DOI: 10.36108/ujees/5202.70.0162

UNIOSUN Journal of Engineering and Environmental Sciences. Vol. 7 No. 1. March. 2025

Investigation on the Mechanical Properties of Rice Husk and Coconut Fibre Epoxy-Filled Composites for Automotive Application

Ogundana T.O., Madueke C.I.,Oginni O.T., Onuh F.A., Olumoroti I.A., Abioye A.O., Bolaji D.O. and Olumilua A.E.

Abstract Sustainable materials are exploring natural fibres like coir fibres and rice husks as reinforcements in polymer composites due to their high tensile strength, durability, and resistance to corrosion. This research developed and characterized coir fibre and rice husk-reinforced epoxy composites, and evaluated their mechanical, thermal, and water absorption properties. Coir fibres and rice husks were extracted, washed, sun-dried, and treated with sodium hydroxide, forming composites using a hand layup process. The samples underwent rigorous testing for tensile, flexural, impact, and thermal stability using various techniques, providing a comprehensive understanding of natural fibre-reinforced epoxy composites. Treated RH composites exhibit increased water absorption at smaller particle sizes of 425 µm and 600 µm, while treated coir composites demonstrate enhanced water absorption at 1180 µm larger particle sizes. Coir/RH blend composites show consistent water absorption across all particle sizes. The results showed that untreated coir and RH composites exhibited higher flexural strength and impact energy, while 425 µm smaller particle sizes were more effective at reinforcing the composite. Treatment improved hardness in coir composites and thermal stability but reduced impact energy in RH composites. The optimal particle size for maximising impact energy was 425 µm for RH composites. Water absorption tests revealed that treatment increased water absorption in RH composites at smaller particle sizes, while treated coir composites showed the highest water absorption at 1180 µm. Coir/RH blend composites absorb water consistently across all particle sizes. Coir and RH composites that have not been treated have higher flexural strength and impact energy. Treatment improves coir hardness but reduces RH impact energy. The study has significant implications for the development of advanced composites, especially in the automotive and construction sectors.

Keywords: Sustainable materials, coir fibre, rice husk, reinforced epoxy composites, particle sizes

I. Introduction

Humanity has utilized materials for various purposes, with technological advancements based on engineering materials. The need for ecological sustainability has grown, leading to the use of renewable and eco-friendly products, enhancing daily life quality [1]. Numerous efforts have been made to create and promote eco-friendly, energy-efficient, and sustainable composite materials [2].

Composites, composed of long cellulose fibers and lignin, are used in construction, automotive, aeronautics, and household fittings to replace traditional materials in engineering applications,

Ogundana, T. O., Onuh, F. A., Olumoroti, I. A., Bolaji, D. O., Olumilua, A. E.
(Department of Mechanical Engineering . Federal University Oye-Ekiti, Nigeria.)
Madueke, C.I.
(Department of Materials and Metallurgical Engineering . Federal University Oye-Ekiti, Nigeria.)
Oginni, O. T.
(Department of Mechanical Engineering . Bamidele Olumilua University of Education, Ikere-Ekiti, Nigeria.)
Abioye, A. O.
(Department of Civil Engineering . Bamidele Olumilua University of Education, Ikere-Ekiti, Nigeria.)
Corresponding Author:: oginni.olanrewaju@bouesti.edu.ng

focusing on strengths over weaknesses [3,4]. Composite reinforcements like fibres, flakes, and particles enhance the durability and adaptability of composite materials, with fibres being the most commonly used form. These materials are known for their sustainability and environmental preservation [5,6,7,8]. Composite materials are increasingly used in automotive and aerospace due to their superior strength/mass and stiffness/mass ratios. Engineers are exploring techniques to improve performance, design lighter structures, and provide stiffness and strength [9].

Natural fiber-reinforced polymer composites are growing due to their high strength, low weight, corrosion resistance, and aesthetic appeal [10]. Composite materials, reinforced with fiber or particulate materials, enhance load-bearing capacity, tensile strength, stiffness, and modulus, with a growing trend of combining natural fiber and particulate in a single matrix. Composite production relies on common matrix materials like polymers, metals, ceramics, and carbon, which influence properties like binding reinforcement, load transfer, and impact resistance [11]. Composite materials, reinforced with fiber or particulate materials, enhance load-bearing capacity, tensile strength, stiffness, and modulus, with a growing trend of combining natural fiber and particulate in a single matrix [12].

Fibre reinforcement in composite production enhances properties by combining fibres with a matrix, enhancing toughness, resisting deformation, and distributing stress, reducing cracking and delamination risks. Chemical treatment enhances the mechanical properties of coir fibre composites, enhancing their strength and potential for industrial applications [13]. Coir fiber and rice husk were found to enhance the mechanical properties of a polymer composite containing vinyl ester [14]. [15] study on jute, bamboo, and coir natural Fibres revealed that longer test spans increased Young's modulus, while bamboo had higher Young's modulus.

[16] investigated the impact of sodium hydroxide treatment on coconut coir fibre. It was found that 7% and 8% NaOH treatment on coconut coir fibres improved sound absorption properties, indicating optimal performance. [17] tested the mechanical properties of coir fibre reinforced epoxy resin composites for helmet shell fabrication. The optimum impact strength value was achieved at a 30% composition, indicating its use for helmet shell fabrication. [18] studied the impact of rice husk and rice husk ash on coconut fibre reinforced polyester composites. Results showed that flexural strength decreases with rice husk ash and rice husk content, while Vickers hardness increases.

Automotive dashboards are made from materials like thermoplastics, polyurethane, or PVC, offering durability, impact, hardness, heat resistance, thermal stability, chemical resistance, UV stability, and a high gloss finish [18]. Traditional dashboard materials like polypropylene, polyurethane, acrylonitrile butadiene styrene (ABS), polycarbonate (PC), thermoplastic olefin (TPO), polyvinyl chloride (PVC), and polyurethane foam (PUF) are cost-effective, easy to process, and balance-enhancing but have environmental impacts, limited recyclability, and brittle fracture potential. Renewable materials like RH and coir epoxy reinforcement composites offer lightweight, cost-effective, and eco-friendly alternatives for automotive applications due to their lower density, higher tensile strength, and thermal stability [19].

