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Development of Bamboo Composite: Application in UAV Structure

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Abstract

Due to the constant rise in the usage of non-renewable resources, composite materials made of natural fibres and plastic are now receiving a lot of attention. To maximise their performance and viability, bamboo composites for use in UAV (Unmanned Aerial Vehicle) plate constructions confront several obstacles that must be overcome. This study was conducted to fabricate the UAV plate structure by using bamboo composite. Bamboo fibre, epoxy resin, epoxy hardener, and fibre mesh are the materials required to produce the sample. The tensile strength of the bamboo fibre evaluated by using Universal Testing Machine followed by ASTM standard D638. The density test of the bamboo fibre measured by using Mettler Toledo mode XS64. As the result of the study, the bamboo composite that weighted gram per area 15 g/150cm^2 has the highest tensile strength, which is 20.075 MPa and for the density test, bamboo composite that weighted per area 5 g/150cm^2 is denser than other conditions which is 1.115 g/cm^3.

1. Introduction

1.1 Background of The Study

A composite material is one that is composed of many materials, as indicated by the name. When two or more constituent materials with distinctly different physical or chemical properties are mixed, a new material with distinctive qualities that are distinct from the constituent elements is created (Rajak et al., 2019).
Due to the constant rise in the usage of non-renewable resources, composite materials made of natural fibres and plastic are now receiving a lot of attention. Researchers from all around the world are attempting to investigate novel methods to efficiently use non-renewable resources for varied uses. One of the greatest alternatives for producing composite goods is natural fibres (Singh et al., 2023).

The growth cycle of bamboo is also much shorter than that of timber because it is one of the fastest-growing plants which is 3 cm per hour. Natural bamboo fibre is said to be the best candidate for reinforcement of polymer composite materials because of these fascinating benefit (Nkeuwa et al., 2022).

Almost all kinds of bamboo have aggressive rhizomes that extend throughout the soil as part of their rapid growth and dissemination. Additionally, many bamboo variants can thrive in temperatures as low as minus 15 to 20 degrees Celsius; for these reasons, bamboo species cover more than 50 million hectares of land. Bamboo production is seen as an intriguing climate change mitigation technique due to its quick growth cycle. Bamboo production is seen as an intriguing climate change mitigation technique due to its quick growth cycle (Borowski *et al.*, 2022).

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1.2 Problem Statement

To maximise their performance and viability, bamboo composites for use in UAV (Unmanned Aerial Vehicle) plate constructions confront several obstacles that must be overcome. These difficulties include the need to enhance the structural integrity and durability of bamboo composites to meet the specific specifications of UAV plate structures, ensure lightweight design without compromising strength and stiffness, and develop effective manufacturing processes to enable the affordable production of bamboo composite UAV plate structures. In addition, the compatibility of bamboo composites with other UAV systems and parts must be considered. Several obstacles prevent bamboo from being widely used, despite its tremendous promise as a renewable and sustainable material for composite applications.

These difficulties include a lack of optimised production processes, poor characterisation methods, and a lack of understanding of the long-term performance and durability bamboo composites. Another issue is the limited understanding of the mechanical behaviour and characteristics of bamboo fibres. To enable the integration of bamboo composites into diverse sectors, it is also necessary to address the scalability and cost-effectiveness of bamboo composite production. To overcome these obstacles and establish bamboo composites as a trustworthy and sustainable material option for UAV plate structures, extensive research and development activities are required.

1.3 Significance of The Study

This study will review physical and mechanical properties of bamboo fibre composite. This study also will show some recent developments of bamboo fibre specifically in UAV applications.

1.4 Objectives

The objectives of this project are as follow:

i. To fabricate a bamboo composite.
ii. To study the physical and mechanical properties through tensile strength analysis and density test analysis of bamboo composite.

1.5 Scope of The Study

The scope of study the development of bamboo composite of application in UAV plate structure shown as below:

i. Bamboo fibre, epoxy resin, epoxy hardener, and fibre mesh are the materials required to produce the sample.
ii. The parameter that has been used for bamboo fibre sample is gram per area.
iii. Three samples of bamboo fibre composite produced are 5 g/150cm^2, 10 g/150cm^2, and 15 g/150cm^2.
iv. The tensile strength of the bamboo fibre evaluated by using Universal Testing Machine followed by ASTM standard D638.
v. The density test of the bamboo fibre measured by using Mettler Toledo mode XS64.

