



## STUDY ON VARIED BAGASSE FIBER AND EPOXY RESIN COMPOSITIONS WITH RICE BRAN FILLER TO BIOCOMPOSITE CHARACTERISTICS

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ARTICLE INFO	ABSTRACT
<p><b>Keywords:</b> <i>Biocomposite;</i> <i>Bagasse;</i> <i>Epoxy Resin;</i> <i>Tensile Strength</i></p> <p><i>Article History:</i> <i>Received: 2023-03-27</i> <i>Accepted: 2024-02-26</i> <i>Published: 2024-03-03</i></p> <p>*Corresponding Author Email: <a href="mailto:eb112@ums.ac.id">eb112@ums.ac.id</a> doi:10.20961/jkpk.v9i1.72587</p>  <p>© 2024 The Authors. This open-access article is distributed under a (CC-BY-SA License)</p>	<p>Natural fibers, with environmental, economic, and cost advantages, are highly sought-after for biocomposite materials. In the present study, the biocomposite samples of epoxy resin (as a matrix), bagasse fiber (as reinforcement), and rice bran (as a filler) were prepared. Tensile strength, strain, and Young's modulus will be the parameters concerning which the quality of the biocomposite can be tested. On the one hand, bagasse fiber is to be a strength enhancer in the resulting biocomposite. On the other hand, rice bran may increase the biocomposite's density. The process research comprises fiber yarn from milled bagasse, alkalinized fiber with KMnO<sub>4</sub>, specimen printing process, and analysis. All the fibers were treated by soaking them in 3 grams of KMnO<sub>4</sub> solution for 30 and 45 minutes. The fiber is drained in an oven at 50 °C for ±1.5 hours. The printed fiber onto a specimen mold was printed with a mixture of epoxy resin and rice bran (1:1 w/w) and left for one day. Variation in the fiber mass was at 3, 4, and 5 grams. The sizes of the specimens were similar to the size of the mold according to ASTM D-638 type IV. Then, the fibers were removed from the mold and tested for tensile strength, strain, and Young's modulus. The results show that the greater the fiber mass, the greater the tensile strength value. These findings indicate that the tensile strength was optimized after soaking for 45 minutes with 5-gram fiber weight, which resulted in the tensile strength of 26.32±0.25 MPa, strain of 9.65±0.14%, Young's Modulus of 3.29±0.05 MPa, and water absorption of 41.99%.</p>
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### INTRODUCTION

Bagasse fiber is one of the natural fibers that can be used as composite materials, which is expected to enhance the strength of the resulting biocomposite material. Sugarcane processing is an agro-based industry making by-products from bagasse in the form of a fibrous residue, almost 32-45% cellulose, 20-32% hemicellulose, 17-32% lignin, 1-9% ash, and many other components in it [1]. Bagasse is a fibrous material containing cellulose as its

main content. It can be effectively used as a natural fiber in biocomposite manufacturing [2]. The rice bran was added as a filler to enhance the density of the biocomposite. Rice bran holds approximately 11.3-14.9% protein, 34.0-62.0% carbohydrates, and 15.0-19.7% oil [3]. Biocomposites are expected to increase the speed of manufacture and recycling with enhanced environmental compatibility [4]. The tensile strength (MPa), Young's modulus (Mpa), and elongation of natural fibers are shown in Table 1.

**Table 1.** The tensile strength, Young's modulus, and elongation of natural fibers

Fiber	Tensile strength (MPa)	Modulus Young (MPa)	Elongation (%)	Ref
Pineapple	38	57	-	[5]
Banana	28	-	2	[6]
Flax	25	-	-	[7]
Bamboo	18,07	-	-	[8]

Advantages of natural fibers include being light, elastic, having huge quantities, and being cheap. The advantages of natural fibers include being lightweight. However, among the many advantages of natural fibers, disadvantages must always come. One of those is cellulose. Natural fibers easily absorb water, and hence,

they are hydrophilic. This can affect the bonding strength between the fiber and the matrix, while with fibers undergoing physical and chemical treatment, chemical treatment can also be carried out by soaking using potassium permanganate [9]. Soaking with potassium permanganate may increase the roughness of the natural fiber. In addition, drinking with potassium permanganate increases the degree of surface interlock in removing a substance known as cellulose while decreasing the hydrophilic properties in natural fiber [10]. Then, the composition of some natural fibers is presented in Table 2.

