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Research article

Potential of mushroom mycelia for sound absorption and thermal insulation in hot and humid climates

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Abstract

Importance of the work: Mycelia have demonstrated potential as a high-performance alternative to conventional insulation materials. However, it remains an emerging technology. This research focused on developing mycelium-based materials under minimal environmental controls outside the laboratory.

Objectives: To investigate the potential of developing sound-absorbing and heat-insulating materials from mushroom species with suitable mycelial properties grown on agricultural waste under minimum environmental controls in Thailand's hot and humid climate.

Materials and Methods: Grey oyster mushroom [*Pleurotus ostreatus* (Jacq.ex Fr) Kummer] mycelia were cultivated in a box using different substrate mixing ratios of raw rice husks and rubberwood sawdust, under temperature and humidity controls in the ranges 30–37ºC and 50–70%, respectively. Subsequently, the optimal substrate mixing ratio was used to cultivate the prototype materials for property testing in a laboratory.

Results: The optimal substrate composition for mycelial growth was a mixing ratio by weight of 2.5:0.1:0.5 (rubberwood sawdust-to-grey oyster mushroom-to-mycelia-to-water). The square-shaped prototypes (10.50 cm, thickness 2.50 cm) had an average density of 279.63 ± 4.28 g/cm³, while the round-shaped prototypes (diameter 13.00 cm, thickness 2.00 cm) had an average density of 329.68 ± 9.58 g/cm³. The developed prototypes complied with the ASTM C423 standards (noise reduction coefficient, NRC > 0.40) and the TIS 2303-2549 standards (thermal conductivity ≤ 0.066 W/m K). They displayed effective sound absorption performance within the frequency range 1,000–5,000 Hz, with rough surfaces achieving a higher average NRC (0.43 ± 0.03) than for smooth surfaces (NRC = 0.41 ± 0.022). The average thermal conductivity (k-value) was 0.065±0.001 W/m K. Additionally, the prototypes demonstrated fire-retardant properties, enhancing their safety profiles for construction and insulation applications.

Main finding: Mycelium-based composite materials developed from grey oyster mushrooms [*Pleurotus ostreatus* (Jacq. ex Fr.) Kummer] cultivated on agricultural waste under minimal environmental control in Thailand's hot and humid climate demonstrated excellent potential for sustainable building applications. The optimal substrate ratio of 2.5:1:0.5 (rubberwood sawdust-to-grey oyster mushroom-to-mycelia-to-water) yielded prototypes that met ASTM C423 and TIS 2303-2549 standards. These prototypes exhibited effective sound absorption (NRC > 0.40), low thermal conductivity (0.065 ± 0.0014 W/mK), and inherent fire-retardant properties, highlighting their suitability as eco-friendly thermal and acoustic insulation materials in sustainable construction.

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Introduction

Major threats to ecosystems and human well-being are posed by environmental issues such as climate change, air and water pollution, biodiversity loss, waste mismanagement, resource overexploitation and water scarcity (Lanz et al., 2016). Resource depletion has been accelerated by unsustainable utilization of natural resources, including water, forests, minerals and wildlife, often resulting in irreversible ecological consequences. Addressing these challenges necessitates the adoption of sustainable strategies that emphasize resource efficiency, greenhouse gas (GHG) emission reduction, biodiversity conservation and the implementation of green technologies and policies.

In the construction industry, building materials, energy consumption and construction methodologies greatly influence environmental sustainability. Conventional materials, such as concrete and steel, contribute to high carbon emissions and energy consumption throughout their lifecycle (Bourbia et al., 2023; Cosentino et al., 2023). Consequently, bio-based materials have emerged as viable alternatives due to their lower embodied energy, renewability, carbon sequestration potential and enhanced thermal performance. The increasing adoption of low-carbon materials—including wood, bamboo, bio-composites and mycelium-based products—reflects a paradigm shift toward sustainable construction practices. Several studies have evaluated the sustainability of circular bio-based materials, providing critical frameworks for their implementation (Linh Le et al., 2023).

Mycelia, the vegetative structure of fungi, have garnered attention as a renewable and biodegradable material with diverse applications across various industries. Specifically, mushroom mycelia, which form during fungal growth, have been explored for use in eco-friendly packaging, artificial leather, biodegradable coffins and construction materials (Ghazvinian et al., 2019). These applications underscore the potential of mycelium-based materials to mitigate environmental challenges while fostering sustainable development.

