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Mycelium Bio-composites for Civil Infrastructure in Indonesia

Atmy Verani Rouly Sihombing[1]*, Retno Utami[1], Luthfi Muhammad Mauludin[1], Nursyafril[1], I Nyoman Pugeg Aryantha[2], Syaiful Aulia Garibaldi[3], Fitria Dwi Ayuningtyas[3], Andro Mindo Matano Napitupulu[3], Mutiara Intan Rismaya[3]

[1] *Department of Civil Engineering, Politeknik Negeri Bandung (POLBAN)*
Jl. Gegerkalong Hilir Ds Ciwaruga, Bandung, 40012, INDONESIA
[2] *Institut Teknologi Bandung*
Jl. Ganesha 10, Bandung, 40132, INDONESIA
[3] *Yayasan Lokus Seni dan Sains, Bandung, INDONESIA*

*Corresponding Author: atmyvera@polban.ac.id
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Abstract

Bio-composite is a composite produced from plants containing lignocellulose whose formation is assisted by fungal mycelium. This study aims to determine the proper method and composition to produce bio-composite that has structural strength for civil engineering buildings such as light concrete, brick, paving and others. The type of fungus used to produce mycelium is a white oyster mushroom which will be mixed in growing medium (substrate) containing lignocellulose and is commonly found in Indonesia as waste, namely: 1) sawdust; 2) rice husk; and 3) bagasse. Bio-composite were test by compressive strength based on the ASTM C39/ C39M-18 test standard The results of this study showed that bio-composite sawdust with white oyster mushroom mycelium at a composition of 7:9 which was printed using plastic at room temperature for 30 days and air-dried for two weeks could produce bio-composite with a compressive strength of 31.91 MPa, which is close to the compressive strength of paving blocks in general. This shows that the bio-composite sawdust in Indonesia has the potential to have structural strength.

1. Introduction

Indonesia is a country rich in biological natural resources; it is even said that Indonesia is the world's leading mushroom warehouse [1]. This is because Indonesia's environmental conditions with a tropical climate and high humidity are very suitable for mushroom cultivation [2]. However, time and location management for mushroom cultivation requires special attention, especially for good types of fungi developed to develop sustainable products.

In civil engineering, the development of sustainable products is necessary to support environmental sustainability. These sustainable products are usually manufactured by utilizing all forms of materials originating from nature that can be renewed such as plants so that they are environmentally friendly, both in the manufacturing and in their business concept [3]. One of the technologies that can be utilized for the development of civil engineering materials is the technology for the development of fungi as a binder in the manufacture of composite materials for buildings, such as paving blocks, bricks, tiles, and others [4]–[7]. These composite

materials are made from a fungus known as mycelium, which is the root network of a fungus that can grow quickly and can act like a natural adhesive, and can digest waste, for example, sawdust, which is adhered together by a network of mycelium hyphae into a structurally active material [4], [8], [9]. When the mycelium enters the metabolic cycle, the building elements or the entire building can be used as compost in post-use [10].

Fungal are involved in the textile industry, also have a crucial role in the food industry (both human and animal), in biofuels making, detergents production, and in many other sectors [11], [12]. The advantages of mycelium composite are (1) A production process that uses little energy, (2) Good insulation, (3) Fireproof, (4) Lightweight, (5) Allergen-free, (6) Good sound-dampening ability, (7) Ability to follow the shape of the design, (8) Ability to adjust the brightness, (9) Different motives, (10) The ability to adjust hardness and flexibility. In addition, mycelium composite is an ideal material for fighting fire because it is more thermally stable, so mycelium composite will burn more slowly and coolly, producing less smoke and carbon dioxide [4]. Apart from that, its use can be a solution for dealing with termites in houses that use wood in some parts of their construction [4].

Architecturally, the use of mycelium can be combined to create unique structural motives and rejuvenate residential, industrial, and public space buildings so that the use of mycelium composite adds value, aesthetically and architecturally [5], [10], [13], [14], but its use has not been studied structurally in the field of civil engineering, especially in Indonesia, where it is classified as a new material, and very limited has ever conducted research on it.

The study aimed to determine the best method, type of fungus, and growing medium to produce composite material, namely biopaving, whose quality complies with the standard specifications for paving blocks. It is expected that with the discovery of civil construction components made of plant-based (bio-degradable), environmentally friendly, and sustainable materials, the quality of civil construction will be in accordance with applicable standards in Indonesia.

2. Fungal Biopolymer for Composite Production

Fungi are a natural and renewable source of valuable structural polymers, such as chitin and chitosan, in contrast to cellulose which is the primary structural polymer in plant cell walls [15]. Chitin is a linear macromolecule composed of N-acetylglucosamine units and is also a primary component of most insect and other arthropod exoskeletons [16]. Chitin is considered to have a tensile strength of 1.6 to 3.0 GPa [17].

