

Introduction to Mycelium Insulation as a Sustainable Insulation Material and Carbon Sink

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Abstract. Climate change is becoming an even bigger threat with the continued production of pollution in the atmosphere. Mycelium insulation offers a potential part of the solution by being a carbon sink and a sustainable material in an otherwise very unsustainable industry of construction and insulation. In this review paper, I present the various materials that can form mycelium insulation, the process of how mycelium insulation is made, and some examples of potential composites that have been studied. Furthermore, I discuss the environmental impact of the insulation industry, and how mycelium insulation can reduce such impacts. Additionally, mycelium insulation is then compared to current alternatives on the market and evaluated by outlining its capabilities across various metrics to determine its performance. I then introduce specific properties of a mycelium composite that can be achieved depending on the substrate make up. Finally, market viability is analysed to show the potential of mycelium insulation. Results show that the current iteration of mycelium insulation may appeal to select individuals that are environmentally conscious, or for specialised cases. Widespread use of mycelium will only be achieved if further innovation occurs or an increase in the need to become environmentally friendly.

1 Introduction

As the effects of climate change become increasingly apparent and extreme, and with no substitute available for many industries that produce greenhouse gasses, The global population is estimated to keep growing to 9 billion by 2050 [1]. This will in turn further increase our need for housing, waste disposal, and transport; the manufacturing of these materials will have to become sustainable. Carbon capture technology is a crucial field that may help the world achieve net zero emissions alongside innovation in manufacturing. One such technology is the growth and use of mycelium as insulation.

Earth is about 1.36 degrees Celsius warmer than in the 19th century, with the past 10 summers consistently breaking records for being the warmest summers to date [2]. While governments have committed to curbing carbon emissions, many heavy industry sectors are proving difficult to decarbonize, such as trucking, aviation, chemical production, and steel production. The manufacturing industry alone accounted for 12% of total carbon emissions in the US in 2021 [3]. This poses a huge threat to our ideal of a circular economy being implemented. A possible solution is to use mycelium as a carbon sink for insulation. Studies have shown that there is huge potential for abatement technologies in the construction industry with short-term reductions in greenhouse gas emissions [4]. From concrete roads to

brick houses, many materials used during the construction of buildings are ripe for innovation and incredibly costly in terms of GHG emissions.

Currently, the materials used for insulation include fibreglass, cellulose, and mineral wool, among others. However, manufacturing these materials is either very labour-intensive or produces a high carbon footprint through the production of plastic. These insulators are becoming increasingly less attractive to our current world as society's aspirations to be eco-friendly increase. Mycelium Insulation is a steadily developing solution to this issue. Furthermore, mycelium has many different combinations of fungus species and substrates that boast different properties and uses [5]. Mycelium itself is already being used in many other industries around the world such as cosmetics, medicine, and food packaging [6].

Mainstream carbon capture is mostly focused on geological storage because of its speed and efficiency compared to biological storage. The initial capital investment is also high due to the need for machinery in carbon scrubbers and the setup of underground geological formations for carbon storage. This, however, presents further issues, such as the potential leakage of pipes and health concerns for personnel. Finally, a combination of a lack of public acknowledgement of this technology, market incentives, and an unclear legality of the transport and storage of carbon, makes geological storage slow to innovation [7]. Another point of concern about developing geological storage technology is its misuse in the oil industry. An example of this is the buyup of Ion Energy, to Chevron the carbon scrubber technology developed by Ion Energy is an air scrubber that captures carbon dioxide from ambient air and stores it underground [8]. However, it can also be used in oil wells, to pump out even more petroleum. This is counterintuitive as the net decrease in carbon captured is vastly topped by the carbon emissions produced from the petroleum that was pumped out. On the other hand, biological storage of carbon, such as in mycelium, may prove to have much fewer side effects while being cost-effective. This paper aims to discuss how Mycelium may replace traditional insulation in some places. Along with its effectiveness as a carbon sink.

2 Production and mechanism

2.1 Material

These species of fungus can then be further customized using different combinations of substrates to form new composites. The reason mycelium has so much potential as a material is its ability to grow from byproducts and waste, making it an affordable alternative to normal materials. It can also be recycled by compost and requires little energy to be produced [4]. The compressive strength of the mycelium ranges from 1.2 N/mm² to 1.8 N/mm² and is impacted by changes in porosity, pore size, and characteristics of the materials that it is grown from [9]. This variability also is a drawback of this technology, making it inconsistent and hard to upscale.