Mycelial cultivation is influenced by several factors, including substrate composition, temperature, humidity, airflow, pH and contamination control (Haneef et al., 2017). Lignocellulosic substrates, such as wood, straw, sawdust, and leaves, serve as essential carbon and nitrogen sources for fungal growth (Houette et al., 2022). Typically, the optimal conditions for mycelial development include a temperature range of 25–30°C, relative humidity of 70–80%, low-light environments to suppress fruiting body formation and while oxygen is crucial for growth, excessive airflow can desiccate the substrate, hindering fungal colonization (Chang et al., 2019). Furthermore, maintaining low CO_2 concentrations and ensuring sterile conditions minimize contamination risks and promote optimal biomass yield (Stamets, P., 2000).

Empirical studies (Stamets, 2005; Islam et al., 2017; Haneef et al., 2017) have demonstrated that mycelia can be cultivated on agricultural waste substrates, presenting an opportunity to reduce dependence on fossil fuel-based materials such as polystyrene and rock wool. The lightweight and porous structure of mycelia, coupled with their mechanical resilience and biodegradability, make them a promising material for applications such as thermal insulation and acoustic absorption. Furthermore, the carbon sequestration ability of the mycelia during the growth phase enhances their environmental sustainability, positioning them as a pivotal material in low-impact construction (Jones et al., 2020).

While most research on mycelium-based materials has been conducted in controlled laboratory settings (Alaneme et al., 2023), cultivating mycelia in external environments with minimal environmental control presents a viable alternative for reducing energy consumption and minimizing production-related carbon emissions. However, adapting mycelial cultivation to Thailand's hot and humid climate poses unique challenges, as most published studies have been conducted in temperate regions (da Conceição van Nieuwenhuizen et al., 2017).

The current study investigated the development of sound-absorbing and heat-insulating materials derived from mycelia grown on agricultural waste within Thailand's challenging climatic conditions. Lignocellulosic agricultural residues, which comprise cellulose, hemicellulose and lignin, are particularly suitable for fungal decomposition and mycelial cultivation (Aiduang et al., 2022). Tudryn et al. (2018) suggested that the combination of these residues enhances fiber degradation, thereby promoting robust mycelial growth. In Thailand, rice husks and rubberwood sawdust—widely used in mushroom cultivation (Phumchai et al., 2015)—have potential as sustainable substrates for low-tech mycelial cultivation.

Mycelium bio-composites have mechanical properties comparable to synthetic foams, such as polystyrene and polyurethane, as well as wood-based composites (Aiduang et al., 2022; Yang and Qin, 2023). These composites have favorable physical and mechanical characteristics, particularly when derived from trimitic mycelia, which form dense and durable fibers (Jones et al., 2020; Yang et al., 2021). Advanced manufacturing processes, such as finely ground raw material preparation and hydraulic press molding, further enhance the density and compression resistance of these composites, making them suitable for applications requiring high durability (Elsacker et al., 2023).

By leveraging Thailand's abundant agricultural waste and optimizing low-tech mycelial cultivation techniques, the current research aimed to contribute to the development of sustainable construction materials. The findings of this study should support the advancement of eco-friendly construction practices while addressing environmental challenges and resource limitations specific to tropical climates.

Materials and Methods

Mushroom species and agricultural waste selections

A review of fungal species commonly utilized for mycelium composite production indicated that the grey oyster mushroom (*Pleurotus ostreatus*) was the most widely used, accounting for approximately 25% of the 22 species in use (Aiduang et al., 2022). This prevalence could be attributed to its fine and dense fibrous structure, which contributes to its mechanical integrity and suitability for composite materials. Furthermore, *P. ostreatus* is extensively cultivated for consumption due to its robust mycelial network, making it an optimal candidate for material development. Consequently, the grey oyster mushroom mycelia were used as the biological component for mycelial cultivation. Specifically, this research focused on utilizing mycelial fibers for thermal and acoustic insulation applications in walls, excluding strength testing for structural wall construction.

Preliminary mycelial cultivation: selection of appropriate waste materials and mixing ratios

The experimental procedure commenced with the removal of large debris and contaminants from the raw rice husks sourced from Ban Hed Khon Suttipong Learning Center, Chon Buri Province, Thailand and rubberwood sawdust sourced from the local market (Matichon Public Company Limited, 2017). Subsequently, these materials were sterilized based on natural sunlight exposure for 24 hr, which served as an alternative to the conventional, energy-expensive steam sterilization. A standardized ingredient ratio by weight was adopted for all formulations, based on research by Phumchai et al. (2015). The ratio of substrate materials (raw rice husks and rubberwood sawdust)-to-grey oyster mushroom mycelia-to-water was set at 2.5:0.1:0.5.

Four substrate formulations were tested: 1) 100% raw rice husks; 2) 100% rubberwood sawdust; 3) 70% raw rice husks and 30% rubberwood sawdust; and (4) 30% raw rice husks and 70% rubberwood sawdust. Each formulation was molded into square specimens (10.50 cm × 10.50 cm, with 2.50 cm thickness) and incubated in a foam box under temperatures in the range 30–37°C and relative humidity levels in the range 50–70% (Matichon Public Company Limited, 2017).

