engineering proceedings

MDPI

Proceeding Paper

Experimental Analysis of Mechanical Properties of Banana Fibre/Eggshell Powder-Reinforced Hybrid Epoxy Composite †

Velmurugan Ganesan [1,*], Jasgurpreet Singh Chohan [2], Ganga Shree Subburaj [1], Hariharan Panneerselvam [1], Kudimi Yaswanth Nagabhushanam [1], Mukesh Kannan Venkatesan [1] and Deepthi Jebasingh [1]

[1] Institute of Agricultural Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai 602 105, Tamil Nadu, India; gangashree500@gmail.com (G.S.S.); hariharanpanneerselvam2817@gmail.com (H.P.); yaswanth11111111@gmail.com (K.Y.N.); mukeshkannan233@gmail.com (M.K.V.); binijebasingh243@gmail.com (D.J.)
[2] Department of Mechanical Engineering, University Centre for Research and Development, Chandigarh University, Gharuan, Mohali 140 413, Punjab, India; jasgurpreet.me@cumail.in
* Correspondence: velresearch032@gmail.com
† Presented at the International Conference on Processing and Performance of Materials, Chennai, India, 2–3 March 2023.

Abstract: Natural fibre–polymer composites are widely used because they are economical and ecologically beneficial in a variety of applications. In order to improve its performance, this study focuses on examining the mechanical characteristics of an epoxy composite material that has been reinforced with banana fibre mats that have undergone NaOH treatment. Additionally, using various configurations both with and without eggshell powder (ESP), the compression moulding method was used to fabricate and investigate the impact of ESP on these mechanical qualities. The results showed that the composite with 25 weight percent banana fibre and 2.5 weight percent ESP had the maximum tensile strength (31.21 MPa), bending strength (33.69 MPa), and impact strength (2.84 kJ/m^2). Strong interfacial adhesion between the banana and eggshell components was discovered via the microscopic examination of shattered surfaces. Notably, compared to untreated banana composites, the alkaline-treated banana materials showed fewer occurrences of pull-outs and fractures, leading to noticeably better mechanical performance.

Keywords: interfacial adhesion; mechanical properties; alkaline treatment; banana fibre; eggshell powder

Citation: Ganesan, V.; Chohan, J.S.; Subburaj, G.S.; Panneerselvam, H.; Nagabhushanam, K.Y.; Venkatesan, M.K.; Jebasingh, D. Experimental Analysis of Mechanical Properties of Banana Fibre/Eggshell Powder-Reinforced Hybrid Epoxy Composite. *Eng. Proc.* **2024**, *61*, 18. https://doi.org/10.3390/engproc2024061018

Academic Editors: K. Babu, Anirudh Venkatraman Krishnan, K. Jayakumar and M. Dhananchezian

Published: 31 January 2024

1. Introduction

Fibres are used to create materials with significantly varied biochemical, physiological, and mechanical behavior for a variety of purposes, with desirable attributes such as high durability and low weight. Polymer-based composites are employed as lightweight, resilient, and durable materials in a variety of industries. Polymers are often classified into two types: thermoplastics and thermosets. Thermoplastics are actively taking over like the biofibre matrix; the most frequently employed thermoplastic materials are polyethylene, polypropylene, and polytrichloroethylene, while thermosetting matrix elements are phenol, urethane, and polyesters [1,2]. Several of the latest and most advanced nano- and micro-reinforcement elements are employed in polymeric technologies. Natural fibres may be used as reinforcement in composite materials in a variety of ways to produce a wide range of composite materials. When contrasted to a clean composite, which consists of a pure textile mat with such a matrix mixture, the production of polymer-based hybrids using natural fibre and fillers can eliminate voids and improve physical properties [3]. Fibres are now widely employed in a variety of industrial industries, including the automobile, maritime, and geotechnical fields. It has several advantages, including strong recyclability, complete recyclability, compostability, cheap production costs, low density, low emissions, large specific mechanical behavior, and excellent thermal and acoustical qualities [4].

