Mechanical properties investigation of green composite from ramie (*Boehmeria nivea* (L.) Gaud) and epoxy

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Abstract. In the last decade, the requirement of friendly environment materials has increased significantly. Green composite material, such as natural fiber reinforced epoxy composite, has been developed to provide an environmentally friendly product. Ramie (*Boehmeria nivea* (L.) Gaud) fiber and bio-epoxy are potential materials to produce an excellent environmentally friendly composite. The physical and mechanical properties of the composite were evaluated. Each composite material has three different layers of ramie fiber orientation, i.e., 0, 45, and 90°. Ramie fiber contents were varied by 5, 7.5, and 10% w/w of composite weight. The content variations of epoxy matrix hardener were 25 and 50% w/w of matrix weight. The replication of each sample was three times. The making of the ramie fiber-epoxy lamina composite was started with mixing the epoxy with a hardener, followed by pouring the matrix on the mold and coating the layers of fibers layer by layer until a composite was obtained according to the specified layer variations. The sample was poured into mold-press for 24 hours. Then, samples were removed from the mold and put in the oven at 60°C for 24 hours. For conditioning, the samples were placed in an open space at room temperature (27°C) for seven days. The dimension of the samples was 150 mm x 100 mm x 3 mm. For the composite materials, tensile testing and flexural testing standard were ASTM D 638 and ASTM D 790, respectively. The research results showed that the composite with 25% of hardener (w/w matrix weight) and 5% of ramie fiber (w/w composite weight) had the lowest thickness swelling (0.17%). However, the highest tensile strength (45.8 MPa) was obtained by the composite with 25% of hardener (w/w matrix weight) and 10% of ramie fiber (w/w composite weight). Meanwhile, the flexural strength of the composites with 50% of hardener, either with 5 or 7.5% of ramie fiber, was higher than the other composites. Composite materials, which contain 10% of ramie fiber (w/w composite weight) and 25% of hardener (w/w matrix weight), had the best mechanical properties.

1. Introduction
In the last few decades, the development of composites based on renewable resources has increased along with the high demand for composite materials and the limited resources of petroleum-based synthetic materials. The low price-performance comparison of natural fiber composites makes it more attractive not only for building and automotive applications but also for packaging, furniture, and even...
aerospace applications. Types of natural fibers that have been developed as composite reinforcement include ramie [1], jute [2-5], coconut [6], kenaf [7, 8], sisal, ramie fiber [9], bagasse fiber [10] and so on. The main advantages of natural fibers are their availability, biodegradability, renewability, low cost, low density, and high specific properties [4].

The use of natural fibers is focused on replacing synthetic fibers. Ramie fiber is a kind of natural fiber derived from the bark. Moreover, it has the highest cellulose content and the lowest lignin content [11] so that it has great potential to be developed into a composite reinforcing material. The chemical content of crude ramie fiber according to Kalita et al. [12] and Sood et al. [13] is 68.6-70.1% cellulose, 9.8-16.7% hemicellulose, 9.25% lignin, 6.95% moisture content, 1.25% ash, 4.8% pentosan and 0.3-0.6% waxed. Ramie fiber has good compatibility so that it is easily mixed with other compounds [14]. It also has very good resistance to the degradation process of organisms [15] and has high tensile strength and Modulus Young. The polymer used as a matrix in composite materials with natural fiber reinforcement is usually a thermosetting polymer, although it does not rule out the possibility of using thermoplastic polymer. Thermosetting polymers can be used to make composite materials with various methods, namely hand lay-up, spray lay-up, compression molding, filament winding. These polymers make it possible to use long natural fibers continuously.

Meanwhile, thermoplastic polymers are suitable as a matrix with an orientation of random and short fibers by injection molding method [10]. Currently, as a matrix, epoxy resins are widely used in various technical and structural applications [6], such as in the electricity industry, energy sector [16], transportation, and military industry, such as bulletproof vests [17, 18]. This resin has good adhesion to other materials, is resistant to chemicals and environmental degradation, has good chemical properties, and insulating properties. Epoxy resin has many desirable properties, such as high stiffness and strength, excellent chemical, and solvent resistance [19]. However, its main drawback is brittleness. The right combination of fibers as reinforcement and epoxy as matrices makes better composites. Therefore, ramie and epoxy fibers have good potential as ingredients in the manufacture of green composites for aircraft body parts, such as wing skins, transportation equipment components, housing facilities, and so on [20]. The effect of ramie fiber content and epoxy hardener on the mechanical and physical properties of lamina-epoxy fiber composite lamina will be presented in this paper.

