Utilizing Agricultural and Industrial Waste for Environmentally Friendly Bricks: Exploring Mycelium-Based Bio-Composites

Jaswant Kandikanti[1]*, Om Joshi[2], Ronit Savale[3], Himanshu Patil[4] and Manisha Survase[5]
Department of Biotechnology, Institute of Biosciences and Technology
MGM University
Chhatrapati Sambhajinagar, India
Jaswantkandikanti123@gmail.com

Abstract. Composite materials combine different materials with distinct physical and chemical properties. Their use in construction dates back 3500 years, when clay and straw composites created sturdy buildings. Today, mud and con-crete bricks have replaced them, offering strength and advantages. However, these bricks cannot be recycled into primary products and contribute to glob-al warming. Consequently, researchers seek sustainable alternatives using biotechnological tools.

Bio composites utilise biological entities like crop fibres, agricultural waste, and furniture waste. Fungal mycelium, a biopolymer made of fibrous hyphae containing chitin, glucan, and proteins, acts as a binding element to form bio-composite materials. Its polymerized structure provides high tensile strength, advantageous for bricks.

In this study, mycelium was grown on rice bran, sawdust, and furniture waste, by-products of the rice milling and woodworking industries. Mycelium spawns were added and incubated to promote growth. The resulting mycelium bio-composite material was obtained by heating the mycelium with the substrate. By utilising agricultural and industrial waste materials as substrates and reducing cement binders, researchers aim to develop environmentally friendly mycelium bricks equivalent to standard construction materials.

Keywords: Bio-composites, fungal mycelial, agricultural waste, biopolymer.

1 Introduction

The composite materials have been used to prepare bricks for centuries. Historically, bricks were manufactured using an ancient method dating back to 6000 B.C., known as the soft mud process. In this process, relatively moist clay is pressed into simple rectangular molds by hand. To prevent the sticky clay from adhering to the molds, the molds may be dipped in water before being filled. This produces bricks with a smooth and dense surface, known as water-struck bricks [1].

Further developments occurred around 1500 BC when early Egyptians and Mesopotamian settlers started using a mixture of mud and straw to create strong and durable buildings. The combination of mud and straw in a brick provides it with properties that make it resistant to squeezing, tearing, and bending [2].

R. Somashekhar et al. (eds.), *Proceedings of the International Conference on Advances in Nano-Neuro-Bio-Quantum (ICAN 2023)*,
Advances in Intelligent Systems Research 69,
https://doi.org/10.2991/978-94-6463-294-1_14

The manufacturing process of bricks underwent slight developments, transitioning from the soft mud process to the dry press process. In the dry press process, clay mixed with water is placed in steel molds and pressed by a machine. The ancient civilizations recognized fired bricks as more durable and weather-resistant, making them more favourable than sun-dried bricks [1].

In modern times, various types of bricks are used, including clay bricks, which are prepared from clay and shale. Clay is an abundant raw material with diverse uses and properties. It consists of natural, earthy, fine-grained minerals of secondary origin, composed of an aluminosilicate structure with additional iron, alkalis, and alkaline earth elements. Common clays are sufficiently plastic to allow easy molding, and when fired, they vitrify below 1100°C [3].

Concrete bricks are also utilized, made by blending Portland cement, sand, and other aggregates with a small amount of water, then pouring the mixture into molds. The blocks are removed from the molds, allowed to set initially, and then cured in a kiln or autoclave. The entire curing process is typically completed within 24 hours [4].

Another type is calcium silicate blocks, created by carefully selecting clean and high-grade sand or crushed flint, which is mixed intimately with 5-8% of high calcium hydrated lime [Ca(OH)2], along with a controlled quantity of water. The plastic mixture is then molded into bricks and autoclaved under pressure in a steam atmosphere for a duration of 3-8 hours, depending on the pressure-temperature level [4].

