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Banana (Musa Paradisiaca) Fiber and Rice Husk (Oryza Sativa L.) Reinforced Composite Materials for Construction Applications

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ABSTRACT

The demand for sustainable building materials in the Philippine construction sector has driven research into natural fiber-reinforced composites. This study investigates the potential of banana fiber and rice husk as reinforcement materials in epoxy composites, evaluating various samples through water absorption and drop weight impact tests. The study evaluated the water absorption and impact resistance of three banana fiber and rice husk composite samples. ANOVA showed no significant differences in water absorption ($p = 0.928$), indicating similar properties across the samples. However, the Drop Weight Impact Test revealed Sample V3 as the most effective, with the highest energy absorption (286.3 J), demonstrating superior resistance to fractures. These findings highlight the potential of these composites, with Sample V3 offering optimal mechanical performance for sustainable material applications. The study concludes that banana fiber and rice husk are viable, eco-friendly alternatives to traditional construction materials, providing durable and cost-effective solutions for sustainable building practices

I. Introduction

The construction sector is a key contributor to the Philippine economy, accounting for seven percent of the country's gross domestic product (GDP) in 2023 (C. Balita, 2024). However, the rapid pace of construction and the increasing demand for housing have resulted in a shortage of traditional building materials. Bricks, cement, sand, and wood are becoming increasingly scarce, posing challenges for the industry's growth and sustainability (Logeshwar et al., 2022). The growing demand for high-quality building materials to replace traditional ones, along with the need for cost-effective and durable options for affordable housing, has driven researchers to explore new and innovative solutions. That's why natural fibers like banana fiber and rice husk have gained attention as sustainable alternatives, offering both strength and eco-friendliness for modern construction materials.

The Philippines has achieved a remarkable feat by becoming the top banana exporter in Asia and the second largest in the world is a testament to the potential of the banana industry. Beyond the superior taste and aesthetic appeal of its bananas, the country has also started to explore other uses of the banana plant, particularly in sustainable industries (Bharath, 2023). One exciting innovation involves utilizing banana trees for their fiber, which has great potential for various applications.

After the fruit-bearing cycle, the banana plant's trunk, known as the pseudostem, can be harvested for its fiber. In particular, the sturdy fibers from these trunks are highly durable, making them an excellent raw material for textiles, ropes, handicrafts, and even structural composites. Similar to how banana plants are propagated in labs to ensure disease-free growth, the extraction of banana fiber can be done with minimal environmental impact, making it a highly sustainable material. This shift opens up opportunities not only for the agricultural sector but also for industries aiming to reduce reliance on synthetic materials.

Natural fibers have many advantages over synthetic ones; no harm to the environment, enhanced energy recovery and biodegradability, low density, high toughness, acceptable specific strength, reduced dermal and respiratory irritation, low cost, renewable resources etc. (Roy, Shit, Gupta, & Shukla, 2014). Natural fibers got a good place in the modern engineering world markets mainly in construction and automotive industry due to its non-polluting features to the environment (Saravanan et al., 2020).

Natural fibers are abundant, biodegradable, and pose no risk to human or animal health. Moreover, natural fiber-reinforced composites hold significant potential as sustainable alternatives to petroleum- and fossil-based materials in construction. These fibers, extracted from various parts of plants, are categorized based on their source. Notably, fibers such as jute, coir, banana, and sisal are extensively available in developing countries across Southeast Asia, offering an eco-friendly option for construction applications. In recent decades, the application of natural fiber-reinforced polymer composites in physical science research has grown significantly. This is due not only to their favorable material properties but also to their environmentally sustainable nature. With increasing attention on environmental pollution and the depletion of petroleum resources, researchers are progressively exploring the potential of natural fibers. The use of plant-based fibers in scientific studies is rising steadily, with different fibers being incorporated into a variety of polymer substrates for material science investigations (Nguyen et al., 2021).

At present, the banana fiber is a waste product of banana cultivation, therefore without any additional cost these fibers can be obtained for industrial purposes. As noted by Ramesh et al. (2014), they have fabricated a 50% banana fiber and 50% epoxy resin composite material that can withstand higher loads when compared with other combinations and is used as an alternative to conventional fiber-reinforced polymer composites.

