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Evaluation of the impact of the eggshell filler on the mechanical properties and biodegradability of hybrid composites

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Abstract

The creation of sustainable and environmentally friendly materials has become more important in order to address concerns about the depletion of nonrenewable resources and the negative environmental impact of traditional materials. In this study, a composite material made of glass fibre, banana fibre, and chicken feathers with varying fibre content percentages (1%, 2%, and 3%) was examined. The composite material was put through tensile, flexural, microhardness, and impact tests. An SEM was used to look at the sample's surface and interior structure. FTIR analysis was performed to detect any contaminants in the sample. The impact of adding eggshell powder to the composite material to improve its qualities was investigated. It was found that the water absorption of the composite was reduced by 12%, and the tensile strength increased by 21% with the addition of eggshell powder. Furthermore, the flexural strength improved by 19%, enhancing the overall mechanical characteristics of the composite material. The addition of eggshell powder altered the interaction between the fibres and the matrix in SEM images. Furthermore, the composite material was subjected to soil exposure for a specific timeframe to evaluate its biodegradability over time. It was observed that integrating eggshell powder into composite materials has the potential to produce more ecologically friendly and sustainable products while reducing waste. This study emphasizes the potential of sustainable and environmentally friendly materials for decreasing environmental effects and ensuring long-term sustainability.

Keywords: Hybrid composite, Sustainable composite, Eggshell filler, Glass fibre, Banana fibre, Chicken feathers, Biodegradability

1. Introduction

The attention given to creating eco-friendly materials has significantly increased. Another type of waste arises from agricultural leftovers such as chicken feathers, eggshells, banana fibre, and more. These agricultural remnants pose serious environmental issues as well [4] [5]. Approximately 350 million tons of chicken feathers are produced annually, and the annual output of 8 million tons of eggshells, as indicated by De Angelis et al. [6], presents an environmental challenge. These two forms of agricultural waste are not only pollutants but also health hazards due to their accumulation in the environment, and this connection might be attributed to their abundance. Repurposing these agricultural leftovers could offer a feasible solution for developing environmentally sustainable materials.

The so-called eco-composites, or natural fibre (NF)-reinforced composites, are the focus of numerous academic and research endeavors as well as numerous business initiatives. The rapid depletion of petroleum resources, new environmental regulations, and growing environmental and social concerns around the world have all contributed to the need for innovative composites and environmentally friendly materials. Moreover, eco-composites could be a combination of NF and a biodegradable polymer matrix [1]. Several advantages over synthetic fibres, such as low cost, low density, high specific strength and modulus, ease of availability, ease of processing, non-toxicity, acoustic insulation, significantly lower processing energy requirements, etc., can explain it [2]. Due to its renewable and sustainable resource, banana fibre offers a distinct advantage in applications for textiles, clothes, crafts, home decor, and agriculture. High tensile strength, long-lasting, biodegradable, lightweight, and environmentally beneficial qualities are also included [21]. A plentiful waste product from the poultry industry is chicken feathers. It is biodegradable, lightweight, and has insulating qualities. It can also spontaneously decay. It can be incorporated into biodegradable materials and polymers. materials for bedding, cushions, and pillows that insulate. following decomposition, soil amendments, and fertilizers. Egg shells play a part because they are a rich source of nutrients like calcium. both environmentally friendly and biodegradable. can be reused to cut down on waste. Regarding their applications, they include dietary supplements, crafts, water purification, and others. Fibreglass has rigidity and high tensile strength and is thermal, chemical, and corrosion-resistant. flexible and portable [22]. Construction and the automotive industries can utilize it because it is non-combustible and fire-resistant. Also, it can be used in the aerospace and textile industries [23] [24]. This paper has shown how to use these four components and how they will affect our environment, as well as whether the composite produced by these components is good enough to replace existing products and how environmentally friendly it will be if we use them in different percentages while making composite. As better waste management is also one of our goals, employing banana fibre, chicken feather, egg shell, or their composites to substitute everyday products can help us achieve that goal.

This study aims to investigate the effects of incorporating eggshell powder as a filler into hybrid composites made from glass fibre, banana fibre, and chicken feathers. The specific objectives of this research are to evaluate the mechanical properties, including tensile strength, flexural strength, and impact resistance, as well as the biodegradability and water absorption characteristics of the composites with and without the addition of eggshell powder. The study further seeks to assess how eggshell powder influences the interaction between fibres and the matrix, as observed through SEM analysis. The ultimate goal is to determine whether eggshell powder can enhance the performance and sustainability of hybrid composites, contributing to the development of environmentally friendly materials.

2. Materials

Epoxy resin and Hardener served as the investigation's matrix materials [25]. Chemicals and reinforcements required by the lab were purchased in raw form from a nearby local market. Banana fibre, glass fibre, and chicken feather fibre were the materials used. Additionally utilized as filler was eggshell. The amount of materials that are used in sample are given in table 1 with percentage variation.