On the other extreme, natural fibre combinations have a few negative characteristics, like incompatibilities between hydrophobic natural fabrics and hydrophobic polymeric substrates. Banana fibre is mostly composed of cellulose, lignocellulose, and phenol. Inside the crop, the banana fibre acts as hyphae to transport the plant's sap. It can be found between the hypothalamus and the epidermis [5]. Banana fibre has some significant advantages over the other fibres, such as recyclability, good stiffness, and reasonably high flexural strength, and it is an excellent alternative to traditional fibres in many circumstances; however, it also comes with a few significant drawbacks, such as high crudeness and rigidity, low expandability, and openness to pathogen infection. The fibres' treatment might enhance the interfacial bonding among biomaterials [6,7]. Chemical treatment is among the most common, convenient, and cost-effective methods of treatment for fibre surfaces. The elimination of lignin by NaOH processing of fibres alters the tensile properties of a fibre. The elimination of lignocellulosic materials by NaOH enhances the exterior purity of the fibre. As cellulose fibres are eliminated, the interstitial area becomes less thick and far less stiff, allowing the fibres to reorganise themselves along a plane of distortion. With the help of NaOH and 5% fresh water at a good temperature, the hydrophilicity of fibres was brought back with a commercially available resin called polyester [8]. The tensile properties of the fibres were enhanced by 15% by adopting these settings. Also, the delamination strain of polyester network fibres treated with NaOH was 90% higher than that of polyester matrix fibres that were been treated. Unsaturated polyester resin is used as a substrate due to its strong toughness; nevertheless, when combined with nano clay (NC), it increases break steadfastness. Several additives have indeed been employed to alter the polymeric matrix, increasing the interface toughness and, as a result, the dynamic characteristics of the hybrids [9]. The use of NC as a filler in polymeric materials is aimed at enhancing the materials' tensile, thermodynamic, and barrier properties. The introduction of NC alters the composite's composition. The diffusion of NC in polymers, for instance, exhibits better characteristics compared to unmodified polymeric materials. As fillers are added to the polymer, the characteristics of the base material alter; such fillers enhance the efficiency of the composite materials. For cost-effective considerations, mineral fillers are employed with industrial polymers to modify physical, electric, and thermophysical properties. Eggshell powder (ESP) is an artificial infill with a molecular structure similar to limestone. ESP offers strong strength features such as tensile and compressive durability, as well as minimal water retention [10,11].

The innovative use of banana fibre and eggshell powder as hybrid reinforcements in epoxy composites is the foundation of the current research's originality. By reusing a waste material, this creative technique not only investigates the improvements in mechanical properties made possible by this special combination but also supports sustainability objectives. This investigation presents an integrated and ecologically conscious approach to material development by fusing materials science, sustainability, and mechanical engineering. It seeks to reveal the opportunity for more resilient and sustainable hybrid materials with a variety of potential uses across industries. The present investigation seeks to enhance the mechanical characteristics (tensile, impact, and flexural) of a NaOH-treated banana fibre mat, ESP, and epoxy matrix nanocomposite. The above-mentioned nanomaterials were created using a compression moulding approach with a motorised swirling procedure for blending the filler ingredients.

2. Experimental Work

2.1. Materials

As a matrix, epoxy resin was employed for the present research. Butha Industries, Bangalore, Karnataka, India, supplied the matrix materials. Due to its low cost and ease of production, ESP is an essential, sustainable filler. Eggshells include calcium as well as potassium, arsenic, silver, iron, manganese, sulphur, and tin. Ball milling was used to create the ESP of white shells. The banana fibre mat with 300 GSM was used as a reinforcement material. The same material was purchased from the local area of Salam, Tamil Nadu, India. The hybrids were created by combining various weight percentages of banana fibre (20, 25, and 30 wt.%) with fixed ESP (2.5 wt.%).

