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To cite this article: J Zach *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **379** 012020

IOP Conf. Series: Materials Science and Engineering **379** (2018) 012020 doi:10.1088/1757-899X/379/1/012020

Utilization of by-products for vacuum insulation panels production

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Abstract. The paper deals with the possibilities of utilization of alternative raw materials from the textile industry for the production of vacuum insulation panels with extremely low thermal conductivity value. The paper presents current research findings on the behavior of fibrous structures on an organic basis at extremely low pressure. In addition, the paper presents the practical findings and results of experimental work in the production area and the behavior of vacuum insulation panels with an alternative core insulator based on organic fibers.

1. Introduction

The development in the field of thermally insulating materials in the civil engineering is very closely related to the current situation in the area of thermal protection of buildings and the demands on building structures from the point of thermal protection. Due to the recent implementation of the European Parliament and committee directive from 2010/31/EU [1] on the development of progressive insulating materials, there's an effort to achieve better thermal insulation properties in their development.

At the same time, however, it is an attempt to use as many renewable materials and by-products in the production of building materials as possible.

From the progressive technologies of thermal properties point of view, the vacuum insulation panels (VIP) are at present the representatives of materials with the lowest equivalent value of the thermal conductivity coefficient. These products reach extremely low values of the thermal conductivity coefficient, which in practice is at the level of 3 mW/(m.K) for the glass wool based core insulators and 5 mW/(m.K) for SiO_2– based insulators (in the form of aerogels or pyrogenic SiO_2). The current problem with the use of VIP is their relatively high price and also their limited life, which is especially problematic when using the materials in civil engineering [2]. In recent years, alternative core insulation, for example on the basis of melamine-formaldehyde fibers [3] are being used in the field of VIP as well as insulants based on by-products.

At the Brno University of Technology, Faculty of Civil Engineering has been researching for several years the possibility of using alternative (especially) organic raw materials in the production of VIP. The aim is primarily to design optimal insulators using natural fibers and fibers based on by-products. A problem with the design and manufacture of these alternative insulators is the selection of suitable fibers with the desired thickness and high purity so that there is no outgassing in the resulting VIP after vacuum or the subsequent degradation of its thermal insulation properties. Also important is the proper orientation of the fibers during the production and design of the insulator at optimal bulk density, so as to avoid rapid degradation of the thermal insulating properties when the pressure inside the panel is increased [4, 5].

2. Design and production of VIP

A selection of suitable feedstock was carried out in the framework of the research. The following raw materials were chosen: hemp fibers, flax fibers, cotton fibers, sheep wool fibers, polyester fibers (primary and secondary).

These samples were studied by their properties and microstructure (see Figures 1 and 2). The thickness and length of the fibers were determined and their microscopic analysis was performed. Bast fiber (hemp and flax) samples have been found to exhibit relatively inappropriate properties for theproduction of vacuum insulations. Classical treatment of plants by mechanical defibering does not cause defibering on primary fibers, but on technical fibers, their thickness is on average more than 90 microns (in terms of fiber thickness, the difference between hemp and flax fibers is not essential).

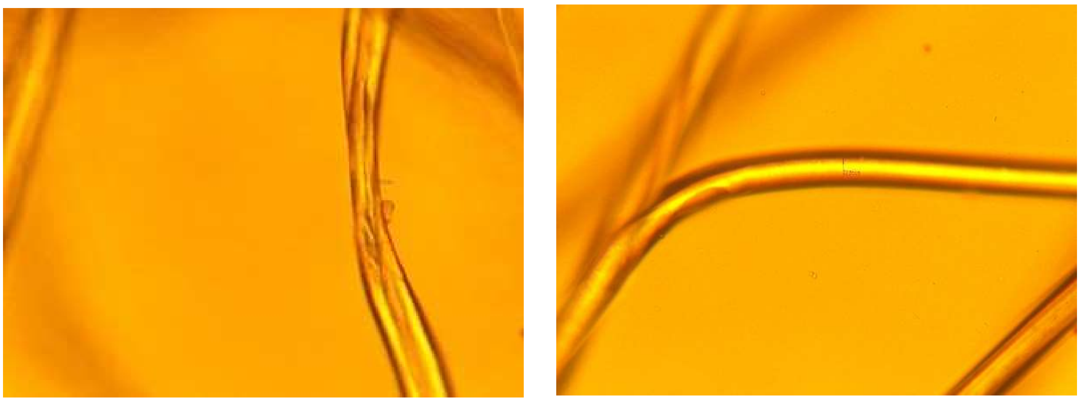

Figure 1. Photo of cotton fiber (left) and PES fiber (right) at 40x magnification**.**

