UDK 620.1:677.494.674:621.315.6 ISSN 1580-2949
Original scientific article/Izvirni znanstveni članek MTAEC9, 53(4)511(2019)

POLYMER-MATRIX-BONDED POLYESTER FIBERS AS A SUBSTITUTE FOR MATERIALS USED FOR THE CORES OF VACUUM INSULATION PANELS

POLIESTRSKA VLAKNA, VEZANA V POLIMERNI MATRICI, KOT NADOMESTEK ZA MATERIALE, UPORABLJANE ZA JEDRA VAKUUMSKIH IZOLACIJSKIH PANELOV

Jiří Zach, Vítězslav Novák*

Brno University of Technology, Faculty of Civil Engineering, Admas Centre, Veveří 331/95, 602 00 Brno, Czech Republic

Prejem rokopisa – received: 2018-09-25; sprejem za objavo – accepted for publication: 2019-01-30

doi:10.17222/mit.2018.208

The paper discusses the use of alternative raw materials for the manufacturing of VIPs (vacuum insulation panels). VIPs are thermally insulating boards with a fibrous core at an extremely low pressure. The research is focused on substituting glass fibers with polyester fibers in VIP cores. Polyester fibers are thermally bonded using BiCo fibers, which, once they have cooled down, form the matrix of a composite VIP core. It is proved that polyester fibers bonded with BiCo fibers show great promise, most notably in terms of their excellent thermal-insulation properties, which they retain for a long time.

Keywords: vacuum insulation panels, polyester fibers, fibrous insulation materials, thermal conductivity

Avtorji razpravljajo o uporabi alternativnih surovin za izdelavo vakuumskih izolacijskih panelov (VIP). To so termične izolacijske plošče z jedrom iz vlaken pri ekstremno nizkem tlaku. Raziskava je bila osredotočena na zamenjavo steklenih vlaken s poliestrskimi vlakni v VIP jedrih. Poliestrska vlakna so med seboj termično vezali z BiCo vlakni, ki po ohladitvi tvorijo matrico kompozitnega VIP jedra. Avtorji so dokazali, da so poliestrska vlakna, vezana z BiCo vlakni, odlični in časovno stabilni toplotni izolatorji in so zaradi teh lastnosti iperspektiven material za panele.

Ključne besede: vakuumski izolacijski paneli, poliestrska vlakna, vlaknasti izolacijski materiali, toplotna prevodnost

1 INTRODUCTION

The development of advanced thermal-insulation materials is an important area, especially in the context of limiting the amount of energy consumed by buildings and reducing CO_2 emissions (see, e.g., the Kyoto Protocol). This relates mainly to the development of new thermal-insulation materials that improve the energy performance of buildings, meeting the constantly increasing requirements (in Europe regulated by Directive 2010/31/EU on the energy performance of buildings) without resorting to overly thick layers of thermal insulation in order to deliver the desired thermal resistance of the structure.

Current demands require seeking solutions among advanced and smart materials, i.e., the ones that combine several positive properties. Among thermal insulators, there have been, for a number of years, some interesting materials made of renewable raw materials and by-products. Some countries (e.g., in Northern Europe) are making an effort to use such materials as a replacement for mineral wool or expanded polystyrene. However, insulations made with renewable and secondary materials often suffer from poorer thermal-insulation properties when compared to the conventional ones, and are often sensitive to moisture.[1]

Research shows that secondary and renewable materials can be used to manufacture an advanced insulation system such as vacuum insulation panels (VIPs).[2] VIPs seal the insulation away from the outside environment, in an airtight envelope that eliminates the danger of moisture sensitivity. On the other hand, only some secondary and renewable materials can be used for VIPs because they need to meet certain limits of the particle size/fiber length and thickness, and need to be chemically pure enough to avoid low-pressure sublimation of unstable compounds (outgassing), which causes thermal-insulation properties to deteriorate after vacuum sealing.[3]

Research has found that fibers obtained by pulping waste textile produced by both textile manufacturing and recycling have very interesting properties and are, in most cases, well suited for use in various thermal- and acoustic-insulation materials. In addition, polymer fibers can be made into a matrix, suitable for VIPs.[4]

