

# Development of a sheet thermal insulation material based on foamed recycled wood from construction demolitions and its characteristics

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## **Souhrn**

*This study focuses on the development of a new type of foamed recycled wood-based sheet thermal insulation material for construction applications. The input raw material for production is a fraction of wood particles obtained by disintegration of secondary wood demolition waste from the construction industry. The production principle is an ecological and low-energy process of foaming the slurry into a mold and subsequent stabilization to the required dimensions of the sheet material. To define the potential for the application of the developed material, its basic characteristics, such as the coefficient of thermal conductivity ( $\lambda$ ) and the coefficient of thermal resistance, were assessed.*

**Klíčová slova:** *Agglomerated material, recycled wood, thermal insulation*

## **Introduction**

Accelerating climate change due to carbon dioxide emissions has a direct impact on people's lives worldwide. The construction sector is responsible for almost 40 % of the world's annual carbon dioxide emissions, highlighting the need to reduce emissions and reform the construction industry (Sovacool *et al.*, 2021). Sustainable architecture trends offer solutions to mitigate the carbon footprint of the construction industry, focusing on building materials, especially thermal insulation (Ali *et al.*, 2020). Thermal insulation is key to maintaining comfortable temperatures in buildings and can significantly reduce energy consumption for heating and cooling, and thus greenhouse gas emissions. Traditional insulation materials are effective, but they often require high energy and water consumption and pose a challenge for recycling (Yildiz *et al.*, 2021). Due to the development of energy resource prices, increasingly stringent requirements are placed on the overall energy balance of residential buildings (Wiprächtiger *et al.*, 2020). This increases the demand for the development of new types of building envelope compositions and new thermal insulation materials with optimal parameters in terms of mechanics, building physics, acoustics, fire resistance, durability, health safety, production costs and ecological degradability (Cabral *et al.*, 2021). However, despite the many advantages of natural insulation materials, consumers and building professionals still face many challenges, including technical limitations, lack of standards and regulations and lack of awareness of the potential of these materials. Therefore, further research and development of these materials is necessary to overcome these obstacles (Hellová *et al.*, 2020). The transition to natural insulation is not only a question of sustainability, but also a question of future environmental protection (Ulutaş *et al.*, 2023). This is a step we must take to achieve goals such as reducing adverse climate impacts and sustainable development (Pescari, 2022). Foam wood has many advantages that make it an innovative and environmentally friendly material. Its lightness is due to the incorporation of air into its structure during the foaming process, which gives it excellent insulating properties. This translates into improved energy efficiency in construction and reduced heating and cooling costs. Foam wood also has increased strength and durability and is sustainable, as it often comes from renewable resources. Its sound absorption and fire resistance further increase the attractiveness of this material, making it a versatile and promising material for a wide range of applications, especially in construction and manufacturing.

## **Material**

Three types of test specimens were produced with dimensions of 500 mm x 500 mm and a thickness of 40 mm. The first type is based on wood fibers (FW1), the second sample is based on wood flour (FW2) and the third type of sample is based on wood flour with the addition of brewer's mash (FW3). An

inorganic blowing agent was used in the preparation of FW1 and FW2. An organic blowing agent was used in the preparation of FW3. These input materials were chosen because of the use of production waste. The test specimen made of thermal insulation material based on foamed wood fibers is conditioned at a relative humidity of  $65 \pm 5\%$  and an air temperature of  $20 \pm 2 \text{ }^\circ\text{C}$  for 168 hours. The moisture content in the thermal insulation material is determined by a moisture analyzer type MB23 (OHAUS Europe GmbH) on samples taken from individual parts of the test material.

The percentage moisture content ( $u$ ) was determined as the weight difference between the wet ( $m_w$ ) and dry ( $m_o$ , dried at  $105 \text{ }^\circ\text{C} \pm 2 \text{ }^\circ\text{C}$  for 6 hours) sample according to the formula:

$$u (\%) = \frac{m_w - m_o}{m_o} \cdot 100 \quad (1)$$

kde

- $u$  ..... material moisture (%)
- $m_w$  ..... weight of test material at a given humidity (kg)
- $m_o$  ..... weight of dried material (kg)

### Measurement procedure

The tested material was placed in a device for determining thermal insulation characteristics, which allows the measurement of thermally insulated protected hot plates TAURUS TLP 900-GS (TAURUS Instruments GmbH, Germany). The principles of the design of the methodological procedure, the test equipment and the basic requirements that must be met for the laboratory determination of the heat transfer properties of building parts are derived from the EN 12939 standard. A plate sample with electrical dimensions specified in the EN 12667 standard was placed between the hot and warm plates of the measuring device of the chamber with applied temperature sensors. The chamber was closed and then started in the measuring mode, the measurement was carried out for 30 hours until the temperature reached a stable state in the density profile of the measured sample. The required parameters for measuring the heat transfer coefficient were set in the device. Sensing probes were applied to the sample under investigation and then the sample was insulated with polystyrene boards, which included testing the material under investigation under the most accurate conditions possible.

**Table 1: Device characteristics of calibrated box with an integrated hot plate TLP 900 (G)S**

Characteristics	Technical data
Measurement range	0.005 – 2.0 W.m <sup>-1</sup> . K <sup>-1</sup>
Test size (mm)	500x500 – 800x800
Sample thickness (mm)	10 – 240
Temperature range	Cooling plate -10 – +50°C
	Heating Plate 0 – +60°C
Voltage	110 – 230 V, 500/60 Hz

Thermal conductivity characterizes the ability of the tested material to conduct heat. It represents the rate at which heat spreads from one heated part to a cold part. The device measures thermal conductivity with an accuracy of  $\pm 0.1\%$ .

