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Mycelium-Based Composite: An Experimental Study on the Utilization of Sawdust and Glass Fines as Substrates for Potential Fungi-Based Bio-Formed Insulation Board

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Abstract: - In the past few decades, there has been a lot of attention given to the integration of living systems into material science for the synthesis of useful materials from biological resources. This is in line with the demand for the creation of innovative materials in a sustainable and environmentally friendly manner. For instance, mushroom-forming fungi's vegetative part is grown on various organic substrates to create composites based on fungal mycelium. This current study investigates the feasibility of using organic and non-organic substrates such as sawdust and glass fine for a fungi-based bio-formed insulation board. Additionally, it delineated the fabrication process of biodegradable "bio-board" out of this type of agricultural waste utilizing a green synthesis method and *Pleurotus ostreatus (P. ostreatus)* mycelium as a natural adhesive material. The composite performed satisfactorily in compressive strength surpassing traditional insulation materials. However, it performed inadequately in terms of moisture absorption. The mycelium also provided greater value rather than commercially available insulation materials in terms of peak temperature except for glass wool insulation. The results of this experiment suggest that an eco-friendly alternative for insulation boards can be developed from waste of both the agricultural and industrial industries.

Key Words: — *Mycelium, Insulation, Thermal Properties, Sawdust, Glass Fines, Substrates.*

I. INTRODUCTION

The present trend for a sustainable and green economy deliberates the creation of bio-based materials from renewable resources in product manufacturing and design. The building industry has expanded its approach to environmental performance due to growing environmental concerns, extending beyond reducing energy use through solar orientation, insulation, and low energy electrical cables to systemic issues that consider the materials used to construct buildings (Mirabella et al, 2018; Moncaster et al, 2018). Bio-composite is a material created by combining natural fiber, either wood or non-wood, and organic or non-organic materials, with a matrix.

One of the most significant major challenges in the fields of biotechnology and civil engineering research is the improvement of technology in the development of renewable materials. The production of materials will deprive a sustainable environment or a circular economy if business is carried out as normal, according to Ghazvinian et al (2019). Recent investigations have shown that it is possible to produce bio-composites from the mycelium substrate structure to replace the traditional building materials. Instead of being manufactured, this biomaterial or composite is cultivated.

Mycelium is the vegetative component of a fungus, consisting of a mass of branching hyphae and a hollow, tubular structure that serves as the binding matrix and stimulates rapid growth. It serves as a natural binder, adhering to any close organic substrates (such as wheat bran, sawdust, coffee husk, straw, and

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bagasse) to form a dense web of threads (Elkhateeb & Daba, 2019; Heisel et al, 2017). Materials made from mycelium have a number of advantages over traditional synthetic materials, including low cost, low density, environmentally friendly, and low energy usage (Jones et al, 2020; Zou & Gao, 2020).

Investigating the potential of mycelium to produce a fungi-based insulation board that complies with the demand for developing innovative materials in a sustainable and environmentally friendly way has been the main objective of this study and that is where innovation comes to place.

II. STATEMENT OF THE PROBLEM

There has been a significant demand placed on the construction material industry due to the growing population that results in a continuous lack of building materials particularly in the previous decade. Production of building materials such as bricks, cement, aggregates, steel, aluminum, wood, and partitioning materials is exponentially needed to meet the world's rising building demand. Traditional building materials like steel and concrete require a large amount of energy to produce. It pollutes our environment, which limits their vast production and utilization (Maraveas, 2020).

In addition, as the world's population is growing rapidly, more agricultural products are consumed annually, producing more byproducts (such as rice husks, cotton stalks, and sawdust). The majority of these byproducts are tracked as purely agricultural waste, which is primarily discarded or burned, producing carbon dioxide, atmospheric particulates, and other greenhouse gasses (Maraveas, 2020).

As the intense heat and hazardous fumes produced during burning, synthetic resin-based products have been identified as the primary cause of serious and fatal fire accidents throughout the world. Over three times faster than previous wood-based structures, modern houses made of exposed engineered wood collapse. Plastic foams frequently play a significant role in the rapid development of flames that produce large amounts of smoke and dangerous chemicals including carbon monoxide and hydrogen cyanide. Mycelium-based composites have many possible uses in highly flammable settings (e.g., packaging and building insulation). However, very little is known about how mycelium and its composites react to heat and fire.

