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Pleurotus ostreatus mycelium biofilters: a sustainable approach for thermal insulation in buildings

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ABSTRACT

Mycelium-bound composite substances are a novel class of sustainable and economical bio composites that were recently developed as an alternative to typical synthetic materials in packaging, fashion, and architecture. Extensive research has been carried out in recent years to study the methods of manufacture and processing, as well as prospective uses for mycelium-bound composite materials. However, the usage of this bio-composite in the construction industry is confined to small-scale prototypes and display exhibits. The main challenges that need to be address when employed as non-structural or semi-structural components are the water absorption, mechanical characteristics and the standard techniques for manufacture and testing of mycelium-bound composite materials as building insulation or blocks. Hence this paper describes the usage of novel Pleurotus ostreatus-mycelium fungal blocks to enhance the indoor thermal preformance of the building. To develop distinct mixing protocols with various substrate materials such as straws, coir pith, saw wood and the combination of the all the substrate were used in the present work. The parameters such as density, thermal resistivity, compressive strength and fire resistant were determined and it was found that the composition of the substrate is highly variable in the tested considered in the work. Straw and coir pith substrate showed a high strength and the thermal resistivity in comparison with the other substrates. Also, the findings show that the mycelium fungal based blocks have a lot of potential for use as an alternative material for insulation for building and infrastructure development, especially as a light-weight material for engineering applications.

Keywords: Mycelium; Thermal Insulation; Pleurotus ostreatus; Sustainable solution; Fungi.

1. INTRODUCTION

The global population is increasing at an alarming rate. To fulfill people's needs, technology has to develop unless doing so leads to degradation of the environment, or the generation of trash, and depletion of natural resources. The result of increase in population, urbanization, the yearly generation of waste is expected to increase by 70% from 2.01 billion tons in 2016 to 2.2 billion tons and 3.40 billion tons in 2025 and 2050, respectively [1, 2]. The primary sources of these wastes are from commercial and industrial buildings, households and agriculture [3]. The improper recycling of the waste from various sources has contaminated the air, water, landfills, and fertile soils [4]. Recycling technology will be an integral component to reduce the environmental impact of such trash. Natural resources are becoming scarcer, forcing a quest for recyclable and renewable materials. By 2050, the United Nations predicts that 66% of people worldwide would reside in densely populated areas [5]. Environmental pollution is a result of such material production practices. Agriculture, Forestry and Land Use directly accounts for 18.4% of greenhouse gas emissions (ourworldindata.org). The bulk of industrially manufactured materials used today, including those for construction and packaging, are toxic to the environment and cannot be recycled. When these conventional components are used, resources are depleted, and contamination of the air, soil, and water occurs during manufacturing, transportation, and demolition 8 to 10% of the world's total carbon dioxide emissions result from the production of building materials [6]. Mycelium is a type of fungus, consisting of an assembly of branching hyphae and a hollow, tubular structure that acts as the binding matrix and stimulates rapid growth [7] as given in Figure 1. Materials bound by mycelium are organic and completely disposable, supporting the shift to a circular bio-economy where the resources worth is preserved across the economy, and

