

How the new insulation materials made with mycelium compares to mineral and hemp wools?

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Abstract. The goal of this study is to design an organic material that will be 100% compostable at the end of its useful life. The material is composed of the mycelium of *Pleurotus ostreatus* grown rye grains and white ash chips. The white ash chips were locally sourced from the activities in the City of Montreal. The objectives are to develop a protocol for the culture of the material and to characterize it and compare it to glass wool and hemp wool, which are two proven insulators. The mycelium is the binder and two sizes of white ash chip were tested: thin and medium. The thermal conductivity was measured using the modified transient plane source sensor. The mycelium on the medium size chip produced the best-insulating properties better than the glass wool and hemp wool. The R factor in SI unit was 15. The wood chip also provided strength to the material. Grown at ambient temperature, its low carbon footprint and its absence of synthetic products make mycelium material an environmentally responsible material choice.

Keywords: Mycelium, thermal insulation, hemp wood, mineral wood.

1 Introduction

The mycelium is the name of the underground vegetative part of the mushrooms that can be observed during a walk in the forest. Mycelium is an excellent binder for plant fibres, with unlimited growth in the presence of nutrients and favourable conditions. Its ability to take on the desired shape and to be inactivated by heat opens many doors to its potential uses. The literature reports thermal conductivity comparable to commercial insulation materials such as glass wool [1]. Few studies have yet been done in Quebec on mycomaterials [2]. On the other hand, many foreign companies are developing packaging products, vegan leather based on mycelium or even vegan bacon based on mycelium [3].

Since 2011, the city of Montreal has been grappling with an endemic plant pathogen that affects *Fraxinus americana* (white ash), the emerald ash borer (*Agilus planipennis*). Consequently, the quantity of dead ash trees in Montreal is very high and forestry crews are slow to cut them down, making their condition less attractive to the board industry. They are transformed into wood chips, but the chip industry is severely

lacking in opportunities despite their low cost. The valorization into mycelium building materials has not yet been investigated. Measurements of the physical properties are needed before doing thermal and building simulations. This exploratory study also aimed at gathering data on bio-based materials to investigate the possibility to make building materials from renewable sources, in the transition to rely on renewable resources. It aims at exploring new frontiers in building materials.

This article is divided into two parts. In the first part, the development of a protocol for the cultivation of the mycelium of *Pleurotus ostreatus* was done in order to achieve the desired material based on vegetable fibre and mycelium. In the second part, the experimental material was compared to glass wool, a well-known insulator, as well as to hemp wool, which is an alternative type of insulation on the market that is bio-based like the experimental material.

2 Material and methods

2.1 Materials

Growth of *Pleurotus ostreatus* mycelium was performed on Sabouraud-chloramphenicol agar at 20°C, 25°C, 30°C for 10 to 14 days in an isothermal calorimeter to determine the temperature with the optimal growth temperature. The temperature with faster mycelium growth was selected. Biological rye grains were hydrated for 24 hours before being sterilized for 40 minutes at 121°C and cooled for 1 hour in the laminar flow hood. Insecticide- and fungicide-free ash chips were hydrated for 24 hours before being sterilized for 40 minutes at 121°C and cooled for 1 hour in a laminar flow hood. Two sizes of wood chips were used, Thin and Medium and the samples are named accordingly. When the wood chips were fully colonized, 3 tablespoons of unbleached flour was added to stimulate the mycelium growth. The wood chips were placed in sterilized culture moulds and covered with a plastic film for incubation. When the colonization of the culture moulds was complete, the resulting bricks were unmoulded. The growth was inhibited during a 24-hour period in an oven at 80°C. The mineral wool and the hemp wool were commercially available products and reference materials. More details on the study are found in the article [2].

2.2 Methods

The thermal conductivity was measured using the C-Therm Trident apparatus with the MTPS (modified transient plane source) sensor who reach ASTM D7984 standard at room condition [4]. Calibration of the device was done with the LAF6720C control material for low thermal conductivity insulating materials [5]. The measurements reported here were in the perpendicular direction of the sample (Fig. 1). The smoothest side of the sample was placed on the MTPS sensor without a contact agent. Measurements were performed in triplicate at one minute interval and also on three positions on the sample.

When the samples were oriented perpendicular to the direction of the fibre, the height of the materials was 0.0762 m for hemp wool and glass wool vs 0.0857 m for Thin and Medium mycelium. When the samples were oriented in the direction of the fibre direction, the thickness of hemp wool and glass wool was 0.0762 m and 0.01 m for Thin and Medium mycelium. No contact agents were used.



Fig. 1. Thermal conductivity measurement perpendicular to the fibre direction

In the field of building physics, the U-value, also called heat transfer coefficient or thermal transmittance, is a measure of how the building envelope materials act as an insulator. The lower the U-value, the best is the insulating behaviour. The value allows to quickly compare several types of insulation to one and others. It corresponds to the value of thermal conductivity λ measured divided by the thickness of the insulating material. The mean thickness and thermal conductivity values were used for each material.

$$U = \frac{\text{Thermal conductivity } \left(\frac{W}{mK}\right)}{\text{Insulation thickness (m)}} = \frac{W}{m^2K} \quad (1)$$

Third, the actual volume and true density of the materials were determined using the Anton Paar Ultrapyc 5000 instrument. True density is the ratio of mass/volume occupied by the mass when all the pores and internal void volume are subtracted [6]. The enormous amount of air space contains in the voids requires accurate and precise measurement methods. The weight of the samples was determined beforehand, and 3 replicas of the same material were selected because of their similar weight. Three respective 10-minute measurement cycles took place for each sample at an internal pressure of 20 psi, and at a temperature of 23°C. Three samples were analyzed for each material, for a total of nine values/material. The gas used was helium for a «flow type» preparation

method for monolithic type samples. The cells used to hold the samples were medium (50 cm^3) for glass wool and hemp wool and large (135 cm^3) for Thin and Medium mycelium [7].