2.2. NaOH Treatment of Banana Fibres

The banana fabric mats were cleaned with refined water before the production process to remove contaminants from the textile mats. Then, it was immersed in a 5% water–salt solution (NaOH). The fibre mat was completely scrubbed, dried, and then submerged in liquid for 45 min. The materials were then gently scrubbed again before being dried at 40 °C.

2.3. Composite Fabrication

As indicated in Table 1, all hybrid configurations were created using a compression moulding process. A banana mat was chopped into 300×300 mm^2 dimensions. The fibre-to-resin proportion was 1:3. The banana was obtained in the amount of 40 g, and the plates were produced using 110 g of epoxy. These matrix material/ESP solutions were dynamically mixed in a hydrodynamic shear blender at 500 RPM for 10 min at room temperature to improve dispersal but then kept in a pressure furnace to eliminate the bubbling. When the bubbles were removed, the mixture was combined with a hardener and sprayed onto the banana mats that were placed within the mould. The mould was then sealed and maintained at 170 °C and 15 bar pressure in a compressed moulding machine, and the composites were dried at ambient temperature for twenty-four hours.

Table 1. Fibre and filler composition of fabricated composites.

Sl.No	Sample Description	Symbol	Fibre Weight %	Filler Weight %	Matrix Weight %
1	Banana/Resin	A	30	-	70
2	Banana/ESP/Resin	B	25	2.5	72.5
3	Banana/ESP/Resin	C	30	2.5	67.5
4	Banana/ESP//Resin	D	20	2.5	77.5

2.4. Material Characterization

Tensile samples were created in accordance with ASTM D3039 [12]. The cross-section of the sample is $250 \times 25 \times 3$ mm^3. Tension examinations were carried out using a universal testing machine with a load capability of 50 kN. During the research, a consistent gauge length of 40 mm and measurement velocity of 5 mm/min were followed. The Charpy instrument was used to assess the fracture toughness in accordance with the ASTM D256 [13] specification. The cross-section of the sample was $65 \times 13 \times 3$ mm^3. The impact test was carried out using impact test equipment with a capacity of 20 J. The results of this experiment showed that the samples consumed a median amount of energy. The flexural test of nanomaterials was performed using an ASTM D790 [14] bending testing machine, with a sample size of $125 \times 12.7 \times 3$ mm^3. The microstructural analysis of the fractured specimen was carried out using the scanning electron microscope (SEM).

3. Result and Discussion

3.1. Tensile Strength

Figure 1 shows the specimen images of before and after the fractures from tensile and flexural testing. The tensile properties of untreated and NaOH-treated banana fibre-reinforced polymers are shown in Figure 2. The mechanical stability of the composite increased marginally with the inclusion of fillers in the banana fibres, both with and without processing. The tensile strength increased more rapidly in NaOH-treated composites. Banana fibres' surface roughness can be increased by NaOH treatment. The process causes the microstructure of the fibre to inflate, which might result in a rise in the area of the surface and roughness. More opportunities for mechanical and chemical interaction between the fibres and the matrix are provided by this improved surface roughness [15]. This demonstrates the poor surface binding of the material and substrate, which would be due to the inclusion of pectin and phenol in the untreated samples compared to the treated ones. The 20 and 30 weight percent inclusions of banana fibre offer less strength than the 25 weight percent. More fibre exceeding the 25 weight percent will result in more moisture absorption. The energy from the applied load may be easily transmitted if the content is less than 25 percent weight. It decreased the tensile strength of the substance [16]. At 25 weight percent banana fibre and 2.5 weight percent eggshell powder, the treated composites' tensile characteristics were determined to be adequate. This is so that the 25 percent of banana fibre can convey the imposed stress without breaking because it takes more energy for this type of fibre to separate the fibrous bundle. The alkaline-processed hybrid banana/ESP filler composites were characterised as exhibiting homogenous distribution and minimal aggregation in the epoxy matrix. As a result, it is suggested that the filler's homogeneous dispersion and less aggregation must have a much more efficient mechanism in the enhancement of tensile strength properties [17].