**Table 2.** Composition of natural fibers

Fiber	Cellulose (wt%)	Hemi cellulose (wt%)	Lignin (wt%)	Wax (wt%)	Moisture (wt%)	Ash (wt%)	Ref
Salago Fiber	79.05	13.6	10.13	-	50.21	60.93	[11]
Red Banana Peduncle	72.90	11.01	15.99	0.32	9.36	2.79	[12]
Coccinia grandis steam	63.22	-	24.42	0.32	9.14	-	[13]
Prosopis juliflora bark	61.65	16.14	17.11	0.61	9.48	5.2	[14]
Manicaria saccifera palm	74.1	12	31.1	-	-	-	[15]
Areca palm leaf stalk	0.66	0.24	0.12	0.024	0.15	0.019	[16]
Acacia leucophloea	68.09	13.60	17.73	0.55	8.83	-	[17]
Sida cordifolia	2.42	3.35	4.34	0.14	1.2	0.04	[18]

Epoxy resin is a thermoset polymer material characterized by its flexibility and two or more epoxide groups in its molecular structure. It enables its use as an adhesive in aircraft manufacturing, oil pipe coatings, construction, automotive, and aerospace [19]. Epoxy coatings can enhance corrosion protection for steel. The limitation of electrolyte penetration in the coating is due to the hydrophobic nature of the resin. A decrease in protection effectiveness over time may result from the degradation of the protective film by UV radiation [20]. Due to their chemical resistance, epoxy resins are utilized in various applications, including composite materials,

machinery, coatings, and electronic packaging [21].

The hand lay-up method for creating biocomposites involves mixing matrix fibers and manually placing them into an open mold before applying light pressure to expel trapped air. The advantages of this method include low cost, no size limitations, and a smooth surface finish, while its drawbacks include the potential for air pockets and extended drying times [22]. Potassium permanganate ( $\text{KMnO}_4$ ) is an inorganic chemical featuring a permanganate group  $\text{MnO}_4^-$  ion. Treatment with permanganate initiates the formation of cellulose radicals through negative ion formation, with the  $\text{Mn}^{3+}$

ion being highly reactive in copolymerization processes [23]. In this study,  $\text{KMnO}_4$  was selected for alkalization due to bagasse's high cellulose content. Alkali pretreatment, followed by bleaching, helps remove other fiber constituents, such as lignin. Beyond eliminating cellulose and lignin, alkalization also enhances adhesion between the fiber/matrix and improves the tensile and flexural properties of the composite [24].

Many previous studies have explored the production of natural-based composites using various methods. These biocomposites are noted for their eco-friendliness, potential availability, and low production costs [25], [26]. However, the studies above have yet to investigate the effect of combining natural fiber bagasse and rice bran filler on the mechanical strength of the composite. Variations in the ratios of materials used (i.e., epoxy resin, bagasse, and rice bran) and immersion times were assessed to determine the optimum condition. Overall, this research aims to elucidate the impact of varying compositions of bagasse fiber and epoxy resin with rice bran filler on the characteristics of biocomposites.

## **METHODS**

Materials utilized in this experiment included epoxy resin, bagasse fiber, aqua distillate, rice bran,  $\text{KMnO}_4$ , and lubricant. The tools employed comprised a beaker glass (1000 mL), a hot plate stirrer, an oven, scales, filters, an acrylic specimen mold (ASTM-D638 Type IV), and containers. This study employed the hand lay-up method, recognized as the simplest technique and represents a foundational approach in the composite fabrication process. The merits of this method encompass ease of execution, cost-efficiency,

absence of size limitations, and the achievement of a smooth surface finish.