Thus, the principal aim of the study is to investigate the potential of the mycelium-based composite as an insulation board. This is achieved by examining physical, mechanical, and thermal properties of the insulation boards made of mycelium composite.

Specifically, it sought to answer the following:

1. How this mycelium-based construction material be described in terms of the following:
    1.1. Thermal Analysis
    1.2. Compressive Strength
    1.3. Moisture Content
2. What are the effects of different substrate proportions in the properties of mycelium-based composite?
3. Is there a significant difference between the traditional insulation materials and mycelium-based board?

In this study, researchers conducted an alternative production from composite material like mycelium. This material shows great potential as a thermal and acoustic insulation board, making it suitable for applications.

III. REVIEW OF RELATED LITERATURES

3.1 Mycelium in Biomaterial Production

Mycelium-based composite materials have been developed and widely used in a variety of industries, including construction, manufacturing, agriculture, and the biomedical field (Yang et al, 2021).

Yang et al (2021) also added that the development of sandwich composites and mycelium-based foam for building materials are progressing. It can be utilized as synthetic semi-structural materials (e.g., paneling, flooring, furniture, decking), greater low-density materials (e.g., synthetic foams and plastics), and synthetic planar materials (e.g., plastic films and sheets).

Additionally, Jones et al (2017) stated that mycelium-based materials have been manufactured for a variety of uses, such as paper, textiles, and foams for packaging, car parts, and electronics packaging materials, with the number of patents which is a good indicator of the viability of the applications.

Mycelium-based packaging has been commercially available for more than 10 years, yet acceptance has lagged despite their enormous promise. Business servers are packaged with mycelium foams by Dell, and IKEA has also shown interest in using mycelium-based packaging (Dell Inc., 2016; Gosden, 2016).

Mycelium is also presently used in the manufacturing of biomaterials like bio-cement, bio-block, and bio enzymes in addition to bioremediation and medical purposes. A few businesses, including MycoWorks, NEFFA, Evocative Design, and MOGU, began developing and marketing mycelium-bound composites worldwide. Since 2007, designers and architects have begun to utilize mycelium-based materials as alternatives to traditional materials, including blocks, masonry units, wall and ceiling panels, kitchen tools, packaging materials, various furniture, and synthetic leather (Alemu et al, 2022).

Research study by Ongpeng et al (2020) showed that bio-composite bricks for environmentally sustainable construction can be made from agricultural waste and mycelium. All the mycelium-infused brick design mixes employed in their investigation had average compressive strengths that met or exceeded the minimum criterion of 3.5 MPa. This is based on the Indian Standard IS1077. Additionally, bricks made from rice bran and sawdust with mycelium had significant increases in compressive strength of 38.5% and 31.0%, respectively, over bricks made from non-mycelium. Fewer cracks are produced when mycelium is added to the flexural test, which increases the ductility of the brick specimens.

Biopolymeric composites in the mycelium class are composed of relatively inexpensive and sustainably sourced materials. Research interest in this category of composites is rapidly expanding on a global scale. Mycelium composites show some potential in this field, notably in the building industry, where the cost-performance indication is a crucial factor. There is growing emphasis on cheaper materials with sustainable and “green” credentials. This type of material converts agricultural waste into economical, low-energy construction materials by utilizing the biological phenomenon of fungal growth (Sabu, 2022). Natural thermal and acoustic insulating qualities can be found in mycelium composites. They have also demonstrated remarkable fire resistance qualities. Mycelium composites do not, however, have good mechanical properties as a result of these lossy characteristics, which are made worse by the material's low hydrophobicity.

Jones et al (2020) added that mycelium-based composite shows great potential as thermal and acoustic insulation foams since they outperform traditional building materials like synthetic foams and engineered woods in terms of low thermal conductivity, high acoustic absorption, and fire safety.

