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## ANALYSIS OF THE EFFECT OF LENGTH AND CONTENT OF WATER IN EACH FIBER ON THE TWISTING STRENGTH OF EPOXY RESIN COMPOSITE MATERIALS USING THE REGRESSION METHOD

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### Abstract

Water hyacinth plants have natural fibres that can be used as a filler or reinforcement for natural composite materials. This research was conducted to determine the effect of fibre length and content on the torsional strength of epoxy resin composite materials reinforced with water hyacinth fibre. The research method uses an experimental research model with ASTM E-143 torsion test specimens for four variations, namely long threads and fibre lengths of 10 mm, 20 mm, and 25 mm, each consisting of 3 fractions of fibre weight (4%, 7% and 10%). The results prove that the length and fibre content of water hyacinth does not affect the torsional strength of each composite variation. The torsion test was carried out by taking specimen testing data at a fibre length of 20 mm with a fibre weight fraction of 7%; the highest torque value was 1.418 Nm, and the highest shear stress value was 29.348 MPa. Testing the specimen with the highest shear strain value of 0.589 at a fibre length of 20 mm with a fibre variation of 4%. Furthermore, from the torsion test data, data analysis is carried out using regression which will produce a regression equation.

**Keywords:** Composite Materials, Water Hyacinth, Regression Method, Epoxy Resin, Torsion Testing.

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### 7 1. Introduction

The use of natural materials has recently continued to increase, with many studies being conducted as substitutes for the chemical-based materials we often use. Composite material combines two or more materials with stronger mechanical properties than constituent materials. Composite consists of two parts: the matrix as a binder or protective composite and the composite filler. Composite materials have advantages in their use, such as being lighter, environmentally friendly, and biodegradable [1].

The problems that arise from water hyacinth materials are low mechanical strength, easy to absorb water, thereby reducing fibre bonding with the matrix, low compatibility of water hyacinth fibres with polymer matrix is low, and the mechanical properties of the resulting composite are relatively low. However, composites using water hyacinth fibre as composite reinforcement have other advantages, namely increased acoustic damping ability and good thermal resistance [2].

Several previous studies regarding natural fibres used in synthetic or polyester composite materials, which of course, cannot be renewed, while in general use, there are still many natural fibres that have not been utilized to become something more useful as a

mixture of natural ingredients [3].

In research conducted by Bagir and Pradana (2008), the results of a study using water hyacinth fibre on tensile strength obtained the highest average tensile strength results obtained in water hyacinth fibre composites with 20% fibre weight of 19 N/mm<sup>2</sup>, while the lowest was accepted in water hyacinth fibre composite with 15% fibre weight of 11.5N/mm<sup>2</sup>. The decrease in the tensile strength of the composite at a variable of 15% can be due to the lack of penetration of the resin in the fibre due to excessive filler (latex) obstruction [4]. Research on composite materials was carried out to determine the effect of the volume fraction of coconut fibre and banana fibre reinforcement, the study aims to determine how strong a material is by carrying out impact testing, and the results obtained that the more fibre composition has seen, the higher the composite impact value. This is due to the increasing number of fibres, and the matrix gets more support from the fibres, which causes the matrix not to break easily. In the range of compositions studied, the highest tensile strength values were obtained in resin: banana stem fibre: coconut coir powder (70%: 15%: 15%), 0.172 N/mm<sup>2</sup>. This value is higher than SNI 03-2105-2006, which is 0.147 N/mm<sup>2</sup> [5]. Torsion test research was conducted by Hasra Hartina (2008). This study aimed

to determine the strength of the composite shaft of waru fibre stems with a polyester matrix against torsion testing and to observe macro photographs of fractures after torsion testing. This research was conducted to determine the torsional strength of the axle of the waru skin fibre polyester composite, which was arranged 30°/-30°, 50°/-50°, 70°/-70°. From the research results, it is known that the average torsional strength for 30° fibre orientation is 7.207 kg/mm<sup>2</sup>, and 50° fibre orientation is 6.262kg/mm<sup>2</sup>. The corner orientation with the optimum torsional strength is 70° with a shear stress of 8.270 kg/mm<sup>2</sup> [6].

Another study on water hyacinth fibre aims to utilize water hyacinth as a natural fibre in composite materials. 90%, 80%. Each fibre volume fraction tested uses the ASTM D638 standard, a mixture of fibre and resin volume fractions greatly affects the composite when testing the mechanical properties of the highest average stress value found in a mixture of 5% fibre volume fraction and 95% resin with a tension value of 9.10514 MPa and a load value of 1632.1 N/mm and the highest strain value was found in sample 6 at 5% fibre volume fraction and 95% resin with a strain value of 6.6% [7].

