatment, generation of product, specific surface area and pore size distribution were thus exposed to different atmosphere (T, RH%).

Experimental

As Volatile Organic Compounds (VOC) are known to have an influence on silica ageing [9], samples were placed in a protective polyethylene bag. These bags inhibit the VOC transfer but let water vapor goes through in the meantime.
The condition (23°C/50%RH) is used as a reference. Samples are aged in climatic chambers with a control over the temperature and the relative humidity. Depending of the product, following conditions were applied: 50°C/70%RH, 50°C/90%RH, 70°C/70%-RH and 70°C/90%RH.

Sorption measurements were performed on BelSorp Max and BelSorp Aqua from BELJAPAN INC, using respectively nitrogen and water probes. Samples were previously treated for 2h at 140°C under vacuum.

BET [10] and BJH [11] methods were applied on nitrogen isotherms in order to respectively extract the specific surface area and the pore size distribution.

Water sorption isotherm are direct pictures of the hydrophilicity. Using the specific surface area extracted from nitrogen sorption (S_{BET}) and the amount of water adsorbed for a relative pressure P/P_0, an index of the local hydrophilicity, ψ [μgW / m^2 $_{SiO2}$] can be determined:

$$\psi = \frac{\tau_{50\%}}{S_{BET}} \qquad \textit{(Eq.1)}$$

where

ψ = surface hydrophilicity [μg_W / m^2 $_{SiO2}$]
$T_{50\%}$ = water content for a relative pressure P/P_0 of 50% (water isotherm) [μg_W / g_{SiO2}]
S_{BET} = specific surface area [$m^2.g^{-1}$]

An estimation of silanol density is also reachable.

Thermal measurements were made on a heat flow meter according to standard EN 12 667.

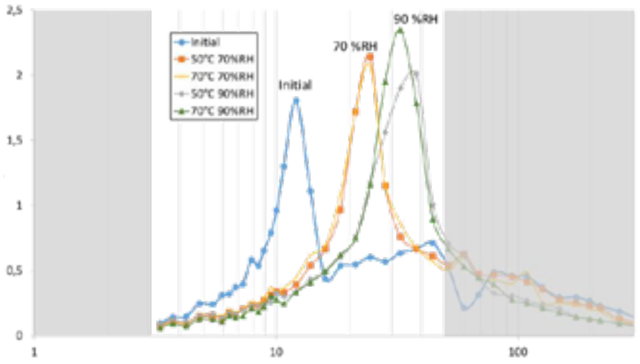

Fig. 1 Pores Size Distributions of silica aerogel (Ref. A) exposed to different conditions for 192 days.

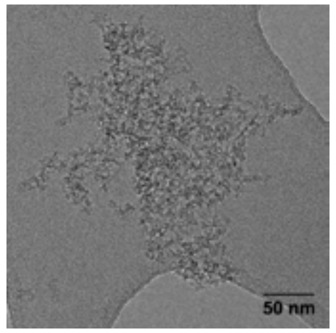

Fig. 2 TEM image of silica aerogel (Ref. B)

Results and discussions

Fig. 1 displays the pore size distribution of an aerogel (Ref. A) aged in different set of condition (T, RH) during 192 days. A shift of the pore size distribution, as well as a broadening could be observed. Such a behavior is associated with a loss of specific surface area, as measured by BET method. Increase of the hydrophilicity, both local (ψ) and macroscopic were also recorded. Such ageing was known for silica powder but not yet published for aerogels.

Duration (days)	0	48	240	360	384
λ (mW.m^{-1}·K^{-1})	14	17.4	17.7	18.1	18.2
Duration (days)	0	96	192	384	
Main Pore Size (nm)	12	33	33	33	

Tab. 1 Thermal conductivity measured on a silica aerogel (Ref. A) aged at 70°C and 90%

Table 1 shows the evolution of conductivity of an aerogel (Ref. A) aged in severe conditions (hot & moist) with time. Main pore size is also indicated. TEM confirmed that texture (Fig. 2) is observable. This gives a first hint to pore and particle neck measurement for all silica nature. As well as structural and chemical evolution, thermal conductivity could be impaired by an exposition to humidity and temperature.

The aim of this set of experiments is to highlight mechanisms involved in silica ageing. Those mechanisms and kinetics associated depend on the nature of the silica (precipitated, pyrogenic, aerogel) and on the process.

Conclusions and outlook

As well as silica powder, silica aerogels show ageing when exposed to hot moist conditions. Changes in structural properties, such as shifting and broadening of the pore size distribution or reduction of the specific surface area were observed. In the meantime, macroscopic hydrophilicity as well as surface hydrophilicity are modified. Those evolutions can possibly increase the thermal conductivity, especially the contributions coming from the solid backbone (growth of the neck diameter between particles) and the water adsorbed.

Nevertheless, after measurements on a panel of commercial products, notables distinction applied. In particular, aerogels with low and sharp pore size distribution are less sensitive to ageing. These properties, which cannot be separated from the hydrophobisation step, depend on the aerogel synthesis. Distinction between pyrogenic and precipitated silica are also highlighted. Such ageing behavior should thus be taken into account in future regulation dedicated to building superinsulation.

References
[1] J.P. Bonsack, Powder Technol. 15 (1976) 53-62
[2] B. Morel et al., 8th Int. Vac. Insul. Symp. (2007) 8
[3] B. Morel et al, Powder Technol. 190 (2009) 225-229
[4] B. Yrieix et al., Energy Build. 85 (2014) 617-630
[5] K.E. Collins et al., Appl. Surf. Sci. 254 (2008) 4029-4035
[6] H. Balard et al., Colloids Surfaces A Physicochem. Eng. Asp. 378 (2011) 38-43
[7] B. Hamdi et al., Colloids Surfaces A Physicochem. Eng. Asp. (2016
[8] B. Hamdi et al., Colloids Surfaces A Physicochem. Eng. Asp. 488 (2016) 46-51.
[9] B. Morel, thesis (2008)
[10] S. Brunauer et al., J. Am. Chem. Soc. 60 (1938) 309-319
[11] E.P. Barrett et al., J. Am. Chem. Soc. 73 (1951) 373-380

Application of vacuum insulation panel in slim façade: thermal bridge evaluation

F. E. Boafo[a]
SM. Kim[a]
JT. Kim[ab*]

[a] School of Energy Systems Engineering, Kongju National University, Cheonan, Chungnam, Republic of Korea
[b] Department of Architectural Engineering, Kongju National University, Cheonan, Chungnam, Republic of Korea
* Corresponding author:
Tel.(+82) 41 521 9333
jtkim@kongju.ac.kr

Keywords:
Vacuum insulation panel (VIP),
slim façade,
curtain wall system (CWS),
thermal bridge,
heat transfer.

Abstract

A wide variety of slim façades characterizes today's buildings; especially curtain wall system (CWS). However, energy demand to ensure comfortable indoor thermal environment is greater in highly glazed curtainwalls as compared to conventional buildings; since glazed systems generally have lower thermal mass than opaque walls. Thus, spandrel sections of CWS are insulated to minimize heat fluxes. In the Republic of Korea, spandrel area is required to satisfy U-value for building envelopes defined in the building energy code, currently limited to 0.21 W/m²K for walls. Traditional insulation materials require thickness in excess of 180 mm to satisfy such regulation; a space that cannot be afforded in CWS. On the other hand vacuum insulation panel (VIP) with minimum thickness of 25 mm satisfies the building code; although thermal bridges become relevant due to metal fixtures and difference in thermal properties with adjacent building envelope components. Based on 2D/3D steady state heat transfer simulations, influence of thermal bridges on the insulation performance of CWS with integrated VIP spandrel component was studied.

Introduction

Dating back to the 19th century, the stock of curtain wall systems (CWS) has evolved and abounds in today's architecture; due to improved daylighting levels and aesthetics, increased speed and quality of construction, smaller wall footprint resulting in extra floor area for occupants, material efficiency due to lighter structure, and structural flexibility and independency [1]. Generally, CWS are prefabricated penalized façades that wraps wholly or partially around a building, forming a barrier for the building against weather, but the curtain wall itself is non-load bearing. According to how they are built, CWS are broadly categorized into stick system, unitized system, column-cover-and-spandrel system and structural glazing system. However, energy demand to ensure comfortable indoor thermal environment is greater in highly glazed curtain walled buildings as compared to conventional buildings, especially during peak summer and winter; Thus increasing pressure to improve CWS thermal and energy performance is occurring globally [2, 3]. Consequently, CWS meticulously designed and prefabricated with glazed (vision) and spandrel sections (non-vision/opaque wall); the spandrel area in particular limits heat losses. In the Republic of Korea, the spandrel area is required to meet the thermal transmittance (U-value) for building envelopes defined in the building energy conservation code, currently limited to 0.21 W/m²K for walls. To satisfy this code, traditional insulation materials require thickness of over 180 mm, space that cannot be afforded in slim CWS. Conversely, vacuum insulation panel (VIP) is exceptional useful for space limited applications. Metal fixtures such as aluminum, steel truss, brackets and bolts, as well as enhanced insulation increases thermal bridges. The focus of this study was to investigate the ensuing thermal bridges and performance of CWS with integrated VIP spandrel sections, using 2D/3D steady state heat transfer simulations.

Methods

For the purpose of this study, computer modelling and simulation method was adopted. Based on selected general cases, the overall thermal performance of 967 mm × 967 mm CWS were investigated by 2D/3D steady state heat transfer simulations with Physibel TRISCO v.13.0 w. The modeling considered the edge effect (linear thermal bridge) between adjacent material panels in the spandrel section, as well as between mullion and façade. Also, point thermal bridges occurring at corner joints were accounted for. Boundary conditions for heat transfer simulations are depicted in Table 1. The VIP was modelled with effective thermal conductivity value of 0.00424 W/mK.

	Temperature, °C	Surface heat transfer coefficient, W/m^{2}K
Exterior	-11.3	25
Interior	20	7.7

Tab. 1 Boundary conditions

Results and discussions

The overall heat transfer coefficient, U_o, is a factor of linear and point thermal bridge, expressed by:

$$U_o = \frac{(U_u \cdot A + \sum_i \psi_{i,length} \cdot l_i + \sum_j \psi_{j,\text{point}} \cdot n_j}{A} \quad (1)$$

where U_u is bulk heat transfer coefficient without thermal bridge (W/mK), A is area (m^2), ψ_{length} is linear thermal bridge, l is length (m), ψ_{point} is point thermal bridge, and n is number of point thermal bridges. Fig 1 and 2 represent the thermal gradients and heat flow contours for simplified highly glazed CWS and stick CWS with vision and spandrel sections, respectively. Table 2 represents results for the highly glazed CWS and CWS with coupled vision and spandrel sections.

Similarly, Table 3 shows results for decoupled spandrel sections of same size as tabulated in Table 2. In Tables 2 and 3, T_d is total thickness, VIPd is thickness of VIP, $U_{1\text{-}D}$ is thermal transfer assuming one-dimensional heat transfer, $U_{2\text{-}D}$ is twodimensional heat transfer, 2D/3D factor is the surplus thermal transmittance correction term for the 2D and 3D effects of thermal bridges compared to the are weighted one-dimensional thermal transmittance, U_{eff} is effective heat transfer coefficient including linear, point and frame thermal bridges, and T_f is temperature factor. From Fig 1, the interior surface temperature of the highly glazed CWS was about 7-13°C while that for the coupled CWS was 15-20°C; heat flow through the former was more than the latter, that is nearly 79 W/m to 56 W/m. $U_{1\text{-}D}$ considers heat transfer with no thermal bridges while $U_{2\text{-}D}$ factors linear thermal bridges. $U_{1\text{-}D}$, $U_{2\text{-}D}$ and U_{eff} for the highly glazed CWS increased from 1.67 to 2.15 to 2.68 respectively (all in W/m^{2}K); reasonably as linear, point, and frame thermal bridges were evaluated at each step. Integrating the VIP spandrel reduced initial $U_{1\text{-}D}$, $U_{2\text{-}D}$ and U_{eff} to 1.14 to 1.28 to 1.89 respectively (all in W/m^{2}K). However, insulation tends to also increase thermal bridges; seen by the increase in 2D/3D factor. For both, the area of intense heat loss was around the mullion joints and mullion-panel junctions (see Fig 2).

In addition, heat flux through the VIP spandrel section was quite restricted to 5-15 W/m^2 while that for the vision section was about 40-70 W/m^2. For the results of decoupled spandrels summarized in Table 3, aluminum frame wood panel spandrel achieved the lowest heat loss, thermal bridges and U_{eff}.

Of significance is T_f, in order to assess the risk of surface condensation. T_f is evaluated using:

$$T_f = \theta_{si,\min -} \theta_e / \theta_i - \theta_e \quad (2)$$

θ_i and θ_e are internal and external boundary condition temperature (°C) and $\theta_{si,min}$ is minimum internal surface temperature (°C). The closer the value is to 1, the less likely that condensation will occur.

Assembly	T_d, mm	ψl_{ength}, W/mK	$U_{1\text{-}D}$, W/m^2·K	$U_{2\text{-}D}$, W/m^2·K	2D/3D factor, W/K	U_{eff}, W/m^2·K	T_f	Heat loss, (W/m)
Fully glazed stick CWS	28	0.47	1.67	2.15	0.94	2.68	0.48	78.5
20 mm VIP spandrel and vision stick CWS	36	0.45	1.14	1.28	1.58	1.89	0.49	55.6

Tab. 2 2D/3D thermal performance of various curtain wall systems

Assembly	T_d, mm	VIP_d, mm	ψ_{length}, W/mK	2D/3D factor, W/K	U_{eff}, W/m^2·K	T_f	Heat loss, (W/m)
Steel truss metal panel spandrel	76	20	0.63	1.36	1.62	0.62	47.4
Aluminum frame wood panel spandrel	59	20	0.54	0.74	0.97	0.72	28.5
Glass clad VIP spandrel	36	20	0.65	1.26	1.56	0.49	45.6

Tab. 3 2D/3D thermal performance of various spandrel sections with 20 mm thick VIP

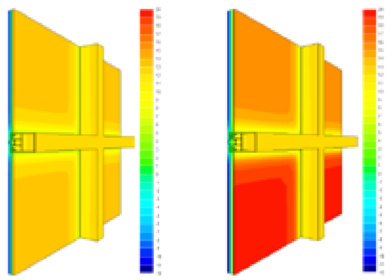

Fig. 1 Isotherms (color increment of 1°C, line increment of 5°C): highly glazed CWS (left) and 50 % vision-50 % spandrel CWS.

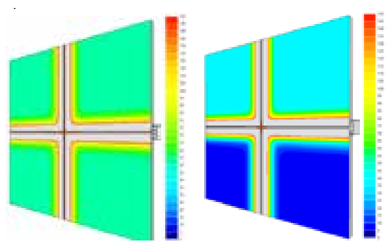

Fig. 2 Heat flow lines (color increment of 0.1 W/m, line increment of 5 W/m): fully glazed CWS (left) and 50 % vision-50 % spandrel CWS.

Conclusions and outlook

Thermal performance of VIP integrated curtainwalls has been studied using 2D/3D steady state heat transfer simulations. By robust design, thermally high performing CWS can be achieved, while maintaining its aesthetics. Such CWS are possible with VIP integrated spandrels that serve to limit heat flux.

Acknowledgements

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References
[1] K. Kazmierczak et al. Proceedings of BEST2 2010
[2] F.P. Torgal et al. Springer 2013
[3] L.D. Carbary et al. Proceedings of ICBEST 2014.

Affordable And Adaptable Super-Insulation Solutions For Energy Efficient Retrofitting Of Public Buildings

A. Uriarte[a*]
I. Garai[b]
A. Ferdinando
O. Nicolas[a]
E. Barreiro[a]

[a] TECNALIA, Edificio 700 Parque Tecnológico de Bizkaia, Derio (Bizkaia) 48160, Spain
[b] ISOLEIKA, Galartza Ind. Pol., 3 48277 Etxebarria, Bizkaia
* Corresponding author: amaia.uriarte@tecnalia.com

Keywords:
Vacuum insulation panels,
superinsulation,
façade retrofitting,
NZEB,
energy efficiency.

Abstract

VIPs represent a huge opportunity to reach Nearly Zero Energy Buildings, especially in the retrofitting of existing buildings. VIPs can be applied in conjunction with façade cladding elements, considerably reducing the heat loss from the building by means of very slim wall construction systems or retrofitting solutions. However the fact that (1) VIPs cannot be cut on-site, (2) can be easily damaged during their handling, installation & use and (3) poor unions and the combination with other materials can lead to thermal bridging effects, has hindered their penetration in the construction market.

The FP7 project A2PBEER has developed two construction solutions that have tackled all these issues and have been installed on the entire facade of two existing buildings (3000 m^2) subjected to an integral rehabilitation process This paper presents the lessons learnt during the design and installation process and the thermal performance achieved after their retrofitting.

Introduction

Accounting for 40% of energy consumption, building construction is one of the main final energy consuming sectors; with space heating and cooling in the occupation phase of the buildings being the most energy demanding activities in a buildings whole lifecycle.

It is estimated that there are 25 billion m^2 of useful floor space in the EU27, Switzerland and Norway [1].

Considering that more than 70% of the EU building stock was built before the first energy crisis (1970's) with low or no energy performance standards, there is a huge potential to reduce energy consumption in the building sector. This, along with annual growth rates of around 1% in the residential sector and with the increasing population projections, have clear implications on future energy needs, e phasising the subsequent urgency for improving the energy performance of existing buildings and increasing the number of zero-energy buildings [2].

The relevance of the building envelope to reach net zero energy building

A nearly Zero Energy Building is a building that has a very high energy saving performance , i.e. very low amount of energy required for heating, cooling, ventilation, domestic hot water and lighting. This very low demand for energy shall be covered, to a very significant extent, by energy from renewable sources.

The building envelope plays a key role in achieving this low energy target, contributing up to 50% of heat losses [3] and thus has been transferred to the requirements of the opaque façade elements of National Building Codes which are setting U values of around 0.2 W / m²K, close to that of PassivHaus.

To reach these thermal transmittance values, a buildings' façade would need an additional 20-25 cm of conventional insulation with thermal conductivities ranging from 0.030 to 0.040 W/mK. When integrated in a façade solution this leads to bulky or voluminous façade solutions which in some cases are not possible when applied on the exterior or occupy valuable internal space. In this sense, VIPs with a declared thermal transmittance of 0.005W/mK allow these targeted façade transmittance values to be achieved in thin solutions with 3-4 cm of insulation.

Retrofitting solutions with VIPs

However the fact that VIPs cannot be cut on-site, can be easily damaged during their handling, installation and building use as well as causing thermal bridging effects have hindered their penetration in the construction market. Based on these premises and the current rehabilitation needs of the existing building stock, the FP7 A2PBEER project has developed two construction solutions; one for the interior and one for the exterior.

The initial design specifications set for the solutions were to reach a thermal transmittance of 0.16 W/m²K with a total thickness of 100mm, to be easily installed and robust, to have correct hygro-thermal behaviour and that the integrity of the system should be guaranteed in possible future uses of the facade without a decrease in the thermal properties.

The solutions deployed are (a) a stud-mounted internal system and (b) an external ventilated façade with 30 mm thickness VIP integrated in both. With a declared thermal conductivity of 0.005 W/mK, 30 mm of VIP can lead to surface-surface thermal transmittance (U) of 0.17 W/m²K.

When integrated in the interior solution the obtained U value is 0.14 W/m²K, calculated by applying the EN 6946 [4] and for the exterior, 0.276 W/m²K including the effects of system edges and the metallic structures thermal bridges, calculated according to the EN10211 [5].

From the overall U value calculations, it can be seen that in highly insulated façades, tackling the elements that lead to 2D and 3D thermal bridges is of upmost importance in order to avoid worsening the overall thermal transmittance of the system.

Challenges In Building Retrofitting With Vips

These VIP solutions have been used in the retrofitting of two existing building retrofitting projects and the major challenges faced at the design stage were to:

> Maximize the thermal performance of the façade, (minimizing edge effects and the use other insulation in corners or any other areas where VIPs could not reach)

> Maximize the number of standard size panels (the most cost effective and those with better overall U because minimum edge effect)

> Minimize the installation time by reaching a reasonable number of non standard panel sizes that need to be handled onsite while keeping the maximum area covered with VIP.

Therefore, the design process followed in the A2PBEER project to integrate the VIP solutions began with the 3D scanning of the demo-site buildings and the deployment of precise drawings; this was followed by the external cladding layout design and concluded with the layout of the VIPs to best fit this configuration.

Results and discussions

These retrofitting projects have been implemented in two existing buildings located in Malmö (Sweden) and Bilbao (Spain), where the their entire façades have been retrofitted with VIP solutions covering an area of 3000 m² as well as a small scale prototype in Tecnalias' KUBIKs Research Centre.

The objective has been two-fold, (a) to assess the VIP installation at a large scale in real construction sites and (2) to assess the hydrothermal behaviour of the façade solution and the overall energy efficiency of buildings after the retrofitting process.

Using the Swedish whole building's space heating monitoring data from the previous year and those after the intervention, preliminary results indicate that an average of 32% energy use reductions has been achieved after the retrofitting of the existing 0.54W/m²K façade with the external VIP solution along with windows replacement.

From the small scale internal solution prototype installed in KUBIK, data driven U values calculated with the application of the ISO 9869 standard to in situ façade monitoring data, have lead to values between 0.164 and 0.385 W/m²K. From the residual analysis and the infrared thermographs, these deviations between values are very likely to be caused by the thermal bridges of the metallic studs connected to the pre-existing 10 cm concrete wall by a timber frame.

Fig. 1 exterior solution installation in Malmö (Sweden) demo site.

Conclusions and outlook

VIPs represent a huge opportunity to reach the new targeted façade thermal transmittance requirements and very low Energy Buildings with thin retrofitting solutions. This has been observed with the retrofitting of 3000 m² of façade elements in two existing buildings, in which preliminary results suggest a 32% energy use reduction after retrofitting. However the need to treat the thermal bridges caused by mechanical fixation of the solutions to the existing façade is of high relevance since they may significantly worsen the overall façade thermal behaviour as has been observed with in-situ data driven analysis and the application of the EN10211.

Acknowledgements

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References
[1] BPIE, Europe's buildings under the microscope, 2011
[2] Directive 2010/31/EU recast
[3] IMPRO-Building, Environmental Improvement Potentials of Residential Buildings, 2008
[4] EN 6946 Building components and building elements - Thermal resistance and thermal transmittance - Calculation method
[5] EN10211:2011, Thermal bridges in building construction - Heat flows and surface temperatures - Detailed calculations

Evaluation of Embedded VIPs for Use in the Building Envelope

K. Biswas[a*]
T. Jiang[b]
D.W. Yarbrough[c]
A.O. Desjarlais[a]

[a] Oak Ridge National Laboratory, 1 Bethel Valley Rd., Oak Ridge, Tennessee, USA
[b] Vanderbilt University, 2301 Vanderbilt Place, Nashville, Tennessee, USA
[c] R&D Services, 102 Mill Drive, Cookeville, Tennessee, USA
* Corresponding author:
Tel. +1 (865) 574-0917
biswask@ornl.gov

Abstract

An objective for expanded use of vacuum insulation panel (VIP) products in buildings will be assisted by an understanding of the relationship between small-scale laboratory thermal measurements and large-scale tests of building components. Thermal resistances of a typical element of VIP embedded in closed-cell cellular plastic (foam) insulation obtained with a heat flow meter (HFM) apparatus are compared with results obtained with a hot-box facility for a building component. Small-scale samples of the foam-VIP composites were measured in single- and multi-transducer HFMs. The multi-transducer HFM was used to determine the heat flow distribution across the different sections of the VIP, i.e. center-of-panel vs. edges and joints. These measurements enable validation of numerical models, which can be utilized to model and evaluate large-scale building components containing VIPs.

Keywords:

Modified atmosphere insulation, composite foam insulation, multi-transducer heat flow meter.

Introduction

Oak Ridge National Laboratory (ORNL) has recently collaborated with industry partners (Firestone Building Products Company and NanoPore, Inc.) to develop composite foam boards containing vacuum insulation panels (VIPs), which can achieve 2-3 times the thermal resistance of current building insulation materials.[1] The VIP used within these prototype composite foam boards is called modified atmosphere insulation (MAI). MAI uses similar core and barrier materials as VIPs [1] and achieves the same center-of-panel performance, but can be manufactured at a much lower cost.[2] Fig. 1 shows a schematic of the composite foam boards containing the MAI panels; MAI panels are the darker sections. During manufacturing, the MAI panels were attached to a 1.3 cm high-density (HD) polyisocyanurate (PIR) foam board and then another 1.3 cm of regular PIR foam was spray-applied on top. The regular PIR foam also filled the gaps between the MAI panels (the gaps between the darker MAI sections in Fig. 1). The MAI panels were 2.5 cm thick, resulting in an overall thickness of 5.1 cm. The composite boards were of standard dimensions used in building construction, 2.44 m by 1.22 m. The prototype boards contained twelve (12) MAI panels each. Four (4) different MAI dimensions were used to obtain fractional area coverage of MAI panels of 0.87, 0.90, 0.91 and 0.94. The first three designs contain 2.5 cm foam gaps between the MAI panels along the length and/or width to accommodate mechanical fasteners commonly used in building construction. The infrared image in Fig. 1 illustrates the variation in heat flows through the MAI and foam-only sections of the composite board. The nominal center-of-panel (COP) thermal conductivity of MAI is 0.004 W/m-K, compared to ~0.026 W/m-K of PIR foam.

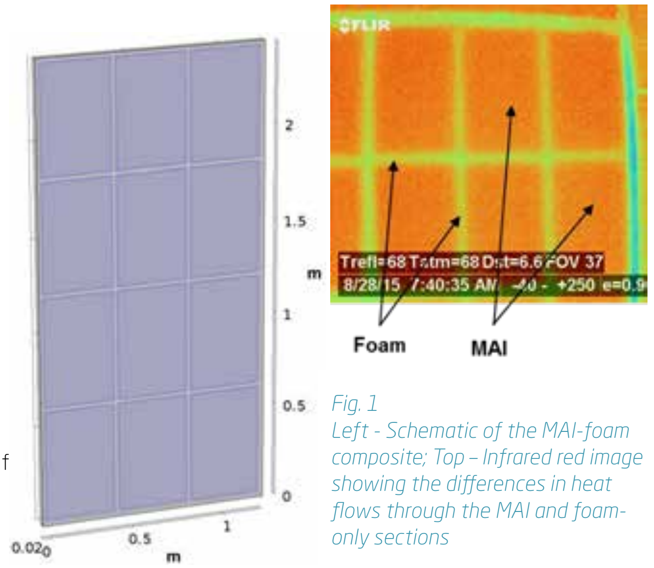

Fig. 1
Left - Schematic of the MAI-foam composite; Top – Infrared red image showing the differences in heat flows through the MAI and foam-only sections

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[1] https://energy.gov/sites/prod/files/2016/04/f30/31395_Biswas_040616-1020.pdf
[2] https://energy.gov/sites/prod/files/2014/07/f17/emt60_Biswas_042314.pdf

Thermal characterization

The prototype composite boards were evaluated using ORNL's guarded hot box according to ASTM standard test method C1363 [2]; two boards were combined to form 2.44 x 2.44 m test samples. Smaller (0.61 x 0.61 m) composite samples were also manufactured, each containing four (4) 0.27 x 0.27 m MAI panels. The cross-section of the smaller composites was the same as the full-size composite boards. In the smaller composites, the MAI panels were embedded with 1.3-2.5 cm foam gaps in between or with the MAI panels adjacent to each other without gaps. The smaller panels were tested according to ASTM C518 [3], with the intent of extrapolating and comparing the results to full-scale samples. The C518 tests were done using a multi-transducer heat flow meter (HFM), which can map the heat flow distribution over the different composite sections. Fig. 2 shows the matrix of HFM transducers and the measured heat flows in two composites with different MAI (blue sections) arrangements. The differences in the heat flows through the MAI COP vs. edges and foam-only sections are clear.

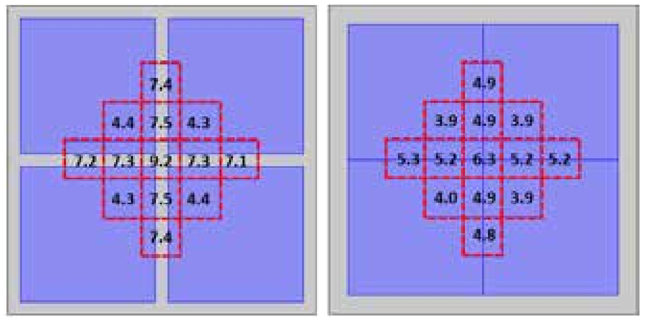

Fig. 2
HFM measurements of small-scale composites; the numbers represent measured heat flows in W/m²

Experimental data and analytical predictions

The heat flow measurements from the HFM tests were combined with series-parallel calculations of thermal resistance to predict the thermal resistance of the full-scale samples and compared against the hot box test results. The following equations were used:

$$R_{Comp.} = R_{HD} + R_{MAI-PIR} + R_{PIR} \qquad \text{(Eq.1)}$$

$$\left({}^{A}/_{R}\right)_{MAI-PIR} = \left({}^{A}/_{R}\right)_{MAI} + \left({}^{A}/_{R}\right)_{PIR} \qquad \text{(Eq.2)}$$

'R' is the thermal resistance in m²-K/W, 'A' is the area in m², the subscripts 'Comp.', 'HD', 'MAI-PIR' and 'PIR' represent the overall composite, the high-density board, the MAI layer with foam-filled gaps and the regular-density polyisocyanurate layer, respectively.

Thermal resistances of six small-scale composites were determined using the HFM. The average temperature for the HFM tests was 23.9°C. The multi-transducer HFM-measured heat flows were averaged to characterize the thermal resistance of the tested composites. Eqs. 1 and 2 were used to calculate the effective thermal resistance of the MAI panels from the average thermal resistance of the composite and previously-measured thermal conductivities of the foam components; the conductivities of the high-density board and regular PIR are 0.029 and 0.024 W/m-K, respectively. One of the six composite panels in the set (number 5) appeared to be an outlier. Table 1 contains the HFM data analysis results.

Next, the estimated MAI resistance and series-parallel calculations were used to estimate the overall thermal resistance of full-scale composites and compared to the ASTM C1363 measurements. The C1363 tests of the full-scale composites were performed at the same average temperature as the HFM measurements.

Sample #	R (Composite)	R (MAI)
1	3.89	6.32
2	3.96	6.74
3	3.33	3.78
4	3.39	3.98
5	4.62	14.59
6	3.83	5.98

Tab. 1
Estimated MAI thermal resistance (R, m²-K/W) using HFM measurements

Table 2 compares the hot-box results with estimated thermal resistances using the HFM analysis. The measured resistances of the composite boards were in the range 3.8-4.2 m²-K/W; the composite boards in three tests contained 1-2 damaged MAI panels, which have a measured conductivity of 0.019 W/m-K. Analytically, two estimates were obtained, one using the average MAI resistance calculated from all six HFM tests and another excluding the outlying HFM test (number 5). The analytical estimates excluding the outlying HFM result showed reasonable agreement with the measured data, within 8-18%.

MAI fraction	R (measured)	R (estimated, with HFM # 5)	R (estimated, without HFM # 5)
0.87	3.80	4.98	4.47
0.90	4.07	4.99	4.49
0.91	4.03	4.82	4.37
0.94	4.18	5.12	4.59

Tab. 2
Measured and estimated thermal resistance (R, m²-K/W) of the full-scale composites

Conclusions and outlook

Measured and calculated thermal resistances of 5.1 cm thick foam-vacuum composite insulation boards are presented. Hot box-measured resistances of full-scale composites were 3.8-4.2 m^2-K/W. In comparison, common foam insulations used in buildings yield 2.1 m^2-K/W or less at 5.1 cm thickness. Analytical estimates using heat flow meter test data of small-scale composites and series-parallel equations were within 8-18% of the hot-box measurements.

Acknowledgements

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References
[1] IEA Annex 39, Subtask A, H. Simmler et al. 2005.
[2] ASTM C1363, Annual Book of ASTM Standards, Volume 04.06 (2014) pp. 798-841.
[3] ASTM C518, Annual Book of ASTM Standards, Volume 04.06 (2014) pp. 156-171.

SESSION 4

Dry and wet application of VIP layers as internal insulation to brick walls. Measurement and Simulation

K. Ghazi Wakili[a*]
Th. Stahl[a]
R. Vonbank[b]
S. Brunner[b]

[a] IABP Institute for applied building physics, Zuercherstrasse 200, CH-8406 Winterthur, Switzerland
[b] Empa Swiss Federal Laboratories for Materials Science and Technology, Ueberlandstrasse 129, CH-8600 Duebendorf
* Corresponding author:
Tel. +41 213 95 95
info@iabp.ch

Keywords:

Internal insulation,
weathering chamber,
wooden beam,
2D hygro-thermal simulation,
double VIP layer.

Abstract

Internal insulation is a topic of interest especially for energy efficient retrofit of historical buildings. The high thermal efficiency of VIP allows a slim construction but influences strongly the hygro-thermal behavior of external walls. The present investigation compares weathering chamber measurements with 2D hygro-thermal simulations of two partitions of a traditional brick wall internally insulated by VIP. On one partition, the VIP has been applied by a dry method using fixing elements and on the second partition the application has been done by a wet method using adhesive mortar.

Introduction

Using internal insulation for energy-efficient retrofit of old and historic buildings remains an up-to-date topic [1] and especially for VIP's with their high thermal resistance allowing slim additional layers leading to a minimum loss of internal surface and volume [2].

An extensive investigation has been carried out to understand the impact of VIP's as internal insulation applied to a brick-wall with respect to heat and moisture transfer, using both experiments and simulation.

Fig. 1
The investigated T-shaped brick-wall with two wooden beams and two different VIP-systems as internal insulation separated by an internal wall

The whole assembly of the investigated brick-wall is shown in Figure 1. Additionally, a horizontal cross-section of the wall including the wooden beams and VIP systems is shown in Figure 2. On the left side, frames for the VIP's were used representing a dry fixing method. On the right side, an adhesive mortar was used to fix a VIP sandwiched between two EPS layers representing a wet method.

Measurements

A weathering chamber was used to simulate weather cycles on the external surface of the investigated wall, whereas the lab climate represented the internal boundary conditions. Temperature and humidity sensors were placed on different sites on the surfaces as well as inside the wall (Fig. 2 P1 to P6).

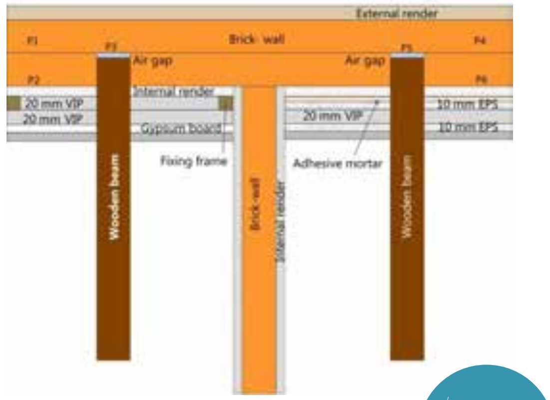

Fig. 2
Horizontal cross-section through the model of the T-shaped brick-wall. Positions of temperature and moisture sensors are indicated by P1 to P6

The wall has been submitted first to 40 cycles, each with a sunny and a rainy phase of 7 hours total length. This is, followed by 3 heat and cold cycles of 24 hours each followed by 5 heat rain freeze and thaw cycles of 24 hours each. Between the different regimes a climate of 20°C/50% rh was kept for 48 hours. Figures 3 and 4 show the temperature evolution and the amount of rainwater for the whole weathering period of 568 hours. Additional measurements were carried out on all the used materials to determine their hygro-thermic properties to be used directly for the 2D simulation in order to avoid using values from literature.

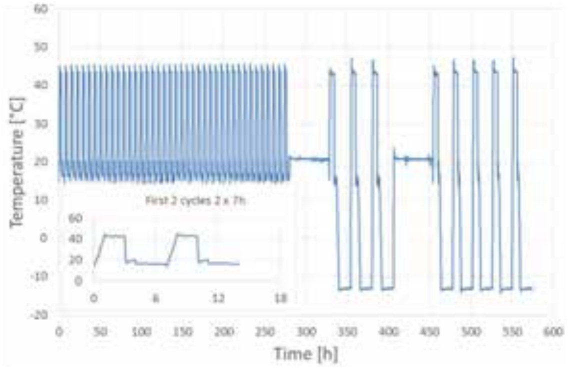

Fig. 3
Measured temperature inside the weathering chamber representing the external air temperature for the investigated wall (2nd half: ice & thaw cycles)

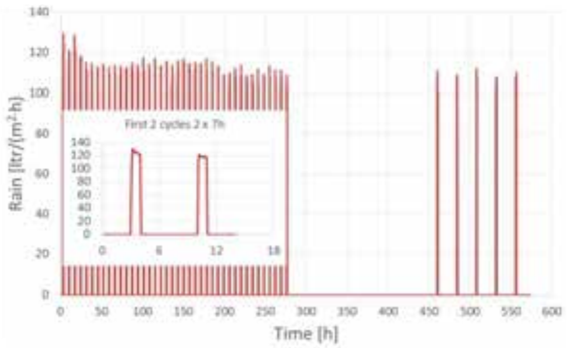

Fig. 4
Measured amount of water through 3 nozzles representing rain in the weathering chamber during the same period as Fig.3

Hygro-thermal simulation

A 2D simulation [3] for time dependent temperature and moisture distribution has been carried out using a very detailed model of the investigated wall (Fig. 5).

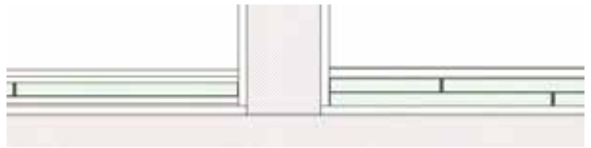

Fig. 5
Details of the model for hygro-thermal simulations considering single VIP's (core, envelope and air gap)

Results and discussions

Measured temperature and rel. humidity at P2 and P6 (Fig.2) are shown for both with and without VIP installation in Figures 6 and 7 respectively. Figure 8 shows the calculated relative humidity at P2 with the VIP's installed dry installation of a VIP double layer increases the rel humidity between VIP and wall (P2) to about 70% when the initial value is around 60%. A wet installation of VIP's shows little drying at the initial wall (P6) as the initial rel. humidity of 100% due to the wet gluing plaster dries out to only 90%.

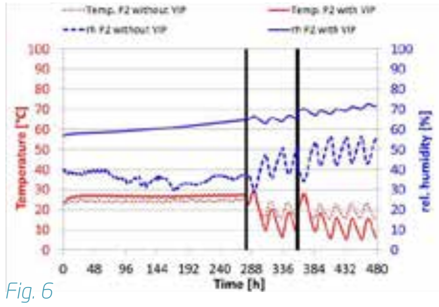

Fig. 6
Measured temperature and rel. humidity at position P2 (Fig. 2) with and without VIP on the wall

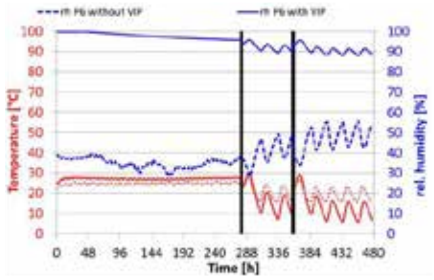

Fig. 7
Measured temperature and relative humidity at position P6 (Fig. 2) with and without VIP on the wall

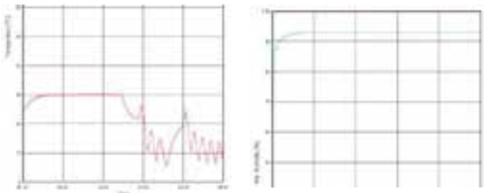

Fig. 8
Calculated temp. at P2 and rel. humidity at P6

Conclusions and outlook

It is very important to use a dry method for installing VIP's as internal insulation. Any additional moisture will be trapped and can damage the underlying wall.

Acknowledgements

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References
[1] M. Morelli et al. J Build Phys 36 (2013) 265-293.
[2] P. Johansson et al. Build Environ 79 (2014) 31-45.
[3] WUFI® 2D, https://wufi.de/en/software/wufi-2d/

VIP as a premium insulating material for Thermal Management of mobility systems

C. Huillet[a*]
C. Blanchard[a]
M. Leborgne[a]
F. Chopard[a]

[a] Hutchinson Research & Innovation Center,
Rue Gustave Nourry
45120 Châlette-sur-Loing, FRANCE
* Corresponding author:
cedric.huillet@cdr.hutchinson.fr

Keywords:

Vacuum insulation Panels,
advanced thermal management,
thermal energy storage,
body insulating system.

Abstract

A Innovation through differentiated solutions – that's how Hutchinson Automotive Thermal Management Systems addresses a wide range of challenges facing the automotive, commercial vehicle and electric vehicles. Drawing on the vast research-integrated chemistry, materials science and mechanical engineering expertise of the Hutchinson Company, Hutchinson Automotive Thermal Management Systems collaborates closely with customers to develop products, powertrain and structural applications that help: boost energy efficiency, improve safety and health, reduce exhaust emissions and increase vehicle quality, durability and robustness.

The integration of superinsulating materials such as VIP in thermal management technologies is one of the key points allowing Hutchinson to design the most efficient systems. The insulation sizing makes Hutchinson possible to fulfill all the issues the OEMs are concerned about like weight, space and heat transfer optimization.

In this paper, two VIP integrated systems will be introduced focusing on the main VIP advantages: thermal storage unit for CO_2 emission reduction and the dynamic body insulating system for batteries lifetime enhancement.

Introduction

European standards become more and more restrictive regarding CO2 emissions for conventional vehicles. In 2017, the limit of dioxide carbon emission in Europe is 116 g/km but this will be lowered to 95 g/km in 2020 and probably to 50-60 g/km in 2030.

Facing to this big issue, the OEM are investigating different ways among witch thermal management systems is one of the most promising technologies. Latent Thermal Energy Storage (LTES) tanks composed of Phase Change Material (PCM) and Vacuum Insulation Panels (VIP) is one of the answer developed by Hutchinson for engine warm-up and consequently for CO_2 emissions reduction during the car start-up.

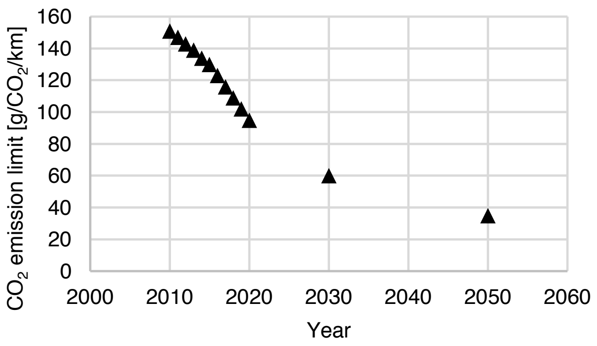


Fig. 1
Evolution of the CO_2 emission limit acoording to European standards

Thermal management solutions could be also involved in the new generations of vehicles such as full electric (BEV) or hybrid (HEV) cars. The lithium-ions battery cells lifetime is very affected by the temperature. The optimal temperature range has to be targeted between 15 to 40 °C or even 25 to 35 °C.

To avoid an extra-cost (from 8 to 12 k€) each 4-8 years due to the battery replacement, a smart thermal system composed of VIP and PCM could be used to maintain this optimal range and then to enhance the durability of the battery.

VIP for Heat Storage Tank insulation

The efficiency of conventional combustion engine during a cold start decreases with the temperature. During the first 3 minute of usage, the engine overconsumption could reach 35%.

A Latent Thermal Energy Storage (LTES) unit could greatly improve the engine warm-up. Hutchinson developed a unique Latent Storage unit based on the combination of materials. This system introduced in Figure 2, is based on PCM and VIP components. PCM could be adjusted according to the temperature involved in the application and VIP thickness can be optimized to reduce the thermal losses.

The soaking phase during the two different car usages imply the best thermal efficiency and thermal insulation to get the bigger calories amount available after 12h of parking.

Fig. 2
Demonstrator of VIP integrated LTES for car and warm-up application

The Figure 3 represents the difference between a Latent Thermal Storage with a conventional insulation material (Polyurethane) or with a VIP for a given storage volume after 12h of soaking phase. The LTES energy is calculated by the following formula:

$$E = ((M_{mcp}Cp_{mcp})+(M_{fluid}Cp_{mcp}) + (M_{component}Cp_{component})) * (T_{int} - T_{ext})$$

Due to the very low thermal conductivities of VIPs (λCOP < 7 mW/(m.K)), the insulation thickness is thinner than for other conventional materials and the available volume to store energy could be increased. The CO_2 emission reduction on a conventional vehicle has been measured around 1,5 gCO_2/km in a New European Driving Cycle (NEDC).

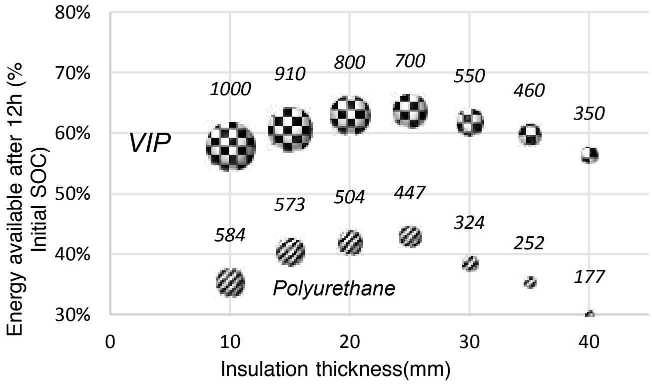


Fig. 3
Improvement of Thermal energy in a LTES by the integration of a VIP insulation against Polyurethane insulation.

At the end, the LTES technology could be also integrated on a water loop for cabin air-preconditioning.

VIP for Battery Thermal Management

Tests on systems made of combination of PCM and VIP were carried out to prove the feasibility and the interest of the technology to enhance battery lifetime.

As presented in the Figure 4, the effect of dynamic barrier composed of PCM and VIP is quite significant and has a great impact on temperature peak shaving, temperature homogenization and thermal preconditioning.

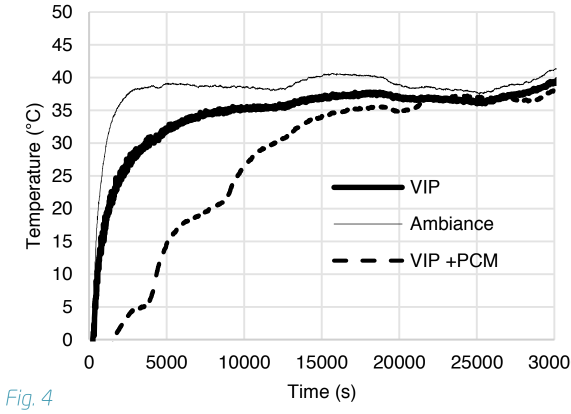
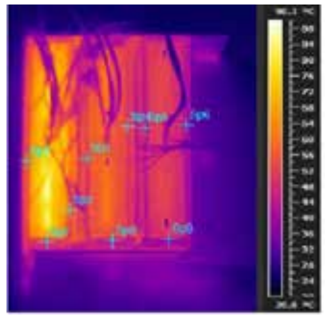


Fig. 4
Impact of VIP and dynamic barrier on battery pack temperature

This autonomous and innovative temperature control system could support the active cooling system traditionally used in lithium-ions batteries.



Then, in case of cells overheating, VIP allows to slow down the heat transfer with a minimum required space/weight and consequently avoid the overheat of other cells in the pack

Fig. 5
Dynamic barrier used in battery module

The results on battery pack with a simulation of long term parking in different ambient conditions show that is it possible to keep in the optimal range of temperature the pack during more than 8 hours.

Conclusions and outlook

Though this two concrete examples, it was shown how superinsulating materials such as VIP could be integrated in thermal systems in order to meeting standards on CO_2 emissions or final customers' expectations regarding the battery lifetime.
Hutchinson is developing strong skills on materials and thermal systems engineering that allows to already test all the components in the final use.
All the VIP requirements including thermal, mechanical, chemical performances and ageing should be took in account to provide the best and the most viable insulation for the automotive applications.

Aerogel Insulation Materials for Envelopes of Heritage Buildings

M. Ganobjak[a*]
J. Wernery[b*]
S. Brunner[b]

[a] Faculty of Architecture, Institute of History and Theory of Architecture and Monument Restoration, Slovak University of Technology in Bratislava, Námestie slobody 19, 812 45 Bratislava, Slovak Republic
[b] Laboratory for Building Energy Materials and Components, Empa - Swiss Federal Laboratory for Science and Technology, Überlandstrasse 129, 8600 Dübendorf, Switzerland
* Corresponding author:
ganobjakm@fa.stuba.sk
jannis.wernery@empa.ch

Keywords:

Aerogel,
architectural heritage,
refurbishment,
energy upgrade.

Abstract

The work intended to present at IVIS deals with existing solution on aerogel based products on heritage objects for preservation of appearance & conservation of the building substance. It compares ordinary refurbishment and heritage building preservation on heritage criteria (Authenticity, Integrity, Reversibility, Compatibility) with specific benefits. Specific positions of product types (plaster, boards, blanket, panels) in application on heritage buildings with benefits and possible harm get covered.

Aerogels bring many positive properties, which can be used in preservation of heritage objects, if they are used according to generally known rules and conditions on heritage objects.

Introduction

Historical buildings can contain several tangible values of architecture. In case of their refurbishment, the owner or the architect representing them might propose that these values should be conserved, or on the other hand, they might be protected officially by the local or national office for monument protection. Conventional insulation materials require the application of thick insulation layers. Aerogels may offer another benefits [1] for envelopes of historical building.

