Evaluation of Physical Properties of Mycelium-Based Bio Composites for Use As Facade Insulation Material

Frank Dehn (frank.dehn@kit.edu)  
Karlsruhe Institute of Technology: Karlsruher Institut fur Technologie  https://orcid.org/0000-0001-7248-4145

Engin Kotan  
Karlsruhe Institute of Technology: Karlsruher Institut fur Technologie

Research Article

Keywords: Mycelium-based materials, thermal conductivity, water vapour diffusion, water vapour diffusion resistance, water absorption coefficient

Posted Date: September 14th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-860965/v1

License: © This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License
Evaluation of Physical Properties of Mycelium-based Bio Composites for Use as Facade Insulation Material

Frank Dehn and Engin Kotan

Karlsruhe Institute of Technology (KIT), Institute of Concrete Structures and Building Materials (IMB) & Materials Testing and Research Institute (MPA), Gotthard-Franz-Strasse 3, 76131 Karlsruhe, Germany.

Email address: frank.dehn@kit.edu; ORCID number: 0000-0001-7248-4145

Contact details for corresponding authors:
Univ.-Prof. Dr.-Ing. Frank Dehn
Karlsruhe Institute of Technology (KIT)
Institute for Concrete Structures and Building Materials
Chair of Building Materials and Concrete Construction
Materials Testing and Research Institute
MPA Karlsruhe
Gotthard-Franz-Str. 3, Building 50.31, Office 501
D-76131 Karlsruhe, Germany
Tel.: +49 721 608-43890; Fax: +49 721 608-48400
E-Mail: frank.dehn@kit.edu; Web: www.betoninstitut.de
Abstract

Background: To evaluate the usability of mycelium-based materials for construction, first tests were carried out to determine their suitability for thermal insulation. Different substrate compositions were tested for various physical properties. The compositions and experimental setups used are described in the “Methods” section.

Results: Materials based on fungal mycelium were found to have promising properties for use in the construction sector. Their thermal conductivities are comparable to those of commercially available ecological insulation materials. As material properties turned out to be dependent on the substrate used for the production of mycelium materials, further optimisation is required.

Conclusion: For first preliminary tests [1] to study the performance of mycelium-based materials, different additives (beech wood, rice husks, coffee silver skin, perlite rock) were added to a base substrate to determine their influence on physical properties. Compared to the characteristics of conventional thermal insulation materials, the test results obtained are rather promising and confirm suitability of mycelium-based materials for building. However, further systematic studies are needed to investigate options to improve major properties and to ensure reproducibility of mycelium materials with largely homogeneous properties.

Keywords: Mycelium-based materials, thermal conductivity, water vapour diffusion, water vapour diffusion resistance, water absorption coefficient
Background

It is a declared goal of the European Commission to have nearly energy-neutral buildings by 2050 [2]. This goal can only be achieved when providing building envelopes with thermal insulation systems. The presently most frequently used insulation materials, expanded polystyrene (EPS) and extruded polystyrene (XPS) [3], have good physical properties, but a bad environmental balance and recyclability and are far from being sustainable and resource-efficient [4].

In the past years, the USA and the Netherlands in particular started to study ecological alternatives to polystyrene-based plastics. These resource-efficient materials are made of organic substrates that are interconnected by the root network of conventional fungi, the so-called mycelium. Having killed the fungal organism by drying, solid material results, whose properties are similar to those of polystyrene products. Such material has already been commercialised as an alternative to polystyrene-based packaging material [5]. First studies revealed that it also has a big potential for façade insulation of buildings. However, systematic fundamental investigations confirming suitability still remain to be carried out.

It is the authors’ central concern to identify fundamental properties of mycelium-based materials and to present possibilities to specifically control major properties. The authors will focus not only on the thermal behaviour, but also on other physical characteristics. The experimental studies reported here are aimed at a characterisation of the materials and at specifically controlling relevant thermal and humidity properties taking into account mechanical loadability and fire protection aspects.
Results

To produce the material specimens, a commercially available substrate was used, which mainly consists of crushed hemp straw on which oyster mushroom (Pleurotus ostreatus) was grown. Various organic and inorganic additives were added to this pre-cultivated material in order to study their influence on major physical properties. Among these additives were beech wood shavings, rice husks, coffee silver skins, and perlite rock. Pressed (compacted) and non-compacted specimens were studied.

Tests using different substrate compositions revealed that material properties significantly depend on the selection of additives. Addition of beech wood shavings, for instance, resulted in a stable structure that was difficult to cut. Edge fraying occurred. Addition of coffee silver skins did not result in any solid structure at all. Specimens made of the pure base substrate turned out to have comparably good processing qualities.