The experimental results indicated that no mycelial growth was observed in the 100% raw rice husk formulation. Additionally, the 70% raw rice husk and 30% rubberwood sawdust mixture was contamination by a black fungus without mycelial colonization. In the 30% raw rice husk and 70% rubberwood sawdust mixture, slow mycelial growth was observed alongside black fungal contamination. The most favorable mycelial growth was achieved using 100% rubberwood sawdust, leading to its selection as the primary substrate for the subsequent experimental phases.

Prototype mycelial cultivation and laboratory property testing

In this stage, mycelia cultivated on sorghum seeds were introduced to rubberwood sawdust substrates. Two prototype sets—square-shaped and circular-shaped—were cultivated under controlled temperature, humidity and lighting conditions. Subsequently, these prototypes were subjected to laboratory testing to evaluate their physical and mechanical properties.

The preparation of materials and equipment followed standardized protocols to ensure experimental integrity. The grey oyster mushroom spawn was cultivated on commercially available millet seeds. Key laboratory equipment consisted of a digital weighing scale, a hot-air oven, and a foam incubation box with dimensions of 60.00 cm × 46.00 cm × 31.00 cm. Molding was performed using square-shaped (10.50 cm × 10.50 cm, with 2.50 cm thickness) and circular-shaped (13.00 cm diameter, with 5.00 cm thickness) molds.

Additional materials were plastic food wrap, distilled water, adhesive (foxy), mixing containers, personal protective equipment (masks and rubber gloves) and ethyl alcohol 75% for sterilization. The sterilization protocol was rigorously maintained throughout all experimental stages to minimize contamination risks, as grey oyster mushroom mycelia are highly sensitive to microbial competition. This stringent sterilization process was crucial in ensuring the accuracy and reproducibility of the results.

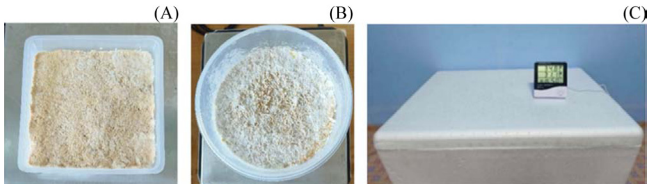

Fig. 1 Prototype mycelial cultivation for testing properties: (A) square-shaped prototype; (B) circular-shaped prototype; (C) foam box containing prototypes during cultivation with a digital thermometer and hygrometer

The evaluation of the thermal, acoustic and fire-retardant properties was conducted using specialized equipment to ensure precise and reliable measurements. The thermal conductivity of the materials was assessed utilizing a heat flow meter, following the steady-state technique in accordance with internationally recognized standards, including ASTM C518 (ASTM, 2017), ISO 8301 (ISO, 1991) and DIN EN 12667 (DIN, 2008).

The acoustic properties were analyzed using an impedance tube to measure both sound absorption coefficients and sound transmission loss values. These assessments adhered to the standards ISO 10534-2 (ISO, 1996), ASTM E1050-08 (ASTM, 2008) and ASTM E2611-09 (ASTM, 2009), ensuring consistency and comparability of results (Lippert, 1953; Nihon Onkyo Engineering, 2023).

The fire-retardant properties were evaluated using a fire spread testing kit, conforming to the MYP standard 8208-52 (Building Control and Inspection Office, 2019). The application of these standardized methodologies ensured the validity, reproducibility and scientific integrity of the experimental outcomes, contributing to the robustness of the findings.

Preparation of materials and equipment for processing prototype material

Preparation of rubberwood sawdust

Initially, the rubberwood sawdust was sorted to remove large debris and subsequently subjected to drying under natural sunlight for 24 hr to eliminate microbial contaminants. The sun-drying method was preferred over steam sterilization to minimize energy consumption. Following drying, the sawdust was sterilized and moistened by adding water to achieve a target humidity level of approximately 60–70% (rubberwood sawdust-to-water ratio = 2.5:0.5 by weight). Then, the prepared sawdust was sealed in clean bags and left in the shade for 24 hr to undergo fermentation, a process that enhances nutrient availability, which is essential for mycelial proliferation (Organic Agriculture, 2021).

Mycelia preparation

Commercially available grey oyster mushroom (*P. ostreatus*) mycelia, commonly used for edible mushroom cultivation, were selected to simplify the inoculation process and ensure consistency in application. To preserve their viability, the mycelia were stored in a refrigerated environment without opening the packaging, as exposure to air could lead to contamination and hinder mycelial growth. The rubberwood sawdust-to-grey oyster mushroom-to-mycelium-to-water ratio used for molding was maintained at 2.5:0.1:0.5 by weight. The components were thoroughly mixed, sealed in sterile bags and left to rest in the shade for 24 hr before proceeding with the molding and cultivation phase. All procedures were conducted under aseptic conditions to prevent microbial contamination.