2.2 Studies of Potential Materials

Previous research revealed that the best mix proportion for a mycelium composite was 0.3:1:0.1 of *Ganoderma resinaceum* mushroom, *Miscanthus x giganteus* fibres, and potato starch (G0.1_M1_P0.1) Yielded a low-density (122 kg/m³) material that was suitable as thermal insulation material [9]. It was found that the material had a high water absorption and increased in weight by 40-580 wt% when in contact with water for 48-192 hours [9]. This does not result in a disadvantage for mycelium insulation as you can just install a protective membrane or a render.

On the other hand, another study used sawdust from birch and poplar for the creation of lightweight mycelium composites (100 kg/m³) and high porosity (>90%) which resulted in high insulation capabilities [10].

2.3 Environmental impact of mycelium insulation

As stated before, mycelium insulation is fully biodegradable while also providing nutrients to the soil. The production of mycelium also produces less emissions compared to other common insulators. However, if the amount of CO₂ absorbed during the growth of mycelium is taken into accounts, it suddenly becomes carbon negative at around 244 kg CO₂eq/m³ with the possibility of reducing even more carbon as energy efficiency increases and renewable energy becomes more commonplace [11]. This can be seen in figure 1 where emissions from mycelium are contrasted with other common insulators.

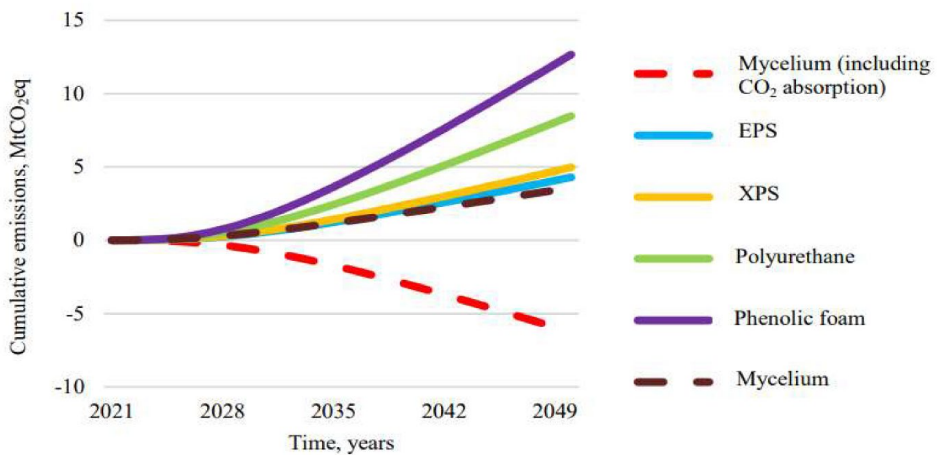


Fig. 1. Comparison of different materials [11]

2.4 Manufacturing Process of mycelium

The process of growing mycelium begins with finding a pure culture of the fungal species in the form of spores, liquid culture, agar plates, or other methods. The growth medium is then prepared by creating a block of substrate, the substrate is usually made of materials that are chosen to make up the composite of the final product, some of these materials include sawdust, grain, agricultural waste, or other organic material. The fungus is then spread evenly using various methods by layering the substrate and inoculum, or mixing the inoculum with the substrate, the inoculum will have to be thoroughly distributed throughout the substrate to achieve desired results. In a sterilized environment such as a laminar flow hood, the mycelium is incubated at around 20-30 degrees Celsius. Once the substrate is fully colonized, the hyphae will have permeated throughout the substrate and formed a dense network that is irregular and has insulation properties. The composite can then be moulded and further processed for specific applications.

3 Evaluation of general and specialized characteristics of mycelium insulation

3.1 Performance of mycelium insulation compared to other materials

Mycelium insulation presents an intriguing alternative to traditional insulation materials across various applications. Typically, mycelium insulation has a R-value of 3 per inch. This is comparable to other organic insulators such as wood fibre, straw, or wool. However, this still falls short compared to the performance of traditional insulators such as fibreglass insulation, which boasts an R-value of 3.7-4.3 per inch. This in turn means that mycelium insulation is less effective at resisting heat transfer, particularly in cold climates. Mycelium insulation demonstrates superior thermal performance—effectively reducing heat transfer and enhancing energy efficiency [11]. This translates to potential cost savings on heating and cooling bills while simultaneously increasing occupant comfort. Additionally, mycelium insulation exhibits sound-absorbing properties—contributing to a quieter indoor environment. However, long-term durability and comprehensive cost comparisons with traditional insulation warrant further investigation [12].