According to Balaji et al. (2020), In the present work composites are reinforced with up to 20 wt% fabric made of banana, a relatively known natural fiber from India. These banana fibers were cut into a similar average length of 10 and 20 mm and two sets of bio-composites were prepared by compression molding process with varying weight percentage of epoxy resin by 0, 5, 10, 15 and 20%.

Banana fiber is derived from the banana stem, which is widely available as waste in many regions around the world. As a result, banana fiber-reinforced polymer composites made from this material exhibit high strength and excellent flame-retardant properties, making them suitable for a variety of applications.

Recently, because of the rising population, carbon overloading, and environmental distress, human beings have needed to increase awareness and responsibility for the reduction of agricultural waste. The utilization of agricultural waste as a filler material in reinforced polymers is a fascinating discovery (Suhot et. al, 2021). Disposing of waste is problematic, and the most significant challenge today is to find novel ways to utilize these residues. According to Cherubin et al. (2018), residues such as rejected crops in the form of leaf litter, straws, sawdust, forest waste, leaves, weeds, and other by-products surged by approximately 33%, as a percentage of the total product. Moreover, agriculture waste reached more than 5 billion Mg in 2013, whereby 47% of the leftover residues were from the Asian continent, followed by America (29%), Europe (16%), Africa (6%), and Oceania (2%).

Rice (Oryza sativa L. genus) is the primary source of daily food intake and has become the world's second most important cereal crop sector due to the demand of billions of human beings. Recently, over 513 million metric tons of milled rice were produced in the last harvesting year worldwide. Traditionally, countries in Asia have the largest share in world rice production (Shabandeh, 2024). The approximate number of rice hull wastes in the Philippines for 2021 is 3.96 million metric tons (Barra et al., 2022). Therefore, these wastes should never be burned, due to various reasons, such as the ashes, harmful gases, and fumes that contribute to air pollution (Athira et al., 2019).

The incorporation of RH (rice husk) residues in biocomposites, along with banana fiber as reinforcement, provides several benefits, such as reducing the reliance on synthetic polymers like resin polymers and certain additives. The tensile strength of these biocomposites is a key factor for assessing the strength performance of the material, with banana fiber enhancing the overall structural integrity. Using RH as a reinforcement has also offered significant enhancements to the tensile properties of composites, as reported by Abdulkareem et al. (2018).

The potential properties of rice hulls and banana fibers can be utilized as an alternative material to replace synthetic fibers due to its strength, environment friendly quality, cost effectiveness and easy availability. Rice hulls and banana fibers are cellulose fibers that exhibit potential mechanical properties founded on the material components of natural fiber reinforced composites (Amador L., 2018)

This research aims to introduce a sustainable solution that incorporates banana fiber and rice husk with epoxy for various applications. Both banana fiber and rice husk have gained recognition for their strength and eco-friendliness, making them excellent reinforcement materials. As discussed in this review, banana fiber and rice husk are natural byproducts, and their integration with epoxy resin offers numerous benefits for environmental applications. Compared to synthetic alternatives, banana fiber-rice husk epoxy composites provide significant advantages due to their biodegradability and enhanced mechanical properties.

II. Materials and Method

a. Gathering of Materials

Two banana stems (Binangay) were collected from a waste disposal site in Sta. Cruz, along with rice husks intended for further processing. The rice husks, after collection, were carefully sun-dried for two days to remove any moisture, ensuring uniformity before being blended. Essential materials were sourced from different locations: a 14 cm x 14 cm plastic container, which was used as a mold, was purchased from Unicity, while a blender and a scale for accurately measuring both the rice husk and the extracted banana fibers were obtained from Blueline Upholstery. Additionally, sodium hydroxide, an important component for fiber extraction, was readily available for use. Before processing the banana stems and bunches, any rotten or damaged parts were removed to avoid contamination or weakening of the final material, ensuring only healthy portions were used in the extraction process.

Figure 1. *Collection of Banana Stem/Bunch*

Figure 2. *Collection of Rice Husk*

b. Preparation and Extraction of Banana Fiber

The banana stems were initially cut into three sections, each measuring 35 cm in length, while the banana bunch was divided into three parts of 25 cm each.Both the stems and bunches were sliced thinly to easily extract the fiber.

