EXPLORING THE CREATION AND EVALUATION OF MYCELIUM-BASED BRICKS FOR USE AS INSULATION MATERIALS IN CONSTRUCTION

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Annotation

Mycelium-based composites are emerging as sustainable building materials that offer an economical and environmentally-friendly alternative to traditional construction methods. These composites use mycelium to enhance bricks, potentially reducing reliance on conventional materials while improving mechanical properties. They can replace wood, plastic, and engineered products in applications such as insulation, paneling, and furniture. These composites are particularly advantageous for thermal and acoustic insulation, exhibiting low thermal conductivity, excellent sound absorption, and superior fire safety compared to synthetic foams. However, challenges like high water absorption and limited mechanical properties currently constrain their use to non-structural applications.

Ongoing research is exploring how living design principles can lower production costs and enhance performance, with a focus on mycelium as a foundational material for innovative, net-zero-energy insulation options. Compared to traditional materials, mycelium composites demonstrate a significantly lower environmental impact and embodied energy, making them particularly suitable for extreme climates. Despite notable benefits, issues such as shrinkage and durability must be addressed. Various processing techniques affect the physical characteristics of mycelium composites, emphasizing the importance of continued research and development in this field to unlock their full potential for sustainable construction.

Keywords: ecological diversity, sustainable architecture, affordable homes, functional dwellings, biological materials derived from mycelium.

1.INTRODUCTION

The mycelium, which is the vegetative part of a fungus or bacterial colony, consists of spreading, thread-like hyphae. In the case of the pixie ring fungus, the mass of hyphae is sometimes called shiro (from figure 1). Mycelium-based infectious states can be present in soil and on various surfaces.. However, when two homokaryotic mycelium combine to form dikaryotic mycelium, this mycelium can give rise to fruiting bodies like mushrooms. Mycelium can vary in size, making it challenging to observe.

In a fascinating process, mycelium-based building bricks are grown in a laboratory setting. Multicellular fungi are nurtured on a substrate, where they develop into dense, fibrous networks. These networks, formed by the mycelium, become the foundation for innovative and sustainable building materials. (Stelzer et al., 2021).

Building sector contributes significantly to mankind's environmental footprint (Takano, Hughes, & Winter, 2014). Buildings are responsible for 40% of energy consumption and 36% of carbon emissions in the EU (Jones & Brischke, 2017). The future of construction is green. A shift towards bio-based, locally sourced building materials is gaining momentum. These materials offer a range of benefits, including low toxicity, durability, reduced environmental impact, and high recyclability, making them a sustainable choice for modern construction. (Joseph & Tretsiakova-McNally, 2010). In Canada, commercial and institutional buildings account for 18% of energy demand, while the residential sector consumes as much as 33% of the national usage (*Energy Use in Buildings*, 2017). To build a sustainable future, we must choose building materials wisely. By considering their entire life cycle, from cradle to grave, and prioritizing products with the smallest environmental footprint, we can create buildings that are both beautiful and kind to the planet. (Joseph & Tretsiakova-McNally, 2010).

Nature's builder, mycelium, is revolutionizing the construction industry. Mycelium-based building blocks use this incredible organism to bind together agricultural waste, creating

sustainable and high-performance building materials. By harnessing the power of mycelium, we can build a greener and more sustainable future. (Cerimi, Akkaya, Pohl, Schmidt, & Neubauer, 2019; Stelzer et al., 2021). In Canada, commercial and institutional buildings account for 18% of energy demand, while the residential sector consumes as much as 33% of the national usage (*Energy Use in Buildings*, 2017).



Figure 1 Mycelium Technology Brick Formation

1.1 MUSHROOMS INSPIRE ENGINEERS TO BUILD A BETTER FUTURE

A futuristic concept is becoming a reality: growing buildings from mushrooms. Scientists are harnessing the power of mycelium, the root-like structure of fungi, to create bricks and other construction materials. As fungi are abundant and natural, and the construction industry is a major contributor to carbon emissions, this innovative approach offers a promising, eco-friendly solution. The application of mycelium is not confined to the construction sector. A diverse range of industries, including fashion, furniture, medical supplies, and electronics, are drawing inspiration from nature's circular principles, where waste is continually decomposed and reconstructed in a closed-loop system.

