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Investigating the Water Absorption Characteristics of Eggshell, Rice Husk, and Banana Fibre Reinforced Epoxy Polymer Composite

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Abstract*—This study investigates the effect of rice husk, eggshell, and banana fibre on the physical properties of an epoxy polymer composite. The aim was to develop a less dense, cost-effective, moisture resistant, and sustainable composite material from agricultural wastes. The fibres were treated with 5% NaOH and the composite composition of 0:25, 5:20, 10:15, 15:10, 20:5, and 25:0 of banana fibre and eggshell with a constant 20% and 55% rice husk and epoxy polymer matrix respectively were used. The density, water absorptions, and thickness swelling of the composite were investigated. The test results showed that the eggshell, which serve as a filler in the matrix composite reduced the water absorption intake, thereby improved the properties of the epoxy polymer matrix composite. The composite's density, thickness swelling and water absorption ranged from 0.8330 to 1.3410 x 10^{-3} g/mm^3, 3.0 to 4.6%, and 0.50 to 3.0% respectively. The result obtained showed that the composite is suitable for various applications in engineering such as car door panels, boat part making etc. due to its lower water absorption capacity and density while addressing environmental concerns. The research contributes to sustainable development goals; it promotes responsible consumption, production, and innovation in engineering materials.

***Keywords*— Polymer composite, water absorption, epoxy, agricultural wastes, engineering applications**

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I. Introduction

The use of natural fibres for composite development is gaining popularity every day [1]. The composites that are produced from natural fibres exhibit better properties that are viable in many engineering applications such as the automotive, manufacturing, construction industries [2],[3], and so forth. The use of composites is on the increase due to its cost effectiveness in terms of production [4] [5]. They are formed from two or more distinctive materials of different physical and chemical properties with the aim of improving the deficiencies in each of the materials that form the composite [6]. There are different types of composites in engineering; metal, ceramics, and polymer matrix composite. Polymer composites are immensely sought after compared to others because of the light weight, recyclability, and sustainability [7]. They are formed from matrix and reinforcing materials. Polymer composites are resistant to corrosion, possess high stiffness and can be utilized for complex designs [8]. However, despite the good characteristics of polymer composites such as resistance to corrosion, specific strength and flexibility, it has a major drawback; high moisture adsorption [9]. The natural fibres are hydrophilic in nature, therefore absorbs water from the surroundings. The water molecules penetration into the epoxy polymer composite which affects the composite's properties. It reduces the interfacial bonds of the fibres and polymer matrix due to the presence of the hydroxyl groups [10]. Water is easily absorbed by the composite at room temperature which results into changes in the structure, composition and properties of the composite but addition of natural filler materials such as eggshell reduce its effects. The integration of natural fibres as reinforcements in polymer composites offers both environmental benefits and the potential to improve the composite's properties [11]. Among these fibres, banana fibre and rice husk have garnered attention for their widespread availability, renewability, and compatibility with polymer matrices [12]. The exploration of egg shell powder as an additional filler adds a novel sustainable dimension to composite fabrication [13]. Despite the promising attributes of the polymer composites, significant challenges persist as discussed which necessitate focus investigation. Therefore, this research aims to investigate the effect of eggshell in improving the water absorption capacity of the composite, thereby making it useful for automobile applications.

II. MATERIALS AND METHODS

A. *Materials*

Biomass The essential materials utilized for this work are epoxy, hardener, banana fibre, rice husk, and eggshells. They were locally sourced i.e. the rice husk was obtained from rice mill, eggshells from the Landmark University Cafeteria, and banana fibre from Opeyemi farm; all in Omu-Aran, Kwara State.

B. *Material* Preparation

(a) Banana fibre and rice husk preparation

The rice husk and banana were individually cleaned with water to remove impurities and then dried in the sun for 3 days. The rice husk sample was thereafter ball-milled to obtain smaller rice husk particles. The screened rice husk particles of 125 µm particle size [14] were used. The banana fibres were cut into 40 mm lengths with scissors [15]. The rice husk and banana fibre were oven-dried at 60℃ for 24 h to get rid of the inherent moisture content. After that, the dried fibres were treated with 5% NaOH in water for 4 h to remove the foreign matter to aid the effective interlocking of the fibres [16]. Thereafter, the fibres were washed thoroughly with water for total removal of the alkalinity solution on the fibres and dry at 60℃ for 10 h to obtain moisture-free fibres [12].