Table 1: Composition of reinforcements in composite samples without eggshell.

Sample No	Name	Fibre Content (%)	Sample weight
1	Epoxy Resin	91	200g
	Hardener	8	
	Banana fibre	0.5	
	Glass fibre	0.25	
	Chicken feather fibre	0.25	
2	Epoxy Resin	89	
	Hardener	9	
	Banana fibre	1.5	
	Glass fibre	0.25	
	Chicken feather fibre	0.25	
3	Epoxy Resin	87.5	
	Hardener	10	
	Banana fibre	2.5	
	Glass fibre	0.25	
	Chicken feather fibre	0.25	

Table 2: Composition of reinforcements in composite samples with eggshell.

Sample No	Name	Fibre Content (%)	Sample weight
4	Epoxy Resin	91	200g
	Hardener	8	
	Banana fibre	0.25	
	Glass fibre	0.25	
	Chicken feather fibre	0.25	
	Eggshell	0.25	
5	Epoxy Resin	89	
	Hardener	9	
	Banana fibre	1.25	
	Glass fibre	0.25	
	Chicken feather fibre	0.25	
	Eggshell	0.25	
6	Epoxy Resin	87.5	
	Hardener	10	
	Banana fibre	2.25	
	Glass fibre	0.25	
	Chicken feather fibre	0.25	
	Eggshell	0.25	

3. Fabrication of Composites

Mold preparation was used to prepare the sample. It was created in a tin mold. The mold's dimensions were 5 × 5 inches. For the preparation of composites, fibres were cut along the length as per the size of the mold. For the sample with eggshell, the eggshell was ground in a ball mill to produce fibre powder. After being poured into a cup, the epoxy resin was weighed in the weight machine. Then, fibres were measured as well. The resin and hardener were then combined with the fibres. After a while, the hard composite was removed from the mold and machined for various test procedures. Resin and hardener were mixed and stirred mechanically in the ratio of 10:1 by weight. First, a layer of epoxy resin was put on the mold with the help of a spatula. Fibres were carefully spread over the resin. There were two variations in the sample, with and without eggshell. Eggshell was spread over the mold in accordance with the percentage. The same procedure was repeated for the rest of the sample with a percentage variation of fibres. All fibres were placed unidirectionally in the mold [26]. Then the mold was kept for a complete day to cure at room temperature. Composites were prepared as per the desired dimensions. The Fig. 1 and Fig. 2 show the sample fabricated using the molding method.

(a) (b) (c)

Figure 1: Hydrid composite samples with eggshell (a) 1% Fibre, (b) 2% Fibre, (c) 3% Fibre

(a) (b) (c)

Figure 2: Hydrid composite samples without eggshell (a) 1% Fibre, (b) 2% Fibre, (c) 3% Fibre

4. Result and Discussion

4.1 Tensile Strength:

From Table 3 we can see that different parameters for rainwater match with the standard requirement of dye house water supply. Here, R1, R2, R3, R4, R5 represents different regions from where we collect rainwater and GW indicates ground water parameter that we use. As we know the quality of dye bath water, no need to do any further treatment with rainwater. All the parameter including pH, water hardness, iron content is in tolerance.

