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THERMAL PROPERTIES OF MINERAL WOOL INSULATION RECOVERED FROM CONSTRUCTION AND DEMOLITION WASTE

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Abstract. Mineral wool is one of the most commonly used types of thermal insulation in the European Union at the present, however, it generates massive amounts of waste. From an environmental standpoint, recycling or reuse of insulation materials seems to be a wise solution. This paper aims to study the thermal and structural properties of recycled mineral wool insulation recovered from construction and demolition waste. The thermal conductivity, the basic parameter characterizing thermal insulation materials, was measured using a heat flow meter. Test specimens with various bulk density (in the range 50–120 kg/m^3) were made from micro-milled and chopped waste material (cladding of 30 years old building). The obtained results were compared with reference samples (non-contaminated blown mineral wool insulation Supafil Loft 045).

Keywords: Construction and demolition waste, recycling, building insulation materials, mineral wool, thermal conductivity.

1. Introduction

1.1. Insulation material waste

Thermal insulation materials are essential in the design and construction of energy efficient buildings [1]. In the last decades, many efforts have been made to improve building comfort, however, along with that, the amount of waste from insulation materials has increased dramatically. Moreover, most of the used building insulation materials simply end up in legal and illegal landfill sites [2].

The construction sector has a significant impact on the environment due to the amount of waste generated, among other issues (e.g., extraction of raw materials, high energy consumption and CO_2 emissions, etc.). Unfortunately, the use of recycled materials in this area is not widespread yet. Nevertheless, building materials produced from waste are considered green materials, thus recycling or reusing them is getting more and more attention. Most insulation waste comes from construction and demolition (C&DW) [3]. It is estimated that C&DW accounts for 25 – 30 % (approx. 890 million tonnes annually) of all waste generated in the European Union (EU) [4, 5]. The EU has set itself the goal of reusing, recycling or recovering 70 % of C&DW by 2020 [3]. It is also assumed that circular economy-inspired actions can improve the sustainability of building and construction sectors using the 3Rs principle – reduce, reuse and recycle [6].

Utilization of thermal insulation material waste could be an important step in improving the recycling percentage of C&DW [5, 7]. There are different types of thermal insulation materials (e.g., glass and stone wool, polystyrene, sheep's wool, spray foam, polyurethane, fibreboard, cellulose) commercially available [1]. Mineral wool is one of the most used materials in Europe for thermal insulation, cold and fire protection, and noise insulation [5]. Mineral wool refers to several different types of insulation, e.g., including various inorganic materials, e.g., rock, wool, glass, slag wool [2].

1.2. Mineral wool recycling

Mineral wool is difficult to recycle, and it's recycling is not in practice in most countries [3, 8], despite the fact that the amount of mineral wool waste produced in the area of EU-28 in 2020 was estimated to be more than 2.5 million tonnes [5]. The Czech Republic generates more than 217,000 tonnes of mineral wool annually. Furthermore, the transport and landfilling of insulation materials is expensive (approximately 1,750 CZK/tonne in the Czech Republic) due to their unfavourable properties. Poor compressibility and low weight-to-volume ratio (mineral wool insulation has a bulk density of 8–100 $\mathrm{kg\,m^{-3}}$) cause problems in landfills [8]. Therefore, it is necessary to develop reliable methods for recycling this type of waste. It should be noted that insulation material waste may contain various contaminants (e.g., nails, screws, rubble, stones, wood, binders, lubricants, mortar, polyurethane foam, etc.) which must be considered when evaluating its reuse potential. From a technical point of view, a mineral wool recycling system should crush/grind the waste insulation material into short fibers and powder with the desired size and sufficiently separate the particles from the contaminants. An ideal machine is cost effective and movable, i.e., insulation materials can be collected or recycled on site.