According to Asdrubali et al (2015), low density mycelium composites, made of high-performance natural insulators like hemp and straw fibers, joined together with mycelial growth, with thermal conductivities of 0.04 to 0.08 W/m·K. This makes them excellent insulation materials that can compete with other natural insulators like sheep wool (18 kg/m^3, 0.05 W/m·K) and kenaf (105 kg/m^3, 0.04 W/m·K) as well as traditional commercial thermal insulation products like glass wool (57 kg/m^3, 0.04 W/m·K) and extruded polystyrene insulation (XPS, 34 kg/m^3, 0.03 W/m·K).

Thermal insulators and acoustic dampers have been the main applications of mycelium-bound composites in the construction industry. The component has also exhibited better fire resistance, making it safer to employ in building applications (Palumbo-Fernandez, 2015).

Basidiomycete mycelium from species like *Pleurotus ostreatus* and *Trametes* versicolor increases the stiffness and tensile strength of synthetic materials (Lelivelt et al, 2015). Moreover, the materials produced by *P. ostreatus* using cellulose are firmer than those produced by *Ganoderma lucidum*, while the addition of dextrose further increases the elasticity of materials created by both fungal species (Haneef et al, 2017).

The economic growth for mycelium production as a fungi-based biomaterial product rises significantly as researchers continuously innovate and maximize its potential. Researchers are equipped with supporting studies which state that the usage of mycelium as a fungi-based biomaterial has outstanding results that satisfy the capabilities of products on the market. Considering certain species like oyster mushrooms that show a remarkable increase on the specifications of the biomaterial product makes it a potential substrate. Production of biomaterial products is slowly being recognized by the public because of its promising outcome.

3.2 Mycelium Growth of Oyster Mushroom (Pleurotus Ostreatus)

The oyster mushroom is a delicious edible fungus. The common name derives from the white shell, which resembles the fruiting body in appearance. They are categorized according to their edibility and fruit body form (Ghareeb, 2019). Additionally, according to Sultana et al (2018), as *Pleurotus ostreatus* is one of the most common oyster mushroom species that can grow on various agricultural wastes, cultivation of oyster mushrooms has greatly risen around the world due to their capacity to grow at a wide range of temperatures and be harvested all year round. Since mushrooms are generally quick-growing organisms, mushroom farming as a simple agricultural venture can provide immediate advantages to society. While most primary production methods are typically constrained by the availability of land, growing mushrooms takes up relatively little area since they may be stacked utilizing shelf-like culture systems (Girmay et al, 2016).

Mycelium, the vegetative component of a mushroom, has the unique ability to use agricultural crop waste as substrates for the growth of its network, which integrates the wastes from pieces to continuous composites without requiring energy or producing additional waste. Examples of such substrates include sugarcane bagasse, rice husks, cotton stalks, straw, and stover (Yang et al, 2021). One recent study of Appels et al

(2018) found that modifying production techniques, fungus species, and substrate type could modify the mechanical characteristics and water uptake of mycelium-bound materials. Temperature and humidity are two significant variables that might impact mycelium growth. Mycelium can grow well in conditions with high humidity (relative humidity 98%), a warm room temperature (24–25°), and fresh air (Hoa and Wang, 2015).

All things considered, oyster mushrooms show that its mycelium production is the common and easiest way to collect. It can easily grow on different agricultural waste, but different substrate types could modify the properties of the mycelium composite. The gathered mycelium from oyster mushrooms adds a factor to biomaterial products.

3.3 About Mycelium Substrates

Several investigations of Jones et al (2017) and Nawawi et al (2017) stated that due to its low energy requirement for development, lack of byproducts, and wide range of potential applications, mycelium has recently attracted increased interest in both academic and commercial research. To create a bio-composite that can be utilized to create both high-value composite materials for structural applications as well as low-value materials (such gap filler and packaging), mycelium combines with organic matter derived from agricultural and industrial wastes. Additionally, the variety of substrates on which mycelium grows and advanced processing techniques make them appropriate as affordable and sustainable alternatives to commonly used, highly flammable petroleum and natural gas-derived synthetic materials (such as plastics, including insulation foams), and resin-based engineered woods (e.g., particleboard).

According to Jones et al (2017), by cultivating mycelium composites, various substrates can perform specific behavior (e.g., structural support, fire resistance, and acoustic insulation). For instance, by adding glass fines and rice husks to the substrates, one may strengthen the fire resistance of the mycelium bio-composite since it can emit a lot of char and silica ash to withstand high temperatures during the burning process.