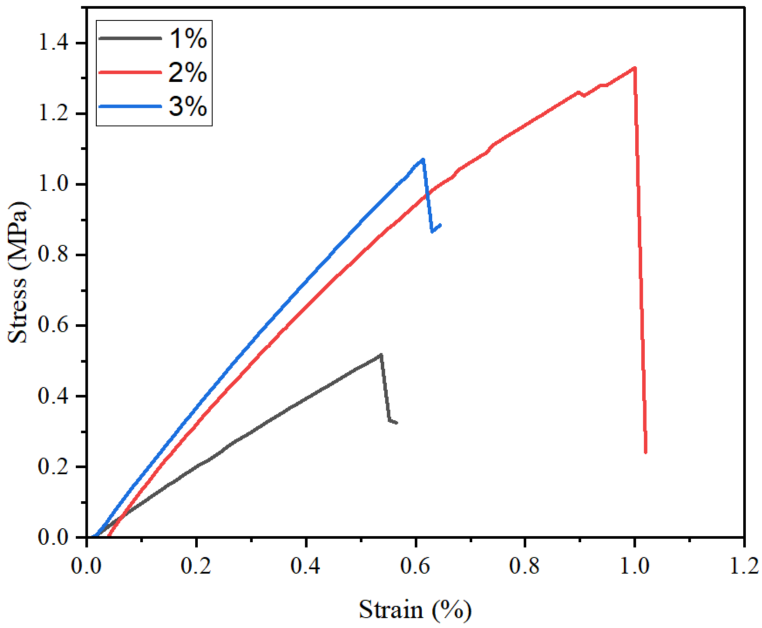


Figure 3: Tensile test curves of the samples with eggshell

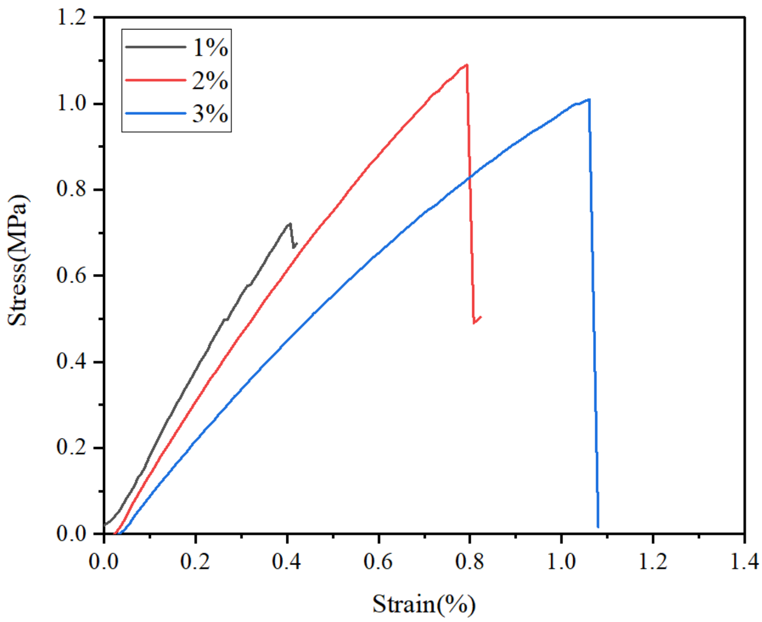


Figure 4: Tensile test curves for the samples without eggshell

This stress versus strain curve shows that between Fig. 3 (with eggshell) and Fig. 4 (without eggshell), adding eggshell increases the strength of the fibre composite, as indicated in red and blue. As a result, employing eggshells can improve strength, which is a material's ability to bear an applied stress without irreversible deformation or failure. This feature is critical in applications where the material must carry enormous loads or withstand external forces, such as bridges and load-bearing structures, i.e., fracture strength will be high when we add eggshell with fibre.

According to the ASTMD 3039 standard, the tensile test was conducted. The test subject's dimensions were 70 mm x 19.6 mm x 11.7 mm. The test was run using a 10-ton-capacity universal testing machine (U.T.M.) [28]. The flat specimens of the requisite size were positioned between the grips of each testing head such that the specimen's longitudinal axis coincided with the direction of force applied to it. A hybrid of banana fibre, glass fibre, and chicken feather with or without eggshell composite's tensile strength is determined by variations in percentage. [8] [9] [11] [18]

The table 3 and table 4 display the percentage variation:

Table 3: Ultimate tensile stress in Composite samples without eggshell

Fibre (%)	Fibre	Weight (gm)	Ultimate tensile stress (MPa)
1% (2gm)	Banana	1.0	0.867
	Chicken feather	0.5	
	Glass fibre	0.5	
2% (4gm)	Banana	3.0	1.10
	Chicken feather	0.5	
	Glass fibre	0.5	
3% (6gm)	Banana	5.0	1.02
	Chicken feather	0.5	
	Glass fibre	0.5	

Table 4: Ultimate tensile stress in Composite samples with eggshell

Fibre (%)	Fibre	Weight (gm)	Ultimate tensile stress (MPa)
1% (2gm)	Banana	0.5	0.520
	Chicken feather	0.5	
	Glass fibre	0.5	
2% (4gm)	Egg shells	0.5	1.33
	Banana	2.5	
	Chicken feather	0.5	
3% (6gm)	Glass fibre	0.5	1.14
	Egg shells	0.5	
	Banana	4.5	

Adding eggshell will be both economical and environmentally friendly, as waste products will aid in the use of less fibre.

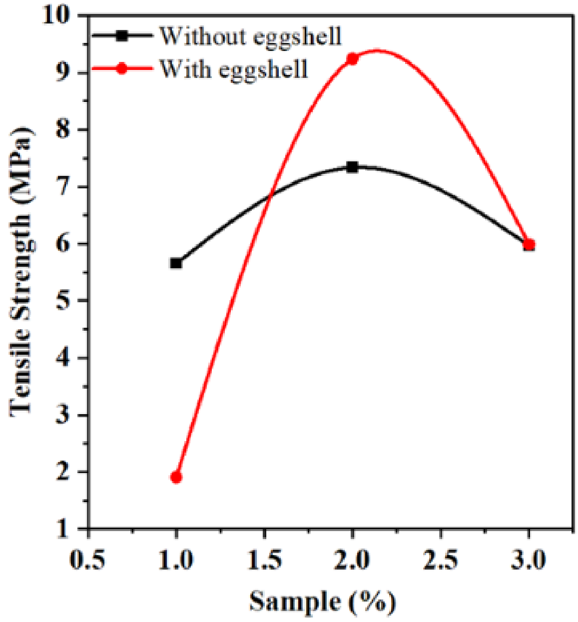


Figure 5: Tensile test curves for the samples without eggshells

According to the aforementioned table, adding eggshell will definitely increase tensile strength with fibre compositions of 2% and 3%, as shown in Fig. 5.