### **1. Pretreatment.**

Bagasse fibers were combed or cleaned to detach any adhering cork from the fiber. Subsequently, fibers within the bagasse were individually selected by hand to procure threads of bagasse fiber, with the gathered fiber threads exhibiting variation in both diameter and ductility.

### **2. Alkalization.**

The alkalization procedure for bagasse fiber threads entailed immersing the threads in a  $\text{KMnO}_4$  solution, maintaining 12 grams of fiber to 6.25 grams of  $\text{KMnO}_4$  and 1 L of distilled water. The beaker glass was positioned on a hot plate stirrer and filled with 1 L of distilled water, and  $\text{KMnO}_4$  was added, with the mixture allowed to blend for 10 minutes. Afterward, the hot plate was deactivated, and the fiber threads were submerged in the beaker. The soaking duration was set per the desired timeframes (30 and 45 minutes). The soaked fiber threads were filtered and placed in an oven to dry at  $50^\circ\text{C}$ .

### **3. Specimen Molding Process.**

During the molding stage, the proportion of epoxy resin to hardener was established at 1:1 to form the matrix. The resin and filler were combined in a beaker glass and thoroughly mixed. Acrylic specimen molds and lubricants were prepared to ease the removal of specimens from the mold. The blend of matrix and filler was then transferred into the mold. The mold was sealed and clamped to minimize air voids within the specimen. Specimens were extracted after a pressing duration of 2-3 hours.

#### 4. Data Analysis.

The mechanical test consisted of tensile strength and Young's modulus tests. The ASTM D-638 standard was employed for the tensile strength test to analyze and determine the specimen's performance when subjected to a static load and pull. This test involves a procedure where a specimen of a certain shape and size is clamped at its top and bottom ends and subjected to a continuous one-way tensile force until failure. During this process, an increase in the test object's length was noted [27]. The tensile test of 3D printed PLA test specimens was evaluated following the ASTM D-638 standard procedure. The specimen geometry was modeled in Solidworks software according to the dimensions specified in the ASTM D-638 standard, as illustrated in Figure 1. Tensile strength and Young's modulus are determined by equations (1) and (2), respectively [28].

$$\sigma_f = \frac{3P_f L}{2bh^2} \quad (1)$$

$$\text{the } E_f = \frac{ML^3}{4bh^3} \quad (2)$$

With  $\sigma_f$  as the tensile strength (N/mm<sup>2</sup> or MPa) and  $E_f$  as the elastic modulus (MPa).

The thermal stability of the biocomposite can be evaluated using the thermogravimetric analysis (TGA) type of Shimadzu DTG-60 at the University Centre of Excellence For Electrical Energy Storage Technology. The samples' weight was around a range of 3.5–7.5 mg, being analyzed by TG/DTA instruments for weight loss and thermal stability. The samples were simultaneously heated from room temperature to 400°C with a heat rate of 5°C/min.

The water absorption can be performed by immersing the biocomposite samples in water for a certain period and measuring the

weight and dimensions change. This test will help determine the biocomposite's suitability for applications requiring moisture resistance, such as outdoor or humid environments. Samples were cut into 2 cm × 2 cm and then weighed to measure the initial mass ( $W_0$ ). Then, samples were placed into 20 ml distilled water inside cups for 10 minutes at room temperature. After 10 mins, the samples were removed from distilled water to measure the final mass ( $W_1$ ). The measurement was given by the equation (3).

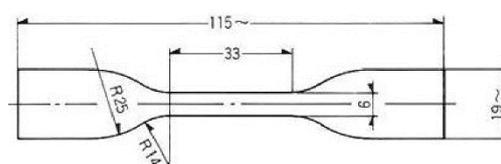


Figure 1. ASTM-D638 Type IV

$$\text{Absorption of water} = \frac{w_1 - w_0}{w_0} \times 100\% \quad (3)$$

To increase the validity of the research results, each experimental variation was repeated three times per sample.

## RESULTS AND DISCUSSION

This study was conducted in four stages: pre-treatment, alkalization, specimen molding, and product analysis. The parameters evaluated were the effects of immersion time (during the alkalization stage) and fiber mass (during the specimen molding stage). The immersion times were 30 and 45 minutes, while the fiber mass varied at 3, 4, and 5 grams.