Figure 3. *Banana Stem*

To facilitate the extraction of fibers, sodium hydroxide of 20 grams was dissolved in a half liter of water to create an alkaline solution. This solution was poured over the thinly sliced banana plant parts to break down the lignin and hemicellulose, which bind the fibers together within the plant tissue. The slices were boiled in this solution for 20 minutes, allowing the sodium hydroxide to penetrate and soften the plant material.

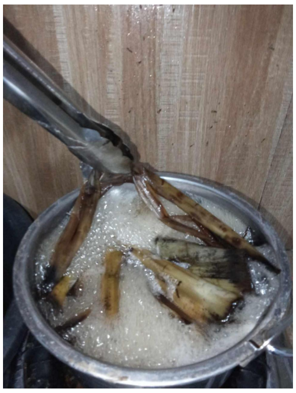

Figure 4. *Banana Stem/Bunch With Sodium Hydro*xide

After boiling, the slices were carefully rinsed to remove any remaining sodium hydroxide and to clean the fibers. The next step involved manually scraping the softened plant material with a knife to separate the fibers from the stem and bunch. This method of scraping is often used to ensure the fibers are extracted intact without damaging them, which is crucial for maintaining their strength and integrity.

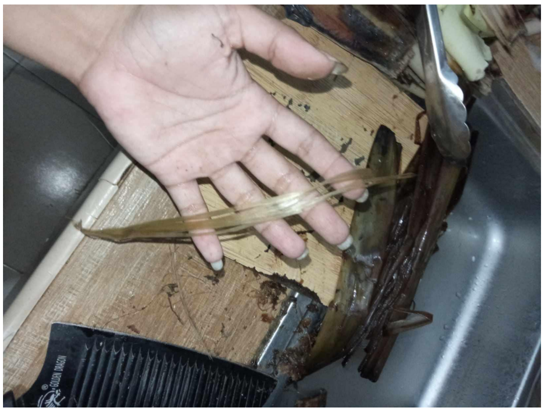

Figure 5. *Fiber Extracted*

Once the fibers were separated, they were hung and dry to remove any remaining moisture. This drying process is essential to prevent the fibers from decaying or becoming moldy during storage.

Figure 6. *Drying the Fibers*

Finally, the dried fibers were cut to a uniform length of 14 cm to fit perfectly into the mold for further processing, such as creating composite materials. This careful method of extraction ensures that the fibers retain their strength, flexibility, and uniformity for optimal use in applications like reinforcement for natural composite polymers.

Rice Husk

The rice husk is properly placed and sun dried for 24 hours. Then, the husk is placed into a blender, ensuring the container is not overloaded to allow for even processing. The husk is then blended in small batches, typically for 1-2 minutes per batch, until it reaches a consistent, fine texture. This fine blending ensures that the rice husk particles are uniform in size.

Figure 7. *Blended Rice Husk*

Epoxy Resin

For the preparation of the composite materials, we utilized commercially available epoxy resin purchased from a local convenience store. The epoxy resin served as the matrix material in which the banana fiber and rice husk were embedded. The resin was chosen for its well-known properties of high mechanical strength, durability, and good adhesion to natural fibers. As per standard composite preparation methods, the epoxy resin was mixed with a hardener in a specified ratio (typically 2:1) to initiate the curing process. This resin was then thoroughly combined with the natural fibers (banana fiber and rice husk) to create a homogenous mixture, which was later used for molding and testing the composite samples. The use of commercially available epoxy resin ensured that the material was easily accessible and cost-effective for producing the biocomposites.

Figure 8. *Epoxy Resin*

c. Fabrication and Preparation of Reinforced Composite Samples

To make the reinforced composite samples, we started by layering banana fiber and rice husk alternately. After each layer, we added a specific amount of epoxy resin to bind the materials together. After layering, we pressed the composite firmly with a hard object to ensure it was compact and well-bonded. The samples were then left to cure until the resin fully hardened.

Figure 9. *Sample A (whole)*

Figure 10. *Sample B (whole)*

d. Preparation of Testing Sample

Once the sample has fully hardened, it is ground to achieve a smooth and uniform surface. After that, every sample is divided into four pieces to make testing easier.