Brick is one of the most important materials in the construction industry. However, the conventional method of brick production has led to undeniable shortcomings. The consumption of earth-based materials such as clay, shale, and sand in brick production has resulted in resource depletion, environmental degradation, and energy consumption. Virgin resources are mined from riverbeds and hillsides to serve the brick industry, leaving the mined areas un-reclaimed. Such mining activities cause environmental degradation, including air pollution, and leave scars on the landscape after operations cease [1].

Due to the current linear economy model of "produce, use, and dispose," the construction sector significantly contributes to global greenhouse gas emissions, destruction of natural habitats, and industrial waste production. The increasing use of non-renewable materials like concrete and steel creates environmental pressure on limited natural resources and is expected to lead to permanent resource depletion in the near future [5]. These challenges have prompted research into bio-composite materials as a solution for the limitations of clay and concrete bricks.

Bio-composites are composite materials made up of a matrix (resin) and natural fibre reinforcement [6]. Bio-composites are commonly categorized into two groups for construction applications: structural and non-structural bio-composites. Structural bio-composites are those that bear specific loads, such as stairs, floors, roofs, and walls in the building industry. They exhibit a wide range of material properties, from low to high performance. Non-structural bio-composite materials, on the other hand, do not require loading during use [7]. Bio-fibres, derived from biological entities such as crop fibres (cotton, flax, or hemp), recycled wood, wastepaper, agro-based by-products, or regenerated cellulose fibres (viscose/rayon), are the main constituents of bio-composites. Animals and plants naturally produce high-strength composites composed of fibrous biopolymers [6].

Fungal mycelium is a complex network of interlaced, microscopic, pipe-shaped fibrous cell chains called hyphae, which form the vegetative part of saprophytic fungi [8]. Saprophytic fungi have the ability to decompose complex molecules like agricultural waste, furniture waste, and chemicals that pollute the soil [9]. The fungal cell wall is composed of chitin, glucans, and proteins [10]. Chitin, a polycrystalline polymeric acetylglucosamine, exhibits high tensile strength, contributing to the tensile strength of the mycelium and reinforcing the fibrous network [11]. Therefore, mycelium acts as a binding material that binds the substrates present in the mold, forming a bio-composite material.

In order to achieve sustainable construction alternatives for interior wall bricks that undergo minimal wetting and drying, this study focuses on utilizing waste products such as rice bran, sawdust, and coconut husk with mycelium. These are by-products of rice milling/coconut processing and woodworking operations, respectively. The binder that holds the substrate together is a bio-composite called mycelium [12]. *Ganoderma lucidum* and *Pleurotus ostreatus*, common fungi species, are used in producing mycelium [8]. The molds are airtight sealed to prevent contact with oxygen, as exposure to oxygen would lead to mushroom growth instead of mycelium formation, which is not the objective of this research [13]. By utilizing agricultural and industrial waste materials as substrates and reducing the use of cement binders, the researchers aim to formulate and produce mycelium bricks that can achieve an environmentally friendly product on par with standard construction materials.

2. Materials and Methodology

2.1 Collection of mycelial fungi:

Rotten wood samples of Ficus benghalensis were collected from the Harsul region of Chhatrapati Sambhajinagar, Maharashtra, India. The samples were placed in petri plates, the plates were filled with soil and it was sprinkled with water and 5% cellulose powder [14]. Inner surfaces of plates were covered with wet filter papers, prior to the above steps. The plates were stored at 280C for 7-10 days. The mycelium produced on rotten wood was streaked on Potato Dextrose agar (200 gm infused potato starch, 4 gm Glucose, 18 gm Agar, 1000 ml Distilled water), incubated at 28^{0}C for 7 days until fungal growth was observed in new petri plates.
Apart from that, spawns of *Ganoderma lucidum* [8] were purchased from MB mushroom farm.