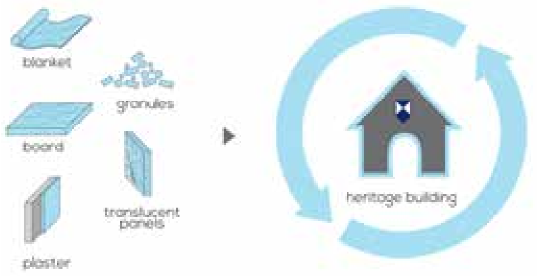


Fig. 1
Types of aerogel insulation products which can be used as additional insulation in refurbishment of historical buildings. [1]

Compared to conventional materials, aerogels achieve the same insulating effect with about half the thickness. There are different types of aerogel materials available on the market. [1, Fig. 1, 2] The article shows the principles of requirements on the materials, i.e. products and systems, for the preservation of cultural heritage.

Available products and systems

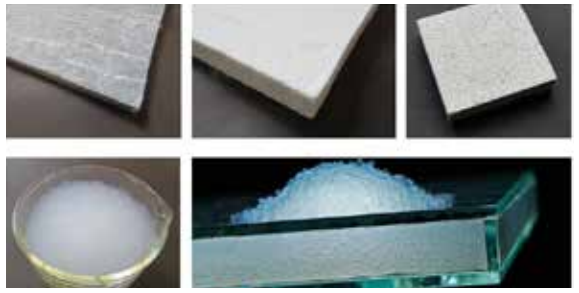


Fig. 2
Available aerogel insulation products – blanket, board, plaster, granules, translucent panel

Product type	Thermal conductivity λ [mW/(m·K)]	Density [kg/m³]	Water vapour resistance factor Mu μ [-]
blanket Spaceloft	15	150	5
board Heck AERO	17	230	3
board Sto Aevero	16	> 150	10
render Fixit 222	28	220 (dry)	4-5
granulate Cabot P300	19	65-85 (bulk)	2-3
translucent panel, *OKAGEL*, 60 mm fill	19 (fill)	n.a.	∞
*rock wool, Flumroc DUO**	34	48	ca. 1
*EPS Polystyrene, Swisspor LAMBDA White 030**	30	19	30

Tab. 1
Technical properties of different aerogel materials represented by a specific product

For comparability, **Erreur ! Source du renvoi introuvable.** lists available aerogel products. The Table also lists the two most common building insulation materials, namely expanded polystyrene (EPS) and rock wool for comparison. Properties are given by producers.

Heritage principles

The value of a historic building is not represented only by its appearance, but represents also the complexity of all present parts [5].

Heritage buildings constitute a special case of refurbishment where the public interest lies in the preservation of the building's appearance and in the conservation of its substance the general principle of the addition of new a material instead of the removal of authentic materials should be used. [6]

New additions to heritage buildings should be recognisable as different "on second sight". Additionally, because of their good performance, the use of aerogel materials and products meets the general condition of minimisation of the necessary intervention. Additions should not change authenticity, and integrity. They should be compatible with authentic structure and should be reversible to previous status. Heritage policies and conventions [5] require that in the conservation process of historical buildings a specific order of steps is used, similar as in medicine. Recommended steps for conservation of historical buildings: (1.Anamnesis – 2.Diagnosis – 3.Therapy - 4.Monitoring – 5.Prevention).

Results and discussions

Potential benefits and harmful effects of aerogels were qualitatively examined. For the different aerogel materials, at least one application example in a historic building is given in the presentation accompanying this paper.

Its combination of properties make aerogels very good materials for the application in historical buildings – in those cases where heritage protection allows the use of modern building materials and techniques at all. A clear disadvantage of aerogels compared to other insulation materials is their high price. The aerogel render fulfils the requirements as the most appropriate material, as it does not need additional fixing equipment and thus has less impact on the integrity of the heritage building.

Conclusions and outlook

Cultural heritage buildings represent a wide spectrum of a natural material base – stones, bricks, wood, lime, mortar and other materials transformed into artistic and architectural details. Therefore is not possible to generalise advice for the preservation of historic facades. Additionally, because of their good performance, the use of aerogel materials and products meets the general condition of minimisation of the necessary intervention [4]. It is clearly distinguishable from original materials. Vapour openness and hydrophobic behavior of applications should be tested. Potential benefits and harms of the application of different aerogel materials with respect to the four criteria of authenticity, integrity, reversibility and compatibility should be examined. A clear disadvantage of aerogels is their high price.

In many cases, there are not many insulation materials that can be used under the constraints of heritage protection, i.e. materials that allow for a thin, high performance insulation which is vapour diffusion open and can thus be applied without the risk of damages to the building structure. It is desirable to see more refurbishment heritage projects using aerogel materials and products with monitoring in the future.

Fig. 3
The protected old mill in Sissach from the 13th century refurbished with aerogel render. Images: Kantonale Denkmalpflege Basel-Landschaft. [3]

References
[1] R. Baetens, B.P. Jelle, A. Gustavsen, Aerogel insulation for building applications: A state-of-the-art review, Energy Build. 43 (2011) 761–769.
[2] K. Ghazi Wakili, B. Binder, M. Zimmermann, C. Tanner, Efficiency verification of a combination of high performance and conventional insulation layers in retrofitting a 130-year old building, Energy Build. 82 (2014) 237–242.
[3] S. Brunner, J. Wernery, M.M. Koebel, High performance thermal insulation - examples from the Swiss built environment, in: Proc. Int. Conf. CISBAT 2015, Lausanne, 2015: pp. 39–44.
[4] M. Ganobjak, E. Kráľová, Aerogel insulation in refurbishment, in: Energy Forum - 10th Conf. Adv. Build. Skins Conf. Proc., Bern, 2015.
[5] ICOMOS Charter - Principles for the analysis, conservation and structural restoration of architectural heritage, ICOMOS, Victoria Falls, Zimbabwe, 2003.

Using SIMs to re-create cultural historical values in buildings from before 1945

P. Johansson[a*]
P. Wahlgren[a*]

[a] Department of Architecture and Civil Engineering, Chalmers University of Technology, 412 96 Gothenburg, Sweden
* Corresponding author:
Tel. +46 (0)31-772 19 66
par.johansson@chalmers.se
paula.wahlgren@chalmers.se

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Listed buildings,
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VIPs,
thermal bridges,
energy efficiency.

Abstract

In Sweden, approximately 25% of the energy use in buildings is attributed to buildings from before 1945. In this study, in-depth inventories were made in 94 buildings of cultural historical values (ornamentation, original materials and paint, etc.) and the interior status of the building (cracks, moisture damage, additional insulation, etc.). The inventories were used to investigate alternative and improved solutions for re-renovation to re-create e.g. architectural details and cultural historical values using novel materials. Two case studies are investigated where super insulation materials can be an alternative during renovation.

Introduction

In order to achieve the national and European environmental objectives, it is necessary to increase the energy efficiency of the old building stock.

A complicating factor when it comes to the older buildings is that many of them are historically valuable. They are therefore protected and only small changes can be made when retrofitting these buildings. In addition, building owners realize the advantage of keeping or restoring old buildings since they are considered more attractive. By using super insulation materials (SIMs), such as vacuum insulation panels (VIPs), the thickness of the wall can be kept at a minimum and thereby increase the possibilities to preserve the aesthetics of the building. Previous studies [1, 2] have shown that the energy use can be reduced by 20-30 % in a building by adding a layer of VIPs in the exterior wall.

In this paper, an overview of 94 buildings in central Gothenburg is presented. Two case studies where SIMs can be used during renovation are then presented. Both buildings are situated in Gothenburg, southwest Sweden, near the coast. The first study (Brämaregatan) investigates the potential energy savings after renovating a building from 1910. The second study (Malörten) concerns a building from 1930 where VIPs were installed in 2010. Measurements of temperature and relative humidity are still ongoing.

Inventories of cultural and historical values

To get an estimate of how many buildings that are in need of renovation and can benefit from SIMs, an existing inventory and status assessment was used. The inventory was performed by Trafikverket (Swedish transport administration) and included site visits and interviews. In Fig. 1, the results for 94 buildings, from before 1945, are shown.

The sensitive and vulnerable artefacts can be stoves, stucco, paintings, tiles and sculptures in the building. Larger retrofit was planned for 25 of the buildings. There is large potential for using SIMs for renovation.

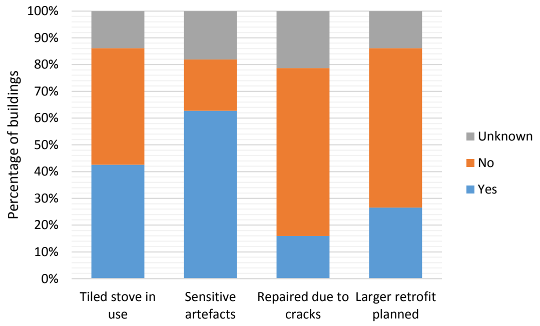

Fig. 1
Information on the 94 buildings in the inventories presented in [3] and by Trafikverket

Case study Brämaregatan- Energy use

Fig. 2
The building at Brämaregatan in its current state, after 2010

Brämaregatan 1, see Fig. 2, is a building from 1910 that has been renovated twice; in 1975 and in 2010.

The building at Brämaregatan has a brick ground floor wall, two floors with wooden walls and an attic floor (habited). At Brämaregatan, the possibility to use VIPs or aerogel blankets is investigated along with other energy efficiency measures, see Table 1. Alternative 1 for windows is to change single-pane windows on the ground floor (U=5.5 W/m²K) and alternative 2 is to change all windows (also double-pane with U=2,5 W/m²K) The building and the investigation is described in more detail in [4].

Brick wall: a. Add interior insulation with R = 1.35 m²K/W b. Add exterior insulation with R = 2.70 m²K/W
Wooden wall: Add exterior insulation with R= 5.41 m²K/W

Tab. 1
Alternatives for insulation of exterior walls

Fig. 3 shows the effect of all measures on the total energy use (including tap water but excluding domestic electricity) and space heating demand.

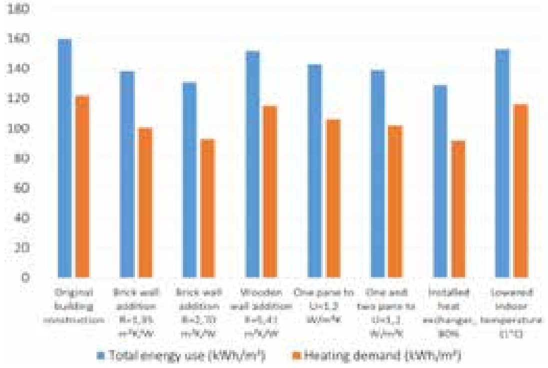

Fig. 3
Total energy use and heating demand for different measures, yearly values per m² floor area [4]

If the best measures to decrease transmission losses are used, the total energy use can be lowered to 108 kWh/m² and heating demand to 70 kWh/m². If heat exchanger and decreased indoor temperature is included, the total energy use can be lowered to 67 kWh/m² and heating demand to 30 kWh/m².

Case study Malörten- Long term performance

1930s building, Malörten, has been insulated with 20 mm VIPs on the exterior. Temperature and relative humidity sensors monitor the wall and the interior and exterior climate. The wall was finished in August 2010. Comparing the reference wall with the retrofitted wall gives an approximation of how much the thermal resistance of the wall has been improved. For this analysis the average temperature for January each year 2011 to 2017 was used to calculate the temperature factor, see Fig. 4. Unfortunately several sensors have been damaged why only one position can be evaluated for all 7 years.

In the reference wall about 64% of the temperature drop was over the uninsulated parts. After the retrofitting only about 17-18% of the temperature drop was over that part of the wall. There is no sign of decreased insulation performance of the VIPs.

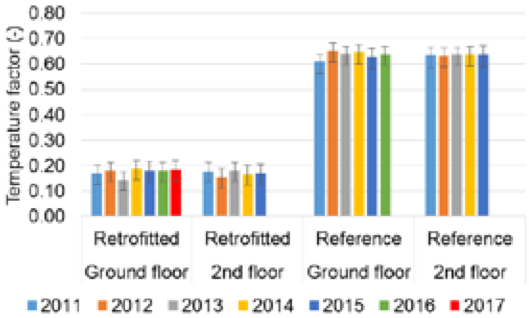

Fig. 4
The temperature factor of January 2011 to 2017 for the retrofitted and reference walls. The temperature factor is the percentage temperature decrease over the original wall compared to the total temperature drop over the wall. The error bars show an accuracy of the sensor of ±0.5 °C.

Results, Conclusions and Outlook

There is a large need in Sweden to renovate older buildings and maintain the cultural and historical values. SIMs can contribute to this development. This will be further investigated in additional case studies in Gothenburg. At Qvidingsgatan, several similar buildings will be investigated. They have been renovated in different time periods and with different measures. One building will soon be re-renovated. The renovated buildings will be evaluated and new methods proposed. At Kvarnbyn, a large industrial area will be converted into a residential area and VIPs will be tested in field and evaluated during and after renovation.

Acknowledgements

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References

[1] P. Johansson, et al., Energy and Buildings, 73 (2014) 92-104.
[2] P. Johansson, et al., Building and Environment, 79 (2014) 31-45.
[3] P. Johansson, et al., Recreation of cultural historical values in buildings from before 1945: Inventory with focus on building physics performance, Proceedings of XIV DBMC, 14th International Conference on Building Materials and Components, Ghent, Belgium, 29-31 May, 2017.
[4] G. Thuresson, Energy use in a re-renovated building from 1910, Master's Thesis BOMX02-17-69, Chalmers University of Technology, Department of Civil and Environmental Engineering, 2017.

SESSION 5

IVIS Paris 2017
13th International
Vacuum Insulation Symposium

September 20-21, 2017

SESSION 5

PST Metallized Films
A New Era of Performance and Prices

Yoash Carmi[a*]
Harel Yitzhaki[a]

[a] Avery Dennison Hanita, Kibbutz Hanita, 2288500, Israel
* Corresponding author:
Tel. +972-525-739186
yoash.carmi@eu.averydennison.com

Keywords:

PST laminates,
PST films,
EVOH films,
high barrier,
price reduction.

Abstract

Due to the thermal bridge effect associated with Al-foil-based VIP envelopes, the refrigeration industry tends to prefer fully metallized or hybrid envelopes. Metallized EVOH films have driven this change, since they provide low enough air permeability to result in good longevity. But EVOH films suffer from three main drawbacks: they are very expensive; they are produced in relatively narrow web width, and their barrier properties degrade substantially in the presence of humidity.

To overcome these disadvantages, Avery Dennison Hanita has adopted a different approach by improving the barrier properties of the Al layers deposited on PET films through a special surface treatment – PST (Proprietary Surface Treatment). It was found that the PST technique reduces air permeation by more than 80% compared to standard metallized PET films, with a substantial production cost reduction. PST films have an air permeation rate ~40% lower than standard METEVOH films, and are substantially cheaper, partially because they can be produced at a much larger web width. No less important, PST metallized PET laminates are much less sensitive to higher humidity levels.

The article describes in detail the barrier properties of the new PST films under different storage conditions, and their advantages over the other metallized films used commercially today.

Introduction

To be attractive for the refrigeration industry, VIPs need to have three basic properties: very low effective thermal conductivity, a slow enough degradation rate and a very low price. The optimal solution is of course the combination of a top-quality fiberglass core with cost effective metallized envelopes that allow an air permeation rate similar to envelopes based on Al foils.

To overcome the challenge of such a demanding barrier level, the VIP industry adopted the solution of adding metallized EVOH films to the laminate structure.

While providing good barrier to air permeation, EVOH films suffer from three major disadvantages: they are expensive, can be produced only in relatively narrow format, and their barrier properties degrade quite substantially when exposed to higher levels of humidity. In contradiction to the standard EVOH solution, Avery Dennison Hanita (formerly Hanita Coatings) recently developed a more advanced solution based on Proprietary Surface Treatment (PST) applied to the PET films. This surface treatment procedure helps to reduce the air permeation rate by a factor of five compared to standard metallized laminates, and about two times lower than standard metallized EVOH laminates. PST laminates were found to be much less sensitive to the presence of humidity than standard EVOH laminates and are substantially less expensive.

The following paragraphs contain a short description of the results of many tests made comparing the barrier properties of PST laminates to those of other laminates commonly used by the VIP industry.

List of tested laminates

V085HB1 – Hanita bi-laminate of metallized PET and metallized EVOH with LDPE sealing layer

V096HB3 – Hanita bi-laminate of metallized PET with Hanita's new Proprietary Surface Treatment (PST) technology with LDPE sealing layer

V08621B – Hanita Tri-laminate of metallized PET film with LDPE sealing layer

Asian 2nd generation MET EVOH laminate - Bi-laminate of metallized PET and metallized EVOH with LDPE sealing layer

Asian 3rd generation MET EVOH laminate - Bi-laminate of metallized special PET and metallized EVOH with LDPE sealing layer

V07941P –Hanita bi-laminate of metallized PET and Al foil with LDPE sealing layer

Test results: How the permeability of the laminates rises at elevated temperatures - The PST laminates showed superior performance.

In order to compare the permeability at elevated temperatures of the different laminates listed in section 1 above, the air permeability was measured for he the six different laminates. The panels were stored at 23°C, 50°C, 80°C, 100°C and 120°C in order to measure how their permeability changes at these different temperatures.

Table 2 summarizes the results of this comparison test. In Fig. 6 and fig. 7 below, the same results are presented graphically, fitted to Arrhenius-like functions. The constant A represents the Permeability at very high temperatures, and Ea is a fitting parameter resembling the role of activation energy. Because of the complexity of the systems (many layers of different films, adhesive layers and Al layers) the actual physical meaning of the Ea constants is not clear.

$$P(T) = A\exp\left(-\frac{E_a}{RT}\right)$$

Arrhenius-like functions

At all temperatures, the relative humidity was kept at ambient level. It can easily be seen that the new METPST (V096HB3) laminates have very low Permeability at ambient, together with a relatively moderate effect by elevated temperatures. The response of the PST laminates to elevated temperatures is not so different from that of laminates containing Al foils (V07941P), indicating that in both cases most of the air permeation occurs through the seals (side permeation).

Laminate/Temperature	22^0C	50^0C	80^0C	100^0C	120^0C
V096HB3	1.35	7	27	60	210
Asian MetEVOH Gen2	4	17	85	210	475
Asian MetEVOH Gen 3	1.4	13	58	175	440
V08621B	6.7	24	80	200	500
V07941P	1.2	6.5	24	55	160

Tab. 1
The air permeability (cm³{STP}/m²year) of five types of laminates at different storage temperatures. The V096HB3 PST laminates showed much lower permeation levels than other metallized laminates and similar behavior to the V07941P Al foil based laminate

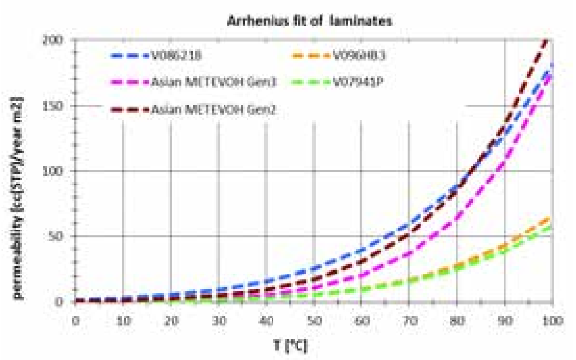

Fig. 1
The air permeability (cm³{STP}/m²year) of the laminates from Table 1 as function of temperature at dry conditions. The V096HB3 PST laminate behaves similarly to the V07941P Al foil laminate

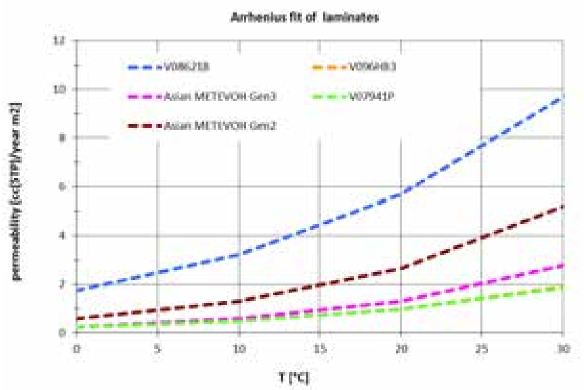

Fig. 2
The graph of fig. 1 with enlarged T scale. Below 300C the V096HB3 PST laminate has very similar permeability to that of the Al foil laminate V07941P

It is important to note that data collected in such tests can be very useful when there is a need to convert the degradation rate measured in accelerated ageing tests to the actual degradation rate during the service life, where the panels can be exposed to very different environmental conditions

Summary and conclusions

1. In the comprehensive set of characteristic tests performed on six types of high barrier film, the new PST laminate showed a very clear advantage in terms of barrier to air, barrier to moisture vapor, sensitivity to humid conditions and performance at elevated temperatures.
2. Superior barrier combined with low production cost make PST films the optimal solution to replace Al foils in VIPs for refrigerators, thus solving the problem of thermal bridge, and providing over 15 years' effective service life.

New technology with improved barrier performance in severe conditions, opening new possibilities of use for VIPs

Yuji Shimizu[a]

[a] IEVAL R&D Department, EVAL Division, Vinyl Acetate Resin Company, Kuraray Co., Ltd.,
* 7471 Tamashimaotoshima, Kurashiki, Okayama, 713-8103, JAPAN

Keywords:

EVOH, KURARISTER™,
high barrier laminate film,
vacuum insulation panels,
longer service life.

Abstract

A vacuum insulation panel (VIP) requires a high-performance laminate film, with high barrier properties and enough mechanical strength to maintain the internal vacuum over the designed period. A vapor metalized biaxially oriented EVOH film (VM-EVOH) is widely used as the main barrier substrate in multilayer laminate VIP structures. These films meet the necessary barrier requirements and help reduce heat bridging at the edges, notably for freezers, refrigerators and other appliances.

Recently, demand for VIP insulation has expanded into new applications in vehicles, transportation, building & construction, hot water storage and other industrial use. VIPs used in such demanding and long life applications require a film with both excellent barrier properties and durability under high temperature and humidity. Kuraray has developed a new technology, KURARISTER™ with both excellent barrier properties and durability under high temperature and humidity compared to conventional inorganic deposited polyester barrier films. In this paper, we report the outcome of our study of the thermal insulation properties of panels using this technology, opening new possibilities of use for VIPs.

Introduction

Aluminum-deposited biaxially oriented EVOH film (VM-EVOH) is widely used for VIP applications like refrigerators, as a material which achieves both a durable barrier property and the reduction of heat bridging [1]. New VIP applications increasingly require longer service life in high temperatures. In such severe conditions there is the possibility of degradation of the envelope, as aluminum hydroxide forms, corroding of the aluminum deposited layer [2]. In order to maintain the vacuum inside of VIPs for a long time, VIPs used in high temperature and humidity conditions also require a further improved barrier property.

Kuraray has developed KURARISTER™, a new high barrier wet coating technology, which can be coated onto polymeric substrates like biaxially oriented PET film. With a barrier layer thickness of 0.5 μm, KURARISTER™ has both excellent barrier properties and durability under high temperature and high humidity. Service life and performance under severe conditions can be extended and improved compared to conventional inorganic deposited polyester films, with barrier layers thicknesses of 20 nm to 100 nm. This paper presents a study of the barrier properties of the VIP envelope containing this new technology and VM-EVOH, and of the thermal insulation properties of VIPs using these films under severe conditions.

Test method

Commercially available barrier films were prepared for the purpose of evaluating barrier performance under several different conditions.

2-1 Sample

VM-EVOH: aluminum deposited EVOH film
VM-PET: aluminum deposited PET film
KURARISTER™: specific barrier coating PET film
AlOX-PET: aluminum oxide deposited PET film
SiOX-PET: silicon oxide deposited PET film
LLDPE: linear low density polyethylene film

#1: KURARISTER™ (12 μm) // KURARISTER™ (12 μm) // VM-EVOH (15 μm) // LLDPE (50 μm)
#2: VM-PET (12 μm) // VM-PET (12 μm) // VM-PET (12 μm) // LLDPE (50 μm)

2-2 Test items and conditions

*Gelbo-flex testing with three cycle under 23°C-50%RH
*Oxygen Transmission rate (OTR) was measured by OX-TRAN 2/21 (MOCON, Inc.). In the measurement, PE layer was always faced toward 0%RH atmosphere.
*Water Vapor Transmission rate (WVTR) was measured by gravimetric method (Kuraray test method*1) or DELTAPERM (TECHNOLOX, Ltd.) or PERMATRAN W 3/33 (MOCON, Inc.).

*1) Calcium chloride (desiccant) was filled in four-side sealed pouches of laminated films. The pouches were stored under controlled condition in a climatic chamber to measure gravimetric change for WVTR.

Barrier Performance of laminated film with KURARISTER™

Fig. 1 shows WVTR results at different temperature (50°C, 60°C, 70°C) under fixed relative humidity (90%RH). In severe conditions, the KURARISTER™-containing structure shows better moisture barrier performance than other conventional transparent inorganic deposited film-based structures. It indicates that film structures with KURARISTER™ can provide superior performance in VIPs due to the stability of barrier performance in severe conditions.

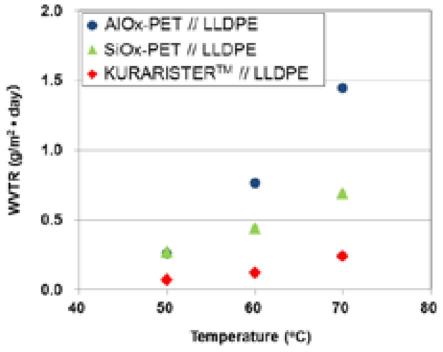

Fig. 1
Temperature dependency of WVTR

Table 1 shows test results of OTR and WVTR w/ and w/o gelbo-flex test at 40°C-0/90%RH. Although the sample #2 loses gas barrier performance after gelbo-flex stress, Sample #1 maintains low level OTR values. This test results can prove that structure with VM-EVOH in combination with KURARISTER™ provides higher gas barrier property and additional durability against possible manipulation during production and installation of VIPs, while keeping excellent WVTR.

Sample	OTR (cc/m² • day • atm)		WVTR (g/m² • day)	
	40°C-0/90%RH		40°C-0/90%RH	
	No gelbo	Gelbo x 3	No gelbo	Gelbo x 3
#1	<0.01	0.03	0.0013	0.16
#2	<0.01	0.68	0.0039	0.17

Tab. 1
Barrier performance after gelbo-flex test

Fig. 2 shows temperature dependency of WVTR of barrier film. Sample #1 shows better moisture barrier performance than Sample #2. These results suggest that the combination of two types of functional barrier film, VM-EVOH for high gas barrier and KURARISTER™ for high moisture barrier, might improve service life and expand the application field of VIPs where current standard 3-ply met-PET structures cannot meet the technical requirements.

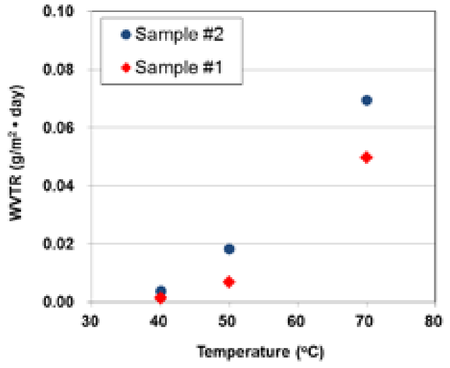

Fig. 2
WVTR performance of envelopes for VIP

Thermal insulation properties of the VIPs

VIPs were prepared with sample #1 and sample #2 in order to evaluate film performance under severe conditions as actual VIPs. Specification of VIPs is as follows:

Size: 350 mm x 350 mm x 10 mm
Core material: Glass fiber
Desiccant: Calcium oxide
Initial pressure: 1.0 Pa
Storage condition: 70°C-90%RH
Thermal conductivity measurement: HC-074
(EKO Co., Ltd.)

Fig. 3 shows the change in thermal conductivity of the two VIPs with aging over time (70°C-90%RH). VIPs with sample #1 show less thermal conductivity increase compared to the VIP with sample #2. It seems that high gas barrier property of VM-EVOH was maintained even in high temperature and humidity condition by the high moisture barrier property of KURARISTER™.

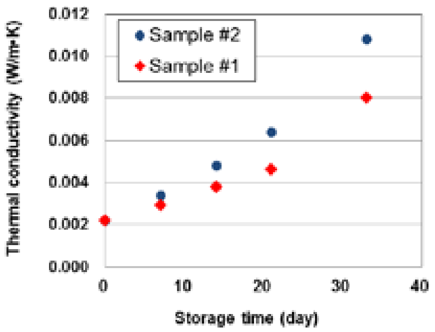

Fig. 3
Thermal conductivity change of VIPs with glass fiber core

Conclusions

A new technology, KURARISTER™ showed durable high moisture barrier properties in conditions of high temperature and humidity. A new laminated structure with higher gas and moisture barrier property was designed by combination of VM-EVOH and KURARISTER™. It was confirmed in this study that high gas barrier and abuse resistance of VMEVOH and higher moisture barrier of KURARISTER™ were maintained even at high temperature, which as expected provided better insulation. This new VMEVOH barrier laminate in combination with KURARISTER™ can contribute to improving not only service life of fiber-core VIPs but also VIPs of other core material like fumed silica and PU, opening new possibilities of VIPs in various fields.

References
[1] Cynthia Teniers, How laminates with Ethylene Vinyl Alcohol film (EVOH) improve the performance of VIPs, 9th International Vacuum Insulation Symposium
[2] S. Brunner, et al. Focused ion beam (FIB) etching to investigate aluminum-coated polymer laminates subjected to heat and moisture loads, Surface & Coatings Technology, 202 (2008) 6054-6063.

Prediction of the VIP durability from the degradation state of barrier envelope

F. Dubelley[a*]
E. Planès[a]
C. Bas[a]
E. Pons[b]
B. Yrieix[b]
L. Flandin[a]

[a] Univ. Savoie Mont Blanc, CNRS, LEPMI,
F-73000 Chambéry, France
[b] EDF R&D, Materials and Mechanics
of Components, Ecuelles
F-77818 Moret-sur-Loing Cedex, France
* Corresponding author:
Tel. +33 4 79 75 86 54
florence.dubelley@gmail.com

Keywords:

Vacuum insulation panels,
kinetic,
durability,
lifetime prediction,
PET degradation,
Permeance.

Abstract

The models for predicting the durability of VIPs are based mainly on the gas transfer through the barrier envelope and on the core behaviour. The lifetimes resulting from modelling are often more optimistic than those obtained from experimental ageing. These differences can be explained by the progressive degradation of the barrier envelope which is not taken into account in the current models. Firstly, this work presents a correlation between PET degradation and loss of VIP performance. Secondly, a kinetic law of PET degradation over a wide range of temperatures and humidities, based on data from the literature, is established. The state of PET degradation corresponding to the end of the VIP service life can be determined. Kinetic law and determined end life-time criterion allow the estimation of VIP durability for any conditions.

Introduction

Modelling VIPs ageing under constant conditions shows that the use of the most efficient VIPs in the buildings is only possible in the case of applications requiring moderate temperatures and humidities. In severe conditions, measurements and experimental observations show an evolution of the barrier envelope and a modification of the core material structure. In order to take into account the panel ageing, studies have recently been carried out. The core modification over time has been integrated into the model through the evolution of its water vapour sorption isotherm [1]. Another improvement would be to consider the ageing of the envelope, the permeance of this latter appearing to evolve depending on the environmental conditions. The aim of this work is not to develop a new numerical model but to look at envelope degradation based on the PET kinetic degradation and at the correlation between the PET degradation and the laminate permeation.

Experimental

Materials

The typical architecture of the studied laminates is composed of three PET metallised with aluminium layers and one sealing layer (PP or PE). The different layers were glued together with a polyurethane (PU) adhesive. VIPs are manufactured with the studied laminates and a standard fumed silica core.

Methods

Ageing: VIPs are exposed in climatic chamber at 70 °C/90 %RH and 50 °C/90 %RH up to 400 and 1000 days respectively.

Permeation: The VIPs permeance (Π (kg/(m².s.Pa)) is measured indirectly through the measurement of the weight increase. The weight gain (Δm (kg)), only considered as water vapour uptake, is recorded at regular intervals (Δt (s)).

$$\Pi = \frac{1}{P_v.A}\frac{\Delta m_{i+1} - \Delta m_i}{t_{i+1} - t_i} \text{(Eq. 1)}$$

P_v = partial pressure of water vapour (Pa)
A = VIP surface (m²)

Results and discussions

The data presented in Figure 1 clearly show an abrupt change in slope. This change occurs after about 100 days of ageing at 70 °C/90 %RH and 400 days at 50 °C/90 %RH. This indicates a variation of the permeation of the laminate (Table 1) leading to a sharp increase of the VIP thermal conductivity.

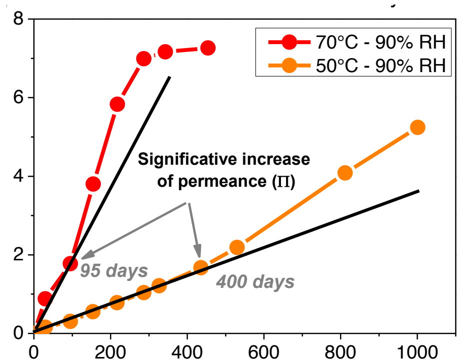

Fig. 1
Weight gain of VIPs as a function of ageing time for different static conditions

Endurance condition	1st slope	2nd slope	Slope change time (days)
50 °C/90 %RH	5.1	8.6	400
70 °C/90 %RH	7.3	18	95

Tab. 1
VIP laminate permeance(10^{-14} kg/(m².s.Pa))

PET hydrolysis is one of the main degradation mechanisms of the barrier envelope. It can be evidenced after 400 days of ageing at 70°C-90 %RH with a surprising homogeneity among the three PET metallised layers [2-3]. The degradation of barrier envelope can be considered as soon as the first metallised PET layer is itself degraded. The state of PET degradation corresponding to the change of laminate permeance, assimilated to the end of VIP service life (loss of performance), needs to be determined. For that reason, a kinetic law of PET degradation over a wide range of temperatures and humidities, based from the literature, was established. The resulting equation is given in Eq. 2 where the molecular weight Mn appears to be the most important parameter to manifest the changes during hydrolysis:

$$\ln\left(\frac{M_n(t)}{M_n(t_0)}\right) = -29.2 \times e^{-\frac{1.10^5}{RT}} \times RH^{1.5} \times t \quad (Eq.2)$$

A correlation was done with data from aged PET films used for VIP aged at 70 °C and 90 %RH [2, 4]. The results are in agreement with the prediction made using Eq.2 and shown Figure 2. At 50 °C/90 %RH and 70 °C/90 %RH, the time, for which the permeance change is observed (Figure 1 - Table 1), is plotted on the kinetic curves (Figure 2). The loss of VIP performance corresponds to a PET molar mass loss of 15 %.

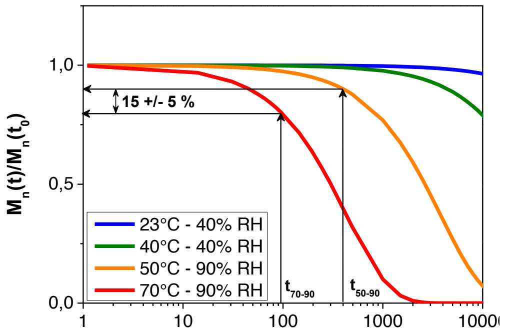

Fig. 2
Prediction PET degradation kinetic at different static ageing conditions

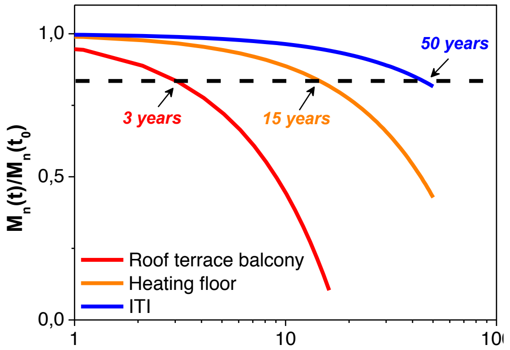

Fig. 3
Lifetime prediction of VIP application using PET kinetic degradation

In return, based on such a criterion, the VIP durability can be estimated for any conditions. The model (Eq.2) was applied to estimate the service life for three VIP applications in the French building, i.e. internal insulation of wall and floor (ITI), heating floor (dry screed) and roof terrace balcony. The operating conditions – temperatures, humidities and exposure duration – have been evaluated by Yrieix et al. [5] and the values for roofs terraces were adjusted according to the measurements of Brunner et al. [6] (Table 2). For the calculation, we supposed that each period exist independently and can be combined using a simple linear superposition of molar mass variation. The results are represented in Figure 3. The time after which the VIP is no longer performing varies from 3 to 50 years depending on the VIP application. Table 2 Operating conditions over 1 year for the hot face of VIP according to applications.

		ITI	Floor	Roof
Period 1	T (°C)	30	50	70
	RH (%)	60	90	95
	Time (days)	30	10	20
Period 2	T (°C)	30	30	45
	RH (%)	50	50	95
	Time (days)	30	200	40
Period 3	T (°C)	20	25	20
	RH (%)	65	50	65
	Time (days)	210	60	210
Period 4	T (°C)	22	22	22
	RH (%)	65	65	65
	Time (days)	95	95	95

Tab. 2
Operating conditions over 1 year for the hot face of VIP according to applications

Conclusions and outlook

The performance of the VIP, and thus its durability, can be related to the resistance to the degradation of the first PET layer of the barrier envelope. A kinetic model was established to follow the PET performance during ageing. A nice correlation between the degradation of laminate and the change of laminate permeation rate allowed estimating the state of PET degradation responsible of the loss of VIP performance. Thanks to the model and the determined end service life criterion, VIP durability can be identified for any environmental conditions for a multitude of applications.

Acknowledgements

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References
[1] A. Batard, PhD thesis (2017)
[2] F. Dubelley et al. Eur.Polym.J 87 (2017) 1-13
[3] F. Dubelley et al. Symposium IVIS2017 (2017)
[4] G. Garnier, PhD thesis (2009)
[5] B. Yrieix et al. Energ Buildings 85 (2014) 617-630
[6] S. Brunner et al. Vacuum 82 (2008) 700-707

Theoretical studies of the time dependent permeation through barrier envelopes for vacuum insulation panels

O. Miesbauer[ab*]
E. Kücükpinar[b]

[a] Technical University of Munich, TUM School of Life Sciences Weihenstephan, Chair of Food Packaging Technology, Weihenstephaner Steig 22, 85354 Freising, Germany
[b] Fraunhofer Institute for Process Engineering and Packaging IVV, Giggenhauser Strasse 35, 85354 Freising, Germany
* Corresponding author:
oliver.miesbauer@ivv.fraunhofer.de

Abstract

Barrier laminates made of two or three metallized polymeric films are required to reduce the permeation of environ-mental gases into the core material of vacuum insulation panels (VIPs) to a large extent. Such laminates can be con-sidered as structures of alternating inorganic and polymeric layers. Numerical simulations of the time dependent per-meation provide deep insight into the barrier performance of such structures, described by the ideal laminate or geo-metric defect model. They show that the permeation rate for structures of alternating layers approaches the steady state value very slowly. A quasi-steady-state approximation is derived, which provides an analytical expression of the time dependent permeation rate for such structures and allows to design VIP barrier laminates with improved barrier performance.

Keywords:

Vacuum insulation panels,
Multilayer,
Defects,
Permeation,
Lag Time.

Introduction

The envelope of vacuum insulation panels (VIPs) pre-vents the ingress of oxygen, nitrogen and water vapor from the environment into the core material to a large extent [1]. Such envelopes consist of barrier laminates made of two or three metallized polymeric films. A ty-pical structure is PET / Al / PU / PET / Al / PU / PET / Al / PU / LDPE [1].

As a first approximation, barrier laminates can be considered as structures P / A / P / A / … / A / P of alternating inorganic (A) and polymeric (P) layers, if adjacent polymeric materials like PET and PU are combined to one layer P. It is well-known that it can take several weeks or even months for such structu-res to approach the steady-state permeation [2].

Barrier laminates for VIPs are expected to show a si-milar time dependent permeation behavior. Therefore, a deeper theoretical understanding of this behavior is important for the development of novel barrier lami-nate structures with improved performance. The theo-retical methods and results, described in the following sections, are taken from [3].

Modelling of permeation

The permeation of substances through the polymeric materials within structures of alternating layers is de-scribed by the solution diffusion model; Henry's and Fick's laws are assumed for sorption and diffusion [4,5]. While the polymeric layers are considered as homogeneous, permeation through inorganic layers like aluminium is restricted to material defects [6]. For gases like oxygen and nitrogen only localized macro-defects are significant permeation paths, while for water vapor additionally quasi-homogeneously distri-buted nanodefects contribute to the permeation rate.

As a consequence, water vapor permeation through multilayer structures can be described by the ideal la-minate model [7] where each layer is characterized by effective solubilities and diffusivities. For gas per-meation the geometric defect model [7] is used where the effect of inorganic layers consists in a restriction of the gas transport to geometrically defined macro-defects.

The transient permeation of gases and water vapor through the modelled multilayer barrier structures was numerically calculated using the finite element method (FEM). The partial pressures at the two boundaries were set equal to $p_0 > 0$ and zero, respectively, and the initial permeant concentration within the structure was zero.

Results and discussions

The normalized flux density $j\,h_A / (D_A\,S_A\,p_0)$ at the boundary with partial pressure equal to zero was cal-culated for the structure A / P / A in the ideal laminate model. In Fig. 1 it is shown as a function of the norma-lized time $t\,D_A / h_{A2}$.

The figure shows that the approach of the flux to the steady-state value is significantly delayed by increa-sing the ratio S_p / S_A between the solubilities for the layers P and A. The corresponding ratios between the layer thicknesses h and between the diffusivities D were set equal to 1 or 10, respectively.

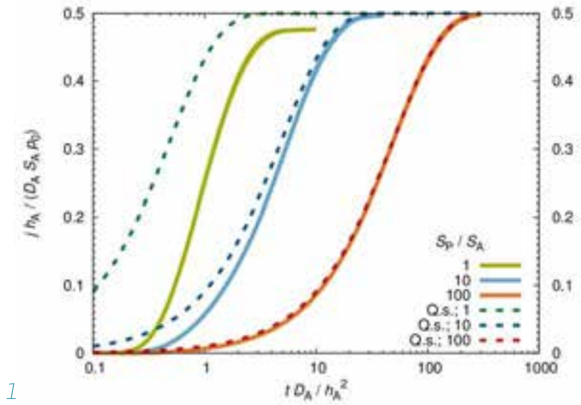

Fig. 1
Structure A / P / A in the ideal laminate model: Normalized flux density at the boundary with partial pressure equal to zero as a function of the normalized time. Solid lines: calculated by FEM; dotted lines: Quasi-steady-state approximation (Q.s.) [3]

This result can be explained by a quasi-steady-state approximation, considering the permeation process as an exchange of the permeating substance between the layer P and the environments with partial pressures $p_0 > 0$ and zero. This exchange occurs through the layers A which lie between P and the environments and are characterized by the permeabilities Q_A. As a result of this process, the partial pressure p within P increases with time.

The approximation was applied to structures A / P / A / … / P / A of alternating layers which contain a number N_P of layers P. This leads to the mass balances for the layers P_i, where $p_0 > 0$ and $p_{NP+1} = 0$ are the boundary partial pressures and j_{i-1} and ji are the fluxes per area through the layers A being adjacent to P_i.

$$h_\mathrm{P}\,S_\mathrm{P}\,\frac{\partial p_i}{\partial t} = j_{i-1} - j_i = Q_\mathrm{A}\left(p_{i-1} - 2p_i + p_{i+1}\right)$$

From the analytical solution of the linear differential equation, given by the mass balance for $N_P = 1$, the flux density at the boundary with partial pressure equal to zero was derived. Fig. 1 shows that this flux density agrees closely with the result of the FEM simulation in the case of a high ratio S_p / S_A. This justifies the validity of the approximation for structures of alternating layers in the ideal laminate model under the given assumptions.

The quasi steady state approximation was transferred to struc-tures described in the geometric defect model with impermeable inorganic matrices. The comparison with FEM results confirms the validity also in this case.

From the developed theory the following results were derived for the lag time of permeation which can be considered as a measure for the time required to approach the steady state [6]. The lag time of gas and water vapor permeation through structures of alternating layers is proportional to the thicknesses of the polymeric layers and to the square of the number of layers. In the case of water vapor, the lag time is additionally proportional to the thicknesses of the inorganic layers and to the ratio S_p / S_A; in the case of gas permeation, the lag time increases with the defect distance and decreases with the defect diameter.

Conclusions and outlook

The high barrier performance of VIP laminates is not only the consequence of a partial compensation of the effect of defects existing within metallic layers. In addition, a slow approach to the steady state permeation can be expected if polymeric materials with large thicknesses are placed between inorganic layers having low permeabilities. Under these assumptions, the transmission rate for typical VIP barrier laminates as PET / Al / PU / PET / Al / PU / PET / Al / PU / LDPE will be kept at a very low level for a long time period. In case of water vapor permeation the time period can be further extended if the solubility for the polymeric materials is increased by dispersing water absorbers like zeolites or hygroscopic salts within them. Systematically using these concepts can improve the barrier performance of VIP laminates and therefore result in a significantly extended VIP lifetime.

Acknowledgements

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References
[1] R. Baetens et al., Energy and Buildings 42 (2010) 2, 147-172.
[2] G. L. Graff et al., Journal of Applied Physics 96 (2004) 4, 1840-1849.
[3] O. Miesbauer, Analytische und numerische Berechnungen zur Barrierewirkung von Mehrschichtstrukturen, Dissertation, submitted to the Technische Universität München, 2017.
[4] C. E. Rogers, in: J. Comyn (Ed.), Polymer Permeability, London, Chapman & Hall, 1985, 11-73.
[5] J. Crank, The Mathematics of Diffusion, London, Oxford University Press, 1975.
[6] H.-C. Langowski, in: O. G. Piringer (Ed.), A. L. Baner (Ed.), Plastic Packaging - Interactions with Food and Pharmaceuticals, Weinheim, Wiley-VCH, 2008, 297-347.
[7] W. Decker, B. Henry, 45th Annual Technical Conference Proceedings, Society of Vacuum Coaters, 2002, 492-502.

Study on the long-term performance of the Vacuum insulation panel using glass fiber core by the permeation of moist air

H.Yamamoto[a]
D.Ogura[b]

[a] Technology Development Division, Aasahi Fiber Glass Co., Ltd, Kanagawa, JAPAN
[b] Department of Architecture and Architectural Engineering, Kyoto University, Kyoto, JAPAN

Keywords:

Vacuum insulation panels,
long-term performance,
glass fiber,
moist air,
micro thermohygrometer.

Abstract

As for the durability of VIP, the thermal performance variation caused by the influence of dry air has been studied while the influence of the permeation of water vapor still has not been clarified. In this research, we focus on the variation of thermal behavior caused by the permeation of water vapor by directly measuring the inner water vapor pressure.

Introduction

Vacuum Insulation Panels (VIPs) is a high performance insulation made by covering the core and adsorbent with an envelope and vacuuming the inside. It has been widely used in refrigerators and vending machines and contributed to improving energy efficiency. In Japan, glass fiber instead of fumed silica, is widely used as a core material in VIPs.

Although the heat insulation property of the VIPs has been mainly researched on a silica core material, while there are few studies on glass fiber core material. In addition, the thermal performance variation caused by the influence of dry air has been studied while the influence of the permeation of water vapor still has not been clarified in terms of glass fiber core. In this study, prediction of long-term performance of vacuum insulation panels using glass fiber core material and investigate the influence of water vapor using micro thermohygrometer.

Aging model which is widely used

Parallel model is widely used to predict the thermal conductivity. Heat transfer of core material can be considered as the conduction through solid and through gas in case of its presence and radiation.

The three modes should be considered simultaneously:

$$\lambda_{cop} = \lambda_s + \lambda_g + \lambda_r \quad (1)$$

where λ_{cop} is the total thermal conductivity of the core material, λ_s is the thermal conductivity via the solid skeleton, λ_r is the radiative thermal conductivity and λ_g is the thermal conductivity of gas within pores.

Thermal conductivity without desiccant

Thermal conductivity without desiccant of VIPs
Expressed:

$$\boldsymbol{\lambda_{cop} = \lambda_{sr,ini} + \lambda_{g(Pa,Pw,T)} + \lambda_s(W,T)} \quad (2)$$

Thermal conductivity with desiccant

Thermal conductivity with desiccant of VIPs
Expressed:

$$\lambda_{cop} = \lambda_{sr,ini} + \lambda_{g(Pa,T)} + \lambda_{ga} \quad (3)$$

Permeability of dry air

According to the mass balance equation of permeation of dry air and ideal gas equation, permeability of dry air could be defined as:

$$\frac{dm_a}{dt} = \frac{M_a \cdot V_{eff}}{R \cdot T} \cdot \frac{dP_a}{dt} = K_{a,total} \cdot (P_{a,atm} - P_a) \quad (4)$$

$$\mathrm{P}_a = \mathrm{P}_{a,atm} - \left(\mathrm{P}_{a,atm} - \mathrm{P}_{\mathrm{a}(0)}\right)\exp\left(-\frac{\mathrm{K}_{\mathrm{a,total}}\mathrm{RT}}{\mathrm{M}_a V_{eff}}\mathrm{t}\right) \quad (5)$$

$$\frac{dP_a}{dt} \cong \left(P_{a,atm} - P_{a(0)}\right)\frac{K_{a,total}RT}{M_a V_{eff}} \quad (6)$$

Water vapor pressure

Permeability of water vapor could be defined as:

$$M_{wv} = M_{void} + M_{adsorb} \quad (7)$$

M_{adsorb} is separeted $M_{core,adsorb} + M_{envelope,adsorb}$,

$$\frac{d(M_{void}+M_{adsorb})}{dt} = K_{wv}(P_{wv,atm} - P_{wv}) \quad (8)$$

$$\frac{dM_{void}}{dt} = \frac{M_{\mathrm{wv}}V_{eff}}{RT}\frac{dP_{wv}}{dt} \quad (9)$$

$$\frac{dM_{adsorb}}{dt} = m_{dry}\frac{dW}{dt} = \frac{m_{dry}}{p_{wvs}}\frac{\partial W}{\partial h}\frac{dp_{wv}}{dt} \quad (10)$$

$$P_{wv} = P_{wv,atm} - P_{wv,atm}\exp\left(-\frac{K_{wv}}{\frac{M_{wv}V_{eff}}{RT} + \frac{\partial W}{\partial h}\frac{m_{dry}}{P_{wvs}}}t\right) \quad (11)$$

Experiment

According to consider the effect of thermal conductivity due to water vaper permeability, we measured thermal conductivity and internal water vapor pressure using VIPs with desiccant and without desiccant.

