Mechanical, Thermal, and Biodegradation Analysis of Fungal Mycelium Composite Blocks for Green Material Engineering

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Abstract. The increasing demand for environmentally sustainable construction materials has accelerated the development of bio-based composites derived from renewable agricultural residues. This study presents the fabrication and comprehensive characterization of fungal mycelium composite blocks produced from sugarcane bagasse reinforced with *Pleurotus ostreatus* mycelium for green material engineering applications. Sugarcane bagasse fibres (1–5 mm) were cleaned, dried, milled, and supplemented with 5–10 wt.% wheat bran before adjusting the moisture content to 60–65%. The prepared substrate was sterilized at 100 °C for 1 h, inoculated with 10–15 wt.% *P. ostreatus* grain spawn, compacted into acrylic moulds, and incubated under controlled conditions (25–28 °C, 70–85% relative humidity) for 30 days. The fully colonized composites were thermally deactivated at 60–80 °C for 24–48 h and subsequently evaluated for their mechanical, physical, thermal, and biodegradation performance. The developed composites exhibited a maximum compressive strength of 0.25 MPa, flexural strength of 0.85 MPa, and tensile strength of 0.42 MPa, demonstrating adequate mechanical integrity for non-structural applications. Density values ranged from 0.20 to 0.32 g/cm^3 with moderate dimensional shrinkage and near-neutral pH, indicating structural stability. Thermal conductivity values of 0.078–0.085 W/m·K confirmed excellent insulation characteristics, while thermogravimetric analysis revealed satisfactory thermal stability. Water absorption tests demonstrated the hydrophilic and biodegradable nature of the composites, highlighting their environmental compatibility. Overall, the developed mycelium-based composites provide a lightweight, renewable, and sustainable alternative to conventional synthetic building boards, offering significant potential for insulation panels, interior partition systems, eco-friendly packaging, and other non-load-bearing building applications.

Keywords: Fungal mycelium composites, Sugarcane bagasse, Pleurotus ostreatus, Mechanical properties, Thermal insulation.

Nomenclature table

Symbol / Abbreviation	Description
APP	Ammonium Polyphosphate
ASTM	American Society for Testing and Materials
B11, B12, B13	Bagasse brick specimen identification
C11, C12, C13	Bagasse block specimen identification
GHG	Greenhouse Gas
LCA	Life Cycle Assessment
MBC	Mycelium-Based Composite
MDF	Medium Density Fiberboard
P. ostreatus	*Pleurotus ostreatus* fungal species
RH	Relative Humidity
TGA	Thermogravimetric Analysis
UTM	Universal Testing Machine
W_1	Initial specimen weight before water immersion
W_2	Final specimen weight after water immersion
P	Applied Load
A	Cross-sectional Area
σc	Compressive Strength
σf	Flexural Strength
σt	Tensile Strength
Ef	Flexural Modulus
L	Span Length
L_0	Original Gauge Length
ρ	Density
k	Thermal Conductivity
T	Temperature
t	Incubation/Drying Time
ΔL	Dimensional Change (Shrinkage)
S	Shrinkage
pH	Hydrogen Ion Concentration
WA	Water Absorption

m_0	Initial Mass
mf	Final Mass
ε	Elongation at Break

1. Introduction

The rising concern for environmental sustainability and the reduced availability of non-renewable natural resources have led manufacturing industries to properly look for materials that are not only derived from renewable sources but also recyclable [1]. The strong need for "green" materials has encouraged the use of natural waste fibers, which are not only abundantly generated by agricultural and wood-processing industries but also are renewable and biodegradable in nature [2]. The growing worries regarding climate change, massive accumulation of waste, and the long-lasting environmental effects of petroleum-based construction materials have not only created a demand for but also a need for research on eco-friendly, biodegradable alternatives [3]. In this scenario, mycelium-based composites have carved a niche for themselves as a very attractive category of sustainable biomaterials [4]. The reason for this is that this family of composites is all due to the growth of fungal mycelium, a dense network of hyphae that binds lignocellulosic substrates into lightweight and structurally coherent materials [5]. Mycelium composites do attract a great deal of attention due to the low-energy fabrication process, very low carbon footprint, carbon-negative life cycle, and complete biodegradability at the end of use, which is one of the reasons why they are so popular. Moreover, by converting low-value residues into high-value functional materials, they very effectively create value from agricultural waste [6].

Fungal mycelium composites have significant sustainability advantages, yet they are still facing several limitations that hinder their widespread industrial adoption [7]. The most significant drawback is their relatively low mechanical strength and load-bearing capacity when compared to conventional construction and polymer-based materials, which is a limitation for their use in structural or lightweight applications only [8]. The moisture sensitivity of mycelium composites, in combination with prolonged exposure to high humidity, results in swelling, degradation, or loss of mechanical integrity, which can be prevented only by applying additional treatments or coatings [9]. Variability in material properties is another issue that can arise, as differences in density, strength, and durability can be caused by the choice of fungal species, substrate type, growth conditions, and fabrication methods [11]. In addition, the production process entails a need for the maintenance of controlled environmental conditions that are controlled and a longer period for plant growth, which, in turn, can lead to an increase in the complexity of the manufacturing process and limitations in production scalability [12]. Non-ignitability and preservation of physical properties over outdoor weathering are still hurdles and are sometimes accompanied by the use of non-biodegradable processes for the sake of post-processing that are intended to increase the stability of the product [13]. Moreover, the absence of uniform testing methods and building codes for mycelium-based substances leads to regulatory obstacles that hinder the industry's acceptance of those materials in large-scale manufacturing and construction practices, thus prolonging their adoption [14-15].

The increasing demand for sustainable and biodegradable construction materials has motivated the exploration of fungal mycelium composites as environmentally friendly alternatives to petroleum-based products [26]. Although previous studies have demonstrated the potential of mycelium-based materials, significant challenges remain regarding standardized fabrication procedures, consistent mechanical performance, thermal insulation efficiency, and long-term environmental sustainability [27]. Furthermore, limited research has comprehensively evaluated sugarcane bagasse reinforced with *Pleurotus ostreatus* using an integrated experimental approach that combines mechanical, thermal, and biodegradation analyses. Sugarcane bagasse is an abundant agricultural by-product with high lignocellulosic content and remains largely underutilized despite its excellent potential as a renewable reinforcement material. Therefore, this study aims to fabricate fungal mycelium composite blocks using sugarcane bagasse inoculated with *Pleurotus ostreatus* under controlled substrate preparation, sterilization, inoculation, incubation, moulding, and thermal deactivation conditions. The developed composites are systematically evaluated through compressive, flexural, and tensile strength tests, density and shrinkage measurements, pH analysis, thermal conductivity, thermogravimetric analysis, and water absorption behaviour to determine their structural integrity, thermal performance, and environmental compatibility. The proposed methodology offers several advantages over conventional fabrication approaches by providing a reproducible and contamination-controlled manufacturing process that promotes uniform mycelial colonization, enhanced interfacial bonding between fungal hyphae and lignocellulosic fibres, improved dimensional stability, and consistent composite quality. Moreover, the process utilizes inexpensive agricultural waste, requires relatively low processing energy, eliminates the need for synthetic binders, and produces lightweight, biodegradable composites with promising thermal insulation properties. These advantages make the proposed methodology a practical and sustainable route for developing eco-friendly building materials suitable for non-load-bearing construction, insulation panels, interior partition systems, and sustainable packaging applications.