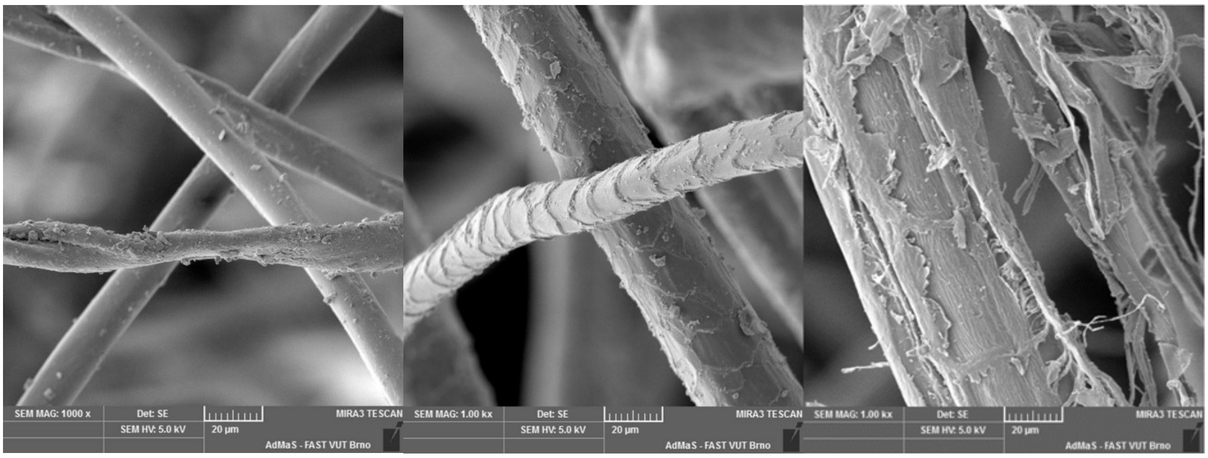

Figure 2. REM picture – detail of structure of insulation based on textile/cotton fibers (left), sheep wool (in the middle) and flax (right)**.**

Further on, it has been discovered that the thickness of the bast/natural fibers can be further adjusted by intensive mechanical separation, whereby it can thus reach up to 10 microns of fiber thickness. In these cases, however, the fiber length is reduced rapidly. The dependence between the length and thickness of the fibers was noted, as seen in Figure 3.

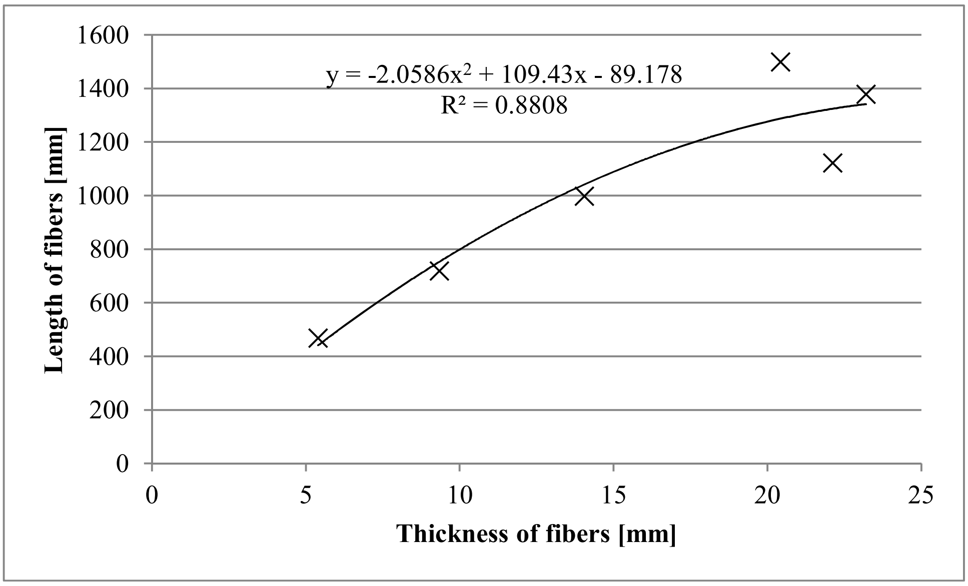

Figure 3. Dependence of length of flax fibers on thickness of flax fibers.