2. Methodology

2.1 Flow Chart

The methodology used in this study will be explained in this chapter. Every step taken to complete this study will be covered in this chapter, from collecting data to analysing the findings.

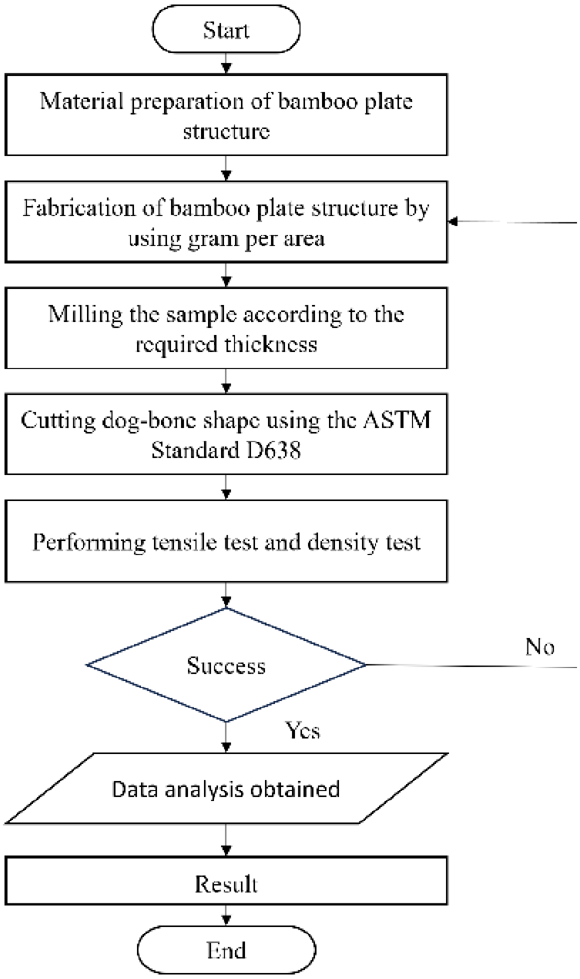

Fig. 1 *Flow chart of the study*

2.2 Materials Preparation

2.2.1 Bamboo Fibre

Figure 2 shows the bamboo fibre that has been extracted. This bamboo fibre is the main material to make the plate structure. This bamboo fibre needs to be shredded first.

Fig. 2 *Extract bamboo fibre*

2.2.2 Fibre Mesh

Figure 3 shows the fibre mesh that has been used in this study. The function of the fibre mesh is to cover the bamboo fibre before applying the epoxies. The fibre mesh needs to be put onto the bamboo fibre.

Fig. 3 *Fibre mesh*

2.2.3 Epoxy Resin

Figure 4 shows the epoxy resin that has been used in this study. After the bamboo fibre has been placed into the mould, this epoxy resin needs to be weighted first before mixing it together with epoxy hardener. Due to its great strength and mechanical adhesiveness properties, epoxy resin has a wide range of industrial uses. If resin is kept in its original containers and kept in cold, dry conditions, it may be kept for at least a year.

Fig. 4 *Epoxy resin*

2.2.4 Epoxy Hardener

Figure 5 shows the curing substance called epoxy hardener that has been utilised in this study. After epoxy hardener mixed with the epoxy resin then the mixture of the epoxies will be applied into the container. Following the addition of the hardener, curing occurs at ambient temperature and air pressure.