Prototype mycelial inoculation

The production methodology was adapted from mushroom cultivation practices in Thailand and existing research, which favor minimal environmental controls over laboratory-grade sterilization. In the initial phase, the pre-fermented sawdust mixture was packed into molds that had been sterilized using 75% ethanol. Then, the materials were weighed and enclosed with food-grade plastic film. Subsequently, the molds were placed inside an opaque foam box designed to simulate optimal mycelial growth conditions, where they remained for 20 d for incubation. During this period, the ambient temperature was maintained in the range 30–37°C and the relative humidity was controlled in the range 50–70% using a digital thermometer and hygrometer, respectively.

At the conclusion of the incubation period, the formed mycelium composite was removed from the mold and transferred to a ventilated space for an initial stabilization period of 1 hr. Following this, the material was placed in a hot-air oven at 80°C for 24 hr to halt mycelial growth and preserve the structural integrity of the composite. There was a second stabilization phase at room temperature for 1 hr before proceeding to additional drying in the hot-air oven. This staged drying process aimed to mitigate the risk of sudden temperature fluctuations, which could compromise the composite's structural stability (Zhao et al., 2020). The final drying phase ensured the removal of residual moisture, a crucial factor for improving the mechanical strength, durability and overall longevity of the mycelium-based composite material (Haneef et al., 2017). Additionally, the drying procedure contributed to enhanced density and dimensional stability, making the material suitable for construction applications where moisture control and structural integrity are essential (Islam et al., 2017).

Laboratory testing of material properties

Density testing

The density of the prototypes was determined following the drying process using a hot-air oven. The specimens were weighed and measured, with values recorded before and after drying. This procedure allowed for the comparison of humidity levels and the calculation of the average density for both the square-shaped and circular-shaped prototypes.

Water absorption

The water absorption capacity of the prototypes was assessed by immersing them separately in a plastic container filled with water for 24 hr, after which, the samples were removed, surface-dried and weighed. Subsequently, they were placed in an oven at 80°C for an additional 24 hr to ensure complete drying before final measurements were taken.

Sound absorption

The sound absorption coefficient (SAC) of the prototypes was measured using an impedance tube. The SAC values were recorded for sound waves within the frequency range of 1–6000 Hz. The average SAC values at 250, 500, 1,000 and 2,000 Hz were used to calculate the noise reduction coefficient (NRC). According to ISO 10534-2, a material is classified as sound-absorbing if its NRC value exceeds 0.40 (Acoustic Standard, 2021).

Thermal conductivity

The thermal conductivity coefficient (k-value) of each prototype was evaluated using a heat flow meter. Each sample was positioned between two temperature-controlled plates, with the temperature of the heating plate set to 50°C. The measured value was compared to the standard thermal conductivity range of insulating materials, which is in the range 0.02−0.40 W/mK, as specified by ASTM C518 (ASTM, 2017).

Fire-retardant

The fire-retardant properties of the prototypes were assessed using a fire-retardant testing kit. Each specimen was exposed to flame at angles of 45°, 90° and 180°, following the MYP 8208-52 standard (Building Control and Inspection Office, 2019). A material is classified as being fire-retardant if it does not ignite within 15 s during the first exposure and within 30 s during the second exposure. This evaluation ensured the material›s suitability for applications requiring fire resistance.

Statistical analysis

A paired t test was used to assess the statistical significance of differences in the properties of the mycelium-based sheets before and after drying. Samples were prepared in two geometries (rectangular and circular) and measured under identical conditions pre- and post-drying. This test is suitable for comparing two related samples, effectively controlling for within-subject variability (Field, 2013). Normality of the differences was confirmed using the Shapiro-Wilk test. Statistical analysis was performed using Microsoft Excel (Microsoft 365; Microsoft Corp.; Redmond, WA, USA), with significant and highly significant results tested at $p < 0.05$ and $p < 0.01$, respectively.

Results and Discussion

Density and dimensions of prototypes

A comparison before and after baking is shown in Fig. 2. Measurements and average density values for the two sets of prototypes, both before and after baking (a total of eight prototypes), were calculated and are presented in Table 2–5.

The dimensional data provided in Table 1 detail the composites› sizes before and after drying. The t test revealed highly significant differences between each parameter before and after baking (Table 1), underscoring the importance of calculating material shrinkage values. The average shrinkage rate of the material was approximately 8%. This shrinkage is a crucial consideration in the design of molds for mycelium-based composites, especially in applications where high dimensional accuracy is essential.