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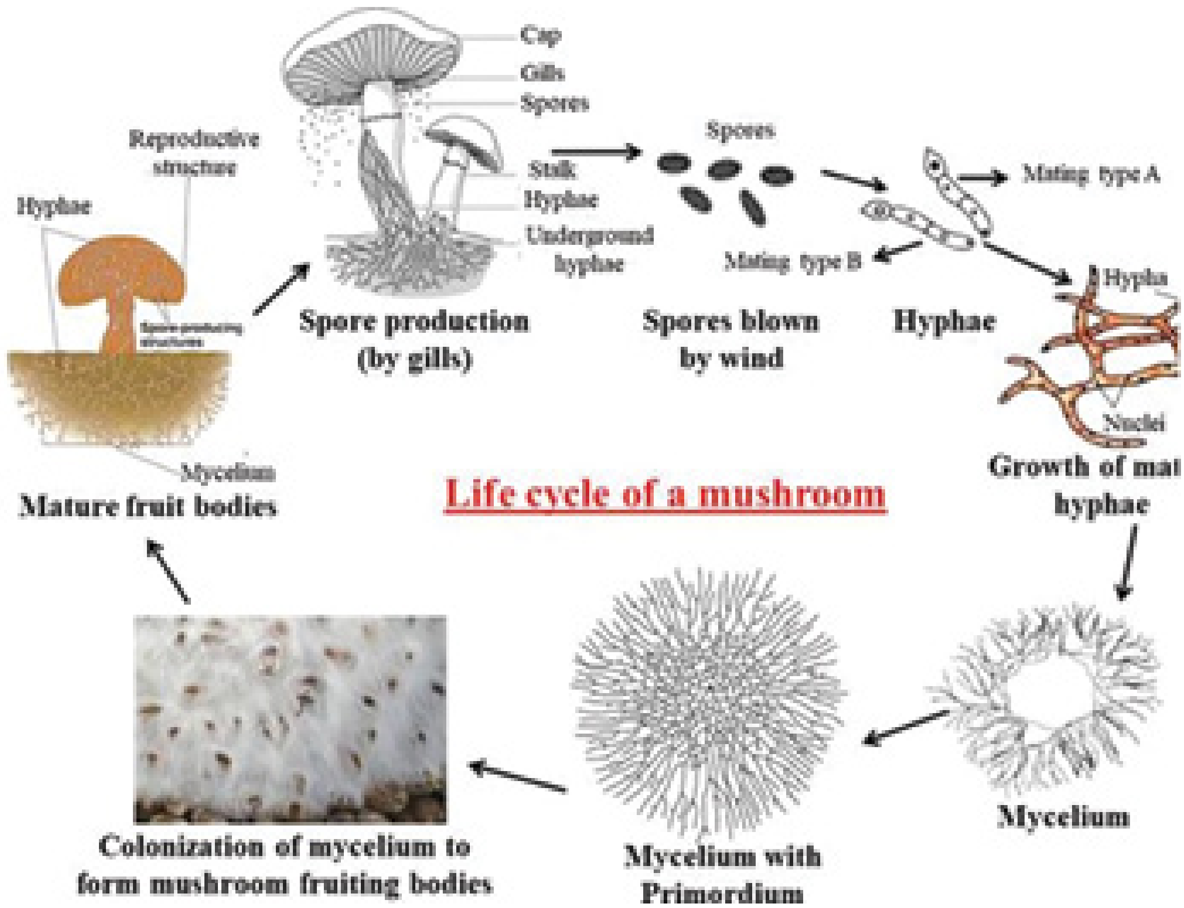

Figure 1: The various stages of the mushroom fungi's life cycle [8].

waste production from byproducts is kept to a minimum. Mycelium-bound products have recently been made available in the construction business is Hence, their range of applications is relatively narrow. They have been employed in numerous from nonstructural to semi-structural applications uses that replace conventional plastic sheets and films, Paneling, furniture, synthetic foams and plastics, and decks making room for substitute environmentally sustainable technologies constructing elements [9–11].

Comprehensive information on the impact of ecologically friendly materials on the fashion industry is provided in a recent evaluation research on the application of leather-like mycelium materials [12]. Mycelium of filamentous fungi, such as Pleurotus ostreatus (P. ostreatus), a common edible species of pearl oyster mushroom, and Ganoderma lucidum (G. lucidum), a medicinal mushroom popularly known as reishi, have been used for the development of mycelium-bound composite materials in the majority of the studies. It is an appealing substitute for synthetic materials because it uses biological growth rather than energy-intensive procedures to transform low-cost byproducts into high-value, biodegradable mycelium-bound material. Production of mycelium-bound composite materials is environmentally friendly and has minimal production and lifecycle disposal costs [13] Mycelium-bound composites are still being developed and sold by a small number of companies. Mycelium-bound composite materials have generally been compared to petrochemical foams in studies to describe them for use in the building industry [14]. Mycelium composites have excellent thermal and acoustic insulation properties, making them ideal for insulating buildings. They can help in reducing energy consumption for heating and cooling. These materials can be molded into various shapes, including bricks and panels, which can be used as structural and non-structural elements in buildings. They are lightweight and can be a sustainable alternative to traditional materials like concrete and gypsum [15, 16]. This material also shows excellent fire resistance, making it safer to employ in building applications [17]. Given all the ecological benefits of mycelium-bound materials, it is curious that they have not been used more frequently for structural and semi-structural purposes. This might be related to the material's weak structural integrity and water resistance. One recent study demonstrated that altering manufacturing procedures, fungus species, and substrate type could modify the mechanical characteristics and water absorption of mycelium-bound materials [18].