Figure 11. *Reinforced Composite*

Water Absorption Test

The test for water absorption assesses how well a material can absorb water given specific conditions. It is commonly utilized to assess materials such as composites, plastics, and construction materials in order to determine their resilience to moisture.

The composite samples were soaked in room temperature water. The water absorption was calculated using Equation (1) for different time intervals. The samples were weighed before and after being removed from water every 72 hours to determine their weight. The water absorption test was carried out over multiple days until the samples reached a constant weight. The average value of multiple measurements was used to calculate the percentage of water absorption at equilibrium. The water absorption percentage was determined utilizing ASTM D570 Equation (1).(Woven Hybrid Composites: Water Absorption and Thickness Swelling Behaviors :: BioResources, n.d.)

$$Water\ absorption(\%) = \frac{W_n - W_d}{W_d}$$

Wn represents the weight of composite samples post-immersion, while Wd represents the weight of the composite samples pre-immersion.

Drop Weight Impact Test

The Drop Weight Impact Test was utilized to evaluate the material's ability to withstand fractures and its potential to absorb an abrupt force. However, the researchers made some modification to the usual method by utilizing a 6 kg mass, which was released onto the sample from a specified height.

$$\mathbf{E = m \times g \times h,}$$

Impact Energy = mass x gravity x height

e. Risk and Safety

The research on banana fiber and rice husk composites involves risks like chemical burns from sodium hydroxide and respiratory irritation from rice husk dust. Proper safety measures, including PPE like gloves, goggles, and masks, and working in ventilated areas, are essential. Waste, including chemical residues, should be disposed of responsibly to ensure safety and environmental protection.

f. Data Analysis

The researchers applied descriptive statistics to analyze and summarize the collected data, providing an organized and concise representation of its key characteristics. Descriptive statistics is a domain of statistics that focuses on presenting, summarizing, and interpreting data meaningfully, without extending conclusions to data outside the given set. This method involves measures such as central tendency (mean, median, mode), which indicate the average or typical value in a dataset, and measures of variability (range, standard deviation, variance), which reflect the spread or dispersion of the data. By using descriptive statistics, the researchers effectively identified patterns, trends, and distributions within the data, enabling a more thorough understanding of the variables under investigation.

To further analyze the data and test for significant differences between groups, the researchers also applied Analysis of Variance (ANOVA). ANOVA is a statistical method used to compare the means of three or more groups to determine if there are any statistically significant differences between them. The computation of ANOVA involves calculating the variance within each group and comparing it to the variance between the groups. If the between-group variance is significantly greater than the within-group variance, the results indicate that the group means are not equal, and further post-hoc analysis may be conducted. The ANOVA computation provided valuable insights into the relationships between variables, helping to identify any significant effects or interactions present in the dataset.

III. Results and Discussion

Water Absorption Test

The water absorption test was modified and performed utilizing accessible resources. This test aims to determine the amount of water a sample can absorb over a specific time duration. Typically, greater water absorption capacity suggests low water resistance, whereas lesser absorption capacity signifies higher water resistance.

Water Absorption Test Result

Table 1.1 *Absorbed (%) of each variant of Sample A Test 1.*

Sample A Variants (1)	Time (hours)	Initial Weight(g)	Final Weight (g)	Absorbed (%)
V1	72 hours	58.05	58.09	0.000689
V2	72 hours	58.05	58.09	0.000689
V3	72 hours	58.05	58.08	0.000517

Table 1.2 *Absorbed (%) of each variant of Sample A Test 2.*

Sample A Variants (3)	Time (hours)	Initial Weight(g)	Final Weight (g)	Absorbed (%)
V1	144 hours	58.09	58.13	0.000689
V2	144 hours	58.09	58.13	0.000689
V3	144 hours	58.08	58.14	0.000861

Table 1.3 *Absorbed (%) of each variant of Sample A Test 3.*

Sample A Variants (2)	Time (hours)	Initial Weight(g)	Final Weight (g)	Absorbed (%)
V1	261 hours	58.13	58.20	0.00120