No.	Ambient Condition	Desiccant
Experiment1	50℃70%RH	Non
Experiment2	50℃80%RH	Non
Experiment3	50℃80%RH	5g
Experiment4	35℃80%RH	5g

*Size:t15 x 390 x 670
*All VIPs used metallized film of low barrier property

Tab. 1
Experimental condition

We could measure water vapor pressure inside the VIPs by micro thermohygrometer attached the transmitter and battery. VIPs with the sensor unit was placed in the climatic chamber controlled at constant themperature and humidity, and measured water vapor pressure from outside. After that, we taken out the VIPs from there, and measured thermal conductivity and water vapor pressure in a room conditioned at 23°C .

Internal water vapor pressure and thermal conductivity

Fig. 1 shows results of inner relative humidity and thermal conductivity. We could measure relative humidity inside the VIPs under the indoor temperature and the climatic chamber using the micro thermohygrometer.

Compered the relative humidity before and after taking out, inner relative humidity did not change. It is considered that water vapor adsorbed to the core material (Fig. 1).

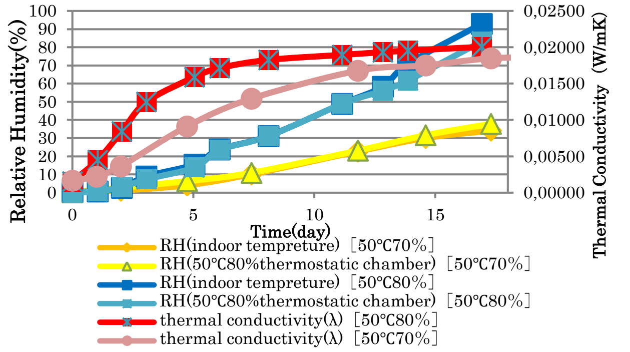

Fig. 1
Thermal conductivity versus water vapor pressure increase under50°C70%RH and 50%80%RH with low barrier mtallized film

Comparison of measured value of the experiment 2 and calculated value in the inner pressure

Water vapor permeability K_{wv} calculated from weight increase in the experiment 3.

$$\boldsymbol{K_{wv} = \frac{m_{wv}}{\Delta t \Delta P_{wv}}} \quad (12)$$

The equilibrium moisture content of glass fiber core was measured by BELSORP-aqua3 made by MicrotracBEL Corp. shown in Fig. 2. From the water vapor permeability K_{WV} and the equilibrium moisture content, we calculated inner water vapor pressure using the equation (11) in Fig. 3.

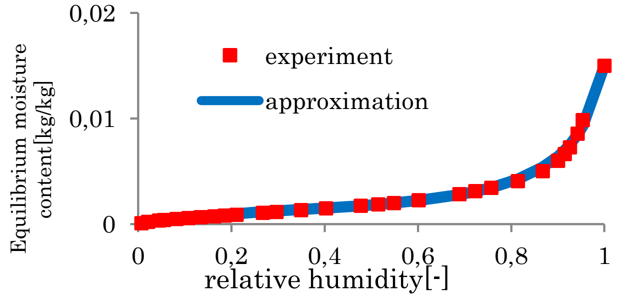

Fig. 2
Sorption isotherm of glass fiber

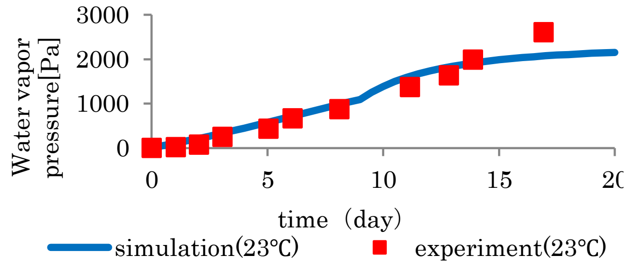

Fig. 3
Comparison experimental value and the calculated value of inner water vapor pressure

Pressure and thermal conductivity increase under T35°C80%RH with desiccant

Subsequently, we measured performance of thermal conductivity and inner water content of VIPs with a small amount of desiccant in 35°C80%RH in Fig. 4. For a while thermal conductivity was stable, and relative humidity was 0%. However, as the thermal conductivity increases, relative humidity also increases. This indicates that the desiccant has been inactivated. Before and after deactivation of the desiccant, we can predict that the influence of thermal conductivity by the water vapor content.

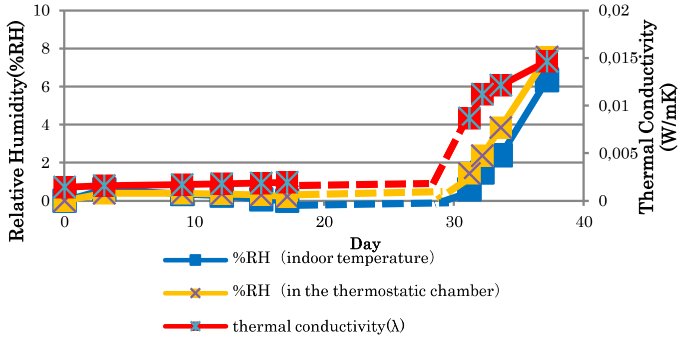

Fig. 4
Thermal conductivity versus water vapor pressure increase under 35°C80% with a small amount of desiccant

Conclusions

In this study, we measured water vapor pressure inside the VIPs using micro thermohygrometer in order to predict long-term performance of VIPs using glass fiber core material. Since the relative humidity inside the VIPs did not change even after taking out from the climatic chamber, as the temperature decreased, the internal relative humidity was kept constant by adsorption of water vapor to glass fiber core material. We confirmed the validity of theoretical calculation compared with these results.
The impact of the water vapor on the thermal insulation performance of VIPs has been clarified. Especially, the gaseous thermal conductivity considering the separate effect of the dry air and water vapor had been created. In the case of VIPs is used for building, it is necessary to design assuming various environments. In the future, we will also start measuring the performance using VIPs with various sensors under the environmental condition in houses.

Symbol

λ_{cop}	thermal conductivity for center of panels [W/mK]
λ_s	solid thermal conductivity [W/mK]
λ_g	gaseous thermal conductivity [W/mK]
λ_r	radiative thermal conductivity [W/mK]
m	mass of inncoming water vapor [kg]
m_{void}	mass of water vapor present in the pore [kg]
M_{adsorb}	mass of water vapor adsorbed inside the VIPs [kg]
M_i	Avogadro's constant [kg/mol]
V_{eff}	volume of VIPs[m^3]
R	gas constant [J/Kmol]
K_i	mass transfer coefficient [g/h Pa]
$P_{i,atm}$	partial pressures of gases under atmospheric pressure [Pa]
P_i	pressure inside the VIPs [Pa]
P_{wv}	water vapor pressure inside the VIPs [Pa]

References
[1] HiPTI - High Performance Thermal Insulation IEA/ECBCS Annex 39, Vacuum Insulation Panels Study on VIP-components and Panels for Service Life Prediction of VIP in Building Applications (Subtask A), 2005.12,
[2] Daniel QUÉNARD, Hébert SALLEE: Micro-nano porous materials for high performance thermal insulation,2ndInternational Symposium on NANOTECHNOLOGY in CONSTRUCTION BILBAO-13-16(2005.11)

SESSION 6

IVIS Paris 2017
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Vacuum Insulation Symposium
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SESSION 6

Aging of Fumed Silica VIP: Predictions and Observations

Ulrich Heinemann[a*]
Daniel Kraus[a]

[a] Bavarian Center for Applied Energy Research
(ZAE Bayern), Division Energy Efficiency
Magdalene-Schoch-Strasse 3,
97074 Wuerzburg, Germany
* Corresponding author:
Tel. +49 931 70564-355
ulrich.heinemann@zae-bayern.de

Keywords:

Vacuum insulation panels,
permeation of gases,
ageing,
degradation of the thermal resistance.

Abstract

From about two decades of research on VIP with high barrier laminates at ZAE Bayern a variety of samples is in the stock, the eldest ranging back to 1998. After several years or even decades of storage in the lab some of them now were tested again in order to check, what is the increase of the internal gas pressure, what is the increase of the mass (caused by permeating water vapor), what is the decrease of the thermal resistance and is it all as expected, extrapolated or predicted. The focus is on VIP with a core made of fumed silica.

Introduction

ZAE Bayern has been involved in development, thermal characterization and optimization of different filler materials for evacuated thermal insulations since the beginning of the 1980s. For about 20 years, the focus was on the thermal properties. Application fields especially were cryos, high temperature electrical batteries and space applications. In some space applications, the vacuum was free. For other applications, following the classical approach, it was thought to be maintained by metal or glass cases. From the mid of the nineties also special high barrier laminates, i.e. aluminum laminates and later on metalized films were considered as flexible to process and cost effective envelopes. Prerequisite were the low requirements on the quality of the vacuum related to core materials with the largest pores in the sub-micrometer range especially those based on fumed silica and silica aerogels. In the following years, experimental and scientific work beside the thermal characterization was extended to questions on tightness, processing, quality control and quality assurance, on durability and ageing. Besides existing application fields such as appliances also, the implementation to buildings was investigated and tested [1], [2]. Methods and procedures were developed and refined to characterize the permeation properties of VIP envelopes and to model the inherent degradation of the thermal resistance with time caused by permeating gases. From about two decades of research on VIP with high barrier laminates a variety of samples is in the stock, the eldest ranging back to 1998. After years of storage in the lab some of them now were tested again with respect to the increase of the internal gas pressure, the increase of panel's mass and the increase of the thermal conductivity. The focus is on VIP with fumed silica core.

Permeation of Gases through VIP envelopes made of high barrier laminates

For the permeation of gases through VIP envelopes made of high barrier laminates one has to distinguish between different components of the air, dry gases and water vapor. Different permeation paths have to be considered. From a theoretical point, one might expect permeation rates related to the area of the planar film, to the length of the edges, to the number of the corners and to the length and geometrical layout of the sealed seams. In practice for the permeation of dry air, most significant contributions were found to be related to the area of the flat film. Additional considerable contributions through the sealed seams have to be taken into account. Thus, the pressure increase of VIP depends on its size, on the ratio of the surface area to the length of seams.

For metalized films, the permeation of water vapor typically is three orders of magnitude larger than that of dry air. Permeation through the flat film here is the dominating path, a permeation through the seams hard to separate. Laminates with a several microns thick aluminum film, are advantageous especially with respect to water vapor permeation. Here the permeation through the sealed seam typically is the remaining and dominating path for water vapor permeation [3],[4]. Beside others extremely low permeation rates of aluminum laminates are deduced from the first test panels made at ZAE Bayern, now 19 years old.

Procedure to predict the degradation of the thermal resistance with time

In the past, a special test procedure on vacuum insulation panels VIP was developed to predict the increase of thermal conductivity with time [5]. The procedure includes the characterization of the thermal properties of the kernel, i.e. the thermal conductivity as function of the gas pressure, temperature and humidity and the sorption isotherm, and the properties of the envelope, i.e. permeation of dry air as well as water vapor as function of temperature and water vapor partial pressure. From variation of the size of the VIP with constant thickness, which changes the ratio of surface area to length of the rim, we were able to separate the permeation rates of the seam and of the high barrier laminates (edge and planar effects) [2]. Small sized panels (e.g. 300*300*10 mm³ and 100*100*10 mm³) were stored for half a year under different climatic conditions: e.g. 25°C, 45°, 65°C, humidity as in the lab (not controlled but recorded) or controlled to 75%. Increases of internal gas pressure and specimens mass with time are the basic information to derive the properties of the high barrier laminates and the seams. From this, depending on panel's size and climatic conditions, the increase of VIP's thermal conductivity with time can be modelled. Thermal conductivity measurements before and after storage were used for validation of the model and/or to identify possible additional aging effects that are not related to permeating gases.

This procedure in the past was applied to several sets of VIP made of fumed silica kernels enveloped by metallized high barrier laminates.

An additional ageing effect, not related to permeating gases, was found.

References
[1] U. Heinemann, R. Caps, J. Fricke, Characterization and Optimization of Filler Materials for Vacuum Super Insulations, Presentation on the 1st IVIS "European Workshop on Vacuum Panel Technology for Superinsulation in Domestic Appliances and Industrial Applications", Sept. 1998, Milano, Italy
[2] R. Caps, U. Heinemann, J. Fricke, P. Randel, Application of Vacuum Insulations in Buildings, Presentation on the 3rd IVIS "Progress in Vacuum Insulation", June 2000, Vancouver, Canada
[3] H. Schwab, U. Heinemann, A. Beck, H.-P. Ebert, J. Fricke., Permeation of different gases through foils used as envelopes for vacuum insulation panels. Journal of Thermal Envelope and Building Science, 2005. 28(4): p. 293-317
[4] IEA Annex 39, Subtask A, H. Simmler, S. Brunner, U. Heinemann, H. Schwab, K. Kumaran, Ph. Mukhopadhyaya, D. Quénard, H. Sallée, K. Noller, E. Kücükpinar- Niarchos, C. Stramm, M.J. Tenpierik, J.J.M. Cauberg, M. Erb, Vacuum insulation panels — study on VIP-components and panels for service life prediction of VIP in building applications (Subtask A), IEA/ECBCS Annex 39 HiPTI — High Performance Thermal Insulation, 2005
[5] H. Schwab, U. Heinemann, A. Beck, H.-P. Ebert, J. Fricke, Prediction of service life for vacuum insulation panels with fumed silica kernel and foil cover, Journal of Thermal Envelope and Building Science, 2005. 28(4): p. 357-374

A methodological framework for the analysis of the service life of VIPs based envelope components in buildings

S. Fantucci[a*]
A. Capozzoli[a]
A. Lorenzati[a]
M. Perino[a]
D. Quénard[b]

[a] Politecnico di Torino, Corso Duca degli Abruzzi 24, Turin 10129, Italy
[b] Centre Scientifique et Technique du Bâtiment, 24 rue J. Fourier, 38400 St. Martin d'Hères, France
* Corresponding author:
Tel. +39 011 090 4550
stefano.fantucci@polito.it

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Vacuum Insulation Panels,
VIP service life,
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ageing,
lifetime.

Abstract

Vacuum Insulation Panels (VIPs) represent one of the most promising solution for building insulation. Nevertheless the VIPs service life may be limited by water vapour as well as gas permeations. The extent of their occurrence is strictly dependent by the severity of temperature and humidity at which VIPs are exposed during their operation. In the context of IEA EBC Annex 65 activities, a common simulation based procedure was introduced to identify potential critical hygrothermal working conditions for VIPs when they are used in different building components. A methodological framework was developed to estimate the yearly profiles of temperature and relative humidity at the boundaries of VIPs considering different indoor and external conditions and envelope configurations.
This procedure provided general data suggesting guidelines for the correct design of VIP based building components considering their actual working conditions.

Introduction

In the context of IEA EBC Annex 65 activities, a common simulation based procedure was proposed and developed to identify potential critical hygrothermal working conditions at the boundaries of VIPs, analysing a comprehensive set of VIP based envelope configurations. The yearly profiles of temperature, relative humidity and partial water vapour pressure at the VIP surfaces were obtained for different weather and indoor climatic conditions. In this paper the methodological framework at the base of the procedure is presented. In addition, the first results related to a wall configuration are described and critically analysed.

The main aims of the research activity were:
> highlight critical building applications/configurations of VIPs due to severe boundary conditions;
> identify potential solutions to mitigate the working conditions and to protect the VIPs;
> provide general guidelines for the correct design of VIPs based building components;
> contribute to the definition of laboratory "accelerated ageing test", considering various component configurations and climatic conditions.

Methodology

The proposed methodology is based on the following steps:
> selection of typical building VIP based components representative of the building technologies for various countries;
> selection of boundary conditions for the analyses (external and indoor conditions);
> assessment of the yearly profiles of: temperature (T), relative humidity (φ), and partial water vapour pressure (p_v), at the VIPs surfaces (by means of numerical simulations);
> results analysis, in order to identify critical conditions at the VIP layer surfaces.

In the following sections each step will be briefly presented and analysed.

Selection of typical configurations

Ten different building components were selected (walls, roof, terraces, etc.), according to the past/current building technologies typical of each country involved in the project.

Selection of boundary conditions

Temperature and relative humidity of the indoor space were defined according to different technical standards [1], [2], [3]. The outdoor weather conditions were those representative of different countries (specifically: France, Germany, Italy and Sweden).

Numerical simulations: approach and assumptions

Numerical analysis were performed by means of 1D and 2D dynamic heat and moisture simulation tools [4]. Erreur ! Source du renvoi introuvable. summarises the criteria used for the simulations. To minimise the computational efforts, a series of simplifying assumptions were adopted:

> VIP panels were modelled as an equivalent homogeneous layer, simplifying the actual structure (envelope and core material);
> 1D & 2D heat and moisture transport phenomena were considered;
> the thermal conductivity of VIP layer was assumed equal to the centre of panel thermal conductivity λ_{cop};
> the water vapour permeability of the VIP layer was considered infinite.

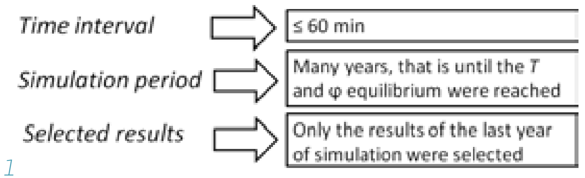

Fig. 1
Simulation approach adopted for the common exercise

Design alternatives

Simulations were performed for various design alternatives varying those parameters that mostly affect the severity of the operating conditions: orientation, external finishing colour, indoor moisture load.

Analysis of the simulation results

Simulation results were post-processed in order to clearly identify the VIPs operating conditions.
For each selected design alternative and for each component, two different set of data related to T, φ and p_v were considered (Figure 2): i) time profiles, ii) cumulative frequency distributions.

The cumulative frequency distributions of each variable were divided in four ranges, from (I) to (IV): the first range represents the less severe operating conditions, while the fourth the worst (**Erreur ! Source du renvoi introuvable.**). The results of the simulations, for all the design alternatives, were organised in summary tables, containing the peak values of T, φ and p_v on each side of the VIP panel, and the percentage of time for which, during the year, the VIPs are exposed to a certain class of severity.

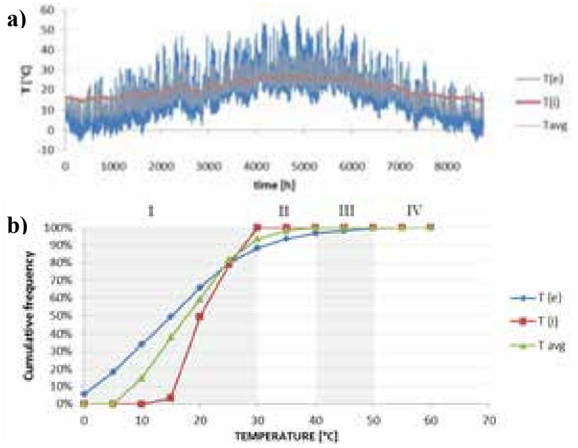

Fig. 2
Simulation outputs. a) Example of yearly time profiles,
b) example of cumulative frequency analysis

Range	T [°C]	φ [%]	p_v [hPa]*
I	T ≤ 30	φ ≤ 50	p_v ≤ 21.2
II	30 < T < 40	50 < φ < 60	21.2 < p_v < 44.4
III	40 < T < 50	60 < φ < 70	44.3 < p_v < 86.3
IV[1]	T ≥ 50	φ ≥ 70	p_v > 86.3

Tab. 1
Ranges of values of temperature, relative humidity and water vapour pressure

Conclusions and perspectives

A procedure was proposed and developed that allows an easy and straightforward analysis of the effect of the working conditions on the ageing of VIP based building envelope components. This procedure makes it possible to assess the VIPs service life expectancy.
The application of this methodology to various cases showed that:

> VIPs placed in between high vapour diffusion tight layers are exposed to higher moisture stress;
> for same climatic conditions, higher peak values of temperature were observed in roofs;
> when a vapour barrier is not used, the influence of the indoor moisture load is always relevant.

Lessons learned for the correct design of VIP based components:

> ventilated air layer or light finishing colour can reduce the severity of the VIP operating conditions for the external wall insulation;
> the protection of VIP with thin traditional insulation layer is always encouraged (especially for VIP behind heater, where it's also possible to add radiant shields);
> ventilated façades are suggested to prevent the water absorption in case of high driving rain;
> for roof application: light colour, performant water proof membrane, ventilated airspace and gravel covering layer (flat roof) are recommended.

Acknowledgements

This work was developed in the framework of IEA -EBC ANNEX 65. The authors gratefully acknowledge all the partners involved in the Subtask 3.

[1] Temperature, relative humidity, and water vapour pressure conditions adopted in ST2 of IEA-EBC ANNEX 65 for ageing test

References
[1] EN 15026:2007, Assessment of moisture transfer by numerical simulation.
[2] ASHRAE 160:2016, Criteria for Moisture-Control Design Analysis in Buildings.
[3] EN ISO 13788:2012, Hygrothermal performance of building components and building elements
Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods.
[4] IBP,WUFI®, Fraunhofer Institute for Building Physics, Holzkirchen, Germany.

Calculation of increase of thermal conductivity of Vacuum Insulation Panels (VIP) according to differing climatic influences

S.Treml[a]*
C. Sprengard[a]
M. Engelhardt[a]

[a] Forschungsinstitut für Wärmeschutz e. V.
München, Lochhamer Schlag 4,
D-82166 Gräfelfing
* Corresponding author:
Tel. +49 89 85800 30
treml@fiw-muenchen.de

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VIP, Internal pressure,
Thermal conductivity,
Artificial ageing,
Life time expectancy.

Abstract

The thermal conductivity of vacuum insulation panels (VIP) depends on the pore size of the core material and the internal pressure of the panel. Due to an unavoidable increase of internal pressure by time because of permeation of water vapor and dry air gases through the barrier film, the thermal conductivity of the panels increases during life time. In the current study for exemplary VIP the partial pressure increase of water vapor and dry air gases was investigated dependent from temperature and relative humidity. The derived functional relation of partial pressure increase and adjacent climate conditions was used to calculate the increase of thermal conductivity in different exemplary building applications in Germany. The results show a dependency of the mean thermal conductivity in the first 25 years of use from the location of the building, the orientation of the building element and the specific construction.

Introduction

The basic research approach is a combination of laboratory scale measurement to determine the partial pressure increase of water vapor and dry air gases as a two-dimensional function dependent from the surrounding temperature and relative humidity and to apply these functionalities on modelling data of climatic stress at the boundary layer between the barrier film and the environment. The long time behavior is determined by means of a saturation function.
The calculated pressure increase is used to further calculate the increase of thermal conductivity based on the known values of $\lambda_{Gas,free}$ and $p_{1/2,Gas}$ and taking into account climatic conditions representative for five constructions with varying orientation and location.

Material and Methods

The determination of pressure increase by time was investigated on VIP with a dimension of 40 x 40 x 1.5 [cm]. All in all 40 panels were stored in three different temperatures varying from ca. 23°C to 70 °C. In each temperature step the relative humidity was altered in three steps from ca. 10 % to 97 %. All in all nine climatic steps were achieved in this way. The internal pressure and thermal conductivity of all panels was measured subsequently in the fresh state and after 1, 3, 6 and 9 months of storage in the described conditions. The internal pressure was determined with a foil lift of method at different temperatures to discriminate between the internal pressure increase of water vapor and dry air gases as described in Kraus et al. 2005.
The thermal conductivity was measured in a guarded hot plate apparatus. The (partial) pressure increase rate in mbar/a was calculated by linear regression techniques. Subsequently surface approximation was applied on the obtained data points of (partial) pressure increase to derive a two-dimensional function that can be utilized to directly calculate the time dependent (partial) pressure increase when certain climatic conditions occur. The calculation of a specific yearly pressure increase (separated for dry air gases and water vapor) then was taken out by inserting hourly dissolved climatic data in the boundary layer of the film barrier and the environment obtained with WUFI® into the described functions.

To obtain exemplary climate data, hygrothermal modelling was performed using WUFI®. The investigation considers five different constructions that are flat roof/roof terrace (horizontal), pitched roof (30° slope of roof), external thermal insulation compound system (ETICS) (vertical), internal insulation (vertical) and a ventilated façade (vertical). The observed locations are Freiburg and Holzkirchen in Germany. The orientation varies from South to West and the internal moisture load is varied from normal to high, according to EN 15026. Furthermore different types of cladding (XPS, GRP) are included.

To consider different thicknesses of VIP the results can be converted using the ideal gas equation according to the changing volume at different thicknesses. The calculation was done separately for the internal and external side of the VIP and the results were averaged and are considered as the partial pressure increase in the first year p_{incs} $(t = 0)$. To calculate the long time behaviour the value p_{incs} is integrated in a saturation function (Eq. 1).

$$p(t) = (p_{end} - p_0) \cdot \left(1 - e^{\left(\frac{-t}{\tau}\right)}\right) + p_o \qquad \text{Eq. 1}$$

where

p_{end}	(partial-) pressure for t --> infinity for dry air gases: 1013.25 mbar for water vapour: according to the mean climate,
p_0	Initial pressure: 2.5 mbar (total internal pressure) 2.125 mbar (part. pressure dry air) 0.375 mbar (part. pressure water vapour),
τ	Damping constant $(p_{end}$ - $p_0)/p_{inc}$ $(t=0)$

The increase of thermal conductivity was calculated stepwise from year to year according to Eq. 2.

$$\lambda = \lambda_0 + \Delta\lambda_{N2} + \Delta\lambda_{H2O} + \Delta\lambda_{MC} \qquad \text{Eq. 2}$$

where

$\lambda 0$	Initial thermal conductivity
$\Delta\lambda_{N2}$	Increase due to dry air gases
λ_{H2O}	Increase due to water vapor
λ_{MC}	Increase due to moisture content of the core

The increase of gas thermal conductivity is calculated taking into account the half-life gas pressure $p_{1/2,Gas}$ and thermal conductivity of the free gas, $\lambda_{Gas,free}$ according to Eq. 3 [2].

$$\Delta\lambda_{Gas} = \frac{\lambda_{Gas,free}}{1 + \frac{p_{1/2}}{\Delta p_{Gas,part}}} \qquad \text{Eq. 3}$$

Gas	$\lambda_{Gas,free}$ in mW/(m K)	$p_{1/2}$ in mbar
N_2	25.6	600
H_2O	18.2	240

Tab. 1
Parameter for calculation of gas thermal conductivity

Based on the sorption isotherm of the core material and the known partial water vapor pressure by time, the moisture content of the core material is calculated and the related increase of thermal conductivity is considered according to Eq. 4.

$$\Delta\lambda_{MC} = C \cdot \Delta MC \qquad \text{Eq. 4}$$

where

C	Factor obtained by calibration measurement
λMC	Increase of moisture content

Results and discussions

In Figure 1 exemplary data of (partial) pressure increase for a pitched roof are shown. It is visible that the evolution of the total internal pressure has a degressive shape. In the observed time frame this is mainly influenced by the saturation of the water vapor partial pressure that reaches around half of the end value after 15 years and is close to the end value of ca. 10 mbar after 50 years of use. On the other hand the partial pressure increase due to permeation of dry air gases in the same time frame remains more or less linear, because of the much higher end value that is close to the atmospheric pressure of around 1013 mbar.

Figure 2 shows the development of the thermal conductivity by time for the observed cases. Again a degressive shape is assessed in all cases. The spreading of the data proofs the influence of the construction, location and orientation of the building element on the specific ageing behaviour. Especially the hygro-thermal loads are sensitive for the evolution of the thermal conductivity. Beside the permeation of water vapor and the subsequent pressure increase, also the increased moisture content of the core is of great impact.

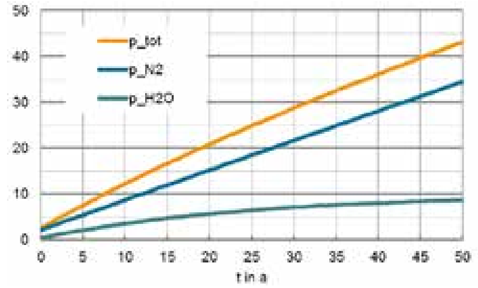

Fig. 1
Exemplary result for (partial) pressure increase by time

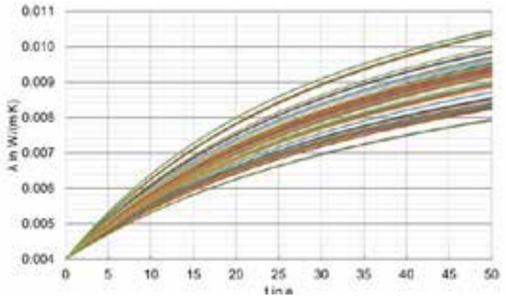

Fig. 2
Range of thermal conductivity increase for the observed exemplary applications

Conclusions and outlook

The results show a degressive functionality of the thermal conductivity by time. Beside the type of construction and the level of temperature especially the hygric loads are of great influence on the evolution of thermal conductivity.

Acknowledgements

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References
[1] Kraus, D., Büttner, D., Heinemann, U., Fricke, J. (2005): Non-destructive Method to Determine the Water Vapour Pressure in Vacuum Insulation Panels (VIP), Bavarian Centre for Applied Energy Research (ZAE Bayern) 2005
[2] Schwaab, H. (2004): Vakuumisolationspaneele - Gas- und Feuchteeintrag sowie Feuchte- und Wärmetransport. Dissertation, Julius-Maximilian-Universität, Würzburg

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Prediction method of the long-term thermal performance of Vacuum Insulation Panels installed in building thermal insulation applications

A. Batard[ab]*
T. Duforestel[a]
L. Flandin[b]
B. Yrieix[c]

[a] EDF R&D – TREE – EDF Lab Les Renardières
77818 Moret-sur-Loing, France
[b] LEPMI – LMOPS - Université de Savoie
Campus Savoie Technolac - Hélios
73376 Le Bourget-du-Lac, France
[c] EDF R&D – MMC – EDF Lab Les Renardières –
77818 Moret-sur-Loing, France
* Corresponding author:
Tel. +33 6 31 65 44 49
antoine.batard@edf.fr

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Vacuum insulation panels,
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modelling,
real solicitations,
performance.

Abstract

Vacuum Insulation Panels (VIPs) are super-insulating products that can be used for different applications. When they are used for building thermal insulation, they have to maintain a very high thermal performance for long-term. The initial thermal conductivity of VIPs with fumed silica core is around 4 mW/m/K. This very low value will increase in time, depending on the nanoporous properties of the core material and on the barrier envelope efficiency which prevents the increase of moisture and internal pressure. To estimate the long-term thermal performance of VIPs, modelling is performed. Simulations show the huge and unforeseen importance of the core material characteristics, and of the external temperature and humidity. That is why it is necessary to study the VIPs behaviour with real service-life solicitations due to each configuration. This paper proposes a methodology for determining the long-term thermal performance of VIPs when they are installed in envelope components for various building thermal insulation applications and various climates. All the methodology, based on hygrothermal modelling at the building and at the components scales for determining the climatic solicitations actually seen by the panels, is described. Severity criteria and performance indicators are proposed in order to estimate the thermal efficiency of VIPs in various applications and climates and to propose guidelines for future standardization.

Introduction

The aim of this paper is to study the VIPs behaviour with the real solicitations that are met during their service life. The first part of this paper describes the overall methodology and the modelling tools that have been used for the determination of temperatures and humidities at the panels' surface when they are installed in systems for various building thermal insulation applications. The studied dynamic model of VIP is described by Batard et al. [1]. The model has to take into account the hygro-thermal behaviour of the panel and the ageing process over 50 years depending on the external solicitations. In a second part, the climate conditions, building, applications and insulation systems that have been chosen for the evaluations presented in this paper, are described. The third part is devoted to the presentation of some simulation results. From these results, an evaluation process of the VIPs performance is proposed in the fourth part, depending on a severity criterion and adapted performance indicators.

Methodology and modelling tools

A three steps methodology is proposed. In a first step, the hygro-thermal solicitations at the walls' surface are determined over 1 year. The temperatures are calculated from simulations of buildings with a classical thermal software [1, 2]. In a second step, each insulation system, associated to its local temperature and humidity solicitations, is simulated with a detailed heat and mass transfer software. Previously calculated temperatures and humidities are imposed at the systems' surfaces. Simulation results give to the temperatures and humidities at the VIP's surface over 1 year. In the last step, these solicitations are imposed at the surfaces of the dynamic model of VIP. These solicitations are looped fifty times in order to make 50 years simulations.

Simulations have been carried out with typical VIPs panel of 0.5 x 0.5 x 0.02 m^3. Three core materials have been studied: C1, C2 and C3. Water vapour and dry air permeances are fixed to constant values measured at 23 °C, on aged panels stored during 10 years at 23 °C and 80 % RH at EMPA [3]. They are respectively maded with silica S1, S2 and S3. Their characteristics and implementation in the numerical model are described by Batard et al. [1]. Silica S1 is a hydrophobic fumed silica obtained from the treatment of the hydrophilic fumed silica S2. Silica S3 is a precipitated silica and is much more hydrophilic.

Description of cases study

It has been chosen to study only French climates. France is decomposed into three main climatic zones: H1, H2 and H3. The corresponding cities are Nancy, Rennes and Nice respectively. A one storey standard individual house has been chosen for this study. The house is covered with a flat roof. The Th-BCE 2012 method developed by CSTB [4] is used to simulate the building. Three relevant insulation applications have been studied: wall insulation, floor insulation and flat roof insulation.

Results and discussions

Temperature evolutions at the wall's and the VIPs' surfaces and water vapour partial pressures have been calculated. For flat roof, in summer the temperature are between 20 and 60 °C. Pressures fluctuate between 500 Pa and 3500 Pa and are always higher in summer than in winter. Then, solicitations calculated at the VIPs' surface have been imposed to the dynamic VIP model for all VIP configurations described in paragraph 2. The simulations can estimate the thermal conductivity evolution of VIPs for each system, climate condition and orientation. The simulation results for flat roof in Nice are presented on Figure 1.

The thermal conductivity evolutions are different depending on the core material. After 50 years, thermal conductivities are between 5.5 and 8.2 mW.m^{-1}.K^{-1} for VIPs with core material C1, between 7.2 and 9.5 mW.m^{-1}.K^{-1} for VIPs with core material C2, and between 7.8 and 10 mW.m^{-1}.K^{-1}. for VIPs with core material C3. These increases estimated for realistic solicitations are much lower than those estimated for long-term ageing tests with constant and rather severe conditions [1].

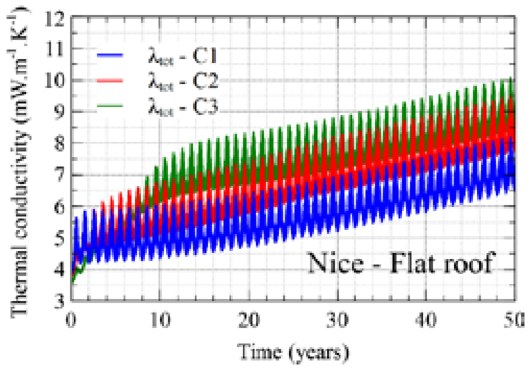

Fig. 1
Thermal conductivity evolution over 50 years of VIPs installed in flat roof in Nice

Severity index and performance indicators

Two types of performance indicators are proposed to calculate the mean thermal performance of VIPs over different periods of time. The mean thermal conductivity calculated only over the heating period is slightly lower but not that different to the conductivity calculated over the entire year. Figure 2 shows the relation between the severity indices and the mean thermal conductivity over 50 years. It can be observed that the mean thermal conductivity over 50 years doesn't depend that much on the applications, but depends more on the climate and even more on the silica. The mean thermal conductivity over 50 years of VIPs installed in building insulation applications is between 4.8 and 7.2 mW.m^{-1}.K^{-1}.

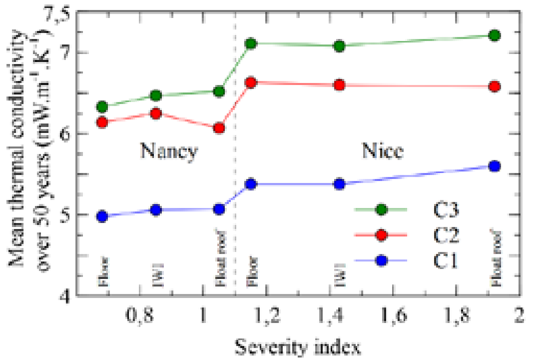

Fig. 2
Relation between the severity indices and the mean thermal conductivity over 50 years of VIPs with core material C1, C2 and C3, installed in floor, IWI in North and flat roof applications, in Nancy and Nice

Conclusions and outlook

Finally, the real solicitations at the VIPs' surfaces are rather moderated and less severe than the solicitations commonly used during short-term accelerated ageing tests. These solicitations lead to mean thermal conductivities which depend on the VIPs configurations, climates and insulation applications, and the worst values are around 7 mW.m-$^{-1}$.K^{-1}. Today, this value is generally considered as the mean thermal conductivity whatever the VIPs, whereas VIPs with hydrophobic silica have the best mean thermal conductivities (between 5 and 5.6 mW.m^{-1}.K^{-1}).

Acknowledgements

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References
[1] A. Batard, T. Duforestel, L. Flandin, B. Yrieix, Modelling of long-term hygro-thermal behaviour of vacuum insulation panels, Energy and Buildings, 2017.
[2] G. Plessis, A. Kaemmerlen, A. Lindsay, Buildsypro: a modelica library for modelling buildings and energy systems, in: Modelica Conference, 2014.
[3] S. Brunner, B. Yrieix, E. Pons, Evaluation of VIPs after mild articial aging during 10 years: focus on the core behavior, in: IVIS 2015, Nanjing (China), 2015.
[4] CSTB, Méthode de calcul Th-BCE 2012, Tech. rep. 2012.

Moisture Management in VIP Retrofitted Exterior Walls

A. Sharma[a]
P. Mukhopadhyaya[a*]

[a] University of Victoria, Victoria, BC
* Corresponding author:
phalguni@uvic.ca

Keywords:

Thermal insulation,
Vacuum insulation panels,
Moisture management,
WUFI-2D,
Exterior wall.

Abstract

Vacuum Insulation Panel (VIP) by virtue of their compact design and high thermal resistance per unit thickness could be used with or in place of conventional thermal insulation materials. This paper discusses the moisture management issues associated with retrofitting existing building envelopes with VIPs. VIPs could be installed on the exterior or interior side of the wall, however, abrupt change in temperature could lead to moisture accumulation inside the wall section and shorten its service life. In this study, a wood-frame stucco cladded wall was retrofitted with VIP and was simulated for a period of three years at eight different North American climatic locations using hygrothermal simulation tool WUFI-2D. The results from hygrothermal simulations show that appropriately designed retrofitted walls can have superior moisture management performance.

Introduction

Household energy consumption for Heating, Ventilation and Air Conditioning around the world is increasing. Older buildings or poorly maintained buildings could lead to increased energy consumption. Addition of thermal insulation is one of the most common method of building envelope retrofit for enhanced energy performance. Insulation can be added to the exterior or interior side of the wall or inside the stud cavity. Addition of insulation leads to increased wall thickness, if not accommodated in the existing wall cavity.

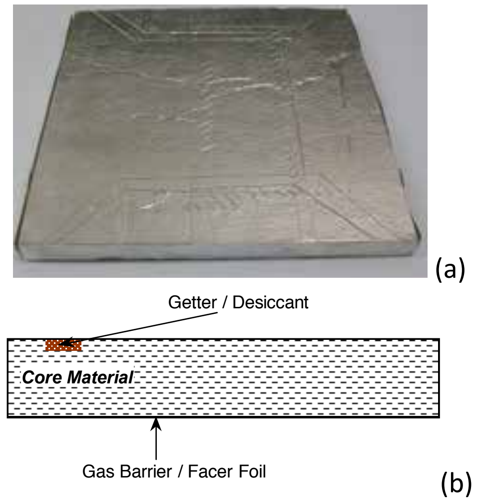

Fig. 1
Photo and construction of VIP

Vacuum Insulation Panel (VIP), as shown in Fig. 1, is a novel insulation material which by virtue of its compact size and high thermal resistance per unit thickness (R-Value) could help in reducing the overall wall thickness, as compared to conventional insulation materials, whilst increasing the overall R-Value of the wall [1]. Due to its higher R-Value and higher vapor diffusion resistance factor, use of VIP could lead to a higher temperature gradient and potential interstitial condensation inside the wall assembly. Thus, wall retrofit options using VIPs need to be thoroughly analyzed for moisture management issues before construction.

Methodology

This study aims to assess the moisture management performance of wood-frame stucco wall retrofitted with VIPs. Hygrothermal simulations were conducted using WUFI-2D at eight different North American climatic locations with Moisture Index (MI) ranging from 0.13 to 1.17. The simulation outputs (WC: water content, RH: relative humidity (RH), and T: temperature) were used to compare the wall performance before and after retrofitting. Fig. 2 describes the arrangement of VIPs on the wall section with the interior and exterior retrofitting options.

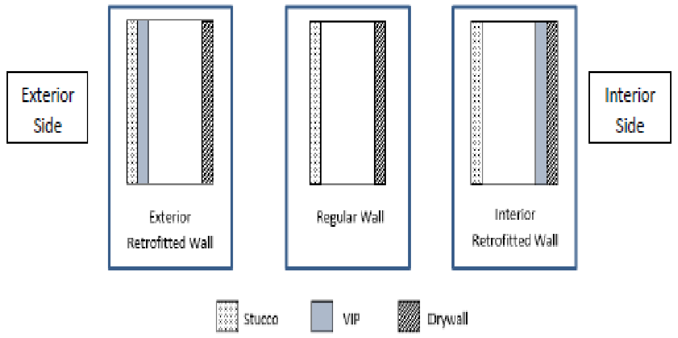

Fig. 2
Interior and exterior retrofitting with VIP

The material data, surface/climate data and the initial conditions were defined using available database in WUFI-2D. The thickness of VIPs used was 13mm. The indoor boundary conditions chosen were according to ASHRAE 160P specifications. The simulations were then carried out for three years starting from January 2013 until January 2016. List of the eight locations with the climate type and moisture index are shown in Table 1.

The simulation results obtained for WC, RH and Temperature from the drywall and OSB (oriented strand board) layer were used to compare the moisture management performance of regular or control wall, interior retrofitted wall and exterior retrofitted wall.

Location	Moisture Index	Climate Type
Phoenix, AZ	0.13	Hot, Dry
San Diego, CA	0.74	Hot, Dry
Winnipeg, MB	0.86	Cold, Dry
Ottawa, ON	0.93	Cold, Wet
Tampa, FL	0.95	Hot, Wet
Vancouver, BC	1.09	Cold, Wet
Wilmington, NC	1.13	Hot, Wet
St John's, NL	1.17	Cold, Wet

Tab. 1
Moisture index (MI) and climate type for chosen locations

Results and discussions

The simulation results only from the third year were considered in this study and compared for the RH, WC and Temperature of regular wall. However, due to space limitations, only the RH results from the OSB and drywall layer are discussed and presented in this paper. The variation of RH range in OSB for all three wall configurations are as shown in Fig. 3. It could be seen that the interior retrofitted wall had smaller ranges for all eight locations, except at Tampa and Wilmington. However, the RH range plots for the regular wall were wider as compared to both exterior and interior retrofitted walls and the maximum RH at St. John's for the regular wall was 90%, which could potentially result in mold growth risk if the other required conditions (temperature, nutrients etc.) for mold growth are sustained for too long.

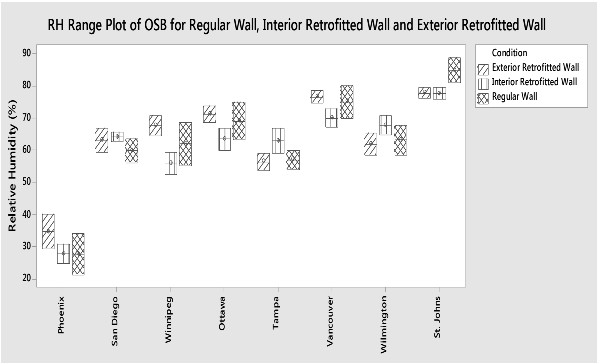

Fig. 3
RH range plots of OSB for regular wall,
interior retrofitted wall and exterior retrofitted wall

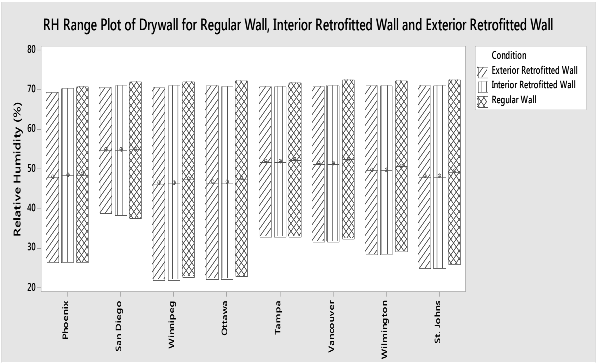

Fig. 4
RH range plots of drywall for regular wall,
interior retrofitted and exterior retrofitted wall

The results for the Temperature and WC for all three configurations could be obtained from the graduate thesis [2].

Conclusions and outlook

Based on WUFI-2D hygrothermal simulations of regular and VIP retrofitted wood-frame stucco walls, following conclusions can be drawn:

1. Compared to regular wall, the moisture management performance of interior VIP retrofitted wall improved in cold climates whereas it decreased in hot climates having moisture index of 0.74 and above (i.e. San Diego, Tampa and Wilmington).
2. The moisture management performance of the interior VIP retrofitted wall was found to be superior to exterior retrofitted wall.
3. Interior retrofitting with VIP could potentially have better moisture management performance than exterior retrofitting with VIP, if and only the indoor boundary conditions are kept under certain threshold values.

References
[1] P. Mukhopadhaya et al. 2011, "Use of Vacuum Insulation Panel in Building Envelope Construction: Advantages and Challenges" 13th Canadian Conf. on Building Sci. and Tech.pp. 1-10
[2] A. Sharma, 2017, MASc Thesis, University of Victoria, BC, Canada

SESSION 7

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SESSION 7

EOTA supports innovation in the construction market

Yannick Lemoigne

CSTB,
84 avenue Jean Jaurès-Champs-sur-Marne,
77447 Marne-la-Vallée Cedex
* Corresponding author:
yannick.lemoigne@cstb.fr

Abstract

The CPR (Construction Products Regulation) lays down harmonised rules for the marketing of construction products in the EU. The Regulation provides a common technical language to assess the performance of construction products. It ensures that reliable information is available to professionals, public authorities, and consumers, so they can compare the performance of products from different manufacturers in different countries.

The EOTA functions as the "Organisation of Technical Assessment Bodies-TAB" pursuant to Article 31 of the EU CPR, which lays down harmonised rules for the marketing of construction products in the EU. The members of EOTA are all Technical Assessment Bodies nominated to the Commission by the member states. o facilitate the co-operation of these Bodies, EOTA was established.
The organisation carries out the following tasks:

> adopts European Assessment Documents (EAD) and ensures that they are publically available;

> coordinates requests for the European Technical Assessment and the procedure adopting a European Assessment Document;

> organises the coordination of all TABs.

Therefore EOTA ensures that reliable information is available to professionals, public authorities, and consumers, so they can compare the performance of products from different manufacturers in different countries gaining free entry to the internal market by being CE marked.

The contribution to the IVIS2017 Symposium will permit participants to understand how EOTA can be of service in facilitating the free movement of construction products and the creation of a strong Single Market.

www.eota.eu

WFTAO/UEAtc : technical approval assessment construction products

Thomas Bruun[a]
Eric Winnepennink[b*]

[a] ETA Denmark - WFTAO
[b] CSTC-WTCB-BBRI Belgium
* Corresponding author:
Harjit.singh@brunel.ac.uk

Abstract

Taking into account the required service life of construction works and the corresponding risks if the intended service life is not met or if parts of the works fail during use, the state-of-the-art in the construction sector develops relatively slowly.

Innovations require time to demonstrate fitness for use in construction works, before being accepted as state-of-the-art. Consequently, in the construction sector, product standards have always been complemented by technical assessments.

Whereas in general, (national) product standards cover products for which codes of practice exist, technical assessments or approvals for unique, innovative and complex products and kits usually cover, apart from product properties and performances, guidance regarding design and installation, limiting conditions or requirements, made specific for the product or kit covered by the technical assessment or approval.

UEAtc, the European Union for Technical Approval in Construction (www.ueatc.eu) and WFTAO, the World Federation for Technical Assessment Organizations (www.wftao.com) provide services related to construction product evaluation of unique, innovative and complex products and kits.

This combined contribution to the IVIS2017 Symposium will permit participants to understand the contribution that these organizations provide related to facilitating market acceptance.

Assessment of Vacuum Insulation Panels (VIP)

H. Cherkaoui[a]
C. Pompeo[b]
D. Quenard[b]
S. Farkh[a]
R. Bouchie[a]

[a] CSTB, DEIS, 84 avenue Jean Jaurès
Champs-sur-Marne
77447 Marne-la-Vallée Cedex
[b] CSTB, DEE, 24 rue Joseph Fourier
38400 Saint-Martin-d'Hères

Keywords:

Vacuum insulation panels,
assessment,
certification,
intended use.

Abstract

CSTB has contributed to a thorough technical assessment of insulation Vacuum Products (VIP). For several years, research activities have been carried out jointly with manufacturers and other research centers to characterize VIP products in order to integrate them into building walls. More recently, the VIP have been the subject of elaboration of two referential documents one for ACERMI certification and one for "Avis Techniques".