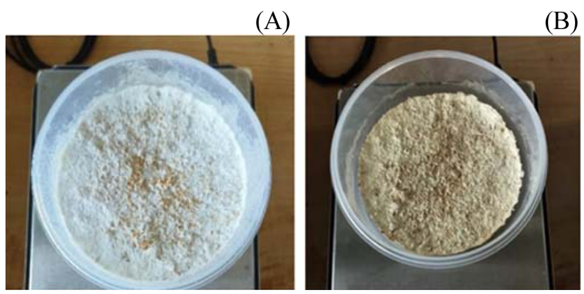

Fig. 2 Mycelium-based prototypes: (A) before baking, showing initial mycelial growth; (B) after baking, with denser more compact structure

Table 1 Dimensions of square-shaped and circular-shaped prototypes before and after baking

Prototype category	Width (cm)		Length (cm)		Thickness (cm)	
	Before	After	Before	After	Before	After
Square	10.21 ±0.12[a]	10.07±0.07[b]	10.16±0.11[a]	10.04±0.06[b]	2.07±0.03[a]	2.03±0.03[b]
Circular	Diameter(cm)					
	12.91±0.06[a]	11.87±0.05[b]	-	-	2.07±0.03[a]	2.03±0.03[b]

Values are mean ± SD of four replicates; different lowercase superscripts indicate significant ($p < 0.01$) differences among means in same row within each parameter.

According to the research by Appels et al. (2019) and Haneef et al. (2017), the primary components of mycelium-based materials can be explained by the highly efficient structure resulting from moisture loss and the degradation of the polysaccharide network that constitutes the cell walls of the effective fibers. After drying, the material is reduced in size due to this structural change. In cases where mycelium-based materials have 8% shrinkage, this must be considered when producing components with precise dimensional requirements. Potential solutions to address this issue include calculating mold expansion based on the expected material shrinkage to ensure the final component maintains the desired dimensions post-drying. Additionally, the drying time can significantly affect the material›s properties (Girometta et al., 2019). Furthermore, the use of reinforcement additives, such as cellulose, may help improve the material›s stability and mitigate the effects of shrinkage. Understanding mycelial shrinkage characteristics is essential in optimizing mold design and ensuring the performance of mycelium-based composites in various industrial applications, as it directly influences the manufacturing process and dimensional accuracy (Islam et al., 2018). This knowledge is crucial for advancing high-performance material technologies.

The density of the square-shaped prototype before baking was in the range 444.70–467.26 g/cm³, with an average of 456.15 ± 9.21 g/cm³ and an average weight of 97.77 ± 4.01 g (Table 2). After baking, the density significantly decreased (range 276.60–285.98 g/cm³), with a mean of 279.63 ± 4.28 g/cm³ and an average weight of 58.37 ± 2.01 g.

The circular-shaped prototype had a higher initial density in the range 651.03–660.26 g/cm³ (mean ± SD = 654.03 ± 7.44 g/cm³) and an average weight per cubic centimeter of 177.42 ± 0.92 g. After baking, the density decreased to a range of 320.70–341.04 g/cm³, with an average of 329.68 ± 9.58 g/cm³ and a mean weight of 7.38 ± 1.88[b] g/cm³.

The paired t test analysis revealed significant reductions in density for both shapes after baking, confirming that the drying process affected material compaction. Furthermore, independent t tests confirmed that the circular prototypes had significantly higher density than the square ones both before baking (p = 0.00003) and after baking (p = 0.0015). These results indicated that the container geometry significantly influenced the structural development of mycelium composites.

Other studies have explored the effects of substrate type, humidity and environmental parameters on mycelial properties (Islam et al., 2018; Appels et al., 2019). Girometta et al. (2019) further emphasized the role of airflow and nutrient distribution in mold cavities as critical factors in fungal development. However, to the best of our knowledge, no prior study has directly compared the effects of mold geometry (circular versus square) on the mycelial density using quantitative statistical methods such as the paired t test. The current study has provided novel evidence that circular molds may facilitate more homogeneous mycelial growth, possibly due to uniform radial expansion and improved internal aeration, leading to denser, structurally sound composites. These findings suggested that container design is a key parameter that should be considered when optimizing production protocols for mycelium-based materials in both research and industrial settings.

Test results for water absorption

The results of average water absorption of the two sets of prototypes before and after soaking (eight prototypes in total) are shown in Table 3. The water absorption values of the prototypes were in the range 23.08 –27.01%, with the average water absorption being 25.42±1.36%, which indicated low water absorption compared to the general water absorption properties of mushroom fiber bio-composites (Appels et al., 2019; Haneef et al., 2017).