3 Results and Discussion

The isothermal calorimetry results allow to determine the optimal growth temperature for the mycelium (Fig. 2 and 3). When the heat flux is increasing, the mycelium is in the exponential growth phase. A plateau means that the mycelium that the growth and mortality rate are the same due to the depletion of nutriment, lower humidity, and accumulation of waste. At 25°C , the mycelium growth on white ash wood chips is faster and reaches the maximum after 120 h, which is 5 days. This rate was selected as it would be the faster expected when scaling up operation. The growth rate of mycelium changes with the substrate and faster rate can occur on other substrates.

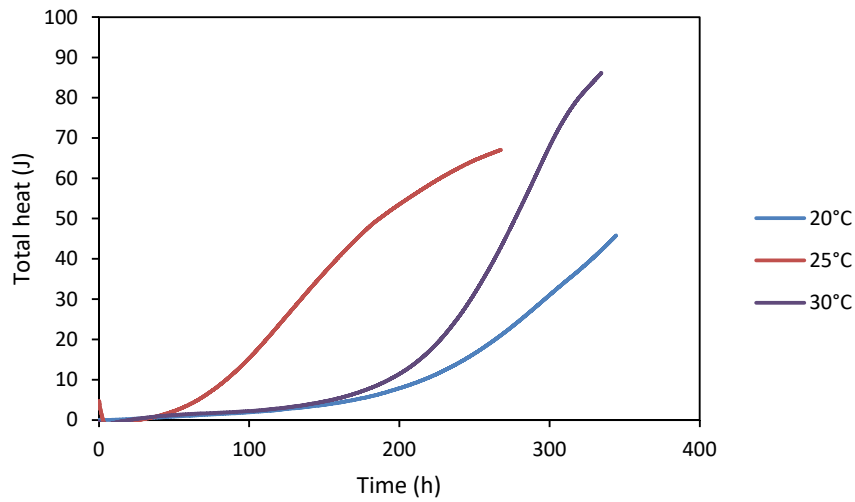


Fig. 2. Total heat from mycelium growth in controlled conditions

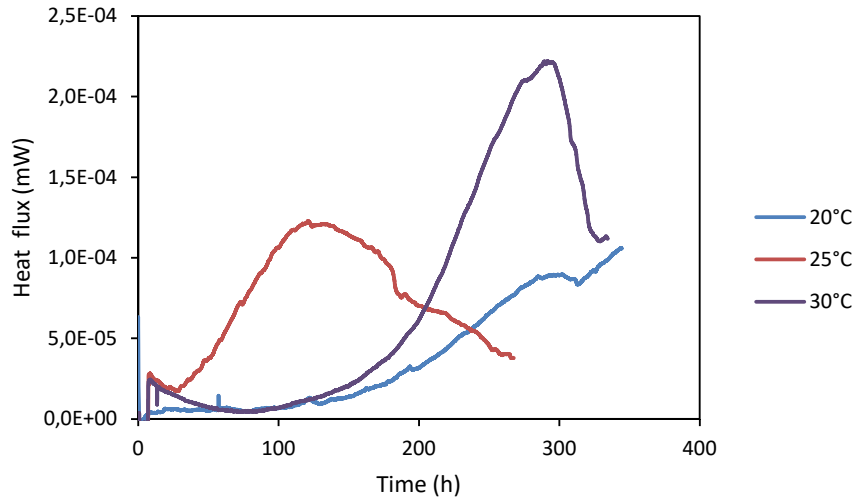


Fig. 3. Heat flux from mycelium growth at three temperatures

The thermal conductivity reported in Table 1 is lower than the thermal conductivity of 0.055 W/m K of a mycelium with a dry density of 123 kg/m^3 measured by others [8], which means that the white ash wood ash provides good insulation. From the thermal conductivity and the thickness of the material, it is possible to calculate the heat transfer coefficient. This value, better known as the U-value, is widely used by the industry to indicate the level of insulation achieved. The lower the value, the better the insulation. Table 1 summarizes the thermal conductivity, U-value, and porosity. Medium mycelium is the material with the best U-value. The four materials are still competitive with each other, and the low standard deviation suggests the accuracy of the values obtained [2]. In fact, 0.0313 W/mK was obtained as the thermal conductivity of glass wool when literature show 0.0300 W/mK which validates the method. The thermal conductivity was not directly linked to the porosity, the Medium mycelium has the lowest porosity. Hemp wool has also a lower U-value than glass wool, while being less porosity. The biological fibres contributed to the insulation, which means that the porosity of the fibres themselves was not considered. Other methods to measure the porosity would need investigation.

Table 1. Thermal conductivity, U-value, and porosity of the materials

Material	Thermal conductivity (W/m K)	U factor W/m ² K	Porosity %
Hemp wool	0.0364	0.476	88.2
Glass wool	0.0313	0.417	99.0
Thin mycelium	0.0379	0.435	78.4
Medium mycelium	0.0321	0.370	75.2

4 Conclusion

In this exploratory study, mycelium was the binder of Thin and Medium white ash wood ash chips. The wood chips needed valorization in Montreal, as the emerald ash borer affected many trees. The Medium mycelium produced the best insulating properties in terms of U-value, when compared to hemp wood, Thin mycelium, and glass wool. This study provides basic data to perform energy modelling, while additional data are needed on the water vapour behaviour and air quality. This study contributes to demonstrating that many bio-based materials are available in the construction sector and they need more investigation on the optimal growth condition, conditioning, test protocol, and construction. The foreseeable applications are more likely for event and seasonal building such specialty shows and fairs.

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