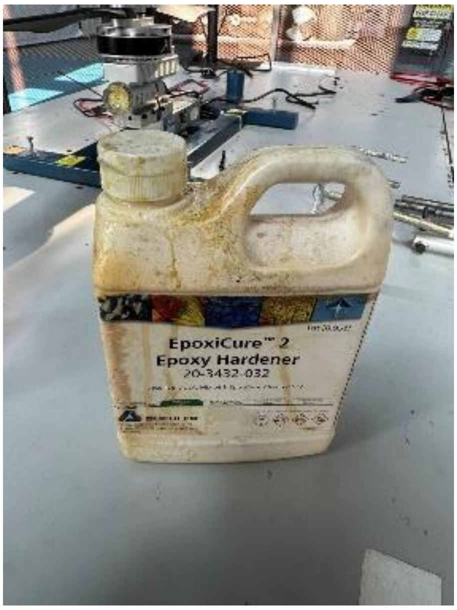

Fig. 5 *Epoxy hardener*

2.3 Parameters of Sample

A rectangular container, measuring 173 mm length x 122 mm width x 48 mm height has been used in this study. The dimension of the sample that has been utilised in this study is 150 mm length x 100 mm width. There are three samples of bamboo fibre in the terms of gram per area which are $5g/150cm^2$, $10g/150cm^2$, and $15g/150cm^2$. The fabrication of bamboo plate is repeatedly for two times so the samples have six samples in total. Each sample did not have the same thickness as the sample need to undergo several processes to get the perfect shape of bamboo plate structure. The fabrications for the composite sample are prepared using a hand layup procedure.

2.4 Facing Process

Cutting a smooth surface perpendicular to the milling cutter's axis is kwon as facing on a milling machine. The work piece or the bamboo fibre plate is fed across the cutter by the table while the facing tool is rotated anticlockwise to remove the excess material. Figure 6 shows the facing process of bamboo fibre plate which is located at milling machine laboratory UTHM.

Fig. 6 *Facing process of bamboo fibre*

2.5 Cutting Process

Samples made from dog bones can be made using a variety of techniques. Most of these techniques may be divided into two groups which are cutting and moulding. A cutting die with the proper dimensions must be constructed to cut a sample. Figure 7 shows that the cutting process of bamboo fibre plate which is located at advanced machining laboratory UTHM.

Fig. 7 *Cutting process of bamboo fibre*

2.6 Bamboo Fibre Tensile Test

After the specimens were created through the facing process and cutting process as well, they were put through a tensile test on a universal testing machine (UTM). The specimen utilised in this study has the dog-bone shape specified by ASTM D638 and ISO 527. Figure 8 illustrates the ideas behind sizing considerations for dog bone shapes. Based on Figure 8, type I, II, III & V is being used in this study due to the suitability of the thickness. The thickness that required is at least 12 mm thickness so the suitable type for this study is type III.

With the use of this test, the tensile strength, including Young Modulus, tensile stress, tensile strain, and maximum force, may be determined. Figure 9 depicts the universal testing machine for the ASTM D638 tensile test. Tensile stresses were measured accurately at the FKMP laboratory, UTHM. The maximum thickness of the machine that can grip the specimen is 12 mm. The tensile tests are being run on the specimen at a standard test speed of 5 mm/min. The highest stress that a material can endure without being stretched, extended, or pulled is known as its ultimate tensile strength. To determine the point at which the plastic specimen will break, tensile stress testing was carried out.

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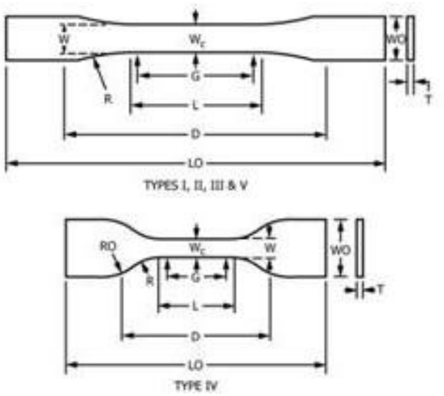

Specimen Dimensions for Thickness, *T*, mm (in.)[A]

Dimensions (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
L—Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02)[C]
WO—Width overall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)
WO—Width overall, min[G]	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)
LO—Length overall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
G—Gage length[I]	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010)[C]
G—Gage length[I]	...	...	...	25 (1.00)	...	±0.13 (±0.005)
D—Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
R—Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
RO—Outer radius (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)

Fig. 8 *Dimension of specimen according to ASTM D638*

Fig. 9 *Universal testing machine for tensile test*

2.7 Bamboo Fibre Density Test

For this experiment, the bamboo fibre was tested to get the density. The sample of bamboo fibre was cut into small piece of fibre to get the density. Mettler Toledo analytical balance model XS64 is used in this experiment to measure the weight in the liquid and the air. Figure 10 depicts how the device operates.