2. Materials and method

The material used in this study was ramie fiber (Boehmeria nivea (L.) Gaud) from East Java, Indonesia as reinforcement, and epoxy as a matrix. Physical-mechanical properties of the fibers and matrices were tested, including moisture content, density, tensile strength, modulus of elasticity, and strain. ASTM D 3379 is used for the tensile fiber test, while the ASTM D 639 standard is used for the epoxy matrix. For the flexural test, ASTM D 790 was used. The making of the ramie fiber-epoxy lamina composite used a hand lay-up method followed by the press. The hardener used in making ramie fiber-epoxy laminate composites was 25 and 50% by weight of the matrix. The concentration of ramie fiber used was 5, 7.5, and 10% by weight of the ramie fiber-epoxy lamina composite. Ramie fiber was made in three layers of fiber. The orientation of the ramie fiber layers in the ramie fiber-epoxy laminate composite were 0, 45, and 90°. The dimension of the sample was 150 mm x 100 mm x 3 mm and made in three replicates.

The making of the ramie fiber-epoxy lamina composite was started with mixing the epoxy with a hardener, followed by pouring the matrix on the mold and coating the layers of fibers layer by layer until a composite was obtained according to the specified layer variations. The sample was poured into mold-press for 24 hours. Then, samples were removed from the mold and put in the oven at 60 °C for 24 hours. For conditioning, the sample was placed in an open space at room temperature (27 °C) for seven days. After the conditioning stage was completed, the ramie fiber-epoxy lamina composite was formed according to the test sample and tested for physical and mechanical properties. Measurement of physical properties included measurements of moisture content, density, thickness
swelling, and water absorption. For mechanical testing, namely tensile tests, and flexural tests, Shimadzu AG-IS 50 kN Universal Testing Machine (UTM) was used.

3. Results and discussion

3.1. Physical properties

Physical properties of the ramie fiber and epoxy resin and mechanical properties were tested, before making the ramie fiber-epoxy lamina composite. The data were obtained, as shown in Table 1. From the table below, the value of ramie fiber density is equal according to data from Pickering et al. [21]; Kalita et al. [12], Reis et al. [22] and higher than data result from Pereira et al. [23], about 1.2 g/cm$^3$. The moisture content value is greater than the data of Kalita et al. [12]. The ideal water content for natural fibers, when mixed with thermoset polymers, is less than 10%.

| Material       | Density (g/cm$^3$) | Moisture Content (%) | Tensile Strength (MPa) | Tensile Modulus (GPa) | Elongation (%) |
|----------------|--------------------|----------------------|------------------------|-----------------------|----------------|
| Ramie fiber    | 1.5                | 8.50                 | 324                    | 9.878                 | 3.80           |
| Epoxy$^1$      | 1.3                | 0.62                 | 42.3                   | 1.113                 | 3.60           |
| Epoxy$^2$      | 1.3                | 0.62                 | 42.3                   | 1.113                 | 3.60           |

Note: epoxy$^1$ used hardener 25% of the matrix weight; epoxy$^2$ used hardener 50% of the matrix weight.

The tensile strength value of ramie fiber is lower than the value of Pickering et al. [21], which is equal to 400-900 MPa, with an elongation value of 2-3.8%. However, the tensile value is higher than Pereira et al. 2020 [8], just about 212 MPa. The tensile strength of epoxy matrices is higher than the value with Neves et al. [11], about 40.10 MPa because the mechanical properties of natural fibers depend on the planting place and the age of the plant. Moreover, the after-harvest process also affects the mechanical, physical characteristics of natural fibers.