### 1. Effect of Tensile Strength and Immersion Time

Potassium permanganate ( $\text{KMnO}_4$ ) generates highly reactive  $\text{MnO}_4^-$  ions that react with hydroxyl groups in cellulose to form cellulose-manganate. This reaction initiates the

graft copolymerization process, leading to the synthesis of fibers with excellent thermal stability. Typically, soaking follows an alkaline pre-treatment with varying concentrations of  $\text{KMnO}_4$ . This treatment removes hydroxyl groups from cellulose and interacts with and degrades lignin in the cell wall, thereby introducing a significant degree of hydrophobicity. When the concentration of  $\text{KMnO}_4$  reaches an optimal level, the fiber's hydrophilicity decreases. The oxidation by

permanganate etches the fiber surface, making it physically rougher; in this scenario, the resultant mechanical interlocking promotes interfacial adhesion while enhancing the contact area between the fiber and matrix. The chemical mechanism of the process is depicted in Equation (1). A schematic representation or illustration of the influence of potassium permanganate ( $\text{KMnO}_4$ ) treatment on natural fiber is presented in Figure 2.

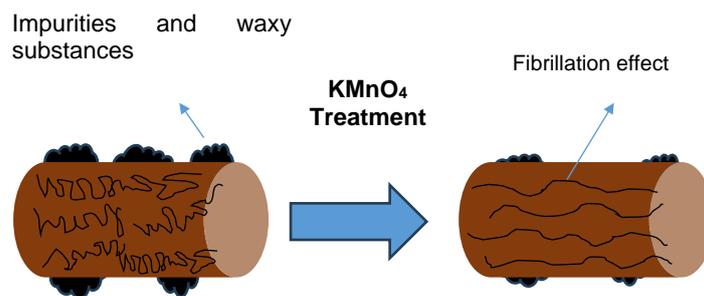
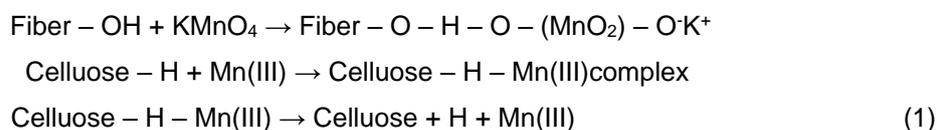


Figure 2. Potassium permanganate treatment on natural fiber.

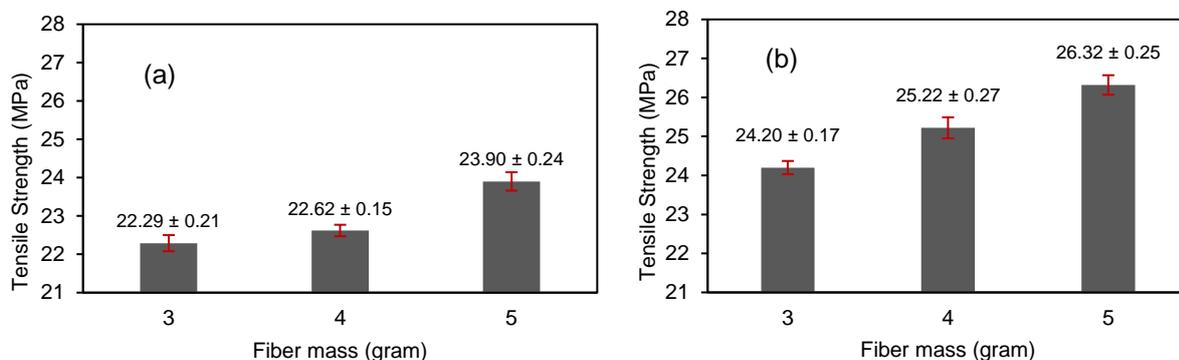
The tensile strength of the samples was determined by conducting a tensile test. Figure 3(a) illustrates the impact of fiber mass on tensile strength for an immersion time of 30 minutes. It was observed that an increase in fiber mass leads to an enhancement in tensile strength. For a fiber mass of 3 grams, the tensile strength measured approximately  $22.29 \pm 0.21$  MPa. In contrast, the tensile strengths for fiber masses of 4 and 5 grams were approximately  $22.62 \pm 0.15$  and  $23.90 \pm 0.24$  MPa, respectively. The augmentation of fiber mass contributes to a notable enhancement in tensile strength. Specifically, the increase in fiber mass from 3