Fig. 10 *Mettler Toledo machine for density test*

According to the Archimedes principle, which the buoyant force exerted upward on a body submerged in a fluid is equal to the weight of fluid the body displaces, was used in this experiment. With the use of this device, the weight of bamboo fibre is calculated. Pan and basket are the two components that make up the machine. Firstly, determine the dry weight of the bamboo fibre for the pan, and the weight of the basket once it has been submerged in water. The water that has been used was distilled water. Figure 11 displays a result that this machine can generate.

Fig. 11 *Result of density test*

3. Results and Discussion

3.1 Tensile Strength Analysis

To assess the bamboo fibre composite's strength, tensile strength study is carried out. The maximum stress and maximum strain of a material are determined through a tensile test. The outcome was achieved by using a speed of 5 mm/min.

3.1.1 Tensile Strength Analysis for 5 g/150cm^2 of Bamboo Fibre

1) Sample one

Max Load	Elong.@Max	Elong.@Break	E.Modulus	Yield Strength	Max.Stress	Max.Strain	Stress@Break	Area
kN	mm	mm	MPa	kN/m²	MPa	%	MPa	mm²
3.53	7.74	8.84	118.56	9681.187	16.19	13.584	11.305	218.310

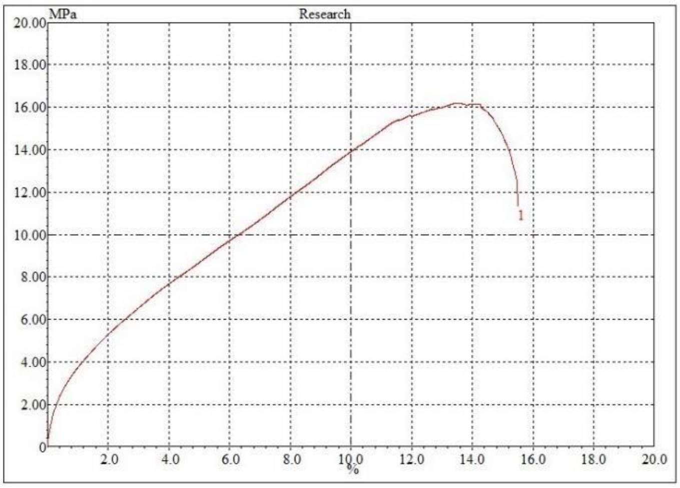

Fig. 12 *Graph of tensile strength for sample one 5 g/150cm^2 of Bamboo Fibre*

Based on the Figure 12, the maximum stress that obtained by the sample one 5 g/150cm^2 of bamboo fibre is 16.19 MPa. Meanwhile the maximum strain that obtained is 13.584.

2) Sample two

Max Load	Elong.@Max	Elong.@Break	E.Modulus	Yield Strength	Max.Stress	Max.Strain	Stress@Break	Area
kN	mm	mm	MPa	kN/m²	MPa	%	MPa	mm²
1.73	8.89	13.27	156.35	5191.144	9.60	15.589	6.721	180.500

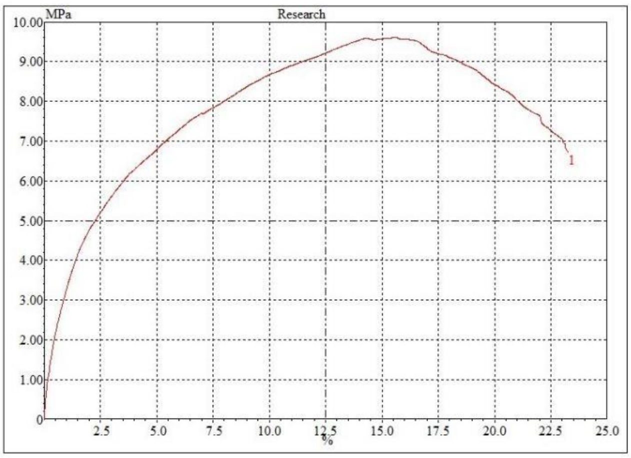

Fig. 13 *Graph of tensile strength for sample two 5 g/150cm^2 of Bamboo Fibre*

Based on the Figure 13, the maximum stress that obtained by the sample two 5 g/150cm² of bamboo fibre is 9.60 MPa. Meanwhile the maximum strain that obtained is 15.589.

