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Adapted the Mechanical Characteristics of Bio-Composite Sisal Fibres Material by Adding Aluminum Particles for Structure

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The e-bike structure is increasingly developing, especially in terms of design, its strength is around 300 MPa in a maximum application of around 160 MPa, as is the case with the scooter bike structure. The strength of sisal, which is a composite reinforcing component, is made from natural fiber from pineapple leaves, which is then mixed with hemp fiber and carbon fiber. In mechanical structure materials, apart from the material being expected to have high yield strength, it is also expected to have good ductility. The reinforcement is then mixed with hard epoxy resin, soft epoxy, and 9 µm aluminum particles which are then stirred for 12 hours, until smooth and even.

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Mathematically, the improvement in this bio-composite is quite significant, obtained from the addition of carbon fiber. The ductility of the material is obtained from sisal, hemp and ductile epoxy mixed with hard epoxy resin. Because the quality of crop yields greatly influences the quality of the fiber, future agricultural processes need to be provided with counseling. The sisal fiber is a leftover product from community farming in the Subang area (Indonesia). Research using local materials is still able to obtain strength reaching ~480 MPa so it is still good. In this research, tensile tests were carried out 3 times so that it was found that the fiber taken from the rope had the greatest tensile strength, reaching around 480 MPa.

Keywords: Tensile test; ductility; bio-composite; ramie; sisal; carbon; epoxy resin.

NOMENCLATURES

- Ec : *Composite elastic modulus*
- Ef : *Fibres elasticity modulus*
- Em : *Matrix modulus of resin*
- Er : *Elasticity Mod. of ramie fibre*
- Es : *Elasticity Mod of sisal fibre.*
- v : *fraction volume*
- v_f : *fraction volume of main fiber*
- v_m : *fraction volume of matrix*
- v_r : *fraction volume of ramie fiber*
- vs : *fraction volume of sisal fiber*
- vc : *fraction volume of composite*
- *Void* : *hole in composite*

1. INTRODUCTION

Pineapple leaf tree fiber (can be called sisal fiber), which is currently a very popular natural fiber, is widely used as bio-composite fiber and is easy to cultivate. South and Central America is believed to be the beginning of its production, and up to 4.5 million tons of fiber are annually produced worldwide, according to the FAO (Food and Agriculture Organization) [1]. Conventional Composites and Bio-composites (green composites), are often used as reinforcing fibers needed by resins in preparing bio-composite materials. In this research, epoxy resin was used with a breaking strength of 70 MPa so that more or less fiber was used. The ease of obtaining it is one of the incentives for industry players to develop it further..

Bio-composite is low density and environmentally friendly and requires little energy in the production and machining processes [2]. Thus it makes many industries try to take advantage of it, and develop it. Increasing environmental concerns and increasing concern about global warming have prompted the transportation, construction and packaging industries to seek to replace conventional synthetic fibers [3]. Natural fiber emerged as a good alternative because it is available in a fibrous form and can be extracted from the leaves, stems, fruits and seeds of plants at very low cost.

The best use of bio-fiber from available natural resources is a major factor for human social and economic development by utilizing the ability to produce its parts [4]. The optimal ability to continue developing the remaining wasted and available natural products is one of the main factors in human social and economic development. Over the last few decades, researchers [1-7] have tried to utilize natural resources in the form of fibers or particles as reinforcing materials to produce composite boards. Natural materials provide adequate strength at low cost, low density, environmentally friendly and non-toxic. The bark of many plants is a material that has economic value and industrial use in many countries and is generally discarded or used as a substitute for firewood [8]. In this study, the mechanical properties and morphology of biocomposites reinforced with walnut shells and coconut fiber were investigated.

Wear-resistant coating materials with bio-composite materials have been widely used because of their very high hardness, good strength and toughness, as well as other properties [5]. Now there are many e-bikes that are marketed almost entirely with reinforcement using low carbon steel frames with plastic fairings. Due to efforts to reduce carbon and eliminate it, carbon steel will be banned from 2030.

