MPRI-JAAER | INTERNATIONAL JOURNAL OF APPLIED & ADVANCED ENGINEERING RES.
VOL. 02 NO. 1 OCT-2023 ISSN: 1116 - 2716

WASTE TO WEALTH USING SPENT MUSHROOM SUBSTRATES (SMS) FOR PRODUCTION OF HOLLOW CONCRETE BLOCK

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Abstract

Waste management and sustainability are growing concerns worldwide which needed modern approaches in tackling them. Spent Mushroom Substrate (SMS) sometimes called Spent Mushroom Composites is one of the newly discovered solutions for the production of light weight hollow concrete blocks. SMS is a by-product of the mushroom industry and consists of agricultural waste such as sawdust, straw, and corn cobs. This study explores how waste reduction, sustainable development, environmental conservation, cost reduction, and quality improvement can be achieved by using SMS

Keywords: Block, Building, Concrete, SMS, Substrate and Weight

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as a raw material for hollow concrete block production. The methodology of this study involves the preparation of SMS-based hollow concrete blocks using different proportions of SMS, cement, sand/quarry dust and water. The physical and mechanical properties of the concrete blocks are then evaluated using compressive strength, water absorption, and density tests. The original control weight of the conventional 150MM X 450MM 6-inch solid concrete block is 16.5kg but when it was partially replaced with 10% of the SMS in terms of mix ratio, the weight came down to 9.7kg after it has been cured for 28days. The objective is to produce high-quality, durable, and sustainable hollow concrete blocks that can replace traditional one and reduce the reliance on non-renewable resources. The study finds that SMS can enhance the workability, strength, and durability of traditional/conventional hollow concrete blocks. The use of SMS in concrete block production can also reduce the environmental impact of traditional concrete production, while contributing to a circular economy. .

Introduction

For more than a decade, the supply of traditional construction materials, such as hollow blocks, cement, bricks, timber, cladding and partitioning materials, has struggled to keep up with an ever-increasing global population causing significant pressure on the construction industry (Madurwar et al., 2012; Pheng & Hou, 2019). The annually generated Spent Mushroom Substrates (SMS) is increasing in volume as the mushroom industry is steadily growing (Kwak et al., 2015). New application of SMS should be explored as a solution to the building construction industry. There has been considerable discussion recently about the potentials of using SMS for production of value-added products.

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One of them is production of 150MM X 450MM 6-inch solid hollow concrete block. Spent mushroom substrate (SMS) is a byproduct of cultivation of oyster mushroom and represents the composted substrate that remains after completion the harvested crop. It is the soil-like material remaining after a crop of mushrooms. Energy are consumed during the production of these conventional construction materials with limited natural resources polluting our air, land and water (Madurwar et al., 2012). The rapidly growing global population has also resulted in growing food demand and increased agricultural output, leading to the generation of agricultural byproducts and wastes, such as mycelium mushroom (Bhuvaneshwari et al., 2019). A good substrate is dense in woody, fibrous materials like lignin, cellulose and hemicellulose. (These contain a lot of carbon, which is the main food source for your mycelium.). When combined with agricultural waste or other organic materials, mycelium can create a sturdy, lightweight material with excellent insulation properties. The use of SMS for the production of hollow concrete blocks has significant potential to contribute to waste reduction, environmental sustainability, and economic development. Wastes are very diverse in composition and consist of rejects, different types of sawdust and ashes in mills having on-site incineration treatment. Low-grade agricultural by-products and wastes are largely discarded as waste or burned, generating carbon dioxide and other greenhouse gases because of their limited applications with their primary use being fertiliser, animal bedding and fillers for building materials and road construction (Laftah, 2019). Mushroom substrate ingredients include; Light coarse fibre rejects, which consists mainly of cellulose fibre and impurities such as limestone and different silicates, Sawdust generated during the processing of timber and Wheat bran which was used as a nutrient source in the substrates to promote productivity. In Europe, approximately 225 Mt of diverse residues including, e.g., waste paper, sawn