3.1.2 Tensile Strength Analysis for 10 g/150cm² of Bamboo Fibre

1) Sample one

Max Load kN	Elong.@Max mm	Elong.@Break mm	E.Modulus MPa	Yield Strength kN/m²	Max.Stress MPa	Max.Strain %	Stress@Break MPa	Area mm²
2.67	2.28	2.29	449.92	7766.988	12.65	4.008	8.792	211.280

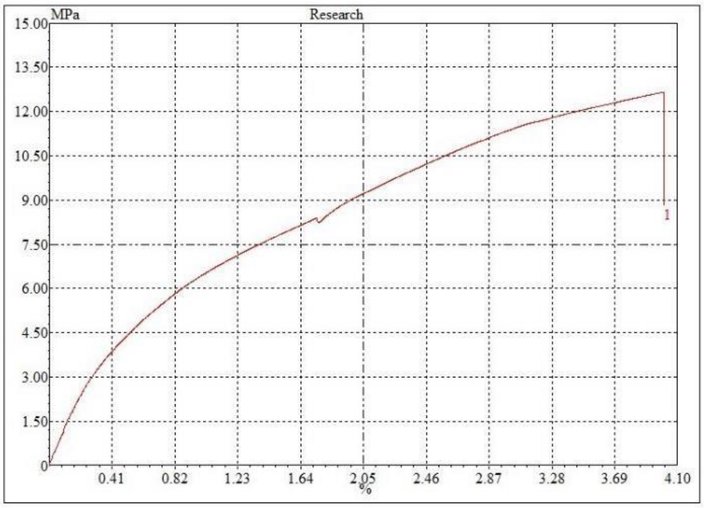

Fig. 14 *Graph of tensile strength for sample one 10 g/150cm² of Bamboo Fibre*

Based on the Figure 14, the maximum stress that obtained by the sample one 10 g/150cm² of bamboo fibre is 12.65 MPa. Meanwhile the maximum strain that obtained is 4.008.

2) Sample two

Max Load kN	Elong.@Max mm	Elong.@Break mm	E.Modulus MPa	Yield Strength kN/m²	Max.Stress MPa	Max.Strain %	Stress@Break MPa	Area mm²
3.69	3.90	3.90	269.92	10318.035	17.36	6.836	11.288	212.420

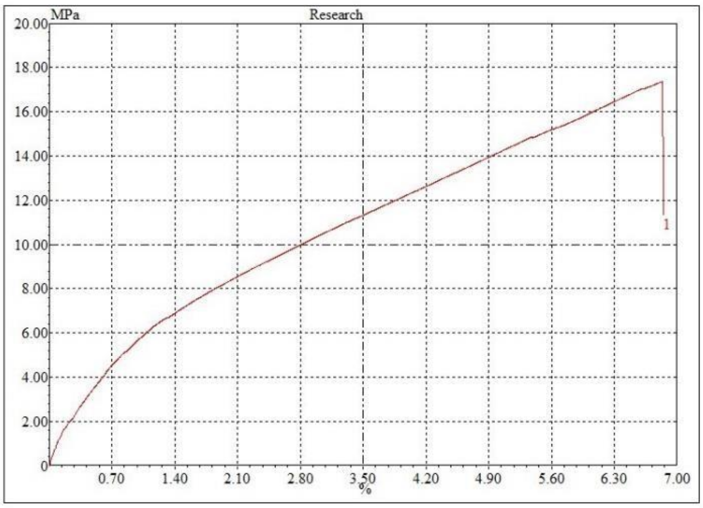

Fig. 15 *Graph of tensile strength for sample two 10 g/150cm² of Bamboo Fibre*

Based on the Figure 15, the maximum stress that obtained by the sample two 10 g/150cm² of bamboo fibre is 17.36 MPa. Meanwhile the maximum strain that obtained is 6.836.

