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Investigation of Mechanical Properties and Thermal Analysis of Bagasse Fiber Reinforced Composite Polymer Foam

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***Abstract*—Bagasse is a waste used as a new material for foam polymer composites as reinforcement. This waste is quite a lot and has not been processed properly to become new material. This waste is adopted as ordinary organic fertilizer, incinerated, or disposed of. For that reason, it needs further research investigation. Due to its advantages, further investigation into the best composition is needed to achieve a tough composite material. It is a lightweight material with high economic value and can be used to overcome environmental problems. Therefore, this research obtains the mechanical properties and thermal analysis of the composite polymer foam reinforced with bagasse fibers. Part of the matrix is a thermoset polymer polyurethane (BQTN 157), and the reinforcement part is bagasse fiber. Bagasse was local waste from traders around Langsa City in Indonesia. The bagasse waste was processed into the fiber. The bagasse composition on a percentage weight ratio. They were mixed with resin and foam ingredients, blowing agent, and catalyst and poured into casting pattern composite material. A mesh of bagasse fiber was the size of 80. Thermogravimetric Analysis has made All specimens that need a tensile test to obtain the material's strength and thermal stability. The result has found that the specimen of polymeric foam composite material with 5% bagasse fiber was obtained based on the results. The tensile strength values are 19.5 MPa. A thermal stability condition changes temperature between 39.95°C – 516.55°C.**

***Keywords*— Composite polymer foam; mechanical characterization; bagasse fiber.**

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I. INTRODUCTION

In the last decade, polymer composite has become one of the materials to be investigated and developed in various applications [1]–[3]. Their use in industrial [4], [5], and household has also increased [6], [7] due to several characteristics of composite materials, which are very good and easy to manufacture [8]–[10]. Therefore, investigations were carried out on polymers as matrices in various applications and types of reinforcement [11], including synthetic [12]–[14] and natural fibers [15]. It was discovered that natural fibers have stable strength [16] and toughness [17] when combined with polymers and can improve physical [18] and mechanical properties [19]. They are also renewable [20] and sustainable materials [21] that are embedded in polymer matrices [22]. Natural fibers are obtained from agricultural sources or as processing waste [22] and used to replace synthetic fibers in various composites, which function as reinforcement [11], [23]. They are available, inexpensive, and easy to manufacture [24].

Natural fibers are widely available in Indonesia, and their use as reinforcement is constantly being investigated to obtain new composite materials with good properties [25]. These materials are light, easy to obtain, and have high rigidity, good strength, and corrosion resistance [26]. Meanwhile, their use in various composite applications gradually increases [27], reducing metal dominance. The natural fibers that are commonly used are banana stems, bamboo, wood, coconut fiber, sugar palm, and sugarcane [28], [29].

Sugarcane, with the Latin name Saccharum officinarum, is a grassed class in tropical climates. Based on statistical data, its production throughout Indonesia was 2.5 million tons. Once extracted, it produces a large amount of a fibrous waste product called bagasse, a complex material consisting of approximately 50% cellulose, 25% hemicellulose, and 25% lignin. This waste is adopted as ordinary organic fertilizer, burned, or disposed of [30].

Using bagasse fiber as a reinforcement for composite materials increases high economic values [31] and reduces environmental problems [32]. Since this waste can still be processed to produce new material, further research and development are needed [33]. In polymer foam composites, the fibers are used as partition boards in engine rooms as sound-dampening materials [34].

Previous research on composites has been carried out, using natural fibers as reinforcement. This includes G. Heath Kumar and colleagues, who investigated the reaction of bagasse and glass fiber on the mechanical strength of composite materials. The research used epoxy as a matrix and as reinforcement by glass and sugarcane fibers [35]. The test samples were prepared with the percentage of sugarcane volume and continuous fiber size, and the manufacturing process used the hand layup method [36].

In this research, composite materials are developed by adding glowing agent material to produce foamed polymers with several advantages, such as being easy to manufacture in large quantities, inexpensive, and lightweight [37]. They can also be applied in automotive, aircraft, and thermal insulators [38]–[40]. Meanwhile, this research focused on the weight ratio faction of the ingredient of each supporting material, which was underreported in previous reports. Variations in the design of the test samples were resin, blowing agent, and bagasse fiber, while the catalyst served to accelerate the reaction. Observing the variable bagasse fiber and resin becomes decisive in obtaining a stronger polymer foam composite material. Furthermore, using a blowing agent can reduce the product's final weight. In making samples, testing was carried out using the casting method and the dimensions of the short fiber (discontinuous fiber), with random directions, compared to the hand layup method and the long fiber (continuous fiber).

This research aims to carry out mechanical tests such as tensile strength on test samples of polymer composite materials reinforced with bagasse fiber and to obtain the thermal stability conditions change of the composite materials.

