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Improvement Mechanical Properties of Epoxy Composite Reinforced with Sisal, Ramie and Carbon Fibers

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Abstract
In this paper, justification of mechanical characteristics is carried out to determine the ability of bio-composites to become structural composite bicycle frames capable of achieving strengths of more than 300 [MPa]. Sisal fiber is a natural fiber that is widely used as a composite fiber and is easy to cultivate. The fiber is believed to originate from Central and South America. Nearly 4.5 million tons of sisal fiber are produced annually worldwide, according to FAO. In building structural materials, in addition to structural strength, it is hoped that the material will also have good ductility. For this reason, the assembled bio-composite material consists of carbon fiber, ramie fiber, sisal fiber. The fiber is then mixed with hard epoxy resin, soft epoxy and aluminum particles 9 µm which are mixed until smooth and even. The significant increase in material strength is obtained from the strength of carbon fiber. Another thing is that the ductility of the material is obtained due to sisal and ramie which are bound by a mixture of epoxy resins. Because the quality of plant products is very dependent on the agricultural process, this study, the residual material was taken from the Subang (Indonesie) area and the ramie fiber was obtained from the Bandung market. Because agricultural cultivation in Indonesia still emphasizes the use of chemicals, basically this also has an impact on plant bio elements. However, research using local materials was still able to obtain strength reaching ~480 MPa, so it is still good. In this research, the tensile test was carried out 3 times so that it is known that the fiber taken from a rope has the greatest tensile strength which reaches around 480 MPa.

Keywords: Tensile test, Ductility, Bio-composite, Ramie, Sisal, Carbon, Epoxy resin.

1. Introduction

Sisal fiber, which is currently a very popular natural fiber, is widely used as a bio-composite fiber and is easy to cultivate. South and Central America is believed to be the beginning of its production, and has reached 4.5 million tons of fiber annually produced worldwide, according to FAO (Food and Agriculture Organization) [1]. Conventional Composite and Bio-composite (green composite), use reinforcing fiber to increase its strength greater than the resin which functions as a glue. In this study, epoxy resin was used, the breaking strength of which was 70 MPa, so that more or less fiber was used on it. The ease of getting it is one that encourages industrialists 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.

Optimum utilization of bio-fiber from available natural resources is a major factor for human social and economic development by leveraging the ability to produce parts. [4] This optimal ability to continue to develop wasted and available natural products is one of the main factors for human social and economic development. During the last few decades, researchers [1-3,4-7] have tried to use natural resources in fibrous form or particle form as reinforcing materials to produce composite boards. Ligno cellulose materials provide adequate strength at low cost, low density, environmental friendliness and non-toxicity. Walnut shell is a lingo cellulosic material and has no economic value or industrial use in India and is generally discarded or used as a substitute for firewood. In this study the mechanical and morphological properties of walnut shell and coconut fiber reinforced bio-composite were investigated.

Bio-composite materials have been widely used as wear-resistant coatings, because of their very high hardness, good strength and toughness, as well as other properties [5].

2. METHODOLOGY

2.1. Preparation Fiber Sisal

This positive study is very encouraging for applications in electric bicycles to replace iron as a conventional material, although it still requires deeper and more detailed studies. [5] Testing of bio-composite materials is carried out in the Bandung State Polytechnic material laboratory to determine material characteristics such as maximum tensile test and ductility. The iron reduction is due to human efforts to eliminate carbon emissions or reduce them as much as possible, as is the case with electric bicycles.

The stress on the bio-composite causes uniform strain throughout the bio-composite layer. The load acting on the bio-composite can be expressed in Eq. (1)

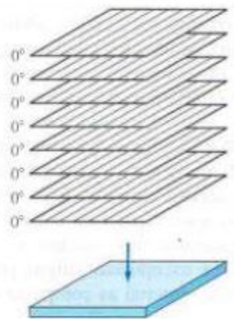

Figure 1 Unidirectional layer [6]

Because the strength of sisal fiber varies, and this research seeks to try to make a material for the structure, it is attempted that has experienced cold working, namely twisting. Fig.2 shows pineapple leaf fibers, and Fig. 3 showing pineapple leaf fiber. [6] What is meant by cold working is sisal fiber that has been twisted into yarn or rope.

Figure 2 Pineapple leaf fiber random fiber

Research has been carried out on the manufacture of composites [8] using pineapple leaf fiber (sisal) which is still in the form of random fiber and ramie fiber, carbon, and epoxy resin as in this study. However, the value of the tension and modulus of elasticity obtained is still too small so it is necessary to use sisal fiber from rope threads, which logically fulfills Fig. 3.