Fungal cell walls are in the form of hyphae, which form a mycelium (collective noun) of hyphal filaments consisting of a thick and complex fibrous network of chitin and other polysaccharides, such as glucans, mannoproteins, chitosan, poly glucuronic acid or cellulose, and small amounts of proteins and glycoproteins [18]. To produce mycelium, fungi need a growing medium to show the unique mechanical properties of lignocellulosic materials, such as wood and cork [19]. However, the mycelium produced from the medium in the form of agricultural residues will produce a mycelium binder that connects the dispersed substrate filler phase with agricultural wastes resulting in a composite with lower density and modulus of elasticity than pure mycelium, which is generally classified as foam [20]. This is because of the air in or between the filler substrate (growing medium), which makes the components porous and loose [21].

Mycelium composites are produced using a low-energy, natural manufacturing process that absorbs carbon which is one of the main advantages of this material. Raw materials or growing medium are needed as precursors that can support the growth of fungi, such as carbohydrates. Agricultural and forestry by-products or wastes containing lignocellulosic are usually used as a fibrous substrate (e.g., straw) or particulate substrate (e.g., sawdust) [22]. Using this agricultural waste as a growing medium for mycelium composites can be a solution in recycling agricultural waste which has had its own environmental issues and to keep mycelium composites economically valuable compared to other composites. However, the use of waste which is a low-quality growing medium/substrate, has low protein-carrying capacity. This impacts the growth of the mycelium of the fungus, which will undoubtedly affect the properties of the mycelium composite material. So, the class of material or growing medium/substrate is also a parameter in increasing the structural strength of the formed composite. Examples of substrates with a higher class of agricultural waste include nutritious wheat grains, or sometimes some use sawdust to obtain a high-grade mycelium composite [23], [24].

Regardless of the class of material, what needs to be done when making mycelium composites for the first time is to immerse the substrate/growing medium in water to hydrate it. Note that humidity is a very important parameter for fungal growth, so the soaking time may vary depending on the substrate used [25]. For example, a substrate such as rice husk absorbs very little water, making soaking duration less critical than an inoculation medium, such as wheat grain, which is very swollen and requires a minimum soaking time of 48 hours [7]. Once the raw material is hydrated, it can then be homogenized to increase the surface area for growth, this can be done using low energy mechanical processes, for example using a kitchen blender or mill depending on manufacturing requirements and scale.

The raw material/substrate is then sterilized to remove microbes from bacteria and fungi previously present in the substrate using an oven (heating to high temperatures up to 123°C). However, using this oven risks drying

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out the substrate. Instead of an oven, bacteria can be removed using a pressure cooker or autoclave. The use of this autoclave can keep the substrate hydrated, so this method is preferred. Chemicals such as hydrogen peroxide (H_2O_2) Hydrogen peroxide can also be used to sterilize substrates, although its energy is less intensive than other sterilization methods and, therefore, less effective due to higher contamination levels [26].

The assembly of the composite itself is accomplished using a natural fungal growth process, which bonds the lignocellulosic materials into a 3D geometry that reflects the shape of the mold in which the substrate is packaged [21]. The lignocellulosic substrate is inoculated by introducing and uniformly distributing 10–32% by weight of each element of fungal biomass, such as spores in an aqueous solution or hyphae or tissue of fruiting bodies growing on a nutrient-rich substrate, such as wheat grain onto the lignocellulosic substrate [5]. Spores have the advantage of being easily dispersed evenly throughout the substrate and providing many initial growth points, but they require a nutrient-rich substrate. Grain- or sawdust-based inocula can provide a nutrient-rich substrate to support early growth [7].

After inoculation, the composite can be stored in a temperature-controlled environment at 25-27°C for a growth period of days to months, depending on the species of fungus and substrate used and the degree of bonding desired [5]. Environmental conditions by utilizing the temperature as it is will result in cheaper costs and more energy-efficient to maintain. Still, they will result in slower growth than environments with high temperatures, so the speed of mycelium growth can also be set depending on how much money is used. After the growth period, the composite material can be removed from the mold and heated in an oven or air-dried to dry the material and neutralize the fungus. This simultaneously ensures that fungus cannot grow further or spread once the composite material has stiffened [26]. The industry favors pressing and oven drying because they are the fastest dehydration processes. Hot pressing also consolidates and compacts the material resulting in higher mechanical properties.

Lignocellulosic substrates commonly found in Indonesia are sawdust, rice husks, and coffee grounds (Fig. 1). The amount of sawdust waste in Indonesia is estimated to be 0.78 million/year [27], As for rice husk, Indonesia, which has around 60,000 rice grinding machines spread throughout the region, can produce as much as 15 million tons per year [28], and in 2019 the total area of coffee plantations in Indonesia reached 1,245,358 ha with a production of 752,511 tons. From the production of 720 tons of coffee, 324 tons of coffee waste were obtained, or around 45% of the total production [29]. This can be a huge potential for Indonesia so that environmental issues related to agricultural and plantation waste can be handled.