The short fibers can be then re-used as blown-in/loose-fill insulation (in open attics, ceilings, etc.) or as filling insulation (in hollow structures, e.g. in concrete and ceramic masonry blocks, etc.). The effectiveness of thermal insulation materials is highly dependent on their thermal conductivity (the heat transfer coefficient). The lambda (λ) value represents the quantity of heat that passes through a unit area of a homogeneous material in a direction perpendicular to its isothermal planes induced by a unit temperature difference across the sample. The lower the lambda value, the better the thermal performance of the insulator material will be. A typical mineral wool has a thermal conductivity of 0.03–0.04 W/(mK), it varies with temperature, moisture content, type of pores and bulk density [1].

In this paper, the thermal conductivity of various samples recovered from construction and demolition waste is studied.

2. Experimental part

2.1. Materials and recycling

Three types of input materials were used for the experiments. Set A includes non-contaminated virgin samples Supafil Loft 045 (Knauf Insulation) – blown-in insulation made of pure natural fiber, which is made of recycled glass without binder and additives, used in new and existing open attics and ceilings above the highest heated floor. Such material was used as a reference. These waste materials have the same origin: they served as thermal insulation of the peripheral cladding of a residential building in Kralupy nad Vltavou built in 1991. The original insulation system from basalt fibers (FOS 125) was replaced with new materials. Mark Set 0 belongs to the "as-received" samples without any other processing, while Set B and C (initial bulk density of 50 kg/m^3) were subjected to different recycling technology and their properties thus differ from each other. While the first material is micro-milled using high speed mill (LAV/K – 350 Tex, Lavaris, s.r.o., Czech Republic), the second is chopped by the similar technology where the mill was replaced with a gear crusher.

Then, the prepared material was uniformly sprinkled into a extruded polystyrene foam frame with internal dimensions 240×240×60 mm. After weighing the container, the bulk density was determined from the weight and the volume of the insulating material. Test specimens with various bulk density (density in the range 50–120 kg/m^3, 6 samples for each bulk density) were made from each material and then subjected to heat transfer coefficient measurement.

The microstructural characterisation of the materials was achieved using optical (Axio ZOOM, ZEISS) and scanning electron microscopy (SEM, Thermo Scientific Phenom XL).

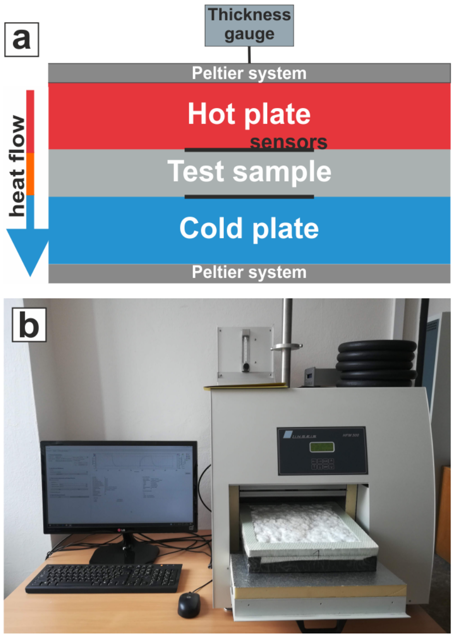

Figure 1. a) Schematic drawing and b) photograph of the Linseis heat flow meter instrument used for the measurement of the thermal conductivity coefficient.

2.2. Thermal conductivity

A thermal conductivity meter was used to determine the thermal conductivity properties of the insulation materials (Figure 1). The Linseis heat flow meter (HFM 300) is a robust and reliable instrument with a high level of accuracy and repeatability. It allows high precision temperature control due to the intelligent Peltier heating and cooling system (in the temperature range from −20 up to +90 °C). The samples were put between a hot and cold plate in order to measure the heat flow. A temperature gradient (30–10 °C) was applied to the samples and the heat flow through the samples was measured by two sensors between the sample and each plate. The thermal conductivity was measured when stable conditions had been reached. The λ-value was determined from the thermal transmittance (calculated from the measured heat flow) and the thickness of the sample using equation (1)

$$\lambda = q/(A \cdot \Delta T) \cdot d, \tag{1}$$

where: q – measured heat flow, A – area of the sample, ΔT – temperature gradient, d – thickness of the sample. The measurements were carried out in compliance with the standard ČSN EN 12667.