Section 2 presents a literature review of mycelium-based composites, characterized by materials and methods used and properties reported in previous studies. Section 3 introduces the materials and methodology used in the current research, including the chosen fungi, substrates, and processing steps. Section 4 explains the setup for the entire experiment, which includes preparation, incubation, and testing. Section 5 deals with results and interpretation, discusses the experimental findings, and presents them in comparison with published literature. Lastly, Section 6 wraps up the research by giving a summary of the main findings, indicating the possible applications and future directions of mycelium-based composites.

2. Literature Review

Various studies carried out in recent times have proven repeatedly that MBCs (mycelium-based composites) have the potential to be the new sustainable and inexpensive options to be considered over traditional building and interior materials. Alemu et al. [16] developed locally available Agro-wastes like sawdust, bagasse, and coffee husk using the fungus Pleurotus ostreatus, indicating that the substrate's nature and the duration of molding markedly affect the mycelium’s density, the material's compressive strength, and its water absorption, with sawdust being the most examined and securing the best strength for indoor use. Aiduang et al. [17] proposed the use of bamboo sawdust and corn pericarp with fungi, and they were able to report that physical, thermal, and mechanical properties of the composites were very much comparable to those of traditional interior materials, along with proven biodegradability, which was confirmed. KIRDÖK et al. [18] and Vašatko et al. [19] investigated the importance of MBCs for the construction industry by looking at their thermal, acoustic, and mechanical features in comparison with those of materials such as MDF, gypsum board, and rock wool, and thus underscoring their being competitive and feasible for the non-load-bearing, insulation, and compression-only applications. Jiménez-Obando et al. [20] focused on examining the lignocellulosic wastes that are specific to the region, and while the insulation properties were quite promising, they also pointed out the problems with shrinkage and water absorption. Özdemir et al. [21] and Özkan & Güzelci [22] employed digital fabrication, reinforcement strategies, and parametric design to improve the structural and acoustic properties of MBCs in interior architecture. Alaux et al. [23] and Babenko et al. [25] proposed the environmental viewpoint, performed life-cycle and multi-criteria assessments, which confirmed lower greenhouse gas emissions in the case of natural insulation and pointed out electricity consumption as the major impact driver. Abdelhady [24] focused on militarizing the architectural field with modular and interlocking mycelium components, suggesting that material optimization, scalable production, and design integration are the core of making MBCs viable for a sustainable built environment application. Table 1 shows the analysis of the existing studies done by the researchers.

Table 1: Analysis of Existing Studies

Author & Year	Aim	Purpose	Methodology	Findings
Alemu et al., 2022 [16]	To develop low-cost, eco-friendly materials from local biomaterials	Replace non-eco-friendly and costly industrial products	Used Pleurotus ostreatus with sawdust, bagasse, and coffee husk; evaluated colonization time, density, water absorption, and compressive strength	Sawdust-based blocks (21 days molding) showed highest compressive strength (750 kPa) and density (343.44 kg/m^3); suitable for indoor construction and packaging
Aiduang et al., 2024 [17]	To fabricate MBCs for modern interior materials	Assess suitability of agro-waste MBCs as interior elements	Bamboo sawdust and corn pericarp with different fungi; tested physical, thermal, mechanical, and	Density: 212–282 kg/m^3; strong compression and impact strength (exceeding some

			biodegradability properties	synthetic foams); high biodegradability and interior application potential
KIRDÖK et al., 2024 [18]	To evaluate mycelium composites as sustainable construction materials	Reduce environmental impact of construction industry	Compared mycelium composites with MDF, gypsum board, and rock wool using thermal, acoustic, compressive, and flexural tests	Comparable or superior thermal and acoustic performance; higher compressive and flexural strength than some conventional materials
Vašatko et al., 2022 [19]	To investigate basic properties of mycelium-based composites	Establish foundational data for architectural use	Beech sawdust with Pleurotus ostreatus and Ganoderma lucidum; density, compression, flexural, and water absorption tests	Suitable for compression-only structures, insulation, and temporary assemblies; provided baseline database for future research
Jiménez-Obando et al., 2025 [20]	To develop MBCs from regional Colombian biomass	Promote circular economy using local lignocellulosic waste	Arboloco pith and Kikuyu grass with Ganoderma lucidum; evaluated physical, mechanical, and thermal properties	Best mix (70% grass) showed improved density (≈60 kg/m^3), compressive strength (0.168 MPa), and insulation; high shrinkage and water absorption limit scalability
Özdemir et al., 2022 [21]	To enhance structural performance of mycelium composites	Improve bending and tensile limitations of MBCs	Robotic additive manufacturing with wood veneer reinforcement	Veneer-reinforced MBCs showed significantly improved bending resistance; reinforcement joints stronger than base material
Özkan & Güzelci, 2025 [22]	To integrate digital fabrication with mycelium design	Develop sustainable acoustic interior components	Parametric design and 3D-printed molds; acoustic simulation (Sabine method)	Mycelium panels reduced reverberation time, especially in speech frequencies; potential for optimized acoustic interiors.
Alaux et al., 2023 [23]	To assess environmental impacts of MBC insulation	Evaluate sustainability via life cycle assessment	Cradle-to-grave LCA with industrial scale-up scenarios	Climate impact comparable to rock wool and better than plastic insulation; electricity use is main GHG contributor
Abdelhady et al., 2023 [24]	To expand architectural design potential of MBCs	Develop modular mycelium-based systems	Computational design, form-finding, and prototyping of interlocking modules	Lightweight modular system achieved without reinforcement; suitable for architectural applications
Babenko et al., 2025 [25]	To evaluate the sustainability of mycelium-straw insulation	Compare MBSIC with conventional insulation materials	Cradle-to-gate LCA (ISO 14040) and Multi-Criteria Analysis (MCA)	Lower GHG emissions under room conditions; outperformed mineral wool in sustainability metrics

3. Research Gap

Even though big steps have been taken in the development of mycelium-based composites (MBCs) and even though much research has already been done, several gaps are still left to be filled. The most common studies made so far are the ones where large-scale laboratory production and a variety of agro-industrial wastes and fungal species are used, leading to great differences in the final product in terms of density, strength, shrinking, and water absorption, which shows that there are no standard processing methods and performance benchmarks yet approved [16–19]. On the other hand, compressive behaviour has been the main focus of mechanical characterization, which means that other factors such as tensile, flexural, shear, fatigue, and long-term durability under realistic service and climatic conditions are still not well studied. However, several recent studies have applied reinforcement and digital fabrication techniques, trying to overcome the limitations in this area [20,21]. The other problem is that MBCs still suffer from very high moisture sensitivity, dimensional instability, and shrinkage, which are the main reasons for their slow acceptance and use in the building industry and humid areas, especially when they are considered to be envelope materials [20]. The architectural and interior applications using modular systems, parametric design, and acoustic optimization have been investigated, but they are still mostly experimental, and there are no systematic connections between material microstructure, geometry, and functional performance [22,24]. From an environmental point of view, life cycle assessment studies confirm the sustainability potential of MBCs, but at the same time, they also disclose electricity consumption, ecotoxicity, and industrial scalability trade-offs that have not been solved yet, to which limited region-specific and conventional materials comparative analyses have been conducted [23-25].