Epoxy-filled composites, incorporating natural fibers, are being explored as sustainable materials in the automotive industry to improve the environmental impact of vehicle components. The dashboard of an automobile is made of natural reinforced fibers like coir and rice husk, which are low-cost, low-density, and unique, enhancing driver comfort and structural integrity while reducing environmental impact [20]. Rice husk, a natural waste material from rice-producing countries, is used in various industries due to its high silica content and potential for building materials, fuel, insulation, and fertilizer. Rice husk, an abundant, low-cost, eco-friendly waste, is being explored as a filler in polymer composites due to its cellulose content, recyclability, and high specific strength [21].

Coir composites are versatile and suitable for various industries such as building materials, automotive components, furniture, packaging, marine, and aerospace. Coir, a natural fibre reinforcement in polymer composites, offers cost-effective, eco-friendly alternatives but faces challenges like moisture absorption and unpredictable properties due to its hydrophilic nature. Research on coir's mechanical properties and applications has been limited, particularly in its hybridization with rice husk. The automotive industry is exploring sustainable, lightweight dashboard materials to combat hydrophilic and thermally unstable materials [22].

This research explores the development, challenges, and potential uses of composites made from rice husk and epoxy, focusing on the mechanical characteristics of these environmentally friendly alternatives, highlighting the importance of understanding their interplay. It explores the effect of different size particles on coir fibre's mechanical properties and develops new composite materials with improved properties, potentially replacing conventional materials in the automotive industry. The impact of fibre treatment and epoxy matrix formulation on thermal stability, structure, moisture absorption, and optimal processing conditions for sustainable automotive composites was investigated.

II. Materials and Method

The use of hybrid rice husk and coconut fibre epoxy-filled composites in automotive dashboards was investigated to improve performance, reduce fuel consumption, and prevent corrosion. The study utilized coir fibre and rice husk as natural fibres to create a composite material and compared its properties with a hybrid composite. Rice husk, with a high ash content, 92-95% silica, lightweight, porous, and a large exterior surface area composite, was prepared using coconut fiber, rice husk, epoxy, and a hardener.

The brown coir extracted from ripped coconut husks was utilized for coir fiber production, as well as white coir from unripe coconuts. The coconut fibres were extracted from the husk, washed with clean water to remove pits and other dirt, and sun-dried for three days to remove the coir. The coir samples were prepared by extracting mature coconut husk from Nigerian farmers, washing, sun-drying, grinding, and dividing into two parts. The treated part was treated with sodium hydroxide, while the untreated part was oven-dried. The RH was obtained from Nigeria's rice milling sector, dried in the sun for three days, and ground into varying fiber lengths using a grinding machine, then separated using a sieve shaker machine.

Coir and RH fibers undergo chemical treatment with sodium hydroxide, including drying, washing, immersion, cleaning, and drying for five days to eliminate moisture, a process repeated for both fibers. Samples were sieved using three sieve sizes (1.18 mm, 600 microns, and 425 microns) to determine their particle size and the prepared samples for composite production. Composites were prepared using ASTM E1131, varying coir fiber and RH weights. Fibers and epoxy were mixed, then hardener was added as shown in Figure 1. A releasing agent was applied to prevent sticking, and the mixture was cured for 24 hours before removal.

The preparations for casting using an epoxy matrix utilize sieve sizes A (0-425 µm), B (426-600 µm), and C (601-1180 µm) for sieving. The study explores composite productions for sieve sizes A, B, and C using treated coir and (RH), varying epoxy mass to 100 g.

Figure 1: Mixing of Samples Components

Thermo Gravimetric analysis (TGA) was conducted on RH and coir composites using a DTG-60 H SHIMADZU apparatus to determine thermal stability and weight loss, following ASTM E1131 standard. The biomineral content of isolated samples was determined using FTIR, aiming to identify compounds, optimize material quality, and predict final product performance. Platinum-coated samples and scanning electron microscope (SEM) instruments were used to evaluate fibre uniformity and orientation in fibre-reinforced epoxy-filled composites, optimizing design and production and enhancing performance for researchers and manufacturers. The flexural strength and modulus of the fibre-reinforced epoxy composite were tested using a universal testing machine, with the specimen placed on supports with a 130 mm span length and 5 mm/min loading rate.

The impact test assessed composite materials' resistance to impact loads, crucial for industrial applications, especially automotive, following the ASTM D7066/D7066M standard, using a dropped weight or pendulum for damage measurement. The tensile test was conducted on fibre-reinforced polymer matrix composite bars using ASTM D7565M-10(2017), determining their tensile properties for industrial applications with a constant 2 mm/min load. The ASTM D570-98 (2018) method was used to assess the water absorption capacity of composite materials, ensuring they meet specifications through physical and mechanical analysis.

III. Results and Discussion

The developed composite samples for tensile, water absorption, impact tests, flexural, SEM, TGA, and FTIR tests are presented in Figures 2 and 3.

A. Flexural Test Result Analysis

i. Flexural test for treated and untreated coir

The test examined the flexural behavior of composite materials under bending forces, ensuring their integrity and safety. Results of Figure 4 showed that untreated coir had higher flexural strength than treated coir and decreased with particle size increase, highlighting the importance of composite material integrity. The

Figure 2: Composite Samples for Tensile, Water Absorption and Impact Test

Figure 3: Composite Samples for Flexural, SEM, TGA and FTIR Test

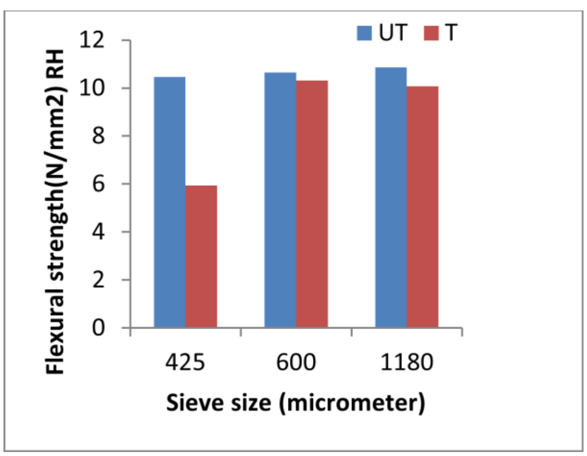

Figure 4: Flexural Strength Properties for 10% RH Reinforcement Composite

study reveals that untreated coir with smaller particle sizes is more effective in reinforcing epoxy composites due to a weaker interface, suggesting the need for re-evaluation of the treatment process.