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wood, food, and plant materials are annually generated according to the International Council on Clean Transportation (Grimm et al., 2021; Searle & Malins, 2016) Wastes generated during the recycling/pulping of waste paper and wood, so-called 'rejects', are considered a problematic material from both the environmental and economic point of view. For the development of a circular economy, the rejected composition from waste can be subdivided into different types and some of these can be seen as an interesting raw material for building environment (Monte et al., 2009). Over the past decade, the vegetative growth of filamentous fungi (mycelium) has attracted increasing academic and commercial interests as a new form of low energy bio-fabrication and waste upcycling (Holt et al., 2012; M Jones et al., 2017; Nawawi et al., 2020; Pelletier et al., 2013). The production of sawdust from virgin wood generates waste but the waste has similar properties to waste from the production of deinked pulp, although with less inorganics (Monte et al., 2009). High amount of cellulose fibre, not suitable for the production of paper but produced from the rejected waste could be used to cultivate high value-added bio-based products such as edible mushrooms. The latter are the fruit bodies of basidiomycetes with a saprotrophic lifestyle (Grimm et al., 2021). Moreover, the use of mycelium substrate can divert significant amounts of waste from landfills, reducing the environmental impact of waste disposal. Considerable quantities of (waste) spent substrate can be gotten from the cultivation of primary decomposer mushroom (Kilpatrick et al., 2008; Pardo-Giménez et al., 2012). In a well-managed mushroom industry, approximately 70 wt% d.b. of the initial substrate may remain as (waste) SMS (Finney et al., 2009; Zhang et al., 2002).

The production of 150MM X 450MM 6-inch solid concrete block using SMS in Lagos Nigeria, is not only to reduces waste but also results in a more environmentally friendly building material by reducing the weight of the

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conventional/traditional block to almost half. Lagos State is a cosmopolitan city with sound economic base, strategic maritime location and socio-political importance which induced a high rate of migration to the State. The weight of the 150MM X 450MM 6-inch solid concrete conventional/traditional block used for building construction in Lagos Nigeria is 16.5kg. With the use of the SMS waste, the weight of the block was reduced to 9.7kg which is almost half of the weight of traditional block after it has been cured for 28days. However, appropriate amount of SMS together with other materials such as water, sharp sand/quarry dust and cement were mixed together in various proportions to attain the block production in certain percentages. Various mix proportions providing (cement: fine aggregate (sand + SMS) tested were ratio 1:6 (0%, 10%, 20% & 30% SMS replacement) and also (cement: fine aggregate (Granite dust + SMS) tested were ratio 1:4 (0%, 10%, 20% & 30% SMS replacement). Though certain percentages worked out while some failed. Experimenting the use of spent mushroom substrates (SMS) as a partial replacement for sand in the production of concrete blocks was carried out. The percentages were in various mix in which there was replacement between the materials. Partial replacement of 10% SMS in addition to other aggregate mix ratio gave the encouraging results of reduction in term of weight.

The used SMS for block production was gotten from Yaba College of Technology Laboratory from the production of edible and medicinal mushroom. The disposal of these SMS waste is considerably expensive due to high transportation volume (Banasik & Kanellopoulos, 2019). This necessitated for the development of smart solutions to reduce costs tied to the production process and also environmental problems. By utilizing these waste and other organic materials, these SMS can be grown in a controlled environment such as Yaba College of Technology Laboratory to produce a strong, lightweight material that can be a partial replacement for sand in

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the production of traditional concrete blocks. The results showed that the use of SMS led to a decrease in the density and compressive strength of the blocks, but also resulted in a decrease in the water absorption and increase in the thermal conductivity of the blocks. Mycelium binds organic matter through a network of hyphal micro-filaments in a natural biological process able to be exploited to produce both low-value materials, such as block, packaging, and higher-value composite materials (Haneef et al., 2017; Holt et al., 2012; M. Islam et al., 2017; M Jones et al., 2017; Pelletier et al., 2013) with little or no commercial value from problematic agricultural and industrial waste materials (Tian et al., 2022). The study concluded that SMS could be a sustainable alternative in partial replacement of sand in the production of 150MM X 450MM 6-inch solid concrete blocks.