3. Results and discussions

Figure 2 shows digital and SEM photographs of the Supafil Loft 045 sample (Set A). The sample is composed

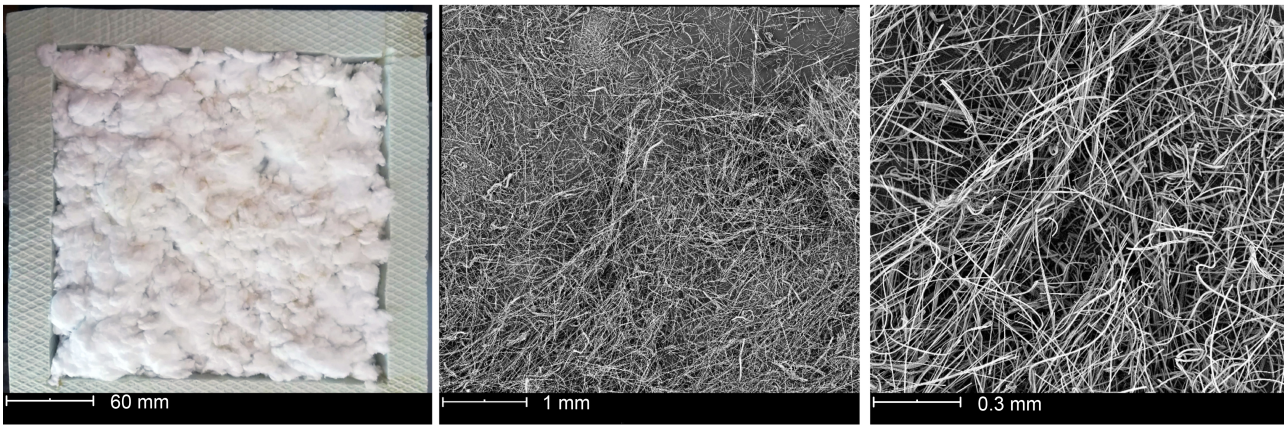

FIGURE 2. Representative optical and SEM images of the non-contaminated Supafil Loft 045 sample (set A).

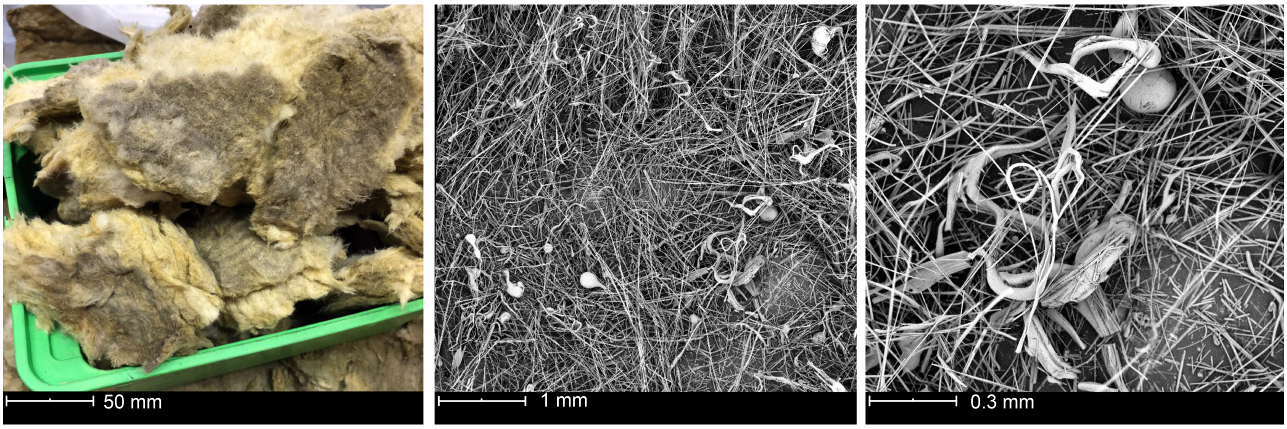

FIGURE 3. Representative optical and SEM images of demoliation mineral wool waste before processing in the recycling line (set 0).

of long intertwined fibers. There is a high number of fibers in the unit volume. No impurities are present in the sample.