3.1.3 Tensile Strength Analysis for 15 g/150cm² of Bamboo Fibre

1) Sample one

Max Load kN	Elong.@Max mm	Elong.@Break mm	E.Modulus MPa	Yield Strength kN/m²	Max.Stress MPa	Max.Strain %	Stress@Break MPa	Area mm²
4.41	7.36	8.05	161.50	11176.796	20.20	12.910	14.122	218.310

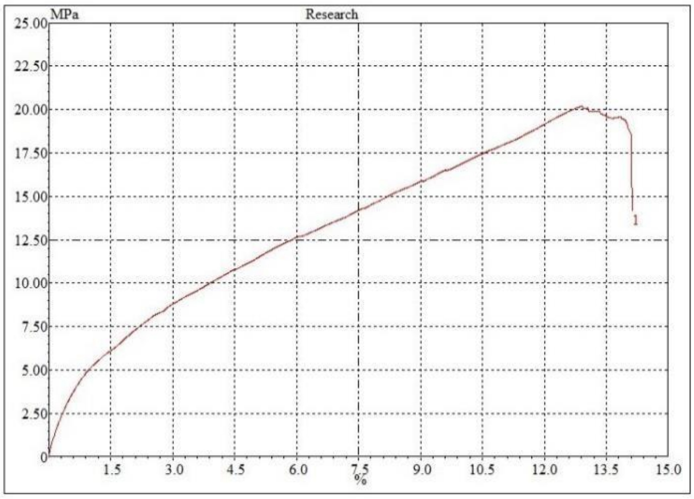

Fig. 16 *Graph of tensile strength for sample one 15 g/150cm² of Bamboo Fibre*

Based on the Figure 16, the maximum stress that obtained by the sample one 15 g/150cm² of bamboo fibre is 20.20 MPa. Meanwhile the maximum strain that obtained is 12.910.

2) Sample two

Max Load kN	Elong.@Max mm	Elong.@Break mm	E.Modulus MPa	Yield Strength kN/m²	Max.Stress MPa	Max.Strain %	Stress@Break MPa	Area mm²
3.68	7.68	9.23	153.15	17509.875	19.95	13.480	13.962	184.300

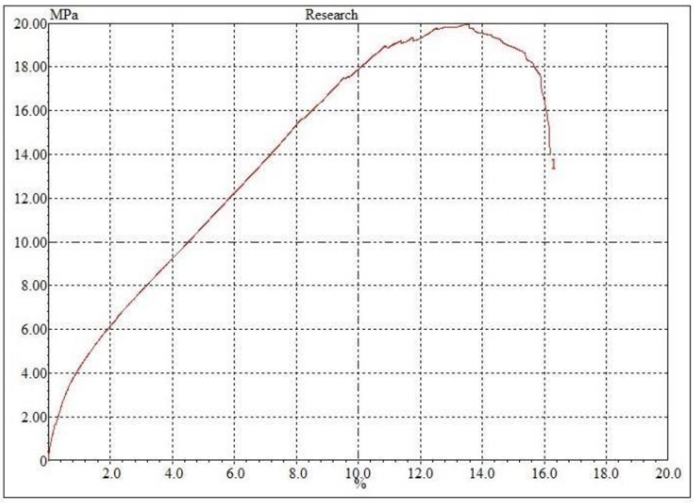

Fig. 17 *Graph of tensile strength for sample two 15 g/150cm² of Bamboo Fibre*

Based on the Figure 17, the maximum stress that obtained by the sample two 15 g/150cm² of bamboo fibre is 19.95 MPa. Meanwhile the maximum strain that obtained is 13.480.