4. Methodology

The main raw material for making mycelium composite blocks has been sugarcane bagasse fibres. ($1-5\ mm$), The fungal binder has been Pleurotus ostreatus grain spawn along with $5-10\%$ of wheat bran, distilled water, and forming by Acrylic Molds for block under sterile conditions. The bagasse has been first washed thoroughly, then oven-dried and milled to the desired particle size, after which it has been mixed with wheat bran and its moisture content has been adjusted to $60-65\%$. The prepared substrate has then been sterilized in an autoclave at $100\ °C\ for\ 1\ hrs$ and allowed to cool under aseptic conditions. Subsequently, the sterile substrate has been inoculated with $10-15\%$ Pleurotus ostreatus spawn and mixed uniformly before being packed and compacted into moulds to ensure consistent density. The moulded samples were incubated in the dark at $25-28\ °C$ and $70-85\%$ relative humidity for 30 days until complete mycelial colonization has been achieved. Finally, the fully colonized composites were oven-dried at $60-80\ °C$ for $24-48\ hrs$ to deactivate fungal growth and stabilize the structure for further testing, as shown in Table 2. Figure. 1 denotes the overall architecture of the proposed work.

Table 2: Mycelium-based Composites

Property	Typical Range	Unit	Test Standard
Density	80–350	kg/m^3	ASTM D1622
Compressive Strength	0.2–2.5	MPa	ASTM D1621
Tensile Strength	0.05–0.60	MPa	ASTM D638
Flexural Strength	0.3–3.5	MPa	ASTM D790
Young's Modulus	5–250	MPa	ASTM D638
Thermal Conductivity	0.025–0.060	W/m·K	ASTM C518
Specific Heat Capacity	1200–1800	J/kg·K	ASTM E1269
Water Absorption (24 h)	20–150	%	ASTM D570
Moisture Content	5–15	%	ASTM D4442
Porosity	60–90	%	Mercury Porosimetry / Micro-CT
Sound Absorption Coefficient	0.30–0.90	NRC	ASTM C423
Thermal Stability	220–320	°C	TGA (ASTM E1131)
Ignition Temperature	250–350	°C	ASTM D1929
Biodegradation Time	30–180	Days	ASTM D5988
Electrical Conductivity	$\sim 10^{-12}$–10^{-9}	S/m	ASTM D257
CO_2 Sequestration Potential	0.5–2.0	kg CO_2/kg composite	Life Cycle Assessment (LCA)

Fig. 1: Overall Architecture

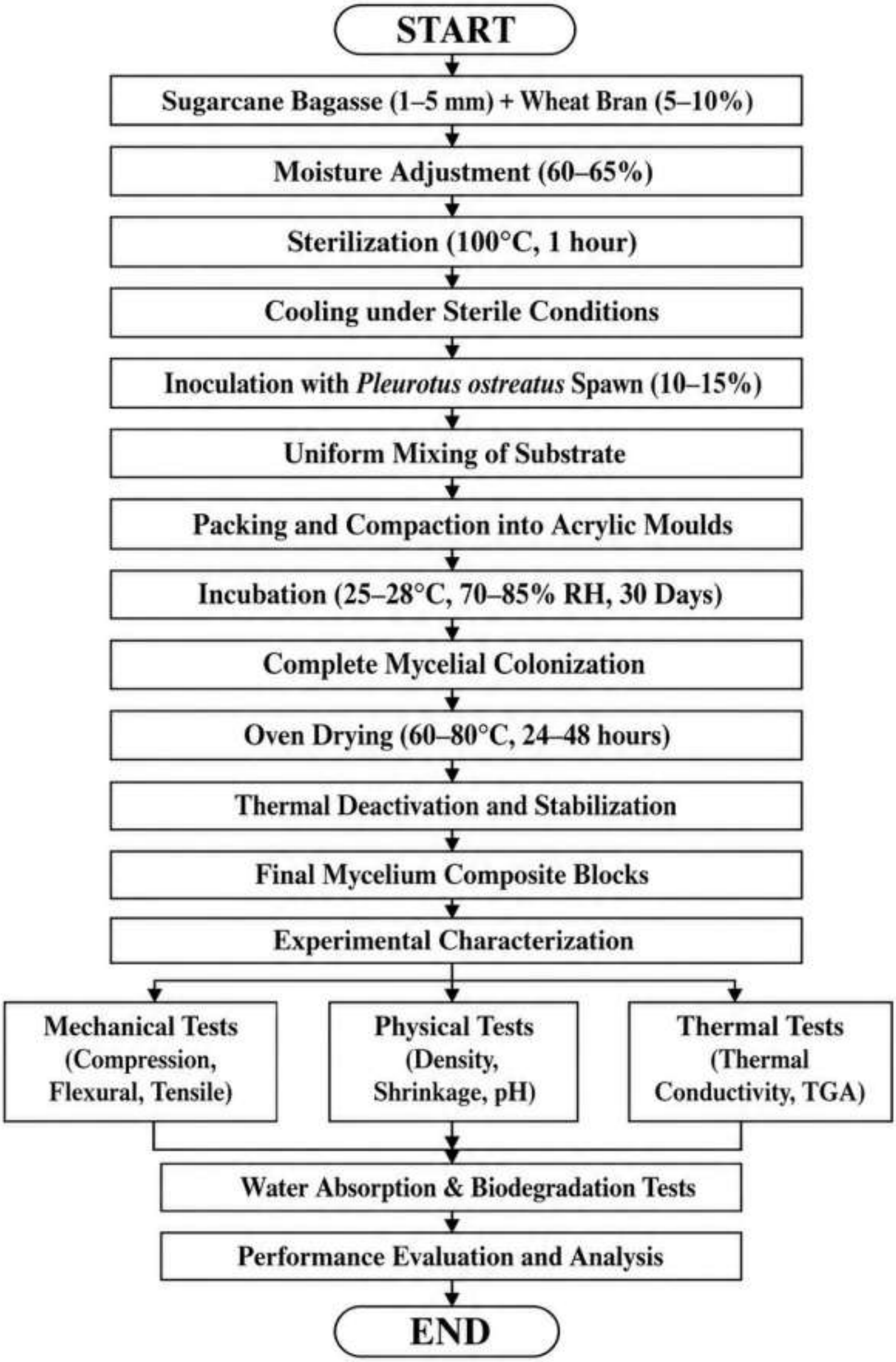


Fig. 2: Flow chart for experimental analysis

4.1.*Materials*

Pleurotus ostreatus has been provided as a grain spawn source of the fungal binding agent, and sugarcane bagasse has been used as the primary lignocellulosic substrate [26]. A concentration of 5–10% Wheat Bran has been added as an additional nutrient source to promote the growth of the mycelium and facilitate the colonization of the substrate by the fungus [27]. The moisture content of the substrate has been maintained at the optimum level for the best action of the fungus with the use of distilled water. Acrylic Moulds were used to produce uniform-shaped blocks of inoculated substrates with consistent geometry and density during production. The production and handling of the substrates were done under sterile conditions in order to reduce the possibility of microbial contamination. The use of sterile polypropylene bags to contain the substrates and gloves & ethanol for handling, aseptic handling, and disinfecting surfaces throughout the experimentation phase were implemented. These materials were selected based on their low availability and cost, as well as their compatibility for supporting fungal growth and producing eco-friendly mycelium-based composite materials for sustainable construction and materials engineering applications. The materials used throughout the entire study are presented in Figure 3 as follows: (a) fungal species, (b) sugarcane bagasse fibres, (c) wheat bran supplement, and (d) distilled water.