The physical properties of the ramie fiber-epoxy lamina composite, i.e., density, moisture content, water absorption, and thickness swelling values, are shown in Table 2. From the table below, it appears that the density values for all test specimens are in the range of 0.99-1.13 g / cm$^3$. This value is lower than the value of epoxy density or ramie fiber. It can occur because the ramie fiber-epoxy lamina composite formed has many air voids, making its value outside the range of matrix and fiber density values.

| Specimen | Fiber content (% w/w of composite weight) | Density (g/cm$^3$) | Moisture contains (%) | Thickness swelling (%) | Water absorption (%) |
|----------|-------------------------------------------|--------------------|----------------------|-----------------------|---------------------|
| TL 25A   | 5.0                                       | 1.06               | 0.095                | 0.17                  | 6.72                |
| TL 25B   | 7.5                                       | 1.13               | 0.053                | 0.28                  | 10.18               |
| TL 25C   | 10.0                                      | 1.08               | 0.059                | 0.25                  | 10.20               |
| TL 50A   | 5                                         | 0.99               | 0.277                | 0.24                  | 7.39                |
| TL 50B   | 7.5                                       | 1.03               | 0.556                | 0.21                  | 6.96                |
| TL 50C   | 10                                        | 1.03               | 0.125                | 0.32                  | 8.16                |

Note: TL 25A: three layers in fiber laminate, hardener content 25% w/w (matrix weight) and 5.0% fiber content (w/w composite weight). TL 25B: three layers in fiber laminate, hardener content 25% w/w (matrix weight) and 7.5% fiber content (w/w composite weight). TL 25C: three layers in fiber laminate, hardener content 25% w/w (matrix weight) and 10% fiber content (w/w composite weight). TL 50A: three layers in fiber laminate, hardener content 50% w/w (matrix weight) and 5.0% fiber content (w/w composite weight). TL 50B: three layers in fiber laminate, hardener content 50% w/w (matrix weight) and 7.5% fiber content (w/w composite weight). TL 50C: three layers in fiber laminate, hardener content 50% w/w (matrix weight) and 10% fiber content (w/w composite weight).
This density value is in line with the density of natural fiber-epoxy from the research results of Huang et al. [16], which is in the range of 1.101-1.128 g/cm³ with a concentration of 8-12% natural fiber. With this density value, it is known that the volume of void content reaches 3.5-4.7%. The presence of void content is due to the inefficiency of the polymeric phase to displace the trapped air within the composite [7]. Moreover, the formation of void content was also due to the presence of moisture in the fiber during fabrication. Ismail et al. [7] have examined void content from kenaf/bamboo fiber epoxy hybrid composites. There is an empty structure in the kenaf/bamboo fiber in the epoxy matrix. It appears that the resin cannot enter into the empty part of the fiber. Also, voids may occur during the resin preparation process when mixing epoxy and hardener with trapped air. The moisture content value of ramie fiber-epoxy lamina composite ranges from 0.053 to 0.556%.

This value is still within the threshold. From the table above, it is also seen that the thickness swelling of the ramie fiber-epoxy lamina composite is below 1%, with a maximum value of 0.32% for 10% ramie fiber content. In general, 50% of hardener content has higher moisture content and thickness swelling values compared to 25% hardener content. Water absorption value of ramie fiber-epoxy lamina composite ranges between 6.72-10.2% for 5-10% ramie fiber content. This value is higher than the results of Huner [23] study, which is 7-9% for 5-10% natural fiber content. The natural fibers used by Huner are flax fibers, and the matrix used is epoxy. It occurs because the fibers contain abundant polar hydroxide groups, resulting in a high moisture absorption level of natural fiber reinforced polymer matrix composites [23]. The tendency of water absorption is mainly due to natural fiber. The water absorption tendency of the composite increases with an increase in ramie fiber content of the composite due to 7.5 and 10% fiber content. This is similar to the result of Tripathi et al.[4].

3.2. Mechanical properties

3.2.1. Tensile strength, young modulus and elongation. The influence of fiber loading on the tensile strength and tensile modulus of the composites is shown in Figure 1, respectively.