II. Material and Method

A. Materials

The composite materials consist of two major parts: a binder and a reinforcement/binder material. Part of the matrix is a thermoset polymer polyurethane (BQTN 157) [41]–[43], and the reinforcement is bagasse fiber, which was local waste from traders around Langsa City in Indonesia. Furthermore, a Natrium Oxide (NaOH) solution is needed to clean oil, dirt stains and remove lignin (delignification) by soaking [44], [45]. A polymer foam composite production requires a blowing agent, and the reaction can be accelerated by adding a catalyst to the formulations.

B. Bagasse Fiber Fabrication Process

The first step in the fabrication process is the production of the fiber according to the 80-mesh size [46],[47]. Making bagasse fiber waste requires several stages, which include:

- The provision of the bagasse in a container
- It is drowned in a solvent of water and NaOH
- The bagasse is washed with pure water and dried in the sun
- Cut into narrow pieces (5-10 cm)
- Crush into meshing parts using a lint crusher to form fine fibers
- Sift fine fibers to 80 mesh size
- The last step is the fiber generated.

A detailed illustration of the processing and manufacturing of the bagasse fiber is shown in Figure 1.

Fig. 1 Stages of the process of making bagasse fibers

C. The Process of Specimens and Preparation

The manufacturing of polymer foam composite materials initiates with the Preparation of ingredients of all materials, consisting of type BQTN 157 of polymer, bagasse fiber, and a blowing agent. Each ingredient was formulated and weighed according to its elemental composition. The initial step is mixing the resin polymer and the bagasse fibers in a bowl and stirring for approximately 10 minutes until the parts are well combined. The next step was followed by adding 5% catalyst composition, blowing ingredients into the mixing bowl, and stirring briefly. The final step is to pour the material into the mold using the casting method to produce a composite polymer foam structure with random and discontinuous fiber directions. Moreover, all process steps were carried out to produce a polymer foam composite.

The dependent variables were BQTN 157 polymer resin, blowing agent, and catalyst. The independent variable was

bagasse fiber, with a percentage weight ratio of 1%, 2%, 3%, 4%, 5%, 6%, 7%, and 8%. Furthermore, the dependent variable was the blowing agent and catalyst, with a percentage weight ratio of 15% and 5%, respectively. All specimens require a label. Therefore, letters A and D are for the tensile test (without fiber and with fiber), and letters S are for thermal stability.

D. Mechanical Properties

Tensile and compressive tests are used to determine the maximum strength of the sample material under load. These tests use a Universal Testing Machine with a Tensilon RTF model type and a load cell rating of 50000 N. Based on the specification, the ASTM standard requirement for the tensile and compressive test specimens is ASTM D-638 [48]. The tests were carried out to obtain the maximum strength and the variations in the specimen fibers' composition. To observe the material's thermal stability using the Hitachi T1000 testing machine.

E. Thermal Analysis

LINSEIS STA Platinum Series (simultaneous thermal analysis) was focused upon to determine the mass change of the specimens with a temperature range of 150-1750°C. This led to the application temperature of the test material. In this study, a fiber extracted from bagasse as reinforcement in polymer matrix composites, the behavior of thermal physical properties in this composite can be investigated by thermogravimetric analysis [49]. Meanwhile, the specimen used was a sample of polymer foam composite material reinforced with bagasse fiber at composition variations are 0%, 1%, 2%, 3%, 4%, 5%, 6%, 7%, and 8%, respectively.

III. Results and Discussion

A. Mechanical Properties

Mechanical properties were determined by testing the specimens without fiber composition (fiber = 0%). A total of four specimens were used as tensile test samples, each labeled A1, A2, A3, and A4. Figure 2 shows the tensile test results with 0% fiber composition.

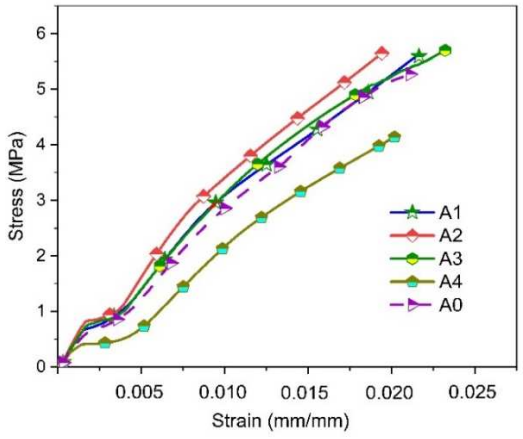

Fig. 2 Tensile test specimen without bagasse

The lowest strength values occurred in the stress and strain magnitudes of 4.139 MPa and 0.020 mm/mm, respectively (label A4). The highest stress and strain values were 5.699 MPa and 0.023 mm/mm, respectively (label A3). Meanwhile, their average values in the stress and strain magnitudes on the fiber-free specimens were 5.269 MPa and 0.021, respectively (label A0), as shown in Figure 2 by dotted lines. These average values will be used as a reference for the tensile strength test without fiber. The stress and strain data from the tensile test results for each sample without fiber can be seen in Table 1.