ii. Flexural test for treated and untreated RH

Figure 5 shows the impact of treated and untreated coir and RH on composite flexural properties. Untreated RH's particle size doesn't significantly influence its strength, suggesting RH's inherent properties determine its reinforcement potential. Treatment improves RH's strength, with larger particle sizes resulting in greater improvements. The study reveals that untreated RH exhibits higher flexural strength than treated RH due to potential damage or degradation, suggesting consistent particle size is more effective for composite reinforcement.

iii. Flexural test of hybridized treated and untreated RH and coir

Figure 6 reveals that the flexural strength of hybrid coir and rice husk in epoxy composites decreases with particle size increase, suggesting smaller particle sizes are more effective. Untreated composites show higher flexural strength at larger particle sizes, suggesting treatment may damage the reinforcing material.

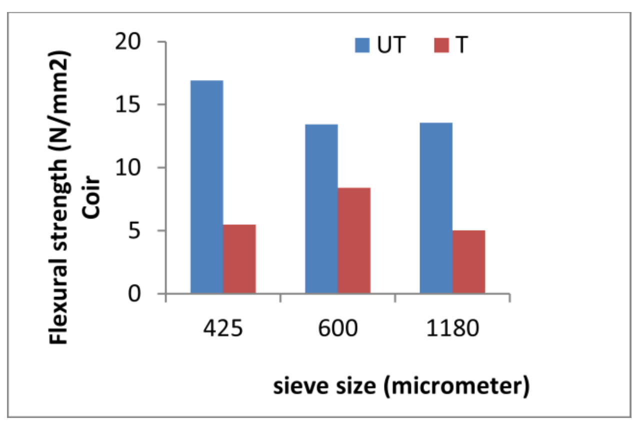

Figure 5: Flexural Strength Properties for 10% Coir Reinforcement Composite

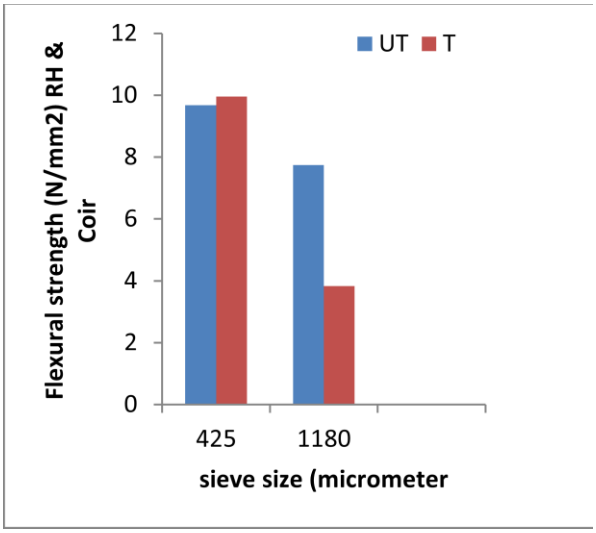

Figure 6: Flexural Strength Properties for 10% Coir/RH Reinforcement Composite

B. Hardness Test Result Analysis

Figures 7 to 10 present the hardness properties for varying percentages of coir/RH-reinforced composite hardness of a 5% coir epoxy-filled composite for 425, 600, and 1180 sieve sizes. Results show that larger particles provide better wear protection, and treated composites have higher hardness than untreated ones. The treatment process significantly impacts coir's properties, enhancing mechanical behavior.