4.2 Flexural Strength:

A three-point bend test was conducted in accordance with ASTM D790-02 specifications. The dimensions of the test subject were 70 x 18.03 x 19.23 mm. On a general testing device, the test was run. The specimen was supported by two parallel roller supports, and load was applied using a loading nose positioned halfway between the supports. The speed of the test was 2 mm/min, and the span length was 63.8 cm. [7] [14] [15] The flexural strength curve for eggs with and without eggshells will be like this:

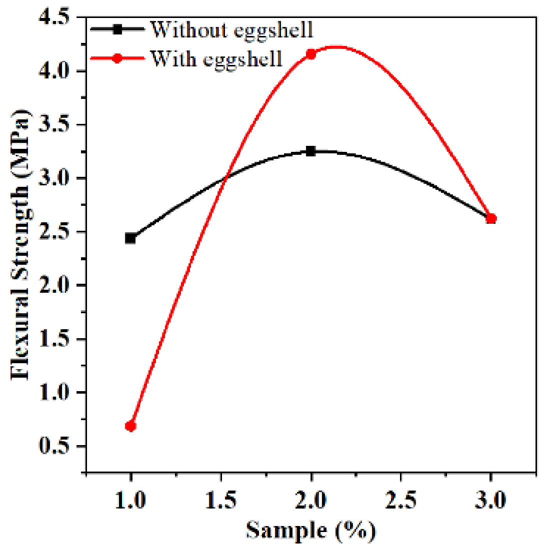


Figure 6: Flexural strength comparison for the samples with and without eggshell

The hybrid of banana fibre, glass fibre, and chicken feather composite has the highest flexural strength, which is assessed by the modification of percentages, in both eggshell conditions. The percentage variation is shown in the table below. [8] [9] [10]. The graph in Fig. 6 clearly shows that flexural strength improves with 2% fibre, with or without eggshell. When comparing the two, it is evident that adding eggshell provides significantly more flexural strength than not adding eggshell. Flexural strength, also known as modulus of rupture, is a measure of a material's capacity to resist deformation under a load applied perpendicular to its long axis. It is a significant mechanical feature, particularly in materials such as concrete, ceramics, and composites, which are frequently subjected to bending or flexing loads. Durability and design flexibility will also increase. [14] [16] [17]. Also calculated value of flexural strength using $\boldsymbol{o_r} = \frac{\boldsymbol{3pl}}{\boldsymbol{2bd^2}}$ stress equation fairly matches the experimental result.

4.3 Impact Strength:

Generally, the impact strength of pure polymer specimens was very poor. Because of their brittleness, energy would be absorbed by the material under a gradual load per unit area, which is defined as impact strength. The introduction of fibres into the polymer can improve the toughness of the composite material, which is conducive to improving the impact strength. [10] The impact strength of the composite fibre factor affects the bonding between fibres and matrix. The impact strength increases as the fibre load increases because of the good adhesion between fibre-polymer composites. [13] [16]

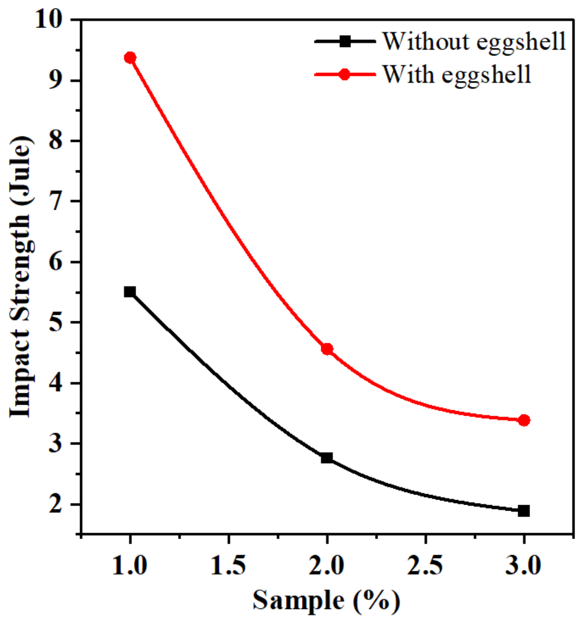


Figure 7: Impact strength comparison for the samples with and without eggshell

The impact strength was better when the addition of eggshell was done. As we know, impact strength refers to a material's ability to withstand sudden loading or impact without fracturing or breaking.

