Development of a myco-material based on textile and agro-industrial waste for thermal insulation

Tomas Simon Gomez [1*], *Luis Miguel* Garcia[2], *Camilla* Vertua[3], *Luis Maria* del Pilar Rivera[2], *Juan Camilo* Oviedo[2], *Carol* Monticelli[3], *Christ* Glorieux[1], and *Nelson* Escobar[2]

[1]Sciences Physics and Astronomy, Laboratory of Acoustics, KU Leuven, Heverlee, Belgium, 91944 Les Ulis Cedex A, France
[2]Escuela de Ingeniería Universidad Pontificia Bolivariana, Medellin, Colombia, Production Department, 91944 Les Ulis Cedex A, France
[3]Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy

Abstract. The European Union is promoting the increased use of thermal insulation to ensure energy conservation in the coming years. This will drive increased demand for materials suitable for such applications. However, the rise in the production of goods combined with the prevalent use of non-renewable resources in thermal insulation pose environmental challenges, leading to increased pollution and solid waste accumulation. In response, this study focuses on developing and characterizing a sustainable, biodegradable mycelium-based composite for thermal insulation. The bio-composite, cultivated from Pleurotus Pulmonarius fungus in agro-industrial and textile waste, offers a promising approach. In this work, two distinct combinations of substrates were utilized: one comprising 70% grass cuttings and dry leaves, along with 30% recycled ground textile, predominantly polyester; the other consisting of 70% sugarcane bagasse and 30% ground textile waste. Additionally, an extra 20% of the substrate weight of Pleurotus Ostreatus grain spawn was added to each combination to facilitate mycelium growth. The mycomaterials were tested for tensile and compression analysis (ASTM D3039 and ASTM D695 standards, respectively) and a thermal conductivity assessment (ISO 8301) was done. The materials showed better performance at compression tests than tensile test. Also, results demonstrate the superior performance of sugarcane bagasse mycelium composites over the dry leaves/grass cutting counterparts in thermal conductivity, tensile and compression tests. The inclusion of synthetic fibres to the mycelium composite may have compromised the mechanical and thermal properties of the samples as polyester fibres have a higher thermal conductivity than the natural components included in the sample. The fibres being synthetic, the mycelium could not feed on it, thus impeding binding and proliferation in some sections of the material.

1 Introduction

In recent years, the necessity to reduce energy consumption related to the construction sector led to strategies aimed at buildings energy conservation. In this regard, one of the cheapest and fastest solutions to improve buildings' energy efficiency concerns the implementation of insulating material on façade systems. However, as buildings increasingly prioritize energy efficiency, the intense utilization of traditional fossil-based insulating materials poses environmental challenges, leading to increased embodied carbon emissions and solid waste accumulation.

To mitigate embodied emissions, studies have demonstrated the efficiency of substituting fossil-based materials with bio-based ones due to their carbon storage potential and reduced life-cycle emissions [1], [2]. Among the different biogenic materials, lignocellulosic ones gained specific attention for construction applications, due to their favourable thermal and acoustic properties, and to their constant availability as residues, coming both from the agro-industrial and forestry sectors.

Indeed, producing totally bio-insulating panels by means of lignocellulosic residues and a natural binder might enhance construction dynamics, while reducing the operational carbon of buildings and avoiding, at the same time, additional embodied carbon for their production.

With respect to natural binders, both research (https://www.fungar.eu/, https://mycl.bio/), [3], [4], [5] and industries (https://www.ecovative.com/, https://mogu.bio/) have shown a raising interest in mycelium, applied for replacing non-sustainable products. Mycelium is the biodegradable vegetative part and root structure of fungal organisms [6] and it has the capacity to both grow on and be incorporated into lignocellulosic bio-composite systems. By doing so, it connects bio-particles and thus enables the production of totally plastic free material composites for thermal and acoustic insulation, with a consequent upcycling of lignocellulosic residues. Research on mycelium composites is promising, due to their biodegradability and to their low environmental impact and carbon footprint, [7], [8]. Moreover, differently from most of the documented bio-composite materials, mycelium-

* Corresponding author: tomas.gomez@kuleuven.be

based composites have been proven to be less prone to ignition and flaming combustion, with degradation starting at temperatures above 220 ◦C [9]. In addition to biodegradation in the matter of weeks as seen in the disintegration in soil test, while maintaining its integrity when not in contact with the elements [10], [11].

In this framework, this paper has thus the aim to enrich the research landscape on the topic, by developing and characterizing a sustainable, biodegradable, carbon-storage mycelium-based composite for thermal insulation. More specifically, this study focuses on the development and thermal and mechanical characterization, (by following ISO 8301 for thermal conductivity assessment, and ASTM D3039 and ASTM D695 standards, for compression and tension respectively), of a bio-composite made of Pleurotus Pulmonarius fungus combined to textile wastes agro-industrial and textile waste, showing an instance of a research development within the technology readiness level (TRL) 3, which accounts for proof of concept. An experimental design with 1 factor and 2 levels was developed in which the proportion of constituents was fixed but the main lignocellulosic substrate was changed to evaluate the effectiveness of each combination for the intended case.

