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REVIEW OF MYCELIUM COMPOSITES AND THE INFLUENCE OF THEIR MICROTEXTURE ON MECHANICAL PROPERTIES

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Abstract. This review article aims to evaluate the application potential of mycelium-based biocomposites and to determine how their microtexture influences key mechanical properties. The objective of the study is to synthesize current scientific knowledge on the relationship between fungal growth characteristics and the resulting material performance. The analysis draws on recent research examining how fungal species, substrate composition, and growth conditions shape microstructural features such as hyphal density, pore distribution, and bonding patterns. These microtexture parameters directly affect compressive strength, elasticity, porosity, and the thermal and acoustic behavior of mycelium composites. The reviewed literature highlights the growing use of mycelium-based materials in construction, packaging, textiles, design, and biomedical applications, emphasizing microtexture as a critical determinant of functionality. The findings indicate that enhanced mycelial growth and optimized microstructural organization can significantly improve mechanical performance, making microtexture control essential for the development of durable and sustainable biocomposites.

Keywords: mycelium-based composite, fungal mycelium, microtexture.

1. Introduction

In recent years, fungal mycelium-based materials have gained significant attention from both the scientific community and industry due to their sustainability, low energy consumption during production, and potential to replace fossil-derived materials (Jones et al., 2020; Attias et al., 2020). The interconnected network of mycelial hyphae growing within lignocellulosic substrates forms lightweight, mechanically stable, and biodegradable composites, whose properties are strongly influenced by the fungal species, substrate composition, and cultivation parameters (Elsacker et al., 2019; Haneef et al., 2017). Owing to these characteristics, mycelium-based composites are increasingly recognized as a promising alternative to conventional synthetic materials such as polystyrene and polyurethane, particularly for applications in thermal and acoustic insulation (Appels et al., 2019; Jones et al., 2020). The growing interest in bio-based construction materials is also driven by the environmental impact of conventional building materials, which are responsible for a significant share of global greenhouse-gas emissions and resource consumption within the construction sector (UN Environment Programme, 2023).

Recent research demonstrates that mycelium composites can exhibit favorable mechanical, thermal, and acoustic performance, while the utilization of agricultural residues as feedstock contributes to waste valorization, reduction of environmental pollution, and the advancement of circular economy principles (Attias et al., 2020; Elsacker et al., 2019). Studies have also demonstrated that agricultural waste materials such as straw can be effectively used to produce impact-resistant mycelium-based composites with improved mechanical performance (Cai et al., 2023). Consequently, there is a growing need for a systematic evaluation of the structural, mechanical, and functional properties of mycelium-based composites, as well as a critical assessment of their application potential across various industrial sectors, including construction, packaging, textiles, and related fields (Heisel et al., 2017; Mohseni et al., 2023).

The aim of this study is to provide a comprehensive review of the application potential of mycelium-based

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biocomposites and to determine how their microtexture influences key mechanical properties. Specifically, the study seeks to synthesize current scientific knowledge on how different fungal species, lignocellulosic substrates, and cultivation conditions shape the microstructural organization of mycelium, and how these microtexture features affect the resulting material's mechanical, thermal, and acoustic performance.

2. Mechanical and structural characteristics of microtexture

Mycelium is the vegetative part of fungi and is composed from tube-like fibers of diameter of approximately 1 µm, called hypha. Hypha grow by apical tip elongation and occasionally branch out or merge with other hyphae, forming a random fiber network-like structure. The wall of a hypha consists of chitin nanofibrils which provide its stiffness and strength. Biologically active hyphae bind to and/or digest organic material by applying mechanical forces and secreting hydrolytic enzymes. Consequently, a natural composite system results in which mycelium functions as a supporting matrix embedding particles that function simultaneously as nutrition and reinforcement. Figure 1 illustrates mycelium composites containing agro-waste particles used as reinforcing components (Islam et al., 2018).

