MECHANICAL AND MORPHOLOGICAL PROPERTIES OF BIOFOAM USING SAWDUST AND TEAK LEAVES AS SUBSTRATES

Nur Mawaddah Majib[1,2,*], Sam Sung Ting[1,2,3], Noorulnajwa Diyana Yaacob[1], Nor Munirah Rohaizad[1] and Nik Noriman Zulkepli[4]

[1]Faculty of Chemical Engineering and Technology, Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia
[2]Centre of Excellence Geopolymer and Green Technology (CEGeoGTech), Universiti Malaysia Perlis, Kompleks Pusat Pengajian Jejawi 2, Taman Muhibbah, 02600 Arau, Perlis, Malaysia
[3]Institute of Nano Electronic Engineering, Universiti Malaysia Perlis, Seriab, 01000 Kangar, Perlis, Malaysia
[4]Faculty of Mechanical Engineering & Technology, Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia

*nurmawaddah@studentmail.unimap.edu.my

Abstract. The demand for the mushroom market has increased globally in latest years, and the profusion of mushroom production has given rise to a new alternative: the manufacturing of biofoam. Also, an abundance of agricultural waste could be converted into biodegradable material. This study aims to produce biofoam from oyster mushrooms and biomass in order to evaluate their mechanical and morphological properties. The lignocellulosic biomass substrate, which included teak leaves and sawdust, are essential for the synthesis of biofoam and their properties, including morphological structure was analyzed using scanning electron microscopy (SEM) and mechanical properties were tested in term of hardness and springiness. Additionally, water adsorption test also has been analyzed. Both spawn; *Pleurotus sajor-caju* (grey oyster mushroom) and *Pleurotus djamor* (pink oyster mushroom) were inoculated at the same amount in sawdust and teak leaves to produce biofoam. Mechanical properties were tested after the mushroom had completely grown to produce foam. It was discovered that teak leaves biofoam is springier than sawdust biofoam in both spawn types, but sawdust biofoam is much harder than teak leaves biofoam. The SEM micrograph revealed the morphology of dense filaments and highly entangled tube-like structures that resembled teak leaves biofoam. Besides, teak leaves biofoam had minimal water absorption compared to sawdust biofoam. Hence, the finding shows the difference in both substrates where this promotes different applications for sawdust and teak leaves as substrates for both spawns.

Keywords: Biofoam, spawn, mechanical, morphological

Article Info

Received 19th January 2023
Accepted 4th April 2023
Published 1st May 2023

ISSN: 1823-7010, eISSN: 2600-7444

Introduction

Agricultural wastes are residues from the growing and processing of raw agricultural products and are non-product outputs of the production process. Increases in agricultural production support Malaysia's economic expansion, but they also have a negative impact on the environment by producing more waste products in the form of biomass. Substrates for the cultivation of fungi can be derived from biomass, helping to lessen the amount of agricultural waste produced. Meanwhile, it has the potential to be produced into a novel product: biofoam, which has significant commercial value due to its structure and property. The novelty of this study is utilizing agricultural waste to grow the edible mushroom in producing the foam. Lignocellulosic wastes such as paddy straw, wheat straw, maize straw, sawdust, rice husk, and oil palm fond are commonly used as the substrates for the growth of the *Pleurotus* species mushrooms [1,2], and prior to previous research, a variety of substrates are used in the production of biofoam [3].

To address the issues caused by the accumulation of agricultural waste and biomass, it has been proposed to utilize sawdust and teak leaves in the production of environmentally beneficial biofoam. Essentially, sawdust is an agricultural byproduct that arises from wood-processing devices such as milling and grinding. Sawdust promotes the growth of fungi in several different ways, which is one of the primary reasons for its wide utilization. Meanwhile, the teak tree is often regarded as one of the species that produces the highest quality and most valuable timber. It contains various nutrients that can provide sustenance for the organisms in the soil. Additionally, research conducted by Ashrafuzzaman et al. [4] proved that teak leaves can be used as a substrate for mushroom cultivation.