The level of e-bike sales has increased worldwide, due to government subsidies, in recent years [9]. This situation has prevented designers of new models and materials used in anticipation of the 2030 regulations from working optimally. Bio-composite researchers are wondering how future mass e-bikes will be applied in real practice. [9] Then, the question is how the e-bike product designer will develop the design and the strength of the materials and other specifications. Based on current construction, almost all of it is built with a structural model reinforced with a low-carbon steel frame. In our proposal it is necessary to use a bio-composite structure that is strong and structural like an airplane.

Today, where the world has developed rapidly, demands the use of high technology that can solve current and future problems [10]. The problems felt by the community are concerns about fossil fuels which are decreasing and will run out and air pollution. This condition is experienced by several countries which directly puts pressure on society.

This observation is intended to suggest a material design that is light and can be designed as a material for vehicles powered by electrical energy. These materials must be able to utilize waste products that are still useful. Designs that are already operational must be redesigned into designs that can utilize e-composites that can be produced by reducing CO_2 emissions. Currently, CAD models have been created and analyzed using FEM software [9-10]. The initial conditions in which a prototype must be created include design, testing and future material availability.

2. METHODOLOGY

2.1 Preparation Sisal Fibres

This positive observation is very encouraging for the application of electric bicycles as a substitute for iron, although it still requires deeper and more detailed studies [5]. Biocomposite material testing was carried out at the Bandung State Polytechnic materials laboratory to determine material characteristics such as maximum tensile tests and ductility. This iron reduction is due to human efforts to eliminate or reduce carbon emissions as much as possible, as is the case with electric bicycles.

The force acting on the bio-composite structure causes strains in the material and can cause the material to experience strains that can be expressed in the press. (1)

$$\sigma = \frac{F}{A_0} \quad (1)$$

$$\varepsilon = \frac{L_f - L_0}{L_o} \times 100\ \% \quad \text{..................................} \quad (2)$$

$$E = \frac{\sigma}{\varepsilon} \quad \text{..} \quad (3)$$

By using the eq. (1) -(3) and its processing, many equations can be used to analyse structural problems in a simple way. Because the strength of sisal is very likely to vary, because it is a natural product, in this study an attempt was made to make material with a strength above 350 Mpa, by undergoing cold work or twisting. Fig. 2 shows the random fibres of pineapple leaves, and Fig. 3 shows the fibres of pineapple leaves [11]. What is meant by cold working is sisal fibres that has been spun into thread or rope.

Research has been carried out on e-composites [12] using pineapple leaf fibres (sisal) which is still a random fibres and hemp fibres, carbon and soft epoxy resin as in this research. However, the stress and modulus of elasticity values obtained are still too small, so it is necessary to use sisal fibres that has been twisted into thread or rope, which logically meets Fig. 3.

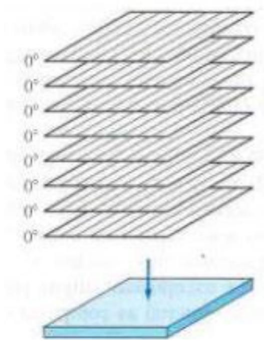

Fig. 1. Unidirectional layer [6]

In Fig. 3 it can be observed that the bigger the rope or thread, the more fiber it will break, so this theory can be seen in experimental studies. This step explains that the sisal fibers become stronger due to static deflection in the sisal. The mechanism for breaking the rope from the sisal fiber is in accordance with Fig. 2, where the outermost fiber will break first and then the rest. [13] Analysis of sisal fiber breaking occurs because the load exceeds its strength. Experimental rules regarding rope strength, an average estimate based on test results, are generally reduced by 20% as a safety factor [14].

Fig. 2. Pineapple leaf random fibres

Fig. 3. Sisal rope or twine

The strength development of a rope under applied loads is quite high, for example, ropes used on ships also experience greater cold working. Laboratory tests have been carried out using fibers from new ropes but the results are greater than random fibers or threads. The fiber that has become a test object is then clamped on a UTM machine and pulled until it breaks, so that σc=F/A0 can be determined.

For other bio-fibers that can be tabulated can be seen in Table 2 [15].

Mechanical characteristics of the resin are always required in the preparation of bio-composites, where these values can be seen in Table 3.