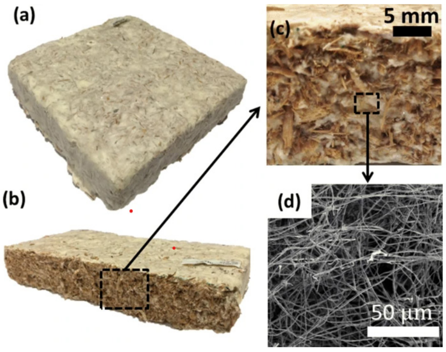

Figure 1. Mycelium composite at various scales: a) macroscale sample (6″ × 6″ × 1″); b) cross section of the macroscale sample (6″ × 1″); c) zoomed view (5 mm scale bar) of the cross section showing particle (brown) distribution within mycelium matrix (white); d) SEM micrograph of mycelium microstructure (50-µm scale bar)

Fungal mycelium is increasingly applied in engineering due to its ability to form lightweight, mechanically robust, and biodegradable composites capable of replacing conventional synthetic materials (Figure 2).

When manufacturing fungal mycelium composites, several material properties must be carefully considered, including mechanical performance, thermal conductivity, thermal degradation behavior, acoustic absorption, water absorption, and fire resistance (Jones et al., 2020; Pelletier, et al., 2013). Table 1 presents a critical evaluation of fungal mycelium composites in comparison with conventional synthetic materials such as polystyrene (PS), polyurethane (PU), and phenol-formaldehyde resin (PF), as well as wood-based products including plywood (PW), softwood (SW), and hardwood (HW) (Madusanka et al., 2024).

The sound absorption coefficient ranges from 0, indicating total sound reflection, to 1, indicating complete sound absorption. For mycelium composites, the sound absorption coefficient has not yet been clearly established. The mechanical properties of wood vary depending on the direction of loading-parallel (∥) or perpendicular (⊥) to the wood fibers. a) Raw material cost only. b) Sound absorption at 1000 Hz (Madusanka et al., 2024).

The data presented in Table 1 indicate that mycelium composites exhibit sound absorption values that are approximately 70–75% higher than those of conventional ceiling panels, plywood, or polyurethane foams (Manan et al., 2021). Experimental studies have also confirmed that mycelium-based composites cultivated on waste paper substrates demonstrate effective sound absorption

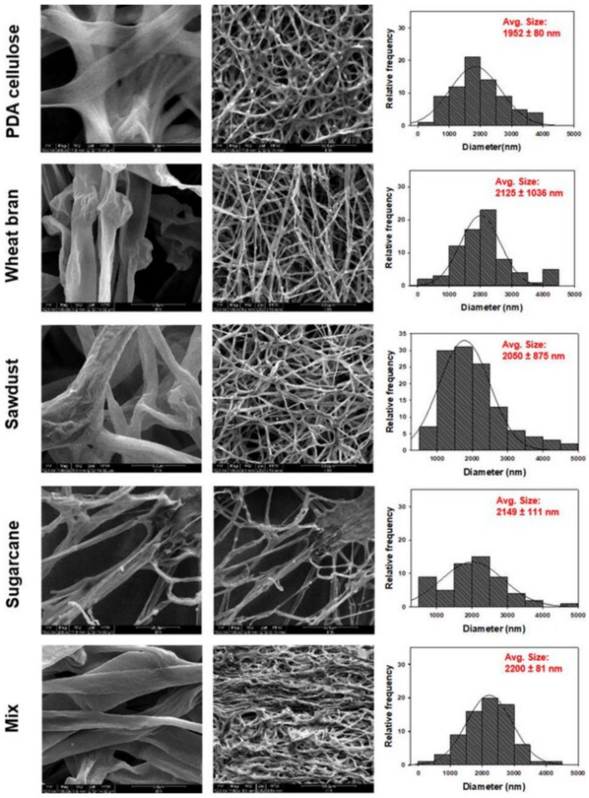

Figure 2. SEM images and diameter distribution of P. ostreatus mycelial hyphae cultivated on different lignocellulosic substrates (PDA cellulose, wheat bran, sawdust, sugarcane, and mixed substrate). SEM parameters: magnification ×5000; accelerating voltage 10 kV; working distance 10 mm. Samples were sputter-coated with a 10 nm gold layer prior to imaging. The histograms represent hyphal diameter distribution (n = 100 measurements per substrate), with mean values of 190.2 ± 50.8 nm (PDA cellulose), 210.8 ± 103.8 nm (wheat bran), 205.0 ± 97.9 nm (sawdust), 214.8 ± 111.0 nm (sugarcane), and 220.0 ± 89.8 nm (mixed substrate) (Joshi et al., 2020)

