STATISTICAL ANALYSIS OF GLASS FIBRE EPOXY COMPOSITES REINFORCED WITH RICE WASTE

Nur Farhana Barahim[1], Nurul Amira Zainal[1], Sayed Kushairi Sayed Nordin[1] and Irianto Harny[2]
[1]Fakulti Teknologi dan Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
[2]Department of General Education, Faculty of Resilience, Rabdan Academy, Abu Dhabi, United Arab Emirates
E-Mail: nurulamira@utem.edu.my

ABSTRACT

The utilization of natural waste-based materials in engineering has garnered growing interest due to their environmental sustainability and material efficiency. This study quantitatively investigates the effect of rice waste as filler on the mechanical properties of glass fibre epoxy hybrid composites. The experimental design includes the fabrication of composite samples with varying rice waste filler content (10%, 40%, 50%, and 70% by weight), produced via the hand lay-up technique. Specimens were machined to ASTM standards using a CNC router. Mechanical characterization was conducted through tensile, flexural, and impact testing, generating quantitative performance data. Statistical analysis, including Analysis of Variance (ANOVA) and regression modeling, was performed using Minitab software to assess the significance of rice waste content on mechanical responses. Results indicate statistically significant effects of filler ratio on tensile strength ($p < 0.05$), flexural strength ($p < 0.05$), and impact resistance ($p < 0.05$). The optimal filler content was identified based on multi-response optimization criteria, balancing mechanical performance across all tests. These findings support the viable integration of agricultural waste in structural composite materials and provide a statistically robust foundation for future material development.

Keywords: rice waste, hybrid composite, mechanical properties, ASTM, ANOVA.

Manuscript Received 6 April 2025; Revised 18 October 2025; Published 15 November 2025

1. INTRODUCTION

The growing global emphasis on sustainability and environmental conservation has significantly influenced materials research, particularly in the field of composite materials. One emerging area is the integration of natural waste-based fillers into polymeric composites, driven by both environmental benefits and performance potential [1, 2]. Among various agricultural wastes, rice waste comprising husk, bran, and straw is abundant, low-cost, and often underutilized, making it a promising candidate for sustainable material development [3, 4].

Composite materials, typically composed of a reinforcement (such as glass fibre), a matrix (such as epoxy resin), and an optional filler, offer tailored mechanical properties for a wide range of engineering applications [5-7]. Glass fibres are known for their excellent tensile strength and stiffness, while epoxy resins contribute to good adhesion, chemical resistance, and durability. The inclusion of fillers such as rice waste can further enhance mechanical performance while simultaneously addressing ecological concerns through effective waste valorization [8,9]. Despite the known benefits of using natural fillers, studies specifically evaluating the mechanical performance of glass fibre epoxy hybrid composites filled with rice waste remain limited. The fibrous and lignocellulosic characteristics of rice waste suggest it has reinforcing potential when embedded in polymer matrices. However, a systematic investigation is necessary to optimize its content and assess its influence on key mechanical properties such as tensile strength, flexural strength, impact resistance, and water absorption.

This study aims to fill this research gap by fabricating rice waste-filled glass fibre epoxy composites at various mixing ratios and evaluating their mechanical performance. The specimens are produced via the hand lay-up technique, machined to ASTM standards, and tested using established mechanical procedures. To ensure a rigorous analysis, the results are interpreted using statistical methods with the aid of Minitab software, allowing the identification of the optimal filler ratio and evaluation of the composite's performance under different conditions. Through this work, we aim to demonstrate the viability of rice waste as a sustainable filler, contribute to the advancement of eco-friendly composite technologies, and provide quantitative insights for future material design leveraging natural agricultural by-products.

2. MATERIALS PREPARATION

The experimental procedures implemented in this investigation are explained in this chapter. It includes the selection of materials, specimen preparation, testing methods, and data analysis techniques that are used to examine the mechanical properties of rice waste epoxy composites. To guarantee the reliability and validity of the research findings, a methodical approach is implemented.