(a) **(b)** **(c)**

Fig. 1 *Lignocellulosic substrate plant waste; (a) Sawdust; (b) Rice husks; (c) Coffee grounds*

3. Materials and Research Method

3.1 Materials

The materials used to make mycelium composite in this study are:

1. White oyster mushroom mycelium (Pleurotus ostreatus)
2. Growing medium: 1) sawdust, 2) coffee waste, dan 3) rice husks
3. Other supporting materials: Bran, lime, and additional components (sawdust, rice husks, and coffee grounds)

All components of the materials used are first sterilized to avoid the risk of contamination. Sterilization is carried out using the wet sterilization method with high steam (Fig. 2). A 200 liter drum is filled with water as high as 20 cm from the bottom of the drum or around 10% of the total volume (Fig. 3).

Fig. 2 *Sterilization drum*

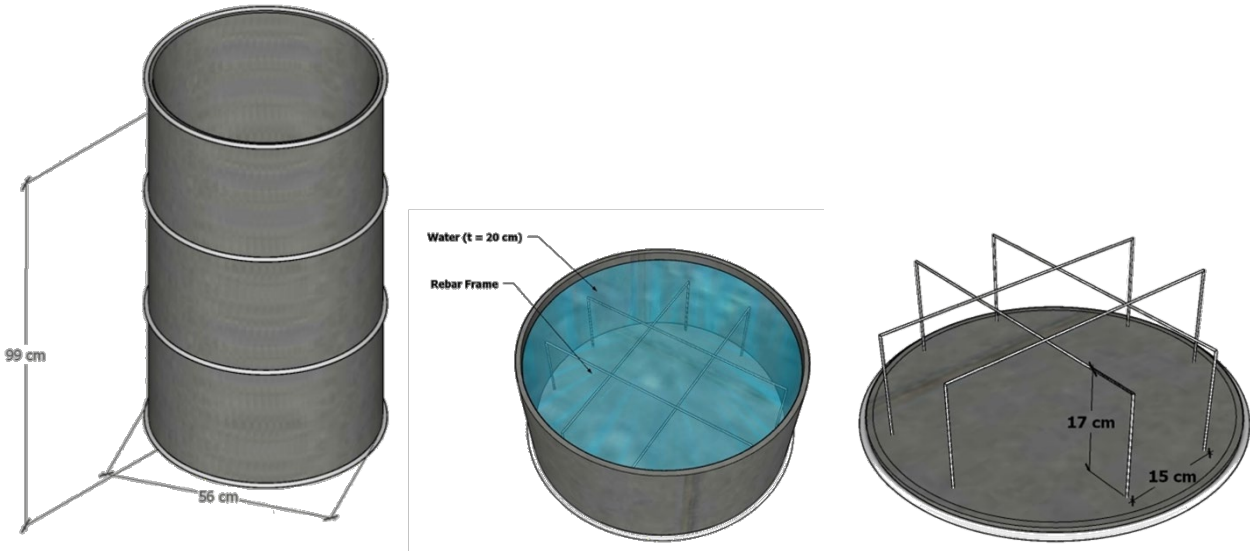

Fig. 3 *Sterilization drum sketch: (a) Drum; (b) Water height; (c) Rebar frame*

3.2 Research Method

The implementation of this research was conducted based on the research workflow shown in Fig 4. In the early stage, the preparation of the material and the location of the mushroom breeding were conducted. Next, the microstructure of the mycelium of the white oyster mushroom (Pleurotus Ostreatus) was observed using an electron microscope test tool (Scanning Electron Microscope, SEM) and a confocal microscope (Confocal Laser Scanning Microscope, CLSM). For observations using SEM, the mycelium samples were dried in an oven for 1 hour, then ion sputtering was conducted to increase the conductivity of the mycelium samples. Observations using SEM were then conducted at 1000x, 2500x, and 5000x. For observations using CLSM, mycelium samples were first stained using Rhodamine B dye, then observed at a wavelength of 546 nm at 200x magnification.

Observation of the microstructure of the mycelium was conducted to determine the potential of the mycelium of white oyster mushrooms as an adhesive to bind the growing medium to form the structure or components of the mycelium composite. The shape of the mycelium hyphae that cross and bind each other is considered to be able to bind the growing medium to form a mycelium composite that has structural strength in accordance with the specifications of civil building materials.