Reducing the thickness of flax fiber to 5.4 microns resulted in a fiber length of 469 microns (0.47 mm), whereby the fiber is inappropriate for making the core insulation using the bicomponent technology of binding by the air-lay method. High organic contamination was discovered during a microscopic analysis of sheep wool, which makes these fibers unsuitable for vacuum.

Table 1. Overview of thicknesses and lengths of fibers.

Type of Fiber	Thickness [µm]	Length [mm]
recycled PES	12.41	49.9
primary PES	12.26	35.5
cotton	10.80	26.1
hemp	90.51	41.2
flax	91.24	38.5
sheep wool	24.12	28.3

The primary and secondary polyester fibers, cotton fibers and flax fibers were selected to produce vacuum insulation (according to results – see in table 1 and availability of fibers). Core insulators were created by thermal bonding method with the addition of 15% connective bi-component PES fibers.

3. Results and discussion

Test samples (size: 200 x 200 mm) were created from the manufactured insulations for laboratory experimental measurements. Determination of the following key properties was carried out: bulk density, thickness, linear dimensions, stress at 10% deformation [6–10]. The bulk density of samples ranged between 81–150 kg/m^3. The lowest value was found for cotton samples and the highest value for hemp samples. The samples showed a higher compressibility of over 10%, which is the standard for determining the mechanical properties according to EN 826. Therefore, compression after vacuuming of panels in all cases exceeds the 10% standard of compression. Samples of insulators were produced for a nominal thickness of 10 mm.

On the test samples, determination of thermal conductivity (according to ISO 8301 [11]) was also carried out in dependence on pressure and under vacuum in dependence on temperature too. Vacuum pressure was determined at 5 Pa/0.05 mBar (99.9% vacuum), which is the typical initial pressure at VIP production. Thermal conductivities for pressures of 1, 10 and 100 mBar were also determined. Subsequently, thermal conductivity was determined at normal atmospheric pressure. The results are shown in the following chart (Figure 4).

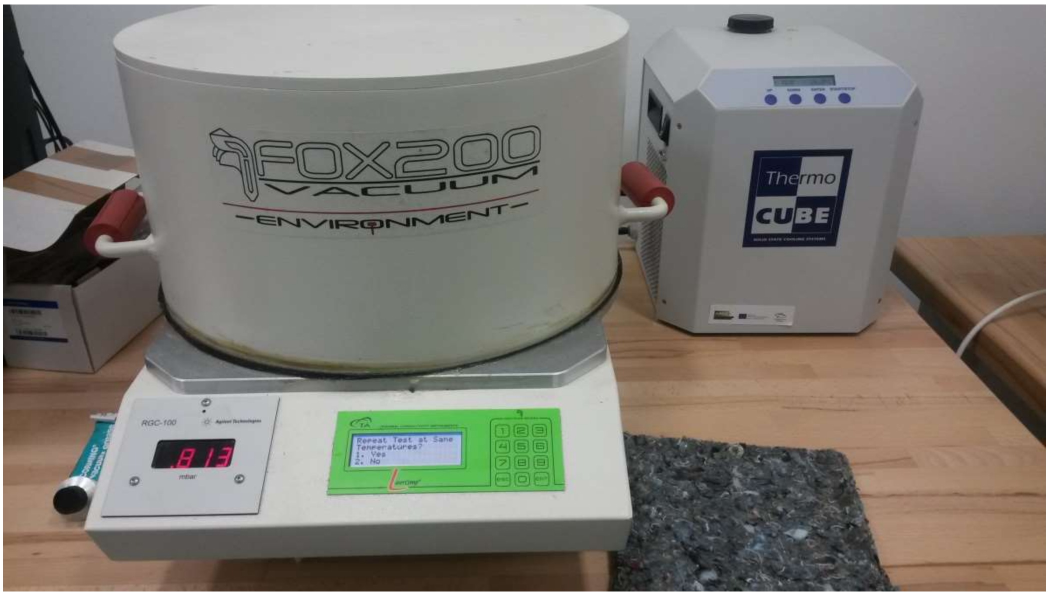

Figure 4. Photo of the test apparatus FOX 200 Vacuum.