Foam is a spongy substance that may be formed into any shape for several applications in industry. Ecovative Design, a biomaterial company focused on creating a new class of ecologically friendly home-compostable biomaterials manufactured primarily from mushrooms, was the first to develop biodegradable foam, also known as organofoam [5]. The production of biodegradable foam involves the cultivation of mushroom species on an agricultural waste substrate. Fungi cultivation involves various operations, including medium culture preparation, medium culture formulation, culture medium packaging and shaping, medium culture sterilization, spawn inoculation, spawn incubation, and mycelium growth [6]. The fungal and substrate utilized, the growth conditions, the cultivation process, and the growth environment significantly affect how the material is formed and how it behaves [3].

To produce fungal foam, the mycelium, the vegetative part of the mushroom, is used in a biological process. Mycelium is a binding agent and natural adhesive. The mycelium binds the agricultural waste together as its strands grow around and through it. Strong, lightweight, waterproof, and fireproof biofoam is made by heat-drying the fungi after the mycelium has developed well [7]. This research was to produce the biofoam from different biomass, which is sawdust and dried teak leaves in the cultivation of grey oyster mushroom (*Pleurotus sajor-caju*) and pink oyster mushroom (*Pleurotus djamor*). The biofoams produced were examined for their morphological properties and mechanical properties to evaluate their value. Since polystyrene is a type of foam that is widely used in the industry, hence the mechanical testing of biofoam was compared to the polystyrene and the targeted values should be in the same range or even better. The targeted value for hardness is at a range of 1300 – 2300 g sec and the targeted value for springiness is a range of 0.5 – 0.9. In addition, the created biofoams were tested on their ability to absorb water. These biofoams, produced utilizing a range of substrates and mushrooms, were compared to determine which fungal foam would be the most practical and effective for use in industrial applications such as packaging materials, wastewater filtration, and also in the construction industry for insulation.

Materials and Methods

Materials and chemicals used in this study include rice bran, calcium carbonate, sawdust, teak leaves, and spawns *(Pleurotus sajor-caju* and *Pleurotus djamor)*.

Preparation of Materials

Pleurotus sajor-caju (grey species) and *Pleurotus djamor* (pink species) were obtained from Perlis, Malaysia. Teak leaves were collected at Wang Ulu, Perlis, Malaysia, dried in an oven, and then grinded into powder. Sawdust and rice bran were provided by a farmer near Padang Besar, Perlis, Malaysia.

Preparation of Medium

Medium for growing fungal was prepared using substrates, rice bran, and calcium carbonate with a ratio of 100:10:1 accordingly. Rice bran was added as a source of nutrition for the growth of mushrooms and calcium carbonate as the mineral source. After mixing the medium, distilled water was added into the medium until it formed a clump. The medium was then compacted into 3/4 of the round container with a dimension of 10 mm height x 7 mm diameter before sterilizing in an autoclave at 121 °C for 30 minutes.

Analysis of Biofoam

Biofoam was analyzed for mechanical properties and morphological properties. Mechanical testing was done using Texture Analyzer to check the hardness and springiness of samples using different spawns and substrates. Besides, polystyrene which is a foam that is currently used in the industry also tested as a control. All samples were placed under the compressor platens connected to the deflect meter. The type of probe used to test the fungal foam was P/75 which consists of a round surface since samples were prepared in a round-shape container. As for morphological testing, the samples were tested using Scanning Electronic Microscope (SEM) to analyze the microscopic structure of biofoam produced and compared each type. The magnification power used for the capturing of SEM images on the cross-sectional view of biofoam produced was 1000 x and the biofoams were sputter-coated with a thin coating of platinum before scanning.

Water Absorption Test

A water absorption test was done on every sample to determine the water update of biofoam. Dry samples were weighted to get the initial reading. Then, samples were soaked in distilled water for 24 hours. Weight after 24 hours of soaking was recorded and water absorption was calculated using equation 1 [8].

$$\% \, Absorption = \frac{w'-w}{w} \times 100 \tag{1}$$

where w' = weight after soaked and w = weight before soaked.