![Figure 1. The influence of fiber loading and hardener content on the tensile strength of ramie fiber-epoxy lamina composites.](image-url)

Figure 1 shows that the tensile strength of all specimens increased with increasing fiber loading rate. From Figure 1, it can be seen that in general, the tensile strength value of ramie fiber-epoxy lamina composites with a 25% hardener is higher than that of lamina composites with 50% hardener.
The difference in tensile strength values between hardener compositions is 7, 9, and 11% for the ramie fiber content of 5, 7.5, and 10%. The increase in tensile strength values for the fiber content of 5, 7.5, and 10% is 20.5% for 25% hardener content. While the increase in the value of tensile strength for hardener 50% is 16.7 and 32.3%. From data, it appears that 10% of fiber content can equal to the tensile strength of the epoxy. Ramie fiber-epoxy lamina composite with 25% hardener has a value of 8.3% higher than the epoxy tensile strength value. In comparison, the ramie fiber-epoxy lamina composite with 50% hardener has a value of 0.5% higher than the epoxy tensile strength value.

Data on the tensile modulus value and elongation of ramie fiber-epoxy lamina composites are shown in Table 3 below. From the table, it can be seen that the tensile modulus values tend to increase along with the addition of ramie fiber content with both 25% and 50% hardener levels. For 25% hardener content, there is an increase in the tensile modulus value of 27% from the fiber content of 5% to 10%. Then for the 50% hardener content, there is an increase in tensile modulus of 186% from the content of ramie fiber from 5% to 10%.

### Table 3. Tensile properties of ramie fiber-epoxy lamina composites.

| Specimen | Fiber content (% w/w of composite weight) | Tensile strength (MPa) | Tensile Modulus (GPa) | Elongation (%) |
|----------|------------------------------------------|------------------------|-----------------------|---------------|
| TL 25A   | 5.0                                      | 30.2                   | 0.96                  | 2.8           |
| TL 25B   | 7.5                                      | 36.4                   | 1.27                  | 2.9           |
| TL 25C   | 10.0                                     | 45.8                   | 1.22                  | 3.6           |
| TL 50A   | 5.0                                      | 27.5                   | 0.37                  | 7.4           |
| TL 50B   | 7.5                                      | 32.1                   | 0.82                  | 3.9           |
| TL 50C   | 10.0                                     | 42.5                   | 1.06                  | 4.0           |

Note:
TL 25A: three layers in fiber laminate, hardener content 25% w/w (matrix weight) and 5.0% fiber content (w/w composite weight).
TL 25B: three layers in fiber laminate, hardener content 25% w/w (matrix weight) and 7.5% fiber content (w/w composite weight).
TL 25C: three layers in fiber laminate, hardener content 25% w/w (matrix weight) and 10% fiber content (w/w composite weight).
TL 50A: three layers in fiber laminate, hardener content 50% w/w (matrix weight) and 5.0% fiber content (w/w composite weight).
TL 50B: three layers in fiber laminate, hardener content 50% w/w (matrix weight) and 7.5% fiber content (w/w composite weight).
TL 50C: three layers in fiber laminate, hardener content 50% w/w (matrix weight) and 10% fiber content (w/w composite weight).

From Table 3 above, it can be seen that the higher the elongation value, the more stretched the specimen receives a load. The elongation value reflects the elongation condition of the specimen. Ramie fiber-epoxy lamina composite with a 50% hardener tends to be more stretchy than composites with a 25% hardener. Elongation at break indicates the damage tolerance of composites. A higher elongation at break of a composite means that it has better damage tolerance [7].

The elongation value of the ramie fiber-epoxy lamina composite above is greater than the results of Khan et al. [6]. He conducted a study of the characteristics of a kenaf fiber-epoxy composite, with an elongation value of less than 1%. From the data in the table above, the higher the fiber content, the greater the elongation value. It shows that epoxy is more brittle than fiber. With increasing fiber content, the characteristics of the ramie fiber-epoxy lamina composite become more resilient. It can be said that the ramie fiber-epoxy lamina composite tends to experience matrix failure [24], i.e., the composite matrix will suffer damage first compared to the fiber.