V2	261 hours	58.13	58.23	0.00172
V3	261 hours	58.14	58.21	0.00138

Table 1.4 *Total (%) Absorbed of each variant.*

Sample A Variants	Initial Weight(g)	Final Ave Weight (g)	Absorbed (%)
V1	58..05	58.20	0.1206
V2	58.05	58.23	0.2067
V3	58.05	58.21	0.1550

Descriptive Statistics ▼

	initial weight	final weight	total percentage absorbed
Valid	3	3	3
Missing	0	0	0
Mean	58.050	58.230	0.001
Std. Deviation	0.000	0.044	2.641×10^{-4}
Minimum	58.050	58.200	0.001
Maximum	58.050	58.280	0.002

Descriptive Statistics

- The final weight exhibits a slight mean increase of 0.180 with a standard deviation of 0.044.
- The total percentage absorbed is very low, averaging 0.001 with a standard deviation of 2.641×10^{-4}.

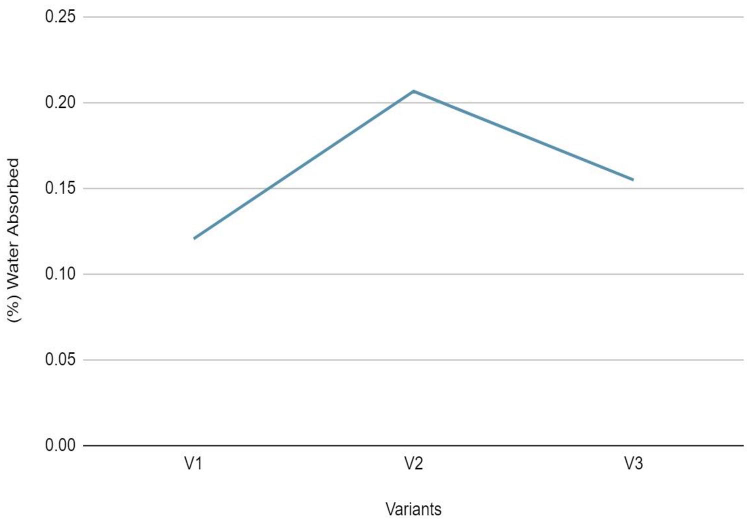

Figure 12. *Graph for the total (%) water absorbed of sample A.*

Table 2.1 . *Absorbed (%) of each variant of Sample B Test 1 .*

Sample B Variants (1)	Time (hours)	Initial Weight(g)	Final Weight (g)	Absorbed (%)
V1	72 hours	62.06	62.09	0.000438
V2	72 hours	62.06	62.09	0.000438
V3	72 hours	62.06	62.09	0.000438

Table 2.2 *Absorbed (%) of each variant of Sample B Test 2.*

Sample B (2) Variants	Time (hours)	Initial Weight(g)	Final Weight (g)	Absorbed (%)
V1	144 hours	62.09	62.13	0.000644
V2	144 hours	62.09	62.13	0.000644
V3	144 hours	62.09	62.14	0.000805

Table 2.3 *Absorbed (%) of each variant of Sample B Test 3.*

Sample B (2) Variants	Time (hours)	Initial Weight(g)	Final Weight (g)	Absorbed (%)
V1	216 hours	62.13	62.15	0.000322
V2	216 hours	62.13	62.16	0.000483
V3	216 hours	62.14	62.15	0.000322

Table 2.4 *Total (%) Absorbed of each variant of Sample B .*

Sample B Variants	Initial Weight(g)	Final Weight (g)	Absorbed (%)
V1	62.06	62.15	0.145
V2	62.06	62.16	0.161
V3	62.06	62.15	0.145

Descriptive Statistics

	initial weight	final weight	total percentage absorbed
Valid	3	3	3
Missing	0	0	0
Mean	62.060	52.820	0.150
Std. Deviation	0.000	16.169	0.009
Minimum	62.060	34.150	0.145
Maximum	62.060	62.160	0.161

Descriptive Statistics

The final weight exhibits significant variability, with an average of 52.820 and a standard deviation of 16.169, suggesting that both the experimental process or corresponding sample variances had a significant influence on the final result. The material's absorption ability appears to be limited, as seen by the relatively low and consistent overall percentage absorbed across samples, with an average of 0.150 and a standard deviation of 0.009.