Previous studies have been performed for life-cycle assessments to evaluate the environmental impact of mycelium bio-composites. Rapeseed straw and cellulose were used as the building blocks to create mycelium bio-composite blocks. A life cycle study from cradle to gate was performed with a focus on the embodied energy and carbon of the manufacturing process. This explains the creation of molds, raw materials, the development of fungus, and the composite. It was possible to determine metabolic CO2—the CO2 that comes from fungus growth—by connecting the dry substrates weight to the carbon that cellulose burns when it is consumed. This covered the emissions and energy related to material cultivation, processing, inoculation, incubation, and sterilizing as part of the manufacturing process. Additionally taken into account were variations in incubation time, transit distance, and processing energy. When compared to normal building materials, the amount of energy contained in them was found to be 860.3 MJ/m3 and the amount of carbon embodied was found to be –39.5 kg eqCO2 m3. Microbial growth was determined to be the main cause of energy use and CO2 emissions. The results of the life cycle analysis still suggested the viability of mycelium as a source of carbon capture material and as a sustainable substitute for conventional building materials, even after taking into account the short life span of mycelium relative with traditional building materials and the amount of carbon dioxide produced during fungal growth [19] Scaling up the production involves several economic considerations that can impact their feasibility and adoption in the construction industry. The key factors to be consider are: raw material costs, production infrastructure, labor costs, environmental and social impact: The cost of mycelium-bound composite materials can vary depending on several factors such as the quality of the mycelium, the type of binding agents used, and the quantity of raw materials required. However, in general, mycelium-based materials are less expensive than conventional building materials like concrete and steel.

Though numerous research works has been carried out to study the importance of mycelium as a building material and the possibility of the adoption of the materials [20]. However, limited work has been performed on the thermal insulation of the sustainable mycelium blocks. Hence the present work focused on the performance of the mycelium blocks for the adoption to enhance the indoor comfortless for the better living environment.