Research on the use of SMS waste as aggregate in concrete block production, is relatively new. Further research would give more confidence to the building construction industry on long term durability of this kind of concrete when used for more sensitive projects. The study aims to reduce the environmental impact of construction materials and promote a circular economy. This will enhance the utilization of SMS waste for the production of concrete blocks by transforming waste materials into valuable resources and contribute to sustainable construction practices. The objective is to produce high-quality, durable, and sustainable concrete blocks that can replace traditional materials and reduce the reliance on nonrenewable resources. Additionally, the use of mycelium in the production process aims to create economic opportunities and jobs, contributing to waste reduction, environmental sustainability, and economic development. This will ultimately create a sustainable, circular, and profitable model that benefits the environment, society, and the economy in the building construction industry. The use of SMS for the production of concrete blocks has the potential to transform waste into wealth not only in the Lagos State but also

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in Nigeria and beyond. The hypothesis of production process is energy-efficient, with low carbon emissions, and uses renewable resources, making it an environmentally sustainable solution to conventional/traditional block that is much heavier. SMS concrete blocks also have excellent insulation properties, reducing the need for additional insulation materials in buildings. This can result in lower energy bills for building owners and occupants, reducing their carbon footprint and contributing to a more sustainable future. The findings of this study show that

SMS are very economical alternative aggregate materials to traditional concrete block aggregate for building construction applications of dead loads and partitioning. Both civil and agricultural engineers with biological scientist must jointly acknowledged that SMS materials is useful and could pave the way for other potential uses of agricultural and biological wastes in the building construction industries as well as other industries. This would definitely enhance the environmentally sustainable concrete industry.

Literature Review

There is limited literature on the use of spent mushroom substrates SMS for the production of concrete blocks, but some research has been conducted in this area. Research on the use of agricultural waste as aggregate such as SMS in concrete production, is relatively new. More research on long term durability of this kind of concrete would give more confidence to the construction industry in using them for their more sensitive projects (Shafigh et al., 2014). There are several key advantages that can be derived from SMS materials over traditional synthetic materials. These includes their low cost, density and energy consumption in addition to their biodegradability, carbon footprint and low environmental impact (Abhijith et al., 2018; Arifin & Yusuf, 2013; Tian et al., 2022). Meeting specific structural and functional requirements including fire resistance, thermal and acoustic

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insulation, wide variety of utilisable substrates coupled with controlled processing techniques (e.g., growth environment and hot pressing) allow mycelium-derived materials to work (Haneef et al., 2017; Holt et al., 2012; Mitchell Jones et al., 2020; Pelletier et al., 2013). Paving the way for new possibilities in environmentally sustainable construction, larger low-density objects

(e.g., synthetic foams and plastics) (Holt et al., 2012; López Nava et al., 2016; Pelletier et al., 2013; Travaglini et al., 2013) can be used as waste-derived environmentally friendly alternatives to synthetic planar materials (e.g., plastic films and sheets) and also as semistructural materials (e.g. panelling, flooring, furniture, decking) (M. R. Islam et al., 2017; Jiang, Walczyk, & McIntyre, 2017; Jiang, Walczyk, McIntyre, et al., 2017; John, 2022).

However, the current application and usage of mycelium materials has been limited from their typically foam-like mechanical properties, high water absorption and many gaps in material property documentation (Mitchell Jones et al., 2020). Targeted usage in specific applications, such as insulation, door cores, panelling, flooring, cabinetry and other furnishings are not limited to further research and development. The successful use of agricultural solid waste as aggregate in structural and non-structural concrete as been discussed in recent studies, spent mushroom substrate and tobacco wastes are among the wastes used for this purpose (J. S. Kim et al., 2016; Y. I. Kim et al., 2012). Also, Oil palm shell (or palm kernel shell), coconut shell, rice husk, corn cob, pistachio shell is not left out (Pinto et al., 2012). The successful use of such agricultural solid wastes, as whole or partial replacement of conventional aggregates, contributes to energy saving, conservation of natural resources, and a reduction in the cost of construction materials since aggregate (sand as fine and gravel as coarse) makes up about 60–80% of the volume of concrete (Faustino et al., 2012; Ganesan et al., 2008; Pinto et al., 2011).

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Materials and Methods

Spent mushroom substrates SMS are the residual materials left after the cultivation of mushrooms. These substrates are the leftover organic materials after the mushrooms have been harvested. The SMS used for this study were collected from Yaba College of Technology biological laboratory where the mushrooms are grown. Fig 1. It was later grinded into powdery form to remove the moisture content and for easy mixing exercise.