This study aimed to determine the effect of fibre content and length on the torsional strength of the water hyacinth fibre-reinforced resin composite material and obtain the optimum fibre content and size, resulting in the highest torsional strength using the regression equation.

## 2. Experimental and Procedures

### 2.1 Materials Preparation

At this stage, tools and materials are prepared to make specimens. The tools prepared include specimen printing equipment following ASTM E143, digital scales, calipers, torsion test equipment and torsion testing software. The materials prepared are epoxy resin, hardener, and non-stick paste.

### 2.2 Water hyacinth Fibre Preparation

The water hyacinth plant is separated from the leaves and roots so that only the stem is obtained, after which it is cleaned of dirt and adhering mud using water until it is clean and dried by drying it for ten days in the sun. Furthermore, after the water hyacinth stems are dry, the fibre is harvested using a wire brush to get the water hyacinth fibre contained in the stem fibre to obtain pure fibre, then cut according to the required length. The ratio between resin and epoxy is 1:1. While the fibre length in this test was 10, 20, 25, and 135 mm, the fibre content was 4, 7, and 10%, while the epoxy resin was 90, 93, and 96%.

### 2.3 Specimen Preparation

Specimens will be made based on the ASTM (American Society of Testing and Materials) standard type E-143 (Standard Test Method for Shear Modulus at Room Temperatures) [8]. Specimens were made using the hand lay-up technique using the printing tool shown in Figure 2.

In this process, the fibres are arranged in the mould in the same direction on each side of the mould, and the epoxy resin mixture is poured into the mould so that the water hyacinth fibres can absorb the epoxy resin and not damage the arrangement fibres, let stand for ± 30 minutes, close the mould and make sure there are no gaps that can cause leakage, then pour the remaining epoxy resin mixture so that the mould is filled. Wait for the specimen to dry for about ± 9 hours at room temperature until it dries. In this study used is the weight fraction for the use of the composition of the composite constituent materials.

### 2.4 Torsion Test Preparation

Preparation of specimens and torsion test equipment is prepared at this stage; ensure that the torsion test equipment can function properly, make sure the existing sensors can read properly, lubricate each shaft on the torsion testing tool before use, make sure the torsion testing software has been installed on laptop or computer and check by rotating the chuck whether the sensor reads the movement of the chuck. The next step is to prepare the specimen to be tested, measure the dimensions using a caliper, and enter the data into the testing software.

This torsion test is intended to determine the value of shear stress, shear strain and shear modulus in the material to be tested, the torsion testing formula is used as follows [9].

Shear Stress:

$$\tau_g = \frac{16.T_{max}}{\pi.d^3} \quad (1)$$

Where  $\tau_g$  = Shear stress (Mpa),  $T_{max}$  = Torsion moment (N.m),  $\pi$  = 3.14, and  $d$  = Radius (mm)

Shear Strain:

$$\gamma = \frac{\theta.r_m}{L_u} \quad (2)$$

Where  $\gamma$  = shear strain,  $\theta$  = angle of twist ( $^{\circ}$ ),  $r_m$  = average radius of the test specimen (mm), and  $L_u$  = length of the test specimen (mm).

Shear Modulus:

$$G = \tau / \gamma \quad (3)$$

Where  $G$  = Shear Modulus ( $\text{kg/mm}^2$ ),  $\tau$  = Shear stress ( $\text{kg/mm}^2$ ), and  $\gamma$  = Shear strain.

### 3. Results and Discussion

#### 3.1 Result of Torsion Test

The test is carried out on the specimen by applying a bending force until it breaks on the specimen of the test object, with the results of the torsion test with the average of the specimens tested can be seen in table 3 below:

Table 1. Fibre Test Results

No	Specimen (%)	Torque (N.m)	Shear Stress (MPa)	Shear Strain	Shear Modulus
1	10 mm/4%	0.247	5.817	0.401	13.561
2	10 mm/7%	0.755	17.784	0.231	95.403
3	10 mm/10%	0.586	13.867	0.492	29.169
4	20 mm/4%	0.316	7.465	0.589	13.112
5	20 mm/7%	1.418	29.348	0.114	258.555
6	20 mm/10%	1.011	23.841	0.103	192.403
7	25 mm/4%	0.945	22.286	0.064	369.408
8	25 mm/7%	1.134	26.716	0.126	266.562
9	25 mm/10%	0.856	20.183	0.088	301.056
10	135 ± 5 mm/4%	0.647	15.108	0.23	66.749
11	135 ± 5 mm/7%	0.641	14.679	0.176	87.164
12	135 ± 5 mm/10%	0.476	11.228	0.226	50.487