Figure 3 Sisal rope or twine

It can be seen in Fig.3 that the larger the rope or yarn, the fiber by fiber will break, so this theory can be seen in experimental studies. This step explains that the strands in the sisal fiber become stronger due to static deflection in the sisal, so that the mechanism of sisal breaking is in accordance with Fig. 2. [11] Breaking analysis of sisal fiber occurs because the load that occurs exceeds its strength. Experimental rules regarding rope strength, the average estimate based on test results, is generally reduced by 20% as a safety factor.

Figure 4 Pineapple leaf fibers that have been twisted

The increase in the strength of a rope against applicative loads, for example those used on ships, of course, has undergone greater cold working. Laboratory tests have been carried out by utilizing fiber from new ropes but the results are greater than random fibers or threads. The fiber that has become the specimen is then clamped on the UTM machine and pulled until it breaks, so that $\sigma_c = F/A_0$ can be determined.

Table 1 Mechanical characteristics of Sisal Fiber in the world

Fiber	Tensile Strength (Mpa)	Young Modulus (GPa)	Fiber Origin
Sisal Fiber	391.00 ± 89	10.7 ± 4.0	Brazil
	462.00 ± 71	7.47 ± 1.37	Algeria
	294.00 ± 113	9.8 ± 0.9	India
	340.02 ± 70.4	12.5 ± 7.8	Morocco
	371 ± 28 MPa	12.43 ± 2.23	Kenya

For other bio-fibers that can be tabulated can be seen in Table 2 below [10]

Table 2 Properties of some bio fibres

Fiber type	Density (kg/m^3)	Water absorption (%)	Young's modulus, E (GPa)	Tensile strength (MPa)
Sisal	800–700	56	15	268
Roselle	800–750	40–50	17	170–350
Banana	950–750	60	23	180–430
Date palm	463	60–65	70	125–200
Coconut	145–380	130–180	19–26	120–200
Reed	490	100	37	70–140

The mechanical characteristics of the resin are always required in the preparation of bio-composites, where these values can be seen in Table 4, as follows.

Table 3 ***Mechanical properties of some fibers and metals***

Material	Young's modulus (Gpa)	Shear modulus (Gpa)	Axial Poisson's ratio	Ultimate strength (Mpa) tension	Strain to failure (%)	Density (Kg/m^3)
Carbon fibre HT-T300	230	23	0.23	3530	1.5	1750
Carbon fibre IM-T800	294	23	0.23	5586	1.9	1800
Carbon fibre HM	385	20	0.23	3630	0.4	2170
E-glass fibre glass	72	27.7	0.3	3450	4.7	2580
S-glass fibre	87	33.5	0.3	4710	5.6	2460
Kevlar 49 fibre	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

Composite resin, namely epoxy which has been mixed with 5% flexible epoxy and 5% aluminum particle then mixed with ramie fiber, sisal and carbon fiber using the hand layup method. [8] The tensile specimen to breaking strength is achievable for fibers with resins as well as the theoretical value of the material. In fact, the experimental strength of the bio-composite test is quite far from its theoretical conditions. Under actual conditions an ideal bond (theoretical) of 74% will be formed, as shown in Fig. 5.

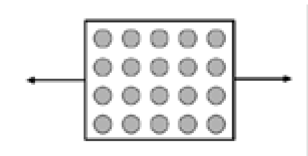

Figure 5 Theoretical conditions of bio-fibres in composites

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 Fig. 5.

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 Fig. 6 which is an iso-strain.

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.

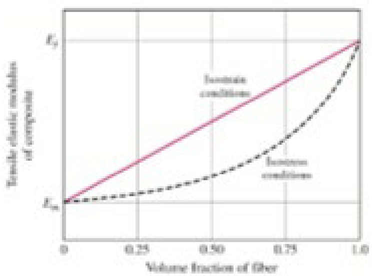

Figure 6 Comparison of composite isostrain and isostress conditions

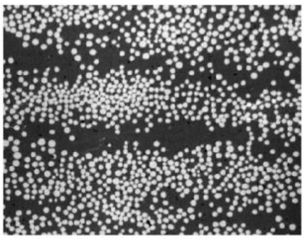

Figure 7 Real conditions of packing of reinforcing fibers in bio-composites

The bio-composite material used in this study is an attempt to obtain ideal conditions from the local market in order to obtain maximum value from the sisal bio-composite combination. Table 1 shows the value of the mechanical characteristics of sisal around the world. It is very clear that almost all of these bio-composite fibers have sufficient use as structural materials. In this case, Sisal from Subang pineapple leaves, which has become worldwide, needs to be mixed with carbon fiber, ramie fiber and aluminum particles in the epoxy resin.

In the preparation of bio-composite is always needed the mechanical characteristics of the resin, where the value is can be seen in Table 4, as follows.