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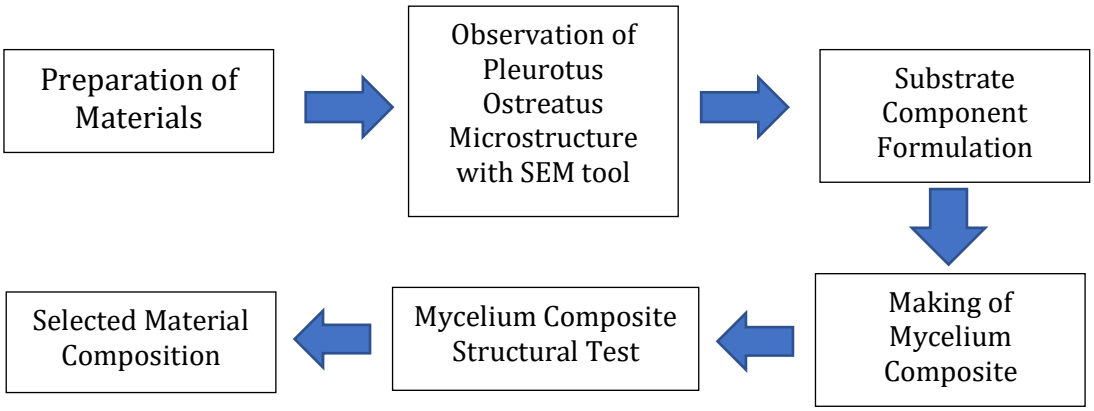


Fig. 4 *Research method*

After conducting microstructural observations, the formulation of the substrate components was done, which is the formulation of the composition of the substrate components to be then built to form a mycelium composite. The formulation of the substrate components is described in Table 1 and Table 2.

Table 1 *Formulation 1 substrate components*

Substrate Variant	Substrate Component Formulation (Kg)				
	Bran	Lime	Sawdust	Additional Components*	Mushroom Seeds
Variant 1 (sawdust)	0.5	4	8.2	7.5	9.0
Variant 2 (rice husks)	0.5	4	4.5	3.8	7.5
Variant 3 (coffee grounds)	0.5	4	6.8	4.0	7.5

Information: * Additional components are adjusted to the type of substrate variant

The formulation described in Table 1 was derived through a series of experimental trials and optimization studies, with sawdust being used as the primary substrate material for all variants. Researchers conducted these trials to determine the most effective combination of substrate components for optimal mushroom growth [30], [31]. The quantities of each component were adjusted based on growth rates, yield, and overall mushroom health, resulting in the formulations presented in Table 1.

Here is a detailed explanation of each component and its purpose:

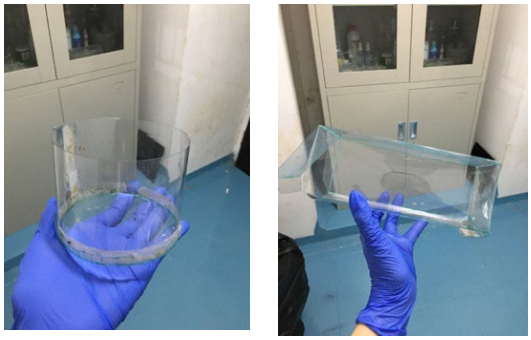
- Bran: Added as a nutrient source to support mushroom growth.
- Lime: Used to adjust the pH level of the substrate, creating an optimal environment for mushroom development.
- Sawdust: Serves as the primary substrate material, providing structure and additional nutrients.
- Additional Components: These are the other substrate materials, such as rice husks or coffee grounds, which are combined with sawdust to enhance growth.
- Mushroom Seeds: The spawn or inoculum used to propagate the mushrooms in the substrate.

Table 2 *Formulation 2 substrate components*

Substrate Variant	Substrate Component Formulation (Kg)					
	Bran	Lime	Sawdust	Additional Components	Mushroom Seeds	High Protein Flour
Variant 1 (sawdust)	0.5	4	7.5	7.5	9.0	1
Variant 2 (rice husks)	0.5	4	4.0	3.8	7.5	1
Variant 3 (coffee grounds)	0.5	4	6.0	4.0	7.5	1

The two substrate component formulations were then mixed to make biopaving. All substrate components were mixed in a large container, according to the calculations in Tables 1 and 2. Then the mixed components were

printed into the mica mold that had been made (Fig. 5). There are two types of mica molds for use in testing in the next test laboratory, with standard test sizes and standard paving sizes.