2.1 Raw Material

The main materials employed in this study consist of woven glass fiber mats, which act as the primary reinforcement, contributing to structural strength and improving the mechanical properties of the composite. The matrix consists of epoxy resin combined with a hardener in a 3:1 ratio, which facilitates adequate curing and optimal adhesion between the matrix and the reinforcement. Rice waste, obtained from agricultural processes, is utilized as a filler material [10]. The material undergoes a systematic procedure to be processed into a fine powder. This includes drying for 36 hours to minimize moisture content, grinding with an electric grinder to attain a uniform texture, and sieving to guarantee consistent particle size. The combination of these materials results in the fabrication of a hybrid composite intended for the evaluation of mechanical properties.

2.2 Specimen Fabrication

The specimens were fabricated using the hand lay-up technique, a widely used method for producing composite materials. Glass fibre sheets were first cut to the desired size and placed into a mold. Subsequently, a mixture of epoxy resin, hardener, and rice waste filler was poured layer by layer over the glass fibre. Each layer was carefully compacted to minimize the presence of air bubbles and ensure uniform distribution of the composite materials. The assembled composite was then left to cure at room temperature for 48 hours to achieve full hardness. This fabrication process yielded consistent specimens with minimal defects, in line with standard hybrid composite manufacturing practices [11].

2.3 Specimen Preparation

After 48 hours of drying and curing, the composite samples were sectioned using a CNC router, following ASTM standards. A total of five different filler ratios were tested, and for each mechanical test, five specimens per ratio were prepared, resulting in a total of 100 test specimens. Before cutting, precise planning was undertaken to ensure dimensional accuracy and compliance with testing standards. For tensile and flexural tests, specimens were cut to dimensions of 250 mm × 25 mm, with five samples allocated per ratio, as per ASTM guidelines [11]. Impact test specimens were prepared according to ASTM D790, with dimensions of 60 mm × 15 mm × 10 mm and included a 45-degree V-notch to facilitate fracture. For the water absorption test, specimens were cut to 30 mm × 15 mm, ensuring consistency across all test conditions.

2.4 Mechanical Testing

Mechanical testing was carried out to evaluate the performance characteristics of the fabricated composites. Tensile tests were conducted using a 100 kN Universal Testing Machine (Shimadzu) at a crosshead speed of 5 mm/min to determine the tensile strength and modulus of the specimens. Flexural tests were also performed using the same machine, equipped with a three-point bending fixture, to assess the bending resistance of the composites. To evaluate the composites' impact energy absorption capacity, Charpy impact tests were conducted using a pendulum impact tester. In addition, water absorption tests were performed to determine the composites' resistance to moisture uptake. For this, specimens were first weighed in their dry state, then immersed in distilled water at room temperature. The percentage of water absorption was calculated using Equation (1) provided in the reference below [11].

$$Mt(\%) = \frac{M_2 - M_1}{M_1} \tag{1}$$

2.5 Data Analysis

The analysis of data was performed utilizing Minitab statistical software. The statistical significance of differences in mechanical properties among the varying rice waste weight fractions is assessed using Analysis of Variance (ANOVA) [12]. Following this, Tukey’s Honestly Significant Difference (HSD) test was employed to determine specific weight fractions that demonstrated significant variations in their mechanical properties.

3. RESULTS AND DISCUSSIONS

3.1 Impact Test Results

Composite specimens were struck with a 150-degree pendulum to fracture. This experiment quantified the energy absorbed. This parameter is essential since it reveals the material's ability to withstand sudden extreme overloads. Energy absorption indicates impact resilience, hardness, and energy dispersion [13]. Charpy impact test using ASTM D256, and the sample is shown in Figure-2. As the specimen fragmented, energy absorption increased to 2.3898 J with a 50% Rice Waste (RW) and 50% Epoxy Resin (ER) ratio. At 70% rice waste, energy absorption reduced to 2.1908 J as displayed in Figure-3. Energy absorption is optimized by equal RW and ER fractions due to structural integrity and bonding. This gives sufficient proof to reject the null hypothesis. Table-1 shows that ANOVA revealed composite ratio-related energy absorption changes with a p-value of 0.009. Tukey's test showed that 10RW90ER absorbed more energy than the other ratios. This study emphasizes the material ratio's energy absorption role.