Fig. 4. Pineapple leaf fibers that have been twisted

Table 1. Mechanical characteristics of Sisal Fibres in the world

Fiber	Tensile Strength (MPa)	Young Modulus (GPa)	Fiber Origin
Sisal Fiber	391±89	10.7±4.0	Brazil
	462±71	7.47±1.37	Algeria
	294±113	9.8±0.9	India
	340.02±70.04	12.5±7.8	Marocco
	371±28	12.43±2.23	Kenya

Table 2 . Mechanical properties of bio fibers

Natural Fiber	Density (g/cm^3)	Tensile Strength (MPa)	Young's Modulus (GPa)
Bagasse	0.8 - 1	200 – 300	17 - 20
Ramie	1.4 1.5	400 - 938	61 - 128
Hemp	1.1 – 1.6	285 – 1 735	14.4 – 44.0
Kenaf	0.6 – 1.5	223 - 1 191	11 - 60
Flax	1.3 – 1.5	340 – 1 600	25 - 81
Oil Palm	0.7 – 1.6	50 - 400	0.6 – 9.0
Jute	1.3 – 1.5	393 - 773	13 – 26.5
Bamboo	1.2 – 1.5	500 - 575	27 - 40
Cotton	1.5 – 1.6	287 - 800	5.5 12.6
Sisal	1.3 – 1.6	468 - 640	9.4 - 22
Sugarcane	1.1 – 1.6	170 - 350	5.1 – 6.2
Coir	1.2 – 1.6	170 - 230	3.0 – 7.0
Banana	0.5 – 1.5	711 - 789	4.0 – 32.7

Table 3. Mechanical properties of some fibers and metals

Material	Young's Modulus (GPa)	Shear Modulus (GPa)	Axial Poisso's ratio	Ultimate Strength Tension (MPa)	Strain to failure (%)	Density (Kg/m^3)
Carbon Fibre HT-T300	230	23	0.23	3530	1.5	1750
Carbon Fiber IM-T800	294	23	0.23	5586	1.9	1800
Carbon Fiber HM	385	20	0.23	3630	0.4	2170
E-glass Fiber glass	72	27.7	0.3	3450	4.7	2580
S-glass fibre glass	87	33.5	0.3	4710	5.6	2460
Kevlar 49 fiber	124	5	0.3	3850	2.8	1440
Steel	206	81	0.27	648	4	7800
Aluminium	69	25.6	0.35	234	3.5	2600

2.2 Preparation Epoxy Resin

This bio-composite resin is formed by pouring epoxy that has been mixed with 5% flexible epoxy and 2.5% aluminum particles, into hemp, sisal and carbon fiber reinforcing materials which are then coated in a mold via hand layup. [16] The specimens were then tested for tensile to breaking strength for fibers with resin as well as the theoretical value of the material. In fact, the experimental strength of the bio-composite test is quite far from the theoretical conditions. Under actual conditions an ideal (theoretical) bond will form of 74%, as shown in Fig. 5. The difference is that there may be zones with imperfectly arranged fibers.

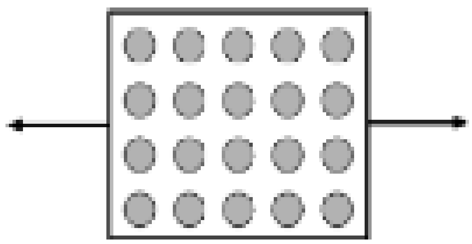

Fig. 5. Theoretical conditions of bio-fibers in composites

The tensile test was carried out by arranging the bio-composite formers in an iso-strain condition arrangement in which the bio-composite specimens were tested for tensile as shown in Figs. 8-10. If you compare the value of the tensile test results under iso-strain and iso-stress conditions, it is obtained as can be observed in the curve of the same Fig. 6.

The theoretical tensile test value will not be achieved in real conditions, thus the reinforcing particle area calculation must be re-calculated in Fig.7.