This allowed a certifying body to attribute a certified value of thermal performance of these products and to correlate it with the provisions of specific installation in walls (durability and thermal bridge).

A Technical Assessment of Experimentation (ATEx) and Avis Technique were published in 2015. The first certificate was published in December 2015 for a thermal conductivity of 0.0052 W/(mK) and thermal resistance up to 8.8 m²K/W for a thickness of 5 cm. In this context, a control by a certifying body set up each year, including audits of manufacturing plants and tests on products.

Introduction

The assessment of innovative systems delivers to construction stakeholders the conclusions of technical experts on the performance reliability and durability of these systems, depending of their intended use. CSTB assists construction stakeholders by encouraging the emergence of innovations and their access to the market, while securing them.

Several types of evaluation procedures are available in an optional way. For example: "Avis Technique (**Atec**)" or "Document Technique d'Application (**DTA**)", "Appréciation Technique d'Expérimentation (Atex", European Technical Assessment (**ETA**), **Certification, testing**….

SIM such as VIP and aerogel can be covered by those assessment procedures.

Avis Technique - Atec

Atec refers to the opinion of a group of experts representing the professions, called the Specialized Group (GS). The opinion is formulated on the rightness for use of innovative construction systems. The Atec are issued by the Commission in charge of Formulating Technical Document (CCFAT)

Certification

The certification validates that the characteristics of a product are consistent according those defined in a benchmark established with expert's group and that a quality monitoring process has been implemented with third party oversight.

Atex

Atex is a quick technical assessment procedure formulated by an expert group on any innovative product, system or equipment. This evaluation is often used either in advance of a Technical Opinion, as it allows initial feedback on the implementation of the processes or for a single site. Examples of ATEx: glass roofs, reversible floors, roof waterproofing, ...

Assessment of characteristics related to intended use

Depending on the intended use, defined by the manufacturer, the characteristics related to this intended use shall be evaluated.

For example, for insulation from the inside of a wall building, manufacturers shall give assessment of some characteristics, for example, of following properties:

- Squaring,
- Flatness,
- Thermal conductivity/ or thermal resistance and its durability assessment,
- Resistance to diffusion of water vapour,
- Dimensional stability,
- Emissivity of external faces and its durability
- Reaction to fire,
- Protection against noise,
- Resistance to corrosion of the envelope,
- Internal pressure and its durability (aging)
- Determination of peripheral thermal bridges

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Thomas Bruun[a]
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- Resistance to corrosion of the envelope,
- Internal pressure and its durability (aging)
- Determination of peripheral thermal bridges

Ageing

The proposed aging tests depend on the field of intended use, for example:

- for insulation of inside of building : 50 ° C and 70% RH for 6 months.
- For insulation of outside of building: 70 ° C and 70% RH for 6 months.
- For other specific applications, the aging will be adapted to the temperatures and humidity level for which the VIP product will be exposed.

The tests consist of measuring some characteristics of the product before and after aging

Thermal characteristic assessment

Thermal conductivity or resistance of product

The determination of thermal conductivity or resistance shall be carried out according to EN 12667:

- Test specimens are conditioned at (23 ± 2) ° C and (50 ± 5)% RH for at least 24 hours.
- Measurement results are determined at 10 °C.

The declared thermal value, shall be given as limit values representing at least 90 % of the production, determined with a confidence level of 90 % according to the calculation rules given in EN ISO 10456 and EN 13162. (Fig. 1)

Fig. 1
Picture of vacuum insulation panel (VIP) sample in heat flowmeter to measure thermal conductivity

Assessment of thermal bridges

Peripheral thermal bridges induced by the metallized envelope can lead to a significant reduction in the overall thermal resistance of the vacuum thermal insulation. A numerical method (2D geometric model) can be applied to evaluate thermal bridges. The coefficients of thermal linear bridges are calculated according to EN ISO 10211. It is also possible to perform testing to evaluate these peripheral heat bridges using a heat flowmeter according to EN 12667 (Fig. 2) or a hot box according to EN ISO 8990 (Fig. 3).

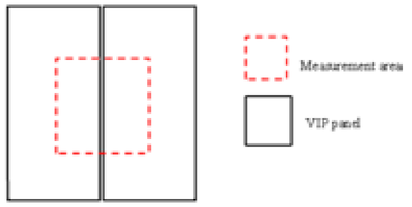

Fig. 2
Measurement of thermal bridge of panel VIP according EN 12667

Fig. 3
Measurement of thermal bridge of panel VIP using hot box according EN ISO 8990

Thermal characteristics of wall

Manufacturer shall describe all the technical elements of the system and also provide information about installation.

This description allows the calculation of the global thermal characteristic of the wall, Up (W/m².K).

Thermal insulation performance of the system installed in a wall can be characterized by:

- coefficient Up which take into account linear thermal bridge of junctions between assembled panels "VIP";
- thermal resistance of the VIP product, taking into account the aging factors and its moisture content;
- superficial thermal resistances;
- thermal resistance of the support wall;
- thermal resistance of other layers in wall;
- any integrated thermal bridges (contact with frames, etc.), fixation of metallic elements.

Evolution of mass of the product exposed to aging

The mass evolution of the product exposed to moisture condition provides information on the water content inside the VIP. It is an indicator of the performance of the envelope.

The mass evolution of the testing sample is carried at several milestones : t = 7 days, 15 days, 30 days, 60 days, 90 days, 120 days and 180 days.

Characterisation of junctions between VIP panels

This characterization is necessary to evaluate the airtightness of wall when it is claimed and/or when the junctions affect either the thermal or other performance of the system.

For each element, mastic or adhesive tape, making it to join the VIP panels, the joining element / panel is characterized according to the standards EN 12316-2 and EN 12317-2.

The tests are carried out on both sides when they are of different natures and according to the manufacturer's instructions with regard to the direction of installation.

For example, it is required to evaluate before and after aging the following characteristics:

- Shear strength according to EN 12317-2 in longitudinal (L) and transverse (T)
- Determination of the resistance to peeling according to EN 12317-2
- Resistance to water vapour transfer to characterize this junction.

Characterisation of junctions between panel VIP and construction support

Each element used to make a junction between panel VIP and construction support shall be characterized according to the EN 12316-2 standard.

The traction test will be carried out on a conventional, watertight and smooth support (galvanized steel) and a conventional porous support (clay briquette or concrete panel).

Characterization of the airtightness

When airtightness of wall is claimed the performance of airtightness shall be evaluated, in particular withsingular points (frame junction, ...). This performance can be carried out accordance EN 12114.

Hygrothermal simulation

The aim is to characterize a wall with respect to hygrothermal transfers, in particular to determine the temperatures and the humidity and to evaluate the possible risk of condensation, in particular at singular points. It is also possible to proceed by hygrothermal simulations.

The climatic conditions must be chosen so as to cover all the regions concerned in the field of intended use.

Results and discussions

All results obtained from the evaluation of the system of insulation and the intended field of use are presented for examination by a committee of experts to decide on the easibility and suitability for use. A key point of the discussions is the quality of manufacturer installation guidelines provided: VIP layout, how avoiding thermal bridges, how providing an air layer in order to avoid VIP to be punctured after installation...

References

EN ISO 10456	Building materials and products -- Hygrothermal properties -- Tabulated design values and procedures for determining declared and design thermal values
EN 13162	Thermal insulation products for buildings. Factory made mineral wool (MW) products. Specification
EN ISO 10211	Thermal bridges in building construction -- Heat flows and surface temperatures -- Detailed calculations
EN 12667	Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Products of high and medium thermal resistance
EN ISO 8990	Thermal insulation -- Determination of steady-state thermal transmission properties -- Calibrated and guarded hot box
EN 12317-2	Flexible sheets for waterproofing. Determination of shear resistance of joints. Plastic and rubber sheets for roof waterproofing
EN 12114	Thermal performance of buildings. Air permeability of building components and building elements. Laboratory test methods

POSTERS

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POSTER 1

Characterization and properties of vacuum insulation panel (VIP) with silica-fly ash powder composite core material

Desire Emefa Awuye[a]
Zhaofeng Chen[a*]
Asim Shahzad[a]
Binbin Li[a]
Wang Xuejia[b]
Lu Xudong[b]

[a] College of Material Science and Technology,
Nanjing University of Aeronautics
and Astronautics, Nanjing, 210016, P.R. China
[b] Yichen New Energy Co.Ltd. Qingdao P.R China
* Corresponding author:
zhaofeng_chen@163.com

Keywords:

Vacuum Insulation panel (VIP),
Silica-fly ash powder,
Composite core material,
Pore structure,
Thermal conductivity.

Abstract

Vacuum Insulation panel (VIP) is a system developed to reduce energy consumption and improve thermal comfort for end users when applied in buildings. VIP consists of an evacuated micro/nano-porous core material and a getter, encapsulated in a multi-membrane envelope. The VIP core material essentially provides the required vacuum level to enhance low thermal conductivity, and also supports the VIP system mechanically. The efficiency and useful service life of a VIP greatly depends on the core materials. A number of conventional and hybrid materials are employed as core materials for VIP. However, the nano-porous nature of fumed/precipitated silica and aerogel core materials produce VIPs with relatively better long-term insulation performance considering aging and durability. Also, fumed/precipitated silica and aerogel core material VIPs are relatively expensive. This study focuses on a VIP with silica and fly ash powders as core material. Microstructural characterization and properties are discussed in this paper. The thermal conductivity of the as-produced silica-fly ash powder composite VIP was 6 mW/m.K at typical gas pressure ($P_{1/2}$) of 1000 Pa. Cost of production of a meter square of this VIP is about $10.

Introduction

The relentless effort of numerous researchers have led to the development of Vacuum Insulation Panel (VIP) which is made up of a porous core material, high quality barrier packaging material and getters [1]. Referred to as Super Insulating Material (SIM), Vacuum Insulation Panels (VIPs), have thermal conductivity much lower than conventional insulators (like polyurethane and polystyrene foams) thus they help curb heat losses [1, 2]. Presently at the fore front of VIP research are methods to maintain or improve performance of VIP materials; thus to promote affordability and to extend its application is of much importance [3, 4]. Major contributors to the high cost of VIPs are known to be the core and gas barrier materials [5]. Common VIP core materials as reported in literature are glass fiber, open cell polyurethane foam, open cell polystyrene foam, precipitated silica and nanogel [6]. Materials need to possess some properties to be suitable for use as core materials. Some of such properties are smaller pore diameter, open pore structure, relatively high mechanical strength, and impermeability to infrared radiation [7]. However, porosity is to enhance easy evacuation and have minimum conduction heat transfer since mechanism of thermal transport in VIPs occur via solid conduction, gaseous conduction and radiation. The most common core material in Europe is fumed silica while glass fiber and open cell polyurethane are common in Asia [8]. Currently, researchers all over the world are working towards developing hybrid core materials (HCMs) with multi component fiber/powders as core materials for VIPs in order to cut down on the cost and enhance its wide usage [1,3, 6]. In this study, the use of fumed silica (FS), fly ash (FA) powder and glass fibers (GF) are used as alternative core material to help produce VIP at a relatively cheaper cost.

Fly Ash

In the production of electrical power, an industrial ash is produced as a waste product when coal is burnt. This ash is known as Fly ash or Pulverized Fuel Ash (PFA). Due to their mode of formation, these fly ash particles are extremely fine, have almost uniform particle sizes and are spherical in shape. Though fly ash composition varies, it mostly includes oxides of silicon (SiO_2), aluminum (Al_2O_3), iron (several kinds), and calcium (CaO). For this experiment, the class F fly ash was used due to its high SiO_2 content. Table 1 gives a detail composition of the fly ash used, where as Fig.1 shows a macrograph of Fly ash powder.

Chemical Compound	Percent Composition
SiO_2	54.90
Al_2O_3	25.80
$Fe_2$03	6.90
CaO	8.70
MgO	1.80
SO_3	0.60
NaO & K_2O	0.60

Tab.1
Composition of class F fly ash used

Fig.1
Image of fly ash powder

Materials and Methods

Fly ash, fumed silica and glass fibers raw materials used were commercial grade provided by Yichen New Energy Co.Ltd. (Qingdao P.R China). 65% of the composite was fly ash, 30% fumed silica and 5% glass fiber. The particle size of the fumed silica was between 6-42 nm while the fly ash particle size was ≤ 100μm. The glass fiber strands also had a diameter and length of 2-6 μm and 6-12 mm respectively. The envelope used in this study comprised of glass fiber cloth (100g) as the outer layer, PE (100g), PA (15g), PET (12g), and Al (7g). Fly ash, fumed silica and glass fiber were mixed thoroughly in their dry state in a mixing hopper in a weight ratio of 65:30:5 respectively and subsequently heated at a temperature of about 140°C to remove any form of moisture. The mixture was transferred into moulds, compressed and subjected to the required density and size using a press. The moulds were placed in evacuable pouches for air evacuation, and transferred into a drier to further get rid of any moisture. After drying, the moulds were wrapped air tight in a thin inner film bag and placed into the gas barrier envelope which was sealed at one end with the other end left open for further evacuation. The semi- finished VIP was finally placed into another evacuation machine where the air was removed mechanically and the typical gas pressure checked after the process. Subsequently, the semi- finished VIP was completely sealed; thereafter its parameters (thermal conductivity, density and typical gas pressure) were checked. Fig. 2 depicts a cut section of the hybrid VIP.

Fig. 2
Picture of a Hybrid Core Material composed of fumed silica, fly ash and glass fibers

Results and discussions

Microstructure

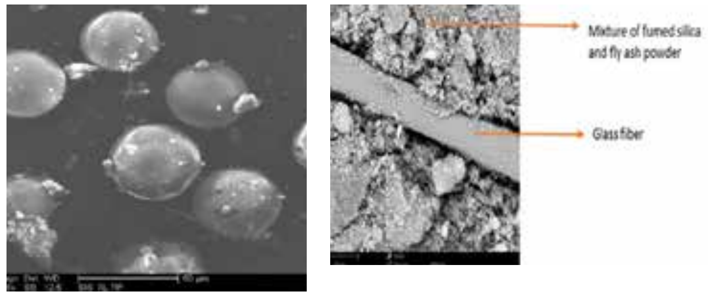

Fig. 3
SEM images (a) Fly ash and (b) HCM

Fig. 3a and 3b show the SEM micrographs of fly ash and the HCM respectively. Generally the fly ash mass was porous. At 50 um magnification and considering unbroken state, the fly ash mass consisted of spherically shaped bubbles, discreetly separated from each other. Some minor impurities, white spots in Fig. 3a, were attached to the outer sphere of the fly ash masses. On the other hand, for the HCM, the glass fiber had a relatively smooth surface and was surrounded with the fumed silica and fly ash powder mixture. One cannot easily distinguish between both powders since they are similar in size and color. Nonetheless, few fly ash spheres can be spotted and the porous nature of the mixture is evident. After several experiments in which ratio was varied, it turned out that the ratio that produced the best thermal insulating properties was 65 % FA, 30% FS and 5% GF. VIPs produced via this method using a composition of 65% fly ash, 30% fumed silica and 5% glass fiber attained a thermal conductivity of 0.006 W/ (m.K) having density of ≤10 kg/m^3 with dimensions of 600 mm × 400 mm. At a gas pressure of 1000 Pa, the initial thermal conductivity was 0.006 W/ (m.K). The graph in Fig. 4 shows the thermal conductivity of the various ratios prepared and it indicated an initial thermal conductivity of 0.006 W/ (m.K) for 65% FA.

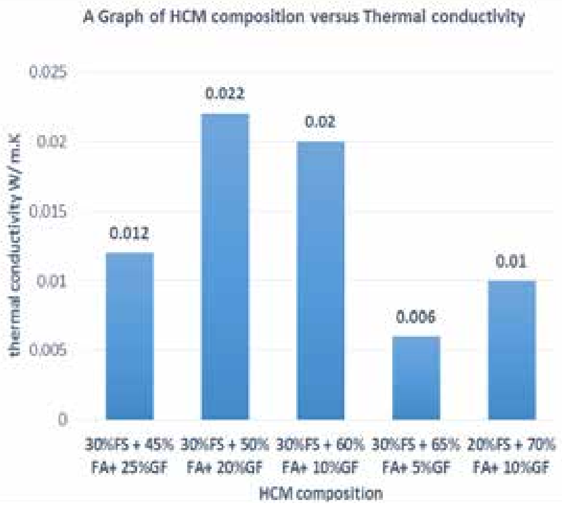

Fig.4
A graph showing the thermal conductivity of various ratios of HCM composition

In order to determine the aging rate as well, tests were also performed on the VIP sample by placing them in a high temperature furnace DHG-9036A at a temperature of 60°C for 30 days intervals. After every 30 days, the thermal conductivity and density of the sample was checked using the heat flow meter Netzsch HFM 436 and recorded. The aging results are presented in Fig. 5. It was observed that, 65% FA maintained a relatively lower conductivity compared with the others until after 60 days when it started rising steadily.

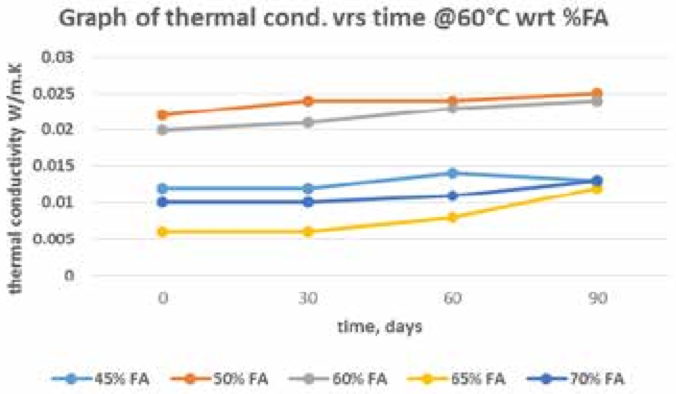

Fig. 5
A graph showing increase in thermal conductivity at a temperature of 60°C

Conclusions

The preparation, characterization and properties of a VIP with hybrid core material (silica-fly ash) have been investigated in this study. After several experiments in which ratio of the constituents were varied, it turned out that the ratio that produced the best thermal insulating properties was 65%FA, 30%FA and 5%GF. Furthermore, this HCM composition maintained a low thermal conductivity at a temperature of 60°C between 0 and 60 days but started rising steadily in thermal conductivity after 60 days. VIPs produced via this method using these raw materials attained an initial thermal conductivity of ≤ 0.006 W/ (m.K) at a typical gas pressure of 1000 Pa. In conclusion, Fly ash powder has thermal insulating properties that is relatively comparable to fumed silica. Especially in China where fly ash is very cheap and readily available as a waste material, it can be used in combination with fumed silica to produce a relatively inexpensive VIP that can be known as SiO_2-FA core VIPs. These VIPs are as half the price of SiO_2 core VIPs. The cost of 1t of FA ranges from $36-43.5.

Acknowledgements

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References

[1] Chen, Z., et al., Energy 93 (2015) 945-954
[2] Boafo, F.E., et al., Energy and Buildings 85 (2014) 644-653
[3] Chang, B., et al. Vacuum 131 (2016) 120-126
[4] Alotaibi, S.S. and S.B. Riffat, International Journal of Energy Research 38 (1) (2014) 1-19
[5] Mukhopadhyaya, P., et al., Journal of Cold Regions Engineering 22(4) (2008)103-123
[6] Mukhopadhyaya, P., et al.,9th international vacuum insulation symposium, (2009) London, UK
[7] Kalnaes, S.E. and B.P. Jelle, Applied Energy 116 (2014) 355-375
[8] Li, C., et al.,Materials & Design 107 (2016) 440-449

POSTER 2

Preparation and thermal performance analysis of novel vacuum insulation stainless steel

Xinli. Ye[ab]
Z. Chen[a*]
J. Zhang[ab]
P. Zhang[a]
C. Sun[a]
Z. Rao[a]

[a] International Laboratory for Insulation and Energy Efficiency Materials, College of Materials Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, P.R. China
[b] Nanjing phoenix source new material technology Ltd, Nanjing 211100, P. R. China
* Corresponding author:
Tel.: +86 18952018969
zhaofeng_chen@163.com

Abstract

A novel vacuum insulation stainless steel (VISS) was developed based on the adiabatic principle of insulation, which was light in weight, low in thermal conductivity. The proposed VISS has advanced innovation in high temperature insulation fields such as nuclear power insulation pipe and heat vulnerable regions of a launch vehicle. Ultrafine glass wool felt was used as VISS core materials to be responsible for the reduction of the gaseous convection and conduction because of its low thermal conductivity. The diameter of the fiberglass is 3μm and the thickness of one single layer is 1mm. Besides, a nickel foil and an aluminum foil were put inside the ultrafine glass wool felt to divided it into three parts, which can be used to reflect high and low temperature hear flow, respectively. In addition, stainless steel foils were used as a sealing layer without linear edge which was distinguished from (vacuum insulation panel) VIP to resist high temperature and keep lower vacuum degree inside. The total density of VISS was 0.25 g/cm^3. The effective thermal conductivity of VISS varies from 0.003 W/(m•K) to 0.009 W/(m•K) in the temperature range from 293 K to 793 K.

Keywords:

Vacuum insulation stainless steel,
high temperature insulation fields,
ultrafine glass wool felt,
lower vacuum degree inside,
effective thermal conductivity.

Introduction

During the last several decades, the world has relied on a great deal of oil to produce energy as energy and environment are the largest problems and challenges to the whole world in all ages. To the reduction of the greenhouse gas and CO$_2$, we use nuclear power to instead of oil. However, heat transfer in nuclear power station dues to the insulation efficiency of pipe material. Traditional materials, glass fiber, ceramic fiber is used in pipe insulation, which has high thermal conductivity and low service time. Therefore, the efficient insulation material is badly in need. This paper aims to show a new grade thermal insulation material called VISS with low thermal conductivity and good overall performance based on traditional procession technology with low cost. Fig 1 shows the external shape of VISS.

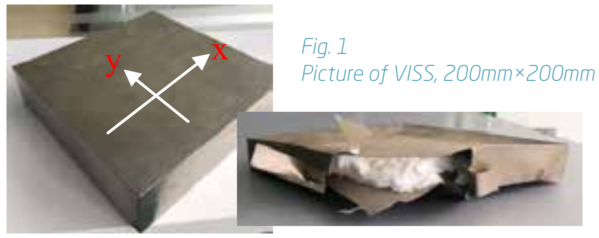

Fig. 1
Picture of VISS, 200mm×200mm×15mm

Experiment

The material fabrication process

To employ this fabrication, the raw materials in the VISS were as follows: ultrafine glass wool with mean fiber diameter of 3μm; nickel foils; aluminum foils and stainless steel foils. Firstly, laser welding was used to weld a square without lid, then ultrafine glass wool felt was put horizontally to cover the bottom. Besides, a nickel foil and an aluminum foil were put inside the ultrafine glass wool felt to divided it into three parts, one prevent heat radiation due to the high reflectivity both in high and low temperature. After the stainless-steel foils were weld around ultrafine glass wool, the VISS with a hole in the surface was put into the high temperature vacuum furnace. When the temperature and pressure reached specified value, the hot melt adhesive over the hole began to plug and seal. Finally, the pressure into the VISS was 1Pa.

Characterization

Effective thermal conductivity was measured by water flow plate method, according to ASTM E422-05 standard. The effective thermal conductivity of materials could be calculated according to the following formula.

$$\lambda = Q \cdot \delta / (A \cdot \Delta T) \qquad (1)$$

Where λ is the effective thermal conductivity of material (W/(m•K)), Q is heat of water absorption per unit time (W), δ is the sample thickness (m), A is the sample area (m^2), ΔT is the temperature difference between hot and cold surface. The heat of water absorption is proportional to the specific heat of water, water flow and water temperature rise.

$$Q = C \cdot m \cdot \Delta t \qquad (2)$$

Where C is the specific heat of water (J/(g•K)), m is the water flow (g/s), Δt is water temperature rise (K).

Results and discussions

The test results of thermal conductivity about the VISS at different temperature was showed in Table 1.

Hot surface temperature /K	Effective thermal conductivity（10^{-3} W/ m·K）			
	Measured			Mean
	λ 1	λ 2	λ3	λ
293	3.0	2.9	3.2	3.03
393	3.7	3.5	3.6	3.60
493	4.7	4.6	4.7	4.67
593	5.9	5.9	6.0	5.93
693	7.4	7.5	7.6	7.50
793	9.0	9.1	9.0	9.03

Tab. 1
Test results of thermal conductivity of the VISS

Table 1 displayed the tested thermal conductivity of VISS with whose temperature range of hot surface was 293~793 K.

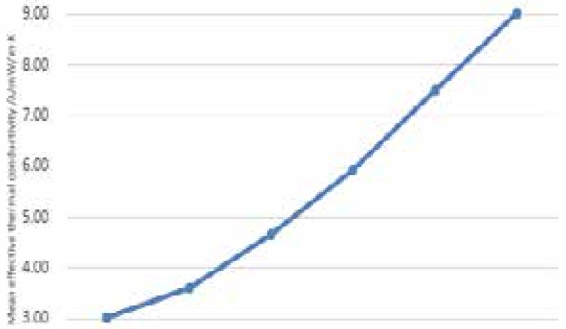

Fig.2
Mean thermal conductivity of VISS at different temperature

It was obvious that the effective thermal conductivity increased with the temperature rising. Below 493K, the mean effective conductivity changed slowly, however, the curvature of slope increased gradually. Meanwhile, its effective thermal conductivity below 10 mW/m·K after times of heating cycling. By contrast, traditional material as glass fibers owned a much higher thermal conductivity about 30 mW/m·K at room temperature.

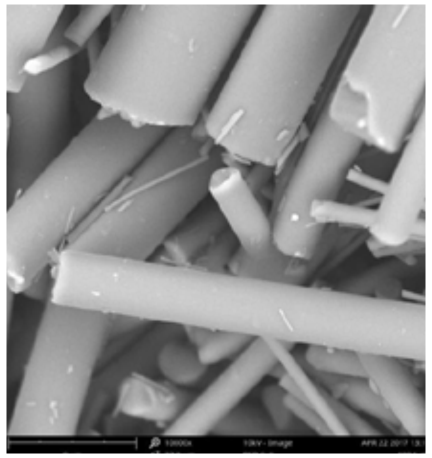

Fig. 3
SEM of VISS core materials

The SEM photograph of the core materials of VISS was shown in Fig. 3. It could be found that the diameter of all fibers is around 3μm, which is satisfied with theoretical calculations. According to the theories, the smaller diameter of the fiber is, the better thermal insulation it owns. And, the result of Table 1 and Fig. 3 supported it.

Conclusions

A novel VISS was prepared by laser welding with low cost. This material is quite different from the traditional inorganic insulation materials according to vacuum package structure, and it showed much lower thermal conductivity between 293 K to 793 K, which could be widely used in high temperature insulation fields such as nuclear power insulation pipe and heat vulnerable regions of a launch vehicle. The SEM results proved the fibers with small diameters (around 3 μm), which was satisfied with the theories and tested results.

Acknowledgements

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References
[1] Fricke J, Heinemann U, Ebert H P. Vacuum insulation panels—From research to market [J]. Vacuum, 2008, 82(7):680-690
[2] Simmler H, Heinemann U, Kumaran K. Vacuum insulation panels: study on VIP-components and panels for service life prediction of VIP in building applications[J]. High Performance Thermal Insulation IEA/ECBCS Annex 39, 2005

Preparation and Performance of Ceramic Fiber Wet Felts

Cao Wu [a]
Zhaofeng Chen [a]*
Fei Wang [a]
Shuting Bao [a]
Zhuo Sun [a]

[a] College of Material Science and Technology,
Nanjing University of Aeronautics
and Astronautics, Nanjing 210016, PR China
* Corresponding author:
Tel. +86 25 52112909
Fax +86 25 52112626
zhaofeng_chen@163.com

Keywords:

Ceramic fiber,
Wet felts,
Thermal conductivity,
Fiber structure.

Abstract

High efficiency and low cost thermal insulation energy saving felts materials containing ceramic fiber were developed by means of the wet process. The morphology of glass fiber felts were observed by SEM, and the influence of moisture content, glass fiber contents and using temperature on the thermal conductivity of ceramic fiber wet felts(CFWFs) were analyzed. The results showed that the thermal conductivity of CFWFs increased with the increase of moisture content and temperature. The thermal conductivity of CFWFs increased by 0.0102W. m^{-1}. K^{-1} when the temperature increased from -18.1°C to 71.69°C. The thermal conductivity was decreased with the increase of glass fiber contents.

Introduction

Low-cost ceramic fiber wet felts(CFWFs), owing to their high stability, excellent thermal resistance, and highly developed specific fibrous structure, have been widely used in thermal insulation applications[1, 2]. In harsh climatic conditions, the use of CFWFs is necessary and is gradually becoming a mandatory requirement in many countries particularly as energy becomes more precious and demand increases[3, 4]. The thermal conductivity of CFWFs is greatly affected by their moisture content, glass fiber contents and using temperature, yet limited information is available on the performance of CFWFs when subjected to actual climatic conditions[3, 5, 6]. Many parameters should be considered when selecting thermal insulation, including cost, water vapor absorption and transmission and [6, 7], most importantly, the thermal conductivity of CFWFs. In this paper, CFWFs were prepared by wet process. The paper aims to enhance the understanding of how the moisture content, glass fiber contents and using temperature affects the thermal performance of CFWFs.

Experiment

Material fabrication

Ceramic fiber wool was provided by Deqing Hengdu Crystal Fiber Co., Ltd. (Deqing, PR China). Glass fiber wool was provided by Suqian NUAA institute of new materials and equipment manufacturing Co., LTD. (Suqian, PR China). Fig. 1 shows the preparation process of the CFWFs by wet process. The dispersed ceramic fiber wool and glass fiber wool suspension was then transported to paper-making machine (AT-CZ-2) and stirred by a blender for 60s. After blending, water was drained out of ceramic fiber wool and glass fiber wool suspension by vacuum pump through an 80 mesh copper net while ceramic fiber wool and glass fiber wool were aligned at the surface of the copper net. Finally, the wet mat was dried at 100 °C for 150 min. The parameters of GWFs are shown in Table 1.

Fig. 1
Preparation process of the GWFs by wet process: (a) Beating; (b) Dewatering; (c) Forming; (d) Drying.

Glass fiber contents (%)	Areal density (g/m^2)	Thickness (mm)	Ceramic fiber diameter (μm)	Glass fiber diameter (μm)
11.38	488.65	5.5±0.1	2±0.2	1.45±0.1
31.34	488.08			
46.4	498.00			

Tab.1
The parameters of CFWFs

Material characterization

In this paper, the thermal conductivity of CFWFs were measured by HFM436/3/1E heat flow thermal conductivity analyzer (Germany). The average fiber diameter was measured according to GB/ T 7690.5-2013. Moisture content was tested by the high temperature blast oven.

Results and discussions

The influence of glass fiber contents on the thermal conductivity

The influence of glass fiber contents on the thermal conductivity for CFWFs is shown in Fig. 2. It can be seen from Fig. 2. that the thermal conductivity of CFWFs decreased with the increase of glass fiber contents. When the glass fiber contents increased from 31.34% to 46.5%, the thermal conductivity of CFWFs decreased rapidly and the thermal conductivity increased by 0.00031 W/m•K. This is due to the smaller fiber diameter of glass fiber helps to improve the thermal resistance of CFWFs.

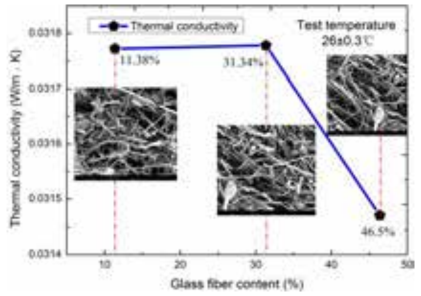

Fig. 2
Thermal conductivity for CFWFs with different glass fiber contents

The influence of moisture content on the thermal conductivity

Figure 3 shows the effect of moisture content on the thermal conductivity of CFWFs. The thermal conductivity for CFWFs increased with an increase of moisture content. When the moisture content increased from 7.4% to 21.4%, the thermal conductivity of CFWFs increased rapidly and the thermal conductivity increased by 0.03858 W/m·K. This is because when the moisture content increases, moisture occupies the pore space of the CFWFs, causing a sharp increase in the thermal conductivity of the material.

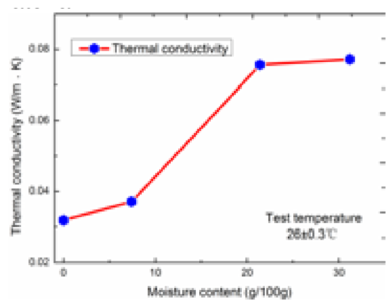

Fig. 3
Thermal conductivity for CFWFs with different moisture content

The influence of using temperature on the thermal conductivity

The influence of using temperature on the thermal conductivity for CFWFs is shown in Fig. 4. It can be seen from Fig. 4. that the thermal conductivity of CFWFs increased with the increase of temperature. When the temperature increased from -18.1°C to 71.69°C, The thermal conductivity of CFWFs increased by 0.0102 W/m•K. This is due to the higher thermal motion of the gas molecules in the pores with the increases in temperature. In addition, the radiation the molecules will also increase, which increases the thermal conductivity of the material.

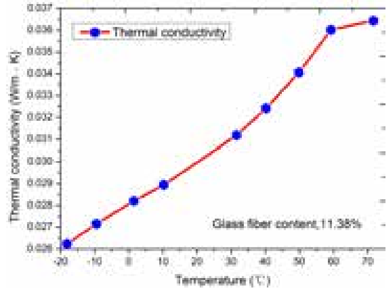

Fig. 4
Thermal conductivity for CFWFs with different temperature

Conclusions and outlook

This study demonstrates that the thermal conductivity of CFWFs increased with the increase of moisture content and temperature. When the moisture content increased from 7.4% to 21.4%, the thermal conductivity of CFWFs increased rapidly and the thermal conductivity increased by 0.03858 W/m·K. The thermal conductivity of CFWFs decreased with the increase of glass fiber contents, due to smaller fiber diameter of glass fiber helps to improve the thermal resistance.

Acknowledgements

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References
[1] Farukh F, Demirci E, Sabuncuoglu B, Acar M, Pourdeyhimi B, Silberschmidt VV. Numerical modelling of damage initiation in low-density thermally bonded nonwovens. Computational Materials Science. 2012;64:112-5
[2] Zhou X, Wei J, Zhang H, Liu K, Wang H. Adsorption of phthalic acid esters (PAEs) by amphiphilic polypropylene nonwoven from aqueous solution: the study of hydrophilic and hydrophobic microdomain. Journal of hazardous materials. 2014;273:61-9
[3] Jerman M, Cerný R. Effect of moisture content on heat and moisture transport and storage properties of thermal insulation materials. Energy and Buildings. 2012;53:39-46
[4] Li C-D, Chen Z-F. Effect of beating revolution on dispersion of flame attenuated glass wool suspension and tensile strength of associated glass fiber wet-laid mat. Powder Technology. 2015;279:221-7
[5] Gomes MG, Flores-Colen I, Manga LM, Soares A, de Brito J. The influence of moisture content on the thermal conductivity of external thermal mortars. Construction and Building Materials. 2017;135:279-86
[6] Abdou A, Budaiwi I. The variation of thermal conductivity of fibrous insulation materials under different levels of moisture content. Construction and Building Materials. 2013;43:533-44
[7] Litovsky E Y SM. Gas pressure and temperature dependences of thermal conductivity of porous ceramic materials: part 1, refractories and ceramics with porosity below 30%. Journal of the American Ceramic Society. 1992;75(12):3425-39

POSTER 4

Performance evaluation of glass wool core VIPs and silica-fly ash core VIPs

Asim Shahzad[a]
Zhaofeng Chen[a]*
Desire Emefa Awuye[a]

[a] College of Material Science and Technology,
Nanjing University of Aeronautics
and Astronautics, Nanjing, 210016, P.R. China
* Corresponding author:
zhaofeng_chen@163.com

Keywords:

Vacuum Insulation Panels (VIPs),
Core materials,
Glass wool,
Silica-fly ash.

Abstract

Temperature maintenance is still one of the dynamic feature for large scale energy consumption in buildings which is 33% of the total consumption. The heavy smog in China resulting from depletion of fossil fuels also demand the development of new technologies that can reduce energy usage in buildings. Number of technologies were developed among which Vacuum Insulation Panels (VIPs) have leading edge. Glass wool was used as core material in VIPs for refrigeration because of their low thermal conductivity ($\lambda \leq 2$ mW/m.K) and low cost (\$20/m^2). Silica-fly ash were preferred as a core material of VIPs for buildings because of their high compressive strength ($\sigma_C > 2$ MPa) and low cost (\$12/m^2). However, the $P_{1/2}$ of the glass wool VIP and silica-fly ash VIP are 10~100 Pa and 1000 Pa, respectively. In this work, performance of VIPs with different cores was compared. Thermal conductivity of VIPs along with the factors affecting thermal conductivity such as density, thickness, internal pressure and porous structures were compared. Effect of core materials on cost of VIPs were also focused. This study will also be helpful in developing standards for VIPs used as building insulations.

POSTER 5

Bio-degradable glass wool cores for vacuum insulation panel : In-vitro and In-vivo biopersistence test

S. Yook[a]*
S. Kim[b]
H. Kim[a]
K. Lee[b]

[a] Advanced Insulation Materials&Technology
Co.,Ltd., Daegu-si 42705, Republic of Korea
[b] Department of Inhalation Toxicology
Research, Korea Institute of Toxicology,
Jeonbuk 56212, Republic of Korea
* Corresponding author:
sw.yook@aimtcorp.com

Keywords:

Vacuum insulation panels,
Glass wool, Biopersistence,
In-vivo, In-vitro

Abstract

The bio-persistence tendencies of certain glass wool fibers that have controlled chemical composition were evaluated by In-vivo and In-vitro test. A controlled circulation system of simulated body fluid (SBF) and intratracheal instillation (ITI) in the rat were employed for the test. Both test showed similar result that indicate close correlation between the In-vivo and In-vitro test.

Only glass wool that have low alumina contents (less than 2 wt%) was dissolved in the SBF, also in the lung of rats. The half-life of bio-degradable glass wool was less than 40 days. The half-life of other experimental group was uncountable.

Introduction

Glass wool has been widely investigated as core materials for vacuum insulation panel due to their high ability to satisfy lowest thermal conductivity around 2 mW/m K. But the inhalation toxicity of fine glass wool has not been reliably evaluated yet, despite the several report of In-vivo biopersistence test. Especially, continuous exposure to glass wool fibers that have low diameter under 3 μm was concerned with causing cancer to human body. Moreover, as widely known, the diameter of glass wool cannot be controlled easily.

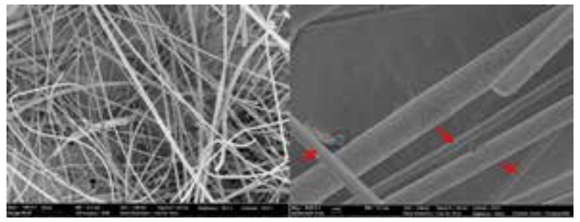
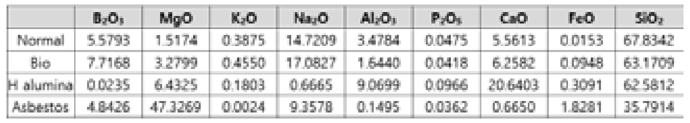


Fig. 1
SEM image of fine glass wool under 3 μm

Until now, only the positive result of In-vivo animal test was valid to be accepted as bio-degradable core material. In-vitro test, which is more simple and fast method to recognize the bio-degradability, is necessary for the in depth study of glass composition. In this study, In-vivo and In-vitro test were tried with same fibrous materials to obtain the correlation between them.

Fibrous materials

The type of fiber used in the experiment was given in Table 1. Principal comparison targets are 'Bio' and 'Normal' glass wool, but asbestos and high alumina wools were added for comparison with worse situations in the animal testing.



	B_2O_3	MgO	K_2O	Na_2O	Al_2O_3	P_2O_5	CaO	FeO	SiO_2
Normal	5.5793	1.5174	0.3875	14.7209	3.4784	0.0475	5.5613	0.0153	67.8342
Bio	7.7168	3.2799	0.4550	17.0827	1.6440	0.0418	6.2582	0.0948	63.1709
H alumina	0.0235	6.4325	0.1803	0.6665	9.0699	0.0966	20.6403	0.3091	62.5812
Asbestos	4.8426	47.3269	0.0024	9.3578	0.1495	0.0362	0.6650	1.8281	35.7914

Tab. 1
Fibrous materials for experiments

In-vivo animal test

To perform inhalation toxicity study of fibrous materials Intratracheal instillation (ITI) method in the respiratory tract of rat (Sprague-Dawley) was adopted. Daily doses of 0.5mg for 4 consecutive days (totally 2mg) were given. Mortality and general symptoms checking, weight measurement and visual observation were carried out during the test period. In addition, the pulmonary tissue was used to calculate the number of remained fibers and half-life, using phase contrast microscope [1].

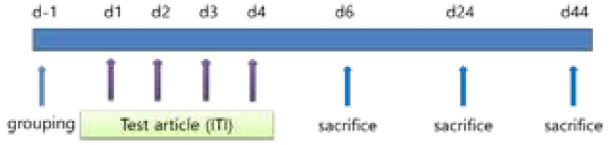


Fig. 2
Schedule of test

In-vitro dissolution test

Artificial body fluids (regular SBF) were manufactured for biodegradable evaluation of test materials [2]. The temperature was kept at 37 degrees Celsius, and the total amount of the solution was 1 liter. The solutions rotated very slowly, and fibrous materials were fixed tightly during the test.

Fig. 3
In-vitro dissolution test

The solution was collected once a week, and the extent of the dissolution was evaluated using the ICP analysis. The solution was changed to clean SBF every week.

Results and discussions

In the In-vivo test, no dead animals were observed due to inhaling test substance during the test period. For a week after injection, rales and weight loss were detected from some animals in the H-alumina group. But they recovered after 1 week. After 20 days, discolorations of lung were detected in the Asbestos and H-alumina groups. No unusual symptoms were found in the normal and bio glass wool groups.

After analyzing the number of fibers in the lung, significant decrease was found only in the Bio-glass wool group, as shown in the Fig.4. The half-life of Bio-glass wool was 40.4 days, but the real half-life is expected less than 40 days due to broken fibers during the test period. Long fibers (over 20 μm) number was critically decreased and they would have contributed to the increase of the number of short fibers.

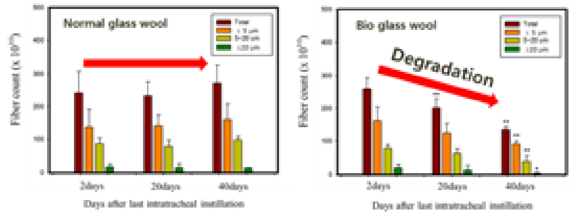


Fig. 4 Analysis of glass wools in the lung

	Total number of fibers	Number of fibers (≤5μm)	Number of fibers (5~20μm)	Number of fibers (≥20μm)
Bio glass wool	40.4 days	45.5 days	40.1 days	16.5 days
Normal glass wool	> 40 days	> 40 days	> 40 days	> 40 days
H-alumina glass wool	> 40 days	> 40 days	> 40 days	> 40 days

Tab. 2 The half-life analysis

The fracture of the fiber was easily visible in the In-vitro dissolution test [Fig.5]. In the real situation, fibers are likely to break more easily due to an active movement of cells.

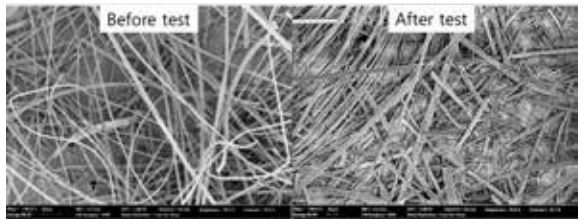


Fig. 5 Fracture of fibers during dissolution

		Normal glass wool			Bio glass wool		
		Ref	1st week	2nd week	Ref	1st week	2nd week
Na	%	0.33	0.34	0.33	0.33	0.33	0.33
K		0.019	0.020	0.020	0.018	0.018	0.018
B	ppm (mg/l)	0.00	0.10	0.17	0.00	**2.40**	**2.00**
Si		0.08	1.80	1.56	0.07	**21.0**	**15.5**
Mg		36	37	36	33	34	33
P		31	31	31	29	19	20
Ca		99	100	101	93	98	99
Al		0.00	0.00	0.00	0.00	0.20	0.60
Fe		0.00	0.00	0.00	0.06	0.05	0.06

Tab. 3 In-vitro dissolution test result (ICP)

After dissolution in the SBF for short period, a significant difference of Si ion was detected. Also, numerical differences were observed in B and P. The dissolution rate of Bio glass wool was extremely faster than normal glass wool, over 10 times. The half-life of Bio glass wool was calculated for less than 4 weeks, based on Si ions as standard. On the other hand, the half-life of other fibrous material (including asbestos and H-alumina glass wool) was more than 40 weeks.

Conclusions and outlook

The results of In vivo and In vitro test of various fibrous materials turned out to be similar. Therefore, In vitro test, the dissolution tendencies in the suitable solution could be considered as a substitution method for In vivo animal test.
The correlation between In vivo and In vitro should be more cleared by further experiments such as dissolution test in the SLF (Simulated lung fluid), and other artificial body fluids.

References
[1] National Institute of Occupational Safety and Health (NIOSH): Method 7400. In NIOSH pocket Guide to Chemical Hazard and Other Databases (DHHS [NIOSH] pub. No 2000 – 130). Cincinnati. Ohio: NIOSH, 2000
[2] M. Marques, R. Loebenberg, M. Almukainzi, Simulated Biological Fluids with Possible Application in Dissolution Testing, Dissolution Technology (2011) 15-28

POSTER 6

Edge conduction of various envelopes for vacuum insulation panels

H. Jung[a,*]
S. Kal[a]
Y. T. Kim[a]
J. Ryu[a]

[a] Advanced Insulation Materials & Technology Co., Ltd., 42, Seongseogongdanbuk-ro 42-gil, Dalseo-gu, Daegu, Republic of Korea (42705)
* Corresponding author:
Tel. +82-10-2422-0145
Fax +82-53-341-8688
hy.jung@aimtcorp.com

Abstract

In this work, an evaluation method of edge conduction is proposed for envelopes of vacuum insulation panels (VIPs). The amount of edge conduction for VIPs with various envelopes is analyzed and measured using newly developed equipment including a heat flux sensor in a vacuum state. Studied envelopes are as follows; both sides Al-foil envelope, Al-metallized hybrid envelope and metalless hybrid envelope. For hybrid envelop, one side of envelope uses Al-metallized laminated film or metalless laminated film and the other side uses Al-foil laminated film. The metalless laminated film includes an organic / inorganic multi-layer, which is newly developed to improve a service lifetime and insulation performance of VIPs at the same time. As a result of this study, the edge conduction reduces 91.2% for the Al-metallized hybrid envelope and 96.2% for the metalless hybrid envelope comparing with the both sides Al-foil envelope. Also, a gas barrier characteristic of the new metalless laminated film is proved by measuring water vapor transmission rate (WVTR), oxygen transmission rate (O_2TR) and acceleration lifetime test (ALT) of VIP samples.

Keywords:

Edge conduction,
Al-metallized laminated film,
Metalless laminated film,
Hybrid envelope,
gas barrier.

Introduction

Most VIPs are enveloped using laminated films or foil film of aluminum and polymer. High thermal conductive material in the envelope makes the edge conduction and it becomes additional thermal path. The effective thermal conductivity of VIPs is simply defined as [1]

$$k_{eff} = k_c + k_{edge}$$

where
k_c = Thermal conductivity at the center
k_{edge} = Thermal conductivity by the edge conduction

In this work, the edge conduction of VIPs with various envelopes is studied analytically and experimentally. A metalless hybrid envelope is developed by the proposed method. Studied films are explained in Fig 1 and they are employed as follows; both sides Al-foil envelope, Al-metallized hybrid envelope and metalless hybrid envelope. The hybrid envelope means one-side of envelope uses specific films and the other side uses Al-foil laminated film.

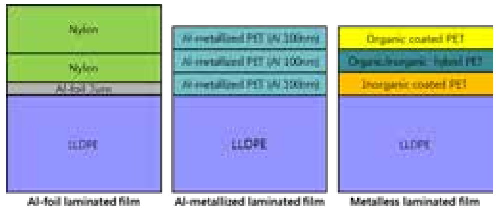


Fig. 1
Various films for an envelope of VIPs.

Analysis for the edge conduction of VIPs

The total heat transfer rate per unit depth through the VIPs is expressed as [2]

$$q' = q'_c + q'_{edge} = \left(k_c + k_{edge}\right)\frac{L}{\delta}\Delta T$$

where
q'_c = heat transfer rate per unit depth through the center of VIPs
q'_{edge} = heat transfer rate per unit depth by the edge conduction of VIPs
L = length of VIP
δ = thickness of VIP
ΔT = temperature difference

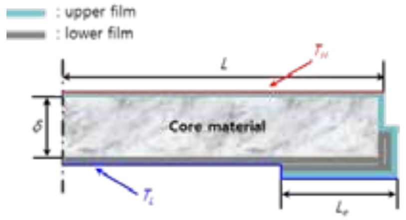


Fig. 2
Simulation model of the edge conduction

A simulation model of the edge conduction is described in Fig 2 and it is a 2-dimensional heat conduction problem with both sides at adiabatic boundary condition. The total heat transfer rate per unit depth through a VIP is calculated with various envelopes using a FVM-based conduction code [3] and kedge is obtained by above equation. The results will be discussed in chap. 4.

Measuring the edge conduction of VIPs

A new experimental apparatus is developed to measure the edge conduction of VIPs as shown in Fig 3. This apparatus can measure only 300 mm x 300 mm sized VIPs.