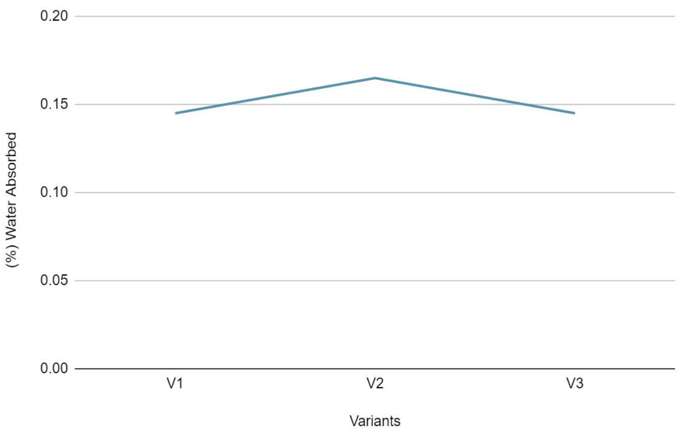

Figure 13. *Graph for the total (%) water absorbed of sample B.*

Table 3.1 *Total Absorbed (%) of each variant of Sample C Test 1.*

Sample C (1) Variants	Time (hours)	Initial Weight (g)	Final Weight (g)	Absorbed (%)
V1	72 hours	83.26	83.28	0.000240
V2	72 hours	83.26	83.28	0.000240
V3	72 hours	83.26	83.29	0.000360

Table 3.2 *Total Absorbed (%) of each variant of Sample C Test 2.*

Sample C (2) Variants	Time (hours)	Initial Weight (g)	Final Weight (g)	Absorbed (%)
V1	144 hours	83.28	83.35	0.000841

V2	144 hours	83.28	83.35	0.000841
V3	144 hours	83.29	83.35	0.000720

Table 3.3 *Total Absorbed (%) of each variant of Sample C Test 3.*

Sample C (2) Variants	Time (hours)	Initial Weight (g)	Final Ave Weight (g)	Absorbed (%)
V1	216 hours	83.35	83.38	0.000360
V2	216 hours	83.35	83.38	0.000360
V3	216 hours	83.35	83.40	0.000600

Table 3.4 *Total Absorbed (%) of each variant of Sample C.*

Sample C Variants	Initial Weight(g)	Final Ave Weight (g)	Absorbed (%)
V1	83.26	83.38	0.144
V2	83.26	83.38	0.144
V3	83.26	83.40	0.168

Descriptive Statistics

	initial weight	final weight	total percentage absorbed
Valid	3	3	3
Missing	0	0	0
Mean	83.260	83.387	0.152
Std. Deviation	0.000	0.012	0.014
Minimum	83.260	83.380	0.144
Maximum	83.260	83.400	0.168

Descriptive Statistics

The final weight exhibits significant variability, with a mean of 83.387 and a standard deviation of 0.012, suggesting that either the experimental process or inherent sample variance significantly influenced the final result. The material's absorption ability appears to be limited, as indicated by the relatively low and consistent overall percentage absorbed across samples, with a mean of 0.152 and a standard deviation of 0.014.