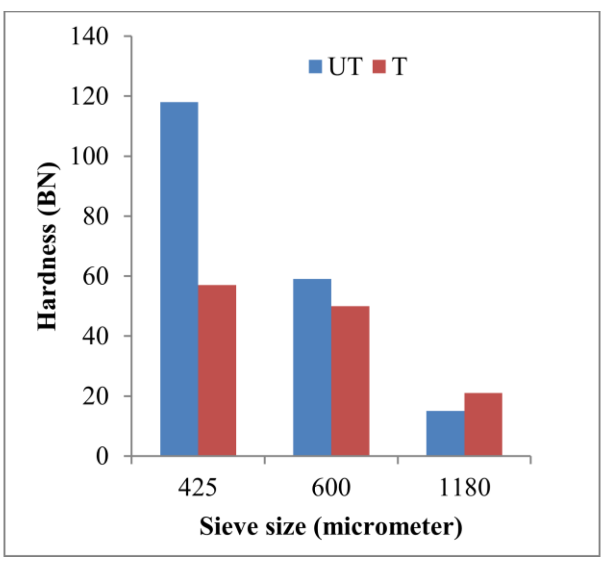

Figure 7: Hardness Properties for 5% RH Reinforced Composite

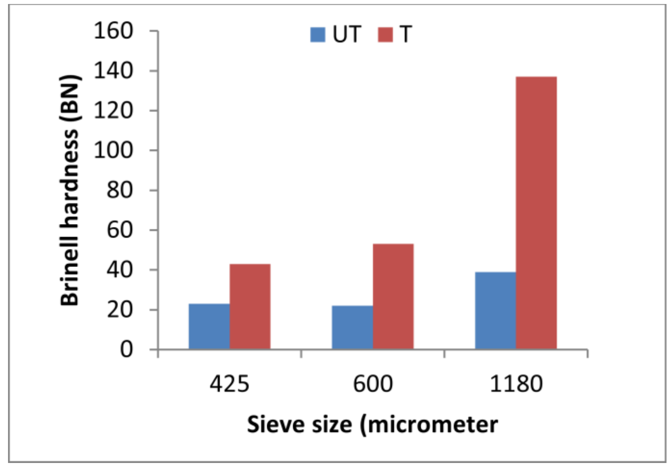

Figure 8: Hardness Properties for 10% RH Reinforced Composite

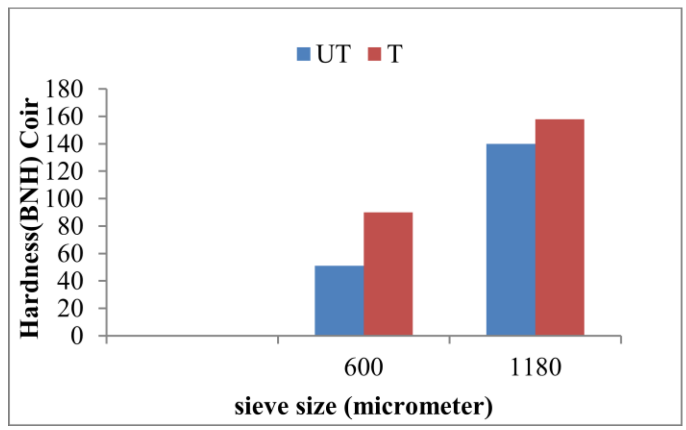

Figure 9: Hardness Properties for 5% Coir Reinforced Composite

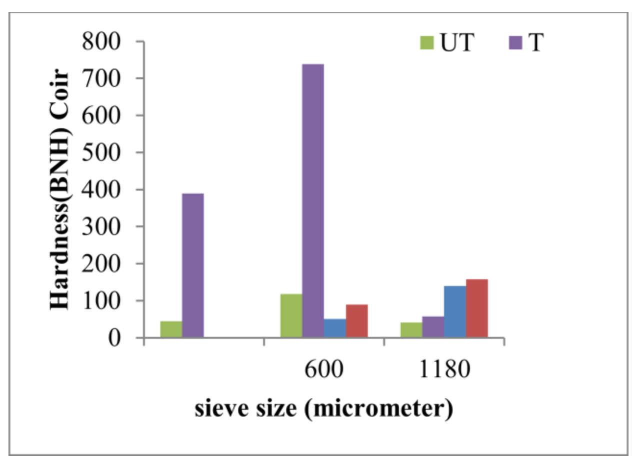

Figure 10: Hardness Properties for 5% and /10% coir/RH Reinforced Composite

C. Impact Energy Results Analysis

i. Impact energy for 10% volume fraction of RH.

Rice husk composites exhibit lower impact energy compared to untreated ones for all particle sizes, with a greater reduction in smaller particles (425 µm and 600 µm) than larger ones (1180 µm) as presented in Figure 11. Untreated composites have higher impact energy values.

ii. Impact energy for 10% volume fraction of coir/RH

Figure 12 reveals that coir/RH composites have a significant impact on energy enhancement at particle sizes of 425 µm and 1180 µm, while the treatment has a minimal effect at 600 µm.

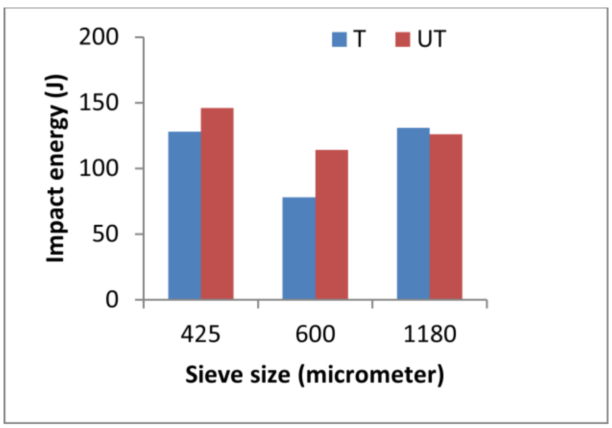

Figure 11: Impact Energy Properties for 10% RH Reinforced Composite

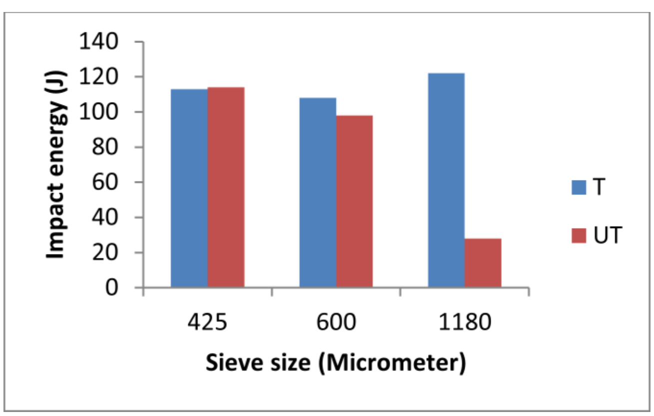

Figure 12: Impact Energy Properties for 10% coir/RH Reinforced Composite

D. Tensile Strength Test Results Analysis

Tensile tests on samples revealed that treatment significantly affects the tensile strength of RH composites, depending on particle size as presented in Figures 13 and 14. Composites treated at 600 µm showed improved strength, while those treated at 425 µm and 1180 µm showed reduced strength. The study reveals that RH composites treated with different particle sizes enhance tensile strength, with the highest strength at 600 µm, while treatment reduces strength at 425 µm and 1180 µm.

i. Tensile strength of treated and untreated coir

Figure 15 showed the tensile strength properties for 10% coir/RH reinforcement composite.

Treated and untreated coir and RH as fillers were compared, finding that treated coir composites have higher tensile strength values than untreated RH composites. The highest tensile strength value is significantly higher for treated coir.

ii. Tensile strength properties of treated and untreated coir/RH

Figure 16 demonstrates that treatment significantly enhances the tensile strength of coir/RH composites, with the highest value recorded at 1180 µm (15.491 N/mm²). These results range from 87% to 343% compared to untreated composites, indicating that this particle size is optimal. The study reveals that treatment significantly enhances the tensile strength of coir/RH composites at all particle sizes, with the highest strength at 1180 µm (15.491 N/mm²), 343% higher than untreated composites. Treatment also improves composites at 425 µm and 600 µm, with greater impact at larger particle sizes.