properties, highlighting their potential for acoustic insulation applications (Walter & Gürsoy, 2022). In addition, mycelium composites are characterized by exceptionally low raw material costs, ranging from 0.07 to 0.17 USD/kg, making them significantly more cost-effective than many conventional materials. In comparison, wood-based products are considerably more expensive, with hardwood priced at 3–11 USD/kg, softwood at 0.7–1.4 USD/kg, and plywood at 0.5–1.1 USD/kg. Synthetic materials exhibit even higher costs, including polystyrene (2.1–2.3 USD/kg), polyurethane (8.2–10.4 USD/kg), and phenol-formaldehyde resin (1.7–1.9 USD/kg). Considering their low material cost combined with favorable functional properties, mycelium composites are increasingly regarded as an economically viable, high-performance, and environmentally sustainable next-generation technology with significant potential to contribute to the future of sustainable construction.

Aiduang et al. (2022) reported that both fungal species and substrate type can directly influence the functional properties of fungal mycelium composites, ultimately affecting their applicability across a wide range of fields. Similar conclusions were reached by Bagheriehnajjar et al. (2023), who demonstrated that the composition of lignocellulosic substrates and manufacturing parameters significantly influence the mechanical performance and environmental footprint of mycelium-based bio-composites. In their study, the mechanical, physical, and chemical properties of mycelium composites produced from four fungal species – *Ganoderma fornicatum*, *Ganoderma williamsianum*, *Lentinus sajor-caju*, and *Schizophyllum commune* – combined with three different lignocellulosic residues (sawdust, corn cobs, and rice straw) were systematically investigated. The results demonstrated that variations in both fungal species and lignocellulosic substrate significantly affected the properties of the resulting mycelium composites. Composites produced from sawdust exhibited the highest density, while those based on *S. commune* combined with all three lignocellulosic residues showed the greatest shrinkage coefficients. The highest degree of water absorption was observed in rice straw-based composites, followed by those produced from corn cobs and sawdust. Furthermore, the thermal degradation temperatures of the mycelium composites ranged from 200 to 325°C, corresponding closely to the thermal degradation behavior of the respective lignocellulosic substrates. The highest compressive, flexural, and tensile strengths were observed in composites produced with *G. williamsianum* and *L. sajor-caju*. Notably, mycelium composites derived from corn cobs and combined with each fungal species exhibited the highest overall mechanical performance, including compressive, flexural, and tensile strength. Subsequent chemical analyses revealed that the pH, nitrogen content, and organic matter content of the resulting mycelium composites ranged from 4.67 to 6.12, 1.05 to 1.37%, and 70.40 to 86.28%, respectively. The highest electrical conductivity was observed in composites produced from rice straw.

Table 1. Comparison of material properties: Mycelium composites, wood-based products, and synthetic foams (Madusanka et al., 2024)

Material property	Mycelium composites	Wood-based products	Synthetic foams
Compressive strength (MPa)	0.17–1.1	SW: ∥ 35–43, ⊥ 3-9 HW: ∥ 68-83, ⊥ 12.7-15.6 PW: 8–25	PS: 0.03–0.69 PU: 0.002–48 PF: 0.2–0.55
Tensile strength (MPa)	0.03–0.18	SW: ∥ 60–100 ⊥ 3.2-3.9 HW: ∥ 11.32–16.2 ⊥ 7.1-8.7 PW: 10–44	PS: 0.15–0.7 PU: 0.08–103 PF: 0.19–0.46
Density (kg/m^3)	59–552	SW: 440–600 HW: 850–1030 PW: 460–680	PS: 11–50 PU: 30–100 PF: 35–120
Flexural strength (MPa)	0.05-0.29	SW: 9.9–11.5 HW: 10.3–11.5 PW: 35–78	PS: 0.07–0.70 PU: 0.21–57 PF: 0.38–0.78
Sound absorption	>70–75 %[b]	SW/HW: 0.05–0.15 PW: 0.1–0.23	PS: 0.2–0.6 PU: 0.2–0.8
Moisture absorption (%)	40–580	SW/HW: 5–190 PW: 5–49	PS: 0.03–9 PU: 0.01–72 PF: 1–15
Material cost (USD/kg)	0.07–0.17[a]	HW: 3–11 SW: 0.7–1.4 PW: 0.5–1.1	PS: 2.1–2.3 PU: 8.2–10.4 PF: 1.7–1.9
Biodegradability	All components	Wood components	None
Degradation time	Weeks–months	Years–decades	Decades–centuries
End-of-life management	Composting	Recycling, incineration, landfill	Recycling, incineration, landfill