(a) Fungal species

(b) Sugarcane bagasse fibres

(c) Wheat bran supplement

(d) Distilled water

Fig. 3: Materials used in this study

4.2. *Substrate Preparation and Sterilization*

Sugarcane bagasse is the main substrate employed, and first of all, it has been thoroughly washed with pure water in order to remove dust, soil, and soluble impurities that were sticking to its surface. The bagasse has been cleaned and then dried in an oven to lower the moisture ratio and thus prevent microbial spoilage during processing. Subsequently, it has been ground and passed through a sieve to get the desired particle size that is uniform and also good for mycelium growth, thus ensuring a good packing density and sufficient surface area for the fungus to take over. The bagasse fibres prepared were then mixed with wheat bran, which acted as a nutritional lure that would assist in mycelium development. Gradually, distilled water was added to this mix, and the moisture content was meticulously set to about 60-65%, which is ideal for the growth of Pleurotus ostreatus. The substrate that had been made wet was then placed in heat-resistant containers and sterilized in the autoclave for 1 hour at 100 °C (Figure 4), thereby killing off all the microorganisms that could compete with the fungus. After sterilization, the substrate was allowed to cool down to room temperature under aseptic conditions so as not to introduce any contaminants. This entire preparation and sterilization process resulted in a substrate that was sterile, nutrient-rich, and homogeneous, thus providing favourable conditions for even mycelial colonization and consistent composite formation.

Fig. 4: Autoclave

4.3. *Inoculation and Molding*

After the substrate underwent the processes of preparation and sterilization, inoculation took place with Pleurotus ostreatus grain spawn at 10–15% concentration by weight of the substrate. The spawn was slowly added to the cold sterile substrate, ensuring blending and also decreasing the chances of infection at the site. The mixing was done meticulously in aseptic conditions to get a uniform mixture that allowed the fungal mycelium to take over the whole substrate without any area being uncolonized. When the inoculum had been mixed well, the inoculated substrate was moved to pre-sterilized Acrylic Molds that had been designed for shaping the composite into blocks or boards of the desired size. The substrate was then compacted in the Molds to ensure uniformity of density through the material, which is very important for mechanical stability and structural integrity of the final mycelium composite. The compaction process was done in such a way that very few air pockets were left, thus facilitating contact between substrate particles and mycelium, which in turn promotes growth rate and binding strength. The moulded samples were then taken for incubation under controlled conditions of temperature and humidity to allow complete mycelial colonization while keeping the desired shape and density, thus resulting in uniform, stable, and high-quality fungal composite blocks that are fit for testing and application. Figure 5 shows that Acrylic Molds used in this study.

Fig. 5: Acrylic Molds

4.3.1. Incubation

Subsequent to inoculation and moulding, the mycelium-substrate blocks prepared were incubated according to a process that has been specifically designed to be the best for fungal growth and total colonization. The substrates were inoculated and delivered in moulds that were later placed in a controlled environment where the temperature was kept between 25 – 28 °C, the optimum temperature for Pleurotus ostreatus cultivation. The relative humidity of 70% owing to 85% has been maintained in the incubation chamber to allow the substrate not to become too dry and also to support the mycelium growth which had to be through the whole material. The samples were kept in the dark to simulate the natural underground condition where fungi normally grow and, hence, no light stress or growth inhibition was caused. This period lasted for 30 days, during which the mycelium gradually took over the substrate, squeezing the fibres together to create a solid, interwoven network that acted as the structure of the composite. There were frequent observations made in order to monitor the growth and development and also to ensure no contamination or abnormality in development. The whole process of incubation was very crucial in this aspect of producing a uniform mycelial network, which then directly affected properties like mechanical strength, density, and overall performance of the final mycelium composite blocks, thus making them ready for drying and physical characterization in the subsequent step. Figure 6 denotes the Incubation used in this research.

Fig. 6: Incubation

4.3.2. Drying

Once the mycelium had completely covered the surface, the composite blocks underwent drying as a means of stopping the growth of fungi and ensuring the material structure was stable. The samples with the mycelium were taken out carefully from the moulds and put into an oven, where they were dried over a period of 24 *to* 48 *hours* at a temperature between 60 *and* 80 °*C*. The thermal treatment not only killed the mycelium but also brought down the moisture content to a point that would not affect the size and strength of the material. The drying process also made the composites more rigid and structurally sound, thus making them ready for the tests and applications shown in Figure 7.

Fig. 7: Dried mycelium (30 days)

5. Experimental Procedure

The experimental setup was designed to comprehensively evaluate the mechanical, thermal, physical, and biodegradation characteristics of mycelium–sugarcane bagasse composite blocks, following relevant ASTM standards, as illustrated in Figure 8. Sugarcane bagasse was collected from a local sugar industry, washed thoroughly to remove impurities, oven-dried at 80 ± 2°C for 24 h, and ground to obtain a uniform particle size of 1–3 mm. The fungal strain Pleurotus ostreatus was selected as the binding microorganism because of its rapid colonization and excellent lignocellulosic degradation capability. Commercial wheat bran (5 wt%) and calcium carbonate (1 wt%) were incorporated as nutrient and pH-adjusting agents, respectively. Distilled water was added to maintain the substrate moisture content at approximately 60–65% before sterilization.

The prepared substrate mixture was sterilized in an autoclave at 121°C and 15 psi for 20 min and inoculated with 10 wt% mycelium spawn under aseptic conditions. The inoculated substrate was transferred into moulds to produce brick specimens (190 × 90 × 90 mm) and block specimens (200 × 150 × 150 mm). The samples were incubated at 25 ± 2°C and 80–90% relative humidity for 14–18 days to achieve complete mycelial colonization. The fully grown composites were then oven-dried at 70°C for 24 h to terminate fungal growth and stabilize the material.

Mechanical characterization included compressive strength testing (ASTM D1621), flexural testing using a three-point bending configuration (ASTM D790), tensile testing (ASTM D638), and density determination (ASTM D792). All mechanical tests were performed using a calibrated Universal Testing Machine (UTM, 100 kN capacity) with a crosshead speed of 2 mm min^{-1} for compression and flexural tests and 5 mm min^{-1} for tensile testing. Thermal conductivity was measured according to ASTM C518 using a heat-flow meter apparatus, while water absorption was evaluated following ASTM D570. Biodegradation behaviour was assessed according to ASTM D5988 by burying the specimens in controlled compost soil maintained at 28 ± 2°C and 60 ± 5% moisture content for 30 days, with periodic weight-loss measurements recorded every five days.

The dimensions and mass of all specimens were measured using a digital Vernier caliper (accuracy ±0.01 mm) and an electronic balance (accuracy ±0.001 g). Temperature and relative humidity during incubation and testing were monitored using calibrated digital sensors. For each experimental condition, five identical specimens (n = 5) were tested, and the reported results represent the mean ± standard deviation. Experimental uncertainty was minimized through instrument calibration before testing, controlled environmental conditions, and repeated measurements. The percentage error was calculated by comparing repeated observations, and the overall experimental deviation remained below ±5%, confirming the reliability and repeatability of the obtained results.

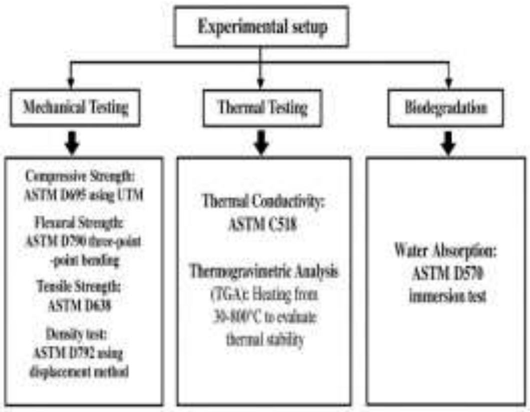


Fig. 8: Experimental flow

5.1. *Mechanical Testing*

The mechanical tests gave the primary strength features of the mycelium-sugarcane bagasse composite blocks. The compressive strength test was performed to determine the amount of load the material would be able to carry in an axial direction. The flexural strength test was carried out to find out the maximum force the samples could bear before being damaged. The tensile strength test, according to ASTM D638, has been carried out to gain insight into the material's response when pulling forces are applied. The combination of these three tests provides a thorough assessment of the mechanical performance and also the compatibility of the composites with the structure.