2.2 Collection of Substrate for fungal mycelium growth:

Mainly, 4 substrates were selected for mycelial growth, which included Rice bran purchased from Kandimalla Milling Industry, Dhramsagar, Warangal, India. While other 2 substrates, saw dust of softwood and hardwood chips were collected from local vendors of Chhatrapati Sambhaji Nagar.
The 4th substrate was Wheat grains (WG), collected from agricultural farms

2.3 Culturing mycelium from fungal spawns:

Sterilised plastic bags (Heat sterilised) were taken and Ricebran, Sawdust, and Hardwood chips substrates were added into plastic bags. Formalin was added to sterilise the substrates and to prevent unwanted fungal growth. Fungal colonies grown on PDA plates were inoculated into the plastic bag and kept in incubation for 7-15 days at 28^{0}C. Another plastic bag was taken where only wheat grains used as substrate and sterilised as above and *G. lucidum* was inoculated and kept for incubation for 7-15 days at 28^{0}C [13].

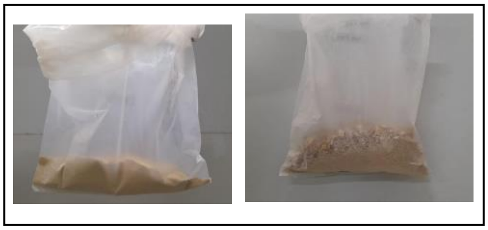

Figure 1 Culturing of mycelium on substrates in sterilized plastic bags

2.4 Production of bio composite material:

Two types of molds were prepared from cardboard of different dimensions of 20 cm × 9 cm × 9 cm and 9 cm × 4. 5 cm × 4.5 cm. Mycelium cultured in the plastic bags was used as spawn for culturing mycelium on the substrates in molds. All the substrates were added with adequate distilled water, to provide a moist environment which favours the proper growth of mycelium. Three types of Bio-composites were prepared as follow:

Type 1: Combination of two substrates:-
3 combinations of the substrates as follow: Rice bran + Sawdust, Sawdust + Hardwood chips, Hardwood chips + Rice bran. The ratio of each substrate was maintained in a 1:1 manner, and these combinations were inoculated with mycelial spawns and transferred in the molds. For simplification, the combination was labelled as C1, C2, and C3 respectively. All the molds were sealed airtight using aluminium foil, and incubated in a dark room for 7-10 days

Type 2: Single substrate:-
Primary 3 substrates Rice bran, Sawdust, and Hardwood chips were added in 3 separate molds inoculated with the mycelial spawns, these molds with different substates were labelled as S1, S2, and S3 respectively. All the molds were sealed airtight using aluminium foil, and incubated in a dark room for 7-10 days.

Type 3: Combination of all substrates:-
All the substrates were added in a single mold, inoculated with the Mycelial spawns, was labelled as CS. The mold was sealed airtight in the similar manner as done with previous molds, and stored in a dark room for 7-10 days (The ratio of each substrate in mold was 1:1).

Type 4: Combination of all substrates with Cellulose:-
Slight modification was done with mold CS, as 5% w/v cellulose powder was added in the mold and inoculated with the mycelial spawns, the mold was labelled as CSC, airtight sealed with aluminium foil and stored in dark room for 7-10 days (The ratio of each substrate in mold was 1:1).

Figure 2 Addition of mycelial inoculated substrate in molds.

3. Result and Discussion

3.1 Collection of mycelial fungi:

After the 7th day of incubation and multiple times of sprinkling water (to keep the filter paper damp) fungal mycelium was found on the surface of wood and in soil regions around wood pieces in small traces, the fungal mycelium was whitish in colour and had a rough structure. This mycelium was transferred onto PDA agar plates and stored at 28^0C.

Figure 3 Petri plates with wood samples covered with soil, a substrate, and 5% Cellulose powder.

3.2 Culturing mycelium from fungal spawns:

The newly produced fungi on PDA plates, were transferred to sterilised bags containing Sawdust, Rice bran, Hardwood chips, while *G. lucidum* was transferred into a jar containing Wheat grains and incubated for 15 days. After 15 days white mycelium was visible spread throughout the substrate in the plastic bags.