Results and Discussion

Mechanical Test

Mechanical property is a fundamental criterion for evaluating the quality of biofoam produced. Analysis of the biofoam's hardness and springiness is the primary focus of this study. Springiness referred to the rate at which a deformed sample returns to its original size and shape when the compressive force is removed [9]. Springiness also called as elasticity of the product can determine and classify the suitable application of the biofoam from different spawns and substrates. The nearer the value of springiness to 1, the more elastic the samples. Figure 1 represents the springiness of biofoam that was subjected to the different types of spawn and different agriculture wastes used as substrates. Biofoam of *Pleorotus sajor-caju* and *Pleurotus djamor* produced using teak leaves showed significantly higher springiness compared to those using sawdust. Based on these findings, it was determined that mycelium is more likely to grow in teak leaves. This is possibly because of the huge array of bioactive compounds in teak leaves [10] and the presence of a good amount of cellulose and hemicellulose that are treated as a food source for fungi. Fungi are believed to be more likely to grow in teak leaves than in sawdust due to the higher formation of hyphae on teak leaves. Its natural property is springy, which conveys springy properties and this explains why teak leaves biofoam is springier than sawdust biofoam. Additionally, biofoam from *Pleurotus djamor* is comparable to polystyrene in terms of springiness and this shows the potential of producing biofoam to replace polystyrene.

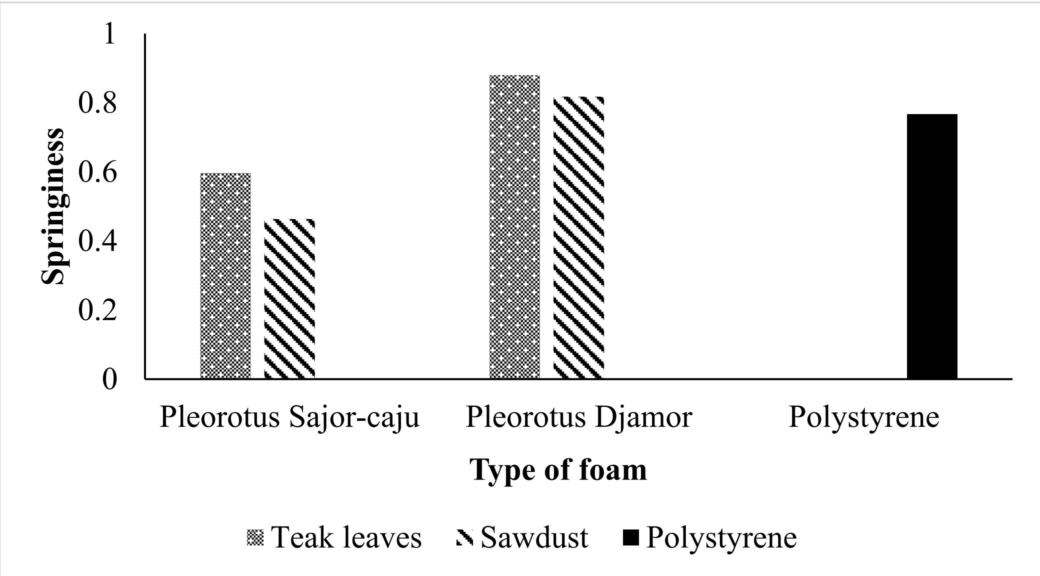

Figure 1: Springiness of biofoam

Hardness is an indicator of a material's toughness. In the case of foam, it represents the material's capacity to withstand the impact force that is typically utilized for this purpose. The parameter of hardness was defined as force exhibited in the first bite at maximum compression. Figure 2 shows the hardness of two different mushroom species in different biomass. From the result obtained, sawdust is significantly harder than teak leaves and polystyrene. Sawdust was a biomass residual composed of small structures and completely disaggregated grains with low material properties. On the other hand, mycelium from mushrooms created a supportive internal structure that makes them a great substrate. The resulting material has excellent mechanical properties. The combination of mycelium and sawdust produced a compacted material [11] as stated by Murugan [12] that mixture of mycelium and sawdust can be compacted to create a material with excellent properties similar to those shown by polystyrene.