2 Materials and methods

The sample production system made use of solid-state fermentation of the fungus Pleurotus Pulmonarius in selected waste materials. This approach involves the collection of agro-industrial and textile residues; processing these residues, followed by pasteurization (to deactivate traces of unwanted microorganisms) and subsequent substrate preparation. An experimental design with 1 factor and 2 levels was developed in which the proportion of constituents was fixed but the main lignocellulosic substrate was changed to evaluate the effectiveness of each combination for the intended case. Sugarcane bagasse was obtained from street vendors; grass cuttings and dry leaves were obtained from the organic waste disposal facilities of the Universidad Pontificia Bolivariana, and the recycled ground textiles were provided by a textile company within Medellín. For the processing of the residues, sugarcane bagasse was shredded into 10 cm long strips, also, any possible non-organic residues that were mixed with the grass cuttings and dry leaves were removed; recycled ground textile was already processed by the provider.

The pasteurization of the residues involved a high temperature and pressure treatment for 45 minutes. After pasteurization, excess moisture was extracted from the residues. Following pasteurization, the substrates were made with a combination of 30% recycled ground textile and 70% lignocellulosic substrate, either grass cuttings dry leaves or sugarcane bagasse, respectively.

These samples were then inoculated with Pleurotus Pulmonarius grain spawn, with an amount corresponding to 20% of the sample’s mass. The cultures were then covered with black bags, to regulate light radiation and oxygen levels, and stored in conditions conducive to fungal growth.

Over 45 days, the cultivation samples were monitored, tracking the growth of mycelium and preventing contamination by other microorganisms. Any fruiting bodies produced during this period were removed. After the cultivation period ended, the samples went through a dehydration process in a convection oven at a constant temperature of 65°C for 24 hours. This process deactivates the fungus while preserving the mycelium, resulting in the production of a mycomaterial, thus, the material does not generate any fruiting body, which is the section of a fungi that generates and disperses spores in this species. The resulting samples had a density of 153 kg/m³.

For the analysis of mechanical properties, tensile and compression tests were conducted following the standard procedure of ASTM D3039-08 and D695-23, respectively.

The thermal conductivity test was conducted using a P.A. HILTON H112A Linear Heat Conduction machine following ISO standard 8301. Test specimens with a diameter of 2.2 cm and a thickness of 0.8 cm were prepared for this procedure.

3 Results

2 mycomaterial variants were made, Figure 1 shows significant mycelial growth in both the grass cuttings, dry leaves and sugarcane bagasse combinations with ground textile and Pleurotus Pulmonarius fungi. The mechanical properties of the mycomaterials are presented in Table 1, there is a notable difference between the sugarcane bagasse and grass cuttings with dry leaves variants.

Table 1. Mechanical strength of mycomaterials.

Sample	Maximum compression strength (kPa)	Maximum tensile strength (MPa)	Elastic modules (MPa)
Grass cuttings/ dry leaves	150.89 ± 161.78	0.01 ± 0.01	0.91 ± 0.01
Sugarcane bagasse	112.22 ± 146.97	0.02 ± 0.01	10.54 ± 3.69

Sugarcane bagasse exhibits superior mechanical properties, possibly due to its fibrous nature, essential for supporting the plant's structure. Conversely, grass and dry leaves, originating from less mechanically demanding parts of plants, demonstrate comparatively lower mechanical strength. Still, sugarcane bagasse, being a byproduct of sugar extraction, undergoes significant processing, potentially compromising its mechanical integrity. However, under compression, both substrates have similar behaviour. The elastic modulus of the developed materials was compared with values found in literature and were found to be higher to those reported in [12] (0.57 MPa).


Fig. 1. (left) Grass cuttings and dry leaves with grounded recycled textile and Pleurotus Pulmonarius mycomaterial, (right) sugarcane bagasse with grounded recycled textile and Pleurotus Pulmonarius mycomaterial.

Table 2 shows the average thermal conductivity for both materials. The insulating performance of the sugarcane bagasse variant is better than that of the grass cutting with dry leaves. However, the obtained thermal conductivity is much higher than those reported by [12] (0.08), [13] (0.09), [14] (0.25-0.06), which could be due to several reasons. First the sample's density, as the density is higher thermal conductivity tends to increase, the fabrication method for the mycomaterial on this paper is similar to those studies mentioned above, thus, the main difference would be the inclusion of the grounded recycled textile which is of synthetic origin and higher thermal conductivity than most lignocellulosic substrates.

Table 2. Thermal conductivity of mycomaterials.

Sample	Thermal conductivity (W/mK)
Grass/cutting dry leaves	1.04 ± 0.17
Sugarcane bagasse	0.85 ± 0.02

4 Conclusion

This paper showcased the creation of a sustainable construction material using easily accessible residues like leaves and grass, emphasizing the potential for a new eco-friendly alternative with minimal carbon footprint. This initiative aimed to repurpose common waste materials to promote sustainability in construction, advocating for reduced reliance on resource-intensive methods.

Throughout all tests conducted, the sugarcane bagasse material consistently outperformed the samples containing grass cuttings and dry leaves in terms of thermal isolation and mechanical strength, indicating a trend towards the superior performance of sugarcane bagasse in this context. Thus, increasing the fibrous substrate, as evidenced by the performance of sugarcane bagasse samples, could improve mechanical properties in various materials. The inherent fibrous structure of sugarcane bagasse provides reinforcement, enhancing the material's strength.

The drying process of the sample and the autoclaving of the substrate are 2 CO2-intensive aspects of production, which could be mitigated using a CO2 neutral solar oven given the low drying temperatures. However, this still pose a notable challenge to scaling up operations at an industrial level, nevertheless, the method remains economically viable, due to the ability of mycelium to grow on and bind low-value agricultural and industrial waste materials, converting them into valuable composite materials for various applications..

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