Fig 1: Spent Mushroom Substrates

The SMS are then dried to remove excess moisture and to sterilize them. The SMS is then mixed with cement, sand, and water in the appropriate proportions to produce a concrete mix. Various mix proportions providing (cement: fine aggregate (sand + SMS) tested were ratio 1:6 (0%, 10%, 20% & 30% SMS replacement) and also (cement: fine aggregate (Granite dust + SMS) tested were ratio 1:4 (0%, 10%, 20% & 30% SMS replacement) respectively. The SMS-cement-sand-water mixture was thoroughly mixed and weighed to ensure that the SMS is well distributed throughout the mixture. This exercise was done manually or a concrete

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mixer can be used for mass production Fig 2



Fig 2: Thoroughly Mixed and Weighed Aggregate with SMS

The concrete mixture is then poured into metal moulds to produce 150MM X 450MM 6-inch solid concrete block Fig 3. The color of the concrete block changes to brownish because of SMS that was added during the mixing exercise.



Fig 3 Showing Molded Mixed SMS Aggregate of 150MM X 450MM 6-inch

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The concrete blocks are left to cure for a period of 28 days. During this time, the blocks will gain strength and durability. In order to achieve a smooth surface after the block has been cured, the Sanding/Polishing processes now took place. The final step in the process is quality control. The blocks are later tested and weighed in the Yaba College of Technology Soil laboratory for strength, durability, and other physical properties to ensure that they meet the required specifications. This process not only reduces weight and waste but also produces a sustainable building material that can contribute to environmental conservation.

Results and Analysis

Performance Testing Analysis: This involved the test on the physical properties and performance on the concrete blocks made with SMS and aggregate. It includes the compressive strength test, water absorption and other relevant properties.

Mixed Design Analysis: The optimal mix design for hollow concrete block was determined by using SMS. This was used to consider the percentage of SMS was added to the aggregate without compromising the strength of the building materials (see Tables 1,2, 3,4 and 5)

Tables and Calculations.

SMS hollow concrete block production.

Size of block 450 x 225 x 150.

Table 1: CONTROLLED SPECIMEN @ 0%

Mix Ratio	1:6	Percentage	100%
sand	14.13kg	sand	85.7%
cement	2.36kg	cement	14.3%



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Table 2:5% PARTIAL REPLACEMENT (SUCCESS)

Mix ratio	1:5.7:0.3	percentage	100%
sand	13.43kg	sand	81.42%
cement	2.36kg	cement	14.3%
SMS	0.7kg	SMS	4.28%



NOTE: In 1:6 mix ratio, 1 signifies cement while 6 signifies sand. 5% was taken off of sand to reduce it from 6 to 5.7, making the mix ratio of 1:5.7:0.3 where 1=cement, 5.7=sand, 0.7=SMS

Table 4: 20 % PARTIAL REPLACEMENT (SUCCESS)

Mix ratio	1:4.8:1.2	Percentage	100%
sand	11.31kg	sand	68.55%
cement	2.36kg	cement	14.3%
SMS	2.83kg	SMS	17.15%



Table 3: 10% PARTIAL REPLACEMENT (SUCCESS)

Mix ratio	1:5.4:0.6	Percentage	100%
sand	12.73kg	sand	77.15%
cement	2.36kg	Cement	14.3%
SMS	1.41kg	SMS	8.55%



0% REPLACEMENT (1:6) = 16.5kg

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Table 5: 30 % PARTIAL REPLACEMENT (FAILED)

Mix Ratio	1:4.2:1.8	Percentage	100%
sand	9.9kg	sand	60%
cement	2.36kg	cement	14.3%
SMS	4.24kg	SMS	25.7%