Fungal biotechnology has enabled the development of a diverse array of products, including packaging materials, leather substitutes, and household objects. As noted by structural engineer and architect Arthur Huang, "Mycelium represents the pinnacle of sustainability. By repurposing organic waste and actively removing unwanted materials, it offers a transformative approach to material production."

1.2 AN OVERVIEW OF MYCELIUM FUNGI

Fungi, comprising an estimated 2-11 million species, of which only approximately 150,000 have been formally classified, are nature's primary decomposers. Mycelia, the filamentous structures of fungi, secrete enzymes that degrade organic matter, including toxic and petroleum-based pollutants such as plastics and unrefined oil. This process, termed my core mediation, enables fungi to remediate contaminated environments. As mycelia consume nutrients and expand, they form a fibrous network that can be cultivated into bricks or other shapes, and subsequently processed into diverse materials. **(**Seyedsina Motamedi, Daniel R Rousse et.al 2023)

Mycelium, a network of fungal threads, is essential for nutrient acquisition. It breaks down complex organic matter into simpler compounds, which are then absorbed. This process is crucial for decomposition, soil health, and plant growth. Mycorrhizal fungi form symbiotic relationships with plants, enhancing nutrient uptake and disease resistance. Mycelium is a versatile term, used both singularly and plurally as "mycelia."

1.3 THE ANATOMY OF MYCELIUM

Mycelium, the vegetative part of fungi, exhibits unique structural and reproductive characteristics compared to other eukaryotic organisms. It comprises a network of filamentous hyphae, each encased in a chitinous cell wall. This contrasts with plant cells, which possess cellulose cell walls. Shown in figure 3.

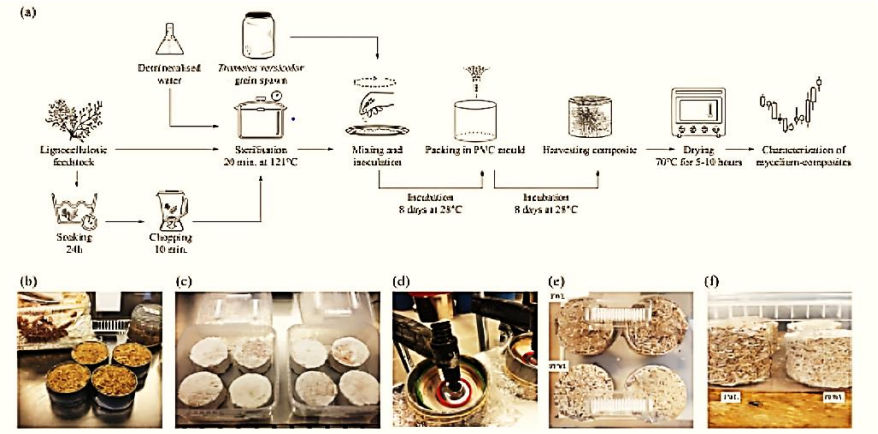


Figure: 2. Fabrication process of mycelium bio-composites (Elsacker, Vandelook, Brancart, Peeters, & De Laet, 2019)

Most parasite hyphae feature additional cell dividers, known as cross-dividers, that divide the long fibres into several end-to-end cells. Most organisms are multicellular as aresult. Numerous growths have cross-dividers with pores large enough to let ribosomes, mitochondria, and even cores spill from one cell to another (Aleksi Vesaluoma (20 June 2017). Fungi can distribute nutrients throughout their bodies by cytoplasmic streaming through the hyphae. As hyphae branch and intertwine, they form a network called mycelium, which provides structural support for the fungus.