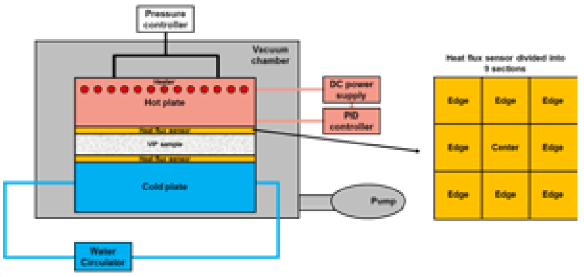


Fig. 3

Schematic diagram of experimental apparatus to measure the edge conduction

Results and discussions

The edge conductions of VIPs with various envelopes are analytically calculated and experimentally measured as shown in below table.

Envelopes	Analysis	Measurement		Error
	k_{edge} [mW/m·K]	k_c [mW/m·K]	k_{edge} [mW/m·K]	[%]
Both sides Al-foil	14.12	2.04	11.56	18.1
Al-metallized hybrid	1.24	1.73	1.06	14.5
Metalless hybrid	0.54	1.57	0.58	7.4

Relative errors between analysis and measurement results are lower than 20%. Main causes of the errors are size of VIPs, thickness of Al-layer and folding leftover pieces of envelopes. VIPs are not perfectly rectangular and 300 mm x 300 mm. The thickness of Al-layer is very difficult to measure exactly. Also, gap is formed between VIP samples and hot or cold plates because of folding leftover pieces of envelopes. The edge conduction dramatically reduces 91.2% for the Al-metallized hybrid envelope and 96.2% for the newly developed metalless hybrid envelope comparing with both sides Al-foil envelope. Reduction of the edge conduction is proved for newly developed metalless hybrid envelope and its gas barrier characteristics are confirmed by WVTR, O_2TR and ALT as shown in below table.

Heat flux sensor in this apparatus can measure the edge conduction of VIPs, because it is divided into 9 sections. Measuring part is put in the vacuum chamber to prevent heat leakage to the air at the edge of sensor. One section measures the heat flux through the center of VIPs and the others measure the heat fluxes through the edge of them at the steady state. Then k_{eff}, k_c, and k_{edge} can easily calculated using the measured heat fluxes and above equation. The results will be discussed in Chap.4.

Envelopes	WVTR [g/m^2·day]	O_2TR [cc/m^2·day·atm]
Al-metallized laminated	0.006	<0.01
Metalless laminated	0.006	<0.005

Envelopes	Average k value [mW/m·K] (ALT condition : 70℃ during 4 weeks)		
	Before ALT	After ALT	$\triangle k$
Al-metallized hybrid	1.82	2.69	0.87
Metalless hybrid	1.79	2.27	0.48

However, above edge conduction data are not useful because it is studied for only 300 mm x 300 mm VIPs. The edge conduction with various sizes is proportional to perimeter and inverse proportional to area of VIPs [4]. Then, the effective thermal conductivity can be simply defined as

$$k_{eff} = k_c + \alpha \frac{l_P}{S}$$

where

α = Constant by type of envelopes

l_P = Perimeter of VIPs

S = Area of VIPs

The constant α can be determined by analysis for various sizes of VIPs by mentioned method above and α is 967.5 for both sides Al-foil envelope, 91.25 for Almetallized hybrid envelope and 36.61 for metalless hybrid envelope. This simple equation is very useful for predicting insulation performance of a system.

Conclusions

In this work, the evaluation method of edge conduction for VIPs is introduced analytically and experimentally. The simple equation to calculate the edge conduction with various sizes of VIPs is developed based on this method. New metalless laminated film is developed using this method. Its edge conduction reduces 96.2% comparing with both sides Al-foil envelope and its gas barrier characteristics are proved by WVTR, O_2TR and ALT. It can considerably improve insulation performance of VIPs.

References
[1] M. J. Tenpierik et al., Journal of Construction Innovation 7 (2007) 38-53
[2] Incropera, F. P et al., Introduction to heat transfer, 5th ed., Wiley, New York (2007) pp. 95-116
[3] S. V. Patankar, Numerical heat transfer and fluid flow, Hemisphere, New York (1980) 59-60
[4] H. Jung et al., International Journal of Heat and Mass Transfer 56 (2013) 436-446

POSTER 7

Novel Characterization Techniques for Cores and Laminates

Eddie Shufer[a]
Yoash Carmi[a]

[a] Avery Dennison Hanita, Kibbutz Hanita, 2288500, Israel
* Corresponding author:
Tel. +972-525-739186
yoash.carmi@eu.averydennison.com

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Abstract

The degradation rate of VIPs is determined by the barrier properties of the envelope, and the response of the core material to the permeating gas molecules. It is therefore extremely important to develop accurate and easy-to-operate characterization test techniques for both the laminates and the cores. The results of these characterization tests serve as a data base for accurate prediction of panel performance through service life in different applications. Many of these new characterization tests are suitable for inclusion in the different International Standards presently being drafted.

The article describes a very reliable technique for measuring the thermal conductivity response of fumed silica to the quantity of water molecules absorbed, together with surprising new test results relevant to the real degradation rate of fumed silica panels in building applications.

Keywords:

Thermal conductivity,
water content,
mVIP,
permeation rate,
water vapor pressure.

Introduction and background

The degradation rate of VIPs depends not only on the permeation rate of the different atmospheric gases through the envelope, but also on the response of the core material to the increasing presence of these permeated gas molecules. Recent lab and field tests on fumed silica (FS) panels show that the degradation rate of FS panels is predominantly determined by the moisture permeating through the envelope, and much less by the permeating air molecules.

This article describes a new generation of measuring technique that allows easy and fast procedures for measuring the dependence of the thermal conductivity of FS panels on the percent of absorbed moisture.

The new measuring technique was applied to three types of fumed silica cores, providing a new understanding of the effect of moisture absorption on the thermal conductivity of the powders. Unexpectedly, important differences were found between the behaviors of the three different cores.

Description of the new testing method

Schematic of this new testing method is shown in Figure 1 below. The core tested is located at the left side of the envelope, while a leak-tight connector is installed on the right side of the bag. The flat left side is used for measuring the thermal conductivity of the core while the connector on the right is used for evacuating the panel and for accurately measuring the internal pressure using two capacitive pressure gauges. This also allows a measured quantity of moisture through a vacuum valve mounted on one arm of the connector into the evacuated space, to enable controlled changes in the moisture content of the FS core.

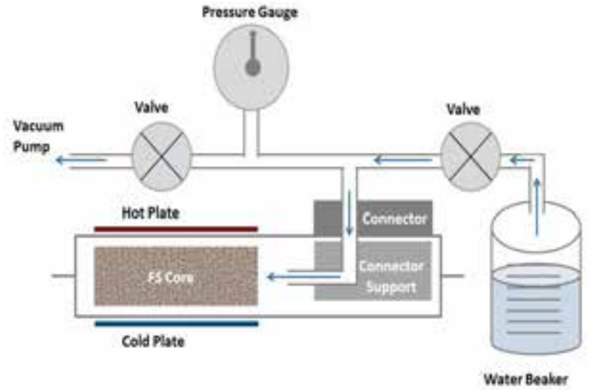


Fig. 1

Drawing of the system for measuring the effect of moisture content on the thermal conductivity of the panel and on the pressure of the moisture vapor

Results: The λvs Water content curve of the tested FS Cores

The graphs below describe the dependence of the thermal conductivity of three different FS panels as function of the water content at steady-state conditions with 2°C on the cold scold plate of the λ machine and 18°C on the warm plate.

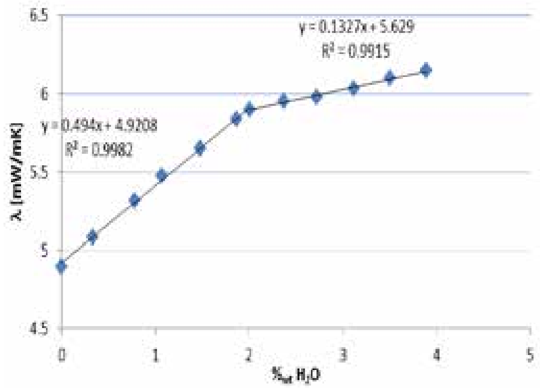


Fig. 2
The center of panel thermal conductivity of the fumed silica core A as a function of the water content of the absorbed moisture

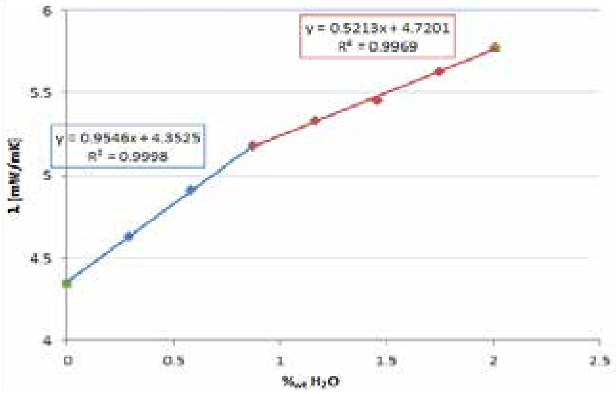


Fig. 4
The center of panel thermal conductivity of the fumed silica core C as a function of the water content.

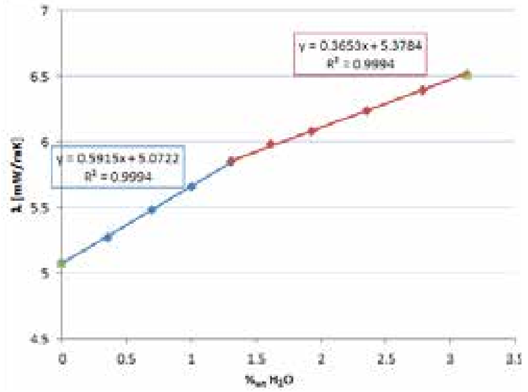


Fig. 3
The center of panel thermal conductivity of the fumed silica core B as function of the water content (2°C-18°C)

Discussions and conclusions

1. A very accurate and easy to operate technique was developed for measuring the dependency of the thermal conductivity of fumed silica cores on absorbed water content.
2. For all three investigated fumed silica cores, the slope dλ/d(%water content) was much steeper at low levels of water content, and more moderate at higher levels of water content.
3. The initial slopes, the turning points and the final slopes were all different for each of the three cores.

Acknowledgements

The research described in this article was funded by VIPA as part of the project:
"An Advanced Technique for Measuring the Effect of Moisture Content on the Thermal Conductivity of Fumed Silica VIPS"

POSTER 8

Retrofitting of Office Building using VIP

How to reach performance Level of new building with Old buildings

POUGET Consultants[a]
Vincent BRAIRE[a]

[a] Building MC2 – 4 place Francois II,
44200 NANTES
* Corresponding author:
Tel. (+33) 2.40.12.21.22
vincent.braire@pouget-consultants.fr
Thermal Engineering Consulting Company

Keywords:

Vacuum insulation panels for Wall,
floor,
roof.

Abstract

In 2012, POUGET Consultants get associated with Magnum Architects and GestionBat (building economist) to work on the MC2 project : 800 m² of office building in the heart of Nantes (44), renovated with a high performance level: Positive Energy Building.

Our huge challenge has been to find the best answer to political expectations regarding energy transition : how to keep value of existing building when targeting the performance level of new buildings ? After 10 months of renovation that ended on June 2014, the building is now fully occupied and 2 full years of consumption data can be analyzed thanks to 73 measuring points. Once a year, a public restitution of the data is given to all the building users (about 50 persons) : the opportunity to show our analysis and to discuss each other in order to better understand results and how to improve performance all together. So far, the real energy consumption is actually over our estimation, for about 20%. It's been reduced of almost 10% between the 1st year and the 2nd (around 80kWhEF/m²).

1952 → 2014

Introduction

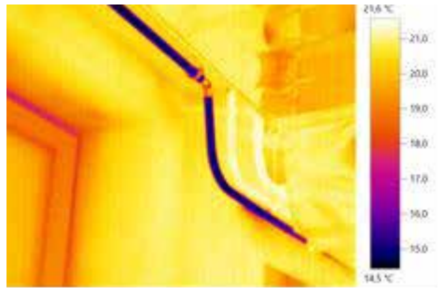
To reach the energy performance targets, we had to explore new technologies, such as VIP.

We worked hard with the the VIP supplier (SINIAT) and the builder (SATI), to find the best application to our project for that particular product that combines both energy & space saving.

SlimVac product from SINIAT

Installation

15 mm panels* on external **windows frames of old walls** (thickness > 50 cm).

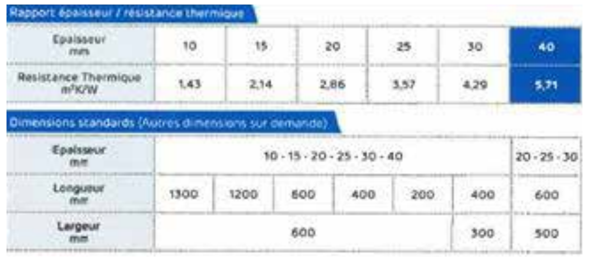


40 mm panels* on **wall insulation of a small office,** to keep the largest useful area.

The VIP window, on the right image, is a real success to show the VIP inside the wall.
40 mm panels*, on an **external floor slab,** below a concrete screed

VIP products require preparation before to be installed on site:
- Early conception : sketches, precise layout, laying technique definition, tests ...
- Implementation: as the product is very fragile, care must be taken. It has to be protected on both side during storage, handling and fixing, especially for a floor application.

As soon as these precautions are fulfill, everything was fine for us.



Rapport épaisseur / résistance thermique

Epaisseur mm	10	15	20	25	30	40
Resistance Thermique m²K/W	1,43	2,14	2,86	3,57	4,29	5,71

Dimensions standards (Autres dimensions sur demande)

Epaisseur mm	10 - 15 - 20 - 25 - 30 - 40						20 - 25 - 30
Longueur mm	1300	1200	600	400	200	400	600
Largeur mm	600					300	500

* information about Energy Performance

Now, we keep on spreading knowledge through many visits of the renovated building, motivating different protagonists, to show everybody that it is possible to renovate building using VIP. !

POSTER 9

SWITCHABLE VIP FOR INTELLIGENT BUILDING FAÇADES

C. Römer[a]*
U. Passon[b]
R. Caps[c]

[a] Bavarian Center For Applied Energy Research (ZAE Bayern), 97074 Würzburg, Germany
[b] Saint Gobain ISOVER G+H AG, 68526 Ladenburg, Germany
[c] va-Q-tec AG, 97080 Würzburg
* Corresponding author: constantin.roemer@zae-bayern.de

Keywords:

Vacuum insulation panels,
Switchable heat transfer,
Energy efficient buildings.

Abstract

This paper presents a novel Switchable Thermal Insulation (STI) based on a Vacuum Insulation Panel (VIP) with a fiber core. It allows the use of solar energy in winter and can be used for cooling in cold summer nights. Contrary to STI developed in previous research, with an envelope made of expensive and thermally inefficient stainless steel sheets, high barrier foils are used for this new kind of super insulation material. The switching function is based on hydrogen gas and corresponding getter materials.

The thermal performance for a STI was investigated before and after aging. A comparison to non-switchable VIPs is given. A prototype was integrated into the south façade of a test building and its performance was measured. The obtained results are compared to numerical simulations with good qualitative agreement for both winter and summer case.

Introduction

Switchable thermal insulations (STI) based on hydrogen and getter materials were investigated in depth at ZAE Bayern in the 90s (Horn et al., 2000, Horn, 2001). In the frame of this research a demonstrator was built, which showed an excellent performance in using solar energy at building façades.

The demonstrator shell was realized by stainless steel sheets to minimize gas exchange with the environment. The research was continued in the funded project "Enotec" (Ebert et al., 2014). In this context, a high barrier foil shell was developed to reduce the thermal bridge at the demonstrator edges and to lower the costs in contrast to a stainless steel STI.

Functional principle

The developed STI affords the opportunity to switch its thermal conductivity between a highly conductive and an insulating state on demand. Therefor a getter material and an electric heater were placed in an evacuated high porous insulation layer which is surrounded by a gas barrier. In case of the heat-insulating state of the STI, the (cold) getter and hydrogen are ligated chemically. Due to the evacuated state of the porous insulation layer, the gaseous thermal conductivity is compensated and the low thermal conductivity of the insulation layer material dominates the effective thermal conductivity. In this state the thermal insulation is similar to the thermal conductivity of a standard vacuum insulation panel (VIP). To get in a highly conductive state the getter is electrically heated to a fixed temperature with a low power. Thus, hydrogen is released by the getter and distributes in the porous insulation layer. Hydrogen has a high thermal conductivity and causes a significant rise of the effective thermal conductivity. As shown in Figure 1 the thermal conductivity in the high-conducting state is about 40 times higher than in the insulating state (≈4 10^{-3} W m^{-1} K^{-1}).

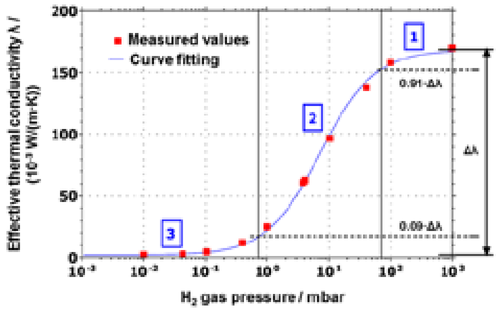


Fig. 1
Determined thermal conductivity values for a porous glass fiber system as a function of hydrogen gas pressure at ambient temperatures (Horn, 2001)

Use of solar energy

The STI setup shown in Figure 2 is used for capturing solar energy at the façade during a heating period. For the integrated STI a switching factor of 24.5 between high-conducting and high-insulating state was measured. The sand-lime brick wall behind the STI with a thickness of 0.24 m provides a good thermal storage. Therefore heat is released indoors even during the night or during overcast sky. On the STI a metal sheet was installed to absorb solar radiation and to press the STI on the sand-lime brick wall by a metal frame. In order to prevent the heated absorber from cooling by outside air convection in winter, a glass panel was installed at a distance of about 40 mm from the absorber and was sealed at the edges. For the heating period 2014/2015 a monitoring of heat flux (inner surface), temperatures and switching states in the STI was initialized.

Fig. 2
STI demonstrator with dimensions 80 cm x 50 cm, installed at a massive test façade before surrounding insulating and plastering

Results and discussions

While conventionally insulated façades without STI show a negative energy input (heat losses), the measured heat flux on the test façade resulted in a (positive) energy input of about 67 kWh m-² during the heating period 2014/2015. The heat flux meters did not sense lateral heat fluxes to the sides, the top and the bottom of the sand-lime brick wall (see Figure 3).

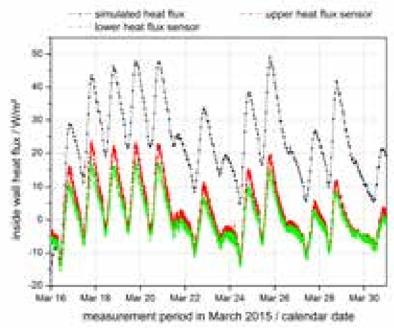


Fig. 3
Measured and simulated heat flux of the STI test façade

Thus, the actual heat flux probably will be higher. The one-dimensionally simulated heat flux values represent an ideal behavior of the STI test façade without lateral heat fluxes. For these calculations, a self-developed validated one-dimensional numerical simulation model for heat transfer was applied. The heat equation is solved considering the switchability of the STI's thermal conductivity, convection and thermal radiation in the air gap as well as heat conduction. Meteorological data recorded during measurements of the heat flow meters was used as boundary conditions for the simulations. While the simulation data show a very good agreement, regarding the curve progression, the measured heat flux is significantly lower. The difference between measured and simulated heat flux mainly is due to lateral heat fluxes in the sand-lime brick wall. The high heat capacity of the sand-lime brick wall behind the STI causes a time offset to the heat input into the room. The time offset between absorber temperature peaks and inside wall heat flux peaks in Figure 4 is about 5 to 6 hours and shifts the heat gains into the room to the night hours (see Fig. 4).

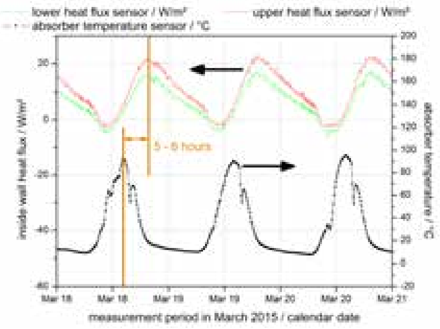


Fig. 4
Time offset between absorber temperature peaks and inside wall heat flux peaks due to the heat capacity of the sand-lime brick wall behind the STI

In comparison to a conventional façade with a calculated energy loss of about -18 kWh m-² the energetic benefit of the STI yields 85 kWh m-². During the heating period, a small maximum electrical energy consumption of 1.5 kWh m-² is necessary to switch the STI.

Conclusions

To raise the energy input of the STI during a heating period the thermal conductivity in the high-conducting state has to be increased by optimizing the function block. The getter material amount in the STI needs to be adapted to an ideal hydrogen filling so that costs for the expensive getter material are minimized while a high thermal conductivity is assured in the high-conducting state. Moreover, the STI can be used as a nightly summer cooling device by using low outdoor temperatures in combination with the high-conducting state.

Acknowledgements

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References
[1] Horn 2001, R. Horn, PhD thesis University Würzburg, Germany, 2001
[2] Horn et al. 2000, R. Horn, R. Neusinger, M. Meister, J. Hetfleisch, R. Caps, J. Fricke High Temperatures - High Pressures, 32(6) 669-675, 2000
[3] Ebert et al. 2014, H.-P. Ebert et al., Conference Procedures of the EnOB-Symposium 2014, 20.-21. March 2014, Essen, 2014

POSTER 10

ISOVIP & OPTIMAVIP: the insulation solution that breaks all records in thermal performance on fhe French market

Anca Zanfir[a]*
Renate von der Ohe[b]

[a] Saint-Gobain Isover, CRIR Insulation Research Center, Rantigny (France)
[b] Saint-Gobain, Marketing Isover France, Suresnes (France)
* Corresponding author:
anca.zanfir@saint-gobain.com

Keywords:

Vacuum insulation panels,
silica,
Isover,
certification,
ACERMI,
technical approval,
Optima.

Abstract

Saint-Gobain Isover presents the new ISOVIP vacuum insulation panel, the solution with the best thermal performance in the French market with a thermal conductivity of 5.2 mW/(m.K). It is the first VIP in France that presents an Acermi certification and is offered as a complete system that is under Technical Approval: OPTIMA VIP (wall application). The insulation system is accompanied by a design service offering the best panel layout possible for a given wall, including singular points, while optimizing the thermal performance of the wall.

Introduction on the ISOVIP

The ISOVIP panel (Acermi certification no. 15/018/1072) is made of an amorphous silica core and a tri-metallized film envelope. The finished product is covered by a thin layer of extruded polystyrene foam used as mechanical protection on both sides. The ISOVIP products are commercially available for thicknesses between 25 and 50 mm in increments of 5 mm. The thermal resistance of each panel can be found in table 1. Currently, ISOVIP is commercialized in 2 dimensions: 600x300 mm and 1000x600 mm respectively. The panel presents two sides with the envelope folding and two sides without the envelope folding. Both cases were evaluated via measurements and thermal models, and the linear thermal transmittances ψ (expressed in W/(m.K)) were determined in order to obtain the thermal resistance (R-value) for the product.

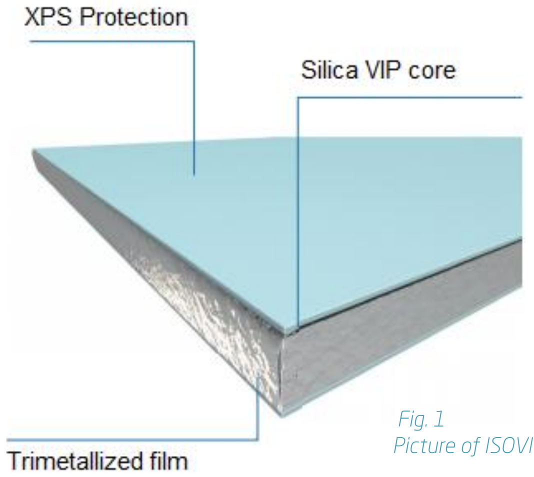


Fig. 1
Picture of ISOVIP

The ACERMI certification ensures that the products and the relevant quality system are respectively submitted to tests of conformity (including CE marking) and periodic audits with sampling for tests, according to the specifications of the Technical Regulations.

OPTIMAVIP

The OPTIMA VIP system is under Technical Approval 20/15-360*V1. The OPTIMA VIP system takes benefit from the Technical Approval “Système d’habillage Isover Optima” (OPTIMA System for interior walls), and associated with the Vario® Xtra and Stopvap/Stopvap 90 airtightness treatment systems, Technical Approvals 20 + 9 / 14-318 and 20 + 9 / 14-319.

Around singular points or areas too small for the ISOVIP panels, glass wool insulation is used as insulation material, more precisely the GR 32 and MULTIMAX ranges (Acermi certified), their thermal conductivity being 32mW/(m.K)and 30mW/(m.K), respectively.

The Technical Approval contains all the necessary information for the implementation of a metallic frame-based system that integrates the VIP and allows the fixation of the plasterboard.

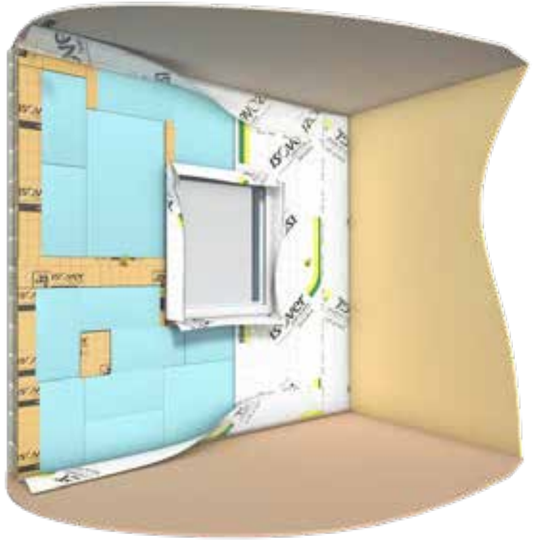
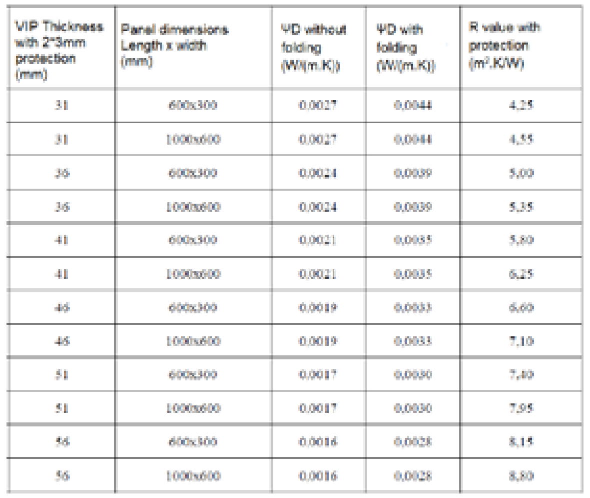


Fig. 2
Picture of OPTIMA VIP System

The calculation of the heat transfer coefficient Up of the wall shall be carried out for each and every wall scenario using a software configurator that is in conformity with Th-Bat rules. This software automatically creates the layout (calepinage) that will be achieved on the construction site and uses this required data for the calculation of the Up value.

The system is intended for the insulation of premises of low to medium hygrometry (W/n ≤ 5g/m³ according e-cahier 3567). The ISOVIP product and the OPTIMA VIP system are intended for the insulation of both new and renovated buildings that are generally heated for common use.



VIP Thickness with 2*3mm protection (mm)	Panel dimensions Length x width (mm)	ΨD without folding (W/(m.K))	ΨD with folding (W/(m.K))	R value with protection (m².K/W)
31	600x300	0,0027	0,0044	4,25
31	1000x600	0,0027	0,0044	4,55
36	600x300	0,0024	0,0039	5,00
36	1000x600	0,0024	0,0039	5,35
41	600x300	0,0021	0,0035	5,80
41	1000x600	0,0021	0,0035	6,25
46	600x300	0,0019	0,0033	6,60
46	1000x600	0,0019	0,0033	7,10
51	600x300	0,0017	0,0030	7,40
51	1000x600	0,0017	0,0030	7,95
56	600x300	0,0016	0,0028	8,15
56	1000x600	0,0016	0,0028	8,80

Tab. 1
The certified R-values and the thermal linear transmittance ψ for every panel dimension and thickness

Conclusions and outlook

The Technical Approval for OPTIMAVIP is exclusively applicable with ISOVIP vacuum insulation panels that is certified by Acermi. This solution is for interior wall applications and can be applied in new or renovation buildings. Services are included through a software that generates automatically the layout (calepinage) and calculates the Up value while taking into account all the linear and punctual transmittance values (respectively ψ and χ).

References
[1] CSTB – LNE, Licence n° 15/018/1072, Certificat Acermi
[2] CSTB, Avis Technique 20/15-360*V1, “Optima VIP application en mur”

POSTER 11

Dimensional instabilities of polyester and polyolefin films as origin of delamination in laminated multilayer

F. Dubelley[a*]
E. Planès[a]
C. Bas[a]
E. Pons[b]
B. Yrieix[b]
L. Flandin[a]

[a] Univ. Savoie Mont Blanc, CNRS, LEPMI,
F-73000 Chambéry, France
[b] EDF R&D, Materials and Mechanics
of Components, Ecuelles,
F-77818 Moret-sur-Loing Cedex, France
* Corresponding author:
Tel. +33 4 79 75 86 54
florence.dubelley@gmail.com

Keywords:

Vacuum insulation panels,
delamination,
dimensional stability,
polymer-metal laminate,
shrinkage,
barrier laminate.

Abstract

Polymer-metal multilayer films provide attractive barrier properties to air and water, particularly appreciated in Vacuum Insulation Panel application. Extreme barrier properties can be reached by staking and gluing aluminised polymers with polyurethane adhesive. A polyolefin layer is additionally used by bonding for sealability properties. With these materials, the adhesion between each layers controls the durability of the envelope and thereby that of the panel. Used in high temperatures and humidities, the interfacial delamination is a well identified and recurrent problem. A similar emergence over time of parallel and periodically placed stripes with homogeneous sizes suggests a well-defined underlying physical mechanism. Delamination should result from interfacial shear stress, and plausibly from difference of shrinkage of the films, due to relaxation of internal stress. A method was developed for measuring the deformations of each individual film. The results indicate that the shrinkage is anisotropic and controls decohesion.

Introduction

The interfacial delamination in polymer-metal laminate is a well identified and recurrent problem. Previous studies have shown that delaminations were formed mainly in cases of stress in severe temperatures and humidities conditions [1-3]. All these authors agree that the delamination of the barrier envelope causes premature failure of VIPs. However, none of these studies addresses. This might be surprising because observations show a similar emergence over time of parallel and periodically placed stripes with homogeneous sizes. These observations are likely to indicate a well-defined underlying physical mechanism. Mainly two hypotheses emerge according to the authors. On the mechanical standpoint, delamination could be induced by shear stress from different hygrothermal expansion properties of metallic and polymeric layers or by the entropic shrinkage of the polymeric films. It was however also proposed that the chemical hydrolysis of the polyurethane adhesive was the principal reason for weakening the interfaces in moist environments. Objective of this paper is to study the first hypothesis and plausible relationship between the shrinkage of polymer films and delaminations formation on VIP multilayer.

Experimental

Materials

Multilayer films are composed of a polypropylene (PP) or polyethylene (PE) layer assembled respectively with three polyethylene terephthalate coated with evaporated aluminium (PETM1F), named C2, or two PETM1F complexed with a PP metallised aluminium layer, named C3. The different layers were glued together with a polyurethane (PU) adhesive. Individual polymeric films were used to study the dimensional stability.

Methods

Multilayer ageing
Two multilayers are exposed at 70°C/90 %RH in climatic chamber for various durations up to 200 days.

Dimensional change measurement of individual polymeric films

Two specimens of polymer shall be prepared. Crosses are lightly drawn every 20 mm to define a regular mesh. Surface characterisation is carried out using the MICROVU (a three-dimensional measurement apparatus use as an optical microscope in reflection mode) before heating.
The longitudinal (MD-0°), transverse (TD-90°), and diagonal (45° and 135°) gauge lengths are determined using ImageJ software (L0). The specimens are then placed flat on a kaolin bed. Surfaces of samples are covered with kaolin. The samples are then exposed at 70°C in a circulating-air oven during 192 days. Regularly, the containers are removed from the oven and surfaces of polymeric films are characterised. For each specimen, gauge lengths are determined (L) for all directions. Changes in lengths δ are expressed as a percentage using the equation:

$$\delta = \frac{L-L_0}{L_0} \ (Eq.\ 1)$$

δ can be positive or negative. A negative value corresponds to shrinkage and a positive value to elongation of the film in the considered direction. The results are presented on a radar chart plot Figure 1, and fitted to eq 2, to estimate the dimensional changes for every direction.

$$\delta = A\cos^2(\gamma-\theta) + B\sin^2(\gamma-\theta) \ (Eq.2)$$

With γ (rad) the angle between the machine direction and the measurement direction, A (%) the minimum of shrinkage (or the maximum of dilatation), B (%) the maximum of shrinkage (or the minimum of dilatation) and θ (rad), angle between the machine direction and the direction according to the A value. Polymeric films may be isotropic or anisotropic depending of their manufacturing process (Figure 1).

Results and discussions

PETM1F presented very little dimensional changes and basically furnished the uncertainty of the measurements. For the PE sealant material, the heat treatment induced an anisotropic shrinkage of about -1.5% in TD (Figure 1).

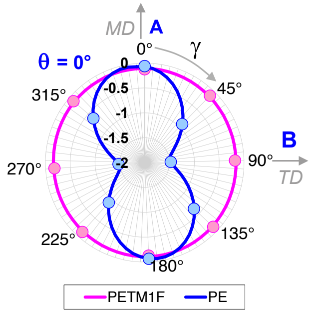


Fig. 1
Angular dependence of thermal shrinkage after 192 days

Figure 2 shows the dimensional changes in MD and TD versus annealing time for these polymers. A typical behaviour was observed for the PE in MD, roughly following an exponential decay. This was also accompanied by a stepwise change that occurs very quickly when the films are heated.

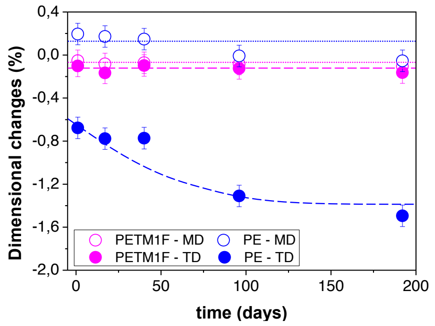


Fig. 2
Dimensional changes with annealing time (70 °C)

At the end of annealing, numerous delaminations at the interface PETM1F/PE could be found in the C3 laminate (Figure 3).

These flaws extended over the entire length of the sample, in rather linear stripes regularly placed in the sample. In MD, the welldefined delaminations periodicity of 32 mm and the regularity in size of 6 mm clearly highlight the underlying physical phenomenon.

Because it may be considered stable at 70 °C, these delaminations are unlikely to result from the PETM1F film by itself. The PE film was found to shrink in TD (Figure 1). The shear stress between the two materials thus induces a tension also oriented in TD. The machine direction of the strips in Figure 3 (right) is coherent with a stress release between the two films in TD.

The debonding failure in MD was connected to the PE shrinkage. This qualitative information has been confirmed on a more quantitative basis [4].

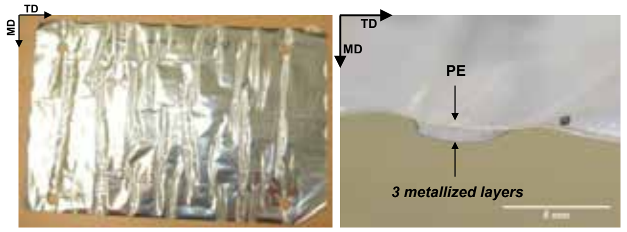


Fig. 3
Pictures of C3 : (left) PE surface of laminate; (right) edge of sample illustrates delamination in MD at PE/PETM1F interface

The same analysed was conducted for the C2 complex (with PP as sealant material). The delamination in TD at PP/PETM1F interface was connected to the PP shrinkage which is in MD.

Conclusions and outlook

A method has been established to determine the shrinkage of polymer films after annealing at 70 °C, the temperature of interest regarding many applications. The metallised PET films were found stable after 200 days of annealing. In contrast, polyolefin analysed exhibit significant and anisotropic shrinkage. The delaminations observed on various polyester/polyolefin interfaces appeared perpendicular to the direction of shrinkage of the polyolefin. A gradual increase in the severity of the delamination was also revealed when the shrinkage of the polyolefin sealant was increased. In summary, the shrinkage of the polymeric film can essentially be held responsible for the decohesions in the laminate. More speciafically, the difference in shrinkage between two films seems to control the appearance of defects. In other words, the durability of the envelopes could be largely improved by selecting films with very low entropic frustration.

Acknowledgements

The authors acknowledge the ANR (French National Research Agency) for its financial support of the EMMA-PIV project n°12-VBDU-004. This work was performed within the framework of the Center of Excellence of Multifunctional Architectured Materials (CEMAM) N°AN-10-LABEX-44-01.

References
[1] H.Simmler et al. Energy Build. 37 (2005) 1122-1131
[2] G.Garnier et al. Polym.Adv.Technol. 22 (2011) 847-856
[3] S.Brunner et al. Surf.Coatings.Technol. 202 (2008) 6054-6063
[4] F.Dubelley et al. J.Polym.Sci.Pol.Phys 55 (2017) 309-319

POSTER 12

Durability of barrier envelope for VIP in severe conditions. Overview of degradation mechanisms

F. Dubelley[a*]
E. Planès[a]
C. Bas[a]
E. Pons[b]
B. Yrieix[b]
L. Flandin[a]

[a] Univ. Savoie Mont Blanc, CNRS, LEPMI,
F-73000 Chambéry, France
[b] EDF R&D, Materials and Mechanics
of Components, Ecuelles,
F-77818 Moret-sur-Loing Cedex, France
* Corresponding author:
Tel. +33 4 79 75 86 54
florence.dubelley@gmail.com

Keywords:
Vacuum insulation panels,
degradation mechanisms,
durability,
multilayer.

Abstract

In order to extend the application of VIPs, especially at high temperatures and humidities, it is necessary to improve the barrier properties of the envelope. This assembly including metallised polymer films represents the most critical component and the limiting factor of VIP durability. Indeed, ageing studies of commercial laminates have revealed their accelerated degradations for temperatures higher than 50°C. In particular, an increase in permeance to water vapour is observed. Therefore, the identification and understanding of the degradation mechanisms at the origin of premature ageing of barrier envelopes of current VIPs seem fundamental. The two main mechanisms identified are the chemical degradation by hydrolysis of PET and PU adhesive, and the microstructural and mechanical properties modifications.

Introduction

Ageing studies of commercial laminates have revealed their accelerated degradation for temperatures above 50°C. After 450 days at 70°C and 90 %RH, the thermal conductivity of the VIP is equivalent to that of the static air (25 mW/(m.K)) (Figure 1). The core material is no longer under vacuum. The VIP is no longer considered as a super insulator. It no longer fulfils its function, which can be explained by the presence of multiple macroscopic defects on the surface of the laminate. In order to confer a sufficient lifetime to the VIPs, it is important to improve their tolerance to high temperatures and humidities. It's therefore necessary to identify and understand the degradation mechanisms at the origin of premature ageing of barrier envelopes of current VIPs.

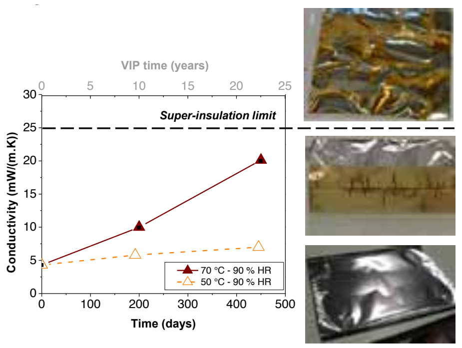


Fig. 1
Evolution of VIP conductivity during ageing for different conditions, and laminates photographs at different degradation stages

Experimental approach

Ageing was carried out at 70 °C-90 %RH on VIP. As the ageing times were relatively long, ageing on laminates and individual polymeric components was carried out in parallel. Thanks to macroscopic and microscopic studies of the different samples by specific experimental methods, identification and classification on a time scale of all existing defects have been possible. For each type of defects, the associated degradation mechanisms have been identified and two main mechanisms have been discriminated.

Materials and Methods

Materials

The typical architecture of the studied laminates is composed of three metallised aluminium layers (here on 12 µm thick PET, named PETM1F) and one sealing layer (PP or PE). The different layers were glued together with a polyurethane (PU) adhesive. VIPs are manufactured with the studied laminates and a standard fumed silica core.

Methods

Ageing

Laminates and individual polymeric components are exposed at 70°C and 90 %RH in climatic chamber up to 200 days. VIPs are exposed in the same conditions up to about 2.5 years.

Characterisation

Many multi-scale characterisation methods have been used: Scanning electron microscopy (SEM), X-ray spectroscopy (EDX), FTIR and µIR spectroscopy, Raman spectroscopies, Differential Scanning Calorimetry (DSC), Dynamic Vapour Sorption (DVS), Tensile test.

Results and discussions

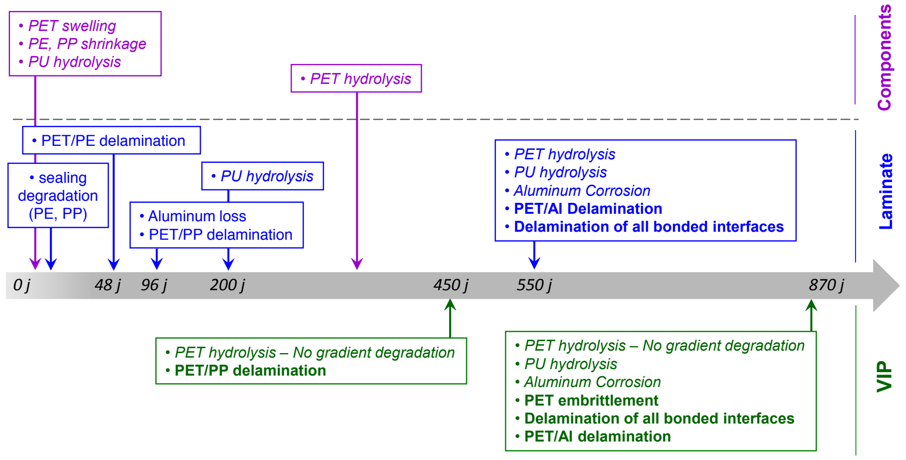

• PET swelling
• PE, PP shrinkage
• PU hydrolysis
• PET hydrolysis
• PET/PE delamination
• sealing degradation (PE, PP)
• PU hydrolysis
• Aluminum loss
• PET/PP delamination
• PET hydrolysis
• PU hydrolysis
• Aluminum Corrosion
• **PET/Al Delamination**
• **Delamination of all bonded interfaces**
0 j
48 j
96 j
200 j
450 j
550 j
870 j
• PET hydrolysis – No gradient degradation
• **PET/PP delamination**
• PET hydrolysis – No gradient degradation
• PU hydrolysis
• Aluminum Corrosion
• **PET embrittlement**
• **Delamination of all bonded interfaces**
• **PET/Al delamination**

Fig. 1
Identification and classification of defects and their origin in laminates after ageing at 70°C/90 %RH

DVS measurements showed that the water sorption leads to a swelling of the PET films followed by a clustering mechanism to a densification [1]. These physical phenomena, driven by temperature and humidity, appear at relatively short times (typically a few days) and contribute to the embrittlement of PET. In the long term, this leads to a loss of mechanical properties of the laminate and to delamination at the polymer-metal interfaces.

At longer times, water leads to PET hydrolysis. This chemical degradation has been demonstrated in the outer layers of different laminates over time by IR spectroscopy using different markers [2]. The formation of carboxylic acids and an increase in the crystallinity, characteristic of the chains scission phenomenon and therefore of the hydrolysis, occurs from 400 days of exposure at 70°C/90 %RH. A more local study by IR microscopy allowed an individual analysis of the internal layers of PET of laminate aged on VIPs. The three layers of PET of the envelope exhibit a very homogeneous degradation after 450 and 870 days of ageing. After 870 days, this can be explained by a very advanced state of degradation of the barrier envelope. After 450 days, the homogeneous degradation in the envelope can be related to the aluminium layers which don't act any more as barrier for water molecules. A simple observation indicates a loss of aluminium at interface. These observations were supplemented by EDX coupled with SEM. The determination of the chemical composition of the surface examined shows a lack of aluminium. Aluminium dissolution would be made possible by the PET hydrolysis. The hydrolysis induced the carboxylic acid which can be responsible for a pH decrease at PET/aluminium interface and thereby promoting corrosion of aluminium.

Moreover, dimensional measurements on the individual polymeric films of laminates [3] have shown that a temperature increase could lead to anisotropic shrinkage of the polymers, caused by internal stresses resulting from the manufacturing process. If the polyolefin films PE and PP exhibit anisotropic shrinkage after 200 days at 70 °C, the metallised PET, probably stabilised by the aluminium layer, does not shrink. The differences in shrinkage between PE / PETM1F or PP / PETM1F appear to be the origin of delaminations localised at laminates interfaces. They result from the mechanical relaxation of internal stress and form perpendicularly to the shrinkage direction. The resulting stresses at interface caused the shearing of PU adhesive. The latter proved to be the weak point of the interface in laminate. In fact, a more detailed study of delamination at the PP / PETM1F interface after 200 days of ageing by FTIR-spectroscopy revealed, on the one hand, the chemical degradation of the adhesive by hydrolysis and, on the other hand, a cohesive rupture at the interface. The degradation of the adhesive is made possible by the loss of the barrier properties of the envelope, but mainly by the transfer of the water molecules via the welds, the weak points of the laminate. Indeed, the delaminations are observed firstly at the level of the welds [4, 5].

Conclusions and outlook

Thanks to the study of different films, laminates or VIPs aged under severe conditions for different times, it was possible to identify and classify on a time scale all the existing defects (Figure 2). For each type of flaws, the associated degradation mechanisms have been identified. Thus, it was possible to discriminate the two main mechanisms of the polymer-metal multilayer degradation. The first is the chemical degradation by hydrolysis of PET and PU adhesive. The second is the microstructural and mechanical properties modifications.

Acknowledgements

The authors acknowledge the ANR (French National Research Agency) for its financial support of the EMMA-PIV project n°12-VB-DU-004. This work was performed within the framework of the Center of Excellence of Multifunctional Architectured Materials (CEMAM) N°AN-10-LABEX-44-01.

References
[1] F. Dubelley et al. J.Polym.Sci.Pol.Phys 55 (2017) 309-319
[2] F. Dubelley et al.J.Phys.Chem.B 121 (2017) 1953-1962
[3] F. Dubelley et al Eur.Polym.J 87 (2017) 1-13
[4] F.Dubelley et al. Symposium IVIS2013 (2013)
[5] E.Planes et al. J.Mater.Sci. 46 (2011) 5948-5958

POSTER 13

Analysis of Mathematical Heat Transfer Models for free-flowing Vacuum Insulation Materials

S. Lang[a*]
D. Bestenlehner[a]
H. Drück[a]
R. Marx

[a] Research and Testing Centre for Thermal Solar Systems (TZS), Institute of Thermodynamics and Thermal Engineering (ITW),
University of Stuttgart, Pfaffenwaldring 6,
70569 Stuttgart, Germany
* Corresponding author:
Tel. +49 711-685-63614
lang@itw.uni-stuttgart.de

Keywords:
Free-flowing vacuum insulation,
mathematical models,
perlite,
fumed silica.

Abstract

In this work published mathematical models describing heat transfer mechanisms through porous materials were analyzed and compared respectively fitted to measured thermal conductivities of three different free flowing vacuum insulation materials. These materials were coarse grained and fine grained expanded perlite and opacified fumed silica. The models described in [2, 4, 7, 9] showed good results in terms of predictability and deviation from the measurements.

Introduction

Free-flowing vacuum thermal insulation materials can be utilized where rigid and vacuum tight walls surround the insulation volume, which can stand the forces induced by the vacuum pressure. Utilizing free-flowing materials, a smaller mass of thermal insulation material is needed compared to compressed thermal insulation materials with higher bulk densities, as e.g. used in vacuum insulation panels.
In this paper some results of the analysis of different mathematical models, describing the different heat transfer mechanisms through porous media are presented. These models were analyzed with regard to their suitability to describe the heat transfer mechanisms in free-flowing expanded perlites and opacified fumed silica by comparing the calculation results with measured values determined by the author and from available measurement results described in the literature.

The aim of this work is to identify respectively develop a mathematical model that can determine the ideal mixture of different thermal insulation materials for a certain application, depending on temperature, vacu-um pressure and bulk density. This mathematical model will also be applied to design the thermal insulation for an ultra-high temperature energy store within the research project "AMADEUS", supported by the European Union (s. Acknowledgements).

Investigated Models and Materials

A widespread method to describe the effective thermal conductivity λ_{eff} [W/(m·K)] of porous media is the superposition of thermal conductivities representing the occurring heat transfer mechanisms (s. Eq.1).

$$\lambda_{eff} = \lambda_g + \lambda_s + \lambda_r + \lambda_c \qquad \text{(Eq. 1)}$$

with:
λ_g Thermal conductivity representing the heat transfer through the gas phase [W/(m·K)]
λ_s Thermal conductivity representing the heat transfer through the solid phase [W/(m·K)]
λ_r Thermal conductivity representing the heat transfer by thermal radiation [W/(m·K)]
λ_c Thermal conductivity representing the heat transfer by coupling effect [W/(m·K)]

Investigated models:

The following list shows sources of some of the most promising models investigated:
> Thermal conduction through gas: [1], [2], [3], [4]
> Thermal conduction through solid: [5], [6], [7]
> Heat transfer by thermal radiation: [8], [9]
> Coupling effect: [4]

Thermal Insulation Materials:

The insulation materials used to analyze the mathe-matical models were coarse grained expanded perlite (cep), s. Fig. 1, measured values from [10], fine grained expanded perlite (fep), s. Fig. 2, measured by the author and opacified fumed silica (ofs), s. Fig. 3, measured values from [11]. Relevant material properties are listed in Table 1.