#### 3.2.2. Flexural strength and flexural modulus.
Bending and tensile testing have significant differences, especially for inhomogeneous and anisotropic materials. In bending testing, it is greatly affected by the conditions of the upper and lower surface of the test specimen, namely the pull on the lower surface of the specimen and the presence of the compressive force on the upper surface of the specimen, which depends on the thickness of the specimen [23]. The results of the 3 point bending tests, which include the flexural strength and flexural modulus of the ramie fiber-epoxy lamina composite, are shown in Table 4 below. From the table, it can be seen that the flexural strength values of the ramie fiber-epoxy lamina composite for 25% hardener levels have increased with the increasing levels of ramie fiber. For
the value of flexural strength, the hardener content of 50% tends to be stable for the unique levels of ramie fiber. The flexural strength value of ramie fiber-epoxy lamina composite with 25% hardener levels increased by 3.96% when ramie fiber levels were added by 2.5% and increased by 22.9% when ramie fiber levels increased by 5%.

The value of flexural strength for this ramie fiber-epoxy lamina composite is higher than the results of Hasan et al. [5] research using sugarcane fiber and coconut fiber. The flexural strength values achieved in both fibers are 16.6 and 29 MPa for 10% fiber content. Nevertheless, the results of the bending test of ramie fiber-epoxy lamina composite have lower values than the results of Neves et al. 2020 [11], reaching 39 MPa for the same fiber content. In his study, Neves et al. [11] stated that the maximum flexural strength conditions of natural fiber-epoxy composites were achieved at 30% fiber content. In contrast, when using a polyester matrix, the highest flexural strength values were achieved at 20% fiber content.

### Table 4. Flexural properties of ramie fiber-epoxy lamina composites.

| Specimen | Fiber content (% w/w of composite weight) | Flexural strength (MPa) | Flexural Modulus (GPa) |
|----------|------------------------------------------|-------------------------|------------------------|
| TL 25A   | 5.0                                      | 25.50                   | 1.623                  |
| TL 25B   | 7.5                                      | 26.51                   | 1.510                  |
| TL 25C   | 10.0                                     | 31.35                   | 1.589                  |
| TL 50A   | 5.0                                      | 34.59                   | 0.476                  |
| TL 50B   | 7.5                                      | 34.95                   | 1.511                  |
| TL 50C   | 10.0                                     | 32.97                   | 1.526                  |

Note:
- TL 25A: three layers in fiber laminate, hardener content 25% w/w (matrix weight) and 5.0% fiber content (w/w composite weight).
- TL 25B: three layers in fiber laminate, hardener content 25% w/w (matrix weight) and 7.5% fiber content (w/w composite weight).
- TL 25C: three layers in fiber laminate, hardener content 50% w/w (matrix weight) and 10% fiber content (w/w composite weight).
- TL 50A: three layers in fiber laminate, hardener content 50% w/w (matrix weight) and 5.0% fiber content (w/w composite weight).
- TL 50B: three layers in fiber laminate, hardener content 50% w/w (matrix weight) and 7.5% fiber content (w/w composite weight).
- TL 50C: three layers in fiber laminate, hardener content 50% w/w (matrix weight) and 10% fiber content (w/w composite weight).

According to Hasan et al. [5], the value of flexural stiffness has a directly proportional relationship with the modulus of elasticity. Fiber reinforcement is the main thing to withstand the load on a composite system. Increasing fiber content up to 10-20% can significantly increase the value of flexural strength. Fiber levels can be increased by using the infusion method and minimizing voids during the sample preparation process. The value of flexural strength that increases with increasing fiber content is not followed by ramie fiber-epoxy lamina composite with 50% hardener content. With 50% hardener content, it appears that the value of flexural strength tends to be constant and even decrease by 4.68% for an increase in fiber content of 5%. It is also more related to the moisture content than the similar values in the ramie fiber-epoxy lamina composite with 25% hardener content. According to Huner [23], flexural stress will decrease along with the increase in fiber content resulting in increased moisture content. The decrease in flexural property associated with moisture content can arise due to the weak fiber interface with the matrix. Composite material with natural fiber reinforcement has many cavities and tubes that allow water molecules to penetrate the material, causing the development in the sample and affecting the fiber and epoxy interface. Furthermore, the bond between the fiber and the matrix will be broken, which causes the strength of the composite to decrease. The value of flexural modulus in the ramie fiber-epoxy lamina composite is relatively stable for 25% hardener content. As for 50% hardener content, the modulus of flexural value increases by 220%, with an increase in fiber content of 5%.