(b) Eggshell preparation

The eggshell was soaked in water for 24 h and washed severally to remove the organic residue and membrane secretion [12]. The washed eggshell was dried at room temperature for 24 h and then grinded using a ball mill. The resulting grounded eggshell material was sieved with a vibratory sieve shaker to obtain 125 µm particle size. The eggshell particle obtained was collected and stored in an air-tight container [17].

C. *Method*

The polymer composites were developed using an open mould hand lay-up method [18]. The epoxy resin was mixed with the hardener in the required ratio (2:1). The hardener, epoxy resin, eggshell (ES), banana fibre (BF), and rice husk (RH) for each test sample were manually mixed at different ratios as shown in Table 1 in a plastic container using a glass rod to form a homogenous mixture. The mould was placed properly on a polythene bag and taped with a cello tape to enable the stability of the various mould. A petroleum gel was used as a lubricant to lubricate the mould before pouring the mixture inside the mould. The polymer matrix was cured at room temperature for a full day prior to its removal from the mould [19] and the physical tests were then carried out on the cured composite sample.

TABLE 1: COMPOSITE COMPOSITION

SAMPLES	ES	RH	BF	EPOXY
A	0	20	25	55
B	5	20	20	55
C	10	20	15	55
D	15	20	10	55
E	20	20	5	55
F	25	20	0	55
Control	0	0	0	100

ES: Eggshell, RH: Rice husk, BF: Banana fibre

The epoxy polymer composite without reinforcement was produced as a control. The epoxy polymer matrix was then reinforced with the various fibres at different mixing ratios as shown in Table 1, and then compared with the Control. Different material composition was used to obtain an improved epoxy natural fibre-reinforced composite [20].

D. *Physical Properties Investigation of Epoxy Polymer Composite*

(a) Density

The density test was performed on each sample of the epoxy polymer composite reinforced with the different natural fibres using ASTM D792-20 [21]. The mass of the sample was firstly weighed using a digital weighing balance (Figure 1). The known mass was put in a 10 ml graduated cylinder containing 5 ml volume of water. The volume of water displaced for each sample was recorded for the triplicate experiment and the density was calculated using equation 1.

$$\rho = \frac{m}{v_2 - v_1} \quad (1)$$

where ρ (g/mm^3) is the density, m (g) is the composite mass, v_1 (mm^3) is the volume of water before immersion, and v_2 (mm^3) is the volume of water after immersion.

(b) Water absorption

Test specimens of 20 mm × 20 mm × 3 mm were prepared for the water absorption test using (ASTM D5229/D5229M-20) standard [22]. The samples were initially weighed using an electronic weighing balance (Figure 1) to know the initial weigh before being submerged in an equal proportion of water in a small container for 24 h. The water absorption test setup is shown in Figure 2. After 24 h, the composites were brought out and dried with a towel before being weighed. The weight after immersion was recorded after it was repeated three times and equation 2 was used for the calculation of the water absorption percentage using the average value.

$$\textbf{Water absorption } \% = \frac{\mathbf{m_1 - m_0}}{\mathbf{m_0}} \times \mathbf{100} \quad (2)$$

where m_0 (g) is the initial mass, m_1 (g) is the mass after immersion in water

Figure 1: Digital weighing balance

Figure 2: Absorption test set-up

(c) Thickness swelling

The thickness swelling test was done on polymer matrix composite samples to establish the swelling rate of the composites when immersed in water [23]. The initial sample's thickness t_0 for the four sides of the composites were determined with a vernier calliper before immersion in a water container. After 24 h of immersion, digital vernier calliper was used to measure the thickness t_1. The experiment was repeated three times and the average value was used for the calculation of the thickness swelling rate using equation 3 [24].

$$\text{Thickness swelling}(\%) = \frac{t_1 - t_0}{t_0} \times 100 \quad (3)$$

Where, t_1 (mm) is the thickness after immersion, and t_0 is the thickness before immersion

III. RESULTS AND DISCUSSION

The density, water absorption, and thickness swelling results are shown in Figure 3-5.

