Impact of Straw Substrate Particle Size on the Mechanical Properties of Mycelium Based Composite Materials

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Abstract This research investigates the application of fungi to the existing linear agricultural and forestry economies to create more circular economic models, reduce CO_2 emissions, and produce building materials aligning with action plans of European governments, towards climate neutrality by 2050. In this context, biomaterials in the built environment are considered a critical way forward. The research studies mycelium-based materials for panel boards in buildings. Mycelial structure was proven to be an effective material binder, but there are potential improvements to product quality and stability in production. After identifying specific fungi for use as material binder, laboratory tests assessed salient mechanical properties of the mycelium-based composite materials on pelletised vs. chopped/chipped substrate materials. The results show that pelletised substrate materials produce composite materials with isotropic characteristics that are more resistant to compressive loads than composite materials made from chopped substrates. This gives promise that pelletised substrates can improve strength, consistency, and reliability of mycelium products while offering an industrial solution to biomass waste management with the production of standardised pellets as an ingredient of mycelium composite materials. The production process thus has the potential to create a circular economic model for agriculture, forestry, and the built environment, while off-setting biomass incineration.

Keywords: Biomaterials, fungi, mycelium-based materials, circular systems, forestry and agriculture waste chains

1. Introduction

The construction sector is known as an energy and resource intensive industry with excessive pollution and waste streams. Many traditional building materials are considered unsustainable in their demand for virgin materials and high energy demand during production processes. With this comes waste of materials and excessive pollution within linear economic models, leading to the depletion of resources and ecologies. Material binders are often toxic glues which are now being incinerated under the waste-to-energy initiative. This energy production has replaced coal as the most polluting energy source in the UK (McGrath 2024). To address these challenges, biomaterials in the built environment are considered a critical way forward, and the EU has released a number of action plans in recent years to engage with the climate targets of the Paris Agreement 2030 and achieve climate neutrality by 2050. These include The Bio Economy Action Plan 2018, A Renovation Wave for Europe 2020, and A New Circular Economy Action Plan 2023 (European commission 2018, 2020, 2023). In line with this, there is a lot of interest in mycelium-based composites mainly due to the sustainable characteristics of the role of fungi in processing waste as 'nature's tech'. The materials can be grown on organic agricultural waste and, at the end of their primary life cycle they have the potential to be completely biodegradable, and waste-free, thus providing a circular material system. Namely, the role of fungi within natural cycles of energy and resources is to recycle and break down matter to extract and trade nutrients, minerals and sugars with other organic organisms, thus returning complex molecules back to simple bio-chemical elements. There is ample opportunity to create high quality, affordable materials of low carbon emissions during production, while managing and mitigating undesirable, wasteful characteristics of other industry waste chains. Considerable investment has been injected into research outputs, and companies in Europe and the US have emerged who have been refining methods of production and application of mycelium-based finish materials, insulation, acoustic treatments, and even some semi-structural functions in the recent years. Thus, the future of construction is likely to see mycelium-based products appear in new buildings. A remaining question for which further research is required, is whether and how the fungal characteristics of decomposition and interconnectivity may be harnessed and applied to the existing linear economies to produce more circular economic models.

In this context, this paper demonstrates how regularising and reducing the micron size of substrate materials has the potential to produce biomaterials with more consistent, reliable properties which, in turn, express the innate structural characteristics of the fungus binder over the substrate in which it is grown.

2. Materials and Methods

The selection criteria for fungal species used in this research was that fungi should: (a) be saprophytic so that they can break down dead and decaying organic matter including cellulose and lignin to extract minerals, sugars and vitamins in a biodegradation process, which reverts complex molecules to simple bio-chemical elements; (b) grow in varied conditions and on varied substrates, providing more resilient business models. The fungal strain selected for this study was King Oyster (*Pleurotus eryngii*), as it satisfied the above criteria. The substrates used for fungal growth were chopped vs pelletised wheat straw, considering that the production of wheat is the biggest producer of straw in Europe (Eurostat 2023). The method of material production was a two-stage incubation with grain spawn. For stage one, liquid culture was added to hydrated, pasteurised wheat grain and was incubated for 14 days at ambient conditions i.e., a temperature range between 20-22°C. For stage two, the grain spawn was added to the bulk substrates at a ratio of 1:4 before the composite mix was added to moulds to be incubated for 28 days at ambient conditions (20-22°C); after 28 days the samples were demoulded and kiln-dried at 65°C.

