PROPERTIES OF MYCELIUM-COMPOSITE BIOBASED INSULATION MATERIALS WITH LOCAL ORGANIC WASTE STREAMS AS SUBSTRATE AND AFTER USE FOR MUSHROOM CULTIVATION.

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Abstract

Mycelium is the vegetative part of a fungus, consisting of a fibrous, dense network, enveloping and attaching itself to organic matter. When grown on a fibrous substrate material and subsequently dried a composite material is created with the fungus acting as the binder. The material its thermal and acoustic insulating properties in combination with the fire-retarding property of the mycelium make these foam-like composites suitable as circular bio-based insulation material. Currently the manufacturing of these composites is expensive relative to other circular insulation materials and conventional insulation materials. This research investigates two possible approaches with the intend to reduce manufacturing costs of mycelium composites: Approach I) Enabling the use of less expensive substrate materials. By using local waste streams instead of primary products material and transport costs can be reduced. Approach II) Using the fungus for both mycelium production and mushroom cultivation. By using *Pleurotus ostreatus* (oyster mushroom) as the binding fungus the developed material can be used for both the cultivation of oyster mushrooms and the intended insulation material. To enable approach I) two local waste streams are identified as suitable substrates in the Netherlands: Tomato stems from greenhouse horticulture and reed from waterfront maintenance by the local Water Board. Tomato stems, reed and the conventional straw are used to grow mycelium composites, with *P. ostreatus* as the binding fungus. Samples are grown until suitable for insulation and partly used to grow mushrooms. For all samples the thermal insulating properties are defined by measuring the thermal conductivity.

Keywords:

Mycelium, Mycelium-composites, Circular, Insulation, Characterization

1 INTRODUCTION

In current practice, mainly mushroom forming white-rot fungi are used in the production of mycelium composites. This is due to their ability to degrade lignocellulose containing materials, such as straw, sawdust [Appels 2019], rice hulls [Jones 2017]. or cotton [Girometta 2019]. This makes it possible to grow the fungus on various existing biomass waste streams. The fungus colonizes the material (substrate) by expanding its network of thin, filamentous cells called hyphae. These hyphae attach to the substrates and secrete enzymes that convert the substrate into nutrients for the fungus. This way the substrate is slowly broken down into nutrients as the amount of mycelium increases. As the mycelium 'root-network' connects itself in this process to all the fibers in the substrate, it acts as a natural glue. The growth process is stopped by heating and/or drying the material [Appels 2019]. With the right application exploiting the characteristics of mycelium composites, fungus can be used to upcycle various agricultural and industrial waste streams. Mycelium composites have promising fire retardant properties exceeding that of XPS foam [Jones 2017].. Mycelium composites have thermal insulation properties in a range that overlap that of other biobased insulation materials, see Tab. 1. However the substrate type does affect the insulating properties of the composite [Elsacker under review][Girometta 2019].

Tab. 1: λ values of biobased insulation materials.

Biobased insulation material	λ value [W/K*m]
Mycelium	0.040 – 0.081
Cork	0.039 – 0.046
Flax	0.039
Wood fibre	0.040-0.044
Straw	0.045-0.080
Reed	0.080

1.1 Insulation

The material its thermal insulating properties in combination with the fire-retarding properties and possibility to upcycle a wide variety of current biomass waste streams, make mycelium a potential biobased insulation material for a circular and/or local built environment. Currently there are several manufacturers offering mycelium products commercially. Regarding the current commercial price of mycelium, the material is currently a factor 10 more expensive per set volume than other biobased insulation materials. This research investigates two possible approaches to reduce the costs of mycelium composites:

I) Enabling the use of less expensive substrate materials. Current mycelium-based insulation products use straw, hemp and cotton as substrate which are primary/valuable products. By using (local) waste streams instead of primary products material and transport costs can be reduced.

II) Adding a second business model by using the fungus for both insulation production and mushroom cultivation. By using *Pleurotus ostreatus* (oyster mushroom) as fungus, the developed material could be used for both the cultivation of oyster mushrooms and the intended insulation material.