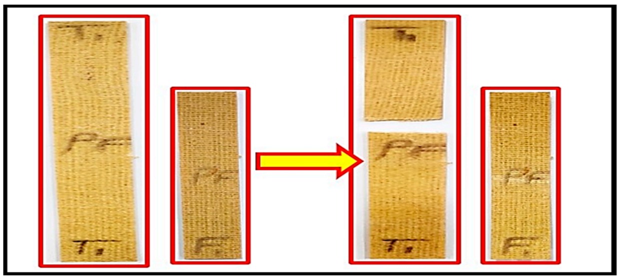

Figure 1. Shows the specimen images of before and after fractures from tensile and flexural testing.

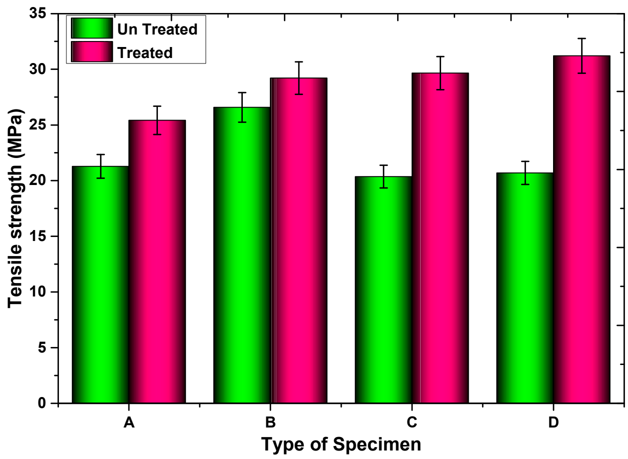

Figure 2. Tensile strength of untreated and NaOH-treated composites of banana/EPS-based hybrid composites.

3.2. Flexural Strength

The variance in the flexural strength of both raw and processed banana fibre-based hybrids is shown in Figure 3. With processed banana fibre materials, the flexural strength of a composite increases. Compared to untreated composites, the NaOH-treated hybrid banana/ESP composites increased by 21%. This occurrence could be explained by the fact that the addition of filler either improves the composite's flexural strength (sodium hydroxide improves the interfacial bonding among the nanocomposites with filler in the mixing board) or the fluff structure shields strain transmission during the flexing loading of the specimens. According to the results, the clean combination of treated and untreated samples displayed less strength than the additive mixture. Lignin, hemicellulose, and pectin are impurities found in natural fibres like bananas. Through a process known as saponification, NaOH treatment aids in the removal of these impurities. These contaminants are broken down into soluble components by sodium hydroxide, making them simple to wash away [18]. Natural fibres that have undergone this washing process are cleaner and purer. The polymer matrix used in the process also makes the natural fibres more wettable. The NaOH treatment increases the fibre surface's hydrophilicity or its attraction to polar substances like water. During the production of composites, this greater wettability enables the polymer matrix to enter and attach to the fibre surface more efficiently. The hydroxyl molecules on the fibre interface and the functional molecules in the structure of the polymer may react chemically more quickly as a result of the alkaline treatment. As a result, covalent connections among the fibre and matrix may develop, improving the interfacial bonding of both substances. This helped improve the flexural properties of the hybrid composites [19].