The mycelium-based material can achieve various structures and material functions by modifying the substrate and processing method. Several substrates, either organic or non-organic, can improve the properties of the composite material. The variety of substrates and mycelium makes a sustainable alternative to traditional materials.

3.3.1. Sawdust as Mycelium-Based Insulation Board Substrate

Sawdust is easily accessible, cost affordable and can be easily integrated with other materials. It contains lignocellulosic material that is essential for growing mushrooms. Various investigations concluded that sawdust gives the composite better compressive and tensile properties. It was also reported that the addition of sawdust showed 30% higher thermal conductivity.

According to Mudakir and Hastuti (2015) the advantages of utilizing sawdust as a growth medium is that it is readily available, cost affordable and it is easily mixed with other materials. In the study of Jones et al (2020) sawdust substrates have reported tensile properties that range widely between studies (0.05-0.18 MPa). Additionally, when compared to fibrous substrates like straw, it appears likely that particle substrates like sawdust give the composite better compressive qualities. The average compressive strength of hardwood sawdust composites was 2.49 MPa, with an interesting variation between samples whose growth took three days longer and had higher values (Vasatko et al, 2022).

In recent study of Wimmers et al (2019), thermal conductivities between 0.051 W/m·K and 0.055 W/m·K were attained during testing that complied with ASTM C518-17. Comparing it to regularly used insulation goods, this is about 30% higher. In addition, the study concluded that mycelium-based insulation boards are a feasible solution that could show a better alternative to existing wood fiber insulation boards and traditional foam-based insulation boards.

Results in study of Charai et al (2020) showed that the properties of unfired clay-based materials' heat transfer are positively affected by the addition of sawdust. In produced composites, the thermal conductivity varies from 0.89 to 0.62 W/m K, a decrease of roughly 30%. With density, heat conductivity rises. Therefore, sawdust integration can be helpful in the development of lightweight, thermally efficient construction materials because the sample's density reduces with increasing additions.

Sawdust, wood chips, and logs are frequently utilized as a growth substrate for oyster mushrooms (Mudakir and Hastuti, 2015). Lignocellulose is a structural element found in both wood and non-wood fibers such as sawdust. It is a significant source of renewable organic material and is composed of three main polymeric carbohydrates. It makes up around 75% of the wood cell wall; these are cellulose, hemicelluloses, and pectins. The majority of the remaining component of the cell wall is lignin, an aromatic heteropolymer. Most microorganisms that live on wood rely mostly on the carbohydrates found in their cell walls and storage tissues for their nourishment (Irbe et al, 2022).

Mycelium composites can exhibit considerably better thermal degradation, fire response, and safety qualities when they contain substrates or fillers that are rich in phenolic natural polymers such as lignin, and silica (SiO_2), either naturally occurring or manufactured synthetically. Sawdust is a potential substrate that can be used for mycelium production specifically for its capacity to improve the product in terms of a high thermal capability.

3.3.2. Glass Fines as Mycelium Substrate for Insulation

Glass fines are largely made of silica, but they can also contain up to 30% of organic surface matter, which is enough for mycelial growth to adhere (Jones et al, 2020).

The inclusion of glass particles to the composite's substrate is one technique to further increase mycelium-based composites' thermal stability. This is due to the fact that glass fines greatly raise the material's combustible content (Fairus et al, 2022).

Additionally, glass fines are regarded as waste materials that are widely accessible and at a reasonable price. When compared to synthetic materials like extruded polystyrene insulation foam (XPS) (61s) and particleboard (173s), mycelium composites with 50% weight of glass particles had substantially longer periods to flashover (311-370s). With regard to the average and peak heat release rates, XPS has (114 kW/m^2 average and 503 kW/m^2 peak) and particle board (134 kW/m^2 average and 200 kW/m^2 peak) while composites containing substantial amounts of glass fines (50 wt.%) have extremely low average (33-42 kW/m^2) and peak (79-85 kW/m^2) heat release rates (Jones et al, 2020).