(a) (b)

Fig. 5 *Mica mold (a) Square Size of l. 20cm x w. 10cm x h. 8cm; (b) Cylinder Size of diameter 10cm x h. 7cm*

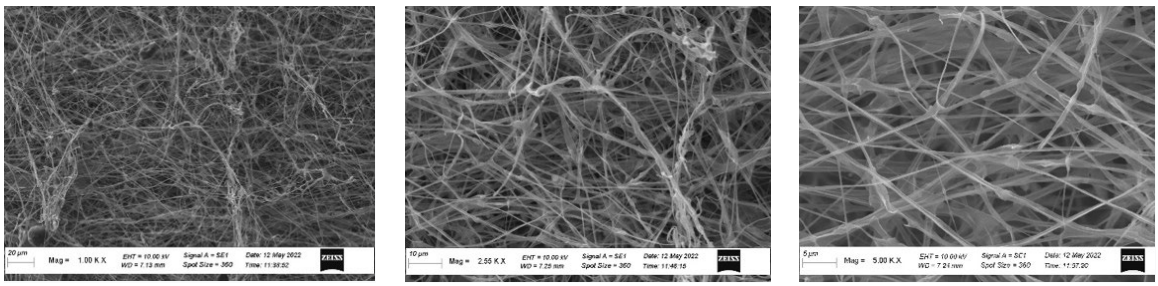
The molded biopaving component mixture was then arranged in a rack covered with dark plastic tarpaulin to avoid sunlight which was incubated for 30 days at room temperature (25°C). Observations were made periodically to see the growth of the white oyster mushroom mycelium and record the growth in the mycelium growth form so that its development was recorded.

After the incubation period, the mycelium composite could be harvested, heated, and compacted according to the shape made from the beginning. The results were then tested structurally by testing 1) appearance and size, 2) compressive strength, 3) absorption, and 4) wear resistance based on SNI 03-0691-1996.

4. Result and Discussion

4.1 Microstructure of White Oyster Mushroom Mycelium

The results of observations of the fungal mycelium using SEM are shown in Fig. 6, while the results of observations using CLSM are shown in Fig. 7. The results of microscopic observations show a mycelium structure that resembles a filament with an arrangement transverse to one another.



(a) (b) (c)

Fig. 6 *Observations of fungal mycelium using SEM at (a) 1000x; (b) 2500x; and (c) 5000x magnification*

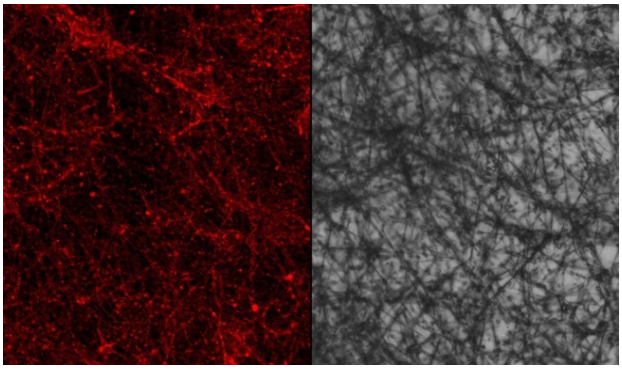


Fig. 7 *Observations of fungal mycelium using CLSM at 200x magnification*

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The results of microscopic observations of the mycelium using the Scanning Electron Microscope (SEM) and Confocal Laser Scanning Microscope (CLSM) show the structure of the mycelium hyphae transverse to one another. This structure allows the mycelium to bind the substrate more firmly so that it becomes a composite. The bonding of the mycelium with the substrate in the formed biocomposite increases the strength of the composite and has characteristics such as anti-heat, high water absorption, sound dampening, lightweight, easy to shape, and easy to decompose [32], [33].

4.2 Mycelium Composite Formulation 1

Mycelium growth processes in 3 substrate variants (Fig. 8) were observed during the incubation time every day. The fungus logs that were contaminated were then separated and discarded, while those whose growth was still good were continued until the mycelium growth filled the substrate. Identifying Trichoderma in mushroom cultivation substrate can be done through visual inspection, smell, and growth pattern. Trichoderma is typically identified by its distinct appearance; initially, it may present as white mycelium but soon develops into green patches as it sporulates, with rapid growth and vibrant green color being key indicators. It often produces a distinct, unpleasant odor, different from the earthy, neutral smell associated with healthy mushroom mycelium, with unusual, pungent, or musty smells being signs of Trichoderma contamination. Additionally, Trichoderma grows rapidly compared to mushroom mycelium, quickly covering large areas of the substrate and outpacing the mushroom mycelium, with this fast, aggressive growth pattern being a clear sign of its presence.

When the mycelium does not fully colonize the substrate, it is considered a failure for several reasons: incomplete colonization means the mycelium cannot establish a robust network to support fruiting body development, resulting in a weak base for mushroom growth; uncolonized areas of the substrate are more susceptible to contamination by other molds, bacteria, and pathogens, whereas a fully colonized substrate provides a protective barrier against these contaminants; poor yield occurs because the mycelium cannot thoroughly utilize the substrate, significantly reducing the number of mushrooms produced; and quality issues arise because incomplete colonization compromises the mycelium's ability to convert substrate nutrients into mushroom fruiting bodies, affecting the mushrooms' size, texture, and flavor. In summary, identifying and controlling Trichoderma is crucial in mushroom cultivation because its presence can significantly hinder mycelium growth and substrate colonization. Successful colonization is essential for achieving high yields and quality in mushroom production.