Experiments have shown that the limit thickness of glass-wool fibers, the dominant insulation used for VIPs today, is 10 μm. Thicker fibers are not good for VIPs because an insulation with thicker fibers will not be improved so much by vacuum sealing and, moreover, any

*Corresponding author's e-mail:
novak.v@fce.vutbr.cz

Table 1: Properties of cotton and PES fibers

Fibers	Cotton				PES							
Type	Primary		Secondary		Primary			Secondary				
Sample	1	2	1	2	1	2	3	1	2	3	4	5
Thickness [μm]	12.74	10.80	12.61	12.54	15.09	10.01	12.35	12.41	12.26	11.49	19.97	21.39
Length [mm]	26.60	26.10	22.40	23.50	47.30	85.60	72.60	49.20	35.50	48.91	61.15	76.20

slight pressure increase inside the insulation will cause a significant detriment to its properties.

2 FIBRE SPECIMENS AND THEIR PROPERTIES

During the research, we selected several suitable primary and secondary materials based on cotton and polyester. The goal was to find fibers with a high purity, low thickness and sufficient length so that they may be made into mats by thermal bonding using BiCo fibers, see **Figure 1**. The actual manufacturing was done with the air-lay method using standard PES fibers with a thickness of 15–20 μm.

We then microscopically examined these fibers to determine their length, thickness, and to study their shape. The following samples were selected for further tests, see **Table 1**.

VIPs require the use of the materials with the finest pore structure or the thinnest fibers.[2,3,5] The measurements show that pure cotton, depending on the type and the place of origin, can reach a thickness of up to 10 μm, which is why these fibers can be considered suitable for the VIP manufacturing. Recycled cotton fibers reach thickness values of 12–13 μm. Both recycled-cotton samples exhibited very similar fiber-thickness values. This is due to the fact that textile manufacturing selects cotton of carefully controlled quality. On the other hand, PES fibers are a little different; there are rather substantial differences between the thickness values of primary and secondary fibers. The primary fibers ranged from 10 μm to 15 μm, whereas the recycled fibers were between 11 μm and 21 μm. When using PES fibers for VIPs, it is therefore important to choose fibers carefully.

3 MANUFACTURING VIP-CORE SPECIMENS AND PREPARATION FOR VACUUM SEALING

The next stage of the research involved the manufacturing of test specimens from the samples of potentially suitable fibers (see above). The following fibers were used:

1 sample of cotton (Sample 2 – see above),

2 samples of recycled cotton (Samples 1 and 2 – see above),

2 samples of primary PES fibers (Samples 2 and 3 – see above),

2 samples of recycled PES fibers (Samples 2 and 3 – see above).

The samples were thermally bonded with an addition of 15 % of BiCo PES fibers (the air-lay method). With this process, we produced mats of 1200 mm × 600 mm, with the highest bulk density the method allowed. These mats were then cut into individual specimens (see below).

In VIPs, the insulation's purity is very important. Every insulation always contains some moisture, which is why it is important to thoroughly dry every core material before incorporating it into a panel. However, it is rather difficult to completely remove all the moisture from a material, which is why a separate part of this research was devoted to drying. While the insulation materials were being dried, they were also continually weighed. It appears that finding an optimum drying regime is not quite straightforward. VIP-core insulation cannot be dried at the standard 105 °C because this temperature does not remove all the bound H_2O and, thus, two negative effects may occur as a result:

1) Bound moisture is released during vacuum sealing, which markedly increases the costs and interferes with the production efficiency,
2) The moisture is released after the insulation is sealed, which increases the internal pressure and reduces thermal-insulation properties. This usually occurs very shortly after vacuum sealing.

These detrimental effects can be minimized by choosing the optimal drying time and temperature for every type of insulation. The above-described insulation materials and a reference glass-wool sample were being experimentally dried at several different temperatures, while weight changes were recorded at specific time intervals. The drying took place at temperatures of (105, 140, 160 and 180) °C at intervals within 0–60 h.