A. Density of the produced samples

The Figure 3 shows the density of the different polymer composite samples containing different compositions of the fibres. Sample A, with 0% wt. ES, 20% wt. RH, 25% wt. BF has a lower density compared to the other samples aside the control sample. As the ES increases, the weight of the composite increases. This is because eggshell is denser compared with other reinforcing material used for the production of the composite [25]. The reinforcing of natural fibres with epoxy polymer matrix increases the density of the composite [26]

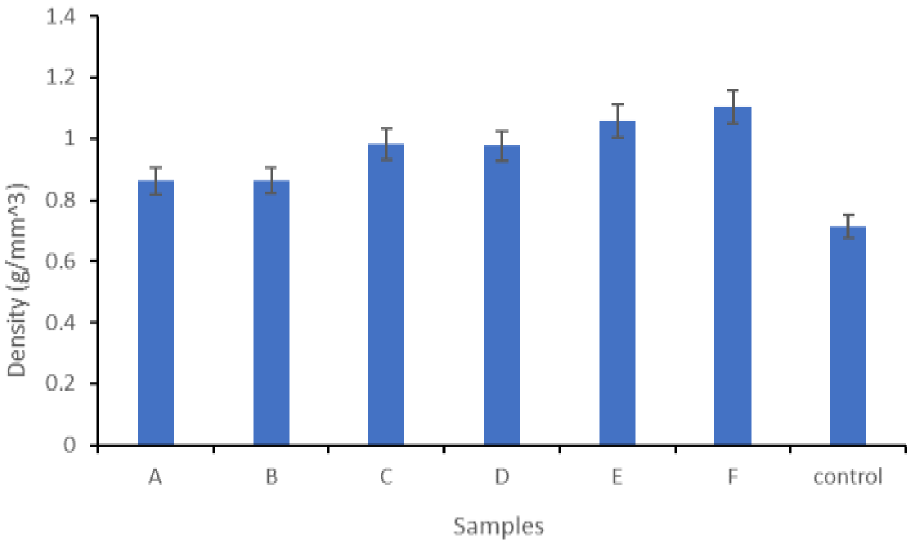

Figure 3: Graph for density of produced samples

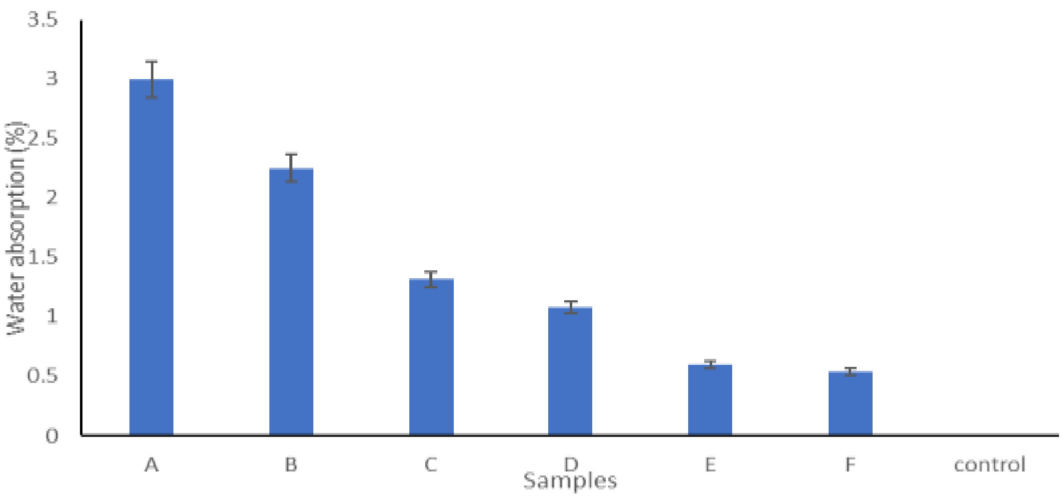

Figure 4: Graph for water absorption of produced samples

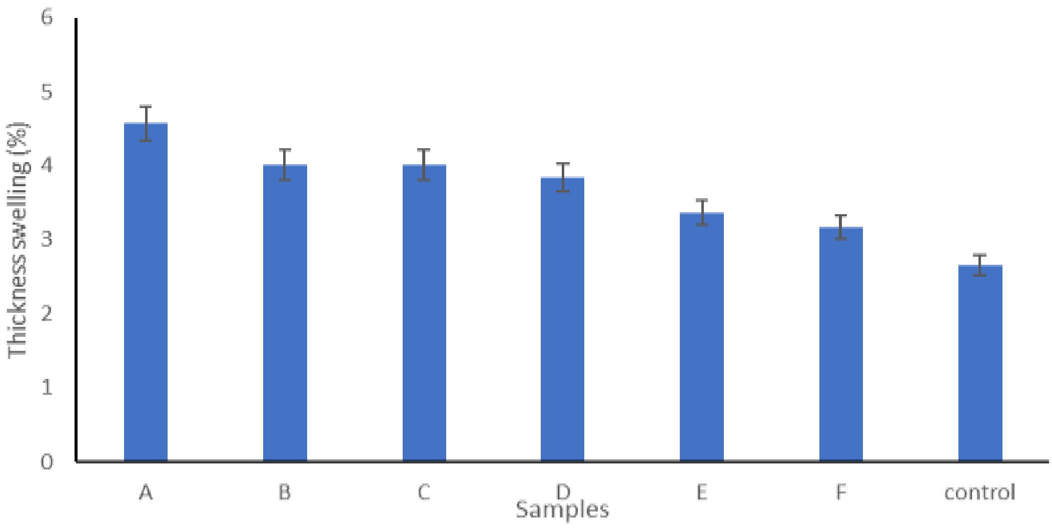

Figure 5: Graph of thickness swelling of produced samples

B. *Water absorption result of produced samples*

The water absorption test measures the material's characteristics in absorbing moisture from the surroundings. This property is significant for conditions whereby the composite material was exposed to moisture. The results from this test revealed the hygroscopic nature of the composite material and its potential impact on performance in moisture-prone environments. The water absorption rate was high for composites with more BF compared with less BF composites as shown in Figure 4. This can be likened into the high cellulose content present inside the banana fibre which is hydrophilic in nature. The reverse was the case when ES content increase in the composite composition; there was a decrease in the water absorption rate. Sample A with composition of 0% wt. ES, 20% wt. RH, and 25% wt. BF has the highest water absorption response with the BF content being 25% wt. This means an increase in the % wt. composition of banana fibre led to an increase in the water absorption response but was reduced by an increase in the ES content by % wt. with every decrease in the BF weight percentage [27]. The water absorption rate for reinforced composite was more than the control sample. The BF contains hydroxy group that has affinity for water which make water absorption high for increased BF contents in the composite [28].

C. *Thickness swelling result of produced samples*