to 4 grams and from 4 to 5 grams resulted in an increment in tensile strength of about 1.48% and 5.66%, respectively. This phenomenon can be attributed to specimens with a higher fiber mass facilitating a more uniform distribution of fibers within the biocomposite, thereby significantly increasing the strength.

Figure 3(b) depicts the relationship between fiber mass and tensile strength for an immersion time of 45 minutes. The outcomes demonstrated a similar trend to those observed with 30 minutes of immersion time, indicating that an increase in fiber mass correlates with higher tensile strength. With 45 minutes of immersion, the tensile strengths were

24.20±0.17, 25.22±0.27, and 26.32±0.25 MPa for 3, 4, and 5 grams of fiber mass, respectively. Consequently, a 45-minute immersion time yielded higher tensile strength than a 30-minute one. The prolonged immersion period

enhances the bonding between the fiber and the matrix. Alkaline immersion is shown to improve the tensile strength of fiber composites.



**Figure 3.** Correlation of tensile strength of fiber composition to the soaking time of (a) 30 minutes and (b) 45 minutes

Fiber-reinforced composites without alkalization exhibit an imperfect bond between the fiber and the resin due to a wax-like layer obstructing the fiber's surface [30]. Conversely, fibers treated with NaOH immersion display enhanced tensile strength values compared to those without alkaline treatment. In this study, the alkaline solution was NaOH at a concentration of 5% in water [31]. Previous research has corroborated that  $\text{KMnO}_4$  treatment can ameliorate the characteristics of fibers [32].

According to the standard SNI 03-2105-2006, which pertains to the Particle Board, the minimum quality of the particle board should be 3.01 kg/cm<sup>2</sup>, or equivalently 0.0304 MPa [37]. Consequently, the tensile strength of the resultant composite surpasses that of particle board. Notably, the specimen treated for 45 minutes with a 5%  $\text{KMnO}_4$  solution achieved the highest tensile strength, approximately 26.32±0.25 MPa. This enhancement can be attributed to the  $\text{KMnO}_4$

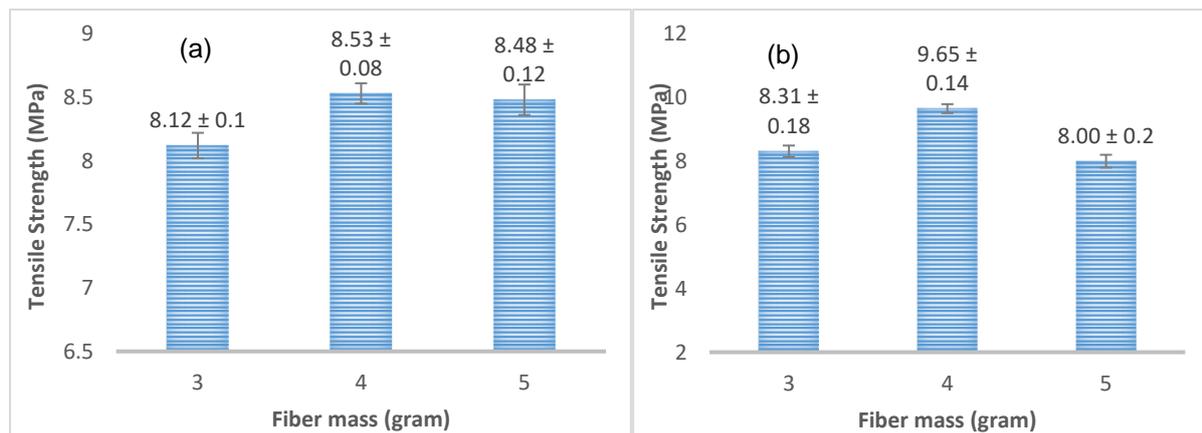
solution's efficacy in improving fiber characteristics and reducing air voids within the specimen.