2 MATERIALS AND METHOD

To enable approach I) two lignocellulose rich waste streams are identified as suitable substrates in The Netherlands: Tomato stems from greenhouse horticulture, of which The Netherlands produces 38.000 ton annually (32 ton/year/ha,1192 ha in the Netherlands and reed from waterfront maintenance by the local Water Board, which is a 20.000 ton per year waste stream. Tomato stems, reed and the conventional straw are used to grow mycelium composites, with *P. ostreatus* as the binding fungus.

2.1 Mycelium and mushroom growth

To prepare the substrates, 2/3 in volume of dried tomato stems, reed or straw (in non-compressed state) is mixed with 1/3 dried hemp flax. Water is added until the mixtures contained 65 weight percent water. The wet substrate is pasteurized, then *P. ostreatus* spawn is added, 5 weight percent of the weight of the wet substrate. The material is left for 5 days to enable the spawn to colonize the substrate. Then the colonized substrate is placed inside thermoformed PMMA molds, for the second growth stage of 7 days. The samples are then dried at 60 degrees. To determine if identified biomass streams are suitable for oyster mushroom cultivation (approach II), another batch is grown in a similar process, but with an additional third growing stage in which the fungus were triggered into mushroom forming, before the samples were dried.

2.2 Thermal conductivity

Thermal conductivity is determined with a steady state one-dimensional test setup. Test setup had known power input (Q), temperatures of both sides of the insulation (T1 and T2) and sample surface (A) and depth (l) were measured. Consequently thermal conductivity (λ) could be calculated with formula (1).

$$\lambda = \frac{Q*l}{A*(T2-T1)} \qquad (1)$$

3 RESULTS

P. ostreatus completely covered the substrates in the growth phase. Observed mycelium growth was similarly for both reed and tomato stem samples. Samples triggered into mushroom growing all developed oyster mushrooms. A dried sample with reed substrate reed and a tomato substrate sample after mushroom growth are shown in Fig. 1.

Fig. 1: Left: dried sample with reed substrate. Right: tomato substrate sample after mushroom growth

3.1 Thermal insulation

Tab. 2 shows the average measured lambda values of the four varieties of samples.

Tab. 2: Measured λ values

Sample type	λ value [W/K*m]
P. ostreatus – Tomato	0.05
P. ostreatus – Reed	0.05
P. ostreatus – Tomato after mushroom growth	0.06
P. ostreatus – Reed after mushroom growth	0.07

4 DISCUSSION

Observations of the mycelium growth indicate that both reed and tomato stems are suitable substrates for mycelium composites with *P. ostreatus* as the binding fungus, indicating the potential of Approach I). The potential for a second business model of mushroom cultivation with used substrates is possible, although results indicated that mushroom growth on the composite negatively affects its thermal insulation properties. This could be explained by the physical change of the substrate due to the mycelium extracting nutrients during the mushroom forming phase. Further research is required to confirm this. To further explore Approach II), food safety tests and long term yield test should be done to determine the oyster mushroom yield on defined substrates. Found lambda values of composites with reed as substrate have similar lambda values similar to reed. Both reed- and tomato-based composites have values about 30% higher than the values of other (cork, flax, wood fibre) biobased insulation materials.

5 REFERENCES

[Appels 2019] Appels, F.V.W.; Camere, S.; Montalti, M.; Karana, E. et al; Fabrication factors influencing mechanical, moisture- and water-related properties of mycelium-based composites. Materials & Design, 2019, 161, 64-71

[Girometta 2019] Girometta, C.; Picco, A. M.; Baiguera, R. M.; Dondi, D. et al. Physico-Mechanical and Thermodynamic Properties of Mycelium-Based Biocomposites: A Review. Sustainability 2019, 11, 281.

[Jones 2017] Jones, M. ; Bhat, T. ; Wang, C. H. ; Moinuddin, K. et al. THERMAL DEGRADATION AND FIRE REACTION PROPERTIES OF MYCELIUM COMPOSITES. 21st International Conference on Composite Materials Xi'an, 20-25th August 2017