3. Results

Figure 1 and Table 1 show results of compression tests on chopped straw and pelletised straw substrates, with and without a fungus binder. Both the chopped and pelletised straw substrates achieved higher compressive strengths when a mycelium binder was used compared to samples without binder. The pelletised straw with mycelium binder achieved more than twice the compressional load of the chopped straw with mycelium binder, supporting nearly 495 times its own weight. Pelletised mycelium-bound straw had about twice the density of chopped straw-mycelium bound samples. Both strength curves of pelletised straw samples display a gradual failure. The unbound straw samples did not demonstrate a high compressional strength within 10% deflection and had sponge-like characteristics. Chopped straw samples were anisotropic due to the preparation process and the layered straw caused shearing when compressed from certain directions. Pellet straw samples were isotropic due to regularised pellet particle size.

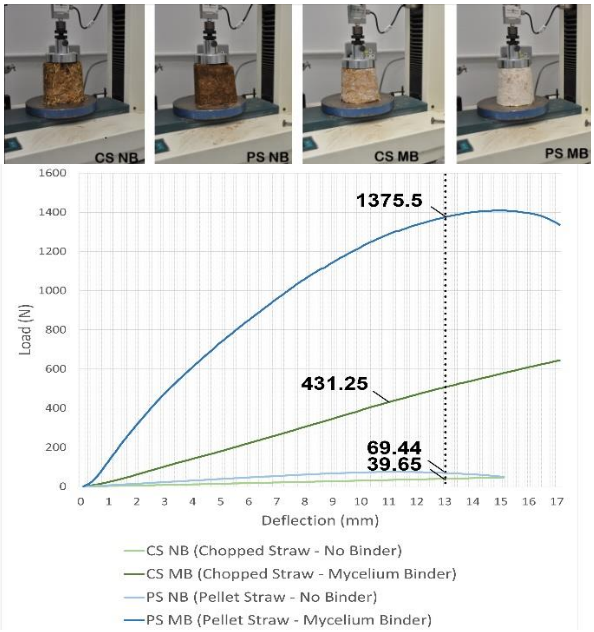

Figure 1. Compression test: chopped vs. pelletised straw, with & without *Pleurotus eryngii* mycelium binder

4. Conclusion

This research investigated the application of mycelium-based binders of pelletised vs. chopped/chipped straw waste substrate materials applied as panel boards in buildings. The results of the compression test support the hypothesis that a regularised, reduced particle size substrate material can produce more consistent results of a higher quality than the unprocessed equivalent material. The initial results give promise that pelletised substrates can improve strength, stiffness, consistency and reliability of mycelium products while offering an industrial solution to biomass waste management with the production of standardised pellets as an ingredient to mycelium composite materials. The production process thus has the potential to create a circular economic model for agriculture, forestry, and the built environment while off-setting biomass incineration.

Table 1. Summary of physical properties and compression test results of the biomaterials

Biomaterial	ID	Height (mm)	Density (kg/m^3)	Deflection, ΔL (mm)	Load (N)	Stress (kPa)	Strain (kPa)	Young's Modulus (kPa)
Chopped straw -no binder	CS NB	130	351.00	13	39.65	6.54	0.1	65.54
Pelletised straw -no binder	PS NB	130	323.00	13	69.44	11.48	0.1	114.78
Chopped straw -mycelium binder	CS MB	110	145.84	11	431.25	54.91	0.1	549.1
Pelletised straw -mycelium binder	PS MB	130	290.00	13	1375.5	175.13	0.1	1751.3

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