Jones et al (2017) stated that although rice hulls produced a large amount of char and silica ash that enhanced fire performance, glass fine-containing composites performed the best due to their much greater silica concentrations and low combustible material content. The results of his study demonstrated that for applications like insulation, furniture, and paneling, mycelium composites are a very cost-effective replacement for extremely flammable synthetic polymers made from natural gas and petroleum, as well as engineered woods.

Also, the study of Bhat et al (2018) regarding the investigation of the effect of different substrates on the fire reaction properties of mycelium composites showed that compared to the synthetic building materials taken into consideration, mycelium composites had substantially lower average and peak heat release rates and a longer anticipated time to flash over. Additionally, they produced substantially less CO_2 and smoke. However, composites incorporating glass fines showed the best fire performance because of their much greater silica concentrations and low combustible material content. Glass waste considerably boosted the composite materials' silica content, which is known to lower flammability and smoke production through fuel dilution and heat sink mechanisms. Additionally, it decreased the percentage of combustible organics, such as cellulose, which are known to induce combustion. Mycelium composites outperformed the studied traditional building materials in terms of cost and fire safety overall. Their extensive use in civil construction would improve building fire safety.

Glass fine substrate was utilized in this study for it has the silica that largely contributes to the composites increasing thermal stability as several studies already show that composites with glass fines outperformed traditional boards in terms of fire safety qualities. Also, this is to further investigate the suitability and application of glass fine as substrate in the mycelium base-formed insulation board.

IV. MATERIALS AND METHODS

4.1 Materials Used in the Study

- Oyster Mushroom (Pleurotus Ostreatus) Spawn. One type of fungi that can be consumed is oyster mushrooms. They are among the mushrooms that are most commonly consumed worldwide. In the Philippines, oyster mushrooms are a common variety of edible mushroom. Their oyster-shaped top and short stem are what gives them their name. It comes in a variety of colors, with white and gray being the most common. Other colors include pink, yellow, and black. A mushroom spawn is used by mushroom farmers in a similar way that seeds are used by farmers and gardeners. It contains the genetic material needed to cultivate mushrooms.
- Sawdust. Sawdust or wood shavings are commonly waste products from furniture, timber, or other wood businesses. It is a by-product produced when you use a saw or other tool to cut, grind, drill, sand, or otherwise pulverize wood; it is made up of tiny pieces of wood.
- Glass Fines. Glass fines or glass sand are small glass particles (often less than 5 millimeters in diameter) that are recovered after processing or crushing. These are industrial waste from the glass recycling process.

4.1.1 Methods

- Collection and Preparation of Mushroom and its Substrates
  - a) The collected sawdust was hydrated until it reaches 50% water content.
  - b) Glass was fined manually using a hammer and was strained to achieve a size of less than 5mm.
  - c) The byproduct materials were sorted in a zip lock bag and were placed in the pressure cooker for 90 minutes to undergo sterilization.
- Preparation of Growth Form

The sizes of growth forms varied on the tests conducted:

a) As for the standard from compression of composites (ASTM D3410), the sample size must have a uniform rectangular cross section between 140 mm to 155 mm long and a width of 25 mm. With that, the sample size for the compression test was 140 mm long and 25 mm width.

b) A 100 x 100 mm sample was commonly used for evaluating moisture absorption of composites (ASTM D5229).

c) For testing thermal analysis using Differential Scanning Calorimetry (DSC) test method, 20 mg weight of sample was required by the laboratory. A 50.8 mm diameter disk and 25 mm thickness were made, based on ASTM E1530.

- Production of Bio-Formed Insulation Board
  - a) Mixing and Proportion

Experimental samples were categorized into three different proportions.

Table.1. Experimental Sample Proportions

Proportion	S (%)	GF (%)	MS (%)
P1	100	-	10
P2	50	50	10
P3	30	70	10

Following proportions were labeled as S for sawdust, GF for glass fines, and MS for mushroom spawn. Proportion 1 was based on Mycologic, a New Zealand-based mushroom business, while Proportion 2 was adopted by the studies of Jones et al (2019) and Yang et al (2017). Proportion 3 was designed by the researchers. Spawns are based on the total weight of the sample wherein spawns should be 10% of the substrates, according to Mycologic.