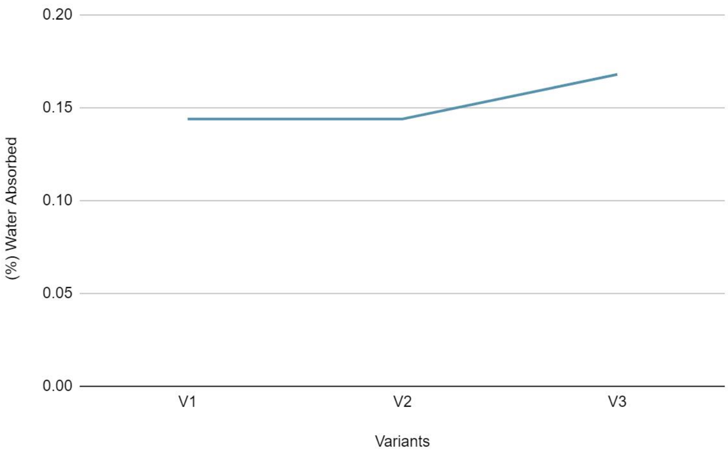

Figure 14. *A visual representation of the summarized data.*

The One-Way ANOVA (Welch's) test results presented in the table indicate the comparison of water absorption among three groups (A, B, and C). The F-value is **0.0765**, with degrees of freedom **df1 = 2** (between groups) and **df2 = 3.46** (within groups), and the p-value is **0.928**. The p-value, being much greater than the typical significance level (0.05), suggests that there are no statistically significant differences in water absorption among the three groups. Welch's ANOVA is appropriate for cases where variances between groups might not be equal, and its results here confirm that the differences in water absorption among the samples are negligible. This aligns with the post hoc results, which also indicate no significant pairwise differences. Hence, the three samples exhibit similar water absorption properties, based on this analysis released onto the sample from a specified.

Post Hoc Tests

Tukey Post-Hoc Test – B

		1	2	3
1	Mean difference	—	0.0104	0.00877
	t-value	—	0.477	0.4006
	df	—	6.00	6.00
	p-value	—	0.885	0.917
2	Mean difference		—	−0.00167
	t-value		—	−0.0762
	df		—	6.00
	p-value		—	0.997
3	Mean difference			—
	t-value			—
	df			—
	p-value			—

Note. * p < .05, ** p < .01, *** p < .001

The Tukey Post-Hoc Test results for water absorption among three samples (A, B, and C) indicate no statistically significant differences between any pair of samples. The **mean differences** between the groups (A vs. B, A vs. C, and B vs. C) are very small (e.g., 0.0104 for A vs. B and -0.00167 for B vs. C). Additionally, the p-values for all comparisons are much greater than the typical significance threshold of 0.05 (e.g., 0.885 for A vs. B and 0.997 for B vs. C), confirming that the observed differences are not statistically meaningful. These results suggest that the water absorption characteristics of the three samples are essentially equivalent, which aligns with the One-Way ANOVA results showing no significant differences across groups. This finding implies that the materials used in the three samples behave similarly in terms of their ability to absorb water, and any minor variations are likely due to random chance rather than true differences in properties.

Drop Weight Impact Test

The Drop Weight Impact Test was modified and performed using a 6 kg mass, which was released onto the sample from a specified height. This test aims to evaluate the material's resistance to fractures and its ability to absorb sudden forces.

Drop Weight Impact Test Results

Table 4.1 *Total Impact Energy of the Variants of Sample A Test 1.*

Sample A Variants	Test Weight (kg)	Drop Height(m)	Drop Weight (kg)	Rebound Height (m)
V1	0.058	3m	6	0.079
V2	0.058	4m	6	0.127
V3	0.058	5m	6	0.163

Table 4.2 *Total Impact Energy of the Variants of Sample A Test 2.*

Sample A	Impact Energy	Energy Rebound	Energy Absorbed	Visual Damage
V1	176.58	4.65	171.93	Scratch only
V2	235.44	7.48	227.96	Scratch only
V3	294.3	9.59	284.71	Scratch only

Descriptive Statistics

	Impact Energy	Energy Rebound	Energy Absorbed
Valid	3	3	3
Missing	0	0	0
Mean	235.440	7.223	228.200
Std. Deviation	58.860	2.476	56.390
Minimum	176.580	4.650	171.930
Maximum	294.300	9.590	284.710

Descriptive Statistics

The data reveals considerable variability in impact energy, with a mean of 235.440 and a standard deviation of 58.650, and in energy absorbed, with a mean of 228.573 and a standard deviation of 56.745. This suggests a strong influence from experimental conditions or inherent sample differences. Energy rebound shows significantly less variability, with a mean of 5.867 and a standard deviation of 2.115. However, the small sample size of three for all measurements limits the reliability and generalizability of these findings. A larger sample size is needed for more robust conclusions.