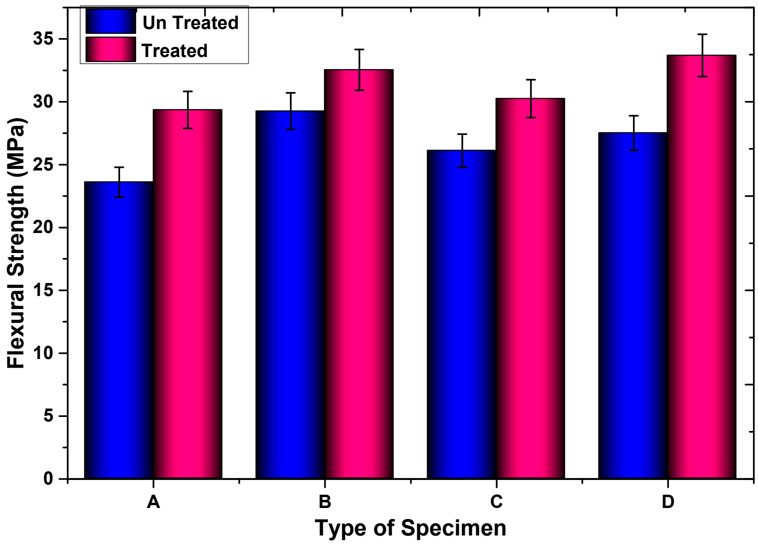

Figure 3. Flexural strength of untreated and NaOH-treated composites of banana/EPS-based hybrid composites.

3.3. Impact Strength

Endurance is a crucial criterion for freshly formed materials in engineering fields. The Charpy technique is used to estimate the composite's strength properties. The quantity of force needed to break the object is used to calculate its strength properties. The mixture of fracture initiation and crack growth is referred to as energies. The phenomena are determined by factors such as fibre-to-matrix adherence, polymer, and fibre tenacity independently, flaws in fibre and matrix packaging, crystallisation structure, and others. The influence of impact resistance on the hybrid's filler loading of both treated and untreated banana fibre-based composites was studied.

Figure 4 shows that the NaOH-treated hybrid padding materials have a somewhat higher impact on durability than untreated materials. Due to a number of reasons, the hybrid composite's NaOH-treated banana fibre with 2.5 weight percent eggshell powder (ESP) probably has the maximum impact strength. The NaOH treatment improves the interfacial adhesion between the epoxy matrix and banana fibre, which enables more efficient stress transmission during impact. The composite's exceptional impact resistance is achieved by proper dispersion of these components within the epoxy matrix and ideal processing conditions, making it the clear option for applications requiring robustness against impact pressures [20]. Due to its optimal loading proportion, which strikes an equilibrium between excellent dispersion and keeping an adequate fraction of reinforcement, 25 weight percent of banana fibre is preferred in composite materials for achieving higher mechanical strength.

This results in better stress distribution and load-bearing capacity. This loading percentage is in line with the particular manufacturing and processing techniques employed in the study and ensures better impregnation and wetting of the banana fibres by the matrix, lowering the danger of fibre clustering and stress concentration spots. Furthermore, it is possible that the choice of 25 wt.% as the best option for maximising durability in these hybrids was impacted by the diversity in mechanical tests and sample sizes [21].

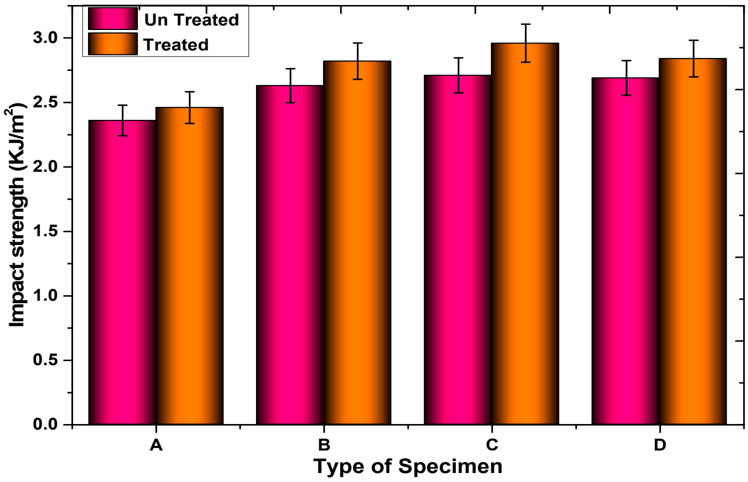

Figure 4. Impact strength of untreated and NaOH-treated composites of banana/EPS-based hybrid composites.