2. MATERIALS PREPARATION AND TESTING

Three fibers such as straws, coir pith and saw dust as shown in Figure 2a have been selected based on the preliminary study. The choice of three specific fibers—straw, coir pith, and sawdust—for a study on mycelium-bound composite materials is likely due to their unique properties and benefits that align well with the goals of developing sustainable and effective construction materials. Straw is a by-product of cereal crops like wheat, rice, and barley, making it widely available and abundant. It represents a significant agricultural residue that can be repurposed for mycelium composites. Coir pith, a by-product of the coconut industry, is plentiful in tropical regions where coconuts are processed. It is often considered waste, so utilizing it for composites adds value to an otherwise discarded material Sawdust is a common by-product of the wood industry, available in large quantities from sawmills and woodworking facilities. Its widespread availability makes it an economical choice for composite production The selected fibers that were intended to be shredded underwent a 24-hour soak in water, followed by a thorough rinsing and a 10-minute mixing with fresh water. Soaking helps soften the fibers, making them easier to shred into smaller, more uniform pieces. This ensures that the fibers can be processed efficiently without causing damage to the shredding equipment. Mycelium requires a certain level of moisture to grow effectively. Pre-soaking ensures that the fibers are adequately hydrated, which can promote better mycelium colonization and growth. Soaking can help remove dirt, dust, and other contaminants from the fibers, which could otherwise inhibit mycelium growth or affect the quality of the composite material. It can also help leach out soluble substances that might be present in the fibers, such as sugars or salts, which could negatively impact the growth of the mycelium.The fibers were manually squeezed, spread on a sheet of paper, and dried at 30°C (say. laboratory temperature) for 24 hours after being sieved using a 5mm strainer [21]. Then, the dried, shredded fibers were put in an autoclave micro cylinder (Figure 2b) at 55°C for 24 hour. The loose, tow, and dust fibers were put directly into a micro box without being treated. The boxes were sterilized and allowed to cool for a full day. For compressive tests, a 2:1 diameter to height ratio boxes were chosen; the test samples have a diameter of 75 mm and a height of 150 mm. The same size of mould has been used for the all type of tests such as water absorption, thermal resistivity and fire test. The molds were filled with a mixture of 20% by weight of substrate, 70% by weight of water, and 10% by weight of Pleurotus ostreatus mycelium spawn (Figure 2c). The moulds were filled in layers, each layer being compressed well to create a compact and dense sample (Figure 2d) and then the molds were wrapped in clear cellophane wrapping with perforations. Three replicates were made for each group. To watch the growth visually, samples were placed in transparent boxed in parallel with the manufacture of the composite in moulds (Figure 2e). All samples were dried for 5 to 10 hours at 70°C in a convection oven (Figure 2f) until their weight stabilized. Each sample was weighed twice: once before drying and once after, along with its diameter and height. The shrinkage percentage was estimated by dividing