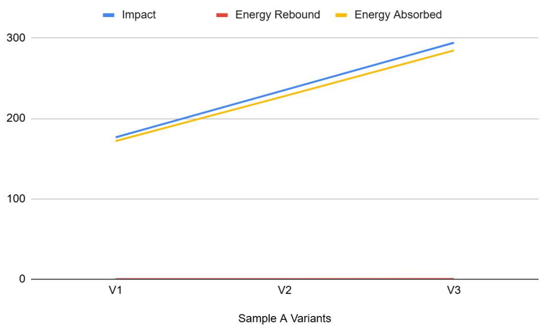

Figure 15. *A visual representation of the summarized data.*

Table 5.1 *Total Impact Energy of the Variants of Sample B Test 1.*

Sample B	Test	Drop Weight	Drop Height	Rebound

Variants	Weight (kg)	(kg)	(m)	Height (m)
V1	0.8526	6	3	0.064
V2	0.8526	6	4	0.099
V3	0.8526	6	5	0.136

Table 5.1 *Total Impact Energy of the Variants of Sample B Test 2.*

Sample B	Impact Energy	Energy Rebound	Energy Absorbed	Visible Damage
V1	176.58	3.77	172.81	Scratch only
V2	235.44	5.83	229.61	Scratch only
V3	294.3	8.00	286.3	Scratch only

Maximum	294.300	8.000	286.300

Descriptive Statistics

The descriptive statistics, based on three samples each, show substantial variability in impact energy and energy absorbed. Impact energy has a mean of 235.440 and a standard deviation of 50.060, while energy absorbed has a mean of 228.200 and a standard deviation of 56.390. This suggests significant experimental or sample-related influences. Energy rebound shows considerably less variability, with a mean of 7.223 and a standard deviation of 2.478. The small sample size limits the reliability and generalizability of these results. A larger dataset is needed for more robust conclusions.

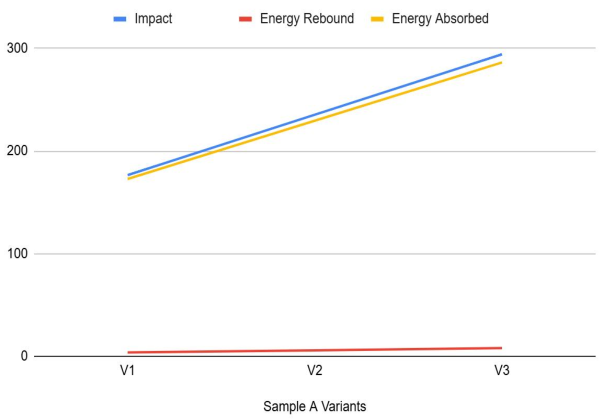

Figure 16. *A visual representation of the summarized data.*

IV. Conclusion and Recommendations

In conclusion, our study on banana fiber and rice husk reinforced with epoxy resin has provided significant insights into the material's performance and potential applications. The results from the water absorption and drop weight impact tests highlight the distinct properties of the tested samples.

The study evaluated the water absorption and impact resistance of three banana fiber and rice husk composite samples. ANOVA showed no significant differences in water absorption ($p = 0.928$), indicating similar properties across the samples. However, the Drop Weight Impact Test revealed **Sample**

V3 as the most effective, with the highest energy absorption (286.3 J), demonstrating superior resistance to fractures. These findings highlight the potential of these composites, with **Sample V3** offering optimal mechanical performance for sustainable material applications. Overall, while water absorption was comparable, the samples differed in their ability to withstand impact, highlighting their potential for sustainable construction applications.

Our statistical analysis further revealed notable differences in the properties of the composites, emphasizing the need to optimize the fiber blend for improved performance. These findings underscore the potential of banana fiber and rice husk as eco-friendly alternatives to traditional construction materials, encouraging further development and adoption of natural fiber-reinforced composites in sustainable building practices.

To further improve the reliability and comprehensiveness of this study, the researchers strongly recommend utilizing a larger sample size. Increasing the number of samples will enhance the statistical power of the analysis and ensure that the findings are more representative of the material's properties. Additionally, extending the duration of the water absorption test is crucial for capturing the long-term behavior of the materials under prolonged exposure to water. This would provide a deeper understanding of their absorption characteristics and potential limitations over time. Furthermore, incorporating thermal insulation testing as part of the experimental process is highly encouraged. Evaluating the samples under varying temperature conditions would not only assess their insulation capabilities but also provide valuable insights into their performance in practical, real-world applications. These additional tests and adjustments would strengthen the study's conclusions and offer a more comprehensive understanding of the materials' properties and potential uses.

V. References

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