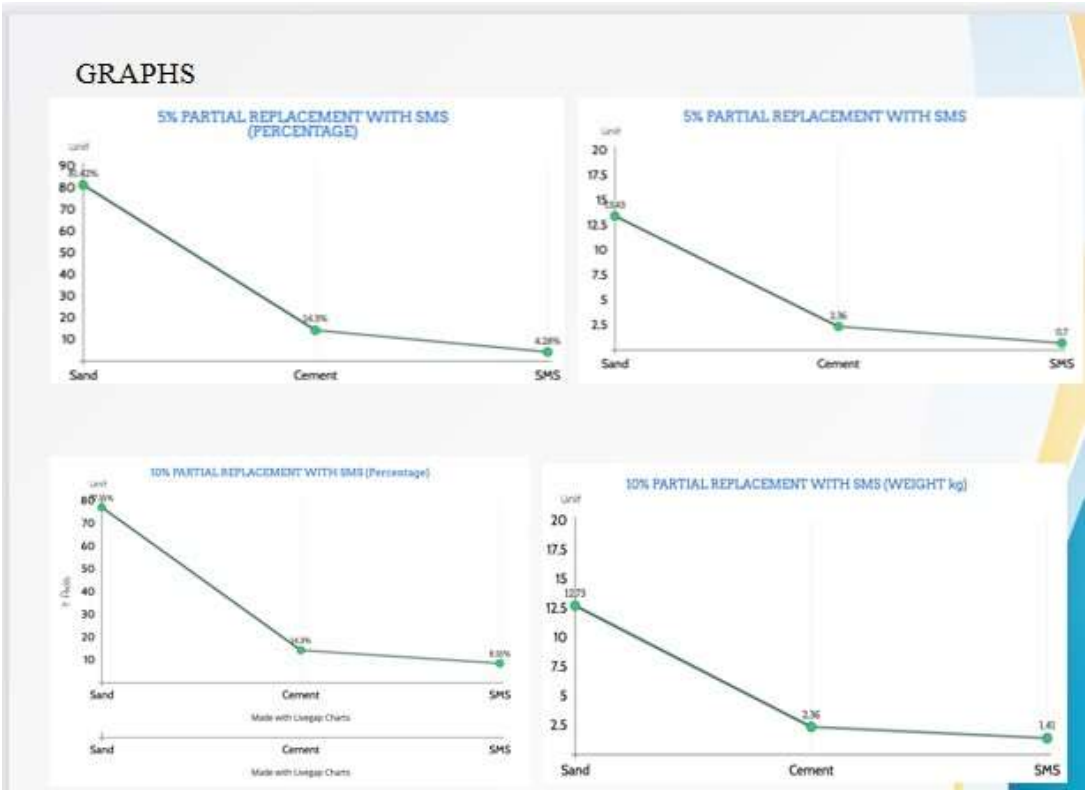
WEIGHTS OF CONCRETE BLOCKS WITH SMS REPLACEMENTS

5% REPLACEMENT (1:6) =12.2kg

10% REPLACEMENT (1:6) =10.6kg

20% REPLACEMENT (1:4) = 9.6kg

30% REPLACEMENT (1:4) = FAILED



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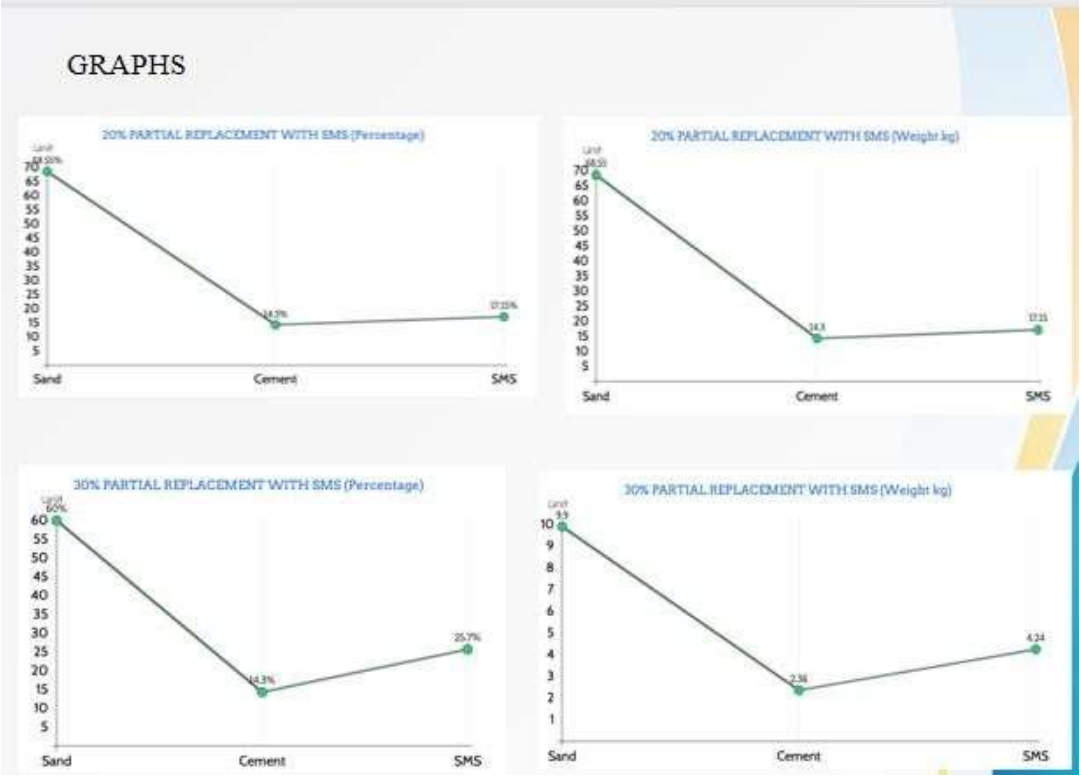

Limitations

There are also limitations to be considered when spent mushroom substrates (SMS) is used for the production of concrete blocks.