The thickness swelling tests was done on the composites to understand its stability or changes when exposed to moisture. The thickness swelling follows the trend of water absorption. As the water absorption increases, the thickness swelling also increases. According to Figure 5, sample A has the highest thickness swelling rate (0% wt. ES, 20% wt. RH, 25% wt. BF) and the least thickness swelling was observed in the control sample. The control sample repel water because it is not hydrophilic in nature. It was observed that there was a decrease in thickness swelling with every % wt. decrease in BF which can be attributed to decrease in the cellulose content as the weight percentage of banana used decreases [29].

IV. CONCLUSION

In this study, epoxy matrix polymer was produced using rice husk (RH), banana fibre (BF), and eggshell (ES) as reinforcements. The following conclusions were derived from the study:

The densities of the various composite samples range from 0.833 to 1.341 g/mm^3. It was observed that the reinforced samples have higher densities compared to the control sample, 0.652 g/m^3. However, the densities of the composite were lower than that of metal matrix composite, and the ceramic matrix composite.

The water absorption for each sample ranges from 0.5 to 3% after 24 h. Samples A, B, C, D, E, F are relatively higher than the control. The samples' water absorption was very low; making it a good prospect for car dash board, door lining, and other engineering applications.

The thickness swelling of the samples ranges from 3 to 4.6% after 24 h. Considering all the samples, banana fibre (BF) has the highest swelling rate when compared to the control due to the absorption of water. A decrease of thickness swelling with every % wt was observed with decrease of the banana fibre.

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REFERENCES

[1] A. Rahman, M. A. Chowdhury, M. B. A. Shuvho, N. Hossain, M. Fotouhi, and R. Ali, "Fabrication and characterization of jute/cotton bio-composites reinforced with eggshell particles," Polym. Bull.,

vol. 80, no. 1, pp. 931–957, 2023, doi: 10.1007/s00289-021-04049-2.

[2] H. A. Aisyah et al., "A comprehensive review on advanced sustainable woven natural fibre polymer composites," Polymers (Basel)., vol. 13, no. 3, pp. 1–45, 2021, doi: 10.3390/polym13030471.

[3] V. Naik, M. Kumar, and V. Kaup, "A Review on Natural Fiber Composite Materials in Automotive Applications," Eng. Sci., vol. 18, pp. 1–10, 2022, doi: 10.30919/es8d589.