Figure 3 shows the waste mineral insulation from the demolition of an external thermal insulation composite system (ETICS) in Kralupy nad Vltavou before processing in the recycling line (Set 0). There are also a high number of fibers in the unit volume and the fibers are long and intertwined. The presence of a large amount of impurities is evident.

Figure 4 shows the waste insulation after high-speed micro-milling (Set B). The integrity of the original sample was disturbed, so the resulting material could serve as recycled blown insulation or as a filling insulation in the cavities of building materials and structures. The amount of impurities coincides with set 0. Dust particles are visible in the sample. The fibers are short and damaged by the milling process.

Figure 5 shows waste insulation after the chopping process (Set C). From a macroscopic point of view, the sample is very fine. SEM images show large amounts of dirt and dust particles. The fibers are very short.

The thermal conductivity coefficient of the samples was determined using a heat flow meter. Figure 6 shows the dependence of the thermal conductivity on the bulk density of samples. The λ-value is an indication of how well a sample conducts heat.

As is evident from Figure 6, the set A (Supafil Loft 045) has very good thermal insulation performance – it has the lowest thermal conductivity coefficient values out of all sets. The sample with bulk density 64 kg/m^3 had the lowest λ-value (0.0379 W/(mK)). It is worth noting that Set A reaches 0.045 W/(mK) according to its manufacturer. However, such a thermal conductivity coefficient corresponds to a very low bulk density of 12 kg/m^3 which is achievable only using a blowing machine. Samples made of recycled insulation (set B and set C) exhibited higher thermal conductivity coefficients than reference Set A, however, both still reached acceptable insulating properties, as their thermal conductivity coefficient oscillated between ca. 0.040–0.055 W/(mK). The results also show that reference material, Set A, is characterised by very stable thermal conductivity (ca. 0.038 W/(mK) when its density is changed in the range of 50–120 kg/m^3. Compared to it, Set B and C exhibited slightly different behaviour. Their thermal conductivity decreases with increasing density (up to ca. 120 kg/m^3), which is clear especially in case of Set C. Such a phenomenon is attributed to the principles of heat transfer; higher porosity of thermal insulation results in lower λ-values because the larger amount of