In industrial contexts, mycelium insulation's versatility is apparent. Its moldable nature allows for customization to fit specific insulation requirements—showcasing a promising option for various industries. Furthermore, its inherent fire resistance and ability to absorb pollutants position it as a potential game-changer in sectors such as construction and manufacturing. While research is ongoing, the initial findings are both encouraging and promising.

3.2 Mycelium composites

The true essence of the advantages of mycelium insulation comes from its ability to gain different attributes depending on the substrate chosen for the mycelium to grow in. One very prominent substrate is wood chips and sawdust. The main benefit that they provide is the fibrous structure which provides a high surface area that encourages mycelial growth. Furthermore, mycelium breaks down cellulose and lignin in wood which acts as a glue that forms a stronger and more complete composite [13]. Biochar is another material that is implemented in composite materials due to its inherent fire-resistive capabilities. Incorporation of biochar allows the result to become more resistant to ignition and combustion. It also has selective anti-fungal properties when optimized properly. These properties create an antifungal effect that can suppress mould without a sizable decrease in mycelium growth. Natural polymers are sometimes also added into substrates to act as a binding agent within the composite. It results in a stronger and more stable material along with increasing insulation capabilities. Some polymers such as starch can add flexibility to an otherwise rigid material, this can allow easier handling of the insulation or for when slight movement may occur throughout the insulation's lifespan. Other materials like agricultural waste and recycled cardboard or paper, which make up most of a composite, are mostly used due to it being readily accessible and cheap.

4 Evaluation of market viability

The viability of mycelium in the insulation market highly depends on the success of a few factors. Mycelium insulation has the potential to massively appeal to audiences that value and appreciate being eco-friendly - which is currently a market with huge potential for growth, or with companies that are seeking to reach goals for their green initiatives. However, for successful implementation of mycelium, it still has many hurdles it has to overcome. A notable issue is the slow production rate of mycelium, and subsequently uncertainties regarding the scalability of this technology. Currently, there have only been tests for industrial implementation at the pilot scale. Scaling up further from this will require

significant capital investment [14]. The insulation market has historically been an industry with little innovation in terms of embracing new inventions. In an industry that focuses on being consistent and has huge consequences for failure, new material with no history will need time to thrive and garner interest. This problem may be combated by asking governments to help push the initiative of using mycelium insulation by pushing out government policies. Additionally, as mycelium insulation is still a very new technology, the scale and speed of production still is very small. Solutions to streamlining the production method, and the inability to utilize economies of scale result in the cost of mycelium insulation being higher compared to traditional insulation [14]. As the raw material used for mycelium production - agricultural waste, is extremely cheap and abundant, the possibility for vertical integration there is still much room to lower costs. Another risk that mycelium faces is the inconsistency of the supply chain. Yes, relying on organic waste material to produce the product indeed does facilitate circular economy and sustainability, but it also poses issues with how the process can be standardized and how quality control on the industrial scale can be maintained in a cost-effective manner. Finally, mycelium has problems with moisture resistance and in turn longevity of the material.

5 Conclusion

This paper discussed the potential of mycelium insulation as an organic carbon sink in combination with being a promising sustainable insulator. Current insulators are often one-time use and are made using unsustainable materials that cannot be recycled. Additionally, carbon capture technology is mainly focused on the underground storage of carbon. These practices have historically been implemented in a counterintuitive manner, leading to a negative public reputation and a decrease in funding and innovation in this sector. The production of mycelium is further illustrated to help readers understand the process that mycelium production goes through, along with introducing some notable composites and substrate materials that have been studied. The carbon footprint of the insulator was then compared with traditional insulation to conclude that mycelium insulation produces significantly less carbon dioxide compared to other technologies when carbon absorption is considered. The market potential for mycelium insulation was then analysed. While mycelium insulation has the advantage of being extremely customisable depending on the situation, as it is still a developing technology, it has a higher cost of production and currently does not perform as well as traditional insulators. On the other hand, as time passes more consumers may be inclined to choose mycelium to be more environmentally conscious and as the product gains a more sophisticated track history. the innovation potential for mycelium insulation is high, and given time, mycelium insulation may even become cheaper than traditional insulation. Mycelium's insulating ability will naturally increase as more efficient composites are discovered.

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