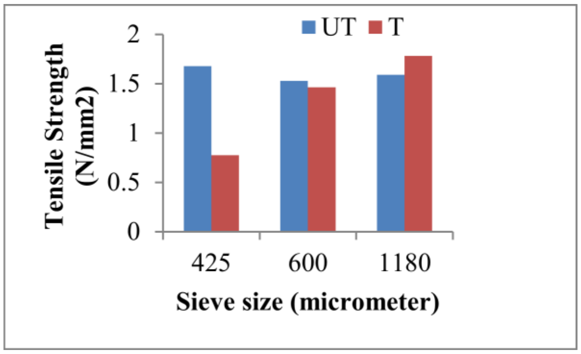

Figure 13: Tensile Properties for 5% RH Reinforcement Composite

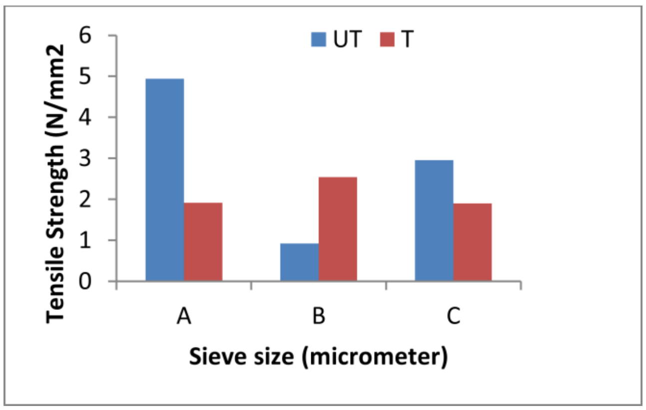

Figure 14: Tensile Strength Properties for 10% RH Reinforcement Composite

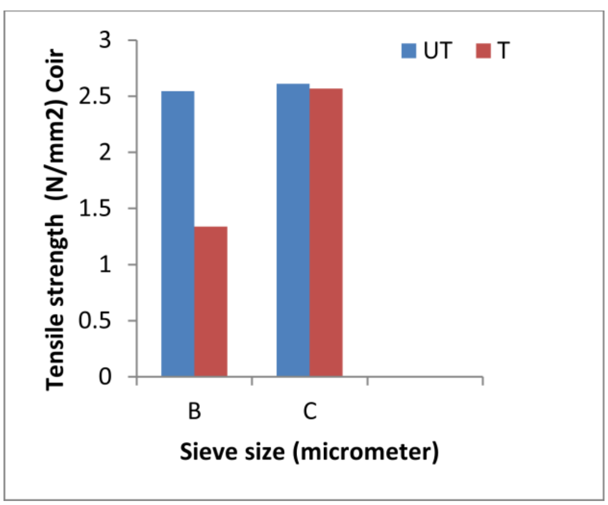

Figure 15: Tensile Strength Properties for 5% Coir Reinforcement Composite

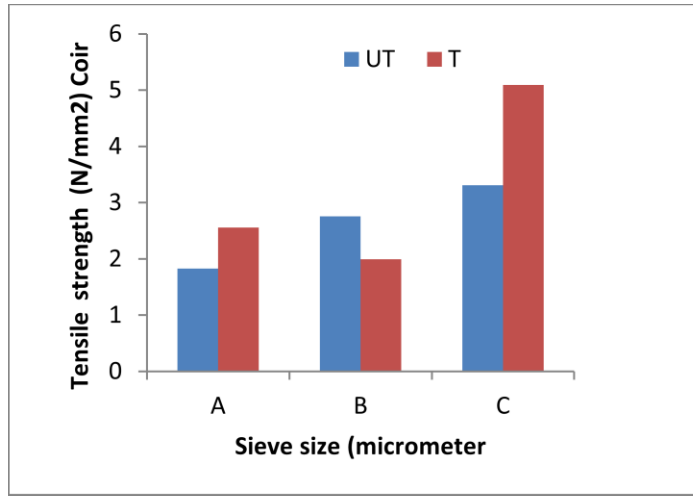

Figure 16: Tensile Strength Properties for 10% Coir Reinforcement Composite

E. Water Absorption Properties Test Results Analysis

i. Water absorption properties for the RH composite

Table 1 reveals that the water absorption properties of treated and untreated RH composites vary based on particle size, with treatment increasing absorption at smaller sizes (425 µm and 600 µm) and decreasing at larger ones (1180 µm), respectively. The study reveals that RH composites' water absorption is influenced by particle size, with treatment improving absorption at smaller sizes (425 µm and 600 µm) and decreasing it at larger ones (1180 µm), with the optimal size being 425 µm.

ii. Water absorption properties of coir composite

The experimental results of Table 1 show that treated coir composites have higher water absorption percentages than untreated ones at all particle sizes. The highest water absorption percentage was observed at 1180 µm (18.51%),