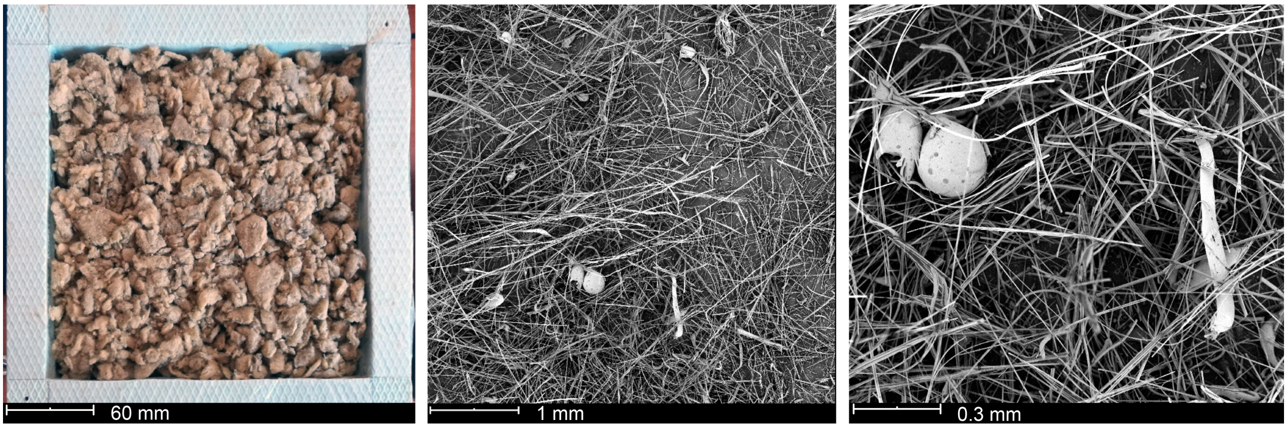

FIGURE 4. Representative optical and SEM images of micro-milled mineral wool waste (set B).

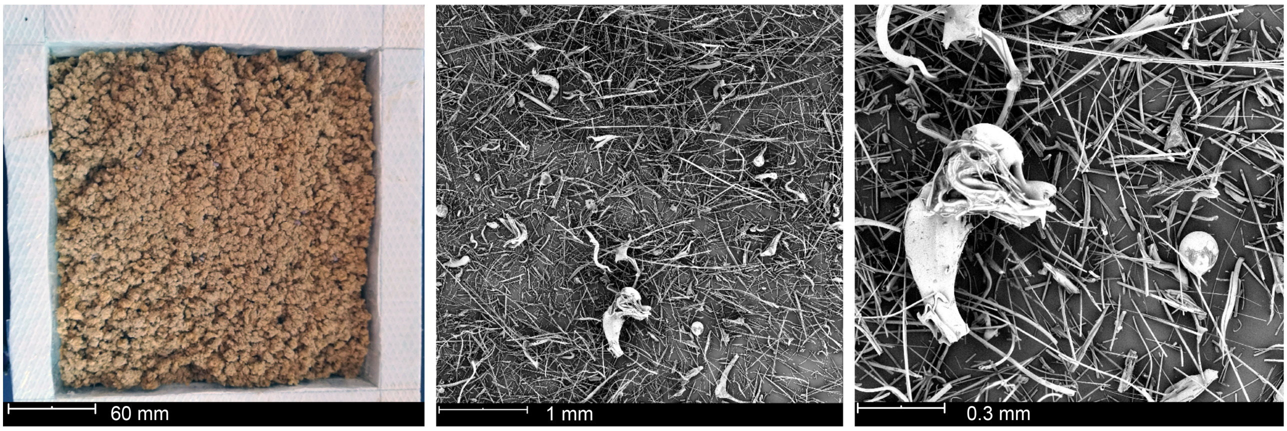

FIGURE 5. Representative optical and SEM images of chopped mineral wool waste (set C).

trapped air within the material restricts heat transfer. However, when a certain value of bulk density is reached, which is individual for specific insulating materials, the coefficient increases. This is due to the fact that if the bulk density of the material is too low, its structure is very porous and heat is allowed to dissipate by convection. On the other hand, if the bulk density of the material is too high, the structure of the insulator is so dense that heat is dissipated to an increased extent by conduction.

For our experiments it is evident that the value of the thermal conductivity can be regulated by the inner structure (particle size and porosity) of the samples, i.e. the characteristics of the output material of the recycler line. While the micro-milled Set B tends to copy the behaviour of Set A, Set C showed massive decrease in thermal conductivity with increasing density. Set B is thus suitable to be used as both recycled loose-fill/blown-in and filling insulation. Set C is more appropriate as filling insulation. Thermal insulation properties of the Set C are poor in small densities (in contrast with blown-in insulation). Some improvement occurs after the density is more than ca. 90 kg/m^3. Density lower than 60 kg/m^3 can not be achieved in this case due to short and too compacted fibers. However, its compactness may cause stability in dismounting, which is strongly limited for filling insulation as stated in ČSN EN 14064-1.