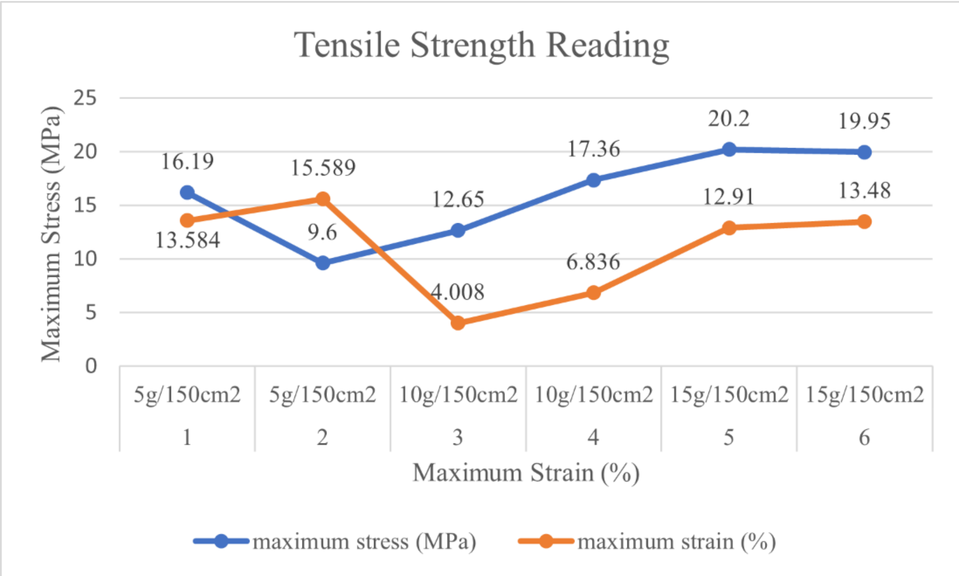

Fig. 18 *Combination graph of tensile strength for three samples which are 5 g/150cm², 10 g/150cm², and 15 g/150cm² of Bamboo Fibre*

3.1.4 Maximum Tensile Strength Analysis of Bamboo Fibre

Table 1 *The maximum tensile strength for sample of bamboo fibre composite*

Sample No.	Sample (gram per area)	Tensile reading (MPa)	Average reading (MPa)
1.	5 g/150cm²	16.19	12.895
2.	5 g/150cm²	9.60	
3.	10 g/150cm²	12.65	15.005
4.	10 g/150cm²	17.36	
5.	15 g/150cm²	20.20	20.075
6.	15 g/150cm²	19.95	

Based on the Table 1, there are two readings that taken for each type of samples so six readings are taken in total during the tensile test. The tensile reading needs to get the average reading so that can get the accurate reading. For sample 5 g/150cm², the average reading is 12.895 MPa. There is an increasing average reading for sample 10 g/150cm² which is 15.005 MPa. The average reading for the last sample which is 15 g/150cm² is 20.075 MPa. Among the three types of samples, the highest average tensile reading is sample 15 g/150cm².

3.2 Density Test

Table 2 *The density result for sample of bamboo fibre composite*

Sample No.	Sample (gram per area)	Density reading (g/cm³)
1.	5 g/150cm²	1.115
3.	10 g/150cm²	1.103
5.	15 g/150cm²	0.808

Based on the Table 2, it has a slightly differences density reading between the three sample of bamboo fibre composite. For sample one, 5 g/150cm^2, the density reading is 1.115 g/cm^3. For sample two, 10 g/150cm^2, the density reading is 1.103 g/cm^3. Lastly for sample three, 15 g/150cm^2, the density reading is 0.808 g/cm^3. It demonstrates that immersion duration affects how well epoxies are absorbed, and as a result, sample one which is 5 g/150cm^2 has the highest fibre density. This is because when the higher the void content of the epoxy, the higher the density.