This mycelium was used as a spawn for production of bio-composite material.

Figure 4 Growth of white colored mycelium visible in plastic bag with substrates after the 15th day of incubation.

3.3 Production of Bio-composite material:

Out of the 4 trails, only T1.1, T3.1 and T4.1 showed positive results, while other test subjects either showed no growth or were unable to produce a compact brick.

Molds	Day 3	Day 7	Day 10	Day 15
C1	NG	NG	G	G++.
C2	NG	NG	NG	G
C3	NG	NG	NG	G
S1	NG	NG	NG	NG
S2	NG	NG	NG	NG
S3	NG	NG	NG	NG
CS	NG	NG	G	G++
CSC	NG	G	G+	G++

Table 1 Results of 4 trials, showing growth of mycelium at Day 3, Day 7, Day 10, Day 15 of incubation period. (Note: NG indicates No Mycelium Growth, G indicates Minimal mycelium proliferation within the substrate, G+ indicates Mycelium covering approximately half of the substrate, G++ indicates Prominent mycelium proliferation, encompassing the entire substrate uniformly.)

As per Table 1, molds C1, CS and CSC were able to produce hard and compact bio composite bricks due to the uniform and predominant growth of mycelium, molds C2 and C3 exhibited partial mycelium growth within the substrate, resulting in the production of a delicate/fragile bio-composite brick. S1, S2 and S3 failed to produce the bio-composite brick due to no mycelium growth within substrate.

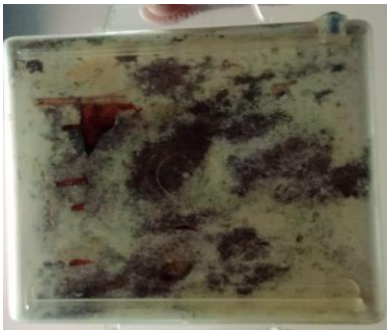

Figure 5 shows bottom view of a plastic tray, whitish mycelium can be observed spread across the bottom surface of the tray.

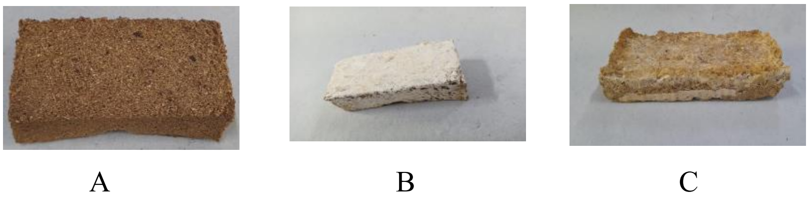

Figure 6 contains three images A, B, C where image A shows C1 mould bio-composite brick; image B shows CS mould bio-composite brick; image C shows CSC mould bio-composite brick.

4. Conclusion

Bio-composite materials, such as mycelium bricks, have the potential to replace commonly used clay bricks and cement bricks. The production of clay bricks and cement bricks contributes to global warming (for example, through the firing process of clay bricks) and depletes natural resources at a rate faster than their replenishment. By replacing these bricks with mycelium bricks, we can allow nature sufficient time to regenerate these resources. Therefore, mycelium bricks offer a sustainable approach to replacing conventional clay bricks and cement bricks.

Mycelium plays a crucial role in the production of bio-composites as it acts as a binder that binds the substrate and produces a cohesive material. In the near future, mycelium can also be utilized to create bio-composite leathers and wood blocks, reducing the need for wild animal skins and deforestation, respectively.

This paper presents the results of 8 types of molds produced by different combinations of substrates, out of which 3 molds were able to produce stable, compact bio-composite brick. Further studies should focus on developing a stable and cost-effective composition that promotes maximum mycelium growth in a shorter time period. Molds exhibiting delayed mycelium growth, were unable to produce a compact and stable bio-composite. This suggests that a more potent fungal species should be isolated, capable of degrading Hard wood chips more effectively than the currently used fungal species.