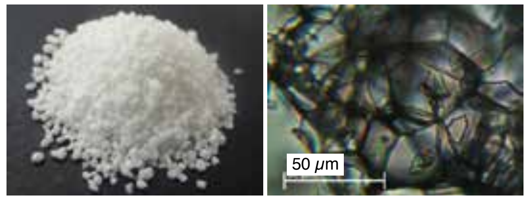


Fig. 1
Coarse grained expanded perlite (cep)

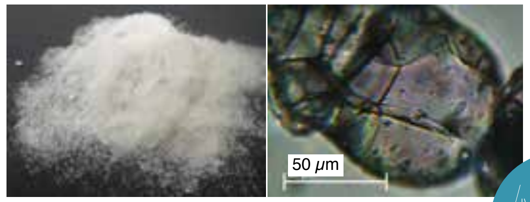


Fig. 2
Fine grained expanded perlite (fep)

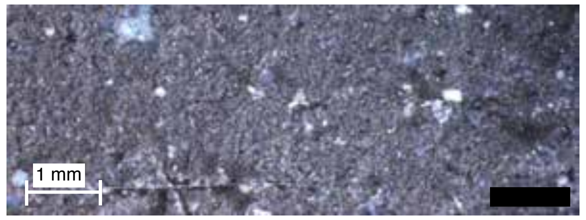


Fig. 3
Opacified fumed silica (ofs) [11]

Material	mean pore size [µm]	bulk density [kg/m³]	Rosseland mean extinction coefficient [m²/kg]
cep	44	76 [4]	43 [4]
fep	30	183	43
ofs	13 [11]	45 [11]	90 [11]

Tab. 1
Some relevant material properties of the investigated thermal insulation material

Results and discussions

To examine the capability of the different models to predict the effective thermal conductivity of the three investigated thermal insulation materials, the results of the calculations are compared with measured data. These measured data of the effective thermal conductivities are either determined by the author or taken from [10] and [11]. The models described in [2] for the heat transfer in gas phase, in [7] for the heat transfer in solid phase and in [9] for the heat transfer by thermal radiation show the best results compared to the other investigated models. The coupling effect was modeled according to [4]. The models for the heat transfer in the solid phase and the coupling effect contain adjustment parameters that cannot be determined by material properties. Thus, these models are not predictive. These parameters were determined by fitting to the measured thermal conductivities at the highest and lowest air pressure. The results of measurements and calculations are shown in fig. 4 for cep and in fig. 5 for fep.

With the models described above, the measured values can be reproduced very precisely. The highest deviations occur between 1 and 10 mbar, at the highest slope of the curve. This could be explained with inaccuracies of the pore size determination or the model for the heat transfer in the gas phase. The influence of the coupling effect is higher for fep compared to cep due to the smaller grain sizes and thus more contact spots where the coupling effect can occur.

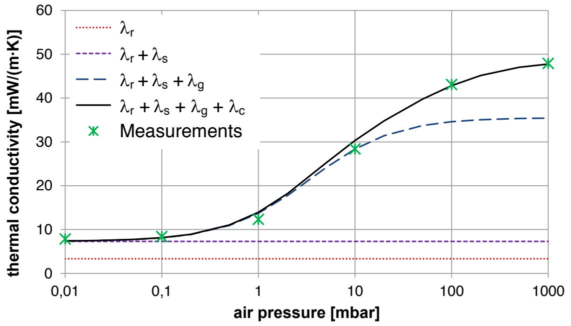


Fig. 4
Results of measurements and calculations for cep at 53°C

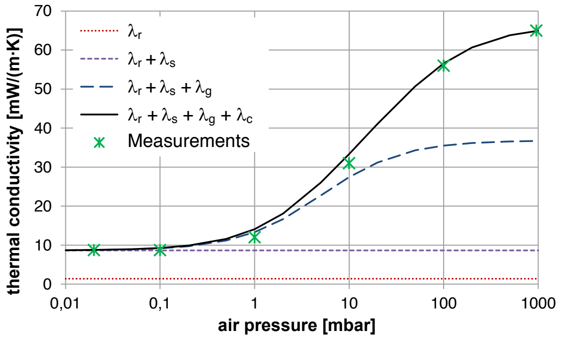


Fig. 5
Results of measurements and calculations for fep at 48°C

Conclusions and outlook

The selected models suitably quantify the heat transfer mechanisms in free-flowing vacuum thermal insulation materials. However, it is necessary to find measurable or predictable parameters to create predictive models for the heat transfers through the solid phase and for the coupling effect.

Acknowledgements

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References
[1] Kennard, E. H. Kinetic theory of gases with an introduction to statistical mechanics, 1938
[2] Schwab, H. Vakuumisolationspaneele- Gas- und Feuchteeintrag sowie Feuchte- und Wärmetransport, Eq. 2-7, Dissertation, Würzburg, 2004
[3] Krause, M. et al. Icarus 214 (2011) 286-296, Eq. 5
[4] Demharter, M. Heat Transport in Evacuated Perlite Powder Insulations and Its Application in Long-Term Hot Water Storages, Eq. 4-7 and 4-31. Master Thesis, München, 2011
[5] Bouquerel, M. et al. Energy and Buildings 54 (2012) 320–336, Eq. 25
[6] Kwon, J.-S. et al. International Journal of Heat and Mass Transfer 52 (2009) 5525–5532, Eq. 9
[7] Kaganer, M. G. (1969). Thermal insulation in cryogenic engineering, Jerusalem, ISBN 13: 9780706506075
[8] Jelle, B. Journal of Building Physics 34, 2 (2010) 99-123, Eq. 4
[9] Fricke, J. et al. Vacuum 82 (2008) 680–690, Eq. 7
[10] Beikircher, T. et al. Superisolierter Heißwasser- Langzeitwärmespeicher, project report, Garching, 2013
[11] Kim, J.; Song, T. International Journal of Heat and Mass Transfer 64 (2013) 783-791.

POSTER 14

Validation of the lift-off technique for measuring the internal pressure of fumed silica VIP

C. Sprengard
S. Regauer*
S. Treml

FIW München – Forschungsinstitut für Wärmeschutz e.V. München (Research Institute for Thermal Insulation) Lochhamer Schlag 4
82166 Gräfelfing
* Corresponding author:
Tel. +49 89 8580059
Fax +49 89 85800-40
regauer@fiw-muenchen.de

Abstract

The internal pressure of a VIP is a suitable indicator to determine the ageing process of VIPs needed for the estimation of the thermal performance over time. To date only indirect methods like the foil lift-off technique are used as there is no accurate and cheap internal pressure sensor available. The foil lift-off technique is the widest spread measurement method due to some advantages in the implementation and because of the convincing theoretical principle.
This measurementmethod is up to now without any regulations by standards nor exist comparative measurements via directly connected pressure gauges. The investigations conducted within the scope of this study are aiming at this validation of the foil lift-off technique and the definition of boundary conditions.

Keywords:

Vacuum insulation panels,
internal pressure,
foil lift-off method,
suction bell,
vacuum chamber.

Introduction

The foil lift-off method is treated as the reference method to determine the internal pressure of VIPs [1] [2]. This indirect measurement method is used for more than a decade now without any evidence or comparison to a direct measurement method. This means, it was never shown how close the lift-off pressure readings are to the actual internal pressure. Detailed information neither on how to conduct a measurement nor about processing gained data is available. According to FIW experiences, there are several influencing factors on the result of the pressure measurement.

The lift-off method is used in two versions for measuring the internal pressure of VIPs:
> The evacuation chamber method on a whole VIP (e.g. integrated in the Vacuum-Press)
> The suction bell method on a small section of a VIP envelope (e.g. for factory production control (FPC)).

Both methods make use of one or more laser distance measuring devices that measure the distance to the surface of the foil while constantly evacuating the sur-rounding - the whole evacuation chamber or the space under the suction bell. The pressure at which the envelope starts to move away from the core is considered to be equal to the internal pressure of the VIP.

Definition of Boundary Conditions

The type and distance of bearing for the VIP, the amount and positioning of the laser devices to measure the movement of the foil surface or the number of lift-off repetitions within one measuring process are among others influencing factors on the measurement data. Before the validation tests of the foil lift-off by comparison with a pressure gauge were started, the following boundary conditions were found to be reasonable during comprehensive test series at FIW. A rectangular bearing is used (250 x 250 mm) to prevent the specimen from deflection. In addition to that, the test rig separates the VIP from the bottom of the vacuum chamber and helps to reduce deviations due to deformations of the whole vacuum chamber. The restriction of the measurement area by a square shaped profile on both sides of a VIP leads to acceptable results throughout the tested amount of specimen. No additional wrinkles are occurring and the lift-off distance of the foil away from the core is not restricted to small values. Additional weight has to be added to the lightweight aluminum profile on top of the specimen. A total weight of 3 kg is sufficient. The resulting setup is depicted in Fig.1. Five lift-off sequences at each measurement are performed and the first one is discarded due to possible adhesion of the foil to the fleece or the core. The lift-off of the foil is reasonable up to a distance of approximately 5 mm. The ventilation of the vacuum chamber in between the lift-offs should be up to a pressure level of at least twice the pressure when proceeding lift-off took place.

Fig. 1
Bearing setup for internal pressure measurement in a vacuum chamber

Processing of Measurement Raw Data

For the further processing of the distance measurement results into the internal pressure results the distance of the movement of the foil during a lift- off is plotted as a function of the pressure of the vacuum chamber as shown in Fig. 2. Before and after every lift-off a linear behavior is assumed. The lift-off of the foil describes a continuous curve which ends in a linear behavior until the chamber is ventilated to start the proceeding lift-off. The short-duration chamber ventilations allow the foil to get in proper contact to the core material again. Two different methods, the tangent method and the triangle method, were applied to evaluate the raw data. Separate analysis of clipped sections of the measurement data each containing a lift-off sequence between the short-duration ventilations of the vacuum chamber has to be done for both methods. There is no automated process of clipping the test data available right now, as there is certain deviation in test data patterns, mostly due to individual kinks in the foil and in some cases uneven panels which affects the bearing situation.

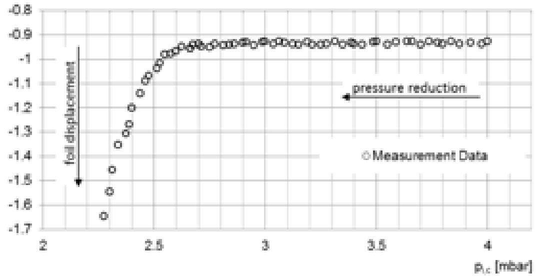

Fig. 2
Exemplary measurement data $s(p_{i,c})$

The basic principle of the tangent method is finding the point of intersection between the two tangents of the linear parts of the measurement curve which defines the internal pressure. A linear regression analysis of the measurement data starting with two data points and increasing the included data point by point is conducted.

A polyline consisting of all measurement points can be closed to a shape that can be basically described as a triangle with a rounded tip. For all measurement points, the distance between these measurement points and the straight line is calculated. The tip of the triangle is the measurement point with the greatest distance from the straight line.

Validation measurements

A validation performed as a comparison of the readings of the measurement equipment gives important evidence about the accuracy. Specimens with a leak-tight connector allow measuring simultaneously the actual internal pressure, the displacement of the envelope and the corresponding pressure inside the vacuum chamber. By doing so, the exact relation between these three measured parameters could be derived.

Therefore a special VIP specimen was designed, consisting of the base plate support of the gauge connector with ring seals at one half of the panel and a standard fumed silica VIP core material on the other half. Both parts are placed inside the same envelope bag and sealed. The connector enables the evacuation of the entire internal volume of the panel and also the internal pressure can be measured very accurately.

The complete unit is placed inside the vacuum chamber and the displacement of the envelope is then detected on the flat silica core side, applying the defined boundary conditions.

Results and discussions

From the remaining four lift-offs an appropriate mean value can be calculated. To have one final internal pressure value as result, the highest accuracy can be obtained by calculating the mean value of the two laser positions from above and underneath the panel. Deviations in between laser distance and direct pressure result from slow pressure accumulation inside the panel after evacuation. A significant pressure drop can be detected in the data of the directly connected pressure gauge from the point of time when the surrounding of the specimen is evacuated. A certain time of at least 24 hours is necessary to reach pressure equilibrium and only then pressure measurements are to be performed.

Conclusions and outlook

The foil lift-off technique is an adequate method to determine the internal pressure of silica core VIPs. The implementation of the boundary conditions on the bearing situation of the panels and the data logging leads to unproblematic data processing.
A quadratic shaped profile to restrict the measurement area is applicable for all panel dimensions and types of foil. Also the positioning of the laser distance sensors is clearly defined by the center of this profile.

Acknowledgements

The authors appreciate the support of VIPA International.

References
[1] H. Simmler, S. Brunner, Vacuum insulation panels for building application. Basic properties, aging mechanisms and service live, Energy and Buildings 37 (2005) 1122-1131
[2] T. Brockmann, R. Herr, S. Rössig, Vakuumisolationspaneele (VIP) in der Baupraxis, BBSR, Bonn 2010

POSTER 15

Compressive behavior of vacuum insulation panels according to EN 826
Difficulties with the measurement results for VIP and possible solutions

Christoph Sprengard[a]
Gerald Coy[a*]

a Forschungsinstitut für Wärmeschutz e. V. München – FIW München – (Research Institute for Thermal Insulation)
Lochhamer Schlag 4; 82166 Gräfelfing, Germany
* Corresponding author:
Tel. +49-89-85800-41
coy@fiw-muenchen.de

Keywords:

Vacuum insulation panels,
compressive behavior,
EN 826,
gypsum coating,
compressive stress.

Abstract

To date, test results of compressive behavior according to EN 826 of vacuum insulation panels show a very high diversity even among one producer. Results depend strongly on the skills and the judgment of the lab personnel. Design issues of VIPs lead to a stress-deformation graph without a linear range and a very long initial range up to 20 % deformation and a corresponding compressive strength value of 5-20 kPa. An evaluation of the compressive behavior at 10 % deformation with the common testing procedure has no significance.

Aim of a study commissioned by VIPA-international to FIW was to find a testing procedure, which leads to reproducible and comparable test results over different producers and to define reasonable boundary conditions for the measurement description in the upcoming product standard for VIPs. The approaches included an investigation of the specimen design, testing procedure, boundary conditions and the relation between compressive behavior and bulk density of the VIP core.

Introduction

Test results of compressive behavior of vacuum insulation panels according to EN 826, regardless of the core material, are difficult to evaluate. With the current testing procedure even tests with specimens of the same producer show a high diversity concerning the stress-deformation graph and a non-linear behavior. The reasons for this high diversity and the wide distribution of the results are mainly the specimen design with surface seams and warping of the panels.
All these points lead to very different results with a very long initial range up to 20 % of deformation mainly at thin panels, which can be seen in fig. 1.
As the stress-deformation graph has no linear range the results can't be evaluated by the algorithms of a testing machine according to EN 826. Test results depend on the professional interpretation of the lab personnel and lead and are not comparable.

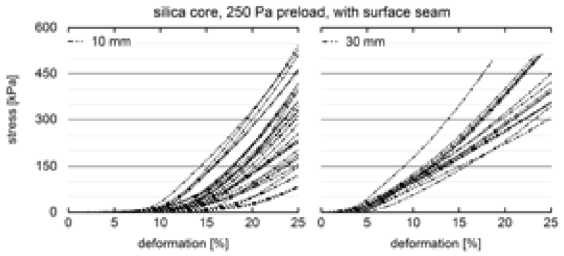

Fig. 1
Compressive behavior of VIPs with a thickness of 10 mm and 30 mm, silica core. Overview of panels with surface seam, different producers. Graphs with a very long initial range, no linear behavior and nearly every test yield a different result.

Aim of the study and approach

The aim of this study was to adjust the test procedure to be suitable for VIPs and their layout to show the compressive behavior of the vacuum panel itself, without the layout effects. The new testing procedure together with the new way of evaluating results should lead to reproducible, comparable results and should be normative easy implementable.
Therefore the study examined the influence of the specimen design on the test results like dimensions and surface seam. Also the effect of different preloads and testing a smaller area of the panel was investigated. All these approaches led to improved but still unsatisfactory results.
The most promising testing method was with a gypsum coating on the panels which equalized nearly all layout effects. Therefore the results of this testing method will be presented in the next chapter plus the relation between compressive behavior and the bulk density of the core material.

Results and discussions

A gypsum layer on the specimens fulfils the criteria of workability, availability, low price, incompressibility and it is already mentioned in the testing standard EN 826 for another harmonized insulation product. The coating has a thickness of approx. 5 mm.

Testing the specimens with a gypsum coating improves the results concerning the values of the compressive stress at 10 % deformation as well as the distribution of the values (at least for separate producers). The influence of the individual layout issues like seam and warping are nearly equalized which lead to a very short initial range.

With this test setup, it is possible to analyze the compressive behavior of the panel itself and it can be noted that the results for a specific producer are closer together and more comparable. As the stress-deformation graph has still no linear range the "zero deformation point" shall be the deformation corresponding to a stress of 250 Pa. The values for the compressive stress at 10 % deformation with a zero deformation point at 250 Pa for silica core panels, improved significantly and ranges from 200 to 250 kPa for 10 mm panels and around 180 kPa for 30 mm, see fig. 2. For fiber core panels, the results vary depending on the core material. Nevertheless, it can be noted that the compressive behavior improved significantly from ca. 20 kPa for 10 mm panels and ca. 60 kPa for 30 mm panel to approximately 150 kPa for both thicknesses with small deviations depending on the producers.

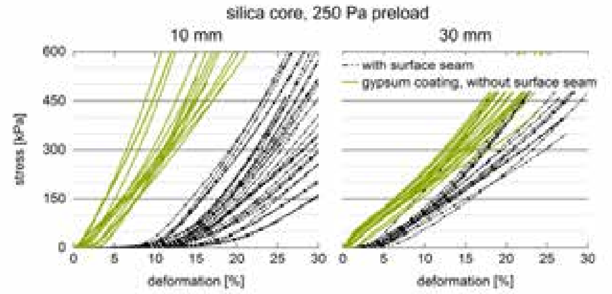

Fig. 2
Deformation curves of 10 mm and 30 mm silica core vacuum panels with gypsum coating compared to specimens with surface seam, both tests 250 Pa preload. Compared to the starting situation the initial range is significantly shorter and the spread of the curves lower. An evaluation of the compressive stress at 10 % deformation leads to applicable results now.

An investigation of the correlation between compressive stress at 10 % deformation and bulk density did not lead to a clear conclusion.

For vacuum insulation panels with a silica core it could be possible to find a correlation for panels with a higher thickness, if high amount of results for each thickness can be provided. At thin panels no correlation was visible and the results were widely distributed, see fig. 3. The compressive behavior does not depend only on the bulk density, also the mixture of the core, the supporting effect of the foil and the level of vacuum seem to have an influence on the results. All compressive strength measurements were performed with a gypsum coating.

For fiber core panels tested within this study no dependence was be found. The results were significantly lower and it seems that the compressive behavior is more influenced by the properties of the core material in compressed state and by the stiffening effect of the foil, rather than by the density.

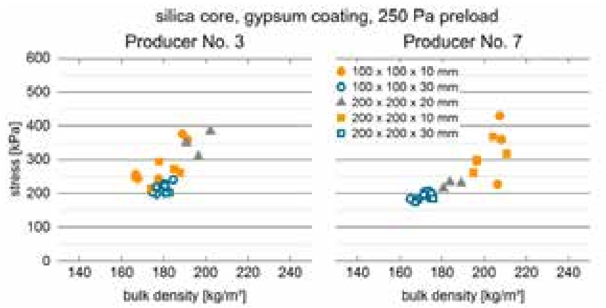

Fig.3
Compressive behavior results versus bulk density for two producers, silica core. Compressive behavior measured with gypsum coating. Results for 10 mm panels have the greatest variation. Linear dependence can be assumed for higher thicknesses, difficult at lower thicknesses depending on the producer. To confirm a linearity more results are necessary. Specimen size has nearly no influence on compressive behavior.

Conclusions and outlook

All test setups lead to improved results, but only the testing procedure with gypsum could reduce the spread of the curves and make the compressive behavior results more comparable. Furthermore, all tests show that vacuum insulation panels with silica core or fiber core do not have a linear compressive stress behavior. According to EN 826 in such cases, the zero-deformation point shall be the deformation corresponding to the preload.

Based on the results achieved within this study, it is not possible to monitor the compressive behavior with a correlation between bulk density and compressive strength for fiber core panels. This property depends more on the core material itself, than on its density, which leads to same compressive values within a wide density range. It is recommended to measure the compressive strength within the FPC directly with a gypsum coating. If a correlation is wanted, it must be ensured that dependence with a clear confidence range is existing; otherwise, a direct testing cannot be omitted. The results of this study will be used to describe the methodology for the compressive behavior measurement within the product standard VIP currently under development.

Acknowledgements

The authors appreciate the support of VIPA International.

References
EN 826:2013-05 "Thermal insulating products for building applications – Determination of compression behavior"

POSTER 16

In Situ Performance of Glass Fiber Core VIPs in Extreme Cold Climate

P. Mukhopadhyaya[a]*
D. MacLean[b]*
J. Korn[c]
M. Ooms[d]
T. T. Zhang[a]
S. Mooney[e]

[a] University of Victoria, Victoria, British Columbia, Canada
[b] Retired, Yukon Energy Mines and Resources, Whitehorse, Yukon, Canada
[c] Yukon Housing Corporation, Whitehorse, Yukon, Canada
[d] Yukon Energy Mines and Resources, Whitehorse, Yukon, Canada
[e] Yukon Research Centre, Whitehorse, Yukon, Canada
* Corresponding author:
phalguni@uvic.ca

Keywords:

Vacuum insulation panels (VIPs),
Glass Fiber Core,
Thermal Insulation,
In Situ Thermal Performance.

Abstract

Glass fiber core vacuum insulation panels (VIPs) are increasingly being considered for building envelope construction. Concerns remain however, about the long-term thermal performance of glass fiber core VIPs particularly when compared to fumed /precipitated silica core based VIPs. Accelerated aging tests have suggested superior long-term performance of fumed/precipitated silica core VIPs over glass-fiber. Credible long-term field performance data to validate these laboratory tests do not exist however, and it is speculated that glass fiber core VIPs may in fact achieve maintain their high performance as they age. In Yukon, Canada, glass fiber core VIPs were used in a commercial building retrofit in 2011, and since then the performance of the VIPs has been continuously monitored. This paper summarizes the thermal performance of the glass-fiber core VIPs, and the lessons learned from the construction challenges and performance observations over a period of seven years (2011-2017). It is anticipated that findings from this study will help the building envelope construction community, researchers, designers, and end-users develop a better understanding of the issues related to the long-term performance of glass fiber core VIPs.

Introduction

VIPs are one of the most promising building insulation materials with an initial thermal conductivity of about 0.004 W/m K, which is 5 – 10 times better than traditional insulations. So far, the most commonly used core material is fumed silica which has low solid thermal conductivity (0.003 – 0.006 W/m K) under a pressure of 20 -100 mbar and a small pore size (0.03-0.1). Its thermal properties are stable at a pore pressure up to about 50 mbar. On the other hand, glass fiber has a relatively large pore size (1-12), resulting in a dramatic drop in thermal resistance when the internal pressure rises above 2.5 mbar, and consequently a shorter predicted service life [1]. Nevertheless, glass fiber cores for VIPs are less expensive and remain an attractive alternative with respect to building economics. In Yukon (Canada), glass fiber core VIPs have been used as thermal insulation for retrofitting a commercial building, originally built in 1988. This paper presents the field performance observed from continuous in-situ monitoring since installation (2011-2017) and the lessons learned from the construction challenges in an extreme cold climate.

Construction and instrumentation

A wall (8.4 m x 3.7 m) of an existing building was retrofitted with VIPs. The VIP specimens were 0.56 m x 0.46 m x 0.012 m in size. Initially, the thermal conductivity of the VIP specimen was measured using a heat flow apparatus with an accuracy of ±2% to be 0.0034 W/m K (R-value per in. = 42.5) at the center of panel [2]. Additional layers of insulation were installed on the exterior of the existing concrete wall (see Figure 1) in the following order. First, a 0.15-mm polyethylene air-vapour-moisture barrier was held in place using sprayed adhesive. Then, 25-mm polystyrene board was adhered to the polyethylene creating an even surface to which was attached glass fiber core VIPs. 50 mm x 75 mm wood strapping was then attached to the polystyrene board and the concrete wall with anchors. The VIPs were adhered between the 50 mm x 75 mm strapping, using a "peel and stick" adhesive on one side. They were then covered with a 6-mm flexible polyurethane foam material that was fixed in place with sheathing tape. Lastly, 25-mm polystyrene board was installed on the outside of the VIPs to decrease the potential risk of condensation and damages from mechanical rubbing [2]. Overall, the construction experience reported was positive. Thermistors were installed to monitor the temperature on the surface of each insulation layer – the interior extruded polystyrene (XPS) layer, the VIP layer, and the exterior XPS layer) (Figure 1). The thermistors were set up approximately 2 m from the south edge of the wall and 1 m from the top of the wall.

Three sensors were placed on the existing wall approximately 2 m from the north edge of the retrofitted area. These sensors were located approximately 1 m, 1.5 m and 3 m from the top of the wall, and were used to monitor the thermal gradients from the top to the bottom of the wall.

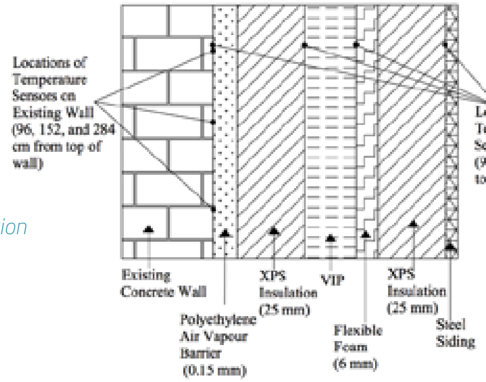

Fig. 1
Schematic diagram of the retrofitted wall cross-section and the locations of temperature sensors

Results and discussions

The VIP insulated wall assembly was monitored over the past seven years, and selected temperature data were analysed from the following five winters:

- December 13, 2011 – April 15, 2012
- December 5, 2012 – May 23, 2013
- November 1, 2013 – January 9, 2014
- February 11, 2016 – March 31, 2016
- November 1, 2016 – January 11, 2017

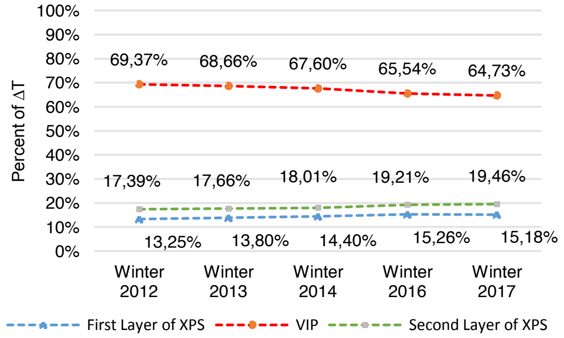

Fig.2
Percentage of temperature drop across wall components, relative to the drop across the entire wall. Data averaged for the winter months 2011-2017

Figure 2 shows the percentage of the total temperature drop across each wall component averaged over the winter months for five selected years. The average drop for the VIP layer is about 68%, while that for the first (exterior) and second (interior) layers of XPS are 18% and 14% respectively. The temperature drop across the VIP layer is about 4.7 times the difference across the interior layer of XPS. The effectiveness of the VIP layer is decreasing very slowly, from about 69% initially to 65% in early 2017, at an average rate of 0.8% per annum.

Accelerated aging tests [3] showed glass fiber core VIPs degrade at a faster rate compared to fumed silica based VIPs, indicating a potentially shorter service life. It is speculated that the relatively slower rate of degradation for in situ VIPs in this study was largely due to the environmental conditions that the VIPs were exposed to. Accelerated aging tests were conducted with cyclic conditions of 23°C, 95% and 70°C, 5% [3], while the in situ performance study reported here was carried out in the subarctic climate of Whitehorse, Yukon with lower temperatures and RH (an average of -13°C and 75% RH over winter months: Nov. – Feb. and an average of 11.5°C and 62% RH over summer months: Jun. – Sept. [4]). As might be expected, glass fiber core VIPs did not show any sign of rapid aging in the subarctic cold climate.

Conclusions and outlook

The energy retrofit project in the Canadian subarctic climate in Whitehorse, Yukon, using a foam-VIP-foam sandwich (i.e., XPS-VIP-XPS) insulation has demonstrated the promising and satisfactory performance of glass fiber core VIPs.

Analysis of the temperature data from monitoring each insulation layer over a period of seven years (2011-2017) has shown a less than 0.8% per year change in the field performance of the VIPs, which indicates that aging of glass fiber core VIPs in a cold climate proceeds at slower rates than previously expected. Moreover, this project has shown that many perceived challenges (i.e. handling, installation, etc.) relating to the application of VIPs in the construction industry can be addressed through careful planning and detailing. Ongoing in situ temperature monitoring of this project provides valuable field data for validating theoretical VIP aging predictions and laboratory accelerated aging results.

Acknowledgements

The authors appreciate the support of Panasonic Canada Inc. and Panasonic Corporation for supplying the vacuum insulation panels used in this project. The authors gratefully acknowledge the National Research Council Canada (NRCC) for providing technical expertise and support. The authors would like to thank Yukon Housing Corporation for providing a wall on one of their buildings for this project, and for providing monitoring equipment. Cold Climate Innovation, Yukon Research Centre, Yukon College, and the Energy Solutions Centre must also be credited for providing financial and technical support for this collaborative project.

References

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[3] P. Mukhopadhyaya et al. Proc. of IVIS 2011, 143-147
[4] Time and date, Accessed: June 10, 2017, https://www.timeanddate.com/weather/canada/whitehorse/climate

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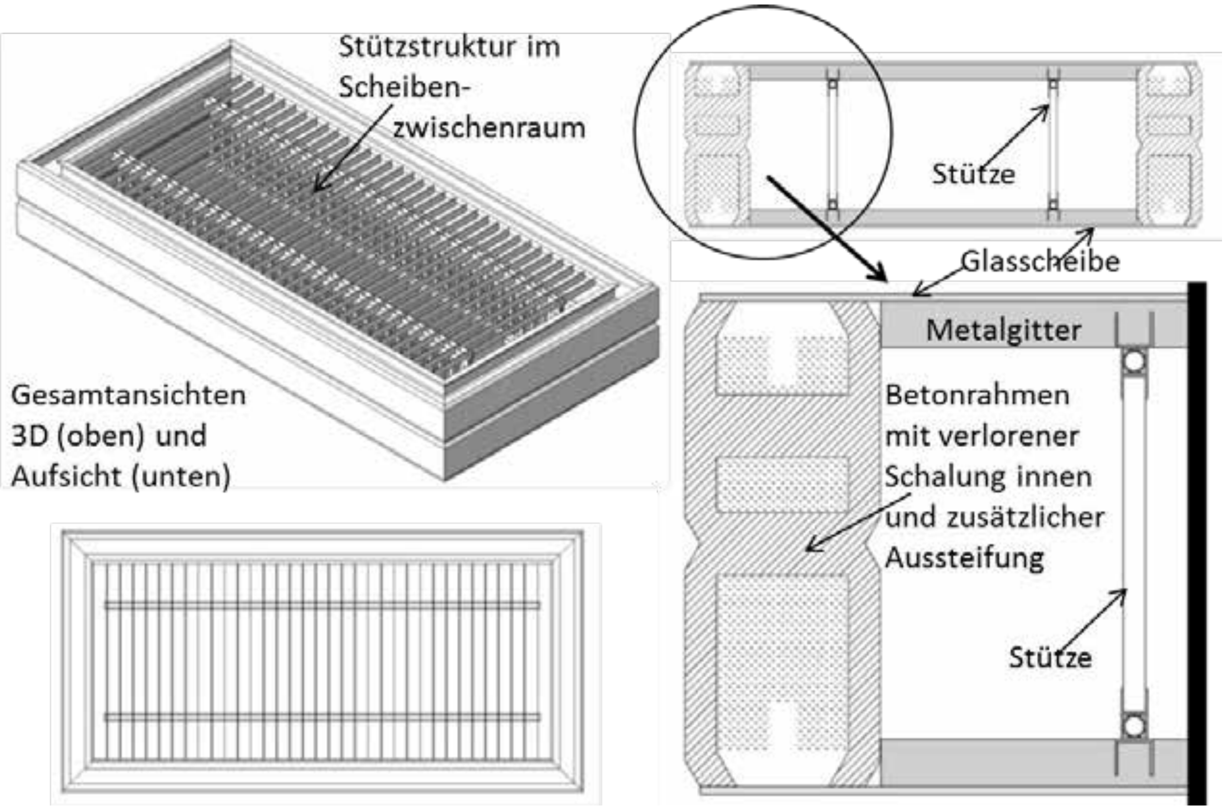
POSTER 17

Vacustruct® -low vacuum insulation glass building system for greenhouses and daylight buildings

Stefan Lück*
Lück's Pflanzenwelt
Firma vacustruct® wird gegründet
An den Weilerwiesen, 61169 Friedberg
* Corresponding author:
Lück's Pflanzenwelt, An den Weilerwiesen 1,
D-61169 Friedberg,
tel. +49 6031 4226,
cell phone +49 173 2841925
fax +49 6031 62999
stefan.lueck@email.de
http://www.vacustruct.com/

Transparent building parts today have – compared with opaque roofs or walls – a low thermal behaviour. Modern glazing systems (like triple glazing or VIG) show good improvements regarding the u-value, but they are not usable for plant production in greenhouses. The g-value is simply too poor and the costs are too high.

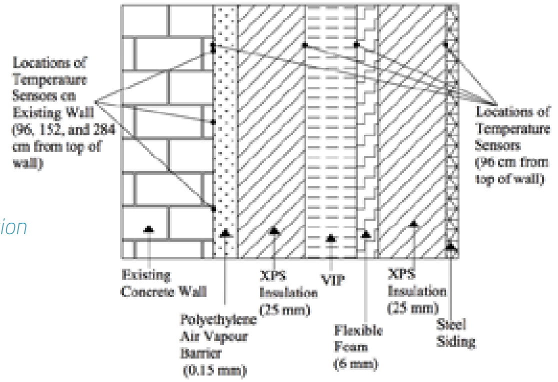
The vacustruct®-system delivers a completely different solution. A framework made out of (vacuum tight) Ultra high performance concrete (UHPC), combined with solar glass, a supporting structure between the glass sheets and the usage of low vacuum in combination with a double sealing and a protective vacuum lead to a new type of building system.



Building element and details. Size for the complete element is from 5000 cm x 170 cm x 30 cm to 600 cm x 300 cm x 30 cm.
The vacuum pump for the protective vacuum is not shown

The structure between the glasses can be made out of cheap tin sheets, shadow systems and heat exchangers can be integrated. Prefabricated construction and easy re-usability of the elements in combination with an u-value from about 0,2 W/(m² x K) will change the market for greenhouses. Mass production – due to the big sizes of this market – will lead to a very good cost/performance ratio and make this building system attractive for other building sectores.

Three sensors were placed on the existing wall approximately 2 m from the north edge of the retrofitted area. These sensors were located approximately 1 m, 1.5 m and 3 m from the top of the wall, and were used to monitor the thermal gradients from the top to the bottom of the wall.



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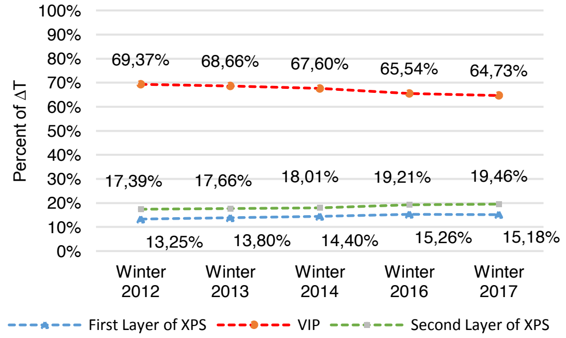

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POSTER 17

Vacustruct® -low vacuum insulation glass building system for greenhouses and daylight buildings

Stefan Lück*
Lück's Pflanzenwelt
Firma vacustruct® wird gegründet
An den Weilerwiesen, 61169 Friedberg
* Corresponding author:
Lück's Pflanzenwelt, An den Weilerwiesen 1,
D-61169 Friedberg,
tel. +49 6031 4226,
cell phone +49 173 2841925
fax +49 6031 62999
stefan.lueck@email.de
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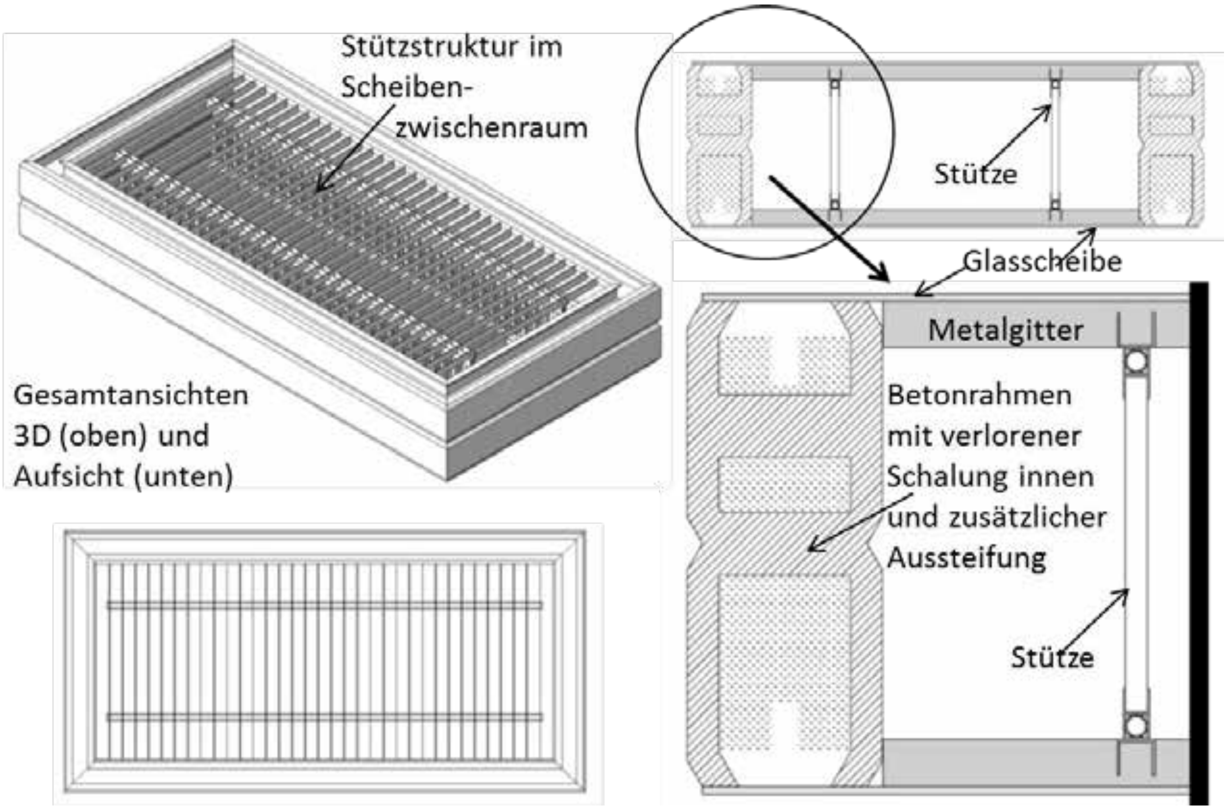

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The research & development project "GIFpro" is about this technology and starts at June 1st 2016

Dieses Projekt (HA-Projekt-Nr.: 493/16-05) wird im Rahmen von Hessen ModellProjekte aus Mitteln der LOEWE – Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz, Förderlinie 3: KMU-Verbundvorhaben gefördert.

Antragsteller

Hochschule Geisenheim University
Dr. Johannes Max

Projektpartner

Stefan Lück, Lücks Pflanzenwelt
G. tecz
Dr.-Ing. Gregor Zimmermann TU Darmstadt
Prof. Dr. -Ing. Jens Schneider
Prof. Dr. ir, Eduardus Koenders

POSTER 18

Practical Applications of SIMs: Retrofitting at the Building Scale

P. Johansson[a]*
B. Adl-Zarrabi[a]*

[a] Department of Architecture and Civil Engineering, Chalmers University of Technology, 412 96 Gothenburg, Sweden
* Corresponding author:
Tel. +46 (0)31-772 19 66
par.johansson@chalmers.se
zarrabi@chalmers.se

Keywords:

Super insulation materials,
case studies,
long-term performance,
thermal bridges,
energy efficiency.

Abstract

In this extended abstract and poster, conclusions from the IEA EBC Annex 65 Subtask 3 on Field scale performance of SIMs are presented. Full scale experiments provide knowledge of practical and technical difficulties as well as data for service life estimations of super insulation materials (SIM). For certain conclusions to be drawn from existing case studies, long-term monitoring is essential.
Unfortunately, monitoring is only performed in few case studies. In total 10 case studies using advanced porous materials (APM) and 22 using vacuum insulation panels (VIP), spread over 12 countries on 3 continents, have been scrutinized. Four main remaining challenges were identified and the status of these are discussed in the report based on discussions throughout IEA EBC Annex 65. The long-term performance (25-100 years) cannot be entirely determined due to lack of data for longer time period exceeding 15 years. However, there were few claims concerning the malfunction of SIMs in construction.

Introduction

To accelerate the introduction of SIMs on the construction market there are some challenges that must be overcome. The first challenge is the cost versus performance ratio. The thermal performance of SIMs is practically two to five times better than conventional materials while the price is generally between 4-15 times higher. The second challenge is the long-term performance of SIMs. The service life of a building is 25-100 years while the SIMs for building applications have been developed in the recent decades. The third challenge is that the construction market is a conservative market, regulated by numerous codes and standards, and thus, introducing new products takes a long time. The fourth challenge is knowledge and awareness among designers concerning using SIM. For instance, due to their nature, VIPs can't be adapted in size on-site by e.g. cutting. This may require additional effort during the design stage of the building process. In this extended abstract and poster, conclusions from the IEA EBC Annex 65 Subtask 3 on Field scale performance of SIMs are presented. The objective of the task was to define the application areas of SIMs and to describe the conditions of the intended use of the products. SIMs can be divided in advanced porous materials (AMPs) and vacuum insulation panels (VIPs) which have different requirements on the design and construction.

Case studies in the field

The long term performance of SIMs has to be determined based on case studies in field and laboratory. Full scale experiments provide knowledge of practical and technical difficulties as well as data for service life estimation. The case studies are distributed in 12 countries on 3 continents with various climate conditions and building traditions, see Fig.1. For certain conclusions to be drawn from the case studies, monitoring is essential. Unfortunately, monitoring and follow up is only performed in few of the case studies.

Fig. 1
In IEA EBC Annex 65, 32 case studies in 12 countries on 3 continents have been scrutinized

Among the conclusions regarding APMs is that they have been successfully installed since the early 2000s in case studies and assemblies. Knowledge of the hygrothermal properties are important to predict the performance at the material, component and building scale. The aerogel-based products, such as blankets, are in general vapor permeable and hydrophobic. In one of the reports on applying aerogel-based blankets as insulation in an old building [1], IR thermography was used to quantify the temperature difference on the exterior surfaces of two buildings, see Fig. 2. The investigation showed no degradation of the insulation performance.

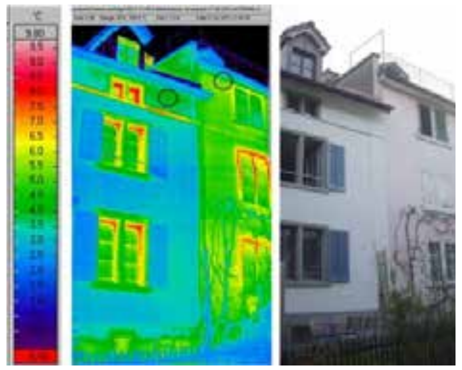

Fig. 2
Infrared and conventional picture of the southern façade taken on February the 17th 2011 [1]

Previous IEA Annex 39 investigated the possibilities to use VIP in buildings during 2002-2005 [2]. In total 20 constructions were analyzed in respect of the consequences on energy use, thermal bridges and moisture performance. In this Annex, 22 more recent case study buildings were investigated. Four of them have long-term monitoring. One example is presented in Fig. 3 which is a masonry wall of a commercial building that was retrofitted on the exterior with VIPs (glass fiber based core) [3]. VIPs were sandwiched between two layers of XPS. The instrumented VIP wall was constructed in 2009. Recorded sensor data and thermographic images till to date (January 2017) show no significant aging or failure of VIPs.

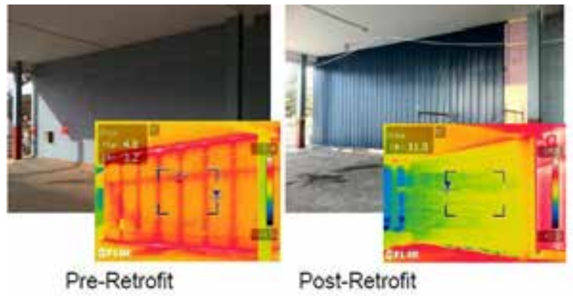

Fig. 3
Infrared image of the retrofitted wall clearly indicating the reduced impact of thermal bridges [3]

Remaining challenges for SIMs

During the work of the IEA EBC Annex 65 several questions regarding the long-term performance of SIMs and their application on the building scale have been identified and discussed. Four main remaining challenges were identified and the status of these are discussed below.

Knowledge and awareness among designers concerning using SIM

Special care is necessary during installation compared to conventional insulation materials, since the VIPs are sensitivity to mechanical puncturing of the envelope. Therefore, there may be a need for certification of craftsmen and need of special training.

Conservative construction market

The building industry is generally conservative to new solutions and materials. The industry is regulated by numerous codes and standards, and thus, introducing new material takes a long time. The ongoing standardization on the material and product levels may trigger building components with SIMs integrated to be introduced on the market.

Cost versus performance

There are valuable savings of space when less area is needed for the building elements which leads to an increased rental income. There can also be technical reasons to select a SIM, i.e. when conventional insulation materials are not a practical alternative or for architectural reasons.

Long-term performance of SIMs

Theoretical considerations and first practical tests showed that VIP, especially those with fumed silica core, are expected to fulfil the requirements on durability in building applications for more than 50 years. Both VIPs and APMs have been successfully installed over the past 15 years in buildings. However, real experience from practical applications exceeding 15 years for VIPs is still lacking.

Conclusions and outlook

The long-term performance (25-100 years) cannot be entirely determined due to lack of data for longer time period exceeding 15 years. However, as seen above and more thoroughly discussed in the report of IEA EBC Annex 65 Subtask 3, there were few claims concerning the malfunction of SIMs in construction.

Acknowledgements

The case studies and conclusions are results of the discussions throughout IEA EBC Annex 65. All the contributors and participants are acknowledged for their contributions. The work by the contributors from Chalmers University of Technology has been financed by the Swedish Energy Agency project 40798-1.

References
[1] K. Ghazi Wakili, et al., Energy and Buildings, 82 (2014) 237-242
[2] A. Binz, et al., Vacuum Insulation in the Building Sector.
Systems and Applications (Subtask B), IEA/ECBCS Annex 39 High Performance Thermal Insulation (HiPTI), 2005
[3] P. Mukhopadhyaya, et al., Energy and Buildings, 85 (2014) 672-680

POSTER 19

Long term thermal performance of VIPs around 100°C for use in district heating pipes

A. Berge[a]
B. Adl-Zarrabi[a*]

[a] Chalmers University of Technology
Sven Hultins gata 8, Göteborg
SE- 412 96, Sweden
* Corresponding author:
Tel. +46 31 772 19 88
Bijan.adl-zarrabi@chalmers.se

Keywords:
Vacuum insulation panels,
VIP,
long term performance,
high temperature,
district heating pipes.

Abstract

In Swedish district heating systems, 10% of the produced energy is lost as heat transmission from the distribution pipe network. Therefor it is of great interest to evaluate VIP for use in district heating pipes. A hybrid set-up where a VIP is surrounded by polyurethane foam have been tested and evaluated by laboratory and field measurements. Field measurements was initiated 5 years ago and an analysis indicate a small degradation of the VIP at a similar rate as for building application, even though the operative temperature is between 80-100 °C. In the laboratory a VIP in a hybrid pipe have withstood exposure to one sided heating at 115°C for over 4 years. It can be concluded that VIPs show promise for use at the temperatures of district heating pipes even for long term.

Introduction

In Sweden approximately 10 % of district heating energy are lost due to heat losses from distribution [1]. For energy sparse systems the losses can be even worse with values up to 40 % [2]. IEA-DHC have suggested some different paths to reduce heat losses by changing the geometry of the pipes [3].
In cylindrical geometries, the influence of the thermal insulation, per volume material, increase closer to the center of the cylinder. This has led to a hybrid concept for district heating pipes where a VIP have been placed close to the pipe center and the rest of the pipe is filled with polyurethane foam (PUR) as presented in Figure 1 [4], [5]. The PUR act as a protection of the VIP while simultaneously fulfills the mechanical demands of the district heating pipes.

This note present research on the main challenge for using VIP in district heating pipes, the high temperatures. The diffusion of gas into the VIPs increase exponentially with temperature [6].