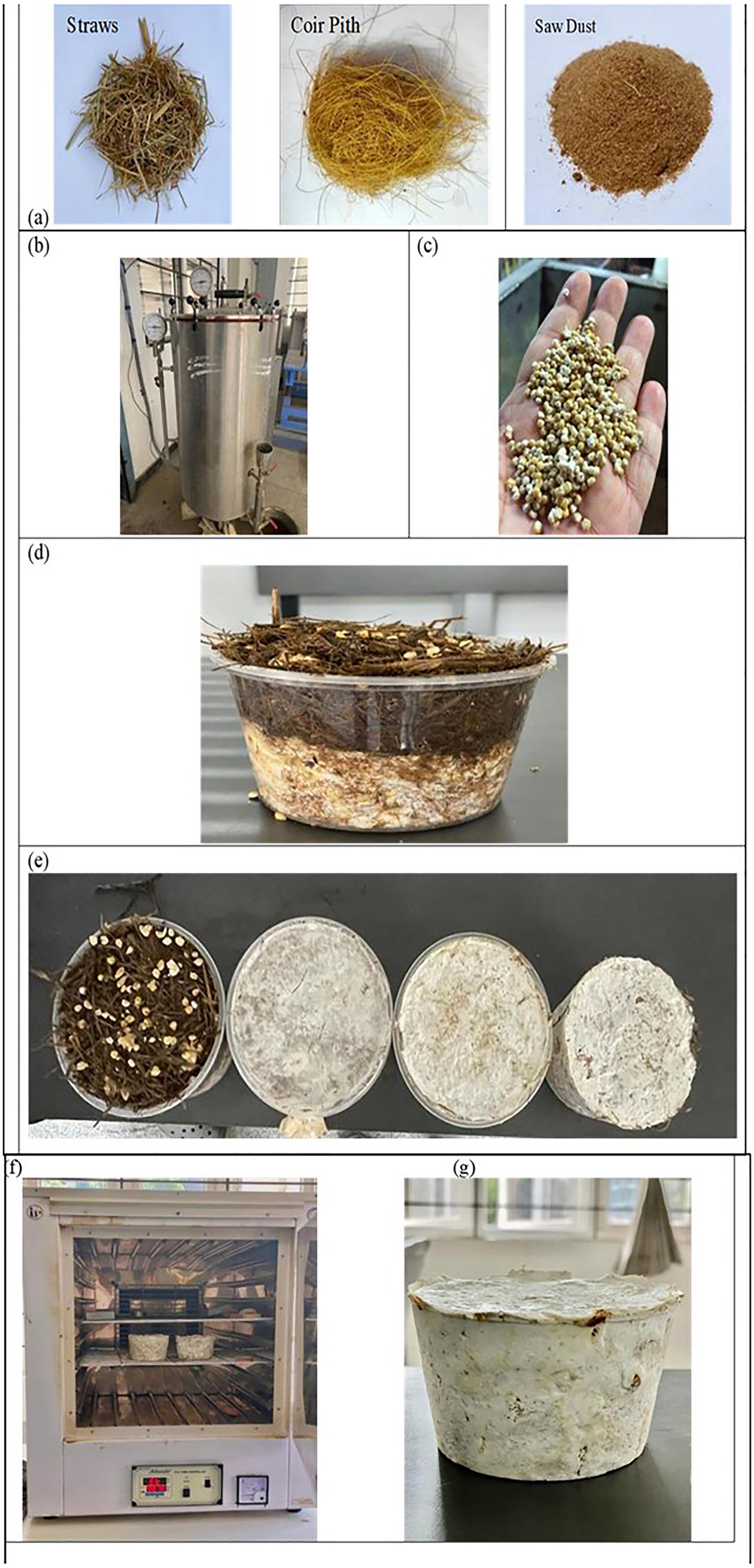

Figure 2: (a) Straw, coir pith, Saw dust, (b) autoclave micro cylinder; (c) Pleurotus ostreatus mycelium spawn (d) half grown mycelium (e) stages of the mycelium growth (f) Oven (g) full grown Pleurotus ostreatus mycelium.

the shrinkage by the wet volume after subtracting the dry volume weight from the wet volume weight. In order to calculate the change in humidity over time for two more specimens, the weight loss was monitored every 60 minutes for six hours. A fully grown mycelium block has been given in Figure 2g.

3. RESULT AND DISCUSSION

3.1. Water absorption test

Mycelium composites are a sustainable and eco-friendly alternative to traditional building materials. They are made by growing mycelium, the fruiting body of fungi, on a substrate of organic materials such as straw or sawdust. The water absorption rate of mycelium composites affects their long-term durability by affecting their ability to maintain moisture. High water absorption rates can lead to moisture loss and weakening of the composites over time. Proper moisture control can help to prevent this and ensure the long-term durability of the composites.When mycelium composite used as interior air quality improvement boards or insulation components, the water absorption rate is a crucial consideration because it affects the material's long-term durability [22]. The water absorption is depicted in Figure 3 in relation to the length of time the specimen was submerged. The initial absorption rates during the first 30 min were comparable for all the mycelium samples irrespective of the substrate as shown in Figure 3. For chopped straw and saw dust, a linear trend didn't emerge until after 30 to 40 minutes; for both, it persisted for 7 to 10 hours until the water absorption rate started to decline. As a result, the samples made of coir pith and straw absorbed water more quickly and did so before reaching their saturation point than saw dust.

3.2. Compression test

The objective of the compression test is to evaluate how the composition of the Pleurotus ostreatus mycelium and substrate affect the material's compression strength, or resistance to load [23]. Figure 4 illustrates the load required to get each material composition So far, the straw and the coir pith combination has produced the strongest composite materials. Samples containing straw and coir pith exhibited the best resistance to load. While the majority of repeats display rather similar features, the sections removed from the center from each sample frequently displayed reduced strain resistance [24]. Compared to the straw and coir pith mycelium samples, the saw dust samples and its combination exhibit distinct deformation performance but are far more consistent and strain-resistant. Higher Strength: Wood-based substrates, especially straw and coir pith, typically result in mycelium blocks with higher compressive strength. This is due to the rigid nature of wood fibers, which provide a strong matrix for the mycelium to bind together. Agricultural Residues (e.g., straw, corn stalks). Agricultural residues often produce mycelium blocks with moderate compressive strength. The lignocellulosic content in these residues provides a decent structural matrix, but their mechanical properties can vary.Finally, the average density of each material composition demonstrated a clear relationship between material density and compression strength, with saw dust having the lowest density and compression strength and straw combination having the highest density and compression strength [25].