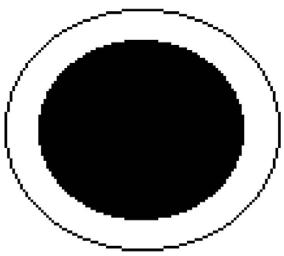

Figure 1: Diagram of a BiCo fiber cross-section

4 RESULTS

It was found that the release of moisture from all the materials depends on the temperature. The residual moisture content ranged within 0.1–2.5 % in all the

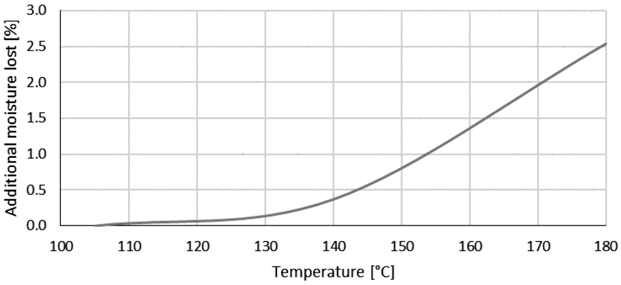

Figure 2: Residual moisture content depending on the temperature of recycled-cotton Sample no. 1

cases. Cotton samples had a higher moisture content than PES samples, see **Figure 2**. Drying at 105 °C was not sufficient for VIPs in any of the cases. Sufficient drying was achieved with temperatures of 160 °C or higher, see **Figure 3.** A suitable drying time appears to be 3–5 h depending on the temperature and type of insulation.

During the next step of the experiment, the mats were cut into specimens with dimensions of 200 mm × 200 mm. The following measurements were made: linear dimensions according to EN 822[6]/EN 12085[7], thickness according to EN 823,[8] and bulk density according to EN 1602.[9]

The specimens were also tested for thermal conductivity according to EN 12667[10] and ISO 8301[11] at the normal and reduced pressure (5 Pa) to assess their overall potential for use in VIPs, see **Table 2**. The

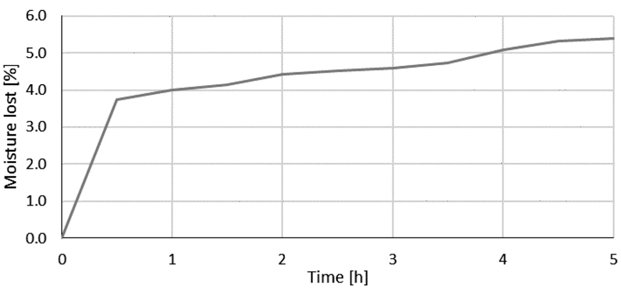

Figure 3: Moisture losses over time at a temperature of 180 °C for recycled-cotton Sample no. 1

Table 2: Values of thermal conductivity at normal pressure and at 5 Pa (vacuum)

Fibers	Type	Sample	Normal pressure	Vacuum
Cotton	Primary	1	0.03275	0.00333
Cotton	Primary	2	0.03112	0.00264
Cotton	Secondary	1	0.03558	0.00385
Cotton	Secondary	2	0.03734	0.00515
PES	Primary	1	0.03325	0.00374
PES	Primary	2	0.02967	0.00221
PES	Primary	3	0.03175	0.00253
PES	Secondary	1	0.03197	0.00276
PES	Secondary	2	0.03602	0.00583
PES	Secondary	3	0.03526	0.00395
PES	Secondary	4	0.03859	0.00552
PES	Secondary	5	0.03912	0.00611

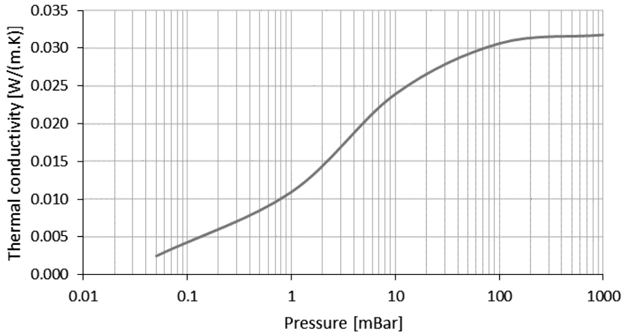

Figure 4: Dependence of thermal conductivity on the pressure for primary-PES Sample no. 2

measurements were made using a FOX 200 Vacuum from TA Instruments at a mean temperature of 10 °C and temperature gradient of 10 °C.