3.1. Recycling line

The construction industry is a major source of waste in developed countries. The purpose of the international waste policy is to reduce the use of raw resources and convert waste material into usable recyclate and reuse it as much as possible. Recycling minimizes the adverse effects of waste generation and reduces the environmental impact. Insulation materials are an underutilized material for recycling. Re-use options for mineral wool waste are limited yet, however after developing an efficient recycling process there is a possibility to turn mineral wool waste from unrecyclable waste into a raw material which can be re-used in the mineral wool manufacturing process or in manufacturing new construction materials such as brick, concrete, cement, ceramics, cement or fiber-based composites, tiles and soilless cultures [3, 7].

We have demonstrated that the utilization of a well-designed recycling line for mineral wool processing could be a promising technique that would enable recycling mineral wool for a variety of purposes. The line was designed as both stationary and mobile. The utilization of a movable machine reduces the amount of waste sent to landfill, thus reducing the carbon footprint of the process. Both assemblies have the

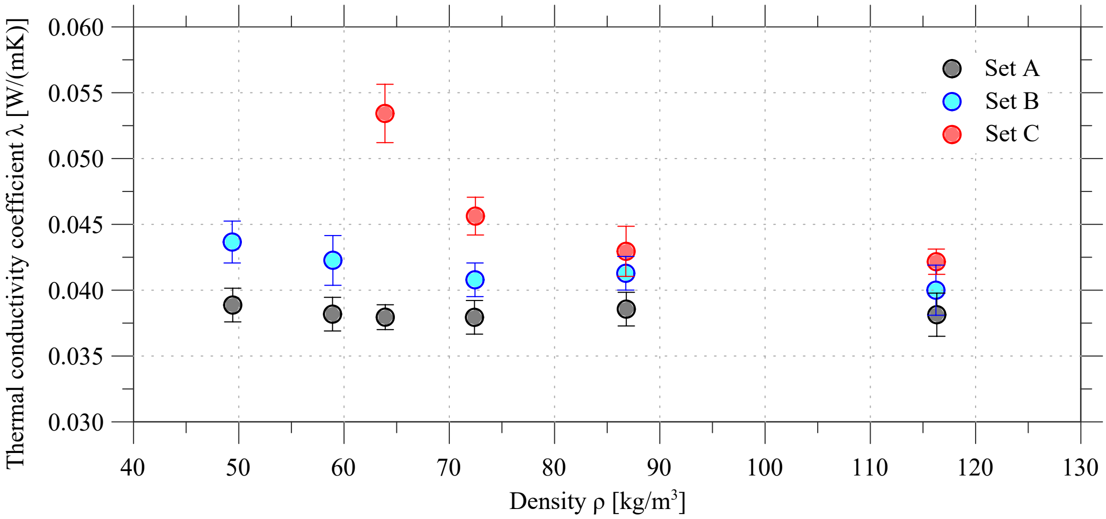

Figure 6. Graph of the thermal conductivity coefficient as a function of the bulk density of samples.

following basic parts: i) crusher or mill, ii) separating cyclone with bag, iiii) double filter. These parts can be combined and optimized, thus the process parameters can be adjusted on demand (e.g., various construction waste materials can be processed at different speeds, i.e., the size and structure of the output material is adjustable).

4. Conclusions

In this paper, samples recovered from mineral wool waste (made from basalt fibers, cladding of 30 years old building in Kralupy nad Vltavou) were prepared and their thermal conductivity was measured using a heat flow meter. The λ-value is crucial indicator for evaluating the performance of insulation materials. We tested the thermal conductivity of various samples (with bulk densities in the range 50–120 kg/m^3): i) non-contaminated virgin sample Supafil Loft 045 (reference), ii) micro-milled and iii) chopped waste material. Samples made of recycled insulation had higher thermal conductivity coefficients that reference samples, however they still exhibited acceptable insulating properties, since their thermal conductivity coefficient was in the range of 0.040–0.055 W/(mK). The micro-milled material seems to be promising to use as both recycled loose-fill/blown-in and filling insulation, on the other hand chopped waste material is more appropriate as filling insulation.

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