1. Types of cultivated mushroom and substrate used during the cultivation process can affect the consistency and predictability of the properties of the concrete blocks produced.
2. Presently, there is no standardized approach for incorporating SMS into concrete block production making it difficult to determine the optimal proportions and processing methods for achieving desired concrete block properties.
3. Limited availability and accessibility of SMS in certain regions or seasons, depending on the local mushroom cultivation industry.
4. Cost of transportation and processing requirements may affect the overall costeffectiveness.

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5. Regulatory and certification requirements may be necessary especially if the blocks are intended for structural applications.

Recommendation

These are recommendations for utilizing spent mushroom substrates (SMS) effectively for the production of concrete blocks:

1. Further research and development efforts should be conducted to establish standardized guidelines and procedures for incorporating SMS into concrete block production.
2. Collaboration between mushroom cultivation industries and concrete block manufacturers can facilitate knowledge sharing and exchange of best practices.
3. Quality control and testing is necessary to ensure the desired properties and performance of the concrete blocks, such as strength, durability, and workability.
4. Creating awareness among construction professionals, builders, and architects about the benefits of using SMS-based concrete blocks is crucial.
5. Working closely with regulatory bodies to establish guidelines and certifications specific to SMS-based concrete blocks can help address any concerns related to structural performance, safety, and compliance with building codes.
6. Developing an efficient and sustainable supply chain for SMS is important.

Reference

Abhijith, R., Ashok, A., & Rejeesh, C. (2018). Sustainable packaging applications from mycelium to substitute polystyrene: a review. *Elsevier*, 5(1), 2139–2145. https://doi.org/10.1016/j.matpr.2017.09.211

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

Arifin, Y. H., & Yusuf, Y. (2013). Mycelium Fibers as New Resource for Environmental Sustainability. *Procedia Engineering*, *53*, 504–508. https://doi.org/10.1016/J.PROENG.2013.02.065

Banasik, A., & Kanellopoulos, A. (2019). Accounting for uncertainty in eco-efficient agrifood supply chains: A case study for mushroom production planning. *Journal of Cleaner*, *216*, 249–256. https://www.sciencedirect.com/science/article/pii/S0959652619301726

Bhuvaneshwari, S., Hettiarachchi, H., & Meegoda, J. N. (2019). Crop Residue Burning in India: Policy Challenges and Potential Solutions. *International Journal of Environmental Research and Public Health 2019, Vol. 16, Page 832*, *16*(5), 832. https://doi.org/10.3390/IJERPH16050832

Faustino, J., Pereira, L., Soares, S., Cruz, D., Paiva, A., Varum, H., Ferreira, J., & Pinto, J. (2012). Impact sound insulation technique using corn cob particleboard. *Construction and Building Materials*, *37*, 153–159. https://doi.org/10.1016/J.CONBUILDMAT.2012.07.064

Finney, K., Ryu, C., Sharifi, V., & Swithenbank, J. (2009). The reuse of spent mushroom compost and coal tailings for energy recovery: comparison of thermal treatment technologies. *Bioresource Technology*, *100*(1), 310–315. https://www.sciencedirect.com/science/article/pii/S0960852408004823

Ganesan, K., Rajagopal, K., & Thangavel, K. (2008). Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete. *Construction and Building Materials*, *22*(8), 1675–1683. https://doi.org/10.1016/J.CONBUILDMAT.2007.06.011

Grimm, A., Eilertsen, L., Chen, F., Huang, R., Atterhem, L., & Xiong, S. (2021). Cultivation of Pleurotus ostreatus Mushroom on Substrates Made of Cellulose Fibre Rejects: Product Quality and Spent Substrate Fuel Properties. *Waste and Biomass Valorization*, *12*(8), 4331–4340. https://doi.org/10.1007/S12649-020-01311-Y

Haneef, M., Ceseracciu, L., Canale, C., Bayer, I. S., Heredia-Guerrero, J. J., & Athanassiou, A. (2017). Advanced materials from fungal mycelium: fabrication and tuning of physical properties. *Springer*, *7*(1), 1–11. https://doi.org/10.1038/srep41292