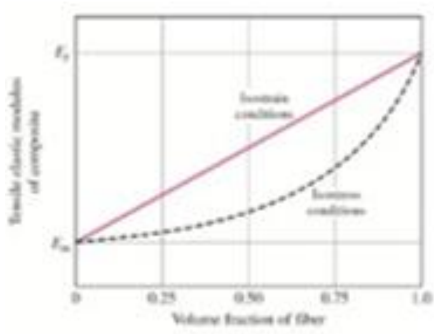

Fig. 6. Comparison of composite iso-strain and iso-stress conditions

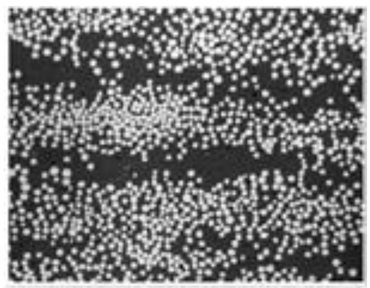

Fig. 7. Real conditions of packing of reinforcing fibers in bio-composites

The bio-composite material used in this study is a study material to become a structural material with a strength > 350 MPa. This material is expected to encourage competition in the e-bike design and manufacturing process. Table 1 shows the value of the mechanical characteristics of sisal around the world. Based on the numbers in the table, it is very clear that almost all of these bio-composite fibers have sufficient utility as mechanical structural materials. In this research, the worldwide use of sisal from Subang pineapple leaves needs to be mixed with carbon fiber, hemp fiber and aluminum particles in an epoxy resin to get maximum results.

Table 4. Mechanical properties of some matrix polymers

Material	Young's Modulus (GPa)	Shear Modulus (GPa)	Axial Poisson's Ratio	Ultimate Strength Tension (MPa)	Strain to failure (%)	Density (Kg/m^3)
Epoxy	3.1	1.2	0.3	70	4.0	1200
Polyesther	3.5	1.4	0.3	70	5.0	1100
Resin RTM 6	2.89	1.08	0.34	75	3.4	1140
Resin RTM 120	2.60	0.96	0.35	77	-	1200

Table 5. Mechanical properties of bio fibers

Mechanical	E-glass	Flax	Hemp	Jute	Ramie	Sisal
Density (g/cm^3)	2.55	1.4	1.48	1.46	1.5	1.33
Young's Modulus (GPa)	73	60 – 80	70	10 - 30	44	38
Tensile Strength (MPa)	2400	800 - 1500	550 - 900	400 - 800	500	600 - 700
Elonggation at failure (%)	3.0	1.2 – 1.6	1.6	1.8	2.0	2.0 – 3.0

Table 4 contains the resins used as binders in the manufacture of bio-composites. The strength of the resin has been shown to play a significant role in the strength of the bio-composite.

Several studies have been carried out by several researechers, to study the possibility of replacing conventional fibers with more environmentally friendly natural (bio) fibers. The researchers investigated the mechanical properties of hemp and sisal fibers in terms of tensile strength and elastic modulus, which gained good results. With the increase in fiber volume fraction, calculations can be performed using Tables 2, 3 and 4. The properties of natural fiber bio-composites have better ductility than conventional composites. This shows that the ability to withstand high loads is needed.

In this research, a bio-composite material composed of pineapple fiber, hemp fiber and carbon fiber was developed into a material that is tough, light, has ductility, and is easy to produce so that it can become the material of choice for industry [17]. The selection of several composite materials is carried out to determine the suitability of these materials for use. The use of electric mountain bikes is one application for developing comfortable composite materials. Because the population will continue to increase and the demand for light and strong will become the main choice. Mountain bikes are also a medium that can test the toughness of materials, because of their random use at high stres.

Pada penelitian ini perkuatan material biokomposit menjadi faktor utama yang menopang beban yang ditanggung oleh serat, yang dalam hal ini adalah,

1. Pineapple leaf fiber (sisal)
2. Ramie fiber
3. Carbon fiber

In this study, the bio-composite material reinforcement is the main factor supporting the load borne by the fiber, which in this case is,

Fig. 8. Resin coating and production of bio-composite stage 3

The specimen manufacturing process is carried out in stages so that the results obtained are in accordance with the requirements and the pressing process so that the specimens can be suitable is carried out using glass (Fig.9), as can be seen in Fig.8.

After applying the press and waiting for the resin drying time, and final finalization, the specimen is shaped and ready for tensile testing. Specimens can be seen in Fig. 9.