4.4 Water absorption test:

The effect of water absorption is important in cases where the material that has been developed for applications comes into contact with water [29]. The composite specimens to be used for the moisture absorption test were first dried in an air oven. Then these conditioned composite specimens were immersed in distilled water at 30 °C for about 6 days. At regular intervals, the specimens were removed from the water, wiped with filter paper to remove surface water, and weighed with a digital balance of 0.01 mg resolution. The samples were immersed in water to permit the continuation of absorption until the saturation limit was reached. The weighing was done within 30 seconds in order to avoid errors due to evaporation. The test was carried out according to ASTM D570 to find out the swelling of the samples. After 6 days, the test specimens were again taken out of the water bath and weighed. The weight gain of the sample was measured as an increase in weight percentage using the formula.

Increase in weight % = (Wet weight-sample weight)/(sample weight)×100

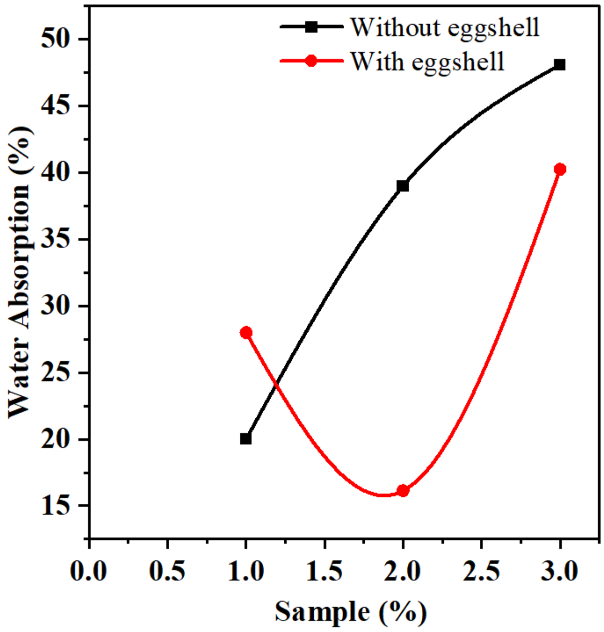


Figure 8: Water absorption comparison for the samples with and without eggshell

This moisture absorption test was performed on 1%, 2%, and 3% samples, both with and without eggshell. The outcome is reflected in the Fig. 8.

Water absorption capacity is another crucial factor to be taken into account when considering the effect of water on the composite material developed. The effect of water absorption is important in cases where the material that has been developed and used for applications comes into contact with water. Based on the above observation, it is apparent that using eggshells can decrease our sample's water absorption, which was the goal of this experiment. Though the results for 1% with or without eggshell appear close, However, adequate equipment may assist us in achieving a more precise outcome.

4.5 Biodegradability test:

Nowadays, the widespread use of synthetic fibre composites such as aramid, glass, and others is posing an issue for the environment because they are not as easily degradable as regular fibres. [20] Regular fibre-reinforced biodegradable composites are being advanced to encourage the use of environmentally friendly materials. Green materials can be used to alleviate problems linked to agricultural leftovers in a different way [5] [8] [12].

In the biodegradability test, hybrid composite samples with and without eggshell powder were cut into uniform sizes and buried in soil at a consistent depth. Periodically, the samples were retrieved to measure weight loss and visually assess physical degradation. After a designated period, final evaluations were conducted to compare the biodegradation rates of the composites based on the collected data. Both fibre compositions, with or without eggshell, were biodegradable. After applying eggshell, the biodegradability of the composite increases.

4.6 Microstructure analysis using SEM (Scanning Electron Microscope):

Tensile Tested With and without eggshells, these samples are taken for the analysis. The SEM images show details like failure morphology, defects, and adhesions between resin and the fibres in the specimen. It can be asserted that the main reason for the fracture was the presence of voids and the tearing of the matrix. Fig. 9 shows the SEM image of the tensile tested without an eggshell sample. Fibre breakage due to brittle fracture, The fracture takes place in the specimen with the application of the tensile load [4]. Crater formation can be observed in Fig. 9. These might have formed due to the lumping of the reinforcement; this clustering can also be observed in Fig. 10. Similar pores have been reported by K. Logesh et al [19]. in their study. These craters support and accelerate crack formation, resulting in an untimely fracture. Besides, Fig. 10 shows the SEM image of the tensile tested with an eggshell sample of a river-like fracture. The "river-like" fracture pattern, characterized by branching channels and a smooth appearance, typically occurs in certain brittle materials, especially those that undergo cleavage or quasi-cleavage during the fracture process. When Brittle fractured, these samples exhibit "river-like" patterns as cracks follow the layer boundaries. Besides, the presence of glass materials with a crystalline or semi-crystalline structure is responsible for the display of this fracture pattern. The presence of eggshell is the reason for the better property because the sample with eggshell shows fewer defects and less fibre breakage, as well as increasing the quality of the composite.is responsible for the display of this fracture pattern. The presence of eggshell is the reason for the better property because the sample with eggshell shows fewer defects and less fibre breakage, as well as increasing the quality of the composite.