3.2 Flexural Test Results

Composite materials are tested for bending durability, tensile, and compressive strengths utilizing a three-point flexural analysis following ASTM D790. The sample of the test is shown in Figure-4. As presented in Figure-5, 10RW90ER had the maximum flexural strength (82.32 MPa), surpassing 40RW60ER (29.58MPa), 50RW50ER (19.56MPa), and 71RW30ER (20.25MPa). Table-2 shows the ANOVA of flexural strength RWER composites, with p-values below the predetermined significance level of $\alpha = 0.05$. There is enough evidence to reject the null hypothesis, which states that all group means are the same (P-value =)

ARPN Journal of Engineering and Applied Sciences

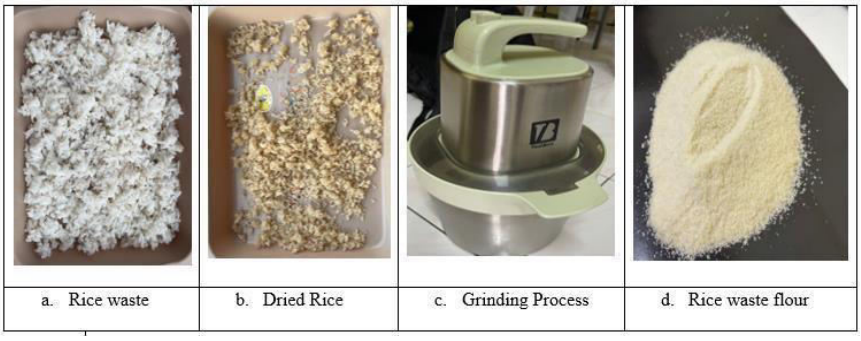

Figure-1. Rice waste powder step processes (a) Raw rice waste (b) Dried rice waste (c) Grinding process (d) Rice waste flour.

Figure-2. Impact test sample.

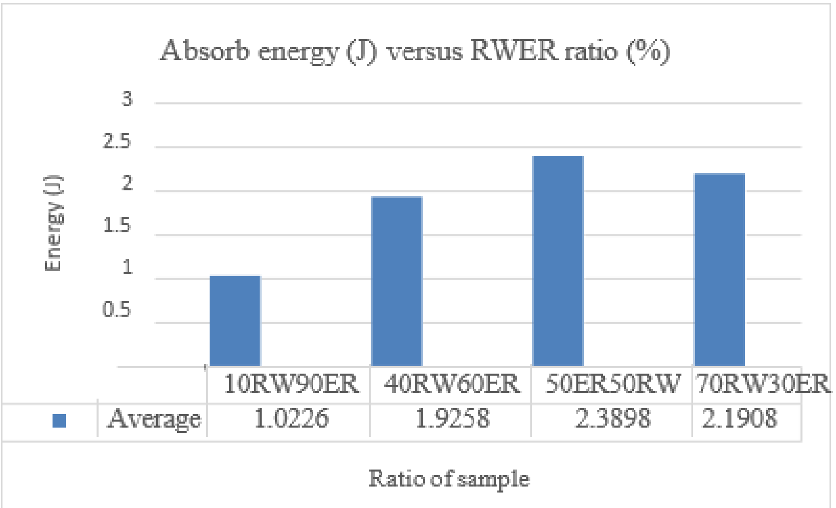

Figure-3. Graph of Absorb Energy (J) versus RWER Ratio (%).

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-1. ANOVA of tensile strength for ratios of RWER composite.

Source	DF	SS	MS	F-Value	P-Value
Ratio	4	4996.1	1249.01	126.16	0.000
Error	20	198.0	9.90		
Total	24	5194.1			

Figure-4. Sample of flexural testing.