Fig. 9. Wax application on glass presses

The tensile test process is carried out in the Polytechnic State of Bandung Machine Materials laboratory, by pulling the specimen on one side and holding it on the other side. The specimen stress is obtained by dividing the pulling force by the surface area at any time. The drawing of the tensile testing machine used is as Fig. 10.

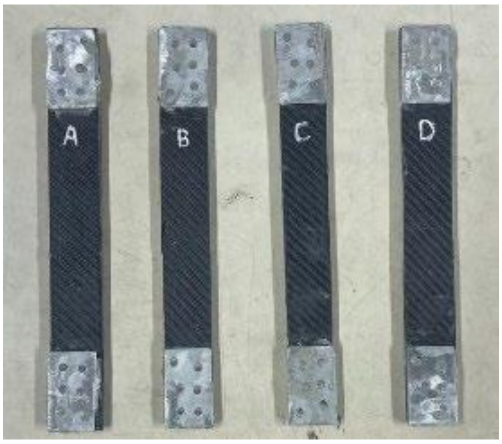

Fig. 10. Bio-composite tensile test specimens

Fig. 11. Polytechnic State Bandung Machine Engineering Tensile Testing Machine

3. RESULTS

3.1 Theoretical

Theoretical studies need to be carried out to determine the difference in theoretical estimation values from experimental studies, on bio-composite test specimens. The theoretical estimate study is 899.43 MPa while the experimental study is 113.55 MPa. The big difference is that the possibility of using sisal fiber is random. Then in the second and third tests by changing the shape of the sisal fiber strands so that the stress increases to 508.44 MPa. Therefore, strength can be increased in the future, so that it will increase again. The composite consists of Sisal Subang pineapple leaf, hemp and carbon fiber in the following order,

- Void proses manufacture: 5%
- Carbon Fiber: 45%
- Subang Pineapple Leaves Sisal Fiber: 25%
- Ramie fiber: 22.5 %
- Alumunium particle: 2.5 %

The material is arranged in such a way that the overall number is 1, but according to the description of the fibers in accordance with Figs.8-10, so that the reinforcing fibers amount to 48.9% of the total composite so that the theoretical characteristics of the bio-composite are iso-strains as follows,

$$\sigma_{com} = \nu_p\, \sigma_p + \nu_{res}\, \sigma_{res}$$

$$\sigma_{com} = (\nu_c\, \sigma_c + \nu_r\, \sigma_r + \nu_s\, \sigma_s + \nu_{void}\, \sigma_{void}) * \nu_p + (\nu_e\, \sigma_e + \nu_{al}\, \sigma_{al}) * \nu_{res} =$$

σ_{com}= (0.45 3530+0.225 500+0.25 268+0.05 0) *0.489+(0.975 70+0.025 0) *0.511 = 899.43 N

The same is true for determining the elastic modulus of a material using the iso strain rule, as follows

$$E_{com} = (\nu_c E_c + \nu_r E_r + \nu_s E_s + \nu_{void} E_{void}) * \nu_p + \left(\nu_{epox} E_{epox} + \nu_{al} E_{al}\right) * \nu_{res}$$

$$E_{com} = (0.45\ 230 + 0.255\ 44 + 0.25\ 15 + 0.05\ 0) * 0.489 + (0.975\ 3.1 + 0.025\ 0) * 0.511 = 60.73\ GPa$$

Paying attention to these theoretical values, it can be concluded that the use of these materials can already be used as structural materials, because their strength and ductility are quite large. Certainty of mechanical characteristic values still requires tensile testing so that many properties can still be obtained. The elastic modulus, also known as the elastic modulus or simply modulus, is a measure of the elasticity of a specimen against the resistance of a material to non-permanent, or elastic, deformation.

3.2 Experimental

The results of the tensile test can be shown in Table 6.