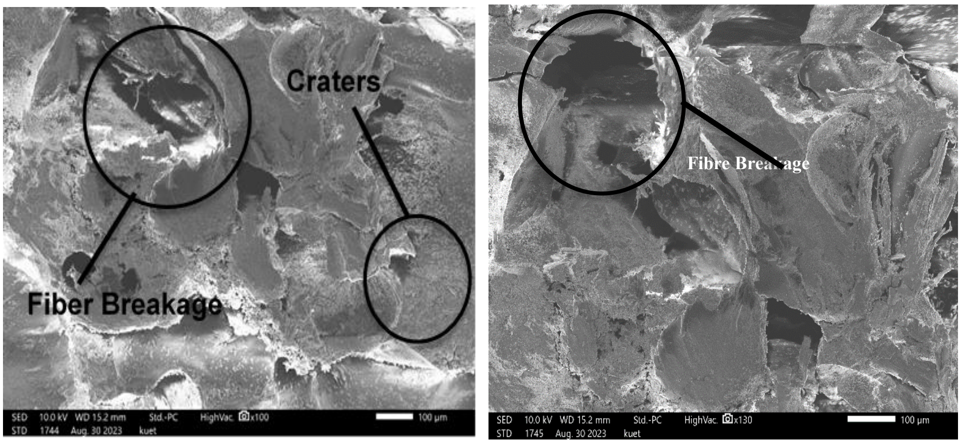
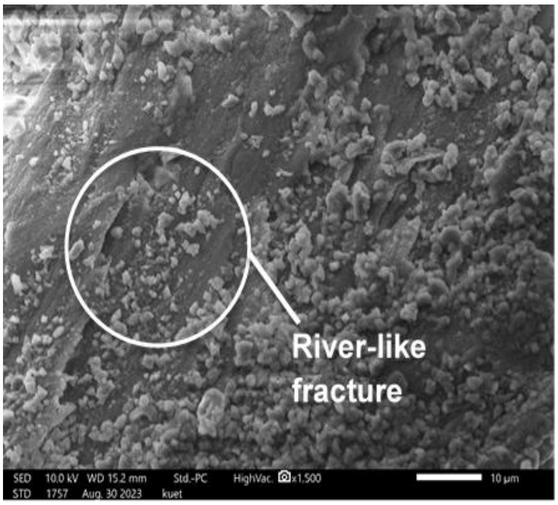


Figure 9: SEM image of the tensile tested sample (without eggshell)



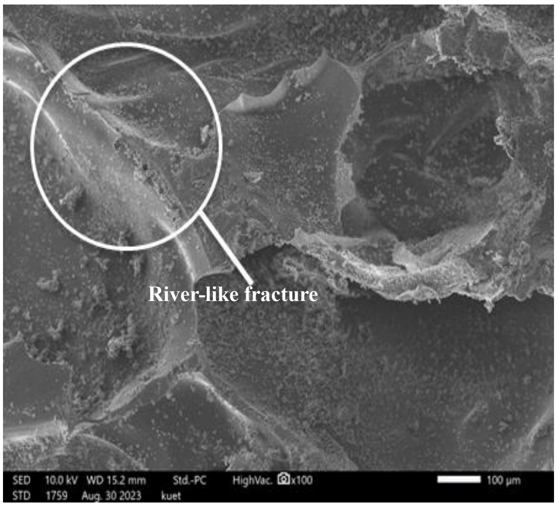


Figure 10: SEM image of the tensile tested sample (with eggshell)

5. Conclusions

According to the testing results, a hybrid of three separate specimens (banana, glass fibre, and chicken feather) has good mechanical qualities, and there is a considerable difference with and without the addition of eggshell. However, it has been discovered that the addition of eggshell can improve qualities such as tensile strength and flexural strength, which is both a beneficial way of using environmental trash and also for many applications where strength is required. At the same time, this will be cost-effective because we can reduce the amount of material used by adding eggshell, which will aid in providing the desired result. This work can be expanded to investigate other tribological features of this composite, such as abrasion, wear, and hardness behavior. Experiments were carried out in order to characterize the surfaces of treated and untreated fibres, as well as to evaluate water absorption in fibre composites. Fibre without eggshell composites absorbs more water than fibre with eggshell, which was the main intention of this experiment, so that waste management will be done at the same time, not just the enhancement of the property for practical application.