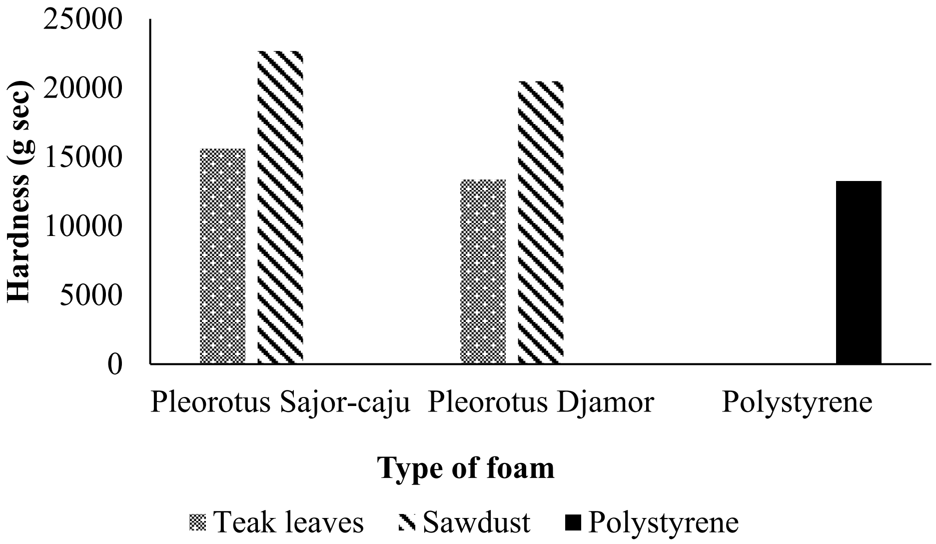

Figure 2: Hardness of teak leaves and sawdust biofoam from different mushroom

Morphological Properties

Figure 3 illustrates SEM micrographs of cross-sectional images of two different spawns using two different substrates from agriculture wastes. The structure of biofoam was represented in a micrograph that was captured under 1000 x magnification power. The white fibrous curvy line in the figure was referred to fungi while the void of the figure was referred to the substrates. As shown in Figures 3(a) and (c), the mycelium growth on the teak leaves substrate was dense which contributed to a compacted structure of the biofoam. Teak leaves biofoam is composed of dense filaments and highly entangled tube-like structures, contributing to the biofoam's springiness. Contrary to that, Figures 3(b) and (d) show mycelium growth on sawdust from *Pleurotus sajor-caju* and *Pleurotus djamor* respectively; it is comparable to teak leaves since we can see clearly more void which means less formation of mycelium on sawdust. However, according to [13], the enzyme produced during the fungal foam formation also indirectly affects the number of hyphae attached to the substrate. Hence, fewer hyphae formed that attached to sawdust.