[4] O. D. Atoyebi, K. O. Iwuozor, E. C. Emenike, D. S. Anamayi, and A. G. Adeniyi, "Physical and mechanical properties of locally fabricated geopolymer-plastic ceiling boards," *Results Eng.*, vol. 19, no. June, p. 101230, 2023, doi: 10.1016/j.rineng.2023.101230.

[5] N. I. Agbeboh, A. Adus, A. A. Adediran, I. O. Oladele and O. L. Ogundipe, "Investigation of the Effects of Oyster Shell Powder Bio-Fillers on the Mechanical Properties of Reinforced Epoxy Composites," 2024 International Conference on Science, Engineering and Business for Driving Sustainable Development Goals (SEB4SDG), Omu-Aran, Nigeria, 2024, pp. 1-6, doi: 10.1109/SEB4SDG60871.2024.10629920.

[6] M. A. Azman et al., "Natural fiber reinforced composite material for product design: A short review," Polymers (Basel)., vol. 13, no. 12, 2021, doi: 10.3390/polym13121917.

[7] Y. G. Thyavihalli Girijappa, S. Mavinkere Rangappa, J. Parameswaranpillai, and S. Siengchin, "Natural Fibers as Sustainable and Renewable Resource for Development of Eco-Friendly Composites: A Comprehensive Review," Front. Mater., vol. 6, no. September, pp. 1–14, 2019, doi: 10.3389/fmats.2019.00226.

[8] M. R. M. Asyraf et al., "Product Development of Natural Fibre-Composites for Various Applications: Design for Sustainability," Polymers (Basel)., vol. 14, no. 5, 2022, doi: 10.3390/polym14050920.

[9] S. Radoor, J. Karayil, and A. Jayakumar, "Investigation on Mechanical Properties of Surface-Treated Natural Fibers-Reinforced Polymer Composites Mechanical Properties of Natural Fibers Drawbacks of Natural Fibers The major drawbacks of natural fibers are their poor mechanical strength , high," 2021.

[10] N. Sienkiewicz, M. Dominic, and J. Parameswaranpillai, "Natural Fillers as Potential Modifying Agents for Epoxy Composition: A Review," Polymers (Basel)., vol. 14, no. 2, pp. 1–17, 2022, doi: 10.3390/polym14020265.

[11] U. Narendra Kumar et al., "Manufacturing and Analysis of Banana-Epoxy Composite fibre," IOP Conf. Ser. Mater. Sci. Eng., vol. 1123, no. 1, p. 012062, 2021, doi: 10.1088/1757-899x/1123/1/012062.

[12] A. A. Adediran et al., "Mechanical properties of hybrid banana fibre , rice husk , and eggshell reinforced epoxy composite," vol. x, no. xxxx, pp. 1–17, 2024.

[13] V. Ganesan, J. S. Chohan, G. S. Subburaj, and H. Panneerselvam, "Experimental Analysis of Mechanical Properties of Banana Fibre / Eggshell Powder-Reinforced Hybrid Epoxy Composite †," pp. 1–8, 2024.

[14] A. B. D. Nandiyanto, S. Fatimah, R. Ragadhita, and D. N. Al Husaeni, "Particle Size and Pore Size of Rice Husk Ash on the Resin-Based Brake Pads Performance: Experiments and Bibliometric Literature Review," J. Eng. Sci. Technol., vol. 17, no. 6, pp. 4065–4081, 2022.

[15] K. Prakash et al., "Influence of Fiber Volume and Fiber Length on Thermal and Flexural Properties of a Hybrid Natural Polymer Composite Prepared with Banana Stem, Pineapple Leaf, and S-Glass," Adv. Mater. Sci. Eng., vol. null, p. null, 2021, doi: 10.1155/2021/6329400.

[16] M. Sahoo, R. Gopinathan, K. P. Kumar, J. J. A. Rani, R. Pradhan, and L. Parida, "Study on the influence of stacking pattern on mechanical behaviour of banana/snake grass fibers hybrid epoxy composite," Mater. Today Proc., vol. null, p. null, 2022, doi: 10.1016/j.matpr.2022.08.185.

[17] R. Ahmad, R. Rohim, and N. Ibrahim, "Properties of Waste Eggshell as Calcium Oxide Catalyst," Appl. Mech. Mater., vol. 754–755, pp. 171–175, 2015, doi: 10.4028/www.scientific.net/amm.754-755.171.