Fig. 8 *Three types of substrates inoculated*

However, in this formula 1 experiment, after 30 days of incubation, the conditions for mycelium growth on all substrate variants were not optimal, marked by the mycelium not fulfilling all substrate parts until the end of the incubation period (Fig. 9).

(a) **(b)** **(c)**

Fig. 9 *Three types of substrates inoculated, but the mycelium did not fulfil the substrates (a) Sawdust; (b) Rice husks; (c) Coffee grounds*

Variant 1: Sawdust

In the process of incubation of mycelium growth in the sawdust substrate in the first round, most of the fungus logs were contaminated by other fungi (Fig. 10), one of which was Trichoderma sp. Mycelium grows twice as fast in sawdust as in husks and coffee grounds.

Fig. 10 *Contaminated sawdust variant*

Variant 2: Husks

In the process of incubation of mycelium growth in the husk substrate in the first round, most of the fungus logs were contaminated by other fungi (Fig. 11), one of which was Trichoderma sp.

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Fig. 11 *Contaminated husk variant*

Variant 3: Coffee Grounds

In the process of incubation of mycelium growth in the coffee grounds substrate in the first round, most of the fungus logs were contaminated by other fungi (Fig. 12), one of which was Trichoderma sp. Coffee grounds are twice as easily contaminated as sawdust and husks. The high nutrient content, moisture retention, slightly acidic pH, larger surface area, and presence of residual sugars and oils make coffee grounds more susceptible to contamination compared to sawdust and rice husks.

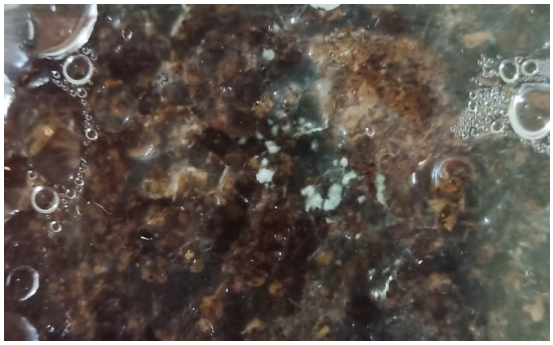

Fig. 12 *Contaminated coffee ground variant*

During the growth process of formulation 1 mycelium composite, most of the fungus logs from the three substrate variants experienced contamination from other fungi besides white oyster mushroom mycelium (Pleurotus ostreatus). In addition, the mycelium growth rate on all substrate variants was also low, so at the end of the incubation period, the mycelium had not filled all substrate parts. Several things most likely cause this; contamination can be caused by the process of mixing the ingredients and the less aseptic room. Meanwhile, the low mycelium growth rate can be caused by poor-quality seeds or substrate base (bran), which is a source of protein in a substrate that is also of poor quality.

In addition, during the mixing process, the mushroom seeds that already contain mycelium are too soft and smooth when crushed, which may destroy the mycelium fibers and make it difficult to grow back on the new substrate.

4.3 Mycelium Composite Formulation 2

Referring to the results of the mushroom growth experiment in formulation one, which experienced contamination and a low growth rate, the method was improved in the second round of experiment by adding high-protein flour to the substrate formulation as an additional protein source for the growth of the mushroom mycelium. In addition, the seed inoculation method was conducted without destroying the mycelium and melting it with the substrate but by inoculating the mushroom seeds into the substrate.

In the fungus logs during the first round of mixing, contamination was observed from the mycelium of other types of mushrooms. One identified was the growth of a mold fungus (Trichoderma sp.), which could become a growth competitor for the targeted white oyster mushroom. Contamination of logs with other fungi inhibits the growth of the white oyster mushroom mycelium and can result in the resulting bio-paving characters not meeting expectations later.

The growth rate of mycelium formulation two was increased by improving and enhancing the mixing method in the second stage by paying attention to the solution from the risk of contamination. In the formulation 2 sawdust variant, the mycelium was found to cover almost the entire substrate.

In formulation 2, with the improvement of the substrate and seed mixing methodology, an increase in growth was obtained compared to the growth in formulation 1 (Fig. 13).

Fig. 13 *Mycelium growth in the second round of experiment*

For the rice husks and coffee grounds variants in formulation 2, they failed to thrive as depicted in Fig. 14. Growth failure for both variations can be influenced by several factors, including:

1. In rice husks, it needs to be ground more finely so that the husks can be reduced
2. In coffee grounds, it is necessary to do the extraction so that the caffeine content in the coffee can be lost

(a) **(b)**

Fig. 14 *Growth failure in: (a) Rice husks variant; and (b) Coffee grounds variant*

Fig. 15 *Condensation on mica molds*

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In addition, the environmental temperature factor of the growth process is also influential. At the initial location, with temperatures <25°C and high humidity, the three mycelium variations experienced a growth slowdown and the mica mold experienced a condensation process. Thus, the mold shows traces of dew and the mycelium growth is not optimal. Fig. 15 shows condensation on the mycelium variation of sawdust with mica molds.