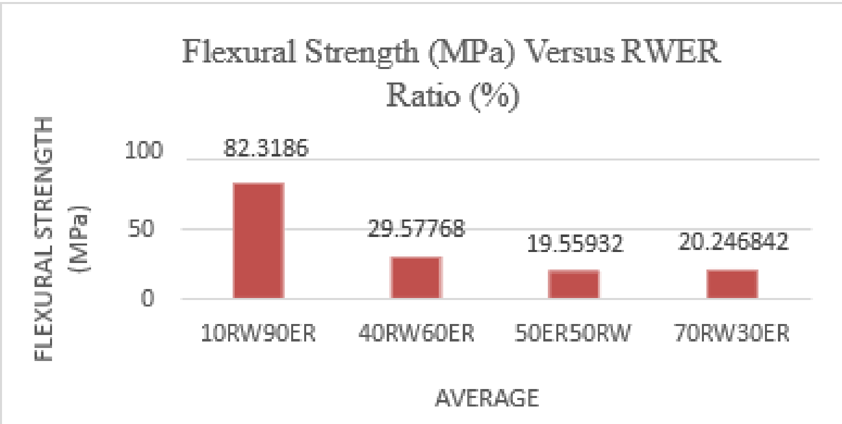

Figure-5. Graph of Flexural Strength (MPa) Versus RWER ratio (%).

Table-2. ANOVA of flexural strength for ratios of RWER composite.

Source	DF	SS	MS	F-Value	P-Value
Ratio	3	13451	4483.81	48.40	0.000
Error	16	1482	92.63		
Total	19	14934			

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

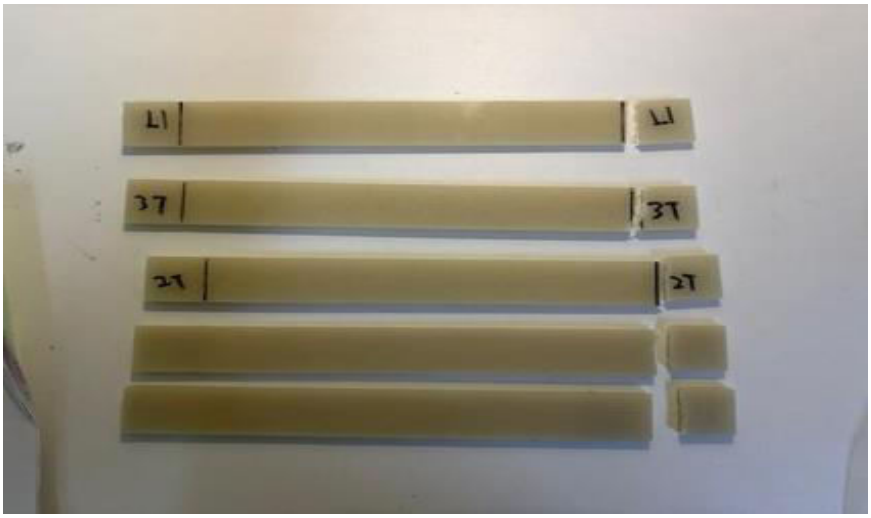

Figure-6. Sample of tensile testing.

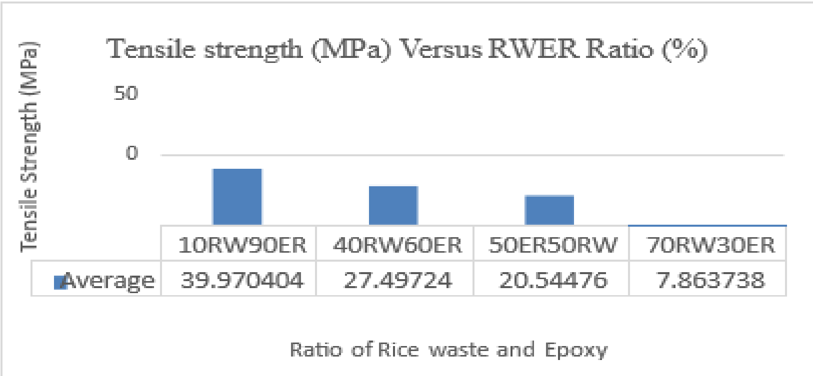

Figure-7. Graph of Tensile Strength (MPa) Versus RWER ratio (%).

Table-3. ANOVA of tensile strength for ratios of RWER composite.