Table 6. Tensile test results

Specimen	A_0 (mm^2)	F_N(max)	σ_{max} (MPa)
A1	103.566	11760	113,55
A2	106,800	8330	78,00
A3	106.436	10290	96,68
B1	104.800	24010	229,10
B2	104,960	31360	298,78
B3	105,862	32340	305.46
C1	126,250	64190	508,44
C2	126.646	59780	472,02
C3	131,325	62720	477,59

It is clear that the test results with normal pineapple fiber reinforcement (A1-A3) are lower than twisted pineapple fibers (B1-B3 and C1-C3). Specimen B and Specimen C are also different because the formation process is slightly different, which affects the volume fraction of the specimen formed. The average test results can be observed in Table 7.

Table 7. Average test results of specimens

Specimen	A_0 (mm^2)	F_N(max)	σ_{max}(MPa)
Ar	105.6007	10126.67	96.08
Br	105.2073	29236.67	277.78
Cr	128.0737	62230	486.02

In the Fig. 12 it can be observed the results of the tensile test from the Subang pineapple leaf fiber specimen which did not experience twisting. It appears in this condition that the tensile strength is between 75 MPa – 225 MPa. This value is quite broad for the users of the fiber.

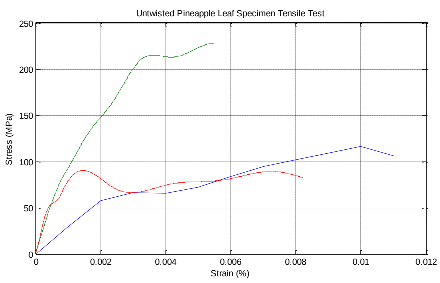

Fig. 12. The results of the tensile test of the Sisal specimen of Subang Pineapple Leaves

Likewise in Fig. 13, it can be observed that by selecting the resulting tensile stress can increase up to about 100%. However, there are fibers whose value is still low.

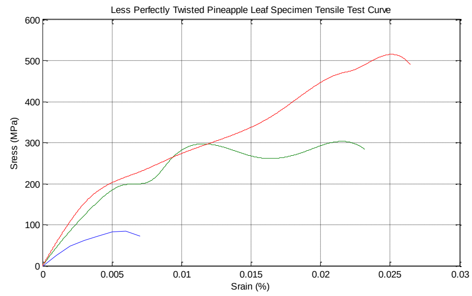

Fig. 13. The yield curve for the tensile test of the specimen is not perfect

Observing in Fig.14, it can be noted that a fairly high deviation value can be achieved, with an error of only 300 [Mpa] for the theoretical value. For this reason, it is necessary to carry out another tensile test using twisted and measured sisal fiber specimens. Currently, the gyre is in the stage of being realized in the Machinery Department.

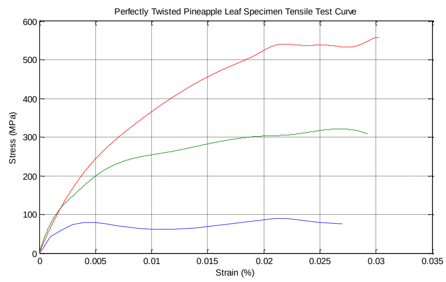

Fig. 14. The residual stress curve is perfectly twisted

4. DISCUSSION

Referring to the results of 3 experimental tests, it can be seen that the experimental value of the bio-composite can reach above the required value as a structural material value. However, it needs to be done again by reducing the volume fraction of carbon fiber, but it is still above the limit value of the applicable regulations. So with more and more experiments, an optimization process can be developed so that in the next few years a better prototype can be obtained.

5. CONCLUSIONS

This research was carried out in a hurry so that this article was very forced to be published. This first publication discusses the experimental study of e-bike structures using bio-composite materials. From the tensile test it is known that it is expected that the structural material has a tensile stress of 300 MPa, and for research materials the maximum size is 480 MPa.

The value of the modulus of elasticity has changed with the addition of 5% flexibility Epoxy resin. This addition has changed the curve model that is usually found in bio-composite materials. In the future, the material will be reduced so that the specific material remains ideal.

The average value of the elastic modulus is 11517.56 MPa; 10964.44 MPa; and 16352.79 MPa.

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We thank the UPPM Polban team for giving us the opportunity to research Subang pineapple leaf fiber products. Even though there is still much to be improved, we are very proud of this nation's local products in bio-composite materials.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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