Overall, the majority of the physical and mechanical properties of the produced mycelium composites were comparable to those of polyimide and polystyrene foams. Consequently, these composites demonstrate strong potential for use in the development of alternative material strategies aimed at effectively replacing conventional polyimide and polystyrene foams in future applications (Aiduang et al., 2022).

Fungal mycelium composites can achieve compressive strengths in the range of 0.5–1.2 MPa, with densities varying between 40 and 200 kg/m^3 (Elsacker et al., 2019). Thermal treatment at temperatures of 80–120°C has been shown to significantly reduce moisture absorption and enhance composite strength by a factor of two to three (Appels et al., 2019). Moreover, mycelium exhibits thermal insulation performance comparable to that of polyurethane foams or mineral wool, with thermal conductivity values (λ) ranging from 0.03 to 0.05 W/

mK, indicating its suitability as a sustainable insulation material for building applications (Babenko et al., 2024; Gauvin et al., 2021; Zhang et al., 2023). Studies have shown that the hierarchical porous structure of mycelium-based composites contributes to their lightweight character and enhanced thermal insulation performance (Zhang et al., 2023).

3. Investigation of the properties and applications of mycelium-based materials

3.1. Applications of materials

Mycelium composites have been extensively explored for applications in construction, packaging, textiles, and biomedical fields (Camilleri et al., 2025).

Biopackaging. In recent years, fungal mycelium–based composites have attracted considerable attention as a sustainable alternative to conventional plastic and polystyrene packaging materials. Such biopackaging solutions are characterized by low density, good impact- and energy-absorbing performance, and complete biodegradability under natural environmental conditions. Moreover, they are produced using agricultural residues (e.g., straw, sawdust), thereby contributing to the implementation of circular economy principles and the reduction of waste generation (Jones et al., 2020). Unlike synthetic materials, mycelium composites contain no toxic additives, and their production process requires significantly lower energy inputs, further enhancing their environmental advantages.

Building materials. In the construction sector, fungal mycelium composites are being investigated as alternative insulation and semi-structural materials. Scientific studies indicate that mycelium-based panels exhibit effective thermal insulation and measurable sound absorption performance comparable to that of conventional mineral wool materials (Appels et al., 2019; Walter & Gürsoy, 2022). From a mechanical perspective, mycelium composites can be compared to particleboard, particularly when substrate composition and growth conditions are optimized. Although these materials are currently employed primarily in experimental or temporary structures, their potential applications in sustainable building systems are being extensively explored.

Textiles and design. In the fields of textiles and design, mycelium is increasingly employed as an innovative, sustainable, and vegan alternative to natural leather. In textile-related applications, mycelium-based materials are investigated for their tunable microstructure, mechanical flexibility, and potential to form uniform, leather-like sheets through controlled growth and post-processing. Studies report that mechanical performance, density, and surface morphology can be adjusted through substrate selection, growth duration, and pressing or coating treatments, making these materials suitable for engineered bio-based laminates (Jones et al., 2020).

Medical applications. Due to its natural origin, porous architecture, and biocompatibility, fungal mycelium is also being explored in the field of biomedicine. Research indicates that mycelium-based structures can be tailored for applications such as wound dressings, bioactive surfaces, and tissue engineering scaffolds. Haneef et al. (2017) demonstrated that mycelium-derived structures provide a favorable microenvironment for cell adhesion and proliferation, suggesting their potential use in regenerative medicine. Although these applications are still at an early stage of development, their potential for future biomedical solutions is regarded as highly promising.