So that later, in formulation two, the test was conducted on the test object with the substrate variant of sawdust. On the results of sawdust substrate variant mycelium formulation 2, a drying process was conducted by baking at a temperature of 80°C for 60 minutes (Fig. 16), an appearance test was then conducted on the drying results by looking at the inside by cutting it. From the results of the appearance test, the inside was still hollow and contained water. Using sawdust as a growing medium is in accordance with statements in the literature, which state that the use of sawdust as a growing medium for fungi to produce mycelium is very appropriate because sawdust is a growing medium that is rich in nutrients [4]. Furthermore, based on the results of the formulation 2 test, drying was conducted again by increasing the temperature to 100°C for 60 minutes. The result of this increase in temperature contaminated the test object.

Fig. 16 *Mycelium variation of sawdust after being in the oven at 80℃ for 60 minutes*

In other formulation two sawdust variant test specimen, the growth process was conducted using a plastic mold (Fig. 17). Drying was done by storing the mycelium composite at room temperature for 14 days until it became air-dry (Fig. 18).

Fig. 17 *Sawdust mycelium with plastic molds*

Fig. 18 *Sawdust mycelium drying result*

5. Results of the Mycelium Composite Structure Test of Formulation 2 Sawdust

5.1 Appearance Test

The appearance test was conducted by visually looking at the structure of the bio-composite from the outside and inside. On the outside, formulation 2 sawdust Mycelium with a plastic mold gave a better coating by covering the entire surface with a leather-like layer that binds perfectly (Fig. 19(a)). While the inside looks, after being cut, the inside of the sawdust bio-composite did not have many cavities and was dry (Fig. 19(b)).

(a) **(b)**

Fig. 19 *Bio-composite appearance test: (a) Surface appearance; (b) Inside appearance*

5.2 Specific Gravity Test

The specific gravity test was conducted on 6 pieces of sawdust bio-composite test object. The results of the specific gravity test of the bio-composite show that the average specific gravity is 0.32. The test results are described in Table 3. An average specific gravity of 0.32 for sawdust bio-composite is relatively low, indicating a lightweight material. Specific gravity is a measure of density and is often correlated with the mechanical properties of materials. Higher and more consistent specific gravity typically indicates better mechanical strength and stability. The lower values in specimens 5 and 6 might imply weaker sections in the bio-composite, which could affect its overall performance.

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Table 3 *Specific gravity of sawdust bio-composite*

Test Specimen Number	Specific Gravity
1	0.35
2	0.35
3	0.35
4	0.34
5	0.25
6	0.28

An average specific gravity of 0.32 for sawdust bio-composite is relatively low, indicating a lightweight material. Specific gravity is a measure of density and is often correlated with the mechanical properties of materials. Higher and more consistent specific gravity typically indicates better mechanical strength and stability. The lower values in specimens 5 and 6 might imply weaker sections in the bio-composite, which could affect its overall performance.

5.3 Compressive Strength Test

Bio-composite compressive strength test was conducted to determine the quality of the bio-composite compared to paving blocks, bricks, and tiles [4], [15], [30]. The bio-composite specimens tested under pressure were made in cylinders and beams, each of which was made of 4 specimens. The test was based on the ASTM C39/ C39M-18 compressive strength test standard. The results of the compressive strength test are described in Tables 4 and 5.

From the results of the compressive strength test, it is known that the compressive strength of sawdust bio-composite with white oyster mushroom mycelium on beam specimens can reach a maximum of 0.64 N/mm^2 and on cylindrical specimens, the maximum is 12.37 N/mm^2. From the results of the compressive strength test of this mycelium composite, it can be seen that the shape of the mold forming the composite greatly influences the compressive strength. This can be seen from the compressive strength of the cylindrical bio-composite, which is much greater than the compressive strength of the bio-composite in the beam mold. The comparison with the compressive strength of composites in general can be seen in Table 6 and Fig. 20.

Table 4 *The results of beam sawdust bio-composite compressive strength test*

Test Specimen Number	Dimension (mm)			Weight (gr)	Area (mm^2)	Load			Compressive Strength (N/mm^2)
	L	W	H			Div	KN	N	
1	54.04	29.04	78.37	33.5	1569.32	410	0.574	574	0.37
2	48.52	29.58	54.97	23.1	1435.22	78	0.109	109	0.08
3	53.84	28.82	56.94	26.3	1551.67	409	0.573	573	0.37
4	38.83	28.67	41.54	14.7	1112.97	505	0.707	707	0.64
								Maximum	0.64

Table 5 *The results of cylindrical sawdust bio-composite compressive strength test*