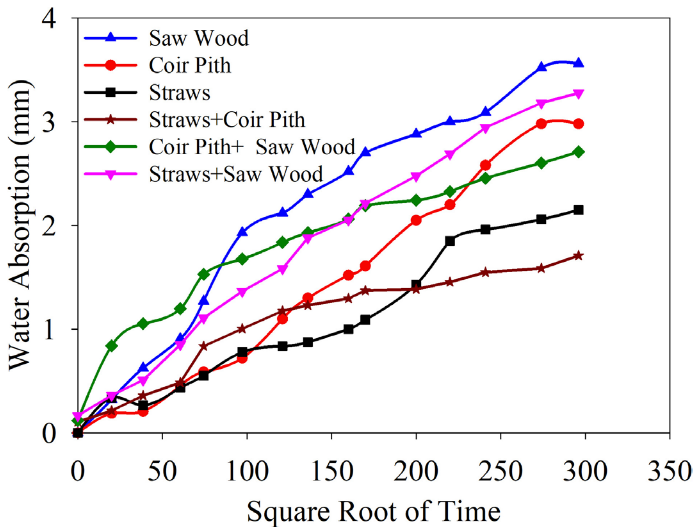

Figure 3: Water absorption capacity of mycelium composites with various substrates at different time intervals.

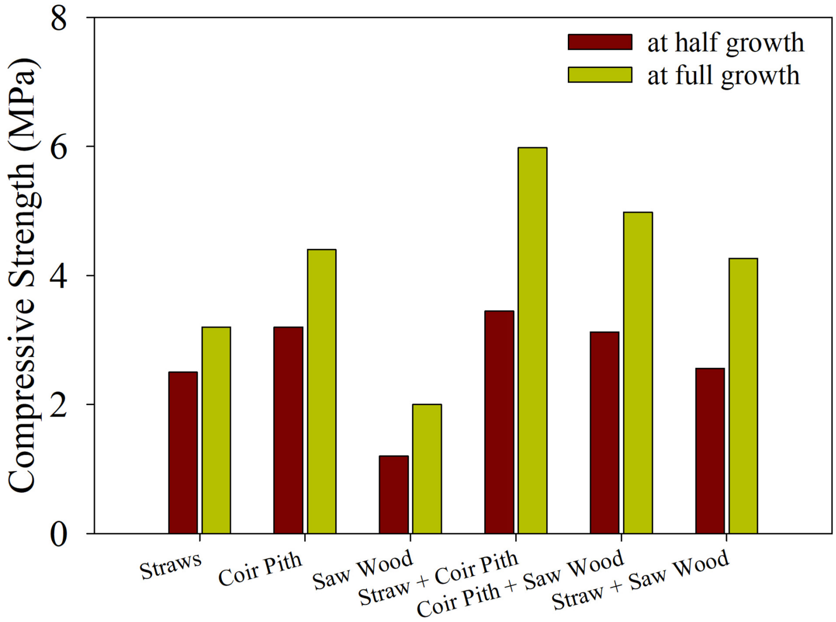

Figure 4: Compressive strength of mycelium block with different substrate.

3.3. Thermal insulation test

The thermal resistivity of substrate fibers was tested in order to determine the mycelium-composites to be employed as an alternative biological insulating material to improve the indoor confort of the building. The experiments were done for all the samples considered in this study. The test results of thermal resistivity of the mycelium products were different as in the case of compressive and water absorption test [25]. In continuation, straw and combination of straw and coir pith showed a low thermal resistivity of about 15 to 25 mK/W (Figure 5). Also, the coir pith with straw performed a good resistance of the thermal resistivity in the range between 10 and 20 mK/W. In the case of straw, coir pith and saw wood individually or with combination showed a similar performance of the thermal resistivity [26]. Altogether, it can be conclude that the thermal resistivity of straw wood had a higher thermal resistivity.