Thermal Conductivity

The most important physical property of insulation materials in the building sector is their thermal conductivity. The specimens covered by this paper were analysed for thermal conductivity according to DIN EN 12664 [6] using the $\lambda$-Meter EP500e (see Figure 1 (right)). The thermal conductivities measured at a specimen centre temperature of 10°C in both dry (furnace drying) and wet specimens (equilibrium moisture at 23°C and 50% relative humidity) are represented in Figure 1 (left).

![Image of thermal conductivity measurement setup](image)

**Fig. 1** $\lambda$-Meter EP500e used to measure thermal conductivity (left) and the values measured in the substrate at a specimen centre temperature of 10°C (D = specimen with added perlite rock, CNC = pure base substrate, CNC-P = base substrate of increased packing density)
To evaluate physical properties, results measured in the dry state are of particular interest. For the measured values shown in Figure 1, nominal thermal conductivity in the form of the 90 % quantile is $\lambda_D = 0.048 \text{ W/(m·K)}$. Conventional products, such as wood fibre boards (Gutex Thermowall) ($\lambda_D = 0.039 \text{ W/(m·K)}$), jute fibre mats, (ThermoNatur ThermoJute) ($\lambda_D = 0.042 \text{ W/(m·K)}$) or EPS WLG 040 (Bachl EPS 040 WZ) ($\lambda_D = 0.039 \text{ W/(m·K)}$) reach better values, but the mycelium-based materials studied still have great potential when using better suited additives in optimised amounts.

**Water Vapour Permeability**

To ensure climate-related humidity protection in the building sector according to DIN 4108-3 [7], knowledge of water vapour permeabilities of materials is indispensable. These characteristics are needed to mathematically prove potential risks (e.g. impermissible reduction of thermal protection, mould formation, corrosion).

To characterise water vapour permeability, water vapour diffusion resistance values were determined in line with DIN EN 12086 [8] at 23-0/50, i.e. at a temperature of 23 ± 1°C and a relative humidity of 0% on one side of the specimen and 50 ± 3% on the other side. Three specimens made of pure base substrate (designated CNC) were found to have a mean water vapour diffusion resistance $\mu$ of 48 with a standard deviation of 3.3. Three specimens with added perlite rock (designated D) reached a mean water vapour diffusion resistance $\mu$ of 43 with a standard deviation of 1.6. Figure 2 shows the prepared specimens (left and centre) and the mean water vapour diffusion resistances compared to conventional insulation materials (right). For thermal insulation layer thicknesses between 5 and 15 cm, water vapour diffusion-equivalent air layer thicknesses $s_d$ between 2.1 and 7.2 m result. This means that the component layer can be classified as diffusion-inhibiting layer according to DIN 4108-3 [7].

| specimen material                                    | $\mu$ [-] |
|------------------------------------------------------|-----------|
| mycelium-based material (pure base substrate (CNC))  | 48        |
| mycelium-based material (with perlite-additive (D))  | 43        |
| jute fiber insulation (ThermoNatur ThermoJute)       | 2         |
| wood fiber insulation board (Gutex Thermowall)        | 3         |
| EPS WLG 040 (Bachl EPS 040 WZ)                       | 70        |
Fig. 2 Specimens used for determining water vapour diffusion resistances (left and centre) and measured water vapour diffusion resistances compared to the corresponding characteristics of conventional insulation materials (right)

Capillary Water Absorption

In addition to determining water absorption of specimens after short partial immersion according to DIN EN ISO 29767 [9], two test series were carried out to determine water absorption coefficients according to DIN EN ISO 15148. Among others, the influence of the specimen surface was studied. Specimen surfaces produced by a saw cut were compared with “natural” surfaces covered by a mycelium layer (see Figure 3).

Fig. 3 Specimen surface cut by a saw (left) and “natural” specimen surface (right) used for determining capillary water absorption

The water absorption coefficient of mycelium-based material with a production-related “natural” surface is below 1.0 kg/(m²·h⁰.⁵). Specimens, whose surfaces were cut by a saw had up to 50% higher water absorption coefficients. A problem encountered in the tests was mould formation in the area of the capillary height after 24 hours already.
Discussion

In principle, production of mycelium-based materials is not complicated. However, production of the specimens has shown that mycelium-based material is highly susceptible to mould formation. Hence, highly sterile conditions are required when using mycelium-based materials.