The flexural modulus value of ramie fiber-epoxy lamina composite is higher than the results of research conducted by Reis et al. [22], using hemp and epoxy fibers, which are 1.31 GPa for 10% fiber content. Flexural modulus is not directly affected by the absorption of water content. The increase in the modulus of flexural value is more related to fiber content than to water content. Fiber reinforcement in flexural stress failure mode is more closely related than in tensile failure mode. It can
be understood that in the flexural test, the sample experiences stress from a combination of compression, shear, and tensile [23].

3.3. Fracture characteristic
Morphological characteristics of fracture test specimens ramie fiber-epoxy lamina composite are shown in Figure 2 below. Figures 2a, 2b, and 2c, represent the fracture profile of the tensile ramie fiber-epoxy lamina composite test sample with 25% hardener content and the levels of 5, 7.5, and 10%, respectively. Meanwhile, Figure 2d, 2e, and 2f are profiles tensile fracture of the tensile test samples of ramie fiber-epoxy lamina composite with hardener content of 50% and levels of 5, 7.5, and 10%, respectively. From this Figure, it can be seen that the composite fault profile with a 25% hardener is good for the fiber content of 5, 7.5, and 10%, which has a finer fracture profile than composites with a 50% hardener content.

Fracture profile for ramie fiber-epoxy lamina composite with a hardener content of 50%, at the location of the composite fracture, the fiber strands appear to be more uprooted and scattered. It indicates that the strength of the fiber interface with the epoxy matrix is weaker than in the lamina composite with a hardener of 25%. The weak strength of the fiber and matrix interfaces causes the composite tensile strength value to be lower, as the strength data in Figure 1. The tensile strength value of ramie fiber-epoxy lamina composite with hardener is 50% lower than the tensile strength value of ramie fiber-epoxy lamina composite with hardener 25%.

![Figure 2](image_url)

**Figure 2.** Fracture morphology of ramie fiber-epoxy lamina composite; with hardener 25%; a. 5% Fiber content, b. Fiber content 7.5%, c. fiber content 10%; with hardener 50%; d. 5% Fiber content, e. Fiber content 7.5%. f. fiber content 10%.
4. Conclusion
The addition of ramie fiber could increase the green composite's mechanical properties. The composite material with 25% hardener content (w/w matrix weight), with every 2.5% increase of fiber content, from 5 to 7.5% and from 7.5 to 10%, the tensile strength value increases to 20.5%. While increasing 5% of fiber content from 5 to 10% will increase tensile modulus value to 27%. For composite material with 50% hardener content (w/w matrix weight), increasing the fiber content from 5 to 7.5% and from 7.5 to 10% will increase tensile strength value to 16.7 and 32.3%, respectively. While increasing ramie fiber content from 5 to 10% increases in tensile modulus value to 186%. The flexural strength value of ramie fiber-epoxy laminate composite with 25% hardener (w/w matrix weight) increased to 3.96% when ramie fiber content was added by 2.5% of ramie fiber content. It increased to 22.9% when ramie fiber content was increased by 5% of ramie fiber content. Meanwhile, flexural strength value of ramie fiber-epoxy laminate composite with 50% hardener (w/w matrix weight) increased by 1.04 % when ramie fiber content was added by 2.5% of ramie fiber content. It decreased by 4.68% when ramie fiber content increased by 5% of ramie fiber content. Composite materials containing 10% of ramie fiber (w/w composite weight) and 25% of hardener (w/w matrix weight) has the best mechanical properties. Therefore, ramie fiber and epoxy have a good possibility as material in the manufacturing green composite.

Acknowledgments
The authors would like to thank all technicians at the Research Center for Biomaterials for contribution in sample preparation-testing and the Indonesian Institute of Science for the funding support.

5. References
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