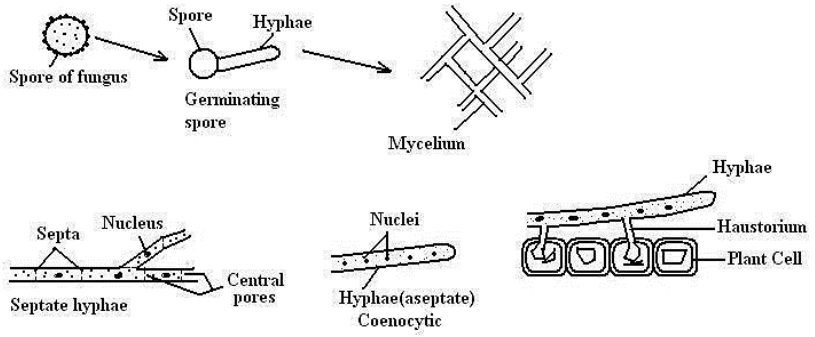


Figure: 3. Structure of Mycelium (Production of Mycelium Bricks Kishan Rahul Kashyap Rohan Tyagi Anshul Jain 2018)

Stelzer et al. (2021) introduced a three-stage procedure for cultivation of the mycelium and substrate. The essence of their idea is first to inoculate the fungus using agar into a pre-culture complete medium. Then, using a sterilized initial substrate to conduct a secondary inoculation (rye 4 is used in this research), and finally using that culture to incubate the main substrate, which is hemp shiv in this case. This way, the growth and distribution of fungi among substrate is claimed to be more efficient (Meyer et al., 2020; Stelzer et al., 2021). The LCA method suggested in this study is described in the manufacturing section of the paper. The structure's snowiness improves contact with the food supply. Parasites are unableto run, swim, or fly in search of food. However, the mycelium makes up for the growth'slack of adaptability by being able to grow quickly while still being sustained by a food source. A parasitic mycelium that branches inside its food source can produce up to a kmof hyphae every day.

AMAZING FUNGAL NETWORK DISCOVERED

Researchers in Oregon have stumbled upon a giant mycelium network! This massive fungus stretches an incredible 5.5 kilometers across, covering an area larger than 1,600 football fields (roughly 9 square kilometers). Scientists estimate it's at least 2,400 years old, making it a contender for the title of one of the oldest and largest living organisms on Earth.

1.4 NATURE'S HIDDEN WEB OF NUTRIENTS

Mycelium, the thread-like network that forms the body of fungi, plays a crucial role in nutrient acquisition for organisms with a heterotrophic lifestyle (meaning they obtain nutrients

from other living things). This extensive network allows them to absorb tiny organic particles from their environment.

Here's how it works: the fungus first releases powerful enzymes into the surrounding area. These enzymes break down external food sources into smaller, readily absorbable molecules. The mycelium then efficiently captures these broken-down nutrients for its own growth.

1.5 CHANGES:

1. Removed unnecessary word "parasite" (mycelium is not parasitic in all cases).
2. Used clearer and more engaging language.
3. Simplified some technical terms for a broader audience.
4. Emphasized the impressive size and age of the discovered mycelium network.
5. Clarified the function of the enzymes released by the fungus.

There are over 100,000 known fungal species, exhibiting a vast array of sizes, shapes, and colours. These fungi play crucial roles in ecosystems, from decomposing organic matter to forming symbiotic relationships with plants. Some fungi are saprotrophs, breaking down dead plant and animal material into simpler substances that can be recycled by other organisms. This figure 4 shows the process is essential for nutrient cycling and soil fertility. Others are parasites, deriving nutrients from living hosts. In fact, approximately 80% of plant diseases are caused by fungal parasites. (https://www.nationalgeographic.com/science/article/paid-content-mushrooms-inspire-engineers)

1.6 FUNGI AS DECOMPOSERS:

1. Fungi are essential decomposers, breaking down dead organic matter into simpler substances that can be reused by other organisms.
2. This process, known as decomposition, is vital for nutrient cycling and maintaining healthy ecosystems.
3. Fungi play a key role in breaking down complex organic compounds like cellulose and lignin, which are found in plant cell walls.
4. By decomposing these materials, fungi release essential nutrients like nitrogen, phosphorus, and carbon back into the environment, where they can be taken up by plants and other organisms.