3.3 Discussion

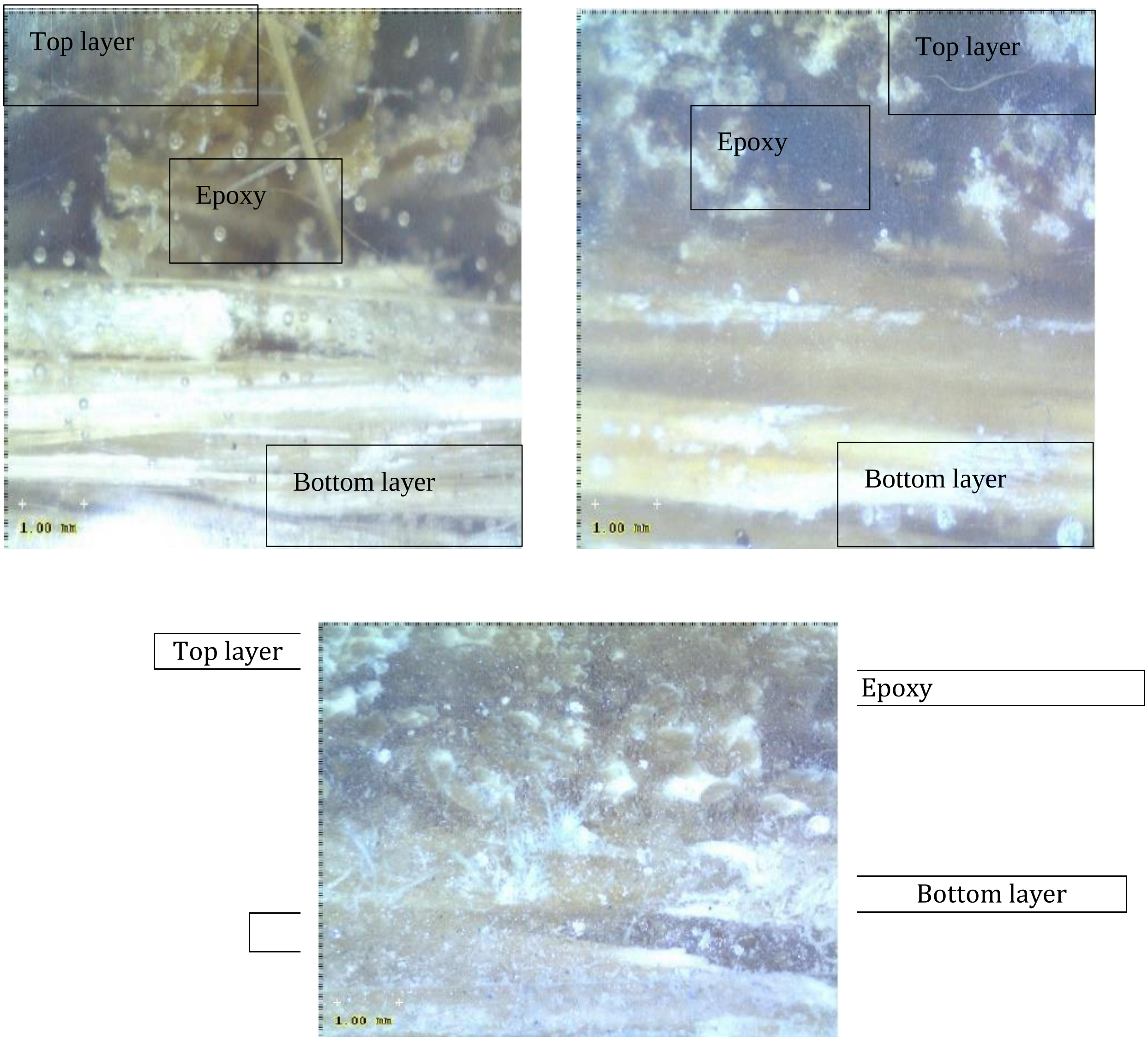

Fig. 19 *(a) 5 g/150cm^2 of bamboo fibre; (b) 10 g/150cm^2 of bamboo fibre; (c) 15 g/150cm^2 of bamboo fibre*

The purpose of discussion in this study is to know the effect of the epoxy towards the bamboo fibre and the characteristics. Based on the Figure 20, there is a comparison between the three samples in the terms of density for (a), (b), and (c). It is shown that the 5 g/150cm^2 of bamboo fibre has the highest density among the three. It has the highest density due to the epoxy content in the sample. It is validated through microscopic analysis which is shown in Figure 19. The orientation of fibres for top layer and bottom can be seen in the figure because there is a clear indication of the epoxy which fills an empty space between the gap of the fibres.

4. Conclusion and Recommendations

4.1 Conclusion

As for conclusion, the development of bamboo composite in the application of UAV structure was studied. It concluded that the study's goals had been met and its findings were positive. For tensile test sample 5 g/150cm^2, sample 10 g/150cm^2, and sample 15 g/150cm^2, the average stress is 12.895 MPa, 15.005 MPa, and 20.075 MPa respectively. As for the density test it is stated that sample 5 g/150cm^2 is better than sample 10 g/150cm^2, and sample 15 g/150cm^2 because the reading of the density test is 1.115 g/cm^3, 1.103 g/cm^3, and 0.808 g/cm^3 respectively. Moreover, the density of the samples is affected by the content of the epoxies. It is because the higher the usage of the epoxies, the denser the sample is. Thus, the objectives to fabricate a bamboo composite, and to study the physical and mechanical properties through tensile strength analysis and density test analysis have been achieved.

4.2 Recommendations

There are some suggestions that can be utilised to enhance future research as below:

i. Choose the bamboo species with desirable mechanical qualities to guarantee the performance of the composite satisfies the criteria of UAV constructions.
ii. Develop methods for collecting, curing, and treating bamboo that are dependable and efficient.
iii. Improve the bamboo fibres' adherence to the matrix material by treating their surfaces appropriately.

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