3.4. Fire test

Mycelium-based composite materials have significant implications for their potential applications in fire-prone environments. Some mycelium-bound composites, especially those made from substrates like saw wood, exhibit inherent fire-resistant properties due to their silica content. This makes them suitable for applications where fire resistance is crucial. Mycelium composites can be treated with fire retardants to enhance their fire resistance. This expands their potential use in construction, particularly in areas with stringent fire safety regulations [27]. It was found that straws and coir pith were high in silica, so the fire resistance experiments were mostly conducted on straws substrates. The samples were made using a process similar to that used to make compression test molds [28]. However, half of the substrates received a 50% weight added during the inoculation process. To ensure maximal colonization, the samples were then placed in an air tight and after about four weeks, the straws substrate started to grow sporocarps. After then, the samples were subjected to culture for a further three weeks. During the fire resistance test, a sample was placed roughly 0.25 inches above a candle with the flame in direct contact with the sample as shown in Figure 6. After burning for 30 seconds, the sample was taken out of the flame. The presence or absence of combustion was noted, and the size of the char that resulted was quantified. The sample was then returned to the flame for a further ten minutes. After 10 minutes, the char area and depth were evaluated. According to the test, saw wood with a diameter of roughly 10 cm was extremely flammable as shown in Figure 6, and the combination of saw wood and other substrate displayed the highest value. Similarly, straw and coir pith showed a lowest value of about 2 cm, which projects the inflammable capability of the fibers in the substrate. The presence or absence of combustion refers to whether a material will ignite and burn when exposed to fire or heat [29]. The size of the char area, on the other hand, indicates the amount of material that remains after combustion, providing insight into the material's resistance to burning. Combustion and char size are essential factors in evaluating fire resistance. The char area can be measured and recorded to determine the extent of the material's ability to withstand fire and emissions standards [30, 31].

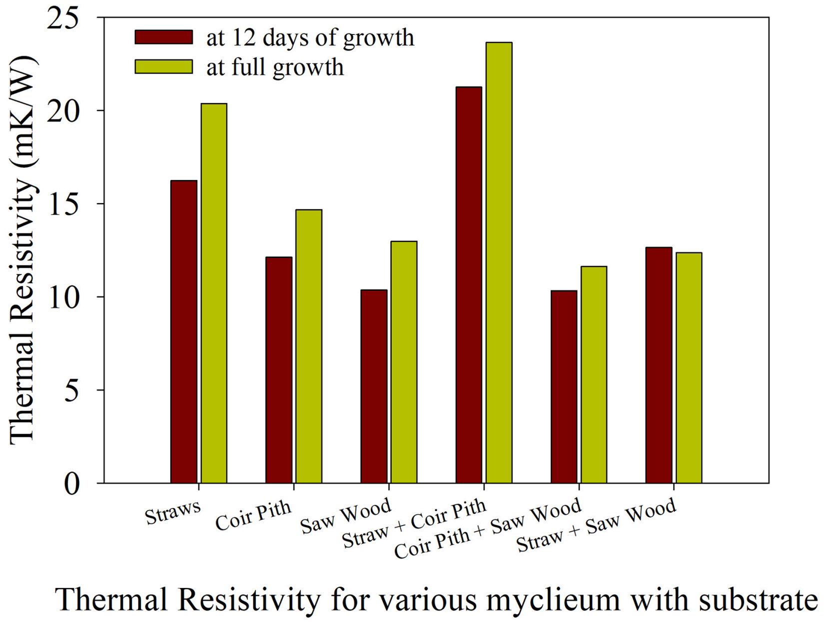

Figure 5: Thermal resistivity of mycelium blocks with various substrates and its comparison.