Source	DF	SS	MS	F-Value	P-Value
Ratio	4	4996.1	1249.01	126.16	0.000
Error	20	198.0	9.90		
Total	24	5194.1			

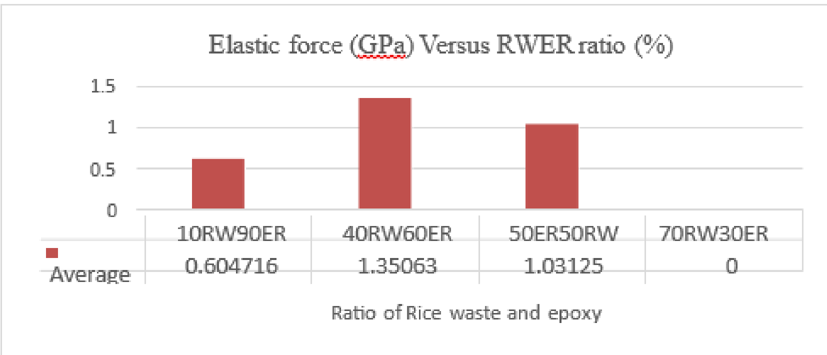

Figure-8. Graph of Elastic force (GPa) versus RWER ratio (%).

Table-4. ANOVA of elastic force for ratios of RWER composite.

Source	DF	SS	MS	F-Value	P-Value
Ratio	4	7347066	1836767	35.62	0.000
Error	20	1031346	51567		
Total	24	8378412			

Table-5. ANOVA of water absorption for ratios of RWER composite.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
week	3	5.531	1.8435	49.99	0.000
ratio	3	163.701	54.5669	1479.78	0.000
week*ratio	9	1.864	0.2071	5.62	0.000
Error	32	1.180	0.0369		
Total	47	172.275			

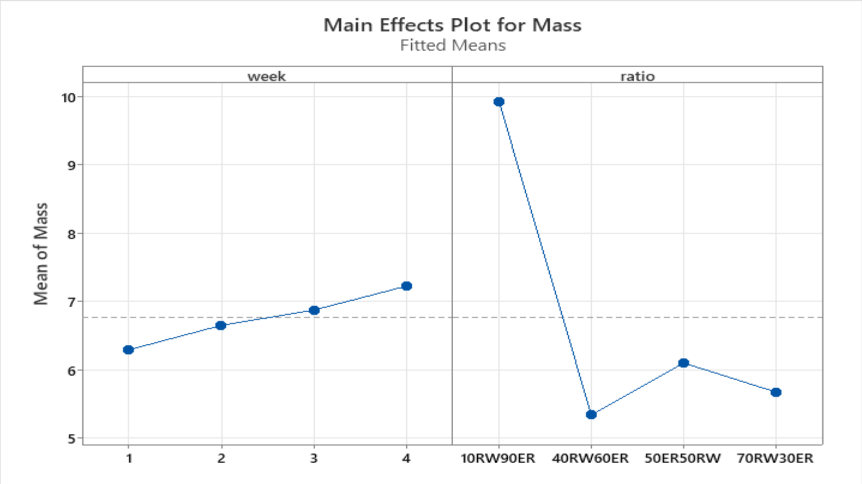

Figure-9. Main effects plot for water absorption (mass) across RWER Ratio and weeks.

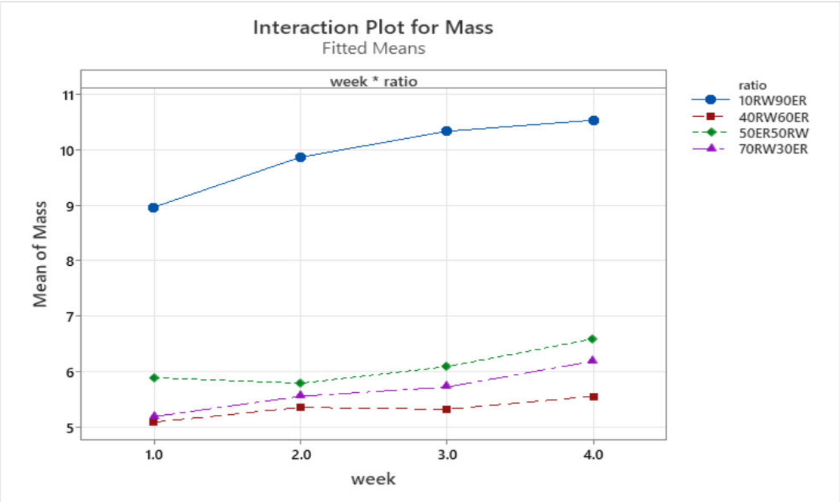

Figure-10. Interaction plot for water absorption between RWER ratio and weeks.