Furthermore, various tests, such as strength and water absorption tests, should be conducted on the produced bricks to assess their physical properties in comparison to conventional clay bricks. Adjustments in composition and the selection of mycelium species can be made based on the findings of these tests.

5. Acknowledgement

The success of any project depends largely on the team work and also encouragement and guidelines of many others. We take this opportunity to express our gratitude to our professors who have been instrumental in the successful completion of this research.
Foremost, we would like to express our sincere gratitude towards Mahatma Gandhi Mission University's Institute of Biosciences and Technology for granting us the opportunity to work in the laboratories of the institute.

References

1. Attias N, Danai O, Abitbol T, Tarazi E, Ezov N, Pereman I,et.al.(2020). Mycelium bio-composites in industrial design and architecture: Comparative review and experimental analysis. *Journal of Cleaner Production.* 246.
2. Dimple Tanwar, Nivedita Sharma, Nisha Sharma and Prashant Kumar Prusty(2020). Isolation and screening of fungi from rotten wood for various hydrolytic enzymes production. *Ann. Phytomed.* 9(1), 122-128.
3. Elammaran Jayamani, Sim Rui Li, Wong Yeng Chiang, Md Rezaur Rahman, Muhammad Khusairy Bin Bakri (2022). Education and awareness of waste and recycled plastic biocomposites recycled. *Plastic Biocomposites, Woodhead Publishing.* 13, 281-197.
4. Geiza E. Oliveira, Jose Nilson Holand (2004). Use of mix of clay/solid waste from steel works for civil construction materials. *Waste Management*. 22, 358-363.
5. Haneef, M., Ceseracciu, L., Canale, C., Bayer, I. S., Heredia-Guerrero, J. A., & Athanassiou, A (2017). Advanced Materials from fungal mycelium: fabrication and tuning of physical properties. *Scientific reports*. 7(1), 1-11.
6. Jeorge J. Venta, P.Eng(1998). Life cycle analysis of brick and mortar products. *the ATHENA Sustainable Material Institute, Canada, Ottawa.*
7. Jones, Mitchell P. & Huynh, Tien & Dekiwadia, Chaitali & Daver, F. & John, Sabu (2017). Mycelium Composites: A Review of Engineering Characteristics and Growth Kinetics. **Journal of** *Bionanoscience*. 11, 241-257.
8. Kishan, Rahul Kashyap, Rohan Tyagi, Anshul Jain (2018). Production of Mycelium Bricks. *International Journal of Innovative Science and Research Technology*. 3(4), 484-518.

9. Lai Jiang, Daniel Walczyk, Gavin McIntyre, Ronald Bucinell, Gregory Tudryn(2017). Manufacturing of biocomposite sandwich structures using mycelium-bound cores and preforms. *Journal of Manufacturing Processes.* 28(1), 50-59.
10. Md. Ibrahim H. Mondal, Md Monirul Islam, Md Inzamamul Haque, Firoz Ahmed (2022). Natural, biodegradable, biocompatible and bioresorbable medical textile materials. *Medical Textiles from Natural Resources, Woodhead Publishing*. 3, 87-116.
11. Ngo, T.-D (2020). Introduction to Composite Materials. Composite and Nanocomposite Materials. *Knowledge to Industrial Applications.* 91285.
12. Pointing, S (2001). Feasibility of bioremediation by white-rot fungi. *Appl Microbiol Biotechnol.* 57, 20–33.
13. Sağlam, Sebahat & Özgünler, Seden(2022). An experimental study on production opportunities of biocomposite by using fungal mycelium, *Journal of Design for Resilience in Architecture and Planning.* 3(2056).
14. Shakir, Alaa & Mohammed, Ali (2013). Manufacturing of Bricks in the Past, in the Present and in the Future: A state of the Art Review. *International Journal of Advances in Applied Sciences.* 2(3).