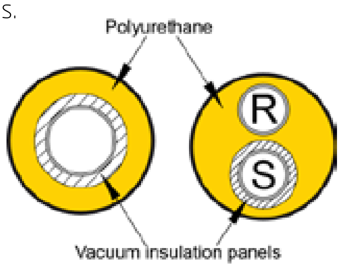

Fig. 1
Concept for hybrid insulation district heating pipes with VIP and PUR

Field measurements

Prototype pipes have been connected to active district heating networks for over 5 years. The temperature have been measured at various points every sixth hour since installation. The results have previously been presented by Berge & Adl-Zarrabi [7] but since then two more years have passed and two new measurement stations have been initiated. The temperature throughout the cross sections have been measured in the points presented in Figure 2.

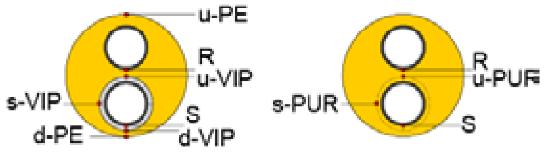

Fig. 2
Positions for temperature measurements in twin pipes

The first measurements were made on twin pipes since these seem more plausible for the use of VIPs. On the other hand the measurement results are harder to evaluate since there are three temperature boundaries with varying temperature. This has led to the choice of single pipes for later measurement stations where the latest was started during the autumn 2016.

Laboratory measurements

The field measurements have been complimented with laboratory measurements on three single pipes with a constant temperature in the supply pipe at 115°C, 125°C and 135°C. The temperature was measured on the center of the VIPs and at the seams which were folded back towards the cold side of the VIP, as presented in Figure 3. The results have been analyzed by the quotient between the thermal conductivities of the polyurethane and the VIP according to the equation:

$$\frac{\lambda_{PUR}}{\lambda_{VIP}} = \frac{\Delta T_{VIP}}{\Delta T_{PUR}} \cdot \frac{\ln\left(r_{out.PUR}/r_{in.PUR}\right)}{\ln\left(r_{out.VIP}/r_{in.VIP}\right)}$$

where

λ thermal conductivity of layer

ΔT Temp difference over layer

r inner and outer radius of layer

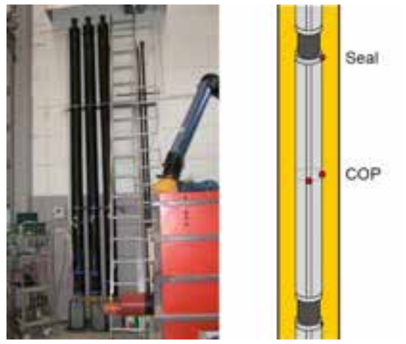

Fig. 3
Description of measurement points

Results and discussions

The results from our oldest field measurements are shown in Figure 4 .There is a large difference in temperatures measured on VIP compared to corresponding positions in PUR both at the beginning and the end of the measurement.

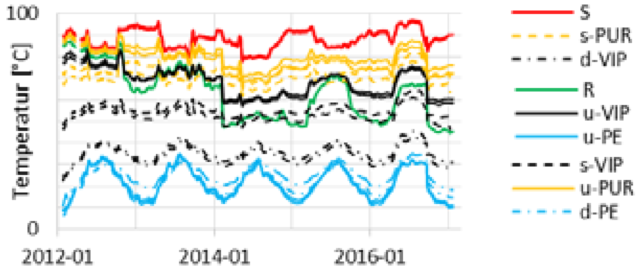

Fig. 4 Results from field measurements.

When the data is analyzed according to the method developed in [7] it is indicated that there is a slow deterioration where the thermal conductivity increase by around 0.2 mW/(m•K) per year. Of the two measured panels one seems to have a considerably faster deterioration.

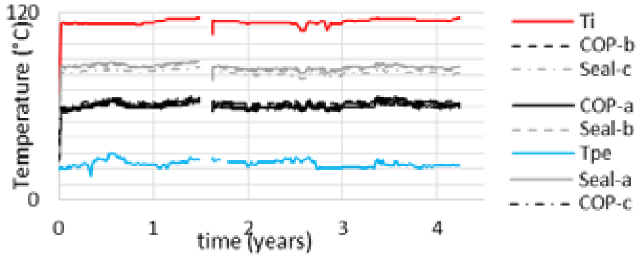

Fig. 5 Temperatures in laboratory measurement

For the laboratory measurements the VIPs at 135°C were destroyed instantaneously and the VIPs at 125°C were destroyed over a period of some days. The VIPs at 115°C are still intact after more than 4 years as shown in Figure 5.
Figure 6 show the results from the calculation of the relative thermal conductivity which show very consistent results with exception of some jumps at 1.5 years and 2.8 years when the measurement equipment was adjusted.
The thermal conductivity of the PUR is around 3-4 times that of the VIP (The PUR is at a much colder position).

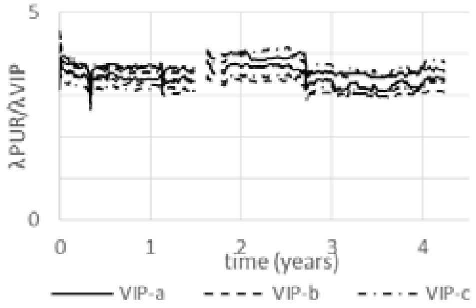

Fig. 5
Relative thermal conductivity for pipes in laboratory measurement

Conclusions and outlook

The results show great promise for the use of VIPs in district heating pipes. The measurements show that the VIPs could withstand long times of one-sided high temperature loads without breaking and without any intense air diffusion. For the VIPs used in the study, there seems to be some limit around 120°C above which the envelope breaks. This gives incentives to develop VIPs further for higher temperatures. For the more recently initiated field measurement stations, new types of VIPs have been used with more heat durable envelopes.

Acknowledgements

The work has been financed by the Swedish district heating association. Prototypes have been produced by district heating pipe producer Powerpipe.

References

[1] Statistics Sweden, EN11 SM1401, 2013
[2] C. Reidhav & S. Werner, Appl. Energy, 85(9) (2008) 867-877
[3] IEA-DHC Annex VIII H. Zinko et al., 2008
[4] A. Berge & B. Adl-Zarrabi, DHC13, (2012) 156-162
[5] A. Berge & B. Adl-Zarrabi, DHC14, (2014) 454-461.
[6] H. Simmler & S. Brunner, Energy Build. 37(11) (2005) 1122-1131
[7] A. Berge et al. Renew. Energy 87 (2016) 1130-1138

POSTER 20

Stripres® Contactless, Battery-less Sensor for Pressure Measurement in Vacuum Insulation Panels

J. Dermol[a]*
M. Žibert[a]

[a] Strip's d.o.o., Kandrše 7, 1252 Vace, Slovenia
* Corresponding author:
Tel. +386 3 567 07 70
Joze.Dermol@strips.eu

Keywords:

Vacuum insulation panel,
vacuum measurement,
quality assurance,
performance monitoring,
contactless sensor,
energy harvesting.

Abstract

Due to the nature of a vacuum insulation panel (VIP) design and manufacturing process, it is challenging to verify the quality of a VIP during its production, as related to the vacuum level achieved in the manufactured VIP. Furthermore, it is even more challenging to monitor the VIP vacuum level after installation, as well as throughout the lifecycle of a VIP. As VIP's thermal isolation performance is directly correlated with VIP's vacuum level, such monitoring is crucial for ongoing panel performance and quality evaluation.

To address these challenges we have developed a cost-efficient, contactless sensor Stripres for measuring vacuum levels in VIPs, both during the manufacturing process and over the course of a VIP's lifetime. Stripres sensor is designed to be permanently installed into VIPs during panel production, and subsequently allows for a vacuum measurement at any time and almost any place, thanks to a contactless measurement process. To ensure longevity the Stripres sensor is battery-less and is powered using energy harvesting from the corresponding wireless reader device.

The Stripres sensor, presented in this paper, is designed for widespread use across a wide scope of VIP applications. Its operating pressure measurement range is between 1 Pa and 500 Pa, with relative accuracy of ±7% for pressures above 20 Pa, and ±15% for pressures below 20 Pa.

Introduction

Vacuum insulation panels (VIPs) provide unparalleled thermal isolation performance at an extremely shallow lateral profile, compared to other generally available insulation materials and solutions, making VIPs both the solution of choice for high-demand applications, and an enabler for new insulation applications which were previously impossible or unfeasible.
While the fundamentals of VIP technology, production and application are well developed, VIP performance in practical applications over time is difficult to consistently and accurately monitor, at least in a ubiquitous and cost effective sense. Furthermore, quality assurance during the VIP production (in terms of ensuring a desired vacuum level) is challenging in itself due to the nature of the manufacturing process. Existing solutions to these challenges are suboptimal, due to factors such as:

- Physical contact with a sensor, built into a panel, is required, which greatly inhibits the ability to measure and monitor panel performance after installation and over time.
- Sensors may not provide a sufficient pressure measurement range, especially for pressures below 100 Pa. As panels are often evacuated to pressures in the 10 Pa range, such sensors are unable to measure such pressure levels, and are furthermore unable to measure the pressure increase gradient over time, at least until their lower measurement threshold is reached, which withholds valuable data from manufacturers and/or panel application users.
- Sensors may require a relatively long time for a measurement to be executed, which may inhibit such sensor's use on a VIP production line.
- The sensor technology may not be feasible for application beyond a VIP manufacturing facility, i.e. for field use where VIPs are installed for their intended use (e.g. as part of building insulation or a white goods appliance).
- Finally, the sensor technology may be too complex or cost-inefficient, which prevents widespread adoption throughout the VIP manufacturer community, and may only be feasible for catering to very specific, niche applications.

Recognizing the need for a better solution we have set out to develop a new, innovative sensor that would overcome these deficiencies. Our key development aims were:

- Contactless sensor reading, allowing measurements to be performed both during the VIP production, and afterwards during the VIP usage.
- Battery-less operation, enabled by harvesting energy from the wireless reader device, allowing for a long sensor service life, matching VIP lifetime.
- Sufficient pressure measurement accuracy and ability to provide reliable pressure measurements starting from 1 Pa.
- Reasonable sensor cost to allow for a widespread sensor adoption in VIP production.

Methodology

The Stripres pressure sensor operates on the principle of weighing gas molecules with a special customized measuring component. The measuring component is sensitive to surrounding gas molecules. Its electrical characteristic is affected by surrounding gas molecules, which in turn results in change of electrical output.

Implementation

The essence of the Stripres VIP pressure measurement solution is a customized measuring component – sensor (8) with an associated electronic circuit (4-11), forming a measuring unit (2) to be installed inside a VIP (1). Operation of the measurement unit is controlled by an external read-control unit (3). Additionally, the external unit receives and processes measurement values from the measuring unit, and provides the wireless energy transfer into the VIP interior, required for the operation of the measuring unit.

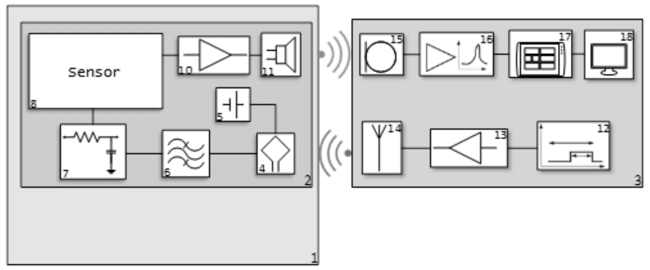

Fig. 1
Stripres vacuum measurement system block diagram

Results and discussions

Test results of a prototype contactless sensor are presented in Fig. 2. The output was measured at 1, 5, 10, 25, 50, 100, 250 and 500 Pa. Calibration gas was laboratory air at 23°C and 60% relative humidity. Measurements were done in an increasing series of pressures, followed by a decreasing series.

This sequence was repeated 3 times. With seven pressure intervals an average mapping curve is obtained by averaging values of measurement points at 1, 5, 10, 25, 50, 100, 250 and 500Pa, which is a piecewise spline of third order polynomial curve, and allows calculation of any pressure on a given interval.

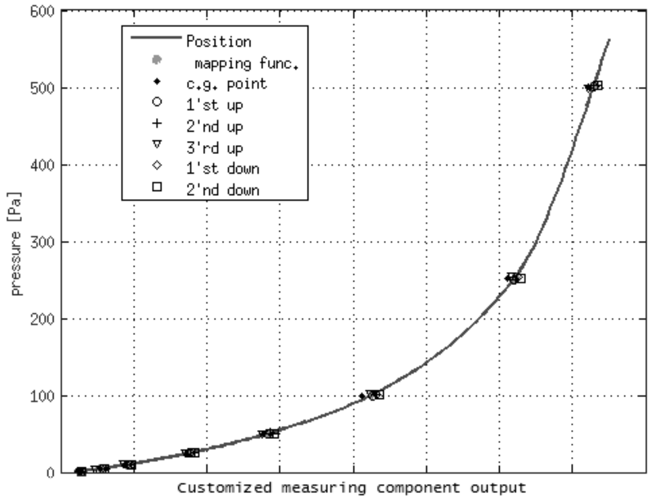

Fig. 2
Average piecewise cubic interpolation curve

Conclusions and outlook

A novel high vacuum pressure measurement sensor has been developed and verified for accuracy against a reference system. The sensor is characterized with high repeatability, temperature stability and low power consumption. The sensor's pressure measurement range has been demonstrated to span from 1 Pa to 500 Pa, with accuracy exceeding 7% above 20 Pa, which makes it well suited for VIP vacuum measurement application.

POSTER 21

The Study of a Performance Evaluation of an Exterior Panel with Vacuum Insulation Panel (VIP) for Building Applications

Jinhee Kim
Jonggwon Ahn
Sangmyung Kim
Juntae Kim

Kongju National University
* Corresponding author:
Tel. (+82) 41 521 9333
jtkim@kongju.ac.kr

The application of vacuum insulation panel (VIP) in buildings is done to make the building envelope thinner while maintaining the current thermal performance by greatly lower the thermal conductivity as compared to that offered by conventional insulation materials. On the other hand, VIP applied to a building may cause thermal bridges, which can then reduce the thermal performance of the VIP envelope due to the very low thermal conductivity relative to those of other building materials. Therefore, the thermal performance of a VIP wall depends on how it is applied to the building envelope, which is affected by the VIP installation method in relation to the other building materials used. Furthermore, VIP for buildings requires a modular or standardized installation method of the type commonly used in construction environments.

In this study, we purpose a VIP exterior panel which is modular or standardized and therefore readily useable with existing construction methods as an external insulation system that is integrated with existing exterior panels. For this purpose, an exterior panel with VIP was fabricated and its performance was evaluated. The aims of this study are to evaluate the performance capabilities of the proposed VIP panel considering current building requirements and to assess the theoretical and experimentally effective thermal transmittance (U-value) of the proposed exterior panel with VIP.

Preparation and characterization of alternative hybrid glass fiber core materials

F. E. Boafo[a]
SM. Kim[a]
JH. Kim[b]
JT. Kim[ac*]
HB. Kim[d]

[a] School of Energy Systems Engineering, Kongju National University, Cheonan, Chungnam, Republic of Korea
[b] Green Energy Technology Research Center, Kongju National University, Cheonan, Chungnam, Republic of Korea
[c] Department of Architectural Engineering, Kongju National University, Cheonan, Chungnam, Republic of Kore
[d] Byucksan Corporation, 216 Gwanghui-dong, Jung-gu, Seoul, Republic of Korea
* Corresponding author:
Tel. (+82) 41 521 9333,
jtkim@kongju.ac.kr

Keywords:

Vacuum insulation panel (VIP),
hybrid core material (HCM),
glass fiber (GF),
hollow glass microsphere (HGM).

Abstract

Recently, so called hybrid core materials (HCMs) with varied ratios of nano and micro sized additives incorporated mainly into fumed silica matrix, to be used as core material for vacuum insulation panel (VIP), has been the focus of many works in open literature. This study investigates alternatives to improve commercial grade glass fiber mats for use either as stand-alone insulation materials or core material matrix for VIP enclosures. Hollow glass microspheres (HGM) were considered as additives. The aim is to improve the micro structural characteristics and thermal performance of the glass fiber mats. 3 glass fiber core material layers were used for each HCM; averaging HCM thickness and density of 10.13-11.52 mm and 98.8-101.8 kg/m^3, respectively. The total thermal conductivity of as-produced HCMs at atmospheric pressure reduced by 0.28-0.33 mW/mK; that is relatively one-third to nearly half of the gaseous thermal conductivity of glass fiber insulation.

Introduction

Buildings continuously use a significant fraction of the total primary energy. For instance, buildings are responsible for 40% of energy consumption within the European Union [1, 2]. Considering the Republic of Korea, energy used in buildings amounted to 18.8% of the final energy consumption; by energy end-use subcategory, residential and non-residential buildings consumed 42.7% and 55% of the total amount of electricity and gas respectively, in 2014 [3]. From 2011-2013, building energy use considering life cycle accounted for about 46% of the final energy consumption in China [2]. In the absence of mitigate measures, studies have predicted that energy use in building sector will continue to dominate other sectors of the economy; mostly due to urbanization related status and social changes [4-6].

To reduce heat losses and gains across the building envelope, efficient building envelope systems, through passive building design strategies incorporated with insulation measures, have been the focus in open literature. Over a decade now, vacuum insulation panel (VIP), said to be one of the highly efficient insulation materials available, has been gradually applied in buildings [7]. Generally, VIP core materials are composed of homogeneous or heterogeneous mixtures of fumed silica, glass fiber, open celled foams, oxide powders, among others. The core material provides the thermal insulating capacity and mechanically supports the ensuing VIP from pressure created on the surface of the envelope especially after it has been evacuated. It is well known that the material behavior and properties of the core material has a bearing on solid (λ_s), gas (λ_g) and radiation (λ_r) thermal conductivities, and thus an inevitable effect on the long-term performance of the resultant VIP. For example λ_s (W/mK), λ_g (W/mK) and λ_r (W/mK) for silica, and glass fiber core materials were found to be 0.0219, 8.12×10-6, 0.0002 and 0.0021, 7.88×10^{-4}, 0.007, respectively [8]. In this study, hybrid core materials (HCM) composed of 3 grades of hollow glass microspheres (HGM) and glass fibers were prepared at different mixing ratios. Thereafter, microstructural behavior and thermal behavior of the as-produced HCM were examined; towards improving the base properties of the glass fiber and to suitable choose an optimum mixing ratio for VIP production.

Materials and Methods

The glass fiber core material and HGM examined are commercial grade materials. For each HCM, 0.5 mass %, 2 mass %, 4 mass %, 8 mass %, and 10 mass % of HGM were mixed with glass fibers and dried at 250°C for a minimum of 3 hours. 3 glass fiber core material layers were used for each HCM, totaling an average HCM thickness of 10.13-11.52 mm. The microstructural morphology and composition of the HGM, glass fiber, and HCM was observed by microscopy (SEM model: MIRA3 TESCAN). Thermal conductivity were evaluated using heat flow meter instrumentation (Netzsch HFM 436) at mean temperature (T_m) of 23°C and 10°C, within temperature range (ΔT) of 10°C.

Results and discussions

The microstructures of glass fiber core material and HGM, as well as composition of HGM are depicted in Fig. 1. The core material consisted of a fluky mass of glass fibers. The core material was porous and highly compressible, with mean fiber diameter of 4.5 μm and porosity ≥ 90%. Likewise, the microstructure of the HGM showed porous spherical bubbles distributed in a space-separated random manner. The nano spheres were intact and almost of same density throughout the matrix. The main elements of the solid HGM phase were Si, O, Ca, and Na, with traces of Al and S. Table 1 summarizes the details and properties of various HCM at atmospheric pressure.

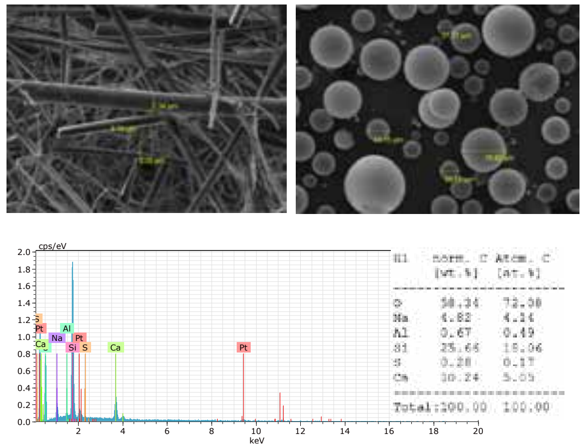

Fig. 1
Microstructure of raw materials: glass fiber (top left) and HGM (top right); and EDS of HGM (bottom)

Sample	Mass% of HGM	Thickness, mm	Density, kg/m^3
1 (no additive)	0	10.27	101.8
2	0.5	10.69	100.2
3	2	10.63	102.1
4	4	10.88	100.3
5	8	10.48	100.6
6	10	11.52	98.8

Tab. 1
Composition and properties of HCM samples

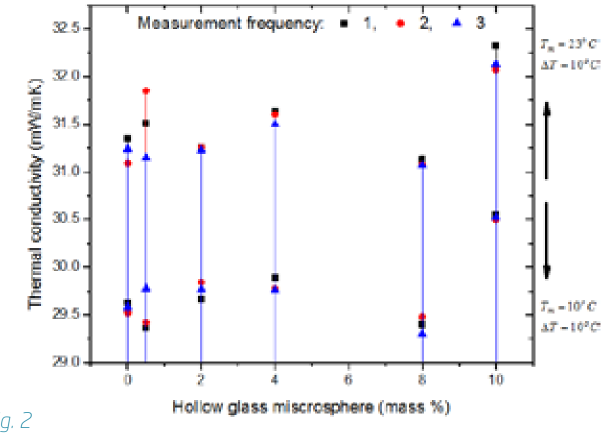

Fig. 2
Variation of total thermal conductivity at atmospheric pressure of HCM with different mass rations of HGM

Fig. 2 summarizes the thermal performance of the HCM in terms of thermal conductivity index at T_m of 23°C and 10°C. Main thermal transport mechanisms of insulators are λ_s, λ_g and λ_r. At atmospheric conditions, λ_s and λ_r are feasible to lessen; λ_g is more dependent on a material's inherent properties such as particle size and distribution, and vacuum state and thus difficult to reduce. Nonetheless, the HCM's structure is typical of a composite where nano sizes particles bond and interlock with adjoining glass fibers, thus altering the material structure; improving mechanical strength, as well as potential to restrict both λ_g and λ_s. From Fig. 2, it is shown that tests conducted at Tm of 10°C yielded lower thermal conductivity values than at T_m of 23°C. However, for both T_m, the lowest thermal conductivity of HCM (as compared to pure glass fiber core material without HGM) corresponded to 8 mass % of HGM. Quantitatively, for 8 mass % of HGM, the thermal conductivity reduced by 0.33 mW/mK and 0.28 mW/mK at T_m of 10°C and 23°C, correspondingly. For glass fiber core materials, the terms λ_s, λ_g and λ_r were found to be 0.0021, 7.88×10^{-4}, and 0.007 (all in W/mK), respectively [8]. Relatively, thermal conductivity of the HCM reduced by one-third to nearly half of the value of λ_g for glass fiber insulation.

Conclusions and outlook

In this study, a hybrid core material (HCM) composed of hollow glass microspheres (HGM) and glass fibers has been synthesized, characterized and discussed. For each HCM, 0.5 mass %, 2 mass %, 4 mass %, 8 mass %, and 10 mass % of HGM was prepared. The microscopic image of HGM showed porous spherical bubbles distributed randomly in a porous matrix. Major phase elements of the HGM were Si, O, Ca, and Na. On the other hand, the density of as-prepared HCM ranged from 98.8-101.8 kg/m^3. Considering mean temperature testing conditions of 23°C and 10°C, the thermal conductivity of HCM reduced by 0.28- 0.33 mW/mK; comparatively one-third to half the magnitude of the gaseous thermal conductivity for glass fibers.

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References
[1] P.A. Fokaides et al. Ener. & Build. 68(2014)203-212
[2] Y. Zhang et al. Ener. & Build. 94 (2015) 240-251
[3] K.E.E.I. Energy Statistics, (2016)
[4] W. Hong et al. ABC Publication (2008) 1-320
[5] IEA Annex 39, Subtask B, H. Simmler et al. (2005)
[6] S. E. Kalnæs et al. Apl. Ener.116 (2014) 355-375
[7] F. E. Boafo et al. Ener. & Build. 85 (2014) 644-653
[8] J. S. Kwon et al. Journal of Heat & Mass Transfer 52 (2009) 5525-5532

POSTER 23

Some fractal properties of porous insulation materials

K. Gudmundsson[a*]
P. Karami[b]

[a] KTH, Civil and Architectural Engineering,
Stockholm, Sweden
[b] Kingspan Insulation Ltd, Hereford,
United Kingdom
* Corresponding author:
Tel. 004687906590
kjartan.gudmundsson@byv.kth.se

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fractal dimension,
thermal conductivity.

Abstract

This study aims to show how a fractal description of porous materials may help in the design of new super insulation materials and provide a method for assessing thermal conductivity. Previous research on the fractal modelling of heat transport in different porous media is briefly described. It is shown how the fractal dimension can be related to the pore size distribution and how the resulting thermal performance can be evaluated.

Introduction

Super insulation materials and components have a thermal conductivity about 2-5 times lower than that of traditional insulation materials thus offering a number of technical advantages. Examples are vacuum insulation panels and aerogels. The ongoing development of new materials does however require efficient tools for measuring and analysing the thermal properties of materials. Previous studies in this field have dealt with different experimental methods for evaluating the thermal conductivity of porous materials. The effect of pore size on thermal transport has also been described, including the effect of characteristic pore size and gas pressure on the thermal conductivity. Several methods are available for the evaluation of pore size distribution and surface area as well as imaging while only recently it has been possible to use advanced electron tomography for 3D imaging and quantitative analysis of particle size and morphology of Nanostructured silica [1]

This study is concerned with the possibilities of using a fractal description of the morphology to evaluate the thermal conductivity porous materials. The objective is to provide a tool that may help explain the performance and possible shortcomings of different materials and be of use for parametric studies in the engineering of new superinsulation materials. Previous efforts relate the fractal geometry of a porous material to its thermal conductivity by using a unit cell model. This study is focused on the evaluation of superinsulation materials and

how the fractal dimension and the corresponding pore size distribution can be used to derive a resulting thermal conductivity in the Knudsen region from a stochastic assembly of cells, each of which have a different thermal resistance that is related to the pore size while the onset of convection and the limits of self-similarity can also be evaluated.

A discussion of the various mechanisms of heat transfer in porous materials can be found in previous work [2] that describes the influence of the air pressure on Nano-porous materials. The thermal gas conductivity can be calculated as a function of the thermal conductivity of free gas and the Knudsen number that is the ratio between the mean free path of air molecules and the characteristic size of pores. The mean free path depends on gas diameter, the temperature and the pressure in the gas. When the pore diameter becomes less than the mean free path the thermal gas conductivity the heat transfer due to gas conductivity will diminish. The onset of natural convection in an open pore system depends on pore diameter and the temperature gradient and can be determined using the dimensionless Rayleigh number [3] that depends on the temperature difference across the pore diameter, the characteristic size of pore, the thermal diffusivity and the kinematic viscosity of the gas. No natural convection will occur for a Ra number below 2000.

Heat transport in fractal porous materials

A fractal is characterized by self-similarity meaning that that each portion of a fractal can be considered a reduced-scale image of the whole [4]. Another feature of fractals is that they have a dimension that is non-integer. A line is one dimensional since one parameter is required to measure its length while a rectangle is two dimensional and requires two parameters for a measure of its area while a box is three dimensional and requires three parameters to define its volume. The line, the square and the cube may also be decomposed into N similar objects giving each line the length of $(1/N)^D$ times the length of the initial line while each rectangle has the area of $(1/N)^D$ times that of the initial rectangle and each box has a volume of $(1/N)^D$ times the volume of the initial box where D is the dimension of the objects. With a general similarity ratio of $r(N) = (1/N)^D$ the dimension can be characterized as $D = -\log N/\log r(N)$. This is usually referred to as the Hausdorff dimension of a fractal. The "box-counting" dimension is another way of determining the fractal dimension of a set S in a Euclidian space. This can be done by placing an evenly spaced grid on the set and by counting the number of boxes of various side lengths that are needed to cover the fractal and by noticing how the number changes as the grid is made finer.

Elaborate explanations of a number of definitions of fractal dimensions can be found in the literature [5]. Chen and Shi [6] used the area fractal dimension of porous media to describe the geometric structure of real soil. Furthermore, they established a model for heat conduction for a given volumetric content and calculated the effective thermal conductivity as a function of the volumetric soil content and the thermal conductivity of the gas and the solid. The volumetric soil content can be evaluated from the fractal dimension with the possibility of correlating for the measured density. The results are verified with measurements. Other similar studies include the work of Shi et al on polyurethane [7]. The models do not count for radiation or convection.

In this study we want to illustrate how the fractal properties can be used to evaluate the thermal performance of a porous material. According to Yu and Cheng [8] the cumulative distribution function of the pore size distribution can be written as a function of the pore size, d and minimum pore size $dmin$.

$$cdf(d) = 1 - \left(\frac{d_{min}}{d}\right)^{D}$$

Results and discussions

Using a minimum pore diameter of 200 nm we can see the effect of the fractal dimension on the pore size distribution in fig 1. We can notice a substantial increase in the Knudsen effect with increase in fractal dimension, as an example there is a reduction by about 35% compared to the thermal conductivity of free gas in about 73% of the pores when the fractal dimension is 1,9 compared to 56% of pores when the fractal dimension is 1,2. This shows that a higher fractal dimension of a fractal material is to be strived for.

We can also generate a stochastic array of unit cells the pore sizes of which correspond to the cumulative distribution function. This can be done by creating a series of k random numbers n_k in the range from 0 to 1 and using each number to get the pore size d_k by using it as an input for the inverse of the cumulative pore size distribution function [9].

$$d_k = \frac{d_{min}}{(1 - n_k)^{\frac{1}{D}}}$$

For each pore in the array we may now evaluate the lambda value of the pore gas. The resulting thermal conductivity can then be calculated by considering the array a row of unit cells connected in series.

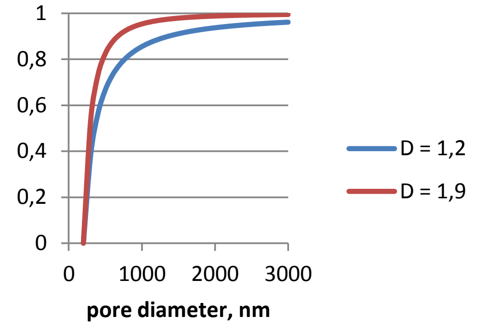

Fig. 1
The cumulative distribution function of pore size for the fractal dimensions of 1,2 and 1,9

Knowing the pore size distribution of a fractal material with pore sizes well beyond nanoscale we also test for the onset of convection using the dimensionless Rayleigh number.

Our ongoing work shows that the relationship between void area and scale ceases to be linear above a certain area scale known as the upper limit of self-similarity which indicated that the morphology is not fractal above a certain scale. With a sparsely compacted matrix of fractal components on macro scale this lead to convective heat transfer.

Conclusions and outlook

The concept of fractal geometry can be used to relate the morphology of a material to its thermal properties which can help to improve the thermal properties. Ongoing and further work includes parametric studies of various hypothetical structures as well as the characterization of existing materials and experimental verification.

References
[1] L. Roiban, G. Foray, Q. Rong, A. Perret, D. Ihiawakrim, K. Masenelli-Varlot, E. Mairea & B. Yrieixb, RSC Adv. 6 (2016) 10625-10632
[2] R. Baetens, B. P. Jelle, J. V. Thue, M. J. Tenpierik, S. Grynning, S. Uvsløkk, A. Gustavsen, Energy and Buildings 42 (2010) 147-172
[3] Y.M. Volfkovich, A.N. Filippov, V.S. Bagotsky, Springer, 2014
[4] B. B. Mandelbrot, Science: 156 (1967), 636-638
[5] M. Frame, B. Mandelbrot, Cambridge University Press, 2002
[6] Y. Chen & M. Shi, J. of Therm. Sci. 8 (1999)102–107
[7] M. Shi, X. Li & Y. Chen, Sci. in China Series E: Techn. Sci. 49 (2006) 468-475
[8] B. Yu & P. Cheng, Int. J. of Heat and Mass Tran. 45 (2002) 2983–2993
[9] https://sciencehouse.wordpress.com/2015/06/20/sampling-from-a-probability-distribution/

POSTER 24

Utilization of Alternative Raw Material Resources for the Production of Core Insulation in Vacuum Insulation Panel (VIP)

Zach[a]*
Hroudova[a]
Novak[a]
Sekavcnik[b]

[a] Brno University of Technology, Faculty of Civil Engineering, Veverí 331/95, 602 00 Brno, Czech Republic
[b] Turvac, inovativne izolacije, d.o.o., Primorska cesta 6b, 3325 Šoštanj, Slovenija
* Corresponding author:
Tel. 54114 7516
zach.j@fce.vutbr.cz

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VIP core insulation,
Fiber Mats,
Recycled fibers.

Abstract

Vacuum insulating panels are currently some of the most advanced building materials available with the rate of their production rising every year. This type of insulating material can have thermal conductivity up to 10 times lower than conventional insulations such an EPS or mineral wool. As the production of VIP increases, so does the consumption of raw materials needed for their manufacturing. The basis of VIPs is the core insulation material, most commonly made of glass fiber boards or pyrogenous SiO_2-based insulation boards. The production of these insulations consumes a great amount of energy – hence the effort to find alternative, more eco-friendly insulations made with renewable and secondary raw materials suitable for this purpose. The paper describes new findings arrived at by the Brno University of Technology during research into the utilisation of alternative raw material resources (mainly secondary textile fibers) in the production of VIP core insulation.

Introduction

The development of thermal insulating materials used in civil engineering and industry is very closely related to issue of environmental protection and to efforts to the reduction of energy performance of buildings, appliances and other industrial applications. It is coming in the field of thermal protection of buildings to progressive implementation of the requirements of Directive 2010/31/EU [1]. In addition to these requirements, there is an increasing tendency to use alternative, easily renewable raw resources and to ensure recyclability of materials after the their primary function for which they were made.
There is also an ever-increasing pressure to reduce CO_2 emissions and also to reduce primary energy intensity (PEI) incorporated in products in the production of materials.
From the point of view of progressive technologies of achieved thermal properties, the vacuum insulating panels (VIP) currently represent the materials with the lowest equivalent value of the thermal conductivity.
In recent years, alternative core insulations such as synthetic fibers [2, 3], as well as insulations based on secondary raw materials (organic), are also being used in the VIP area. This topic has been devoted to research at the AdMaS Center, at the Faculty of Civil Engineering in Brno in last years. Experimental measurements have shown that a lot of alternative insulations based on natural and organic textile fibers show very good thermal insulation properties at very low pressure. These results were published by the BUT authorship team at the previous IVIS 2015 Symposium [4]. However, from the point of view of the use of these alternative insulations for VIP production, it is necessary for alternative insulation to exhibit good stability under low pressure [5].

Test specimens and methodology of experimental works

Test samples based on natural synthetic fibers were designed within this research devoted to alternative core materials of VIP. 3 basic types of core insulations were proposed: A) Insulation based on recycled cotton fibers from pulled old textile with a purity higher than 95 % - core insulation A; B) Insulation based on recycled cotton and polyester (PES) fibers in ratio 1:1 additionally cleaned and freed from admixtures - core insulation B; C) Insulation based on pure polyester fibers (PES) with thickness 0.9 dTex - core insulation C.
At the beginning of all works, microscopic analysis was performed on test samples of selected raw fibers and their basic characteristics (fiber length and thickness) were determined. Additionally, test samples were produced from raw resources by air-lay method with using 15 % bicomponent fibers.
On test sampes were determined these properties, thickness (EN 823) and density (EN 1602). Determination of the thermal conductivity was made in dependence on the pressure with instrument FOX 200 Vacuum (EN 126 67/ISO 8301; conditions: mean temperature 10 °C and a temperature gradient 10°C).

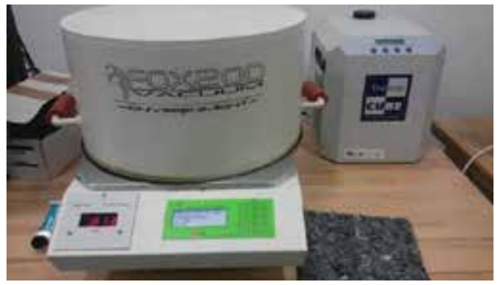

Fig. 1
Photo of device FOX 200 Vacuum from company TA Instruments during vacuum process

Results of measurements

The microscopic analysis and determination of the length and thickness of the fibers was first performed on the test samples. The results are shown in the following table 1.

Insulation mixture	A	B	C
Thickness of fibers [μm]	21.5	16.5	10.0
Length of fibers [mm]	13.70	6.85	10.19

Tab. 1
Properties of raw

At first, the modification of bulk density was made on test insulations and in all cases the test samples were produced with three different bulk densities by heat press (the samples were heated and dried at + 160 °C). Linear dimensions, thickness and bulk density were determined on these test samples. In the next step, it was made determination of thermal conductivity at normal pressure and under vacuum (about 20 Pa) on dried test samples. The results are shown in the following table 2.

Insulation mixture	Density class	Density [kg/m^3]	Thermal conductivity W/(m·K)
A	I	122.4	0.00515
	II	131.2	0.00467
	III	164.4	0.00468
B	I	119.7	0.00514
	II	196.9	0.00414
	III	234.1	0.00393
C	I	128.5	0.00187
	II	198.9	0.00191
	III	287.5	0.00363

Tab. 2
Selected properties of test samples

Discussions and conclusion

From the measurement results it is significant that the thermal conductivity of the core materials depends on the fiber thickness and the bulk density. Optimal area of the bulk density is decreasing with the fiber thickness. Overall, the best results were obtained on a sample of pure PES fibers with the lowest thickness (Mixture C).
Test samples were subjected to determination of thermal conductivity in dependence on pressure and also temperature by vacuum. The following was found:

- In all cases, the higher pressure caused rapid degradation of thermal insulation properties;
- The rate of degradation was 200-600% for all insulations. The lowest degree of degradation of the thermal insulation properties was found in the area of the bulk density about 200 kg/m^3;
- In case of mixture C, test specimens with bulk density 198.9 kg/m^3 even at 1 mBar pressure maintained a thermal conductivity of less than 0.01 W/(m·K);
- In addition, it was found that thermal conductivity with increasing temperature in most test specimens was reduced (measured mean temperature from 10°C to 40°C), by some samples occurred at a temperature higher than 20 °C to subsequently increase in thermal conductivity. This behavior depends on the type of fibers and the bulk density of the insulations.

VIPs were produced from mixture C in company TURVAC in Slovenia. There have been observed key parameters such as shrinking rates, aging problematic, production process parameters. It can be concluded, that organic fibrous insulations are a suitable and interesting alternative to glass wool insulations. From a technological point of view, the rate of shrinkage after vacuum process depends on the initial bulk density. It has been found, that from a technological point of view, it is necessary to tune the drying process in a suitable way for this type of material, for two main reasons:

- During the drying process it is necessary to remove all bound moisture, so it is necessary to adjust the temperature and drying time
- By using a higher temperature, it has been found that activation of the bicomponent fiber wrapper with increased temperature results in better orientation of the fibers during vacuuming and to obtain a better (smoother) VIP surface.

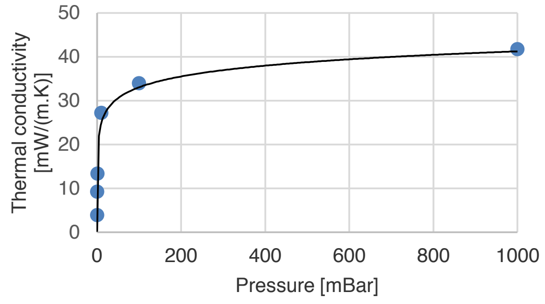

Fig. 2
Dependence of thermal conductivity on pressure (test sample B-III)

Acknowledgements

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References
[1] Directive 2010/31/EU of the European Parliament, Official Journal of the European Union (2010)
[2] S. Brunner, K. G. Wakili, T. Stahl, B. Binder, Vacuum insulation panels for building applications - Continuous challenges and developments, Energy and Buildings 85 (2014) 592-596
[3] V. Nemanic, M. Žumer, New organic fiber-based core material for vacuum thermal insulation, Energy end Buildings 90 (2015) 137-141
[4] J. Zach, J. Hroudova, V. Novak, Examination of Thermal Technical Properties of Organic Based Fibre Insulation Core Materials under Low Pressure. IVIS 2015 Proceedings of 12th International Vacuum Insulation Symposium (2015) 90-94
[5] R. Caps, H. Beyrichen, D. Kraus, S. Weismann, Quality control of vacuum insulation panels: Methods of measuring gas pressure, Vacuum 82 (2008) 691- 699

POSTER 25

Evaluating the impact of the edge thermal bridging on the overall thermal performance of vacuum insulation panel (VIP) assemblies

J. L. Castro Aguilar[a*]
J. Kośny[a]
N. Shukla[a]

[a] Fraunhofer USA - Center for Sustainable Energy Systems CSE, Boston, MA, USA
* Corresponding author:
Tel. +1 617 379 5707
jose@ecotecnics.com

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COMSOL.

Abstract

Vacuum insulation panels (VIPs) have a very low thermal conductivity, around 10 times lower than conventional thermal insulation materials. Typically, VIP comprises of a core material that is packaged by a barrier film with thermal conductivity 2-3 order of magnitude higher than the core. However, connections between VIPs can produce severe thermal bridging affecting the overall insulation thermal performance. COMSOL Multiphysics, a 3D heat transfer simulation program is used to calculate the total insulation value (R-value), including an impact of connections between VIPs. Different barrier films, the VIP edge quality, and connection configurations are considered. Our goal is to pinpoint the impact of the thickness and conductivity of the barrier film as well as the level of straightness at the edge, which helps in avoiding the air gaps between VIPs. To examine the effects of thickness and edges on the overall heat transfer, thermal performance of several VIP and VIP edge assemblies with varying geometry and materials is measured. A systematic analysis of the contribution of various design parameters is presented including the sensitivity of the assembly R-value: thickness, thermal conductivity and number of layers of the barrier film at the edge; connection type and air gap between VIPs.

Introduction

As shown in Figure 1, a connection between two VIPs can generate a notable thermal bridge effect, because thermal conductivity of the VIP edge materials is significantly higher than the VIP core. The infrared image of the building insulated with VIPs shows significantly different temperatures in places of VIP connections [1].

Fig. 1
Infrared imaging of a house insulated with VIPs. First wall retrofit with VIPs in the U.S.A.

COMSOL Multiphysics is used to analyze the heat transfer through a VIP core and through VIPs considering only one edge assembly (butt connection between two VIPs). Two sizes of the VIP are analyzed, thickness is 0.02 m. The thermal conductivity (k) of the VIP core, aluminum (Al) foil and stainless steel foil is considered to be 0.004 W/m·K, 225 and 25 W/m·K, respectively. Metallized film consists of 3 layers: HDPE (50 µm thick, k=0.32 W/m·K), PET (40 µm thick, k=0.24 W/m·K) and Aluminum (10 µm thick, k=200 W/m·K) [2-3]. The boundary conditions are as follows: outside temperature = -10°C and inside temperature = 20°C.

Heat transfer through VIPs considering only one edge assembly between two VIPs

Table 1 shows the results considering only one edge assembly between two VIPs. Several configurations are considered: different VIP sizes and VIP edge thicknesses/materials (in one edge assembly). Air gaps and expanded polystyrene (EPS) at the exterior, interior and edge are also considered.

Tab. 1
R-value and effective R-value % reduction for the butt connection between two VIPs

Configuration	R-value ($m^2 \cdot K/W$)	Effective R-value % reduction
VIP Core	5.15	-
VIP Core + EPS (Ext/Int)	5.78	-
VIP SIZE 1: 0.91 m (length) * 0.61 m (height)		
1a) Aluminum 8um	4.70	8.82%
1b) Aluminum 20 µm	4.63	10.03%
2a) Stainless steel 50 µm	4.73	8.19%
2b) Stainless steel 200 µm	4.61	10.51%
3a) PET 90 µm + Al 10 µm	4.68	9.20%
3b) PET 80 µm + Al 20 µm	4.63	10.12%
3c) PET 90 µm + Al 10 µm + AirGap 1mm	4.62	10.27%
4a) Metallized film	4.68	9.21%
1c) EPS + Al 20 µm	5.43	6.04%
VIP SIZE 2: 0.1524 m (length) * 0.3048 m (height)		
Metallized film + air 0 mm	4.16	19.14%
Metallized film + air 0.5 mm	4.02	22.04%
Metallized film + air 1 mm	3.88	24.57%
Metallized film + air 2 mm	3.69	28.33%
Aluminum 100 µm	4.25	17.53%
EPS (Ext/Int/Edge)	4.34	24.95%
EPS (Ext/Int/Edge) + (Aluminum 100 µm)	3.65	36.85%

Effective R-value % reduction depends also on the length of the edge and VIP area, higher effective R-value % reduction is found in the second VIP size compared to the first VIP size. A layer of EPS (0.0127 m thick, k=0.04 W/m·K) was added at the exterior/interior and to each VIP edge. R-value is increased when EPS is added at the exterior and interior, however if EPS is added to the edge of the VIP as well. In this case, a local thermal bridge is created decreasing the overall R-value. Effective R-value % reduction in all cases with EPS are compared to the case VIP Core + EPS at the exterior/interior (5.78 $m^2 \cdot K/W$). The impact of thermal bridges in VIPs with other layers of building materials should also be considered. In configuration 1c, with EPS, effective R-value reduction is lower than configuration 1b. Only VIP edges in one edge assembly between VIPs were considered in this section. Figure 2 shows temperatures of the configuration 1b using COMSOL heat transfer simulations.

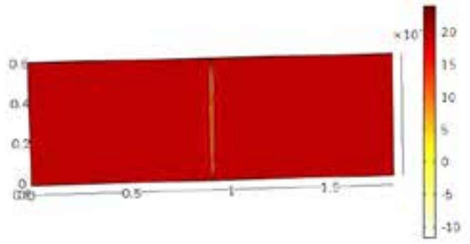

Fig. 2
VIP configuration 1b showing different temperatures in COMSOL heat transfer simulations

Heat transfer through a Wall with 15 VIPs

Wall with 15 VIPs of size 1 was analyzed for the following configurations: VIP core); 1a) Aluminum foil 8 µm; 2b) stainless steel foil 200 µm; 2b) with a layer of gypsum board (0.02 m thick, k=0.16 W/m·K) inside and brick (0.2 m thick, k=0.5 W/m·K) outside; 2b) with EPS inside and outside. Table 2 shows the results.

Configuration	R-value ($m^2 \cdot K/W$)		R-value % reduction	
	2 VIP	Wall	2 VIP	Wall
VIP Core	5.15		-	
Brick/Gypsum	5.68		-	
EPS (Ext/Int)	5.78		-	
1a) Al 8µm	4.70	3.21	8.8%	37.6%
2b) S. steel 200µm	4.61	2.83	10.5%	45.1%
Brick/Gypsum + S. steel 200µm		3.19		43.8%
EPS (Ext/Int) + S. steel 200µm		4.48		22.4%

Tab. 2
Comparison of R-value ($m^2 \cdot K/W$) and R-value % reduction between two VIPs and the wall

Because of the higher geometric representation of the VIP connections in the entire wall area, the overall R-value is highly reduced in the wall calculations in comparison with just two VIPs. R-value % reduction is still considerable in the wall with brick and gypsum. However, with EPS, R-value % reduction is half. As expected, thermal bridge effects in VIPs edge assemblies are reduced when they are covered with foam insulation. In this work, thermal analysis was only performed for the center of the wall. VIP edges at the top, bottom and sides of the wall were not considered in this study. Figure 3 shows temperatures of the wall with VIPs.

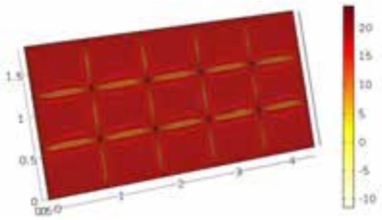

Fig. 3
Wall VIP configuration 2b showing different temperatures in COMSOL heat transfer simulations

Conclusions

A reduction of R-value caused VIP edges compared to the VIP's center area is a function of the VIP size and its geometry. It is between 8.19% and 10.51% for size 1 and between 17.53% and 28.33% for size 2. However, in the case of wall containing 15 VIP panels of the size 1, R-value was reduced between 37.6% and 45.1% for the edge configurations which were analyzed. When a layer of insulation is added to the interior and exterior surfaces, the nominal R-value is reduced only by 22.4% (instead 45.1% - as in the VIP case without the foam). Furthermore, in the analogic wall case with a layer of gypsum board installed on the interior surface and a brick outside finish, the nominal R-value was reduced by 43.8% if the VIP edge thermal bridging was considered. This work shows that due to significant impact of thermal shorts, a detail VIP edge performance analysis can be very helpful in thermal load calculations in the case of the VIP whole building applications.

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References
[1] J. Kośny et al. ASHRAE Transactions (2014)
[2] M. Tenpierik, H. Cauberg. Journal of Building Physics (2007) 185-215
[3] IEA Annex 39, Subtask A, H. Simmler et al. 2005

POSTER 26

Experimental investigation of the thermal and hygrothermal performance of a lightweight envelope incorporating Vacuum Insulation Panels (VIPs)

I. Atsonios[a*]
I. Mandilaras[a]
D. Kontogeorgos[a]
M. Founti[a]

[a] National Technical University of Athens,
School of Mechanical Engineering,
Lab. of Heterogeneous Mixtures and
Combustion Systems, Heroon Polytechniou 9,
15780 Zografou, Greece
* Corresponding author:
Tel. 030 2107722314
atsoniosgiannis@central.ntua.gr

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Vacuum insulation panels,
monitoring,
thermal bridges,
humidity transfer,
experimental study.

Abstract

In the present study, a lightweight metal frame drywall building envelope insulated with VIPs is experimentally investigated. Temperature, humidity and heat flux monitoring observations at several locations of the envelope, obtained over a period of one year, are presented and analyzed. The building, located in Switzerland, was unoccupied for the whole measuring period and the indoor temperature was maintained stable during the winter months The measurements showed that the VIPs reduce the thermal transmittance of the central part of the wall by ca 50%, as well as the impact of thermal bridges due to metal studs and junction between the elements of the building envelope. Additionally, the VIPs prevent the transfer of humidity through the layers of the envelope.