- Molding in Growth Form

a) All the growth form was sanitized using ethyl alcohol to prevent contamination.

b) Spawns were alternately placed in the growth form with the substrate mix until the growth form was full. The mixed composite was then sealed using a plastic wrap then punctured with tiny holes for ventilation

c) The mushroom spawn was inoculated to the substrates. Inoculation is bringing the spawn into contact with the substrate to initiate its growth and development.

- Drying and Heating

a) The samples were set aside for 14 days until it is fully colonized by the mycelium.

b) The fully-grown mycelium bio-composite was then placed in an oven for 2 hours at 120 degrees Celsius.

- Testing of Composite Board Samples

a) Thermal Analysis using Differential Scanning Calorimetry (DSC) Test Method

b) Compressive Strength Test conforming to ASTM D3410.

c) Moisture Content Test conforming to ASTM D4442.

V. RESULTS AND DISCUSSIONS

The experiments were conducted out on a composite board using a standard-size specimen in accordance with ASTM standards (D3410, D4442, D3418). The experimental setups were executed on different amounts of substrates: Proportion 1 (P1) - 90% sawdust and 10% mushroom spawn; Proportion 2 (P2) - 45% sawdust, 45% glass fines, and 10% mushroom spawn; Proportion 3 (P3) - 30% sawdust, 60% glass fines, and 10% mushroom spawn.

5.1 Thermal Analysis using DSC Test Method

Table.2. Summary of DSC Profile

Sample ID	Peak Temperature	Entalpy
P1	77.81	157.8457
	148.71	1.4576
	167.74	1.3171
	270.33	8.1486
	340.76	3.5444
P2	77.44	203.2993

	148.83	3.4956
	163.78	0.2847
	327.53	6.7284
P3	68.65	88.9036
	344.73	11.4708

The samples' thermal transitions were examined using a differential scanning calorimeter (DSC). From the result, the highest recorded values for the peak temperature or the melting point (Tm) are 340.76 °C, 327.53 °C and 344.73 °C respectively. This suggests that the fungal cell wall present in P3 is greater than the other two proportions. However, all the test results that were gathered from the proportions are relatively close to the others. The achieved enthalpy (ΔH) indicates the difference between the enthalpies of formation of sample and reference material. The test sample with a higher ΔH value is not always more stable than the test sample with a lower ΔH value.

5.2 Compressive Strength Conforming to ASTM D3410

Table.3. Test Result for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading (ASTM D3410)

Sample Identification	Maximum Load (N)	Compressive Strength	
		MPa	Average
P1 - 1	300	0.52	2.48
P1 - 2	2100	3.48	
P1 - 3	2100	3.43	
P2 - 1	1900	4.22	3.34
P2 - 2	700	1.32	
P2 - 3	2000	4.49	
P3 - 1	100	0.14	1.77
P3 - 2	1800	2.76	
P3 - 3	1700	2.42	

According to the Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading (ASTM D3410), the expected compression strength of the specimen is 3.17 MPa. P2 had noticeable compressive strength and surpassed the expected compression strength of 3.17 MPa conforming to ASTM D3410. However, P1 and P3 failed to do so by lacking 21.77% and 44.16%, respectively from the minimum.

5.3 Moisture Content Test Conforming to ASTM D4442

Table.3. Initial Weight of Sample Specimens

Sample Identification	P1 -1	P1 - 2	P1 - 3	P2 -1	P2 -2	P2 -3	P3 -1	P3 -2	P3 -3
Initial Weight, Wi (g)	119	116	120	126	125	125	138	135	140

Table.4. Result for Direct Moisture Content of Wood and Wood-Base Materials (ASTM D4442) – Method A - Oven-Drying (Primary)

Sample Identification	Oven-dried Weight, (g)	Weight after exposed (g)	Moisture Content (%)	Average
P1 - 1	37	38	2.70	6.41
P1 - 2	36	40	11.11	
P1 - 3	37	39	5.41	
P2 - 1	48	50	4.17	5.25
P2 - 2	45	47	4.44	
P2 - 3	42	45	7.14	
P3 - 1	57	59	3.51	2.85
P3 - 2	57	58	1.75	
P3 - 3	61	63	3.28	

The substrate's composition had a significant impact on the rate at which mycelium bio-composites absorbed moisture. As shown in Table 4, as the amount of sawdust in composite increases, moisture absorption also increases. This was because sawdust has high water porosity and hydrophilic properties, according to Burlacu et al (2022). This will result from the structure of the composite and sawdust interacting less on the surface when combined, increasing moisture absorption.