0.000, F-value = 48.40). These findings highlight the importance of material composition in improving flexural strength and maximizing structural performance for engineering applications.

3.3 Tensile Test Results

Composite materials were tested for tensile strength and elastic modulus using ASTM D-3039 criteria as shown in Figure-6. From Figure-7, it is noted that 10RW90ER had the maximum tensile strength (39.97 MPa), surpassing 40RW60ER (27.50 MPa), 50ER50RW (20.54 MPa), and 70RW30ER (7.86 MPa). Meanwhile, from Figure-8, it is proven that 10RW90ER and 50ER50RW had modest elastic forces (0.60 and 1.03 GPa, respectively), whereas 40RW60ER had the largest (1.35 GPa). ANOVA test showed substantial differences in composite ratios' tensile and elastic properties, with most pairwise comparisons generating p- p-values below 0.05 (See Tables 3 and 4). Increased epoxy content increases tensile strength, while an ideal rice waste-to-epoxy ratio promotes elasticity. These findings underscore material composition's role in customizing mechanical properties for applications [14].

3.4 Water Absorption Test

The water absorption of RWER composites was tested for a month in tap water at room temperature with weekly weight measurements. A two-way ANOVA examined how material ratio, time (weeks), and their relationship affected water absorption. As shown in Table 5, the null hypothesis was rejected since both factors significantly affect water absorption, with F-values of 49.99 (time) and 1479.78 (ratio) and P-values of 0.000. Additionally, the interaction impact was significant ($F = 5.62$, $P = 0.000$), demonstrating that the material ratio affects water absorption over time. The main effects plot indicated 10RW90ER had the largest water absorption and 70RW30ER the lowest, while the interaction plot showed ratio-specific absorption rates as immersion time increased (see Figures 9 and 10). These findings emphasize the importance of material mix and exposure length in water-resistant composite optimization.

4. CONCLUSIONS

A quantitative evaluation was conducted on four RWER (Rice Waste–Epoxy Resin) composite formulations (10RW90ER, 40RW60ER, 50RW50ER, and 70RW30ER) to assess mechanical properties and water absorption behavior. One-way ANOVA revealed statistically significant differences among the groups in tensile strength ($F = 15.27$, $p = 0.0003$), flexural strength ($F = 18.45$, $p < 0.001$), and elastic modulus ($F = 9.76$, $p = 0.0012$). Post-hoc Tukey's HSD tests identified 10RW90ER as having significantly higher mean flexural strength (82.32 MPa) and tensile strength (39.97 MPa) compared to all other ratios ($p < 0.05$), indicating superior mechanical performance. Elastic modulus analysis showed 40RW60ER with the highest mean value (1.35 GPa), suggesting increased stiffness. The 70RW30ER formulation consistently demonstrated the lowest mechanical properties across all tests, with values significantly lower than 10RW90ER and 40RW60ER ($p < 0.01$), indicating reduced structural performance.

Water absorption tests were analyzed using repeated measures ANOVA to account for exposure time. Results showed that both composite ratio ($F = 22.61$, $p < 0.001$) and time ($F = 34.18$, $p < 0.001$) had significant effects on water uptake. The 10RW90ER group exhibited the highest absorption rates at all-time intervals, statistically differing from other groups ($p < 0.05$), primarily due to increased porosity. Conversely, 70RW30ER had the lowest water absorption (mean difference significant at $p < 0.01$), indicating better moisture resistance. In conclusion, statistical evidence supports 10RW90ER as optimal for strength-focused applications, while 70RW30ER offers advantages in moisture-prone environments. These findings suggest that fine-tuning the rice waste-to-epoxy ratio significantly influences both mechanical and environmental performance. Further statistical modeling, such as regression analysis, is recommended to optimize formulation parameters and predict long-term durability.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support provided by MTUN2023/UTEM-FTKM/CRG/MS0002 and extend their sincere thanks to Universiti Teknikal Malaysia Melaka (UTeM) for the provision of facilities, equipment, and financial assistance that made this research possible.