Table 1: Water Absorption Test Results

S/N	Sample	W_1 (g)	W_2 (g)	W_A (%)
1	Untreated RH 600mic 5/95	78.8	69.4	11.93
2	Untreated RH 1.18mm 5/95	96.7	91.6	5.27
3	Untreated RH 425mic 5/95	90.4	85.9	4.98
4	Untreated RH 600mic 10/90	92.1	83.8	9.01
5	Untreated RH 1.18mm 10/90	89.2	80.6	9.64
6	Untreated RH 425mic 10/90	91.9	80.6	12.30
1	Treated Coir 600mic 5/95	70.3	60.8	13.51
2	Treated Coir 1.18mm 5/95	77.3	67.9	12.16
3	Treated Coir 425mic 10/90	84.6	73.3	13.35
4	Treated Coir 1.18mm 10/90	91.8	74.8	18.51
5	Treated Coir 600mic 10/90	72.5	65.0	10.34
6	Treated Coir 425mic 3/97	74.9	63.3	15.48
1	Untreated Coir 1.18mm 5/95	96.2	70.2	27.02
2	Untreated Coir 425mic 10/90	84.0	77.5	8.13
3	Untreated Coir 425mic 5/95	80.7	73.5	8.92
4	Untreated Coir 1.18mm 10/90	84.0	77.2	8.09
5	Untreated Coir 600mic 10/90	66.4	59.0	11.14
6	Untreated Coir 600mic 5/95	81.3	74.6	8.36
7	Untreated Coir 425mic 3/97	73.8	66.1	10.43
1	Treated RH 1.18mm 10/90	84.1	77.9	7.62
2	Treated RH 600mic 10/90	93.2	83.2	10.73
3	Treated RH 425mic 5/95	70.4	65.5	6.96
4	Treated RH 1.18mm 5/95	88.3	81.4	7.81
5	Treated RH 600mic 5/95	93.2	85.3	8.47
6	Treated RH 425mic 10/90	99.5	86.1	13.46
1	Untreated RH/Coir 425mic 10/90	86.2	79.4	7.89
2	Untreated RH/Coir 600mic 10/90	65.1	56.5	13.21
3	Untreated RH/Coir 1.18mm 10/90	75.9	66.7	12.12
4	Treated RH/Coir 600mic 10/90	82.1	74.1	9.74
5	Treated RH/Coir 1.18mm 10/90	60.5	55.1	8.92
6	Treated RH/Coir 425mic 10/90	88.8	81.2	8.55

while untreated coir had the lowest at 425 µm (8.13%). The treated coir composite showed a significant increase at 1180 µm (18.51%) compared to the untreated counterpart (8.09%). Treatment significantly enhances water absorption in coir composites, with increases of 64%, 15%, and 129% compared to untreated coir. The highest absorption percentage (18.51%) is observed at 1180 µm, making coir composites suitable for high water absorption capacity applications.

iii. Water absorption properties of coir/RH composite

It was observed in Table 1 that treating coir/RH composites increases water absorption at smaller particle sizes but decreases at larger ones, potentially improving durability and resistance to water exposure. Untreated composites have higher water absorption percentages, with the highest at 600 μm (13.22%). The treated coir/RH composites have higher water absorption percentages than untreated ones at all particle sizes, with the highest value at 600 μm (9.89% treated) and the lowest at 425 μm (8.55% treated). Untreated composites have higher absorption percentages at larger particle sizes.

The treated and untreated coir and R as fillers were compared, finding that treated coir composites have higher tensile strength values than untreated RH composites. The highest tensile strength value is significantly higher for treated coir.

F. Thermal stability of the composites

The TGA test was conducted to assess the thermal stability of samples, evaluating factors such as onset temperature, endset temperature, and organic waste residue as presented in Figures 17 to 22. Onset temperature indicates better thermal stability, while endset temperature indicates a prolonged decomposition phase. Samples with higher endset temperatures can withstand higher temperatures over a long period. Organic waste residue is preferred for good thermal stability. Top samples with the highest onset and endset temperatures and lower residues show better thermal stability. Samples with low residue percentages show effective decomposition and minimal remaining material. The best samples for overall performance with high thermal stability are A4 (TRH 90/10) and sample F4 (URH 90/10).