## 2. Strain Analysis by Fiber Composition

Results from the strain analysis based on fiber composition are depicted in Figure 4. Panel (a) illustrates the strain outcomes for specimens with varied fiber masses subjected to a soaking time of 30 minutes. Strain values for fiber masses of 3, 4, and 5 grams were approximately 8.12±0.1%, 8.53±0.08%, and 8.48±0.12%, respectively. Panel (b) reveals the correlation of strain to fiber mass for a soaking duration of 45 minutes, at a fiber mass of 3 grams, with strain measured around 8.31±0.18%. An increase in fiber mass to 4 grams led to a strain value of 9.65±0.14%. However, further increasing the fiber mass to 5 grams caused a decrease in strain to 8±0.2%. Consistency in this pattern was observed across both 30-minute and 45-minute immersion times. The effect of fiber mass on

the tensile strength and strain values suggests that a higher fiber mass reduces strain. A possible decrease in fiber wetting by the resin with an increased quantity of fibers might reduce effective bonding. Observations align with prior studies that pinpointed fiber content,

particularly in bagasse, as a crucial determinant of mechanical properties. An increase in fiber content leads to enhanced elongation and strain, attributed to fibers' greater length and surface area, thereby improving matrix adhesion [33, 34].



**Figure 4.** Correlation of strain on fiber mass with the soaking time of (a) 30 minutes and (b) 45 minutes

The maximum strain, or stretch value, observed was 9.65%, achieved with a fiber mass of 4 grams and an immersion time of 45 minutes. Such findings indicate that the bonds between the matrix and the fiber could not absorb energy effectively during the loading process, potentially due to the relatively stiff characteristics of the fibers. As a result, the strain value was comparatively low [35]. Literature indicates that the stiffness of epoxy resin significantly influences the strain value; thus, augmenting the resin content in the composite reduces strain. Increased strain correlates with diminished mobility of the polymer chain molecules, rendering the biocomposite specimens more rigid and brittle [36].

### 3. Young's Modulus: Influence of Fiber Addition

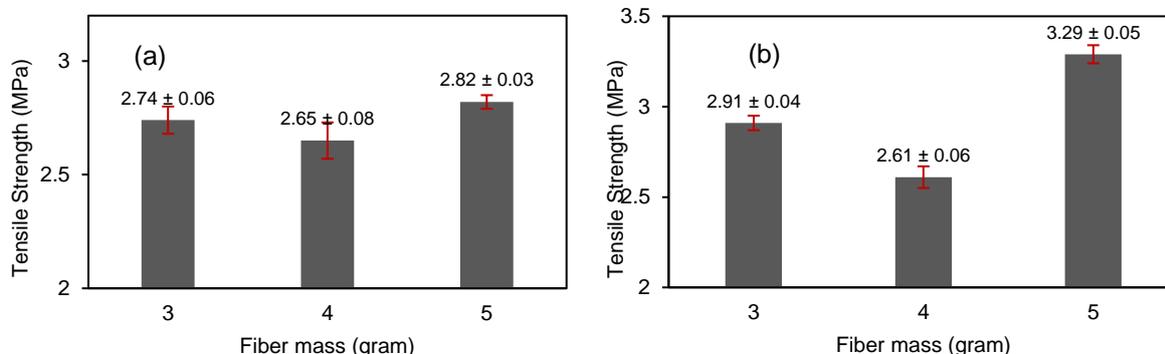
Figure 5 presents Young's modulus as influenced by varying fiber masses

subjected to immersion times of 30 and 45 minutes. In the 30-minute immersion scenario illustrated in panel (a), the peak Young's modulus occurred with a 5-gram fiber mass, marked at  $2.82 \pm 0.03$  MPa. Fiber masses of 3 and 4 grams yielded Young's modulus measurements of roughly  $2.74 \pm 0.08$  and  $2.65 \pm 0.08$  MPa.