6. References

[1] Bogoeva-Gaceva, G., Avella, M., Malinconico, M., Buzarovska, A., Grozdanov, A., Gentile, G., & Errico, M. E. (2007). Natural fibre eco-composites. Polymer Composites, 28(1), 98–107. https://doi.org/10.1002/pc.20270

[2] Islam, M. (2020, October 30). Inorganic Natural Nano Particles To Upgrade Tensile Properties Of Waste Jute Fibre Reinforced Nylon Composite. Exploratory Materials Science Research, 1(1), 014–021. https://doi.org/10.47204/emsr.1.1.2020.014-021

[3] Bot, B. V., Axaopoulos, P. J., Sakellariou, E. I., Sosso, O. T., & Tamba, J. G. (2022, September). Energetic and economic analysis of biomass briquettes production from agricultural residues. Applied Energy, 321, 119430. https://doi.org/10.1016/j.apenergy.2022.119430

[4] Lomov, S., Ivanov, D., Truong, T., Verpoest, I., Baudry, F., Vanden Bosche, K., & Xie, H. (2008, September). Experimental methodology of study of damage initiation and

development in textile composites in uniaxial tensile test. Composites Science and Technology, 68(12), 2340–2349. https://doi.org/10.1016/j.compscitech.2007.07.005

[5] Vibhakar, C., Sabeenian, R. S., Kaliappan, S., Patil, P. Y., Patil, P. P., Madhu, P., Sowmya Dhanalakshmi, C., & Ababu Birhanu, H. (2022, January 3). Production and Optimization of Energy Rich Biofuel through Co-Pyrolysis by Utilizing Mixed Agricultural Residues and Mixed Waste Plastics. Advances in Materials Science and Engineering, 2022, 1–9. https://doi.org/10.1155/2022/8175552

[6] De Angelis, G., Medeghini, L., Conte, A. M., & Mignardi, S. (2017, October). Recycling of eggshell waste into low-cost adsorbent for Ni removal from wastewater. Journal of Cleaner Production, 164, 1497–1506. https://doi.org/10.1016/j.jclepro.2017.07.085

[7] Vijaya Ramnath, B., Junaid Kokan, S., Niranjan Raja, R., Sathyanarayanan, R., Elanchezhian, C., Rajendra Prasad, A., & Manickavasagam, V. (2013, October). Evaluation of mechanical properties of abaca–jute–glass fibre reinforced epoxy composite. Materials & Design, 51, 357–366. https://doi.org/10.1016/j.matdes.2013.03.102

[8] Chandramohan, D., & Presin Kumar, A. J. (2017, August). Experimental data on the properties of natural fibre particle reinforced polymer composite material. Data in Brief, 13, 460–468. https://doi.org/10.1016/j.dib.2017.06.020

[9] Preet Singh, J. I., Dhawan, V., Singh, S., & Jangid, K. (2017). Study of Effect of Surface Treatment on Mechanical Properties of Natural Fibre Reinforced Composites. Materials Today: Proceedings, 4(2), 2793–2799. https://doi.org/10.1016/j.matpr.2017.02.158

[10] Ramesh, M., Palanikumar, K., & Reddy, K. H. (2013, May). Mechanical property evaluation of sisal–jute–glass fibre reinforced polyester composites. Composites Part B: Engineering, 48, 1–9. https://doi.org/10.1016/j.compositesb.2012.12.004

[11] Ahmed, K. S., Vijayarangan, S., & Naidu, A. (2007, January). Elastic properties, notched strength and fracture criterion in untreated woven jute–glass fabric reinforced polyester hybrid composites. Materials & Design, 28(8), 2287–2294. https://doi.org/10.1016/j.matdes.2006.08.002

[12] Xu, X., Jayaraman, K., Morin, C., & Pecqueux, N. (2008, March). Life cycle assessment of wood-fibre-reinforced polypropylene composites. Journal of Materials Processing Technology, 198(1–3), 168–177. https://doi.org/10.1016/j.jmatprotec.2007.06.087

[13] John, K., & Naidu, S. V. (2004, August). Sisal Fibre/Glass Fibre Hybrid Composites: The Impact and Compressive Properties. Journal of Reinforced Plastics and Composites, 23(12), 1253–1258. https://doi.org/10.1177/0731684404035270

[14] Mohan, R., Kishore, Shridhar, M. K., & Rao, R. M. V. G. K. (1983, March). Compressive strength of jute-glass hybrid fibre composites. Journal of Materials Science Letters, 2(3), 99–102. https://doi.org/10.1007/bf00722222

[15] Mishra, S., Mohanty, A., Drzal, L., Misra, M., Parija, S., Nayak, S., & Tripathy, S. (2003, August). Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites. Composites Science and Technology, 63(10), 1377–1385. https://doi.org/10.1016/s0266-3538(03)00084-8

[16] Ahmed, K. S., & Vijayarangan, S. (2008, October). Tensile, flexural and interlaminar shear properties of woven jute and jute-glass fabric reinforced polyester composites. Journal

of Materials Processing Technology, 207(1–3), 330–335. https://doi.org/10.1016/j.jmatprotec.2008.06.038

[17] Cheung, H. Y., Ho, M. P., Lau, K. T., Cardona, F., & Hui, D. (2009, October). Natural fibre-reinforced composites for bioengineering and environmental engineering applications. Composites Part B: Engineering, 40(7), 655–663. https://doi.org/10.1016/j.compositesb.2009.04.014