[18] M. Farhad Ali, M. Sahadat Hossain, T. Siddike Moin, S. Ahmed, and A. M. Sarwaruddin Chowdhury, "Utilization of waste chicken feather for the preparation of eco-friendly and sustainable composite," Clean. Eng. Technol., vol. 4, no. July, p. 100190, 2021, doi: 10.1016/j.clet.2021.100190.

[19] I. O. Oladele, B. A. Makinde-Isola, A. A. Adediran, M. O. Oladejo, A. F. Owa, and T. M. A. Olayanju, "Mechanical and wear behaviour of pulverised poultry eggshell/sisal fiber hybrid reinforced epoxy composites," Mater. Res. Express, vol. 7, no. 4, 2020, doi: 10.1088/2053-1591/ab8585.

[20] O. O. Daramola et al., "Optimization of the mechanical properties of polyester/coconut shell ash (CSA) composite for light-weight engineering applications," Sci. Rep., vol. 13, no. 1, p. 1066, 2023, doi: 10.1038/s41598-022-26632-x.

[21] M. A. M. Daud, A. F. A. Ghani, K. A. Zakaria, M. Z. Selamat, S. Dharmalingam, and M. Thirukumaran, "The Effect of Pineapple Leaf Fiber as a Filler in Polymer Matrix Composite for Interior Part in Automotive," Int. J. Nanoelectron. Mater., vol. 14, no. Special Issue ISSTE, pp. 363–372, 2021.

[22] M. H. M. Hamdan et al., "Water absorption behaviour on the mechanical properties of woven hybrid reinforced polyester composites," Int. J. Adv. Manuf. Technol., vol. 104, no. 1–4, pp. 1075–1086, 2019, doi: 10.1007/s00170-019-03976-9.

[23] P. P. Ikubanni, A. A. Adeleke, T. A. Adekanye, O. J. Aladegboye, O. O. Agboola, and B. T. Ogunsemi "Particleboard from biomass wastes: A review of production techniques, properties, and future trends," Res. Eng. Struct. Mater., vol. x, no. xxxx, pp. 1–28, 2024, doi: 10.17515/resm2024.265ma0502rv.

[24] S. W. Ghori, G. S. Rao, and A. A. Rajhi, "Investigation of Physical, Mechanical Properties of Treated Date Palm Fibre and Kenaf Fibre Reinforced Epoxy Hybrid Composites," J. Nat. Fibers, vol. 20, no. 1, 2023, doi: 10.1080/15440478.2022.2145406.

[25] O. L. Ogundipe, A. A. Adediran, P. P. Ikubanni, T. A. Adekanye, E. S. A. Ajisegri and O. M.Ikumapayi, "Influence of eggshell addition on the properties of natural fibre-reinforced epoxy composite – A mini-review," 2024 International Conference on Science, Engineering and Business for Driving Sustainable Development Goals (SEB4SDG), Omu-Aran, Nigeria, 2024, pp. 1-7, doi: 10.1109/SEB4SDG60871.2024.10629942.

[26] Z. Zainudin, N. I. S. Mohd Yusoff, M. U. Wahit, and S. H. Che Man, "Mechanical, Thermal, Void Fraction and Water Absorption of Silane Surface Modified Silk Fiber Reinforced Epoxy Composites," Polym. Technol. Mater., vol. 59, no. 18, pp. 1987–2002, 2020, doi: 10.1080/25740881.2020.1784215.

[27] V. Ganasan et al., "Mechanical, Moisture Absorption and Thermal Stability of Banana Fiber/Egg Shell Powder-Based Epoxy Composites †," Eng. Proc., vol. 61, no. 1, pp. 1–8, 2024, doi: 10.3390/engproc2024061011.

[28] O. O. Daramola, A. D. Akinwekoni, A. A. Adediran, O. Akindote-White, E. R. Sadiku, "Mechanical performance and water uptake behaviour of treated bamboo fibre-reinforced high-density polyethylene composites,"Heliyon 5(7), 1-6, 2019, doi.org/10.1016/j.heliyon.2019.e02028.

[29] S. Sunardi et al., "Assessment of eggshell-based material as a green-composite filler: Project milestones and future potential as an engineering material," J. Mech. Behav. Mater., vol. 32, no. 1, 2023, doi: 10.1515/jmbm-2022-0269.