5.2. *Compressive Testing*

A certified Universal Testing Machine (UTM) has been utilized in accordance with the relevant ASTM standards to determine the compressive strength of the mycelium-sugarcane bagasse composite blocks. Specimens possessing standard dimensions were prepared and subsequently tested after being conditioned in a controlled environment. The samples were centrally placed between the UTM compression platens to ensure that the load was distributed uniformly. A constant loading rate was applied until either failure or significant deformation occurred. The compressive strength was found by dividing this load by the cross-sectional area. Different samples were tested to get a consistent result, and the average values were reported to accurately indicate the compressive performance of the composites, as shown in Figure 9.

Fig. 9: Compression test (UTM)

5.3. Flexural Testing

The flexural strength of the specimens was measured with a Universal Testing Machine that had a three-point bending attachment. Composite rectangles of standard dimensions were placed on the two supports in a horizontal position, which had a fixed spacing between them. At the middle of the sample, a load was applied in a controlled manner until either fracture or a significant bending failure was noticed. The test was performed at a constant speed of the crosshead so as to keep the application of stress uniform. The maximum load together with the corresponding deflection was recorded, and the flexural strength was computed by means of standard equations. The testing of several specimens assured the reliability of results and made possible the assessment of the bending resistance and the integrity of the mycelium composite blocks' structure. Figure 10 shows the three-point bending flexural testing used in this research.

Fig. 10: Three-point bending flexural testing

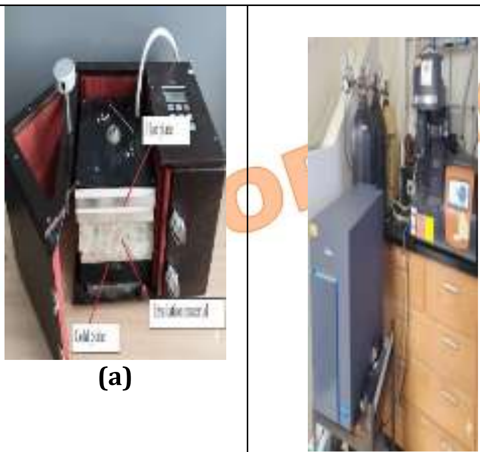
5.4. Tensile Testing

The tensile strength testing has been conducted using a Universal Testing Machine that has been fitted with suitable grips for the tensile test, and it has been done in accordance with the ASTM D638 Standard (Figure 11). The specimens had the shape of a dog-bone, and they were made to the standardized dimensions so as to achieve uniform stress distribution during loading. The samples were tightly held in the grips of the UTM, and a single tensile load was applied at a constant strain rate until the specimen failed. Load-elongation data were recorded throughout the testing process continuously. The tensile strength was determined by dividing the maximum load the sample withstood by its original cross-sectional area. Re-testing of different specimens several times made sure that the data obtained was reliable and also gave a better understanding of the composite's load-bearing and ductility characteristics.

Fig. 11: Tensile testing

5.5. Thermal Conductivity & Thermogravimetric Analysis

The thermal characterization of the mycelium–sugarcane bagasse composite blocks has been done by thermal conductivity testing and thermogravimetric analysis in order to evaluate their insulation performance and thermal stability, as shown in Figure 12 (a). The measurement of thermal conductivity has been performed by using a Guarded Hot Plate Apparatus in accordance with standard testing procedures. Uniform-thickness composite specimens were placed between the hot and cold plates, and a steady-state heat flow condition was maintained. The temperature difference across the sample and the corresponding heat flux were recorded to calculate the thermal conductivity, which gave an idea of the material's suitability as a thermal insulating material. Thermogravimetric analysis (TGA) was performed using a calibrated Thermogravimetric Analyzer to check the thermal degradation behaviour of the composites, as shown in Fig 12 (b). The samples were heated under an inert atmosphere at a controlled rate, and the weight loss was continuously monitored as a function of temperature. The TGA identified moisture loss, decomposition stages, and residual mass, thus revealing the thermal stability and decomposition characteristics of the mycelium-based composites under high-temperature conditions.



(a) (b)

Fig. 12: (a) Guarded Hot Plate Apparatus, (b) Thermogravimetric Analyzer

5.6. Biodegradation Testing

The biodegradation behaviour of the mycelium-sugarcane bagasse composite blocks has been tested in this research through a water absorption experiment to figure out their moisture interaction and environmental stability, as shown in Figure 13. Distilled water was used, and then the dried composite samples were weighed and immersed in it for a time set beforehand under ambient conditions. The samples were then taken out, the surface water was very gently wiped off, and the specimens were weighed again to calculate the percentage of absorbed water. The weight gain has been a sign of the material's water intake capacity, which directly connects to its porosity and compostable nature. A higher water absorption level suggests the presence of the hydrophilic properties of the natural fibres and the fungal matrix, which in turn indicates that the material is more likely to undergo biological degradation in moisture-rich conditions.

Fig. 12: Water absorption test

5.7. Results & Discussion

The mycelium–sugarcane bagasse composite blocks are to be subjected to experimental analysis that will yield a wide collection of performance indicators, namely the mechanical, physical, thermal, and biodegradation characteristics. The compressive strength values, which will be in MPa, are going to be the reflections of the load-bearing power of the composites that are affected by the mycelial binding efficiency, the substrate particle size, and density. The flexural strength and flexural modulus are pretty much expected to show the bending resistance and the stiffness; thus, the applicability of the material for panel and board applications can be inferred. The tensile strength and the elongation at break will probably reveal the composite's cracking resistance and its deformed behaviour under tensile loading, respectively, and, thus, the fungal network will be recognized for imparting a certain degree of brittleness and ductility through the aforementioned properties. On the other hand, the density measurements are to provide an inverse correlation where the high porosity will turn out to be the leading cause of lightweight traits and at the same time reduce the strength of the composite mechanically. The thermal conductivity values, measured in $W/m \cdot K$, are likely to be quite low owing to the porous microstructure, thus leading to the conclusion that there is potential for thermal insulation applications. The parameters of thermogravimetric analysis (TGA), such as onset of decomposition and char residue, are likely to show the thermal stability and degradation behavior of the composites, with char residue indicating the lignocellulosic and fungal biomass content. The water absorption rate results are likely to indicate moderate to high moisture sorption because of the natural fibres and mycelium being hydrophilic, which in turn will affect the dimensional stability in humid conditions Table 3.