[18] Lomov, S., Ivanov, D., Truong, T., Verpoest, I., Baudry, F., Vanden Bosche, K., & Xie, H. (2008, September). Experimental methodology of study of damage initiation and development in textile composites in uniaxial tensile test. Composites Science and Technology, 68(12), 2340–2349. https://doi.org/10.1016/j.compscitech.2007.07.005

[19] Logesh, K., Hariharasakthisudhan, P., Arul Marcel Moshi, A., Rajan, B. S., & K, S. (2019, December 2). Mechanical properties and microstructure of A356 alloy reinforced AlN/MWCNT/graphite/Al composites fabricated by stir casting. Materials Research Express, 7(1), 015004. https://doi.org/10.1088/2053-1591/ab587d

[20] The, D. T., Yoshii, F., Nagasawa, N., & Kume, T. (2003, December 8). Synthesis of poly(butylene succinate)/glass fibre composite by irradiation and its biodegradability. Journal of Applied Polymer Science, 91(4), 2122–2127. https://doi.org/10.1002/app.13345

[21] Johri, N., Mishra, R., & Thakur, H. (2019, January). Synthesis and Characterization of Jute- and Chicken-Feather-Fibre-Reinforced Polymer Hybrid Composites. Mechanics of Composite Materials, 54(6), 821–832. https://doi.org/10.1007/s11029-019-9786-4

[22] Abhijith Vaidya, S., Shreenivasaiah, P., Jayadeva, C., & Satyanarayana, G. (2023, May). Mechanical behaviour evaluation of glass fibre and chicken feather hybrid composite. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2023.05.423

[23] McCarthy, R., Haines, G., & Newley, R. (1994, June). Polymer composite applications to aerospace equipment. Composites Manufacturing, 5(2), 83–93. https://doi.org/10.1016/0956-7143(94)90059-0

[24] Safin, R., Safina, A., Valeev, K., & Fakhrutdinov, R. (2021). Method for Obtaining Composite Material Based on Waste of the Textile Industry and Arabinogalactan. Proceedings of Higher Education Institutions. Textile Industry Technology, 6, 297–302. https://doi.org/10.47367/0021-3497_2021_6_297

[25] Kim, H. S., & Khamis, M. A. (2001, September). Fracture and impact behaviours of hollow micro-sphere/epoxy resin composites. Composites Part A: Applied Science and Manufacturing, 32(9), 1311–1317. https://doi.org/10.1016/s1359-835x(01)00098-7

[26] Yawas, D. S., Sumaila, M., Sarki, J., & Samuel, B. O. (2023, February 27). Manufacturing and optimization of the mechanical properties (tensile strength, flexural strength, and impact energy) of a chicken feather/egg shell/kaolin hybrid reinforced epoxy composite using the Taguchi technique. The International Journal of Advanced Manufacturing Technology, 127(5–6), 2211–2226. https://doi.org/10.1007/s00170-023-11108-7

[27] Bahl, S., Cambow, R., & Kumar Bagha, A. (2020). An experimental study to measure the acoustical properties of natural fibres at real case broadband excitations. Materials Today: Proceedings, 28, 1279–1284. https://doi.org/10.1016/j.matpr.2020.04.228 \

[28] Prasad, D. S., Shoba, C., & Ramanaiah, N. (2014, January). Investigations on mechanical properties of aluminum hybrid composites. Journal of Materials Research and Technology, 3(1), 79–85. https://doi.org/10.1016/j.jmrt.2013.11.002

[29] Yawas, D. S., Sumaila, M., Sarki, J., & Samuel, B. O. (2023, February 27). Manufacturing and optimization of the mechanical properties (tensile strength, flexural strength, and impact energy) of a chicken feather/egg shell/kaolin hybrid reinforced epoxy composite using the Taguchi technique. The International Journal of Advanced Manufacturing Technology, 127(5–6), 2211–2226. https://doi.org/10.1007/s00170-023-11108-7

[30] Bahl, S., Cambow, R., & Kumar Bagha, A. (2020). An experimental study to measure the acoustical properties of natural fibres at real case broadband excitations. Materials Today: Proceedings, 28, 1279–1284. https://doi.org/10.1016/j.matpr.2020.04.228 \

[31] Prasad, D. S., Shoba, C., & Ramanaiah, N. (2014, January). Investigations on mechanical properties of aluminum hybrid composites. Journal of Materials Research and Technology, 3(1), 79–85. https://doi.org/10.1016/j.jmrt.2013.11.002

[32] Johnson, P., Aurtherson, P. B., Suthan, R., & Madhu, S. (2022, December 5). Experimental investigation of pineapple fibre and calcinated poultry egg shell powder epoxy composites. Biomass Conversion and Biorefinery, 13(5), 4385–4392. https://doi.org/10.1007/s13399-022-03609-4