TABLE I
TENSILE TEST SAMPLE WITHOUT FIBER

No.	Label	Stress (MPa)	Strain (mm/mm)
1.	A1	5.591	0.022
2.	A2	5.648	0.019
3.	A3	5.699	0.023
4.	A4	4.139	0.020
average	A0	5.269	0.021

Subsequent tests measure the tensile strength of the specimen with variations in fiber as reinforcement. These were carried out to obtain variations in the composition of bagasse fiber with good strength. The variation in the specimens' fiber plant was 1%, 2%, 3%, 4%, 5%, 6%, 7% and 8%, respectively. As for the percentage of fiber implanted in the composite is then labeled D1, D2, D3, D4, D5, D6, D7, and D8. Figure 3 describes the strength of the specimens. The stress and strain occur in the tensile test due to differences in fiber composition. The results showed that the tensile strength value increased with the fiber composition embedded in the specimen [50], [51].

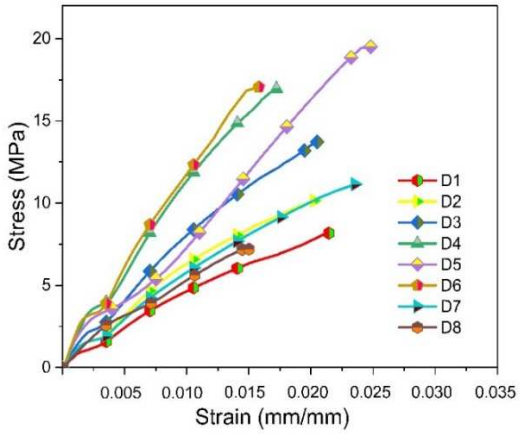

Fig. 3 Tensile test specimen with bagasse fiber

The stress and strain data from the tensile test results for each sample with fiber percentage can be seen in Table 2.

TABLE II
TENSILE TEST SAMPLE WITH FIBERS

No.	Label	Stress (MPa)	Strain (mm/mm)
1.	D1	8.177	0.021
2.	D2	10.146	0.020
3.	D3	13.722	0.021
4.	D4	16.960	0.017
5.	D5	19.507	0.025
6.	D6	17.061	0.016
7.	D7	11.148	0.024
8.	D8	7.203	0.015

While the maximum tensile strength occurred in the composition of 5% (label D5), the addition of fiber composition will increase strength by up to 5% and subsequently decrease. The minimum stress and strain occurred in the specimen of 8% fiber (label D8), with values of 7.203 MPa and 0.015 mm/mm, respectively. Meanwhile, the maximum tensile strength was obtained in the stress and strain of 19.507 MPa and 0.025 mm/mm, respectively (label D5). The distribution of strength values for each composition is presented in Figure 3. When compared with the strength of the composite without fiber (the curve in Figure 2), it shows that adding 5% fiber fraction weight on the formation of the composite material (Figure 3), also increases the maximum strength of the material. This research is in accordance with previous research that has been done [52].

The modulus of elasticity (E) from the tensile test results is shown in Figure 4, where the specimen without fiber has a value of 41.169 MPa (label A0). The addition of the percentage of fiber is expected to affect the magnitude of the elastic modulus [53]. Therefore, the highest-fiber addition from the tensile test results is 5%, producing a maximum elastic modulus (E) of 98.8 MPa (label D5).

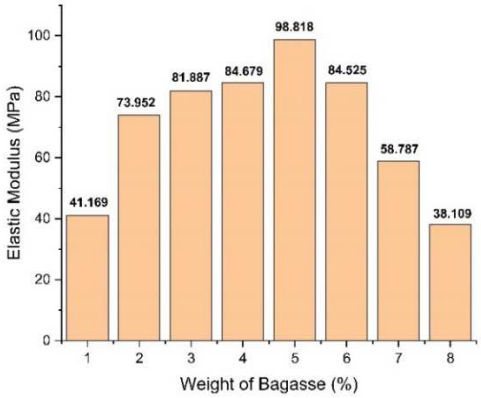

Fig. 4 Modulus of elasticity of the bagasse fiber

Thermal test analysis focuses on determining the test sample's decomposition temperature. This test was carried out with variations in fiber composition of 0%, 1%, 2%, 3%, 4%, 5%, 6%, 7%, and 8%. then the test specimens are labeled S0, S1, S2, S3, S4, S5, S6, S7, and S8. Figure 5 shows the thermal stability test using TGA with test sample without fiber and sample with the percentage of fibers. This study provides an overview of the distribution modulus elasticity of natural fibers that are very effective and can be used as reinforcement in a mixture of polymer matrix composite [54].