3.4. Microstructural Examination

In the course of our analysis, we carefully examined SEM images obtained from several composite specimens made up of diverse mixtures of NaOH-processed and unprocessed materials. The interfacial relationships between the fibres and matrix were clearly seen in these SEM micrographs, especially when it came to treated and untreated fabric categories, as shown in Figure 5a,b. The investigations showed that, compared to the hybrid composites, the banana fibre/epoxy-based (Figure 5a) composites had instances of fibre pullouts and debonding events, which are signs of insufficient binding among the filler and the base material and present as voids on the damaged surfaces [22]. Notably, it was determined that the existence of air gaps could be seen as a factor in lowering the composite strength. Additionally, the comparison shown in Figure 5b highlights the spatial arrangement of eggshell powder (ESP) in the structure of the matrix. The polymer epoxy matrix seemed to have a good distribution of the hybrid filler comprising banana fibre. These findings highlight the importance of filler dispersion and pullout phenomena, fabric-matrix attachment, and the existence of air voids as major causes of the strength loss seen in this hybrid laminate structure [23].

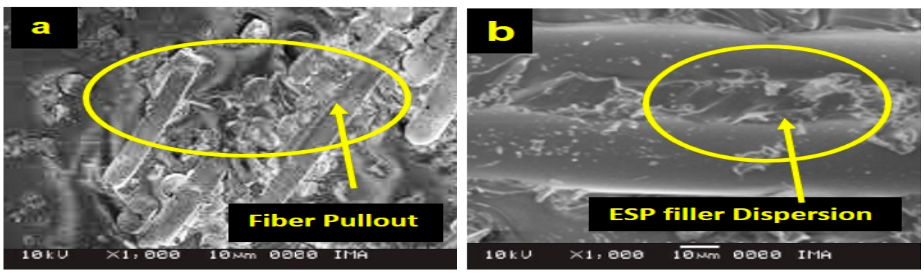

Figure 5. SEM image of banana-based hybrid epoxy composites (**a**) without ESP filler; (**b**) with ESP filler after tensile testing.

4. Conclusions

In conclusion, this study's experimental research on the mechanical characteristics of a hybrid epoxy material reinforced with banana fibre and eggshell powder has shed important light on the possibilities of using discarded eggshells and natural fibres as fillers in epoxy composites. The results imply that adding these environmentally friendly fillers can greatly improve the mechanical qualities of materials made of epoxy.

- By combining banana fibre with ESP (2.5 wt%), the resulting hybrid composites exhibit remarkable improvements in both flexural and tensile properties. The synergy between banana fibre (25 wt%) and ESP (2.5 wt%) plays a pivotal role in enhancing the impact resistance of the composites. In comparison to the empty resin, the mentioned combinations effectively enhanced the tensile strength by 11%, the flexural strength by 8.9%, and the impact strength by 12%.
- The existence of voids on the fracture surface is frequently used as evidence that there has been an occurrence of fibre extractions and separating events, which can lead to inadequate interaction between the filler and the substrate.
- The microstructure's apparent air holes cause the composites' overall strength to decline. It is notable that the hybrid filler in the epoxy matrix reinforced with banana fibres appeared to be evenly distributed in this investigation.

The experimental examination's findings still provide a solid basis for prospective research and development projects aiming at developing eco-friendly material combinations with improved mechanical characteristics, thereby advancing the development of environmentally friendly engineering solutions.