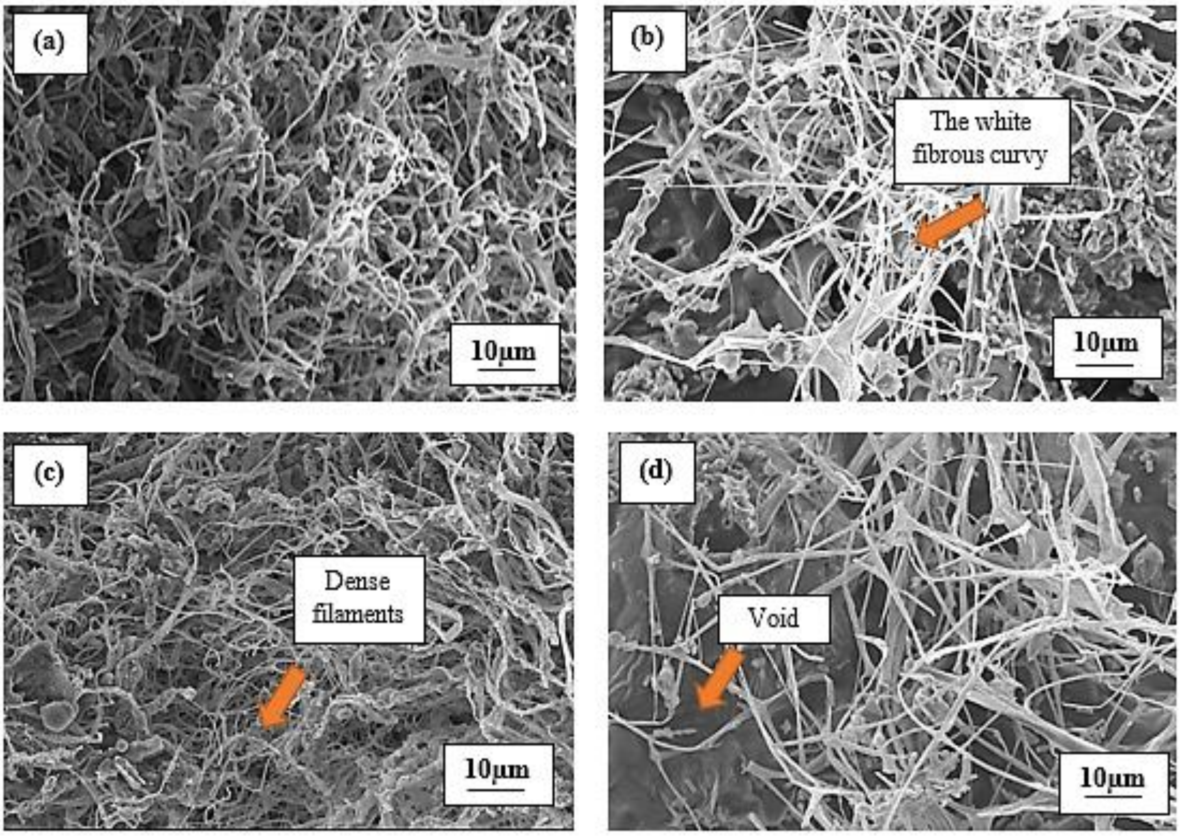

Figure 3: SEM micrograph of biofoam from (a) *Pleurotus sajor-caju* in teak leaves, (b) *Pleurotus sajor-caju* in sawdust, (c) *Pleurotus djamor* in teak leaves and (d) *Pleurotus djamor* in sawdust

Water Absorption Test

This testing was performed to determine the ability of different biofoam to absorb water. Therefore, this test was used to identify the water uptake of different fungal foam substrates. Basically, the porosity and compactness of biofoam can influence the percentage of water absorption.

Based on the SEM micrograph in Figure 3, there were still presented of voids in between the sawdust substrate as shown in the SEM image, this explained why the water absorption ability of this biofoam was considerably high. Figure 4 demonstrates that the water absorption obtained for biofoam from sawdust was greater than those obtained for biofoam from teak leaves for both spawns. Biofoam of sawdust is more porous compared to teak leaves biofoam from both spawns. The increase in water uptake was influenced by the porosity [14] and this can be justified by the morphological test of SEM that shows the void sawdust biofoam is more than in teak leaves biofoam.