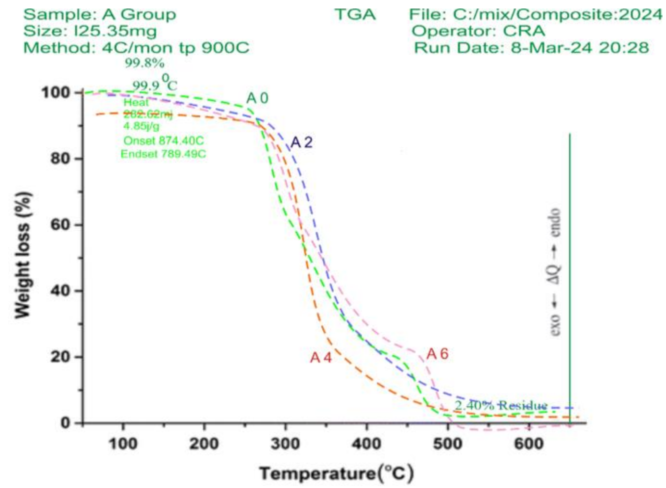

Figure 17: TGA Results for Group A Samples

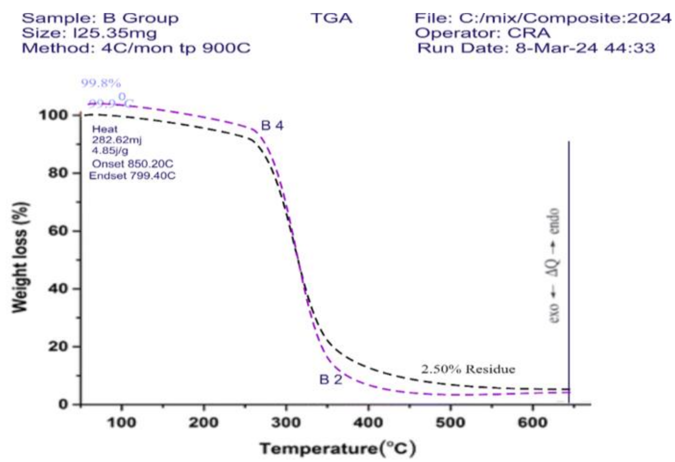

Figure 18: TGA Results for Group B Samples

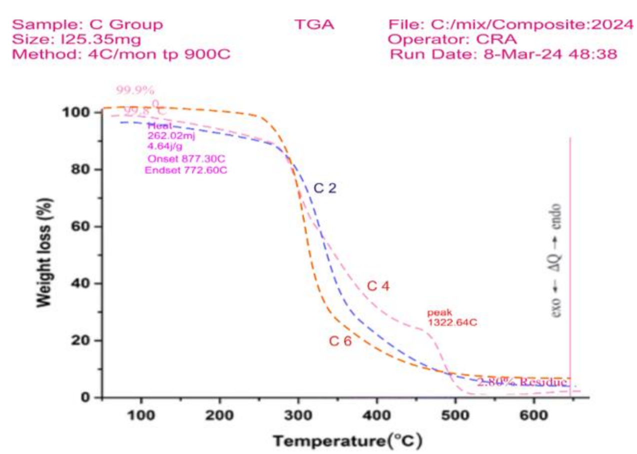

Figure 19: TGA Results for Group C Samples

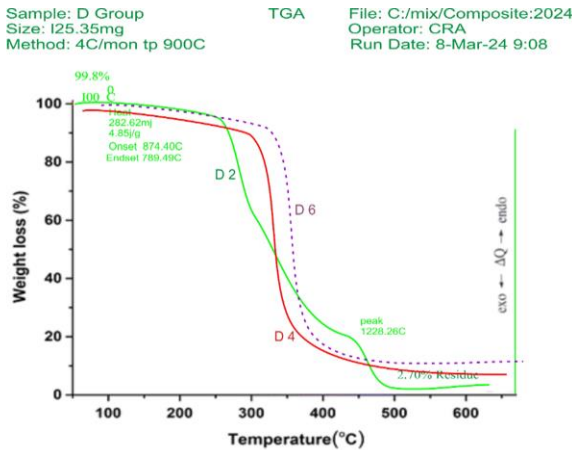

Figure 20: TGA Results for Group D Samples

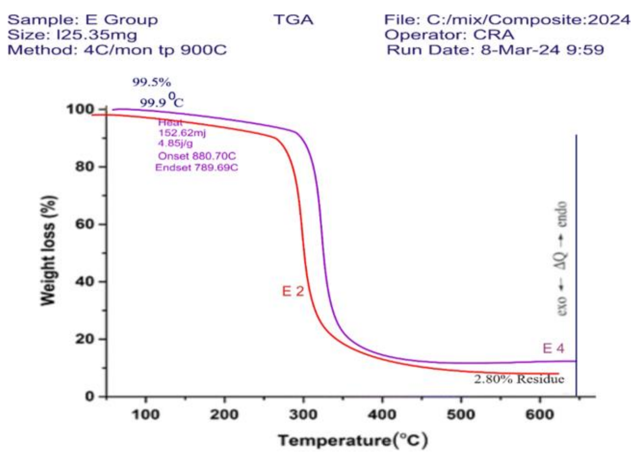

Figure 21: TGA results for Group E Samples

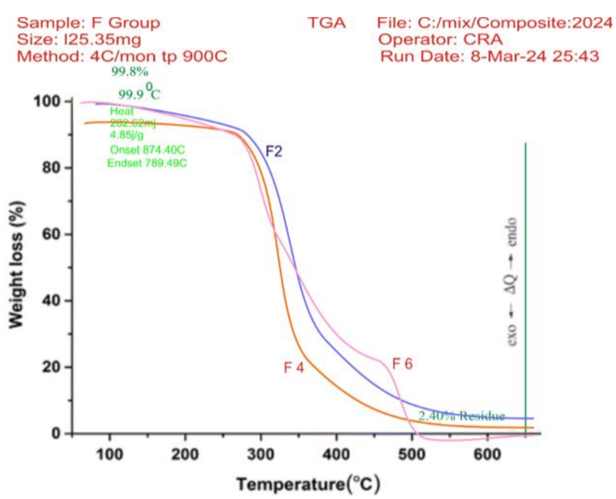

Figure 22: TGA Results for Group F Sample

G. FTIR Results Analysis

The FTIR analysis of fibre reinforced epoxy-filled composite material reveals functional groups such as hydroxyl groups, amino groups, alkyl groups, carbonyl groups, C=C stretching, ether groups, and alkyl halide groups, suggesting the presence of epoxy resin, polymer chains, additives, degradation products, and impurities, potentially useful in automotive applications. The study reveals that moisture absorption, epoxy resin presence, additives, unsaturated bonds, ether linkages, and impurities affect material properties in automotive applications. Sample E4 is the most suitable material for dashboard applications due to its presence of epoxy resin, absence of hydroxyl groups, ether linkages, lower alkyl halide intensity, and balanced functional groups. Further testing and characterization are needed for specific automotive applications.

IV. Conclusions

The study explores the use of natural and renewable materials like coir and rice husk for composite reinforcement in the automotive industry, focusing on lightweight materials for fuel efficiency and vehicle performance, and highlighting the unique reinforcement combination's potential for sustainable practices. The study found that untreated coir and rice husk-reinforced epoxy composites have higher flexural strength and impact energy, while smaller particle sizes (425 µm) are more effective. Treatment improved coir composite hardness but reduced RH composite impact energy. The study reveals that RH composite treatment enhances water absorption at smaller particle sizes (425 µm and 600 µm) but decreases it at larger ones (1180 µm), thereby improving tensile strength. The study suggests using smaller particle sizes (425 µm) and untreated coir and RH for reinforcement of epoxy composites, with the optimal particle size for treated coir/RH composites being 1180 µm for tensile strength. The study provides insights into particle size effects and practical guidance for industry applications, demonstrating that hybridized materials can be lighter while maintaining stiffness performance.

.

References

[1] Choi, J.Y., Jeon, J.H., Lyu, J.H., Park, J., Kim, G.Y., Chey, S.Y., Quan, Y.J., Bhandari, B., Prusty, B.G. and Ahn, S.H. Current applications and development of composite manufacturing processes for future mobility. *International Journal of Precision Engineering and Manufacturing-Green Technology*, vol.10 No. 1, 2023, pp 269-291. https://doi.org/10.1007/s40684-022-00483-3.

[2] Ganasan, V., Chohan, J.S., Subburaj, G.S., Harika, K., Yedari, V., Sivakumar, N.S., Raheena, S. and Durai, A.J. Mechanical, moisture absorption, and thermal stability of banana fiber/eggshell powder-based epoxy composites. *Engineering Proceedings*, vol. 61 No. 1, 2024, pp 11-25. https://doi.org/10.3390/engproc2024061011.

[3] Verma, D. P., Gope, A., Shandilya, A., Gupta, M.K. and Maheshwari, G. Coir Fibre Reinforcement and Application in Polymer Composites: A Review. *J. Mater. Environ. Sci.* vol. 4, No. 2, 2013, pp 263-276, ISSN: 2028-2508.