Author Contributions: Conceptualisation, V.G. and J.S.C.; methodology, G.S.S. and H.P.; writing—original draft preparation, V.G.; review and editing, K.Y.N.; supervision, D.J. and M.K.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Singh, S.P.; Dutt, A.; Hirwani, C.K. Experimental and Numerical Analysis of Different Natural Fiber Polymer Composite. *Mater. Manuf. Process.* **2023**, *38*, 322–332. [CrossRef]
2. Mylsamy, B.; Aruchamy, K.; Subramani, S.P.; Palaniappan, S.K.; Rangappa, S.M.; Siengchin, S. State of the Art of Advanced Fiber Materials: Future Directions, Opportunities, and Challenges. *Fiber Mater. Des. Fabr. Appl.* **2023**, 357–372. [CrossRef]
3. Radhakrishnan, S.; Khan, A.; Dwivedi, S.P.; Sharma, B.; Gupta, S.; Gupta, P.; Chaudhary, V. Studies on Mechanical, Thermal, and Water Immersion of Plant and Animal Wastage Nanofiller–Based Bio-Fiber-Reinforced Composites. *Biomass Convers. Biorefinery* **2023**. [CrossRef]
4. Sheeba, K.R.J.; Priya, R.K.; Arunachalam, K.P.; Avudaiappan, S.; Maureira-Carsalade, N.; Roco-Videla, Á. Characterisation of Sodium Acetate Treatment on Acacia Pennata Natural Fibres. *Polymers* **2023**, *15*, 1996. [CrossRef]
5. Pokhriyal, M.; Rakesh, P.K.; Rangappa, S.M.; Siengchin, S. Effect of Alkali Treatment on Novel Natural Fiber Extracted from Himalayacalamus Falconeri Culms for Polymer Composite Applications. *Biomass Convers. Biorefinery* **2023**. [CrossRef]
6. Arpitha, G.R.; Jain, N.; Verma, A. Banana Biofiber and Glass Fiber Reinforced Hybrid Composite for Lightweight Structural Applications: Mechanical, Thermal, and Microstructural Characterization. *Biomass Convers. Biorefinery* **2023**. [CrossRef]
7. Rana, R.S.; Singh, I.; Sharma, A.K. Ultrasonic Welding of Banana Fiber Based HDPE Composites with Energy Directors. *Compos. Struct.* **2023**, *320*, 117222. [CrossRef]
8. Ganesan, V.; Kaliyamoorthy, B. Utilization of Taguchi Technique to Enhance the Interlaminar Shear Strength of Wood Dust Filled Woven Jute Fiber Reinforced Polyester Composites in Cryogenic Environment. *J. Nat. Fibers* **2020**, *19*, 1990–2001. [CrossRef]
9. Sosiati, H.; Ma'arif, M.G.; Firmansyah, W.A.; Hamdan, S. Characterization of the Properties of Bio-CaCO3 Waste Eggshell and Abaca Fiber Reinforced Hybrid Composites. *Mater. Sci. Forum* **2023**, *1087*, 1320. [CrossRef]