Table 3. Material properties of mycelium composites

Property	Bagasse Brick	Bagasse Block	Unit
Density	0.294	0.298 *	g/c m^3
Tensile Strength	0.42	0.35	MPa
Compressive Strength	0.25	0.19	MPa
Flexural Strength	0.85	0.72	MPa

5.8. Compressive Testing

The compressive strength of the bagasse-based mycelium composites has been identified as the material's load-bearing ability under axial compression through the strength tests re shown in Table 4. The compressive strength of the bagasse brick specimen was around 0.25 N/mm^2, which was the result of the maximum applied load of 4.3 kN and the cross-sectional area of 17,100 mm^2. Meanwhile, the bagasse block specimen has been able to bear a marginally heavier load of 4.4 kN but due to its greater cross-sectional area of 22,500 mm^2 it exhibited a compressive strength of around 0.20 N/mm^2. The difference illustrates that one of the factors that influence compressive strength the most is indeed the geometry of the specimens and the distribution of effective stress rather than the load only. The stronger bagasse brick has been a sign of better compaction and mycelial bonding in the area of the thinner cross-section, which has led to greater resistance to compressive fracture. These findings lend support to the claim that bagasse-based mycelium composites have a compressive strength that can be classified as moderate; it can be used in non-structural areas and lightweight building materials in situations when sustainability and biodegradability are more important than having high mechanical strength.

Table 4: Compressive Test Result

Material	**Load (KN)**	**Area (mm^2)**	**Compression strength (N/ mm^2)**
Baggas Brick	4.3	17100	0.25
Baggas Block	4.4	22500	0.19

6. Flexural Testing

The flexural strength results for the mycelium–bagasse composite specimens clearly indicate their bending performance and suitability for non-structural and lightweight building applications, as shown in Table 5. Among the different composites tested, the bagasse brick sample received the highest recognition with a maximum load of 145 N. It was evaluated using a span length of 200 mm, a specimen size of 200 × 50 × 25 mm, and achieved a flexural strength of 0.85 MPa and a flexural modulus of 95 MPa. On the other hand, the bagasse block specimen was able to withstand a maximum load of only. 130 N under the same testing conditions and dimensions, resulting in a flexural strength of 0.72 MPa and a flexural modulus of 80 MPa. The bagasse brick is said to have higher flexural strength and stiffness due to the better compaction and more uniform mycelial bonding, which are able to resist bending stress. The bagasse block has lower values when compared with the brick, which is an indication of a more porous structure inside the material, leading to a reduction in stiffness but an increase in flexibility. The flexural strength values, however, are considered typical for mycelium-based composites. The results also imply that the materials developed are mechanically fit for purposes like interior partitioning, insulation boards, and lightweight panels where moderate bending resistance and sustainability are the key performance requirements.

Table 5: Flexural Test Result

Material	**Maximum Load (N)**	**Span Length (mm)**	**Specimen Size (mm)**	**Flexural Strength (MPa)**	**Flexural Modulus (MPa)**
Bagasse Brick	145	200	200 × 50 × 25	0.85	95
Bagasse Block	130	200	200 × 50 × 25	0.72	80

6.1. Tensile Testing

A sample made of bagasse in the shape of a brick reached a maximum load of 210 N with a gauge length of 50 mm and a specimen size of 165 × 19 × 5 mm, which led to a tensile strength of 0.42 MPa and an elongation at break of 2.8%. The sample of bagasse block, on the other hand, experienced a maximum load of only. 185 N in the same testing conditions, leading to a tensile strength of 0.35 MPa and a slightly higher elongation at break of 3.2%. The tensile strength of the brick made from bagasse is mainly due to the interlocking of fibers being better and mycelial bonding being stronger, leading to more tensile stress resistance. On the other hand, the bagasse block's larger elongation at break reflects a structure that is more porous and hence allows more deformation before it actually breaks. In general, the values for tensile strength are in the range that is typically referred to for mycelium-based composites designed for non-structural applications ae shown in Table 6.

Table 6: Flexural Test Result

Material	Maximum Load (N)	Gauge Length (mm)	Specimen Size (mm)	Tensile Strength (MPa)	Elongation at Break (%)
Bagasse Brick	210	50	165 × 19 × 5	0.42	2.8
Bagasse Block	185	50	165 × 19 × 5	0.35	3.2

6.2. *Density Result*

The density changes of the bagasse-based mycelium composite specimens during the first 30 days of observation give a great deal of information about their physical stability and structural evolution. Initially, moisture was present, so the density of all the samples decreased gradually as time went on; thus, it can be attributed to moisture loss, relaxation of the internal structure, and the stabilization of the mycelial network in the lignocellulosic matrix. Specifically, specimens B11, B12, and B13 had initially higher densities of $0.305\ to\ 0.316\ g/cm^3$ on Day 1, which then dropped to about $0.294 - 0.299\ g/cm^3$ on Day 30. This slight reduction indicates good compaction and strong mycelial bonding, which in turn led to the enhancement of the dimensional stability. In contrast to the others, samples C11, C12, and C13 had lower initial densities, particularly C12 and C13, which started at $0.264\ g/cm^3\ and\ 0.222\ g/cm^3$, respectively, and then further decreased to $0.246\ g/cm^3\ and\ 0.198\ g/cm^3$ at the end of Day 30. This larger density drop in these samples suggests that the internal structure is highly porous and not very compact, which might be a reason for the material being lightweight but not so strong mechanically. The minor changes happening at the intermediate intervals, such as small increases around Day 20, can be accounted for by temporary moisture absorption or environmental humidity variations shown in Figure 13. The density results, however, show that bagasse-based mycelium composites are indeed lightweight materials with densities that are much lower than those of conventional masonry products. The trends observed signify the impact of the composition of the specimen and the compaction on the stability of the density, thus indicating that these composites are suitable for non-structural applications such as insulation panels, lightweight blocks, and interior partition systems where reduced weight and sustainability are the key performance requirements, as shown in Table 7.

Table 7: Density Variation of Bagasse-Based Specimens Over Time (g/cm^3)

Specimen	Day 1	Day 5	Day 10	Day 15	Day 20	Day 25	Day 30
B11	0.309	0.303	0.299	0.295	0.301	0.297	0.294
B12	0.305	0.3	0.297	0.294	0.302	0.302	0.299
B13	0.316	0.309	0.306	0.304	0.305	0.302	0.299
C11	0.307	0.302	0.295	0.297	0.306	0.301	0.298
C12	0.264	0.258	0.254	0.251	0.253	0.249	0.246
C13	0.222	0.216	0.216	0.212	0.209	0.201	0.198

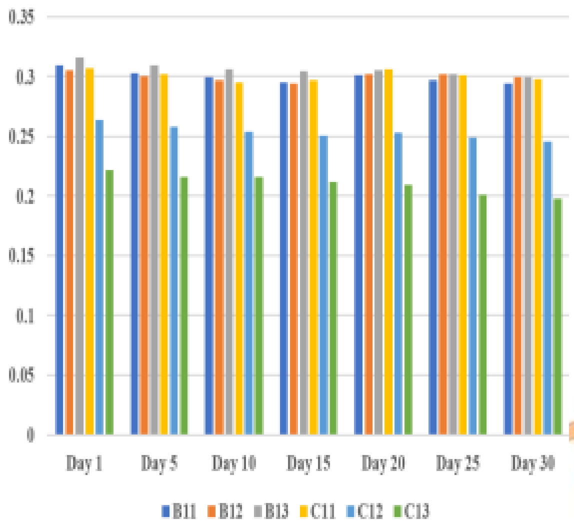


Fig. 13: Density Variation of Bagasse Graph

6.3. *Shrinkage*

The dimensions of the original specimens were compared with those measured after the drying process in order to assess the shrinkage effects of the different mycelium-based composite materials made from various lignocellulosic substrates are shown in Table 8. Once again, the volumetric basis was the parameter used for the evaluation of the dimensional stability, the latter being an important factor for construction and panel applications. Out of the tested materials, the composite made with bricks had the least shrinkage at 6.41%, whereby the dimensions decreased from $190 \times 90 \times 90\ mm$ to $186 \times 88 \times 88\ mm$. The decrease in volume indicates very good structural integrity along with high mycelial binding, thereby enhancing the drying process and tolerating fluctuations in size. The material produced from sawdust showed a remarkable shrinkage of 10.62%, and this was the outcome of an ideal combination of porosity and moisture evaporation. The bagasse composite was in the opposite corner with a shrinkage of 14.03%, which is the drawback of the fibrous and more hygroscopic nature of bagasse that attracts more water, thus leading to more evaporation and shrinkage of the volume. On the other hand, the soya composite presented a considerable shrinkage of 21.41%, which could mean a lack of strong internal bonding and higher moisture sensitivity. The wheat straw was the one with the highest shrinkage at 24.02%, which confirms its poor dimensional stability resulting from its very porous structure and uneven packing of fibres. The composite materials with less shrinkage, e.g., the brick and sawdust ones, are the better candidates for applications where the dimensional precision is of great importance, while the others with the higher shrinkage need to undergo processing changes or incorporation of additives to secure their stability for practical use, as shown in Figure 14.