Table 4 Mechanical properties of some matrix polymers

Material	Young's modulus (Gpa)	Shear modulus (Gpa)	Axial Poisson's ratio	Ultimate strength (Mpa) tension	Strain to failure (%)	Density (Kg/m^3)
Epoxy	3.1	1.2	0.3	70	4.0	1200
Polyester	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 properties	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
Elongation at failure (%)	3.0	1.2–1.6	1.6	1.8	2.0	2.0–3.0

Several studies were conducted to study the possibility of replacing conventional fibers with better natural (bio) fibers. The researchers investigated the mechanical properties of ramie and sisal fibers in terms of tensile strength and elastic modulus. With increasing fiber volume fraction, calculations can be carried out 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.

3. Materials and Methods

In this study, the composite material composed of pineapple fiber was attempted to become a material that is tough, lightweight, has ductility, and is easy to produce as an industrial material of choice. [9] Selection of several composite constituent materials is carried out to determine the feasibility of these materials can be used. Mountain e-bike is one of the composite material development applications. The mountain bike is also a medium that can test the toughness of the material.

In this study, fiber reinforcement was used as follows,

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

Carbon fiber is added to these materials primarily to obtain a strong and rigid material to replace the material structure of e-bike vehicles.

The process of making specimens is carried out in stages and is carried out with emphasis through the use of glass, as can be seen in Fig.9.

Figure 8 Resin coating and production of bio-composite stage 3

After using pressure and resin drying time, as well as the final finalization, the specimen is formed and ready for tensile testing. The specimen can be seen as in Fig. 10.

Figure 9 Wax application on glass presses

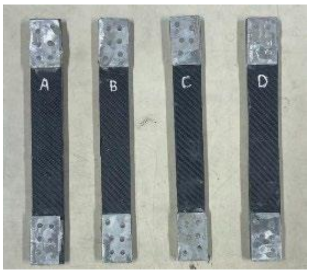

Figure 10 Bio-composite tensile test specimens

The tensile test process is carried out in the Polban 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.11.

Figure 11 Polban Machine Engineering Tensile Testing Machine

4. Results and Discussion

4.1. Theoretical

Theoretical studies need to be carried out to determine the estimated value of experimental studies, bio-composite test specimens. For example, a study obtained a ramie tensile strength value of 128 [Mpa], in which the study stated that the strength can be made more precisely, so that the strength will increase again. The composite is composed of Sisal Subang pineapple leaves, ramie 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 Fig.8, 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,

$$\sigma_{comp} = v_p.\sigma_p + \sigma_{res}.v_{res}$$

$$\sigma_{comp} = (v_c.\sigma_c + v_r.\sigma_r + v_s.\sigma_s + v_{void}.\sigma_{void}).v_p + (v_e.\sigma_e + v_{al}.\sigma_{al}).v_{res} =$$

$$\sigma_{comp} = (0.45.3530 + 0.225.500 + 0.25.268 + 0.5.0).0.489 + (0.975.70 + 0.025.0).0.511 \quad = 899.43\ N$$

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

$$E_{com} = (v_c E_c + v_r E_r + v_s E_s + v_{void} E_{void}) * v_p + (v_{epox}.E_{epox} + v_{al} E_{al}) * v_{res}$$

$$E_{com} = (0.45.230 + 0.225.44 + 0.25 * 15 + 0.05.0) * 0.489 + (0.975 * 3.1 + 0.025 * 0) * 0.511 = 60.73 GPa$$

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.

4.2. Experimental

The results of the tensile test can be shown in Table 6, as shown below,

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 *(mm²)*	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*

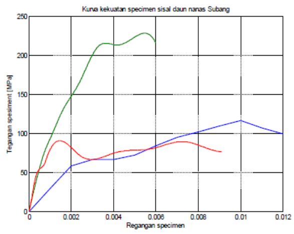

Figure 12 The results of the tensile test of the Sisal specimen of Subang Pineapple Leaves

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.

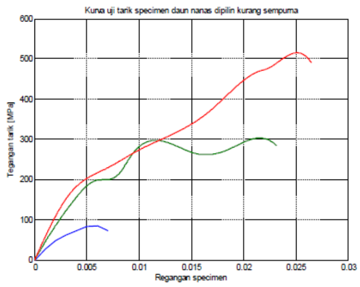

Figure 13 The yield curve for the tensile test of the specimen is not perfect

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,

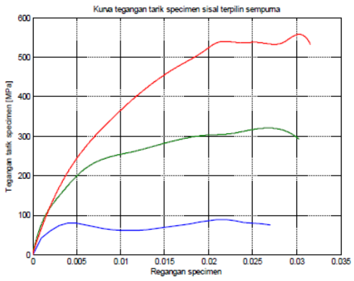

Figure 14 The residual stress curve is perfectly twisted

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

5. Conclusion

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.

6. Numenclature

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

7. Acknowledgement

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.

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