1.7 FUNGI AS PARASITES:

1. Some fungi are parasitic, meaning they obtain nutrients from living hosts.
2. These fungi can cause diseases in plants, animals, and even humans.
3. Fungal parasites can infect a wide range of hosts, including trees, crops, and humans.
4. Fungal infections in humans can range from mild skin infections to serious systemic diseases.

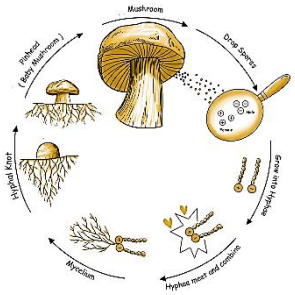


Figure 4: Mushroom mycelium

1.8 PROBLEM DEFINITION AND IDENTIFICATION

According to the carbon war room, we distribute 1.23 trillion bricks globally. Ifthey were stacked end to end, they could reach the moon and circle the globe 325 times. (Kishan Rahul, Kashyap Rohan et.al). These are made by extracting earth from the ground and solidifying it in a heater. According to estimates, the production of this many blocks has the potential to continuously release 800 million more carbon dioxide into the atmosphere than the amount of pollution produced by planes on a daily basis. (According to William McDonough, a renowned

practical architect, waste is equivalent to food in his film https://youtu.be/4pwCFH1LkCw?t=3). Chinawill need 200 million dwellings if the usual block material is used. For the mud, it takes 25% of the best layer of horticulture, and for the burning of the blocks, it takes over 50%of the coal reserves in China. Real health risks are being created by the block furnaces' massive release of deadly components. The block ovens emit hazardous vapour that is harmful to the eyes, lungs, and throat because it contains suspended particulate problemsthat are high in carbon particles and a high concentration of carbon monoxide and sulphuroxides (SOx). Children's psychological and physical development is hampered by this air pollution. According to the data, activity vehicles (55.8%) are the main source of SOx, the substantial contaminants visible everywhere, followed by the block manufacturing business (28.8%) Additionally, the primary sources of NOx (nitrogen oxides) pollutions are the construction industry (8.8%), followed by the transportation sector (54.5%).Additionally, the nation uses between 25 and 26 percent of its annual wood production for building blocks, which results in deforestation. Mycelium is also identified as a complementary material in cutting-edge bio-composite architectural structures. (Scott et al. (2022))

1.8 AIR POLLUTION FROM BRICK KILNS

Brick kilns release various pollutants into the air, including:

Particulate Matter (PM): This is primarily caused by incomplete combustion of fuel and the presence of impurities like coal dust and soil particles in the fuel.

Hydrocarbons and Carbon Monoxide: These are released due to incomplete combustion of fuel in the kilns.

Sulfur Oxides: The amount of sulfur oxides released depends on the sulfur content of the fuel. High-sulfur fuels contribute significantly to sulfur oxide emissions.

Dust: Dust is generated during the removal and disposal of ash, as well as during the process of stoking the kiln



Figure 5: Air pollution from brick kilns
(https://www.pranaair.com/in/blog/bangladesh-demolish-brick-kilns/)

Health Risks

Workers in brick kilns, particularly those involved in handling ash and stoking the kiln, are exposed to high levels of air pollutants. Inhalation of these pollutants can lead to respiratory problems such as silicosis and pneumoconiosis, as well as skin and eye irritation. (Shown in Figure 1.4)

Environmental Impact

Air pollution from brick kilns can also harm agricultural crops and livestock. The emissions can damage crops like mangoes and other fruits, reducing yields and quality. To mitigate the environmental impact of brick kilns, it is essential to adopt cleaner technologies, improve fuel efficiency, and implement stricter pollution control measures.