The calculation is given by the relation (EN 12667):

$$\lambda = \frac{\varphi d}{A (T_1 - T_2)} \quad (2)$$

where

- $\lambda$  ..... thermal conductivity coefficient (W.m<sup>-1</sup>.K<sup>-1</sup>)
- $T_1$  ..... average temperature on the warm side of the sample (K)
- $T_2$  ..... average temperature on the cold side of the sample (K)
- $d$  ..... thickness of the tested material (m)

- A ..... specific areas of the sample (m<sup>2</sup>)
- φ ..... average heat flow (W)

Calculation of thermal resistance *R*

Thermal resistance characterizes the amount of heat that passes through a structure with an area of 1 m<sup>2</sup> when the temperature difference between its surfaces is 1 K.

The calculation is given by the formula (EN ISO 6946):

$$R = \frac{d}{\lambda} \tag{3}$$

where

- R* ..... thermal resistance of the structure (m<sup>2</sup>.K.W<sup>-1</sup>)
- d* ..... thickness of the tested material (m)
- λ ..... coefficient of thermal conductivity (W.m<sup>-1</sup>.K<sup>-1</sup>)

The measurement results were compared with each other in Table 2.

**Table 2: Measurement results**

Specimen	λ [W.m <sup>-1</sup> .K <sup>-1</sup> ]	R [m <sup>2</sup> .K.W <sup>-1</sup> ]	ρ [kg.m <sup>-3</sup> ]
FW1	0.041	0.97	97.8
FW2	0.044	0.90	265.7
FW3	0.051	0.97	228.3

The results were compared. The thermal conductivity of FW1 and FW2 is similar, even though they are two very different materials. FW1 has larger pores and a much lower density. The longer wood fibres allow the material to create a more porous and lighter structure. FW2 and FW3 were made from wood flour, which has a fibre length of around 0.2 mm, and therefore produces a much denser material with much smaller pores. In the case of FW3 with the addition of brewer's grains, the thermal conductivity result is higher than for the other two materials. The structures of the individual measured materials are shown in Figures 1, 2 and 3.

The measured foamed wood base materials were magnified under a SMZ 1270 stereomicroscope (Nikon, Japan) and photographed with a DS-FI3 camera (Nikon, Japan).



**Figure 2: Sample structure FW2 12,7x063**

The measured values of the three developed foam wood materials were compared with selected commercially produced materials. The materials selected were STEICO ISOVER (wood fiber insulation) (Steico AG, Germany), ISOVER UNI (mineral wool) (Saint-Gobain Construction Products CZ a.s., Czech Republic), KOBE ECO HEMP FLEX (hemp fiber insulation) (KOBE-cz s.r.o., Czech Republic) and EKOPANEL (straw insulation) (EKOPANELY CZ s.r.o., Czech Republic). The resulting values of the material parameters are given in the following table 3.

**Table 3: Comparison of foamed wood (FW) with selected thermal insulations**

Specimen	$\lambda$ [ $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ ]	R [ $\text{m}^2\cdot\text{K}\cdot\text{W}^{-1}$ ]	$\rho$ [ $\text{kg}\cdot\text{m}^{-3}$ ]
FW1	0.041	0.97	97.8
FW2	0.044	0.91	265.7
FW3	0.051	0.97	228.3
STEICO ISOVER	0.040	1.00	160.0
ISOVER UNI	0.035	1.14	40.0
KOBE ECO HEMP FLEX	0.040	1.00	35.0
EKOPANEL	0.099	0.40	379.0

The value of the thermal conductivity coefficient for the material FW1 was determined to be  $\lambda = 0.041$  ( $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ ), for the material FW2  $\lambda = 0.044$  ( $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ ) and for the material FW3  $\lambda = 0.051$  ( $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ ). The results of the samples FW1 and FW2 show that, compared to other commercially produced thermal insulation materials, it has comparable parameters to insulation materials based on wood or straw fibers, but it shows worse parameters than insulation materials based on mineral wool. In the case of FW3, the result in terms of thermal conductivity is slightly worse. However, the material FW3 is made of 100% organic input material. From this point of view, we can compare it with straw-based insulation in terms of thermal conductivity.

Similar results are confirmed by the evaluation of thermal resistance  $\text{RFW1} = 0.97$  ( $\text{m}^2\cdot\text{K}\cdot\text{W}^{-1}$ ),  $\text{RFW2} = 0.91$  ( $\text{m}^2\cdot\text{K}\cdot\text{W}^{-1}$ ),  $\text{RFW3} = 0.97$  ( $\text{m}^2\cdot\text{K}\cdot\text{W}^{-1}$ ), where the results show that, compared to other commercially produced thermal insulation materials, it has comparable parameters to insulation materials based on wood or straw fibers, but it shows worse parameters than insulation materials based on mineral wool.

## Conclusion

The aim of this work was to determine the basic thermal insulation properties of new foamed wood-based thermal insulation materials in terms of their potential for application in the construction of the building envelope. The materials were produced using wood fibers, wood flour and brewer's spent grains. These input materials were selected with regard to the use of production waste. The resulting parameters were compared with each other and with four other types of thermal insulation materials from commercial manufacturers. The materials investigated in this paper are prototypes of insulating materials using the principle of blowing material based on wood fibers of various sizes. The ability to use even a small proportion of wood fibers in the form of wood flour allows the use of a smaller proportion of wood waste, or rather wood waste of lower quality.

## Acknowledgements

We wish for the support of the project "Development and analysis of thermal insulation materials based on cellulose fibres", No. A-09-23, financed by the Internal Grant Agency (IGA) of the Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Czech Republic.

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