Panel (b) of Figure 4 presents Young's modulus values at various fiber masses following a 45-minute immersion period. Values were approximately  $2.91 \pm 0.04$ ,  $2.61 \pm 0.08$ , and  $3.29 \pm 0.05$  MPa for fiber masses of 3, 4, and 5 grams. The observation of lower Young's modulus values at lower fiber masses corroborates findings from previous studies, which suggested that an increase in bagasse content results in films with reduced Young's modulus. Such reductions could stem from alterations in the starch composition's structure upon fiber addition, leading to a lack of

coalescence in the specimen matrix [37]. Conversely, an increase in Young's modulus for fiber masses of 5 grams at 30 and 45 minutes of immersion times indicates that a larger mass

allows for a more uniform distribution of fibers as reinforcing material throughout the specimen, enhancing its mechanical properties.



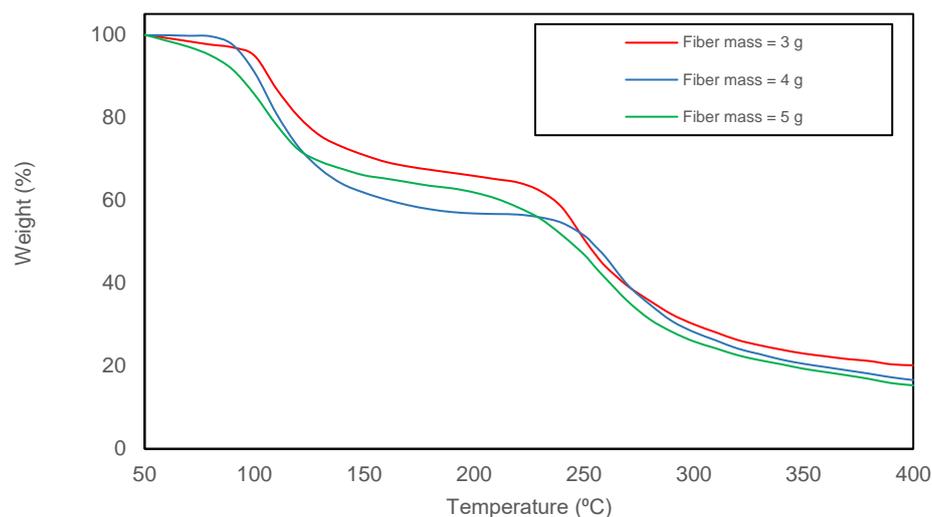
**Figure 5.** Correlation of fiber mass to the Young's modulus with the soaking time of (a) 30 minutes and (b) 45 minutes

#### 4. Thermogravimetric Analysis (TGA) of Samples

The thermal degradation of biocomposites encompasses the behavior of materials as they are exposed to increasing temperatures, including changes that do not involve chemical transformations and those that do. This process is critical for understanding the various chemical mechanisms involving structural alterations, the impact of biocomposite morphology, reactions involving additives, and the dynamics between fillers and the matrix.

Thermogravimetric analysis (TGA), as illustrated in Figure 6, provides insight into the decomposition stages of biocomposites. The initial stage, between 50 to 125°C, involves reducing and releasing moisture or water. This phase is characterized by the loss of very light volatile compounds, primarily due to the evaporation of water, marking the

commencement of the thermal decomposition process. The second stage, spanning temperatures from 125 to 300°C, is crucial for the thermal decomposition of biocomposites. During this phase, volatile matters are released, driven by the decomposition of bagasse and rice bran, which contain amylose particles capable of forming volatile carbohydrate lipids composed of carbon, hydrogen, and oxygen. This stage is marked by rapid thermal decomposition and significant mass loss, accelerated by oxygen. The final stage, occurring at temperatures above 300°C, follows the release of volatile substances. This phase is characterized by the flammability of charcoal, which is now surrounded by volatile matter and oxygen. The interaction between oxygen and the charcoal surface facilitates the combustion of charcoal and volatile matter. This stage culminates in forming fixed carbon within the sample, often regarded as a by-product.