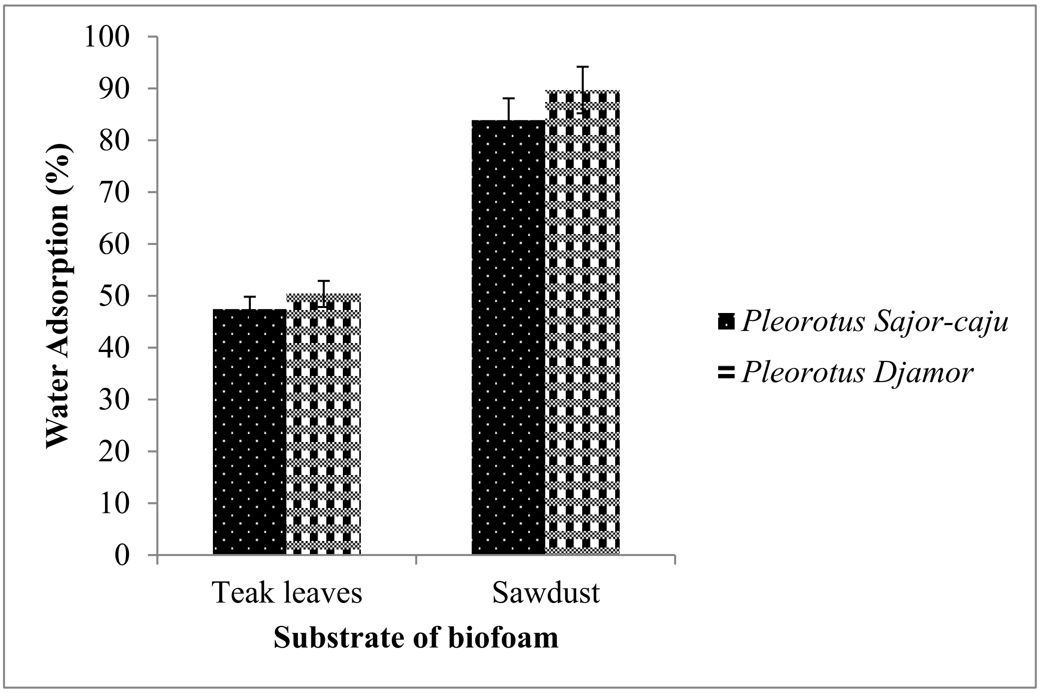

Figure 4: Water absorption of biofoam

Conclusions

In conclusion, despite being waste, each type of agricultural residue has a unique particular value. This biomass can be utilized appropriately and systematically for commercial purposes. Converting agricultural waste items into value-added products such as biofoam was able to reduce waste while ensuring environmental sustainability. According to the study's findings, both types of biomass, sawdust and teak leaves, possess unique strengths that make them well-suited for various applications in the industrial sector. From the scanning electron microscope, the compact morphology of biofoam was responsible for the material's mechanical properties and water absorption characteristics. On the other hand, both types of *Pleurotus* species have no significant difference but substrates help build and determine the properties. By means of the results obtained, sawdust biofoam is suitable for the absorption application due to its porosity property and ability to absorb water while teak leaves biofoam is ideal for packaging materials.

Acknowledgements

The authors acknowledge and greatly appreciate for the financial support from the Fundamental Research Grant (FRGS/1/2020/TK0/UNIMAP/03/4) from Ministry of Higher Education, Malaysia.

Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare

Compliance with Ethical Standards

The work is compliant with ethical standards

References

[1] Saha, D., Shukla, C. & Awadhiya, G. (2018). Evaluation of various organic substrates for maximization of biological efficiency of Pleurotus species. *International Journal of Chemical Studies*, 6(1), 1178–1181.

[2] Ibrahim, R., Yasin, N. F. L., Arshad, A. M. & Hasan, S. M. Z. S. (2015). The Growth and Post-Harvest Performances of Different Species of Oyster Mushroom (Pleurotus sp.) Cultivated on Sawdust and Oil Palm Frond. *Malaysian Applied Biology Journal*, 44(1), 75–82.

[3] Nashiruddin, N. I., Chua, K. S., Mansor, A. F., A. Rahman, R., Lai, J. C., Wan Azelee, N. I. & El Enshasy, H. (2021). Effect of growth factors on the production of mycelium-based biofoam. *Clean Technologies and Environmental Policy*, 24, 351–361.

[4] Ashrafuzzaman, M., Kamruzzaman, A. K. M., Razi Ismail, M., Shahidullah, S. M. & Fakir, S. A. (2009). Substrate affects growth and yield of shiitake mushroom. *African Journal of Biotechnology*, 8(13), 2999–3006.

[5] 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.

[6] Jeznabadi, E. K., Jafarpour, M. & Eghbalsaied, S. (2016). King oyster mushroom production using various sources of agricultural wastes in Iran. *International Journal of Recycling of Organic Waste in Agriculture*, 5(1), 17–24.

[7] Fish, E. (2011). [Online]. [Accessed Fungus 19th July 2022]. Available from World Wide Web: https://www.adandp.media/articles/fungus-foam

[8] Intertek. Water Absorption ASTM D570 (2019). [Online]. [Accessed 6th July 2019]. Available from World Wide Web: https://www.intertek.com/polymers/testlopedia/water-absorption-astm-d570/

[9] Tuoc T. K. & Glasgow, S. (2012). On the texture profile analysis test. Chemical Engineering Conference (CHEMECA2012), Wellington, New Zealand, 23-26 September 2012.

[10] Devadiga, A., Shetty, K. V. & Saidutta, M. B. (2015). Timber industry waste-teak (Tectona grandis Linn.) leaf extract mediated synthesis of antibacterial silver nanoparticles. *International Nano Letters*, 5(4), 205–214.

[11] Miralbes, R. B., Ranz, D. & Zouzias, D. (2021). Study of the Use of Sawdust and Mycelium Composite as a Substitute of EPS. In 10th International Joint Conference on Mechanics, Design Engineering and Advanced Manufacturing, (JCM2020), Virtual, Online, 2-4 June 2020.

[12] Murugan, S. S. (2020). Mechanical Properties of Materials: Definition, Testing and Application. *International Journal of Modern Studies in Mechanical Engineering* (IJMSME), 6(2), 28–38.

[13] 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), 41292, 1–11.

[14] Garrett, T. D., Cardenas, H. E. & Lynam, J. G. (2020). Current Research in Green and Sustainable Chemistry Sugarcane bagasse and rice husk ash pozzolans: Cement strength and corrosion effects when using saltwater. *Current Research in Green and Sustainable Chemistry*, 1–2 (January), 7–13.