Scientific studies indicate that the majority of mycelium composite applications are currently found in insulation materials, small consumer-goods packaging, acoustic solutions, and sustainable architecture, as these application areas do not require high mechanical strength. However, to enable the use of mycelium composites in load-bearing or high-strength structural applications, further research and the advancement of manufacturing technologies are required. In addition, an analysis of the reviewed scientific literature suggests that the most commonly used substrates include sawdust, straw, and sugarcane bagasse, owing to their high lignocellulosic content and suitability for mycelial growth, which directly contributes to improved mechanical performance. Moreover, increased mycelial growth density is generally associated with higher compressive strength. Table 2 summarizes recent literature demonstrating how biodegradable mycelium-based materials are already being successfully applied – or show strong potential for application – in the construction sector as alternatives to conventional building materials (Camilleri et al., 2025). Several studies have demonstrated the feasibility of using mycelium-based composites in architectural applications. For example, Heisel et al. (2017) reported the development of the MycoTree, a load-bearing mycelium-based structural system designed through informed structural engineering. Other research has explored modular construction components, 3D-printed mycelium elements, and bio-fabricated panels suitable for lightweight architectural applications (Mohseni et al., 2023; Lingam et al., 2023).

3.2. Methodology for material property characterization

Based on the conducted literature review, the compressive strength of mycelium-based materials is reported to range between 0.5 and 1.2 MPa. The compressive strength ($\sigma_{u,c}$) is defined as the ratio of the applied axial compressive force to the cross-sectional area of the specimen.

$$\sigma_{u,c} = \frac{N}{A}, \tag{1}$$

where N – the axial force acting on the specimen; A – the cross-sectional area of the specimen.

Table 2. Mycelium-based composites with different fungi and substrates

Fungal species	Substrate	Product/Application	Results
Pleurotus ostreatus	Waste cardboard	Acoustic panels	The MBCs were successfully used to replace the petrochemical-based materials within the architectural industry for sound-absorbing properties. The MBCs performed well structurally and acoustically.
Pleurotus ostreatus	Bagasse, coconut husk, Juncao grass, mixture of coconut husk and bagasse. Rice husk was added to all for mycelium nutrients.	Insulating material, Packaging of small consumer goods, False ceiling.	Juncao grass – flexural strength = 399.39 kPa, compressive strength = 783.4 kPa. Bagasse MBC showed good fire resistance properties. These MBCs can successfully replace non- biodegradable and high-cost products such as Styrofoam, asbestos ceiling tiles, blown mineral fiber, polystyrene beads and urea formaldehyde foam.
Mycelium growing kit was used.	Hemp	Modular and interlocking components used in sustainable architectural application. Do not require the use of fasteners.	Hemp substrate showed very good stiffness and can be easily assembled and disassembled. This MBC can replaced the use of expansive materials such as aluminum, copper, etc. used for architectural applications. One such example is the use of MBC material to build the "MycoTree" at the Seoul Biennale of Architecture and Urbanism.
Pleurotus ostreatus	Waste cardboard	3D-printed MBCs	They work showed successful production of MBCs using 3D printing that can eliminate the wastage of the mould if the moulds are not reusable or recyclable. Further, this technique can print intricate and complex geometries.
Ganoderma lucidum	Rice straw, wheat straw, corn straw	Thermal insulation material, construction materials.	The manufactured MBCs have promising thermal degradation and fire resistance properties. Can successfully replace polyurethane foam as commercial insulation material. Rice and wheat straw MBCs compressive strength =6.4 MPa. This is equivalent to clay brick and higher than EPS panel.
Fomitopsis Pinicola, Agaricus bisporus, Trametes versicolor	Sawdust, bamboo, wood shavings	Construction materials.	Maximum tensile strength achieved = 0.49 MPa. Recommendation is to further develop MBCs to improve its mechanical properties to incorporate it in construction industries.
Trametes versicolor	Poplar and birch Sawdust	Thermal insulation material, Packaging, Construction materials	Excellent thermal insulating properties were found, better than expanded polystyrene (EPS). Can successfully replace plastics used in packaging.