5 DISCUSSION

The results show that recycled textile fibers can be a suitable feedstock for the VIP manufacturing. However, it is important to choose the fibers with the correct shape and thickness. Cotton fibers are particularly problematic because they are not completely straight, thus affecting the final properties at the normal pressure as well as the vacuum.

It is also necessary to choose the correct drying regime with regard to the type of fibers, residual moisture and the overall behavior during drying. The nature of the fibers does not allow them to be dried at very high temperatures. It was found that the best temperature is at least 160 °C (depending on the type of fibers) and the best drying time is at least 5 h. It was found that the core insulation based on alternative fibers is comparable to the behavior of glass-wool materials. This is evidenced by the results shown in **Table 2**. In the framework of further research, we will predominantly verify the use of getters to reduce the effect of drying on the properties and durability of VIPs based on this alternative insulation.

6 CONCLUSIONS

The results of the thermal-conductivity tests show that at both the normal pressure and vacuum, PES samples perform better than cotton samples of the same thickness, due to a generally better structure of PES materials made with the air-lay method (the difference is a result of the shape of the fibers – see above). However, the results for both fiber types are comparable. As for secondary fibers, they had similar properties to those of primary materials (in both PES and cotton); however, it is always important to choose the correct type.

Acknowledgment

This research was carried out under projects GA17-00243S, Study of the behavior of insulating materials under extremely low pressure, and FV20127, Research and development of advanced thermal and acoustic insulating materials based on waste textile and natural fibers.

7 REFERENCES

[1] J. Hroudová, J. Zach, V. Novák, M. Reif, The behaviour of the natural fibrous insulations under specified temperature and moisture conditions, Construmat, (**2016**), 227–237

[2] S. Brunner, Vacuum insulation panels for building applications-Continuous challenges and developments, Energy and Buildings, 85 (**2014**), 592–596, doi:10.1016/j.enbuild.2014.09.016

[3] L. Yuying, W. Huijun, H. Gongsheng, Y. Jianming, W. Huan, Thermal performance and service life of vacuum insulation panels with aerogel composite cores, Energy and Buildings, 154 (**2017**), 606–617, doi:10.1016/j.enbuild.2017.08.085

[4] J. Zach, V. Novák, J. Peterková, Study of the behaviour of thermal insulation materials made with recycled textile fibers, IOP Conference Series: Materials Science and Engineering, 385 (**2018**), 1–6, doi:10.1088/1757-899X/385/1/012065

[5] L. Yuying, W. Huijun, H. Gongsheng, Y. Jianming, D. Yunfei, Prediction and optimization of thermal conductivity of vacuum insulation panels with aerogel composite cores, Procedia Engineering, 205 (**2017**), 2855–2862, doi:10.1016/j.proeng.2017.09.909

[6] EN 822:2013 Thermal insulating products for building applications – Determination of length and width, International Organization for Standardization (ISO), Geneve

[7] EN 12085:2013 Thermal insulating products for building applications – Determination of linear dimensions of test specimens, International Organization for Standardization (ISO), Geneve

[8] EN 823:2013 Thermal insulating products for building applications – Determination of thickness, International Organization for Standardization (ISO), Geneve

[9] EN 1602:2013 Thermal insulating products for building applications – Determination of the apparent density, International Organization for Standardization (ISO), Geneve

[10] EN 12667:2001 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, International Organization for Standardization (ISO), Geneve

[11] ISO 8301:1991 Thermal insulation – Determination of steady-state thermal resistance and related properties – Heat flow meter apparatus, International Organization for Standardization (ISO), Geneve