Table 2 Volume, weight and density of square-shaped and circular-shaped prototypes before and after baking

Prototype category	Volume (cm³)		Weight (g)		Density (g/cm³)	
	Before	After	Before	After	Before	After
Square	214.31±6.82[a]	208.70±5.07[a]	97.77±4.01[a]	58.37±2.01[a]	456.15±9.21[a]	279.63±4.28[a]
Circular	293.53±5.23[b]	243.47±4.34[a]	177.42±0.92[b]	73.87±1.88[b]	654.03±7.44[b]	329.68±9.58[b]

Values are mean ± SD of 4 replicates; different lowercase superscripts indicate significant ($p < 0.05$) differences among means in same low.

Table 3 Water absorption of eight square-shaped prototypes (2.50 cm, with 2.50 cm thickness)

Prototype	Size before soaking (cm)			Weight (g)	Size after soaking (cm)			Weight (g)	Water absorption (%)
	Width	Length	Thickness		Width	Length	Thickness		
1	2.69	2.70	2.08	3.69	2.82	2.84	2.18	5.06	27.075
2	2.68	2.69	2.04	3.46	2.80	2.82	2.14	4.57	24.289
3	2.68	2.69	2.10	4.38	2.80	2.82	2.21	5.91	25.888
4	2.69	2.68	2.04	3.69	2.82	2.81	2.14	4.94	25.304
5	2.58	2.67	2.04	3.91	2.70	2.80	2.14	5.28	25.947
6	2.59	2.68	2.00	3.39	2.72	2.81	2.10	4.64	26.940
7	2.68	2.67	2.06	3.81	2.81	2.80	2.16	5.07	24.852
8	2.69	2.67	2.00	3.38	2.82	2.80	2.10	4.39	23.007
Mean	2.66±1.36	2.68±1.36	2.05±1.36	3.71±1.36	2.79±1.36	2.81±1.36	2.15±1.36	4.98 ±1.36	25.413 ±1.36

Test results for sound absorption properties

The test was carried out on the two sides of each sample: side A, the smooth surface, which was the ‘back’ side attached to the mold; and side B, the rough surface, which was the ‘front’ side not attached to the mold. Fig. 3 shows the results from the SAC at frequencies 125, 250, 500, 1,000, 2,000, 4,000 and 5,000 Hz. Based on these results, the rough surface of the prototypes absorbed sound slightly better than the smooth surface. However, both surfaces had good sound absorption values (above 0.40) for the frequency range 1,000-5,000 Hz, with the best sound absorption values being at 3,000 Hz.

The SAC values at frequencies of 250, 500, 1,000 and 2,000 Hz (ISO 10534-2 standard; ISO, 1996) were used to calculate the NRC values for both the smooth and rough sides, with values for smooth/rough at each frequency of 0.39/0.41, 0.41/0.43, 0.41/0.44 and 0.42/0.45, respectively. The average NRC value for the smooth side was 0.41 ± 0.022, which was slightly lower than the average NRC value for the rough side (0.43 ± 0.033). Both values are within the criteria setting the ISO 10534-2 industry standard (ISO, 1996), indicating that that the prototypes mycelium-based compounds could be developed into a sound absorbing material, as shown in Table 4.

Studies by Zhang et al. (2020) and Jones et al. (2021) indicated that porous bio-composites with a rough surface had enhanced sound absorption due to increased surface irregularities that promoted higher sound wave dissipation. The slightly higher NRC observed for the rough side aligned with these findings, suggesting that surface texture plays a role in the acoustic performance of mycelium-based composites. Additionally, fibrous structure of mycelia is known to enhance sound absorption due to its natural porosity and interwoven network (Ren et al., 2019). These results highlighted the potential of mycelium composites for sustainable acoustic applications, particularly in interior design, construction and eco-friendly noise control systems.