**Figure 6.** TGA profile of biocomposites with varied fiber mass

Figure 6 reveals that an increase in the mass of bagasse fiber correlates with a heightened rate of biocomposite decomposition. This phenomenon is attributed to the larger quantity of water retained within the biocomposite as the mass of bagasse used increases, allowing the material to combust at temperatures surpassing 125°C. This analysis underscores the complex interplay between material composition and thermal behavior, highlighting the importance of understanding thermal degradation for optimizing biocomposite performance.

### 5. The Water Absorption Analysis

Water absorption analysis aimed to quantify water uptake by biocomposites reveals that changes in water absorption fluctuate with variations in fiber mass. A direct relationship exists between the fiber mass and water absorption: as the fiber mass increases, so does the water absorption (swelling), and the inverse is also true [39]. The surge in water absorption is attributable to the hydrophilic

nature of the fibers, which enhances the attractive force between the fiber and water, leading to an uptick in water absorption within the biocomposite. This phenomenon is largely due to the fibers' propensity to form chemical bonds (affinity) easily with H<sub>2</sub>O, as evidenced by their capacity to adsorb water.

Table 3 illustrates a proportional correlation between bagasse fiber mass, soaking time, and the biocomposite's ability to absorb water. A larger fiber mass entails more water bound within the biocomposite. Similarly, an extended immersion time increases the opportunity for water to permeate the biocomposite. These findings align with those reported in a previous study [26]. Water absorption percentages at 30 minutes of immersion time for fiber masses of 3, 4, and 5 grams were recorded at 16.37%, 36.29%, and 39.96%. For a 45-minute immersion period, water absorption for fiber masses of 3, 4, and 5 grams were observed at 32.26%, 36.33%, and 41.99%.

**Table 3.** Absorption of water results

Fiber mass (g)	Immersion time (minutes)	Initial mass (g) ( $W_0$ )	Final mass (g) ( $W_1$ )	Absorption of Water (%)
3	30	0.421	0.532	26.37
4	30	0.463	0.631	36.29
5	30	0.548	0.767	39.96
3	45	0.434	0.574	32.26
4	45	0.501	0.683	36.33
5	45	0.562	0.798	41.99

## CONCLUSION

Biocomposites were synthesized employing epoxy resin, bagasse fiber, and rice bran. The fabrication entailed extracting fiber yarn from milled bagasse (pre-treatment), alkalizing the bagasse fiber with  $\text{KMnO}_4$ , conducting specimen printing, and performing various analyses. During the alkalization phase, bagasse fibers were immersed in a potassium permanganate solution for predetermined durations of 30 and 45 minutes, with fiber masses being adjusted to 3, 4, and 5 grams. The biocomposite's quality was evaluated based on the analysis of tensile strength, strain, Young's modulus, thermogravimetric (TGA), and water absorption. It was observed that augmenting the fiber mass significantly improved tensile strength. Specifically, 3, 4, and 5 grams fiber masses resulted in tensile strength values of approximately  $22.29 \pm 0.21$  MPa,  $22.62 \pm 0.15$  MPa, and  $23.90 \pm 0.24$  MPa. The optimal conditions, entailing a 45-minute soaking period with a fiber mass of 5 grams, yielded a tensile strength of  $26.32 \pm 0.25$  MPa, a strain of  $9.65 \pm 0.14\%$ , a Young's Modulus of  $3.29 \pm 0.05$  MPa, and a water absorption rate of 41.99%. The biocomposites produced were of average quality. Several adjustments could be considered for enhanced composite outcomes, including optimizing the ratio of epoxy resin to reinforcing material, adjusting humidity levels,

experimenting with different reinforcing materials, and employing alternative methods for preparing the matrix and filler. According to the SNI 03-2105-2006 standards regarding Particle Board, the minimum quality for particle board is set at  $3.01 \text{ kg/cm}^2$ , equivalent to  $0.0304 \text{ MPa}$  [37]. Thus, the tensile strength of the developed composite surpasses that of standard particle board, indicating superior mechanical properties.

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