The thermal decomposition process changes through stages can explained in Figure 5. The first stage occurs in the fiber less sample at about 26.52°C – 353.48°C. Moreover, the second stage occurs at about 353.49°C – 436.53°C, and the third stage is at 436.54°C – 512.31°C. The first stage of the test sample with 1% of fiber occurs at about 28.53°C – 353.48°C. Moreover, the second stage occurs at about 353.49°C – 436.53°C, and the third stage is at 436.54°C – 512.53°C. The test sample with 2% fiber 37.53°C – 349.08°C. Moreover, the second stage occurs at about 349.09°C – 435.35°C, and the third stage is at 435.36°C – 514.91°C. In the test sample with 3% fiber, thermal decomposition occurs in the first stage at temperatures around 34.75°C - 341.15°C. The second stage change occurs around 341.16°C – 436.16°C. The third stage is 436.17°C – 513.96°C. The test sample with 4% fiber changed thermal decomposition, with the first stage occurring at a temperature of around 32.15°C – 341.98°C. The second stage occurs at a temperature of around 341.99°C – 431.78°C, and the third stage occurs at a temperature of 441.79°C – 515.73°C.

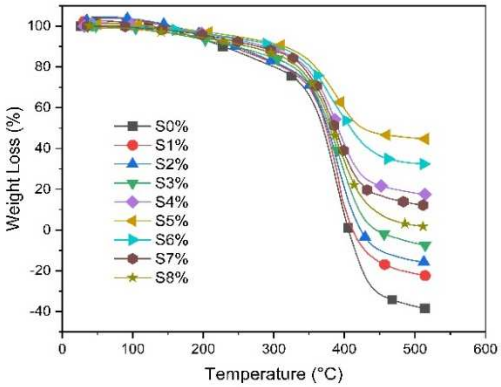

Fig. 5 Thermal Gravimetric Analysis curve of the test sample

Decomposition changes in the fiber sample of 5% fiber; the first stage occurs at a temperature of around 39.95°C – 336.24°C. The change in the second stage occurred around 336.25°C – 429.14°C. At the same time, the third stage was 429.15°C – 516.55°C. The test sample with 6% fiber changed thermal decomposition, with the first stage occurring at a temperature of around 44.39°C – 327.91°C. The second stage occurs at a temperature of around 327.92°C – 438.06°C, and the third stage occurs at a temperature of 438.07°C – 512.63°C. The test sample with 7% fiber changed thermal decomposition, with the first stage occurring at a temperature of around 36.62°C – 336.18°C. The second stage occurs at a temperature of around 336.19°C – 428.74°C, and the third stage occurs at a temperature of 428.75°C – 515.63°C. And the test sample with 8% fiber changed thermal decomposition, with the first stage occurring at a temperature of around 39.63°C – 337.68°C. The second stage occurs at a temperature of around 337.69°C – 444.53°C, and the third stage occurs at a temperature of 444.54°C – 512.66°C. The result of thermogravimetric analysis decomposition weight loss material composite polymeric foam reinforced by bagasse waste fiber is shown in Table 3.

TABLE III
RESULTS OF THE THERMOGRAVIMETRIC ANALYSIS (TGA) TEST

Fiber (%)	T_{on} (°C)	T_{Mi} (°C)	T_{en} (°C)	Weight loss (%)
0	353.49	371.68	436.53	100
1	338.43	373.32	432.68	100
2	349.09	377.55	435.35	100
3	341.18	380.71	436.53	97.7
4	341.99	392.20	431.78	77.01
5	336.25	424.21	429.14	50.74
6	327.92	409.93	448.06	63.97
7	336.19	386.61	428.74	83.53
8	337.69	383.59	444.53	94.33

T_{on} = Temperature onset T_{Mi} = Temperature Midpoint
T_{en} = Temperature enset

The calculation of the total mass loss for samples with 5% fiber (having a maximum tensile test) occurred at around

50.76%. Furthermore, Solvothermal changes the weight percentage at temperatures between 39.95°C to 516.55°C. In this study, a fiber extracted from bagasse as reinforcement in polymer matrix composites, the behavior of thermal physical properties in this composite can be investigated by thermogravimetric analysis [55].

IV. Conclusion

Based on the results, the highest composition of bagasse fiber that can be mixed into the polymeric foam composite material was 5%. Furthermore, determining the maximum strength of the composite material reinforced with bagasse fiber showed that maximum tensile strength values are 19.5 MPa, and the Percentage of the thermal change between 39.95°C - 516.55°C, and mass loss of decomposition process occurred at around 50.76%.

Nomenclature

A	surface area	m^2
L	length	m
F	Force	N
Δl	length of change dimension	m
T	Temperature	°C
Greek letters		
σ	Stress	MPa
ε	Strain	mm/mm
E	Modulus Elasticity	MPa

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