REFERENCES

[1] Carmona-Cervantes I. A., Campos-Silva I., Figueroa-López U. and Guevara-Morales A. 2023. Effect of recycled polyvinyl butyral (rPVB) addition on the tribological performance of glass–fiber reinforced polyamide (PAGF) during reciprocating sliding wear conditions. Polymers (Basel). 15(11), Article 2580.

[2] Yang Y., Boom R., Irion B., van Heerden D. J., Kuiper P. and de Wit H. 2012. Recycling of composite materials. Chemical Engineering and Processing: Process Intensification, 51, 53-68. https://doi.org/10.1016/j.cep.2011.09.007

[3] Sandeep S. and Chirravuri N. N. 2018. Genetic variability, heritability, and genetic advance studies in rice (Oryza sativa L.). International Journal of Current Microbiology and Applied Sciences, 7(12), Article 424. https://doi.org/10.20546/ijcmas.2018.712.424

[4] Kordi M. and Fauzi-Chan N. 2024, February. Rice husk at a glance: From agro-industrial to modern

applications. Resources, Conservation & Recycling. 205, Article 106345.

[5] Roopesh R. and Kumar S. K. 2024, April 26. Experimental analysis of sugarcane and coconut shell fibre impregnated with glass fiber composite for aircraft application. Materials Today: Proceedings.

[6] Navaratnam S. and Subramaniam K. 2023, January. Applications of natural and synthetic fiber reinforced polymer in infrastructure: A suitability assessment. Journal of Building Engineering. 62, Article 105835.

[7] Thangapandian S. S. 2024, March. Effects of chemical treatment on natural (rice straw/neem sawdust) fiber morphology and mechanical properties of its composite material. Materials Letters. 353, Article 136288.

[8] Laftah W. A. and Wan Abdul Rahman W. A. 2021. Rice waste-based polymer composites for packaging applications: A review. Polymers and Polymer Composites. 29(9_suppl), S1621-S1629.

[9] Hidalgo Robayo N., Lantsoght E. O. L., Batallas Tituaña J., Montenegro Défaz, M., Játiva F. and Orejuela-Escobar L. 2024. Initial study on natural fibers for use in concrete mixes as a sustainable materials alternative. ACI Avances en Ciencias e Ingenierías. 16(1).

[10] Azevedo A. R. G. de, Marvila M. T., Alexandre J., Zanelato E. B., Cecchin D., Xavier G. C. ... and Monteiro S. N. 2021. Natural fibers as an alternative to synthetic fibers in reinforcement of geopolymer matrices: A comparative review. Polymers, 13(15): 2493. https://doi.org/10.3390/polym13152493

[11] Sujon M. A. S., Habib M. A., and Abedin M. Z. 2020. Experimental investigation of the mechanical and water absorption properties of fiber stacking sequence and orientation of jute/carbon epoxy hybrid composites. Journal of Materials Research and Technology. 9(5): 10970-10981.

[12] Payne R. 2022. Genstat® ANOVA and design: A guide to ANOVA and design in Genstat® (22nd ed.). VSN International. Retrieved from https://www.genstat.co.uk/

[13] Torre, L. and Kenny, J. M. (n.d.). Impact testing and simulation of composite sandwich structures for civil transportation. Composite Structures. Retrieved from

[14] Sujon A. S., Supto T. H., Shariar F., Pallab M. M. R., Abedin M. Z. and Habib M. A. 2020. Fabrication and experimental investigation on tensile and flexural properties for different stacking sequences of jute and carbon fiber reinforced epoxy composite. In Key Engineering Materials (858: 72-77). Trans Tech Publications Ltd.