10. Okokpujie, I.P.; Tartibu, L.K.; Babaremu, K.; Akinfaye, C.; Ogundipe, A.T.; Akinlabi, E.T. Study of the Corrosion, Electrical, and Mechanical Properties of Aluminium Metal Composite Reinforced with Coconut Rice and Eggshell for Wind Turbine Blade Development. *Clean. Eng. Technol.* **2023**, *13*, 100627. [CrossRef]
11. Srivastava, A.K.; Dwivedi, S.; Nag, A.; Kumar, D.; Dixit, A.R.; Hloch, S. Microstructural, Mechanical and Tribological Performance of a Magnesium Alloy AZ31B/Si3N4/Eggshell Surface Composite Produced by Solid-State Multi-Pass Friction Stir Processing. *Mater. Chem. Phys.* **2023**, *301*, 127694. [CrossRef]
12. Ganesan, V.; Shanmugam, V.; Alagumalai, V. Composites Part C: Open Access Optimisation of Mechanical Behaviour of Calotropis Gigantea and Prosopis Juliflora Natural Fibre-Based Hybrid Composites by Using Taguchi-Grey Relational Analysis. *Compos. Part C Open Access* **2024**, *13*, 100433. [CrossRef]
13. Velmurugan, G.; Kumar, S.S.; Chohan, J.S.; Kumar, A.J.P.; Manikandan, T.; Raja, D.E.; Saranya, K.; Nagaraj, M.; Barmavatu, P. Experimental Investigations of Mechanical and Dynamic Mechanical Analysis of Bio-Synthesized CuO/Ramie Fiber-Based Hybrid Biocomposite. *Fibers Polym.* **2023**. [CrossRef]
14. Velmurugan, G.; Suresh Kumar, S.; Chohan, J.S.; Sathish, R.; Panneer Selvan, S.; Muhammed Abraar, S.A.; Elil Raja, D.; Nagaraj, M.; Palani, S. Hybrid Calotropis Gigantea Fibre-Reinforced Epoxy Composites with SiO_2's Longer-Term Moisture Absorbable and Its Impacts on Mechanical and Dynamic Mechanical Properties. *Mater. Res. Express* **2023**, *10*, 115302. [CrossRef]
15. Velmurugan, G.; Natrayan, L. Experimental Investigations of Moisture Diffusion and Mechanical Properties of Interply Rearrangement of Glass/Kevlar-Based Hybrid Composites under Cryogenic Environment. *J. Mater. Res. Technol.* **2023**, *23*, 4513–4526. [CrossRef]
16. Rani, G.E.; Murugeswari, R.; Rajini, N. Detection of Material Strength of Composite Eggshell Powders with an Analysis of Scanning Electron Microscopy. *Bull. Mater. Sci.* **2023**, *46*, 74. [CrossRef]
17. Sarmin, S.N.; Jawaid, M.; Zaki, S.A.; Ali, M.R.; Fouad, H.; Khiari, R.; Rahayu, S.; Salim, N. The Effect of Eggshell Fillers on the Physical, Mechanical, and Morphological Properties of Date Palm Fibre Reinforced Bio-Epoxy Composites. *J. Polym. Environ.* **2023**, *31*, 5015–5027. [CrossRef]
18. Cree, D.; Owuamanam, S.; Soleimani, M. Mechanical Properties of a Bio-Composite Produced from Two Biomaterials: Polylactic Acid and Brown Eggshell Waste Fillers. *Waste* **2023**, *1*, 740–760. [CrossRef]
19. Cree, D.; Soleimani, M. Bio-Based White Eggshell as a Value-Added Filler in Poly (Lactic Acid) Composites. *J. Compos. Sci.* **2023**, *7*, 278. [CrossRef]
20. Maamoun, A.A.; Barakat, M.A.Y.; El-Wakil, A.E.-A.A.; Zulfiqar, S.; Oghenekohwo, V.J. Valorization of Eggshell Waste in Designing Flexible Polyurethane-Based Piezoelectric Composite Materials for Ultrasonic Transducers. *J. Polym. Res.* **2023**, *30*, 286. [CrossRef]
21. Doddashamachar, M.; Sen, S.; Nama Vasudeva Setty, R. A Novel Artificial Neural Network-Based Model for Predicting Dielectric Properties of Banana Fiber Filled with Polypropylene Composites. *J. Thermoplast. Compos. Mater.* **2023**, *36*, 4106–4123. [CrossRef]
22. Latha, A.D.; Kumar, A.S.; Singh, S.J.; Velmurugan, C. Experimental Investigations of Flammability, Mechanical and Moisture Absorption Properties of Natural Flax/NanoSiO_2 Based Hybrid Polypropylene Composites. *Silicon* **2023**, *15*, 7621–7637. [CrossRef]
23. Jagadeesan, R.; Suyambulingam, I.; Divakaran, D.; Siengchin, S. Novel Sesame Oil Cake Biomass Waste Derived Cellulose Micro-Fillers Reinforced with Basalt/Banana Fibre-Based Hybrid Polymeric Composite for Lightweight Applications. *Biomass Convers. Biorefinery* **2023**, *13*, 4443–4458. [CrossRef]