The force acting on the specimen is determined from the compression stress-strain diagram. Figure 3 illustrates generalized stress-strain curves for ductile and brittle materials, commonly used in the characterization of low-density bio-composites. These curves are included to explain deformation mechanisms relevant to mycelium-based materials as reported in prior research.

It can be stated that some materials exhibit both ductile and brittle material. After testing a real specimen of the mycelium composite and describing stress strain curve we will investigate deformation behavior.

However, two key aspects must be considered when testing mycelium composites under compression:

Relatively low strength, which necessitates the application of low compressive forces and the use of specimens with a larger cross-sectional area.

Material heterogeneity and non-uniformity, which require the use of the actual cross-sectional area A_{netto} rather than the nominal measured area A_{bruto} measured.

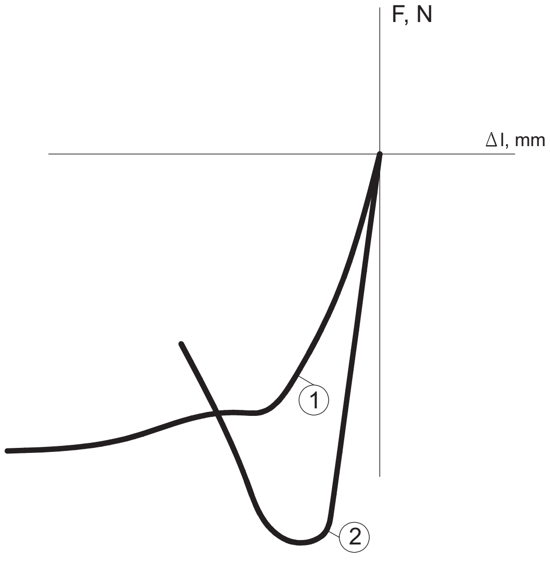

Figure 3. Compression diagrams

Determining the real cross-sectional area can be challenging, and due to the inherent porosity of the material, image-based analysis or graphical recognition software may be required.

The application of low compressive forces does not pose significant difficulties, as universal testing machines equipped with appropriate grips can operate at forces as low as 10 N with an accuracy of approximately 1%. However, when testing low-strength materials, the specimen cross-sectional area must not be smaller than:

$$A > \frac{N}{\sigma_{u,c}}. \tag{2}$$

Accordingly, when testing materials with a compressive strength of approximately 0.1 MPa using a maximum applied force of 2000 N, the specimen cross-sectional area must be no less than 40 cm². Therefore, compressive strength should be determined using specimens with a square cross-section, with a side length exceeding 7 cm. In practice, and in the present study, a square cross-section with a side length of 10 cm is adopted. An additional advantage of using a larger cross-sectional dimension is the ability to calculate a more accurate effective cross-sectional area A_{netto}.

When performing a compression test on a relatively ductile material, the determination of an appropriate failure criterion is of critical importance. In the absence of a clearly defined yield point, the failure criterion is defined as the point at which a noticeable increase in the slope of the stress-strain curve is observed.

4. Conclusions

Mycelium composites represent an environmentally sustainable alternative to conventional plastics and synthetic materials, contributing to the advancement of the circular economy and the achievement of the United Nations Sustainable Development Goals. The composition of the substrate, environmental growth conditions, and thermal treatment enable targeted control of the mechanical and physical properties of these composites.

Research on mycelium-based materials provides a foundation for the development of innovative, biodegradable materials capable of replacing polystyrene, polyurethane, and other fossil-derived products. Such biocomposites can be applied in the production of packaging, construction materials, textiles, and biomedical products, while offering natural biodegradability and reduced energy consumption during manufacturing.

From a structural perspective, mycelium composites are low-strength, porous materials. Accordingly, the compressive strength in this study is determined using specimens with a square cross-section (10 cm side length), with the effective compressive area calculated based on the actual cross-sectional geometry.

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