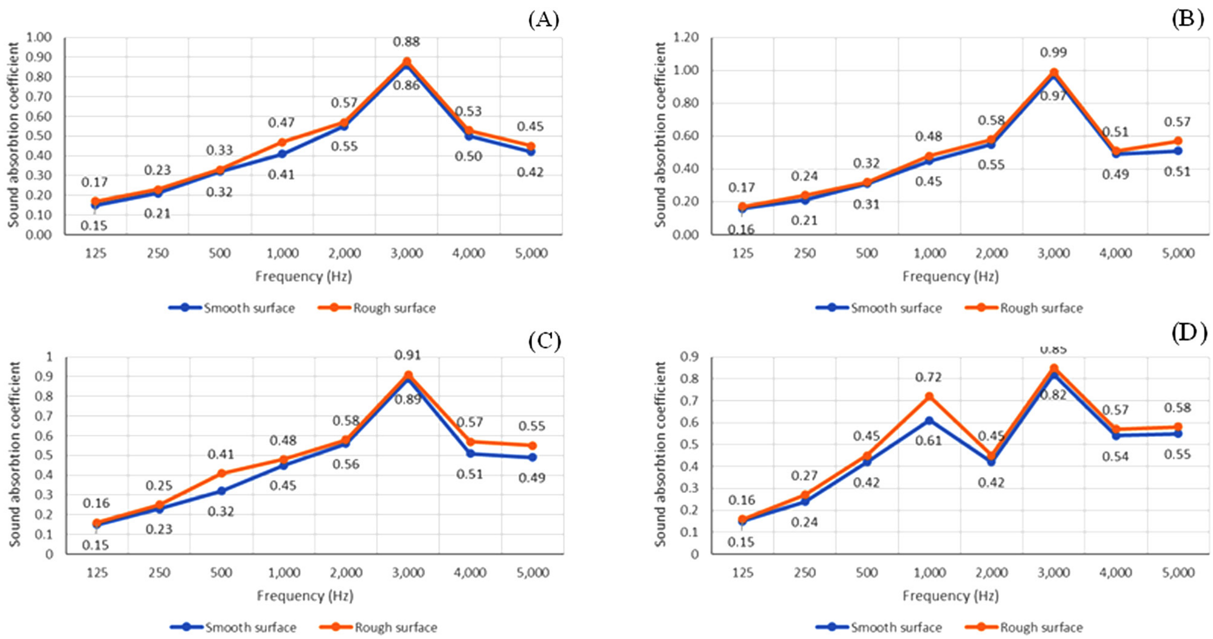

Fig. 3 Sound absorption coefficients of smooth and rough surfaces of four prototypes at varying frequencies

Table 4 Noise reflection properties (sound absorption coefficient and noise reduction coefficient) of four mycelium-based prototypes (MCC-1 to MCC-4) for side A (smooth surface) and side B (rough surface)

Sample 1 (MCC-1)	Size (cm)		Sound absorption coefficient) (ISO 10534-2)								Noise reduction coefficient
	Diameter	Thickness	125	250	500	1000	2000	3000	4000	5000	
MCC-1/A smooth	9.80 and 2.80	2.00	0.15	0.21	0.32	0.41	0.55	0.86	0.50	0.42	0.37
MCC-1/B rough	9.80 and 2.80	2.00	0.17	0.23	0.33	0.47	0.57	0.88	0.53	0.45	0.40

Note: Standard deviation (SD): side A-smooth surface = ±0.022; side B-rough surface = ±0.033

Sample 2(MCC-2)	Size (cm)		Sound absorption coefficient (ISO 10534-2)								Noise reduction coefficient (NRC)
	Diameter	Thickness	125	250	500	1000	2000	3000	4000	5000	
MCC-2/A smooth	9.80 and 2.80	2.00	0.16	0.21	0.31	0.45	0.55	0.97	0.49	0.51	0.38
MCC-2/B rough	9.80 and 2.80	2.00	0.17	0.24	0.32	0.48	0.58	0.99	0.51	0.57	0.41

Note: Standard deviation (SD) : side A-smooth surface = ±0.022; side B-rough surface = ±0.033

Sample 3 (MCC-3)	Size (cm)		Sound absorption coefficient (ISO 10534-2)								Noise reduction coefficient (NRC)
	Diameter	Thickness	125	250	500	1000	2000	3000	4000	5000	
MCC-3/A smooth	9.80 and 2.80	2.00	0.15	0.23	0.32	0.45	0.56	0.89	0.51	0.49	0.39
MCC-3/B rough	9.80 and 2.80	2.00	0.16	0.25	0.41	0.48	0.58	0.91	0.57	0.55	0.43

Note: Standard deviation (SD): side A-smooth surface = ±0.022; side B-rough surface = ±0.033

Sample 4 (MCC-4)	Size (cm)		Sound absorption coefficient (ISO 10534-2)								Noise reduction coefficient (NRC)
	Diameter	Thickness	125	250	500	1000	2000	3000	4000	5000	
MCC-4/A smooth	9.80 and 2.80	2.00	0.15	0.24	0.42	0.61	0.42	0.82	0.54	0.55	0.42
MCC-4/B rough	9.80 and 2.80	2.00	0.16	0.27	0.45	0.72	0.45	0.85	0.57	0.58	0.47

Note: Standard deviation (SD): side A-smooth surface = ±0.022; side B-rough surface = ±0.033

Table 4 presence of two "Diameter" values corresponds to the use of two different impedance tubes for testing different frequency ranges. Specifically, the smaller diameter tube (2.80 cm) is used for measuring higher frequencies, while the larger diameter tube (9.80 cm) is used for lower frequencies, in accordance with standardized methods such as ISO 10534-2 (ISO, 1996) and ASTM E1050–08 (ASTM, 2008). These standards recommend varying tube diameters to ensure accurate measurement across a wide frequency spectrum.