Table 8: Comparative Shrinkage Behaviour of Mycelium-Based Bio-Composites

Material	Original Dimension (mm)	Dimension After Drying (mm)	Shrinkage %
Brick	190 × 90 × 90	186 × 88 × 88	6.41 %
Sawdust	190 × 90 × 90	186 × 87 × 85	10.62%
Bagasse	190 × 90 × 90	181 × 86 × 85	14.03%
Soya	190 × 90 × 90	189 × 80 × 80	21.41%
Wheat straw	190 × 90 × 90	185 ×79 × 80	24.02%

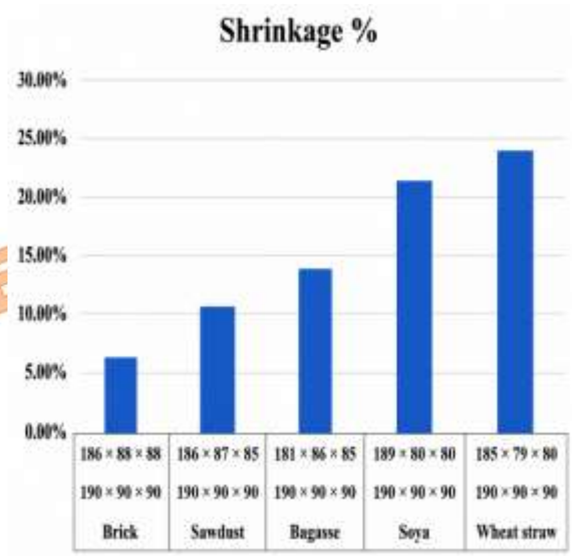


Fig. 14: Shrinkage Behaviour of Mycelium-Based Bio-Composites

6.4. *pH Results*

The pH assessment of various lignocellulosic substrates employed in the manufacture of mycelium composites is a powerful tool in determining their chemical milieu and compatibility with the growth of fungi and the development of materials image shown in Figure 15.

Fig. 15: pH experimental image

Table 9 shows that sawdust, of all the tested substrates, showed the least acidic character, indicated by the lowest value of pH. 4.82. The growth of mycelium colony in such acidic conditions might be slow, thus requiring longer incubation periods or adding buffers to attain uniform growth. Contrarily, bagasse had a pH value of 6.06 which is very close to neutral and hence considered very favourable for the growth of Pleurotus ostreatus since this fungal species usually flourishes in slightly acidic to neutral conditions. Soya was the one with the highest pH value of 6.42, which indicates that the substrate was slightly alkaline. This condition can be beneficial for rapid initial mycelial growth, but at the same time, it poses the risk of uneven colonization or increased contamination if the situation is not properly controlled. The pH of wheat straw has been 5.98, which is a good range for fungi and hence good compatibility as a substrate, as shown in Figure 16. The pH levels of bagasse, soya, and wheat straw are all in the very best range for mycelial binding, enzymatic power, and substrate consumption. The low pH of sawdust may slow down the decomposition of lignocellulosic components and, in turn, affect the composite's density and strength. Thus, the findings have indicated that substrate pH is among the most important factors that determine the growth of mycelium, the efficiency of bonding, and the properties of the material in the end. Hence, the right choice or adjustment of substrate pH is a must to attain a steady quality of composite and to maximize the mechanical and physical performance of mycelium-based eco-friendly building materials.

Table 9: pH experimental Results

Substrate	pH Results
Sawdust	4.82
Bagasse	6.06
Soya	6.42
Wheat straw	5.98

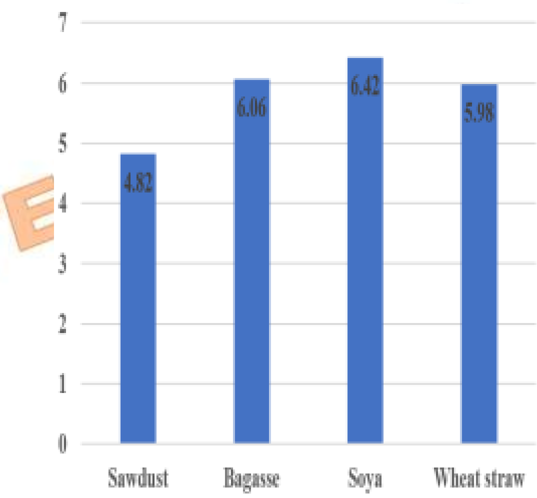


Fig. 16: pH Behaviour of Mycelium-Based Bio-Composites

6.5. Thermal Conductivity

The thermal conductivity measurements of the mycelium composite materials indicate they might be used as insulation materials and for non-structural building applications. The bagasse brick, which has a density of 0.30 g/cm^3, has a thermal conductivity of 0.085 $W/m \cdot K$, reasonably indicating that the insulation is moderate due to its relatively dense structure and low air voids. The wheat straw composite, on the other hand, although having a higher density of 0.32 g/cm^3, behaved the same, with a thermal conductivity of 0.085 $W/m \cdot K$, which means that the softening and fiber arrangement can still limit the heat flow reduction in natural fiber-based materials. The bagasse block sample with a very slightly lower density (0.28 g/cm^3) still displayed an insulation behavior improvement due to a reduced thermal conductivity of 0.078 $W/m \cdot K$, which is attributed to increased porosity and trapping of air pockets within the mycelium network. At a density of 0.26 g/cm^3, the sawdust composite gave the lowest thermal conductivity value of 0.068 $W/m \cdot K$ thus confirming that the presence of finer particles together with higher porosity has a significant effect in the process of heat conduction; they block the flow of heat by conducting it through them. The soya-based composite, with a density of 0.27 g/cm^3, exhibited a thermal conductivity of 0.075 $W/m \cdot K$, indicating a balanced structure with moderate insulation effectiveness. In general, the results point out that there is a close inverse relationship between density and thermal insulation performance, in such a way that the ones with high density and low porosity are the ones with high thermal conductivity, contrary to Figure 17. These values are in line with the previously existing literature about mycelium-based insulation materials and further confirm that the developed composites are capable of large-scale heat transfer reduction. Therefore, the ideal for the mentioned applications where thermal efficiency and sustainability are key design considerations: insulation panels, lightweight wall systems, ceiling boards, and interior partitions (Table 10.