Holt, G. A., McIntyre, G., Flagg, D., Bayer, E., Wanjura, J. D., & Pelletier, M. G. (2012). Fungal Mycelium and Cotton Plant Materials in the Manufacture of Biodegradable Molded Packaging Material: Evaluation Study of Select Blends of Cotton Byproducts. *Journal of Biobased Materials and Bioenergy*, *6*(4), 431–439. https://doi.org/10.1166/JBMB.2012.1241

Islam, M. R., Tudryn, G., Bucinell, R., Schadler, L., & Picu, R. C. (2017). Morphology and mechanics of fungal mycelium. *Scientific Reports 2017 7:1*, *7*(1), 1–12. https://doi.org/10.1038/s41598-017-13295-2

Islam, M., Tudryn, G., Bucinell, R., Schadler, L., reports, R. P.-S., & 2017, undefined. (2017). Morphology and mechanics of fungal mycelium. *Nature.Com*, *7*(1), 13070. https://www.nature.com/articles/s41598-017-13295-2

Jiang, L., Walczyk, D., & McIntyre, G. (2017). A New Approach to Manufacturing Biocomposite Sandwich Structures: Investigation of Preform Shell Behavior. *Journal of Manufacturing Science and Engineering, Transactions of the ASME*, *139*(2), 1–11. https://doi.org/10.1115/1.4034278/376914

Jiang, L., Walczyk, D., McIntyre, G., Bucinell, R., & Tudryn, G. (2017). Manufacturing of biocomposite sandwich structures using mycelium-bound cores and preforms. *Journal of Manufacturing Processes*, *28*, 50–59. https://doi.org/10.1016/J.JMAPRO.2017.04.029

John, S. (2022). Fungal Biopolymers as an Alternative Construction Material. *Fungal Biopolymers and Biocomposites*, 169–188. https://doi.org/10.1007/978-981-19-10005_10

Jones, M, Huynh, T., & Dekiwadia, C. (2017). Mycelium composites: a review of engineering characteristics and growth kinetics. *Journal of Bionanoscience*, *11*(4), 241– 257. https://www.ingentaconnect.com/contentone/asp/jobn/2017/00000011/00000004/art000 01

Jones, Mitchell, Mautner, A., Luenco, S., Bismarck, A., & John, S. (2020). Engineered mycelium composite construction materials from fungal biorefineries: A critical review. *Materials & Design*, *187*, 108397. https://doi.org/10.1016/J.MATDES.2019.108397

Kilpatrick, M., Sharma, H. S. S., & Lyons, G. (2008). Mushroom compost production - a review of industry quality assurance frameworks in Ireland. *Mushroom Biology and Mushroom Products. Proceedings of the Sixth International Conference on Mushroom Biology and Mushroom Products, Bonn, Germany, 29 September - 3 October, 2008*, 61–73.

Kim, J. S., Lee, Y. H., Kim, Y. I., Ahmadi, F., Oh, Y. K., Park, J. M., & Kwak, W. S. (2016). Effect of microbial inoculant or molasses on fermentative quality and aerobic stability of sawdust-based spent mushroom substrate. *Bioresource Technology*, *216*, 188–195. https://doi.org/10.1016/J.BIORTECH.2016.05.056

Kim, Y. I., Lee, Y. H., Kim, K. H., Oh, Y. K., Moon, Y. H., & Kwak, W. S. (2012). Effects of

Supplementing Microbially-fermented Spent Mushroom Substrates on Growth Performance and Carcass Characteristics of Hanwoo Steers (a Field Study). *AsianAustralasian Journal of Animal Sciences*, *25*(11), 1575–1581. https://doi.org/10.5713/ajas.2012.12251

Kwak, A. M., Min, K. J., Lee, S. Y., & Kang, H. W. (2015). Water Extract from Spent Mushroom Substrate of Hericium erinaceus Suppresses Bacterial Wilt Disease of

Tomato. *Mycobiology*, *43*(3), 311–318. https://doi.org/10.5941/MYCO.2015.43.3.311

Laftah, W. (2019). Rice waste–based polymer composites for packaging applications: A review. *Applied Polymer Science*, *2021*(9S), 1621–1629. https://doi.org/10.1177/096739111211046775

López Nava, J. A., Méndez González, J., Ruelas Chacón, X., & Nájera Luna, J. A. (2016). Assessment of Edible Fungi and Films Bio-Based Material Simulating Expanded Polystyrene. *Materials and Manufacturing Processes*, *31*(8), 1085–1090.

https://doi.org/10.1080/10426914.2015.1070420

Madurwar, M., Ralegaonkar, R. V, Mandavgane, S. A., Madurwar, M. V, & Mandavgane, S. A. (2012). Application of agro-waste for sustainable construction materials: A review.