Test Specimen Number	Dimension (mm)		Weight (gr)	Area (mm^2)	Load			Compressive Strength (N/mm^2)
	Diameter	Height			Div	KN	N	
1	71.18	108.23	119.6	9194.43	15.0	60	60013.67	6.53
2	57.03	104.89	100.5	8635.68	18.5	74	74013.67	8.57
3	63.02	107.23	114.4	9025.30	10.0	40	40013.67	4.43
4	65.43	109.29	131.5	9375.42	29.0	116	116013.70	12.37
							Maximum	12.37

Table 6 *Compressive strength of bio-composite compared to composite in general*

Composite Type	Compressive Strength (N/mm^2)
Beam Sawdust Bio-composite	0.64
Cylindrical Sawdust Bio-composite	12.37
Paving Block	39.22
Red Brick (20 cm x 10 cm x5 cm)	2.45
Lightweight Brick (60 x 20 x 7.5 cm) (Andres, 1989)	1 – 15

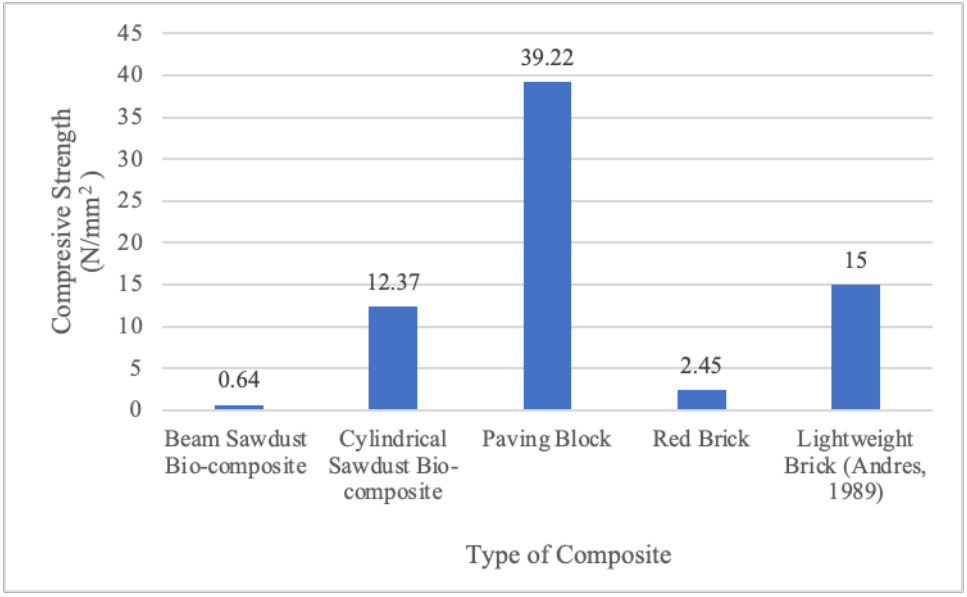

Fig. 20 *Compressive strength of bio-composite vs composite*

Based on the results of the comparative analysis of the compressive strength of bio-composites and composites, it is generally known that cylindrical sawdust bio-composite has a compressive strength that falls within the compressive strength range of lightweight bricks and is greater than the compressive strength of red bricks. Whereas the beam sawdust bio-composite has a very small compressive strength but is close to the minimum compressive strength of lightweight bricks. This shows that bio-composite sawdust with white oyster mushroom mycelium has the potential to be used as a building material that has structural strength.

6. Conclusions

The conclusions that can be drawn from the results of this study are

1. Sawdust mixing using white oyster mushroom mycelium (composition 7:9) with formulation 2, molded using plastic and air-dried in room conditions, is the ideal condition to produce bio-composite.
2. The shape of the mold in the making of sawdust bio-composite influences its compressive strength.
3. Sawdust bio-composite with white oyster mushroom mycelium has the potential to have structural strength with the same compressive strength as lightweight brick, which is 12.37 N/mm^2

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Atmy Verani Rouly Sihombing; Retno Utami; Luthfi Muhammad Mauludin; Nursyafril, I Nyoman Pugeg Aryantha, Syaiful Aulia Garibaldi, Fitria Dwi Ayuningtyas;* ***data collection:*** *Atmy Verani Rouly Sihombing; Retno Utami; I Nyoman Pugeg Aryantha, Syaiful Aulia Garibaldi, Fitria Dwi Ayuningtyas, Andro Mindo Matano Napitupulu, Mutiara Intan Rismaya;* ***analysis and interpretation of results:*** *Atmy Verani Rouly Sihombing; Retno Utami; I Nyoman Pugeg Aryantha, Syaiful Aulia Garibaldi, Fitria Dwi Ayuningtyas;* ***draft manuscript preparation:*** *Atmy Verani Rouly Sihombing; Retno Utami; All authors reviewed the results and approved the final version of the manuscript.*

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