Table 10: Thermal Conductivity experimental data

Material	Average Density (g/cm^3)	Thermal Conductivity (W/m·K)
Bagasse Brick	0.3	0.085
Bagasse Block	0.28	0.078
Sawdust Composite	0.26	0.068
Soya-Based Composite	0.27	0.075
Wheat Straw	0.32	0.085

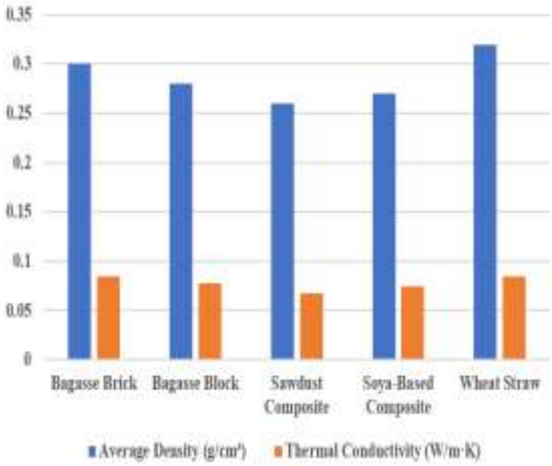


Fig. 17: Thermal conductivity of Mycelium-Based Bio-Composites

6.6. *Water Absorption Rate*

The analysis of the water uptake by the mycelium-based composite specimens was done by weighing the samples before and after water immersion, which helped in knowing the moisture absorption and durability of the materials in wet conditions are analysed in Table 9. The brick sample weight rose from 95 g ($W1$) to 105 g ($W2$), which indicates that water absorption was moderate due to its relatively dense structure and lower open porosity. On the other hand, the sawdust composite showed an enormous weight gain from 67 g to 102 g, which is a clear sign of a high-water absorption capacity; the high particle surface area and the very porous structure helped the water penetration through capillary action. The bagasse sample definitely exhibited a significant quantity of moisture uptake since its weight increased from 59 g to 94 g, suggesting that the lignocellulosic fibres and the associated mycelial network played a role in the material's very hydrophilic characteristic. The soybean-based composite had one of the most powerful water absorption reactions, as its mass increased from 63 g to 105 g, thus, confirming extensive pore connectivity and higher water affinity. Conversely, wheat straw experienced a water weight increase only from 45 g to 77 g, which is low compared with the other materials, probably due to its hollow fiber and being only partially resistant to water ingress. The main conclusion of the study is that the type of substrate, density, and internal porosity of the composites all have a strong impact on water absorption. The higher moisture content, which is good for the biodegradability of the material, is a drawback for dimensional stability and strength under humid conditions table 11. The need for surface treatments or protective coatings comes up when mycelium-based composites are used in moisture-prone applications, but their green, lightweight, and biodegradable character still makes them good for construction materials and hence acceptable in the case of sustainability figure 18.

Table 11: Water Absorption Rate experimental result

Specimen	W1 (gm)	W2 (gm)
Brick	95	105
Sawdust	67	102
Bagasse	59	94
Soya	63	105
Wheat straw	45	77

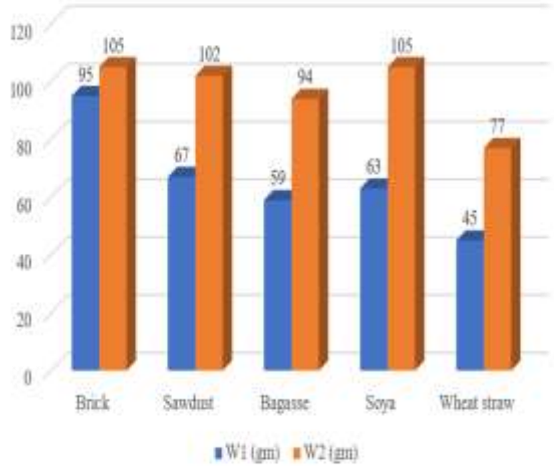


Fig. 18: Water Absorption Rate of Mycelium-Based Bio-Composites

6.7 *Comparative analysis*

The experimental performance of the developed sugarcane bagasse–mycelium composites compares favourably with previously reported mycelium-based bio-composites. The maximum compressive strength obtained in the present study was 0.25 MPa, which is higher than the 0.168 MPa reported in [20], although lower than the 0.75 MPa achieved in [16], primarily due to differences in substrate composition, compaction, and processing conditions. The developed composites exhibited a density of 0.20–0.32 g/cm^3 (200–320 kg/m^3), which is comparable to the 212–282 kg/m^3 range reported in [17], confirming their lightweight characteristics. The flexural strength of 0.85 MPa and tensile strength of 0.42 MPa are within the typical performance range reported for non-structural mycelium composites [19,21]. Furthermore, the measured thermal conductivity of 0.078–0.085 W/m·K closely matches the insulation performance reported in [18,23], demonstrating excellent thermal insulation capability. Compared with existing studies, the proposed composites combine competitive mechanical properties, low density, and good thermal insulation while being produced from renewable sugarcane bagasse without synthetic binders, making them suitable for sustainable insulation boards, partition panels, and other non-load-bearing building applications.

7. Conclusion

The growing demand for sustainable and biodegradable construction materials has increased interest in mycelium-based bio-composites as eco-friendly alternatives to conventional products. Sugarcane bagasse, an abundant agricultural waste, offers significant potential for value-added utilization while reducing environmental pollution. However, comprehensive studies on its mechanical, thermal, and biodegradation performance remain limited. This research addresses these gaps by experimentally evaluating mycelium–bagasse composites to determine their suitability for lightweight, sustainable building applications. The research has been successful in the production and methodical evaluation of fungal mycelium composite blocks made of sugarcane bagasse inoculated with Pleurotus ostreatus. Besides, it highlighted their advantages as replacements for conventional synthetic materials that are eco-friendly and bio-based. The whole experimental process from substrate preparation, mycelium growth under control to thermal deactivation and property evaluation resulted in rigid, lightweight composites with continuous structural integrity. The mechanical performance characterized by moderate compressive, flexural, and tensile strengths indicates that non-structural applications like insulation panels, partition boards, and packaging materials are the best use areas for these composites, rather than being imposed on them as load-bearing elements. Their low density, neutral pH, and acceptable dimensional stability support, together with their eco-friendliness, construction and material engineering applications. Their low thermal conductivity and good thermogravimetric stability thus mark these composites for thermal insulation applications, while the high-water absorption and biodegradability argue for their eco-friendliness and thus their end-of-life advantages over petroleum-based boards. Future research will focus on enhancing the mechanical strength and moisture resistance of mycelium–sugarcane bagasse composites through natural additives and surface modifications. Long-term durability, fire resistance, and thermal aging studies will be conducted under different environmental conditions. Furthermore, large-scale manufacturing, life cycle assessment, and structural applications in sustainable building materials will be explored.

There were some limitations of the study despite its promising results. The mechanical strength is still far lower than that of engineered wood and polymer composites, thus limiting the scope of its applications. On top of that, the hydrophilic characteristic of the material could be a disadvantage when it comes to its use in humid environments unless some kind of protective coating is applied. The experiment has been carried out on a laboratory scale and did not take into consideration variations from large-scale production, long-term aging, and real environmental exposure. Looking for other agricultural residues, fungal strains, and process optimizations could also be factors to further performance enhancement. Long-term durability studies, life-cycle assessments, and scale-up feasibility analyses have to be conducted, and this will be the crucial step in transferring mycelium-based composites from the group of experimental materials to commercially viable and sustainable solutions for the construction and insulation sectors.

Conflict of Interest

The authors have no conflict of interest.

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Competing Interests

The authors have no competing interests to declare that are relevant to the content of this article.

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