1.9 EFFECTS ON HUMAN FROM BRICK KILNS

Since people are exposed to so many different toxins in various locations throughout their lifetimes, it is difficult to determine how many people pass away suddenly or are killed as a result of air pollution. Nonetheless, as per WHO for air contamination roughly 3 million individuals have passed on every year. Among them, 800,000 individuals pass on rashly consistently because of lung growth, cardiovascular and respiratory maladies, which are caused by outside air contamination (WHO, 2000). Roughly 150,000 of these passing are assessed to happen in South

Asia alone (World Bank, 2003).The most common way for contaminants to enter the body of a person and impair their respiratory system is through their own breath. (Baker, M. (2016)

Exposure to air toxins can overwhelm or deplete the body's natural defense mechanisms, which can lead to or exacerbate respiratory illnesses like lung development, asthma, chronic bronchitis, and emphysema. Other important systems, such as the cardiovascular system and the central nervous system, can also be negatively impacted byair pollution . The most significant negative impacts of outdoor air pollution on human health are caused by particle matter (PM). The main sources of Add up to Suspend Particles (TSP) in the valley, according to the World Bank (1997), are bond plants (36%),block ovens (31%), local fuel burning (14%), street resuspensions (9%) and vehicle exhausts (3.5%).However, particulate matter under 10 microns (PM10) concentration, which is another important factor in the harm to the respiratory system, was found to be most prevalent from block ovens and was found to be around 28% (World Bank, 1997).

According to the EPA, small airborne particles or mist concentrations smaller than 100 micrometers are all referred to as total suspended particulate matter (TSP) (EPA, 2012). The bulk of block ovens are poorly constructed, which results in poor coal ignition. Carbon Monoxide (CO), which is produced during this dispersed burning, increases the risk of cardiac diseases. If elastic car rubber tyres were used as fuel, along with CO, the outflow fromblock ovens would also include hydrocarbons, fine clean particles, Sulphur dioxide (SO2), nitrogen oxides (NOx), fluoride mixtures, and a small amount of cancer-causing dioxins (Joshi and Dudani, 2008). All of these standard block ovens burn wood, garbage, coal, old motor oil, fuel oil, diesel, tyres, and plastics as fuel. Actually, the majority of what they will use as fuel depends on what is available to the block producers. However, the harsh reality is that each of these energies oversees the emission of dangerous gases.Open block furnaces in Spain were also capable of producing fluoride, chlorine, and bromine in addition to other dangerous gases. Block furnaces are accounted for as the source of PM2.5 in Bangladesh.

Since it has the potential to move into the respiratory system and cause prematuredeath and respiratory conditions, this fine PM is even more harmful to human wellbeing shown in figure 6. Because our immune systems are weaker during these stages of life, seniors and children generally suffer more from these PM than people of any other age group (OAQPS Truth Sheet, 1997). In their analysis, the American Lung Association (ALA) discovered that the unanticipated loss rate for PM in air was three times higher than that of earlier studies. In addition, the number of fatalities related to air pollution rose(ALA, 2006). An average grill emits about 863 pounds of toxins per generation, covering roughly 10,000 blocks, according to recent assessments (TCEQ, 2002). (https://www.tceq.texas.gov/waterquality/assessment/02twqi)

a) According to a health assessment, those who live close to coal furnaces are more prone than those who live elsewhere to have illnesses brought on by the contamination of the ovens.

b) According to Joshi and Dudani (2008), schoolchildren who lived close to block furnaces had worse health overall and were more susceptible to upper respiratory tract diseases such tonsillitis and pharyngitis.