Elsevier, *38*, 872–878. https://doi.org/10.1016/j.conbuildmat.2012.09.011

Monte, M., Fuente, E., Blanco, A., & Negro, C. (2009). Waste management from pulp and paper production in the European Union. *Elsevier*, *29*(1), 293–308. https://www.sciencedirect.com/science/article/pii/S0956053X08000573

Nawawi, W. M. F. B. W., Jones, M., Murphy, R. J., Lee, K. Y., Kontturi, E., & Bismarck, A.

(2020). Nanomaterials Derived from Fungal Sources-Is It the New Hype? *Biomacromolecules*, *21*(1), 30–55. https://doi.org/10.1021/ACS.BIOMAC.9B01141

Pardo-Giménez, A., Picornell Buendía, M. R., De Juan Valero, J. A., Pardo-González, J. E., Cunha Zied, D., & De Cogumelos, M. (2012). Cultivation of Pleurotus ostreatus using supplemented spent oyster Mushroom substrate. *Acta Horticulturae*, *933*, 267–272. https://doi.org/10.17660/ACTAHORTIC.2012.933.33

Pelletier, M., Holt, G., Wanjura, J. D., Pelletier, M. G., Holt, G. A., Wanjura, J. D., Bayer, E., & Mcintyre, G. (2013). An evaluation study of mycelium based acoustic absorbers grown on agricultural by-product substrates. *Elsevier*, *51*, 480–485. https://doi.org/10.1016/j.indcrop.2013.09.008

Pheng, L. S., & Hou, L. S. (2019). *The Economy and the Construction Industry*. 21–54. https://doi.org/10.1007/978-981-13-5847-0_2

Pinto, J., Paiva, A., Varum, H., Costa, A., Cruz, D., Pereira, S., Fernandes, L., Tavares, P., & Agarwal, J. (2011). Corn's cob as a potential ecological thermal insulation material. *Energy and Buildings*, *43*(8), 1985–1990. https://doi.org/10.1016/J.ENBUILD.2011.04.004

Pinto, J., Vieira, B., Pereira, H., Jacinto, C., Vilela, P., Paiva, A., Pereira, S., Cunha, V. M. C. F., & Varum, H. (2012). Corn cob lightweight concrete for non-structural applications. *Construction and Building Materials*, *34*, 346–351. https://www.sciencedirect.com/science/article/pii/S0950061812001201

Searle, S., & Malins, C. (2016). Waste and residue availability for advanced biofuel production in EU Member States. *Elsevier*, *89*, 2–10. https://www.sciencedirect.com/science/article/pii/S0961953416300083

Shafigh, P., Mahmud, H. Bin, Jumaat, M. Z., & Zargar, M. (2014). Agricultural wastes as aggregate in concrete mixtures – A review. *Construction and Building Materials*, *53*, 110–117. https://doi.org/10.1016/J.CONBUILDMAT.2013.11.074

Tian, B., Zhao, W., Guo, Q., Energy, Y. T.-, & 2022, undefined. (2022). A comprehensive understanding of synergetic effect and volatile interaction mechanisms during copyrolysis of rice husk and different rank coals. *Elsevier*, *254*, 124388. https://www.sciencedirect.com/science/article/pii/S0360544222012919

Travaglini, S., Noble, P. ., Ross, & Dharan, C. K. . (2013). Mycology matrix composites . *Proceeding of the American Society for Composites 28th Technical Conference*, 9–11. https://scholar.google.co.uk/scholar?q=related:r6CoZ6pEmaIJ:scholar.google.com/&scio q=Mycology+Matrix+Composites,+28th+Annual+Technical+Conference+of+the+Amer ican+Society+for+Composites&hl=en&as_sdt=0,5

Zhang, R., Li, X., & Fadel, J. (2002). Oyster mushroom cultivation with rice and wheat straw. *Bioresource Technology*, *82*(3), 277–284. https://www.sciencedirect.com/science/article/pii/So 960852401001882