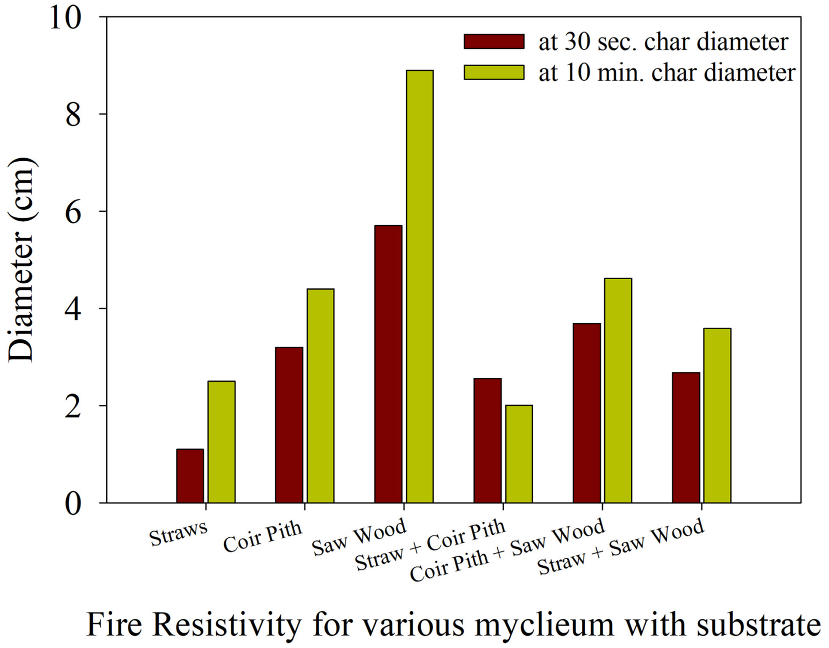

Figure 6: Fire test on various substrates on mycelium blocks and a sample of specimens with fire test.

4. CONCLUSION

The findings of this work contribute significantly to the field of biological materials since they provide an extensive review of the procedures used for producing, as well as the mechanical and physical properties of composites on the mycelium. Also, mycelium-bound composite materials offer several contributions to ongoing efforts to reduce the environmental footprint of the construction industry. The key ways in which these materials can make a significant impact: Sustainable Raw Materials, Reduced Carbon Emissions, Improved Indoor Air Quality Fire Resistance etc. Based on the study following conclusion has been drawn

1. During the initial and subsequent growing seasons, it was observed that both dust flax and dust straw exhibited inadequate development. This underperformance can be attributed to potential nutrient deficiencies within

the composite and a possible deficiency of air gaps. Nutrient shortages could hinder the proper growth and development of the mycelium, while a lack of air gaps may impede the necessary oxygen exchange essential for fungal growth.

2. Water absorption capacity is a critical factor to consider when evaluating a material's suitability for use as insulation. In this study, the researchers investigated the water absorption characteristics of various substrates. Their findings indicate that the combination of straw and coir pith exhibited a notably lower water absorption capacity compared to other substrates tested. Specifically, the water absorption capacity of the straw and coir pith combination was found to be below 2 mm. This suggests that this particular combination is less prone to absorbing water, making it potentially more effective as an insulation material. This conclusion is significant as it highlights the potential benefits of utilizing straw and coir pith as a composite material for insulation purposes, offering improved resistance to moisture infiltration compared to alternative substrates.
3. The performance of Pleurotus ostreatus mycelium-based composites in terms of compressive strength was notably better when utilizing a combination of substrates rather than a single substrate. This observation aligns with findings from previous tests, where it was consistently evident that the combination of straw and coir pith yielded significantly higher compressive strength compared to utilizing sawdust alone. Specifically, the composite incorporating a combination of straw and coir pith demonstrated a remarkable compressive strength of approximately 6 MPa, whereas the strength decreased to approximately 2 MPa when utilizing sawdust as the sole substrate. This highlights the importance of substrate selection and the synergistic effect of combining different substrates in enhancing the compressive strength of Pleurotus ostreatus mycelium-based composites.
4. The test results indicate that saw wood exhibits notably poor performance in terms of fire resistance, with a measured value of 8 cm, followed closely by coir pith. However, when considering the combination of the substrate with mycelium composite, the fire resistance values were comparable across all combinations. Additionally, the resistance values fell within the range of 2 to 4 cm at a 10-minute char diameter. Overall, these findings suggest that the combination of the substrate demonstrated satisfactory performance in the conducted test, showcasing its potential for use in fire-resistant applications.

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