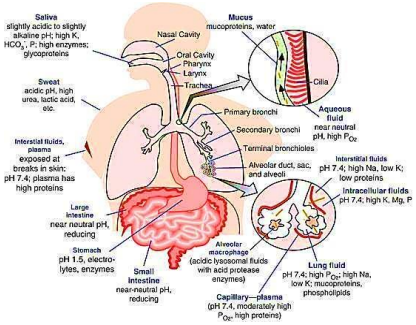


Figure 6: Effects of dust from brick kilns on humans (Joshi and Dudani) (2008),

2. METHODOLOGY

To begin, mushroom spores are combined with sterilized agricultural waste and water in plastic bags. These bags are incubated in a dark, cool environment to promote mycelium growth. Once the mycelium matures, it's transferred to sterilized sawdust and given nutrients. After colonizing the sawdust, the mycelium-filled mixture is molded into brick shapes. Finally, the bricks are heat-treated to kill any remaining bacteria and solidify the structure shows in figure 8. Mycelium is also identified as a complementary material in cutting-edge bio-composite architectural structures. Scott et al. (2022) fabricated a series of prototypes using the integration of mycelium and bacterial cellulose on knitted wool-based scaffolds shows in figure 7.

Figure 7: Initial structural permutations (a). Early bio-inspired morphologies (b). Topology from net to inverted dome (c). Modularisation of form for production (d). Visualisation in-situ (e) (Scott et al., 2022).

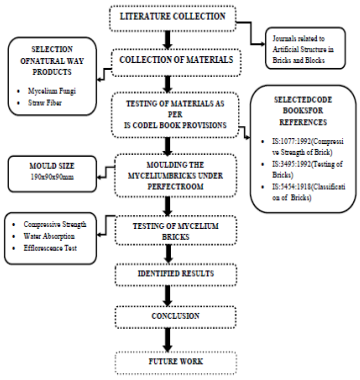
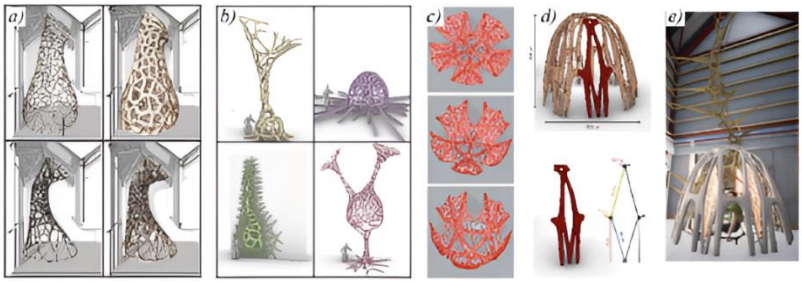


Figure 8: Methodology of Work



3. EXPERIMENTAL STUDY

The enhancement points for the process of creating mycelium blocks are introduced in this section. There was virtually no information or none at all, about how to make plasticblocks available in the widely disseminated Due to this lack of information, the investigationfocused on mycelium blocks with restricted access to writing. To develop the mycelium building blocks innovation, the current study included a thorough experimental approach. The main goal of the inquiry was to pinpoint the exceptional factors that affect thecharacteristics of plastic used as a construction material. The use of the leftover plastic goesbeyond what most people would think is possible.

The purpose of the activity was to make it easier for this "new" material to later advance in the block business. The compressive quality is selected as the benchmark metricwith the intention of streamlining the progression process. Given the inherent significance of compressive quality in the fundamental design of block structure, this is not unusual. Even though mycelium can be used to make a variety of construction materials, including chairs, mycelium pieces, and asphalts.

3.1 MATERIAL USED

1.	Mushroom Seeds	Saw Dust
2.	Straw	Formalin
3.	Logs	Fungicide

4. Cellophane Sheet Brick Mould

3.2 MYCELIUM THAT IS GROWN FROM MUSHROOM SEEDS

The vegetative portion of a parasite or growth-like bacterial settlement, known as the mycelium, is made up of mass-expanding, string-like hyphae. The hyphal mass is occasionally referred to as shiro, especially inside the pixie ring parasites (figure 1.1). Mycelium-based parasitic communities can be discovered in soil and on many substrates. When two healthy homokaryotic mycelium's are combined to form dikaryotic mycelium, the mycelium may develop fruiting bodies, such as mushrooms. A regular single spore sprouts into a homo karyotic mycelium, which cannot reproduce sexually. A mycelium may be large or small, framing a province that is difficult to see.