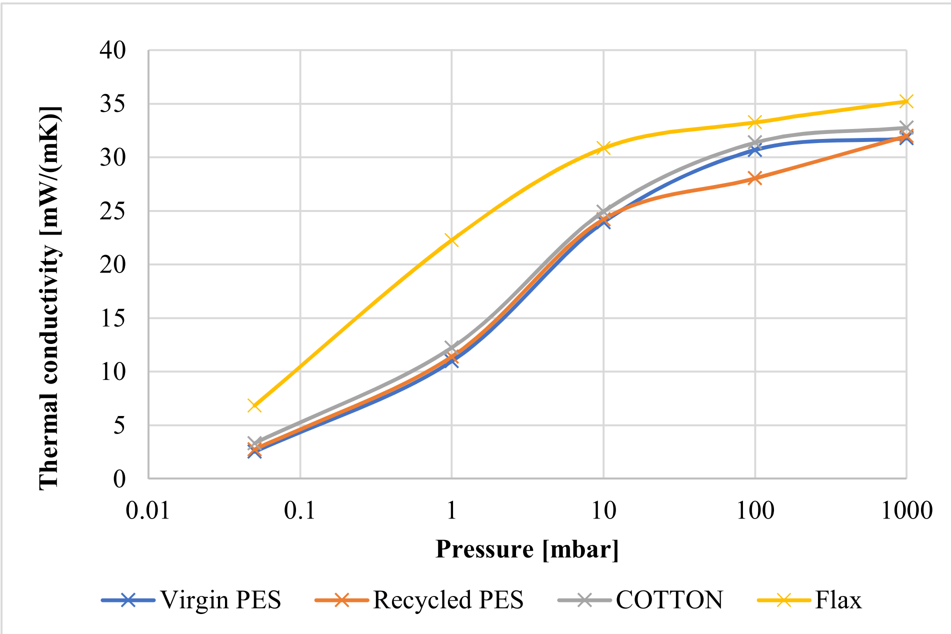

Figure 5. Dependence of thermal conductivity of core materials on pressure.

The results show that for all test specimens the increase in pressure led to a rapid degradation of the thermal insulation properties. The best results were achieved in PES samples, where, for both core insulators, a thermal conductivity of under 3.0 mW/(m.K) was achieved with a pressure of 5 Pa, specifically for the Virgin PES sample it was 2.5 mW/(m.K) and for the recycled PES sample it was 2.8 mW/(m.K). Those result are comparable with the best result with VIP based on very fine glass fibers [2]. In the case of cotton, the value was 3.3 mW/(m.K) with a lower thickness of fibers. This is due to worse defibering and especially the curvature of the cotton fibers, which leads to poor orientation of fibers in the production of mats and to the creation of more contact surfaces in the direction of the heat flow. The flax-based sample showed the worst heat-insulating properties due to the high fiber thickness in both the vacuum (a value of 6.8 mW/(m.K) was reached), and the subsequent pressure increase, when even the pressure of 1 mBar caused increase in thermal conductivity to 22 mW/(m.K). In case of flax fibers is possible to see negative aspect of higher thickness of fibers – in accordance with results of other scientific work [12].

4. Conclusion

As can be seen from the obtained results, primary and recycled PES samples can be used to produce VIP with very good thermal insulation properties, especially as an alternative to a glass wool based core VIP. An advantage of the recycled PES is the use of the by-product in the production of advanced thermal insulation, as well as a lower price compared to very fine fibers based on glass wool.

As is obvious from the dependence of thermal conductivity on pressure, all insulators have a rapid degradation of thermal insulation properties in the area of higher pressure. The degree of degradation of the thermal insulation properties in dependence on pressure is practically identical for the primary PES, recycled PES, and cotton based insulations too. VIPs made from these insulators, therefore have a lower durability and are particularly suitable for use in refrigeration and for example in packaging technology (here the advantage is, in particular, the consequent recyclability of these insulators and possible reuse for next VIP production).

In addition, even better results can be achieved by optimizing the inner structure of the insulators (targeted fiber orientation) and by optimizing the bulk density of the insulators. This is next direction of research currently underway, and it is highly probable that the value of the thermal conductivity for fiber-based insulators on an organic basis will be effectively reduced to at least about 2.0 mW/(m.K).

Acknowledgements

This paper was elaborated with the financial support of the project GA 17-00243S “Study of the behavior of insulating materials under extremely low pressure”.

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