5.4 Effectiveness of Mycelium-Based Composite

Mycelium-based composite is an innovative engineering material that has many positive aspects. The effectiveness of the mycelium-based board as an insulation material in comparison to other materials using standards and different studies were shown in the following tables.

Table.5. Compressive Strength of Various Materials

Insulation Material		Compressive Strength	
		MPa	Standard
Mycelium-Based Composite	P1	2.48	ASTM D3410
	P2	3.34	

	P3	1.77	
Partition Walls		2.5	Ohijeagbon et al (2020)
Mycelium Insulation Materials		0.35 - 0.57	Amstislavski et al (2020)

Table 5 shows the compressive strength of the mycelium-based composite compared to different studies. The compressive strength of P2 developed from this study was recorded to be 3.34 MPa which performed satisfactorily based on the required minimum for composite board that could be used as a partition wall which was 2.5 MPa, according to Ohijeagbon et al (2020). Additionally, in the study of Amstislavski et al (2020), mycelium insulation materials showed compressive strength ranging between 350 kPa and 570 kPa (0.35 MPa and 0.57 MPa) which demonstrates boards from this study were higher. On this note, the mycelium-based board developed in this study had compressive strength that exceeded what other recent studies suggested and demonstrated.

Common insulation boards in the Philippines include glass wool insulation, polyethylene foam, expanded polystyrene foam board (EPS), and extruded polystyrene rigid insulation (XPS). Table 8 and Table 9 show the comparison of properties between common insulation materials and mycelium-based insulation boards.

Table.6. Mechanical Properties of Common Insulation Materials and the Mycelium-Based Composite

Insulation Material		Compressive Strength		Moisture Content	
		MPa	Standard	%	Standard
Mycelium Composite	P1	2.48	ASTM D3410	6.41	ASTM D4442
	P2	3.34	ASTM D3410	5.25	ASTM D4442
	P3	1.77	ASTM D3410	2.85	ASTM D4442
Glass Wool Insulation		-	-	<2	BS 2972
Polyethylene Foam		0.17	ASTM D3575	0.57	ASTM D3173
Expanded Polystyrene Foam Board (EPS)		0.41	ASTM C578	<0.5	ASTM C1338
Extruded Polystyrene Rigid Insulation (XPS)		0.69	ASTM C578	≤3	EN 13164

Table.7. Thermal Properties of Common Insulation Materials and the Mycelium-Based Composite

Insulation Materials		Peak Temperature (°C)	Standard
Mycelium-Based Composite	P1	340.76	ASTM D3418
	P2	327.53	ASTM D3418
	P3	344.73	ASTM D3418
Glass Wool Insulation		705	NOHSC: 1008
Polyethylene Foam		123	ASTM D3418
Expanded Polystyrene Foam Board (EPS)		200	Directives 67/548/EEC and 1999/45/EC
Extruded Polystyrene Rigid Insulation (XPS)		93 and 98	EPS-IA

As shown in Table 6 and Table 7, mycelium-based composite performed significantly in compressive strength surpassing traditional insulation materials. However, in moisture absorption, it showed that mycelium-based composite performed less effectively. The mycelium composite also provided greater value rather than the listed insulation materials in terms of peak temperature except for glass wool insulation.

VI. CONCLUSION

In this study, a mycelium-based composite was successfully developed utilizing oyster mushroom spawn, and sawdust and glass fines as substrates. The results of this study support the hypothesis that the capacity of a mycelium to grow properly as well as the physical, thermal, and mechanical properties of the mycelium-based composite can be influenced by a variety of factors including the fourteen (14) day inoculation period using various feeding substrates, the growth mediums, temperature, and moisture content.

The findings of this investigation indicate that agricultural and industrial waste can be used to create an eco-friendly substitute for insulating boards. By introducing a paradigm shift on how we generate our future construction materials based on the concept of circular bio-economy, mycelium-bound composite materials have the potential to alter the future of the construction industry.

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