A parasite absorbs nutrients from its environment through its mycelium. It uses a two organize process to accomplish this. The hyphae first release proteins onto or into the food supply, which break down organic polymers into smaller components like monomers. Following that, these monomers are kept in the mycelium by promoting dispersion and dynamic transport. In terrestrial and aquatic biological systems, mycelium is essential for thebreakdown of plant matter. They increase the amount of organic matter in the soil, and as theygrow, they release carbon dioxide back into the atmosphere (see carbon cycle). Extrametrical mycelium from Ectomycorrhizal growths as well as mycelium from Arbuscular mycorrhizalgrowths improve water and nutrient retention in most plants and offer some plant pathogen protection. For some soil spineless organisms, mycelium is an essential source of food.

In the same way that "parasite" can be understood as a mass entity, "mycelium" is a word that can be either singular or plural. However, similar to "organisms," the word"mycelia" is frequently used as the preferred plural frame. See figure 1.1 for mycelium and figure 9 for mushroom seeds.



Figure 9. Mushroom Seeds

3.3 SUBSTRATE

A substrate is a substance that allows the mycelium to grow. Anything can be a substrate, including sawdust, wheat, agricultural waste, etc. Diverse kind of substrate as follows:-

STRAW - A suitable substrate can be made from grain straw made from wheat, rye, or oats. They are reasonably priced and simple to obtain. They must first be prepared since they contain microorganisms that could hinder mycelium growth



Figure 10. Straws

LOGS - As was previously mentioned in the Introduction, mycelium can grow on anything. Logs made of wood make excellent mycelium substrates as well. Any swiftly degrading hardwood that isn't too dense, though, will usually work. A few decent options include cottonwood, elm, beech, alder, and ash. It will take a lot longer for thicker hardwoods, like oak, to develop mushrooms. However, it takes too long for mycelium to colonise wooden logs.



Figure 11. Wooden logs

ENRICHED SAW DUST

A substrate for growing mushrooms that is more frequently used by commercial cultivators than by amateur growers is enriched sawdust. There are a few things to consider, even though it works well with a number of different mushrooms. Like wood logs the best sawdust is made of hardwood rather than softwood. Additionally, the sawdust will be sterilized before mycelium colonizes it.



Figure 12: Saw Dust

Chemicals Used – Formalin - Formalin is another name for formaldehyde. Following a previous trade name, "formalin," "formaldehyde" was first used as a generic trademark in 1893. At room temperature, formaldehyde is one of a wide group of chemicals known as volatile organic compounds, which evaporate and become gaseous. Formaldehyde is dissolved in water at a 40 percent concentration for use as a preservative and disinfection for chemical specimens. Formaldehyde is an important precursor to many other materials and chemical compounds.



Figure 13: Formalin

Fungicide - Fungicides are pesticides that kill or prevent the growth of fungi and their spores. They can be used to control fungi that damage plants, including rusts, mildews and blights. They might also be used to control mold and mildew in other settings. A fungal static prevents their expansion. It is significant because the fungi that are present in the substrate are stopped by it.



Figure 14. Fungicides

Cellophane Sheet - To make the mould airtight, polypropylene sheets called cellophane are utilized. Cellophane is a thin, transparent sheet made of regenerated cellulose. Its low permeability to air, oils, greases, bacteria, and liquid water makes it useful for food packaging. Cellophane is highly permeable to water vapors, but may be coated with nitrocellulose lacquer to prevent this.



Figure 15: Cellophane Sheet

BRICK MOULD - Brick mould is used to grow the mycelium in the shape of brick. Brickmold is used as casing around exterior doors. It is molding around the window and door frames that abuts the exterior facing material of the building and serves as an aesthetic boundary between the siding and the frame; most used in pre-hung units. It is also known as trim, casing and and an architrave.



Figure 16: Filling in the brick mould

OVEN - Oven is used to kill the bacteria. These are used for sterilizing biohazard waste, media/reagents for aseptic assays, or dissecting instruments. Besides, this is also used for heating, drying, and testing environmental stresses, such as changes in light, temperature, and humidity.



Figure 17: Laboratory Oven

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