Investigation of capillary water absorption revealed that the material is of hydrophobic character. Tests without the “natural” mycelium coating produced far higher water absorption coefficients. For this reason, hydrophobicity is explained by this outer layer. The main constituent of the outer mycelium layer is chitin, a water-soluble polysaccharide. In case of longer water contact, the chitin may be assumed to dissolve and water absorption properties of the surface will change. Specimens, whose surfaces were cut by a saw, exhibited first mould formation after 24 hours already. Hence, cutting of the materials is not recommended. Due to the simple and flexible production process, it is theoretically possible to produce custom-made elements of any shape, but local conditions may require unplanned adaptations, which is why this must be considered a drawback.

Recently, the fire behaviour of insulation materials was subject of many discussions. Most insulation materials have a critical fire behaviour. Studies of the fire behaviour of mycelium-based materials suggest that the outer mycelium layer carbonises when it is heated to high temperatures and, thus, forms a fire-retarding layer around the substrate [10]. It is not yet clear whether this is sufficient for use as a thermal insulation material in the building sector. Further studies are required.
Conclusions

The studies reported here have shown that properties of mycelium-based materials considerably depend on the composition of the substrate used. Addition of beech wood shavings to the base substrate produced a stable structure, but specimens were more difficult to cut with a saw. The results obtained confirm that mycelium-based materials are suited in principle for use as thermal insulation materials in the building sector from the physical point of view. Depending on material composition, conditioning, and test conditions, thermal conductivities range from 0.047 to 0.058 W/(m·K), which is quite good for insulation materials. Products based on polystyrene and mineral wool reach far better values of up to 0.032 W/(m·K) [11, 12], but mycelium-based materials still have a big optimisation potential.

Water vapor diffusion resistance $\mu$ of mycelium materials ranges from 40 to 50 and may be compared with that of polystyrene products. Using an exemplary wall structure, components were verified and compliance with the requirements outlined in DIN 4108 was confirmed [1]. The water absorption coefficient depends on the surface properties of mycelium-based materials. If materials have to be cut, measures should be taken to protect the cut areas against moisture.
Methods

As little is known about the use of mycelium-based material for building, the tests reported here were carried out in two stages. Various substrate compositions, production methods, and testing methods were used in preliminary experiments. In the main experiments, the methods were optimised based on the findings obtained from the preliminary tests and important physical properties were determined.

The basis of all substrates was a pre-cultivated substrate made of crushed hemp straw on which the oyster mushroom (Pleurotus ostreatus) was grown. This base substrate was mixed with various additives in the form of organic waste or by-products. Finally, beech wood shavings, rice husks, and coffee silver skin additives were used. One substrate was mixed with bloated perlite rock. Moreover, wheat flour was added to all substrates in order to provide the fungus with the carbon chains needed for growth. Figure 4 shows the substrate compositions selected (left) and the specimens produced.

| substrate material       | A  | B  | C  | D  | E  |
|--------------------------|----|----|----|----|----|
| base substrate           | 67 | 67 | 67 | 67 | 50 |
| beech wood shavings      | 33 | 0  | 0  | 0  | 13 |
| rice husks               | 0  | 33 | 0  | 0  | 13 |
| coffee silver skin       | 0  | 0  | 33 | 0  | 13 |
| perlite                  | 0  | 0  | 0  | 33 | 13 |

As obvious from Figure 4 (right), specimens of substrates with beech wood shavings and perlite rock exhibited smallest contaminations with foreign organisms. As the specimens with perlite rock have a comparably small mass-related humidity content, the main tests were carried out using specimens with perlite rock and specimens made of pure base substrate for comparison. After a growth phase of six days at 20°C and 70% relative humidity, these were dried at 93°C. Then, thermal conductivity, water vapour permeability, and capillary water absorption were measured.

Tests to determine thermal conductivity were carried out in accordance with the DIN EN 12664 standard for thermal insulation materials [6] using the instrument \( \lambda \)-Meter EP500e by Lambda-Messtechnik GmbH. To keep the mass constant during measurement, the specimens were wrapped with PE foil and then installed in the centre of the instrument.
Thermal conductivity was measured for dry and wet specimens at specimen centre temperatures of 10°C and 23°C.

Water vapour diffusion resistances were determined according to DIN EN 12086 [8]. For this purpose, cylindrical specimens were embedded in wax on one side and then fixed on a vessel with calcium chloride desiccant in an air-tight manner. From the mass variations measured, the water vapour diffusion coefficient was determined for subsequent calculation of the water vapour diffusion resistance and the water vapour diffusion-equivalent air layer thickness.