[4] Wang, S., Zheng, Z., Long, J., Wang, J., Zheng, K., Ke, Z., Luo, Z., Pokrovsky, A.I., and Khina, B.B. Recent advances in wear-resistant steel matrix composites: A review of reinforcement particle selection and preparation processes. *Journal of Materials Research and Technology*, vol. 29, No. 1, 2024, pp 1779-1797. https://doi.org/10.1016/j.jmrt.2024.01.195.

[5] Ahmed, H., Noyon, M.A., Uddin, M.E., Jamal, M. and Palaniappan, S.K. Biodegradable and flexible fiber-reinforced composite sheet from tannery solid wastes: an approach of waste minimization. *Polymer Composites,* vol. 44, No. 11, 2023, pp 7545-7556. https://doi.org/10.1002/pc.27644.

[6] Akter, M., Uddin, M.H. and Anik, H.R. Plant fiber-reinforced polymer composites: a review on modification, fabrication, properties, and applications. *Polymer Bulletin*, vol. 81, No. 1, 2024, pp 1-85. https://doi.org/10.1007/s00289-023-04733-5.

[7] Chichane, A., Boujmal, R. and El-Barkany, A. Bio-composites and bio-hybrid composites are reinforced with natural fibers. *Materials Today: Proceedings*, vol. 72, 2023, pp 3471-3479. https://doi.org/10.1016/j.matpr.2022.08.132.

[8] Nasri, W., Djebali, R., Chamkha, A. J., Bezazi, A., Mechighel, F., Reis, P. and Driss, Z. Thermal behavior of mesoporous aramid fiber-reinforced silica aerogel composite for thermal insulation applications: microscale modeling. *Journal of Applied and Computational Mechanics,* vol. 10, No. 1, 2024, pp 140-151.

https://doi.org/10.22055/jacm.2023.44601.4247.

[9] Sharma, S., Sudhakara, P., Misra, S.K. and Singh, J. A comprehensive review of current developments on the waste-reinforced polymer-matrix composites for automotive, sports goods, and construction applications: Materials, processes, and properties. *Materials Today: Proceedings*, vol. 33, 2020, pp 1671-1679. https://doi.org/10.1016/j.matpr.2020.06.523.

[10] Abhishek T.H.M., G.K. Mrutyunjaya G. Evaluation of Mechanical and Water Absorption Behavior of Coir and Rice Husk Reinforced Composites. *International Journal of Research in Engineering and Technology*, vol. 5, No. 3, 2016, pp 89-94.

[11] Umma A. Utilization and Mechanical Properties of Rice Husk as Useful Agro Waste and Reinforcement in Composites Fabrication: A Critical Review. *African Journal of Engineering and Environment Research*. vol. 3, No. 2, pp 102-116. ISSN: 2635-2974.

[12] Timothy K. Mulenga, Albert U. Ude, and Chinnasamy V. Concise review on the mechanical characteristics of hybrid natural fibres with filler content. *AIMS Materials Science,* vol. 7, No. 5, 2020, pp 650–664. DOI: 10.3934/matersci.2020.5.650.

[13] Samia S. Mir, Syed M. N. Hasan, Md. J. Hossain, and Mahbub H. Chemical Modification Effect on the Mechanical Properties of Coir Fiber. *Engineering Journal*. Vol. 16, No. 4, 2012, pp 83-97. ISSN 0125-8281, doi:10.4186/ej.2012.16.2.73.

[14] Vasanta V. C., Udayakumar P. A. and Ramalingaiah. Mechanical characterization of coir and rice husk-reinforced hybrid polymer composite. *International Journal of Innovative Research in Science, Engineering, and Technology*, vol. 2, No. 8, 2013, pp 97-115.

[15] Subhankar Biswas, Qumrul Ahsan, Ahmed Cenna, Mahbub Hasan, and Azman Hassan. Physical and Mechanical Properties of Jute, Bamboo, and Coir Natural Fiber. *Fibers and Polymers*, vol. 14, No. 10, 2013, pp 1762-1767. DOI 10.1007/s12221-013-1762-3 No. 10.

[16] Sanjay, M.R., Arpitha, G.R., Naik, L.L., Gopalakrishna, K. and Yogesha, B. Applications of Natural Fibers and Their Composites: An Overview. *Natural Resources*, vol. 7, No. 1, 2016, pp 108-114.

[17] Chizoba O. and Edith I. Mechanical Properties of Coir Fiber Reinforced Epoxy Resin Composites for Helmet Shell; *Industrial Engineering Letters*, vol. 5, No. 7, 2015, pp 122-134.

[18] Santos, T.F., Santos, C.M., Aquino, M.S., Suyambulingam, I., Kamil Hussein, E., Verma, A., Rangappa, S.M., Siengchin, S. and Nascimento, J.H. Towards sustainable and eco-friendly polymer composite materials from bast fibers: a systematic review. *Engineering Research Express*, vol. 12, No. 2, 2024, pp 55-62. https://doi.org/10.1088/2631-8695/ad2640.

[19] Bujjibabu G., Chittaranjandas V., Ramakrishna M. and Nagarjuna K.

Investigation on Mechanical, Thermal, and Water Absorption Properties of Banana/Coir-Reinforced Polypropylene Hybrid Composites. *Journal of Composite and Advanced Materials*. vol. 30, No. 4, 2020, pp 123-131.

[20] Valasek, P., Müller, M., Sleger, V., Kolar, V., Hromasova, M., D'Amato, R. and Ruggiero, A. Influence of Alkali Treatment on the Microstructure and Mechanical Properties of Coir and Abaca Fibers. *Materials*. vol. 14, No. 2, 2021, pp 26-36.

[21] Libo Y., Nawawi C., Liang H. and Bohumil K. Effect of alkali treatment on microstructure and mechanical properties of coir fibers, coir fiber-reinforced polymer composite, and reinforced cementitious composite. *Construction and Building Materials,* vol. 112, 2016, pp 168-182.

[22] Patel, M., Pardhi, B., Chopara, S. and Pal, M. Lightweight composite materials for automotive: a review. *International Research Journal of Engineering and Technology,* vol. 5, No. 11, 2018, 41-47.