Thermal conductivity coefficient (k-value)

Table 5 shows that the average thermal conductivity coefficient (k-value) was 0.065 ± 0.0014 W/m K, which can be used to calculate the thermal conductivity (C-value = 3.116 W/m^{2}K) and the thermal resistance (R-value = 0.32 m^{2}K/W). The test results for the k-value were within the standard criteria for industrial products TIS.2303-2006 (TISI, 2006), which specifies the coefficient of thermal conductivity must not exceed 0.066 W/m K.

Fire-retardant test results

The results from the fire test of the sample were within the standard criteria of M.Y.P. 8208-52 (Building Control and Inspection Office, 2019), in which the material must not catch fire within 30 s after initial contact with flame and the surface temperature and internal temperature of the sample must not increase by 30°C compared to the beginning of the test. Meeting these criteria satisfies the requirements for classification as a non-combustible material. The prototypes were tested after 30 s had passed; the materials were not combustible, as shown in Fig. 4. Thus, these prototypes mycelium-based materials had insulating properties and did not spread fire (Table 6).

Table 5 Thermal conductivity properties of mycelium-based prototypes

Sample	Size (cm)			Weight (g)	Density (kg/m^3)	Thermal conductivity coefficient (*k*-value) at test temperature 50ºC (W/m K)
	Width	Length	Thickness			
1	10.12	10.13	2.08	60.98	285.98	0.06677
2	10.00	10.01	2.04	56.78	278.06	0.06623
3	10.14	10.00	2.10	58.90	276.60	0.06525
4	10.01	10.01	2.04	56.80	277.88	0.06345
Average	10.07	10.04	2.07	58.37	279.63	0.06543

Table 6 Fire-retardant properties of mycelium-based prototype when exposed to different angles and durations of burning, with recorded weight before and after burning

Sample	Angle for burning	Burning duration			Weight(g)	
		Second ignition	15 sec	30 sec	Before	After
1	45º	-	Not flammable	Not flammable	103.61	103.61
2		-	Not flammable	Not flammable	95.15	95.15
3		-	Not flammable	Not flammable	97.15	97.15
4		-	Not flammable	Not flammable	95.15	95.15
1	90º	-	Not flammable	Not flammable	103.61	103
2		-	Not flammable	Not flammable	95.15	94.9
3		-	Not flammable	Not flammable	97.15	97.15
4		-	Not flammable	Not flammable	95.15	95.15
1	180º	-	Not flammable	Not flammable	103	103
2		-	Not flammable	Not flammable	94.9	94.9
3		-	Not flammable	Not flammable	97.15	97.15
4		-	Not flammable	Not flammable	95.15	95.15

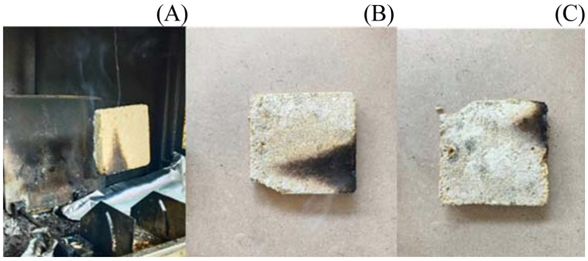

Fig. 4 Fire-retardant performance of mycelium-based prototype: (A) exposed to flame; post-exposure surface showing partial charring; (C), Further assessment of burn patterns

Conclusions

Overall, the results demonstrated that the mycelium-based composites had favorable material properties, including density variations influenced by shape, effective thermal insulation, low water absorption, and fire resistance. The density of the prototypes decreased significantly after baking, with the square-shaped prototype reducing from 456.15 kg/m³ to 279.63 kg/m³ and the circular-shaped prototype decreasing from 654.03 kg/m³ to 329.68 kg/m³. The circular prototypes had higher density values than the square ones, suggesting that container shape had influenced mycelial growth, with circular molds being more favorable. The prototypes had low mean water absorption value (25.42 ± 1.36%) and a mean thermal conductivity coefficient (k-value) of 0.065±0.0014 W/m K, meeting the industrial product standard criteria (TIS.2303-2006). Fire testing confirmed that the material was non-combustible in compliance with the regulations (Building Control and Inspection Office, 2019), indicating its safety for construction applications. These findings highlighted the material›s potential for integration into building envelopes, such as wall panels, ceiling tiles and other architectural components requiring thermal and sound insulation, particularly in hot and humid climates such as in Thailand. Furthermore, the utilization of agricultural waste in its production aligns with circular economy principles, reducing waste and promoting sustainable material development in the construction industry.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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