Introduction

Current construction challenges require advanced building envelopes combining high thermal performance with easy and fast implement, seismic resistance and recyclability of wastes. In an effort to meet this need, lightweight steel framed building systems coupled with Vacuum Insulation Panels (VIPs) form an attractive solution.

Lightweight buildings have become more and more widespread due to their advantages [1]. The major challenge for the enhancement of these buildings regarding their thermal behavior is the strong impact of thermal bridges due to the metal frame. An effective way to address this challenge is the installation of additional insulation.

VIPs are innovative insulation components with very low thermal conductivity. Several experimental studies [2] have been carried out regarding the thermal and hygrothermal properties of VIP.

In this study, a lightweight steel framed building envelope incorporated VIPs is monitored for a whole year aiming to assess the thermal and hygrothermal behavior of the envelope. The contribution of VIPs on the thermal performance and the thermal bridges of the wall are investigated.

Test site, construction and materials

The test site is located at Laupersdorf in Switzerland. It is a mock-up building constructed by dry-wall materials and lightweight steel framed structure (Fig 1). The construction methodology follows the same rules applied to real scale houses of this type. The wall is insulated by two layers of mineral wool (λ=0.035 W/m•K) and one layer of VIP (thermal conductivity at the center of panel, λ_{cop}=0.004 W/m•K) (Fig 1). The effective thermal conductivity of the VIPs (taking into account thermal bridges at the joints) was estimated with the procedure described by Ghazi Wakili et al [3]. Only one of the junctions between the adjacent walls was not well insulated with VIPs due to construction irregularities (Fig 2).

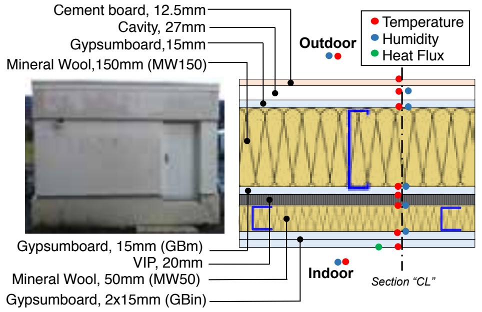

Fig. 1
The mock-up building and the measuring locations shown at a section of the wall

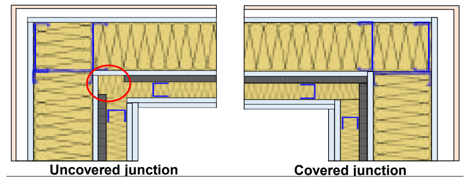

Fig. 2
Proper insulation (right) and construction irregularity (left)

Theoretical calculations and experimental methodology/equipment

The thermal properties of the materials used for the construction of the walls was either measured by a guarded hot plate apparatus or provided from manufacturer's tables. The U-value at the central part of the wall was theoretically calculated according to ISO 10211 using numerical simulations (COMSOL) taking into account the thermal bridges caused by the metal studs. For the in-situ measurement of the thermal transmittance the Average method described in ISO 9869 was used. For the monitoring of the building envelope, temperature, humidity and heat flux sensors were installed at several locations, as well as a data acquisition system that was utilized for the collection of data. Infrared thermographic captures were taken using an infrared camera.

Results and discussions

Table 1 presents the theoretical and experimental Uvalues for the wall including the effect of metal studs.

	Theoretical	Experimental
U-value [W/(m^2·K)]	0.1105	0.1169 (6%)

Tab. 1
Theoretical and experimental U-value

The experimental U-value is in a good agreement with the theoretical, providing a difference ca. 6%. Further numerical investigation of the wall indicated that the theoretical U-value of the wall without the layer of VIP is 0.2467 W/(m^2•K). So, the VIP layer reduces the Uvalue at the center of the wall by 53%. The contribution of insulation materials at the resulting temperature difference of the wall is presented in Fig 3. The results are referred to the section "CL" (Fig 1) where the lowest influence of metal studs is presented. The VIP layer causes the 52% of the total temperature difference, while the 150 mm and 50 mm thickness mineral wool is caused ca.33%, and 10%, respectively. The other materials cause the rest 5%. The results are in agreement with the simulations in steady state conditions. The effect of the VIP at the junction between two walls is presented in Fig 4 using infrared thermography. The uncovered junction was colder by 1°C than the covered junction. Hence, the VIP layer reduce the impact of thermal bridge. A humidity test was carried out. Two humidifiers were turned on until the indoor relative humidity reached 45% for 8 hours. Fig 5 illustrates the Relative Humidity (RH) and the humidity ratio (w) at the interfaces between the layers of the wall. It is observed that the RH at the interfaces in front of the VIP is increased at the same time, while the RH behind the VIPs (MW150-GBm) is not influenced by the increase of the indoor humidity. At the same line, the humidity ratio in front of the VIP increases, while the humidity ratio behind the VIPs follows the outdoor ratio. Hence, the VIPs act as a barrier for the mass transfer. Moreover, an absence of condensation was observed at the surfaces of the VIPs during the whole measuring period.

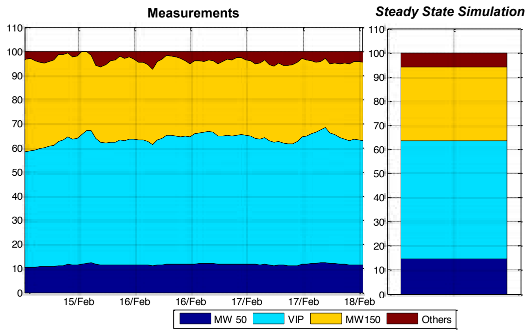

Fig. 3
The contribution of materials at the percentage temperature difference

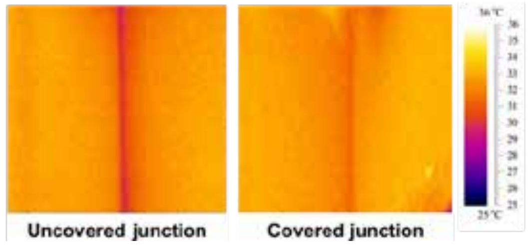

Fig. 4
Infrared thermography at the uncovered and covered by VIPs corners

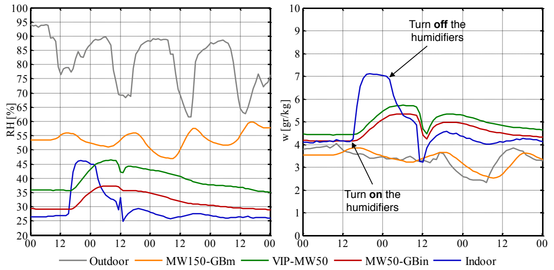

Fig. 5
TRH and humidity ratio between the layers of the wall during the humidity test

Conclusions and outlook

The extensive monitoring of the thermal and hygrothermal behavior the envelope revealed the degree of the thermal performance improvement. The VIPs are more effective than conventional insulation with 7.5 times larger thickness. Also, it is shown that the presence of VIP decreases the impact of thermal bridges at the junctions between the walls. Finally the humidity test revealed that the barrier of VIPs prevents the humidity transfer through the wall.

References
[1] N. Soares et al. Renewable and Sustainable Energy Reviews 78 (2017) 194-209
[2] M. Alam et al. Energy and Buildings 69 (2012) 442-450
[3] K. Ghazi Wakili et al. Energy and Buildings 43, (2011) 1241–1246

Thermal resistance measurement of VIP based envelope with an energy room method

D.M. Marquis*
A. Koenen
Y Garcia

Laboratoire national de métrologie et d'essais
(LNE), 29 Avenue Roger Hennequin,
78197 Trappes Cedex, France
* Corresponding author:
damien.marquis@lne.fr

Abstract

A test facility based on energy room was developed inside a climatic chamber, for evaluating thermal performance of insulating system at large scale. Five of the six faces of it have been highly insulated with vacuum insulation product to reduce the edge heat loss. The front panel was equipped with the representative sample to be studied. The measure principle is based on the guarded hot box method. The energy room has been calibrating with a well-known insulation material installed on the front wall. The experimental uncertainty associated has been estimated. The study present the results obtained on the VIP based envelop. Three methods are compared based on theoretical method, co-heating method, and the use of heat flow sensors on wall to determine the overall thermal resistance of the system.

Keywords:

Vacuum insulation panels,
coheating,
heat flux sensor,
Energy room method.

Introduction

The evaluation of thermal performance of envelope elements is one of the prerequisite for reaching the target of greenhouse gas emission defined during the last Paris climate conference (COP21).

From a theoretical point of view, it is possible to evaluate the thermal performance of the envelope of a building by calculating on conventional climate. These properties are determined from standard methods like heat flow meter (ISO 8301), guarded hot plate (ISO 8302) or guarded hot box (ISO 8990). However, based on the performances of individual elements, the values derived from the normative calculation may sometimes be very different from those observed in actual operating situations [1]. Furthermore, the theoretical calculations assume that measurements are performed on "ideal" wall under condition perfectly controlled. At large scale, the thermal performance of a building envelope can be measured by different approaches:

> The "energy-consuming approach" or "co-heating", is to achieve a simple energy balance within a building [1]

> The infrared thermography is a widely used method. It's a non-intrusive and exhibiting high spatial and thermal resolutions method, largely used to detect defects. To determine the thermal performance of a building additional measurement are necessary.

> The third approach consists in instrumenting the walls with thermocouples and heat flow sensors. This type of method is more expensive and requires more instrumentation. The test method is described in ISO 9869-1.

A need exist to have methods to determine the thermal performance of building with associated uncertainty. In this context, test facility based on energy room is developed at LNE to evaluate the thermal performance of envelope in large scale. The energy room has been calibrated with a well-known insulation material. The experimental uncertainty associated has been determined.

The study present the results obtained on Vacuum Insulated Panels (VIP) based envelop. Three methods are compared based on theoretical method, co-heating method, and the use of heat flow sensors to determine the overall thermal resistance of the system.

Laboratory apparatus and test method

The LNE has developed an energy room inside a climatic chamber, for evaluating thermal performance of insulating system at large scale. This test facility called 'REBECCA (Research and Testing of Buildings and Heat Emitters under Artificial Climate) has been specially built to reproduce the characteristic of a guarded hot box described in the standard ISO 8990. The facility is composed of an internal cell (energy room) with the dimensions of a dwelling (3.8 m of side on 2.6 m high) surrounded by 4 air-conditioning enclosures (front cell, guard, floor and ceiling) regulated independently, in which it is possible to modify the temperature between -7°C and 35°C and to generate any type of transient regime (hot cold, cycle, etc.).

This test room was dimensioned by numerical modelling using COMSOL multiphysics V5.2. Five of the six faces of it have been highly insulated (Rwall > 10 m².K.W^{-1}) with VIP to reduce the edge heat loss. The front panel was equipped with the representative sample to be studied. The test specimen is a wall element of 7.1 m², which separates two large rooms kept at controlled temperature. Thermal guards and test rooms are regulated at the same temperature.

The principle involves exposing the test specimen to a temperature gradient and measuring the total heat flow density which passes through it as a function of the temperature difference. Knowing the internal and external surface temperatures, $T_{s,i}$ and $T_{s,e}$, the thermal resistance of the wall will be given by:

$$R_p = S\frac{T_{s,e}-T_{s,i}}{\phi} \qquad (1)$$

In our case the heat flow will be determined by two methods. The first method, referred to hereafter as "energy consumption" is typically a "co-heating" method. The method measures the energy consumption necessary to maintain a constant difference of temperature between the inside and the outside of the test cell. The heat flow going through the walls under test is then equal to the power released by the heating device. The second method, hereafter referred to as a "flowmeter method", uses specific sensors to measure locally a heat flow density which passes through the wall. Then, these two methods will be compared to evaluate their reliability. Results are compared to numerical prediction performed with COMSOL multiphysics V5.2. The test is carried out under steady state condition which occurs after a long period of time (several day). As soon as the thermal equilibrium is reached, it is then possible to determine the performance of the wall. The energy room was highly instrumented to measure the heat losses. The positions of sensor on the test specimen are reported on the Fig 1. The position was defined to observe local variation of thermal resistance.

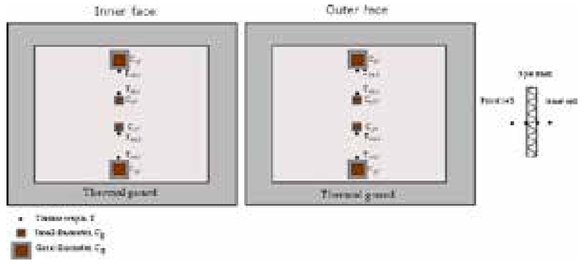

Fig. 1
Position of heat flow sensor on test specimen

The test sample is composed by a VIP sample (15 mm thick) between two plaster boards (10 mm thick).

The total thermal resistance of the test sample is evaluated at (3.81 ± 0.38) m².K/W. This value is based on guard hot plate measurement of each element which constitutes the envelope and calculation. It does not consider the intrinsic thermal bridge.

Results and discussions

This section present the results obtained by different method on VIP based envelop (see table 1). In considering experimental uncertainties, the methods give highly dispersed results.

ΔT_a [°C]	Global thermal resistance R_p [m².K/W]			
	GHP + Calculation	Flowmeter inner position	Flowmeter outer position	Co heating
10.2	3.81 ± 0.38	3.57±0.88	3.14±0.57	2.48 ± 0.63
15.2	3.81 ± 0.38	3.73±0.72	2.96±0.56	2.41 ± 0.44
20.2	3.81 ± 0.38	3.66±0.62	3.07±0.66	2.38 ± 0.36

Tab. 1
Global thermal resistances of VIP based envelope obtained from different methods

For heterogeneous structure with VIP, the global thermal resistance obtained by the flowmeter method is strongly dependent of the sensors position (inner or outer). When the sensor is positioned on a thermal bridge, the value is significantly reduced. Moreover, this type of method can hardly detect the deterioration of the thermal performance of VIP without the prior use of an infrared camera for detecting thermal bridges.

Conversely, the energy consumption method is perfectly adapted to take into account the degradation of PIV performance. It now appears as a reference method for accurately estimating the thermal performance of a heterogeneous structure with vacuum panels. The methods show that internal thermal bridges reduce significantly the thermal performance of VIP. Finally, the IR thermovision control (Fig. 2) has revealing defects (drilled panel) of the VIP based buildings envelopes which explain the value obtained by the co heating method.

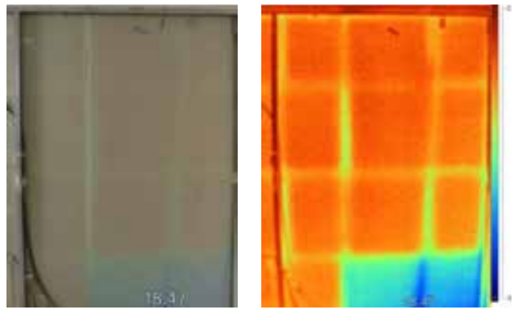

Fig. 2
Defects of VIP based envelop observed by IR thermovision

Conclusions and outlook

The thermal performance of a VIP envelope were evaluated at large scale in an energy room Different method use give highly dispersed results. Finally the energy consumption method appears as the re reference method to measure the thermal performance of heterogeneous envelope with intrinsic thermal bridge like the VIP envelope.

References
[1] S. Doran, Fields investigations of the thermal performance of construction elements as built, November 2000, Report BRE n° 78132, http://projects.bre.co.uk/uvalues/U-values.pdf

POSTER 28

Prediction on Long-term Thermal Performance of Vacuum Insulation Panels (VIP) using Glass Fiber Core Considering Differences in Hygrothermal Environment and Size of VIP and Influence of Desiccant

D. Ogura[a*]
A. Iwamae[b]
T. Tasaka[c]
K. Mabuchi[c]
Y. Senda[c]
K. Kugimiya[d]

[a] Department of Architecture and Architectural Engineering, Kyoto University, Kyoto, JAPAN
[b] Faculty of Architecture, Kindai University, Osaka, JAPAN
[c] Japan Testing Center for Construction Materials, Saitama, JAPAN
[d] Panasonic corporation, Eco Solutions Company, Osaka, JAPAN
* Corresponding author:
Tel. +81 75 383 2918
ogurad@archi.kyoto-u.ac.jp

Abstract

Various studies have been made on methods for predicting the long-term performance of VIP of silica core material. However, regarding the permeation of air at the edges of the film or the film itself of VIP of the glass fiber core material as well as size of VIP, the model considering desiccant and adsorbent are not sufficiently clarified. In order to establish a long-term performance prediction method of VIP for glass fiber core material, several aging tests were carried out, and prediction of thermal conductivity change considering the influence of temperature by Arrhenius plot of dry air permeability and conversion of a size was investigated based on the existing prediction model.

Keywords:

Long term thermal performance,
Glass fiber core material,
Arrhenius plot.

Introduction

Various studies[1)] on the long-term performance prediction method of VIP of silica core material have been investigated, but the long-term performance prediction of VIP of fiber core material has not been considered sufficiently. In this core material, it is essential to properly design the capacity of the desiccant so that it can sufficiently adsorb the permeated water vapor, and the prediction of the permeation amount of the dry air is important in the change of the thermal performance. For the purpose of establishing a long-term performance prediction method of VIP of the fiber core material, we showed a prediction model that can take into consideration differences in environmental conditions and sizes, and analyzed based on the accelerated test results.

Aging model which is widely used

Thermal conductivity

Parallel model is widely used to predict the thermal conductivity. Heat transfer of core material can be considered as the conduction through solid and gas in case of its presence and radiation. The three modes should be considered simultaneously:

$$\lambda_{cop} = \lambda_s + \lambda_g + \lambda_r \qquad (1)$$

Note that symbols are explaind at the end of the paper. Thermal conductivity with desiccant of VIPs expressed :

$$\lambda_{cop} = \lambda_{sr} + \lambda_{g(Pa,T)} \qquad (2)$$

Permeability of dry air

Dry air pressure change is shown using the following mass balance equation of permeation of dry air and ideal gas equation.

$$\frac{dm_a}{dt} = \frac{M_a \cdot V_{eff}}{R \cdot T} \cdot \frac{dP_a}{dt} = K_{a,total} \cdot (P_{a,atm} - P_a) \qquad (3)$$

$$\mathrm{P}_a = \mathrm{P}_{a,atm} - \left(\mathrm{P}_{a,atm} - \mathrm{P}_{\mathrm{a(0)}}\right)\exp\left(-\frac{\mathrm{K_{a,total}RT}}{\mathrm{M}_a V_{eff}}\mathrm{t}\right) \qquad (4)$$

$$\frac{dP_a}{dt} = P_a^{'} \cong \left(P_{a,atm} - P_{a(0)}\right)\frac{K_{a,total}RT}{M_a V_{eff}} \qquad (5)$$

$$\mathrm{P}_a(\mathrm{t}) \cong \mathrm{P}_a(0) + P_a' t \qquad (6)$$

Where $k_{a,total}$ is

$$K_{a,total} = K_{a,A} \cdot A + K_{a,L} \cdot L + K_{a,p} \cdot A \qquad (7)$$

Relationship between thermal conductivity and internal pressure of dry air

The relationship between the internal pressure of dry air and thermal conductivity is approximately expressed by the following equation.

$$\lambda_{cop} = \lambda_{sr} + \lambda_{ga} = \lambda_{sr} + \frac{\lambda_{ga,0}}{1+\frac{P_{1/2}}{P_a}} \qquad (8)$$

The change of time of the thermal conductivity of VIP is obtained by equation (6) and the equation(8).

Prediction of long term thermal conductivity under certain environmental conditions

Long term prediction of thermal conductivity is possible under constant conditions if relationship between internal pressure and thermal conductivity, and $P_{a(0)}$ and P'_a under constant environmental conditions are obtained. In the following, we will examine the conversion method to obtain the value of P'_a under a given condition using the results obtained under the reference environmental conditions. We also examined the difference in size.

Prediction under different environmental conditions

Under different temperatures and dry condition, dry air transmittance is obtained for VIP of the same size, and an Arrhenius plot for an arbitrary temperature condition is obtained. Also, dependence on relative humidity is separately determined and multiplied by the Arrhenius plot of temperature to examine the dependence on temperature and humidity. Based on the internal pressure rise $P'_{a(Tref,Href)}$ in the case of the reference temperature and humidity conditions T_{ref} °C., H_{ref}% R.H., The internal pressure rise $P'_{a(T,H)}$ in the case of arbitrary temperature and humidity conditions T °C., H% R.H. is,

$$P'_{a(T,H)} = P'_{a(T_{ref},H_{ref})} \cdot \frac{K_{a,total(T,H)}}{K_{a,total(T_{ref},H_{ref})}} \qquad (9)$$

Prediction under different size of VIP

(a) VIP using aluminum foils (ALF)

Assuming that all the permeation of air can be regarded as only the edge of film, dry air permeability is,

$$K_{a,total} = K_{a,L} \cdot L. \qquad (10)$$

Based on the internal pressure rise in the case of the reference of the edge length Lref, the increase in internal pressure in the case where the length of an arbitrary edge of film is L is obtained by the following expression.

$$P'_{a(L)} = P'_{a(L_{ref})} \cdot \frac{V_{eff(ref)}}{V_{eff}} \cdot \frac{L}{L_{ref}} \qquad (11)$$

(b) VIP using aluminum coated multilayer foils (MF)

In consideration of permeation of air from the covering material in addition to ignoring the defective pinhole,

$$K_{a,total} = K_{a,A} \cdot A + K_{a,L} \cdot L \qquad (12)$$

Note that $K_{a,A}$ and $K_{a,L}$ are obtained separately from measurements. Based on the rise in internal pressure in the case of the reference area A_{ref} and the reference egde length L_{std}, the increase in internal pressure in the case of arbitrary area A and edge length L is obtained as follows.

$$P'_{a(A,L)} = P'_{a(A_{ref},L_{ref})} \cdot \frac{V_{eff(ref)}}{V_{eff}} \frac{K_{a,total(A,L)}}{K_{a,total(A_{ref},L_{ref})}} \qquad (13)$$

Results and discussions

We measured the aging of thermal conductivity of VIP using glass fiber core material and aluminum foils for a ceratin size under several environmental conditions. Figure 1 shows the dry air permeability of VIP with respect to temperature change and Allenius plot. The plot agrees well with the measured value under dry conditions. Figure 2 shows the calculated results by the model using this plot and measured results of the thermal conductivity under 23°C and 50 %R.H. The calucutated results agree well with the measured results. Figure 3 shows the calculated results by the model using eq. (14) under 50°C and 70 %R.H. The reference size is 0.2 m X 0.3 m X 0.015 m and the calculated size is 0.3 m X 0.5 m X 0.015 m. The calculated results agree will with the measured results.

Conclusions and outlook

We showed a prediction model for aging of thermal conductivity considering differences in environmental conditions and sizes. The calculated results compared with the measured results under the aging tests under constant environmental conditions. The calculation results using the model agree well with the measured results. In the presentation, we will show the results of the validity of the model for VIP using aluminum coated multilayers foils and the aging model of the VIP with absorbent as well as the results in the paper.

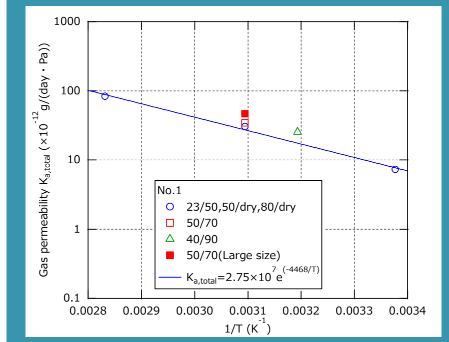

Fig. 1
Dry air transmittance of VIP

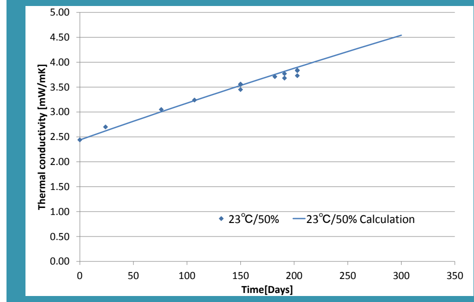

Fig. 2
Thermal coductivity

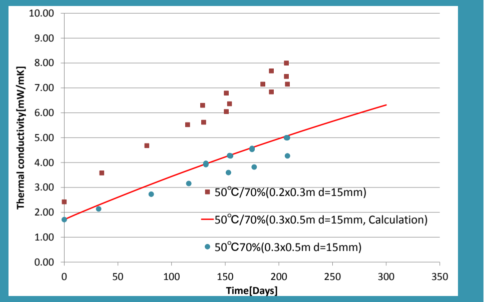

Fig. 3
Thermal coductivity

Symbol

λ_{cop}	thermal conductivity for center of panels [W/mK]
λ_s	solid thermal conductivity [W/mK]
λ_g	gaseous thermal conductivity [W/mK]
λ_r	radiative thermal conductivity [W/mK]
λ_{rs}	solid and radiative thermal conductivity [W/mK]
m_a	mass of inncoming dry air [kg]
M_a	molar weight of dry air [kg/mol]
V_{eff}	volume of VIPs[m^3]
R	gas constant[J/Kmol]
$P_{a,atm}$	dry air pressures of gases under atmospheric pressure [Pa]
P_a	dry air pressure inside the VIPs[Pa]
$K_{a,total}$	transmittance of the entire coating material of dry air [g / (day•Pa)]
$K_{a,A}$	transmittance per unit area of the film of dry air [g / (m^2•day•Pa)]
$K_{a,L}$	transmittance per unit length of the edge of the film of dry air [g / (m•day•Pa)]
$K_{a,p}$	transmittance of the defect of pin hole per unit area of the film of dry air [g / (m^2•day•Pa)]
L	length of the edge of VIP [m]
A	Surface area of the film [m^2]

Acknowledgements

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References
[1] IEA Annex 39, Subtask A, H. Simmler et al. 2005

POSTER 29

Commercial Aerogel Insulation Toolbox Wall-ACE, a H2020 project

Brice Fiorentino

ENERSENS, 15 avenue des frères Lumière,
38300 Bourgoin-Jallieu, FRANCE
* Corresponding author:
brice.fiorentino@enersens.fr

Keywords:

Silica aerogel,
coating,
plaster,
patching filler,
insulating bricks and external render,
refurbishment.

Abstract

Wall-ACE will develop a consistent package of new advanced sustainable insulation products and systems. The HONEST (High performance Optimized Nanomaterial Energy efficient SysTem) package is a "modular toolbox system" providing a set of complementary solutions that will address most of the complex challenges raised by thermal renovation as well as new construction.

Introduction

The Wall-ACE project, in which Enersens is a major partner, aims to accelerate the development and commercialization of several very high performance insulation solutions, particularly adapted to the renovation but also for the construction of new buildings. These solutions (coating, plaster, patching filler, insulating bricks and external render) are environmentally friendly and offer a wide range of possibilities to significantly improve the energy efficiency of buildings.

The approaches under investigation will be developed and then tested in real-life situations on demo-sites to prepare for their commercialization. At the same time, the Wall-ACE project will make valuable contributions to European standards and regulations.

Silica aerogel

Silicate aerogels are comprised of a very light amorphous silica structure; it contains more than 95% captured air in nanometre-sized pores. This air-filled structure provides the lowest thermal conductivity "λ" known to date for applications at ambient pressure.

The thermal conductivity of the core material is as low as 0.012 W/(m.K). Composite products made from silicate aerogels feature a lambda of between 0.014 and 0.027 W/(m.K) (compared with 0.039 W/(m.K) for mineral insulation materials like wood fiber and glass fiber).

This product will be used as an additive by 4 other industrials partners. They will develop 5 highly efficient insulation systems, usable internally and externally (Figure 1). The performance of the silica aerogel will provide those industrial products with the required insulation, noise reduction, breathability and sustainability properties. The materials are mineral based and will improve the durability of systems in terms of both use and performance, being inherently more 'stable' than the organic materials normally used in such situations. Where applied, the retrofitted materials will enhance building characteristics with regard to CO_2 emissions and grey energy.

Fig. 1
Schema of the 5 insulation products developed within the Wall-ACE project

High Efficient mineral indoor Insulation envelopes

Research and development from laboratory to industrial scale of new materials/systems will be undertaken to develop internal products containing new nano-technological solutions (aerogel). Specifically, the aim is to scale up materials for three types of different products:

- > Highly efficient internal insulating plaster, lightweight, premixed, ready to use, for the insulation of internal walls, to be used both in new buildings as well as in refurbishment of existing buildings (Vimark-Enersens);
- > An insulating thermal coating-finishing, lightened, premixed, ready to use for the correction of thermal bridges, the increase of insulation capacity of walls, the displacement of the point of surface condensation with consequent limitation in mould growth and improving living comfort (Vimark-Enersens);
- > Insulating interior patching filler with increased thermal insulating power, easy to apply and with improved properties, suitable for renovation, levelling and internal (Toupret- Enersens).

High Efficient mineral outdoor Insulation systems

To reduce energy losses from buildings, efforts have been made in recent years to improve the insulation behaviour of bricks, mortar and render. However, the integration of additives with excellent insulation properties in wall systems has often failed as a result of the high cost of the additives, which has rendered these systems uneconomic. With the help of these advanced materials, new high performance and cost-effective outdoor mineral insulation systems will be scaled up as follows:

- > Development of fire resistant and cost-effective insulation renders for outdoor applications with high mechanical resistance and excellent durability and resistance to climate influences, fungi and bacteria. The thermal conductivity of the insulating render will be less than or equal to 0.03 W/(m.K) (Quick-mix-Enersens).
- > Production of an economic and sustainable charge mortar with thermal conductivity of less than or equal to 0.02 W/(m.K) by the integration of appropriate amounts of high-performance mineral insulation materials (Quick-mix-Enersens).
- > Production of cost efficient insulation material filled wall bricks with a low thermal conductivity of less than or equal to 0.06 W/(m.K). Leipfinger-Bader will achieve this goal by making an appropriate choice of hole pattern of the outdoor wall bricks selected, which will be a balance of sophisticated brick bridges on the one hand and compressive strength on the other hand. These novel designed bricks will be filled with mineral based insulation materials in pure form and / or combined with a mineral based binder system as described above (Leipfinger-Bader, Quick-mix-Enersens).

Demonstration building

The different prototypes developed will be tested at a laboratory scale in order to validate their properties under different conditions. Experiments will be carried out at CEA-INES on the laboratory test facility "FACT", at the Politecnico di Torino on the BETcell climatic chamber and on EOTA test walls at University of Stuttgart (USTUTT).

The tests will focus on two main aspects: on one hand the application of the developed products (provided by the industrial companies) will be used to highlight potentials and barriers when installed in real buildings and, on the other hand, an extensive analysis on the building stock owned/managed by the involved partners (ATC, CASE, Agitech, BRE) will allow to assess the replicability of these interventions and the expected impact on the market.

Results generalization, scalability, and replicability evaluation will be carried out (BRE, Polito, CEA, USTUTT, Effin'Art), through the use of existing simulation models amended to reflect the subsequent measured changes in wall U-values and impact on the whole-building energy performance. Guidelines on design and installation will be provided in order to help the owners or builders to install, to use, to maintain and to evaluate the pay-back time and cost.

Conclusions and outlook

The Wall-ACE Project objective is to significantly increase the technology level available to the building industry and provide added value sustainable insulation solutions.

This project will develop a consistent package of new advanced insulation products and systems which will be instrumental in meeting the demands and requirements of the Energy Performance set by the Building Directive (2010/31/EU). Such innovative systems will strengthen the competitiveness of Europe through innovation and excellence.

Acknowledgements

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Consortium partners: Enersens, Quick-Mix, Vimark, TouPret, Leipfinger-Bader, Agitec, Effin'art, CEA, USTUTT, Politecnico di Torino, BRE, ATC and Wavestone.

POSTER 30

Vacuum Insulation Panels Express Tests Using FOX Heat Flow Meter Instruments

A. Tleoubaev[a*]
P. Scotto[b]

[a] TA Instruments – Waters LLC, 107 Audubon Rd, Building 1 Suite 40, Wakefield, Massachusetts 01880 USA
[b] TA Instruments – Waters LLC, 159 Lukens Drive, New Castle, Delaware 19720 USA
* Corresponding author:
Tel. +1-781-233-1717
atleoubaev@tainstruments.com

Keywords:

Vacuum insulation panels,
express test,
heat flow meter,
quality control,
thermal effusivity.

Abstract

Typically, testing vacuum insulation panels' (VIPs') thermal properties is a very time-consuming process. Now commercially available FOX Heat Flow Meter (HFM) instruments can be used for express tests of the VIPs. A VIP, which initially has room temperature, is placed on the FOX instrument's lower plate which is maintained at a constant temperature ~15°-20°C above or below the room temperature. The FOX instrument's plate has a sensitive heat flow meter, whose readings are being recorded. Using these readings and the temperature difference, thermal effusivity ε of the VIP (ε equals square root of thermal conductivity times specific heat and density) can be momentarily calculated, thus any defective VIP with poor thermal insulation performance can be quickly revealed and removed in ~30-60 seconds, or even less. This transient express test method will dramatically accelerate the vacuum insulation panels' quality control (QC) process. For more accurate thermal properties tests the FOX HFM instruments can be used in their regular manner – i.e. according to ASTM C1667, ASTM C518, ISO 8301, EN 12667, and EN 1946-3 Standards for thermal conductivity, and ASTM C1784 – for specific heat tests.

Introduction

A preliminary concept for this kind of express tests was presented earlier [1], and it is based on dynamics of the heat flux $q(t)$ [W/m^2] between a flat, thick enough (to be considered as an infinitely thick) sample with initial temperature T_1 , and an isothermal flat surface of constant temperature T_0 - immediately after their contact [2]:

$$q(t) = \varepsilon(T_1 - T_0)(\pi \cdot t)^{-1/2}$$

where

λ_g = thermal effusivity of the sample, equals square root of product of thermal conductivity γ and volumetric specific heat C_ρ.
π = 3.14159...
t = time after the moment of the contact

According to [3], time t_L required for the thermal layer (i.e. temperature disturbance) to reach the back surface of the flat sample of thickness L equals $L^2/(8a)$, where a is thermal diffusivity. I.e. in case of a 25 mm-thick good vacuum insulation panel with typical thermal diffusivity a≈4.3x10^{-8} m^2/s this limiting time t_L is about 30 minutes. And in case of the same bad (i.e. with no vacuum anymore) panel with typical thermal diffusivity a≈2.9x10^{-7} m^2/s, this limiting time is about 5 minutes, which still is more than enough for express tests to assume that the sample behaves as an infinitely thick one - i.e. according to the theory [2].

New express tests software

New modified version of the WinTherm32 software used by the FOX instruments now can calculate and display a flat thermal insulation sample's thermal effusivity as a real-time graph almost immediately - as it is shown on Fig.1 - after placing the panel on the instrument's lower plate.

We can see that after about 30-60 seconds the difference between good and bad VIPs becomes clearly visible, so bad panels can be quickly revealed and separated during a high volume quality control (QC) process, thus saving enormous amount of time. Temperature difference and time from the moment of the physical contact are used to calculate VIP's thermal effusivity. Transient heat flux is measured by the instrument's calibrated heat flow meter (lower plate's HFM). All FOX instruments are calibrated using IRMM-440 Certified Reference Material and NIST 1450d Standard Reference Material.

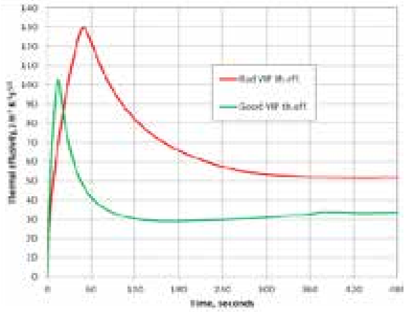

Fig. 1
Graphs of the calculated values of thermal effusivity ε (J m^{-2} K^{-1} s$^{-1/2}$) versus time t (in seconds) for good (green line) and bad (red line) VIPs

Express test procedure

It is assumed that the vacuum insulation panels initially have room temperature, so it should be entered before starting the express tests. Lower plate's temperature usually is entered as ~15°C-20°C higher or lower than room temperature.

Plate's opening is set at about its maximum – 50 mm for FOX200 instruments, 100 mm for FOX314, or FOX304, and 200 mm for FOX600 and FOX800. ASTM C1667-15 Standard recommends that size of VIP should be at least 3 times bigger than size of the heat flow meters (HFMs) to minimize influence of the edges heat flow, but transient tests are much less sensitive to the edge heat flows.

Length of the vacuum panels can be much longer than the instrument's plates because instrument's doors stay opened during the tests.

FOX instrument	Plates size	HFM size
FOX200	203x203mm (8"x8")	76x76mm (3"x3")
FOX314 or FOX304	305x305mm (12"x12")	102x102mm (4"x4")
FOX600L	610x610mm (24"x24")	305x305mm (12"x12")
FOX600	610x610mm (24"x24")	254x254mm (10"x10")
FOX800	762x762mm (30"x30")	305x305mm (12"x12")

Tab. 1
Dimensions of the FOX instruments' plates and their heat flow meters (HFMs)

As soon as the lower plate reaches its setpoint temperature, express tests can be started. VIP is placed on the lower plate, and after that moment the heat flow meter's signal is used to calculate and to display the panel's thermal effusivity using the formula shown above. Heat flux $q(t)$ equals the lower heat flow meter's calibration factor times its signal (small voltage). After the initially disturbed plate's temperature becomes stable again, the calculated value of thermal effusivity becomes stable to see after only 30-60 seconds if the panel is good or defective. Next panel can be tested almost immediately after removing the previous one, with no waiting time, which makes this express test method an extremely efficient and fast one.

Results and discussions

Several different types and sizes of the panels were successfully tried using different FOX instruments. Panels' surfaces should be reasonably flat, and the panels should not be too light – to create thermal contact with the instrument's lower plate.

Thermal effusivity values can be verified using the FOX instruments which can measure independently both thermal conductivity λ and volumetric specific heat C_ρ of the vacuum panels, or other thermal insulation materials.

Conclusions and outlook

This express tests capability makes our FOX instruments even more useful for the needs of the thermal insulation manufacturers and industry because it provides this new badly needed and reliable acceleration of the VIP quality control (QC) process.

Acknowledgements

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References
[1] A. Tleoubaev and A. Brzezinski, Dynamic Heat Flow Meter for Quick Thermal Properties Measurements Using Finite-Difference Method, – Presented at the 15th Symposium on Thermophysical Properties, Boulder, Colorado, 2003
[2] P. J. Schneider, Conduction Heat Transfer, – Addison-Wesley Publishing Co. Inc., Reading, Massachusetts, 1955
[3] W. C. Reynolds and T. A. Dolton, The Use of Integral Methods in Transient Heat Transfer Analysis, - Dept. of Mech. Engineering, Report No. 36, Stanford Univ., Stanford, California, Sept.1, 1958

POSTER 31

Regolith thermophysical properties in the insulating layer of moon structures

Aleksandr Lanko[a]
Daria Zaborova[a]
Tatiana Musorina[a]

[a] Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia
* Corresponding author:
a2102241@yandex.ru
zaborova-dasha@mail.ru
tamusorina@mail.ru

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thermal properties,
dome, insulation,
heat capacity,
wall thickness,
lunar design,
lunar construction.

Abstract

The article analyses thermo physical properties of the lunar soil (regolith) and the calculation of the wall thickness of the protective dome for comfortable habitat with physical and technical conditions on the surface of the moon. The article also describes a variant of the construction of lunar settlements using spatial dome, located at the bottom of the lava cave. Currently, many national space agencies of USA, Europe, Russia, Japan, China, India, planning to build long-term research stations on the moon. The analysis of possible methods of construction of various structures, as well as the solution of the problem of obtaining building materials from lunar soil (regolith) are very relevant. The article analyze data obtained during space missions and laboratory experiments. This analysis allows to calculate the necessary thickness of the protective layer. The domes appear to be the most relevant spatial design, as they can cover large areas with minimal number of materials. This property of the domes can be used to convert lava caves in the first lunar construction.

POSTER 32

Coupled heat, moisture and pollutants transport for simulating VOC emissions from building materials

Anh Dung Tran Le[a*]
Nadège Blond[b]
Coralie Schoemaecker[c]
Thierry Langlet[a]

[a] Laboratoire des Technologies Innovantes,EA 3899 – Université de Picardie Jules Verne, IUT Amiens, Avenue des Facultés – Le Bailly, 80025 Amiens Cedex 1, France
[b] Université de Strasbourg, CNRS, Laboratoire Image Ville Environnement (LIVE) UMR 7362, F-67000 Strasbourg, France
[c] Université de Lille 1, CNRS, Laboratoire de Physico-chimie des Processus de Combustion et de l'Atmosphère (PC2A) F-59655 Villeneuve d'Ascq, France
* Corresponding author: anh.dung.tran.le@u-picardie.fr

Keywords:

HMCOV model,
Indoor Air Quality,
heat and mass transfer,
Dynamic simulation.

Abstract

A coupled heat, moisture and pollutants transport model (HMCOV model) is presented in this paper for predicting the Volatile Organic Compounds (VOC) emissions from building materials. The physical model takes into account the effect of moisture and temperature on the pollutant emissions, which can be used to simulate VOC emissions from materials under real dynamic conditions. The model is implemented in the environment SPARK (Simulation Problem Analysis and Research Kernel) which is suited to complex problems using finite difference technique with an implicit scheme. The model is then validated by comparing the numerical results with the experimental ones found in the literature and a good agreement is obtained. The numerical model proposed can be use for a fast estimation of the hygrothermal comfort and pollutant levels in a room under dynamic conditions, which are very useful for the building design.

Introduction

Volatile organic compounds (VOC) level in building is one of the most important factors for evaluating the indoor air quality. To control indoor VOC level, it is necessary to know the VOC emission rates from building materials. Some studies show that the temperature and humidity could significantly affect VOC emission from materials [1;2]. Therefore, the main objective of this paper is to develop a new numerical model that allows determining the VOC emission under real dynamic conditions of temperature and humidity.

Coupled heat, moisture and pollutants transport model

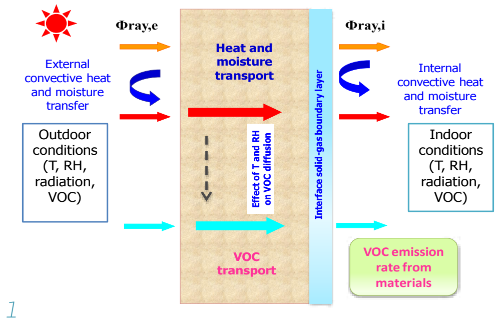

Fig. 1
Schematic of coupled heat, moisture and pollutants transport model in a wall

Mechanisms of moisture transport in a single porous building material have been extensively studied. In this article, the model that takes into account moisture (liquid and vapor phases) transport is used [3]. Forms of moisture transport depend on the pore structure as well as on the environmental conditions. The liquid phase is transported by capillarity whereas the vapor phase is due to the gradients of partial vapor pressure. With these considerations, the mass conservation equation becomes:

$$\frac{\partial \theta}{\partial t}=\frac{\partial}{\partial x}\left(D_T\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial x}\left(D_\theta\frac{\partial \theta}{\partial x}\right) \qquad (1)$$

Where θ is moisture content in the material (m³/m³), D_T D_θ are mass transport coefficients associated to a temperature and moisture content gradient. With the following boundary conditions respectively for the external (x=0) and internal (x=L) surfaces of the wall:

$$-\rho_l\left(D_T\frac{\partial T}{\partial x}+D_\theta\frac{\partial \theta}{\partial x}\right)\bigg|_{x=0,e}=h_{M,e}\left(\rho_{ve,a,e}-\rho_{ve,s,e}\right) \qquad (2)$$

$$-\rho_l\left(D_T\frac{\partial T}{\partial x}+D_\theta\frac{\partial \theta}{\partial x}\right)\bigg|_{x=L,i}=h_{M,i}\left(\rho_{ve,s,i}-\rho_{ve,a,i}\right) \qquad (3)$$

where the subscript a represent the adjacent air and s the solid surface of the material, while the subscripts e and i correspond respectively to the external and internal neighboring environment (a) or solid surface (s).

One dimension of the energy conservation equation with coupled temperature and moisture for a porous media is considered and the effect of the adsorption or desorption heat is added. This equation is written as:

$$\rho_0 Cp_m\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)+L_v\rho_l\left(\frac{\partial}{\partial x}\left(D_{T,v}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial x}\left(D_{\theta,v}\frac{\partial \theta}{\partial x}\right)\right)$$

(4)

where Cp_m is the average specific heat which takes into account the dry material specific heat and the contribution of the specific heat of liquid phase; λ is thermal conductivity depending on moisture content. More details about this model can be found in [4].

Concerning the pollutant transport model, for a dry material with homogeneous diffusivity the VOC mass transport within the wall can be described by the following equation:

$$\frac{\partial C_m}{\partial t}=\frac{\partial}{\partial x}\left(D_m\frac{\partial C_m}{\partial x}\right) \qquad (5)$$

Where C_m is VOC concentration in the material (mg/m³), D_m is diffusion coefficient of the VOC in the material (m²/s). Here the D_m is a function of temperature and relative humidity in the material which can be determined from equation 1 to 4 while the dependence of Dm on pollutants concentration is neglected as generally accepted because it is very small. At the material-air interface, we assume an instantaneous equilibrium between VOC concentration (mg/m³) in the air near material surface (C_{as}) and the one in the surface layer (C_{ms}):

$$C_{ms}=K.C_{as} \qquad (6)$$

Where K is the partition coefficient. With the following boundary conditions respectively for the external (x=0) and internal (x=L) surfaces of the wall:

$$-D_m\frac{\partial C_m}{\partial x}{}_{x=0,e}=h_{m,e}\left(C_{a,e}-C_{as,e}\right) \qquad (7)$$

$$-D_m\frac{\partial C_m}{\partial x}{}_{x=L,i}=h_{m,i}\left(C_{as,i}-C_{a,i}\right) \qquad (8)$$

Where $C_{a,i}$ and $C_{a,i}$e are concentration in the room air and outside (mg/m³), and $H_{m,e}$ and $H_{m,i}$ are convective mass transfer coefficients (m/s).

Numerical solution and model validation

The previous set of equations has been solved using the finite difference technique with an implicit scheme. The Simulation Problem Analysis and Research Kernel (SPARK), a simulation environment allowing to solve efficiently differential equation systems has been used to solve this set of equations.

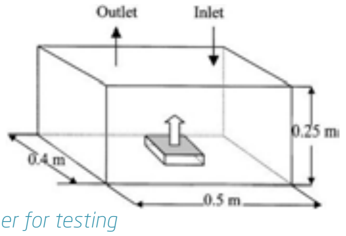

Fig. 2
Small scale chamber for testing

Concerning coupled heat and moisture model, it has been fully validated by Tran Le et al, 2009 [4]. In this section, the developed model tool for pollutant prediction will be validated using the experimental data of Yang et al, 2001 [5]. This one concerns a small test chamber (0.4*0.5*0.25 m³) with a pollutant emitting panel material inside as illustrated in Fig 2. The figures 3 and 4 compare the simulating VOC concentrations using data proposed by [4] for the tested case of PB2 (particle board). The results showed a very good agreement between the numerical model and experimental results after the few hours.

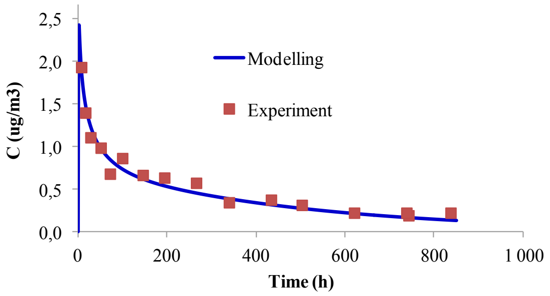

Fig. 3
Validating for VOC concentration (Hexanal) emitted from PB2

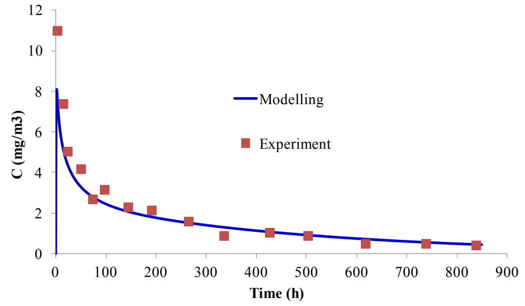

Fig. 4
Validating for VOC concentration (Pinene) emitted from PB2

Conclusions

In this article, a new numerical coupled heat, moisture and pollutants transport model is presented and validated for predicting the Volatile Organic Compounds (VOC) emissions from building materials under real dynamic conditions. The developed model takes into account the effect of moisture and temperature on the pollutant emissions. Therefore, this numerical model is very useful for the building design and can be used for estimating indoor pollutant levels in building under dynamic conditions of T and RH.

References
[1] Liang W., Lv M., Yang X. The combined effects of temperature and humidity on initial emittable formaldehyde concentration of a medium -density fiberboard. Building and Environment. 98: p. 80-88, 2016
[2] Blondeau, P., Tiffonnet, A.L., Allard F. Haghighat, Physically based modelling of the material and gaseous contaminant interactions in buildings: models, experimental data and future developments, Adv Build Energy Res, 2 (2008), pp. 57–93
[3] Philip J.R., De Vries., D.A. Moisture movement in porous materials under temperature gradients. Transaction of American Geophysical Union 1957; 38(2): 222-232
[4] Tran le A D., Maalouf C., Mendonça K C., Mai T H., Wurtz E. Study of moisture transfer in doubled-layered wall with imperfect thermal and hydraulic contact resistances. Journal of Building Performance Simulation 2009; 2: 251-266
[5] Yang X., Chen Q., Zhang J. S., Magee R., Zeng J., Shaw C. Y. Numerical simulation of VOC emissions from dry materials. Building and Environment. 36(10): p. 1099- 1107, 2001

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