To determine the capillary water absorption behaviour, area-related water absorption was determined after short partial immersion and the water absorption coefficient was calculated taking into account the root of the time according to DIN EN ISO 15148 [13]. The tests were carried out using specimens with an undamaged outer mycelium layer and specimens with a saw-cut surface having no “natural” mycelium layer.
Declarations

Authors’ contributions

All authors read and approved the final manuscript.

Acknowledgements

The authors thank Mr. B.Sc. Roman Ficht for carrying out most of the measurements in the course of his bachelor’s thesis.

Competing interests

The authors declare no competing interests that could have appeared to influence the work reported in this paper.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

Ethics approval and consent to participate

Not applicable.

Funding

No funding.
Additional files

Not applicable

Figure captions

Figure 1: λ-Meter EP500e used to measure thermal conductivity (left) and the values measured in the substrate at a specimen centre temperature of 10°C (D = specimen with added perlite rock, CNC = pure base substrate, CNC-P = base substrate of increased packing density)

Figure 2: Specimens used for determining water vapour diffusion resistances (left and centre) and measured water vapour diffusion resistances compared to the corresponding characteristics of conventional insulation materials (right)

Figure 3: Specimen surface cut by a saw (left) and “natural” specimen surface (right) used for determining capillary water absorption

Figure 4: Substrate compositions studied (left) and specimens used to determine thermal conductivities (right)
Bibliography

[1] Ficht R. „Untersuchungen zu bauphysikalischen Eigenschaften von Materialien auf Pilzmyzel-Basis im Hinblick auf deren Nutzbarkeit als alternatives ökologisches Wärmedämmmaterial“. Bachelor thesis at the Institute of Concrete Structures and Building Materials (IMB) & Materials Testing and Research Institute (MPA). Karlsruhe Institute of Technology (KIT). 2019.

[2] Bürger V, Hesse T, Quack D, Palzer A, Köhler B, Herkel S, Engelmann P. Klimaneutraler Gebäudebestand 2050. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Dessau-Roßlau. Februar 2016. http://www.umweltbundesamt.de/publikationen/klimaneutralergebaeudebestand-2050.

[3] Struktur der Wärmedämmverbundsysteme in Deutschland nach Dämmstoffart 2013 I Statistik. https://de.statista.com/statistik/daten/studie/310349/umfrage/anteil-derverbauten-daemmstoffarten-in-deutschland/. Accessed 12 Sept 2019.

[4] Ökobaudat, EPS-Hartschaum (Styropor *) für Decken/Böden und als Perimeterdämmung B/P-035 (de). https://www.oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=ee10b277-07b5-4c0a-8a48-e0412a9630ff&stock=OBD_2019_III&lang=de. Accessed 25 Sept 2019.

[5] MycoComposite™ - Ecovative Design. https://ecovativedesign.com/mycocomposite. Accessed 25 Sept 2019.

[6] DIN EN 12664:2001-05. Bestimmung des Wärmedurchlasswiderstandes nach dem Verfahren mit dem Plattengerät und dem Wärmestrommessplatten-Gerät. Beuth Verlag GmbH. 2001.

[7] DIN 4108-3:2018-10. Wärmeschutz und Energie-Einsparung in Gebäuden – Teil 3: Klimabedingter Feuchteschutz – Anforderungen, Berechnungsverfahren und Hinweise für Planung und Ausführung. Beuth Verlag GmbH. 2018.

[8] DIN EN 12086:2013-06. Wärmedämmstoffe für das Bauwesen – Bestimmung der Wasserdampfdurchlässigkeit. Beuth Verlag GmbH. 2013.

[9] DIN EN ISO 29767:2019-11. Wärme- und feuchtetechnisches Verhalten von Baustoffen und Bauprodukten – Bestimmung des Wasseraufnahmekoeffizienten bei teilweisem Eintauchen. Beuth Verlag GmbH. 2019.

[10] Jones M et al. Thermal Degradation and Fire Properties of Fungal Mycelium and Mycelium – Biomass Composite Materials. Sci Rep. Jg 8. Nr 1. p 17583. http://www.nature.com/articles/s41598-018-36032-9. 2018.

[11] KARL BACHL GmbH & Co KG. Hg. Herstellererklärung zum Bauprodukt BACHL EPS Fassadendämmplatte EPS 032 WDV. Nov 2017.

[12] Deutsche ROCKWOOL GmbH & Co KG. Hg. Technisches Datenblatt Putzträgerplatte Coverrock. Jun 2019.

[13] DIN EN ISO 15148:2018-12. Wärme- und feuchtetechnisches Verhalten von Baustoffen und Bauprodukten – Bestimmung des Wasseraufnahmekoeffizienten bei teilweisem Eintauchen. Beuth Verlag GmbH. 2018.