The data above are the results of torsion testing to get strain, stress, and torsional modulus results for each specimen. The test results are different for each sample, and this is due to the different fibre density and size for each specimen and the density of the matrix and fibre. The test with a fibre length of 10 mm showed that the highest average torque was obtained with a 7% fibre composition of 0.755 Nm and a shear stress of 17.784MPa, but the largest average shear strain was obtained from a 10% fibre composition of 0.492.

From the test results on the 20 mm fibre length test, the results with the highest average torque were obtained on 7% fibre specimens with 1.418 Nm with a moderate shear stress of 29.348 MPa. The highest strain results were obtained from 4% fibre variations with an average yield of 0.126. The results of testing on 25 mm fibre obtained the highest average torque results on 10% fibre specimens of 1.134 Nm with a moderate shear stress of 26.716 MPa, an average yield of 0.126. Whereas for long fibres of 135 ± 5 mm, the highest average torque test results were obtained at a 10% percentage of 0.988 Nm, with the largest shear stress of 23.841, while for the largest strain at 4% fibre percentage of 0.230.

#### 3.2 Result of Effect of Percentage of Fibre Content

The results of the calculation of the torsional test of water hyacinth fibre reinforcement with an epoxy resin matrix shown in table 4 show that short fibres have better torsional strength than long fibres. Table 4 shows that long fibres have decreased in terms of torsional strength from the percentage of 4%, 7% and 10% fibre. This is due to the decrease in the average torsional strength of composite specimens as the percentage of fibre weight contained in the torsion test specimens increases. This is corroborated by the research conducted by Bagir & Pradana (2008) [4] concerning the strength of water hyacinth fibre in compression testing with similar results for the addition of weight to the compressive test specimen affecting the compressive strength of the composite.

The relationship between the length of the 10 mm composite fibre and the percentage of 20 mm fibre affects the torsional test results experienced by the composite shaft until the composite shaft fails to break. However, the fibre length of 10 mm and 20 mm with a fibre length of 25 mm decreased the results of the torsion test experienced by the composite shaft until it failed to break; this is because the longer the fibre used, the bonding process between the fibre and the resin is not good enough to affect the lower torsional strength.

After testing, the results showed that the relationship between the percentage of fibres 4%, 7% and 10% for long fibres and fibres with lengths of 10 mm, 20 mm and 25 mm on the composite shaft did not affect torsional strength.

#### 3.3 Result of Macros and Microscopic Observations

After carrying out the torsion test, the specimen will experience a brittle or flexural fracture. From the results of these fractures, microscopic and macroscopic observations will be carried out. The results show that the fracture occurs due to debonding, namely the release of the interfacial bond between the water hyacinth fibre and the epoxy resin when loading occurs, and the thread peels off from the matrix.

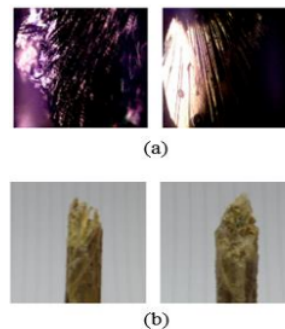


Fig. 1. Morphology (a) Micros and (b) MacroscopicView

### 3.4 Result of Regression Method

After getting the results of the research, then to find out the relationship between fibre length and torsional strength is shown using the regression method. While for the graph and the equation between fiber length to the result of strain, stress, and shear modulus of the composite shaft on long fiber, using Ms. Excel, the test results are in the form of an equation that can be used to predict the torsional strength of the fiber length and fiber content reinforced by epoxy resin [10].

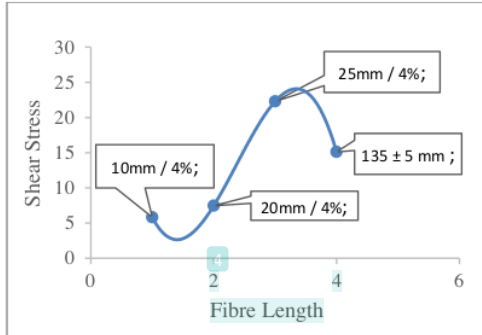


Fig. 2. Fibre Length and Tension Curve (4% Fibre Content)

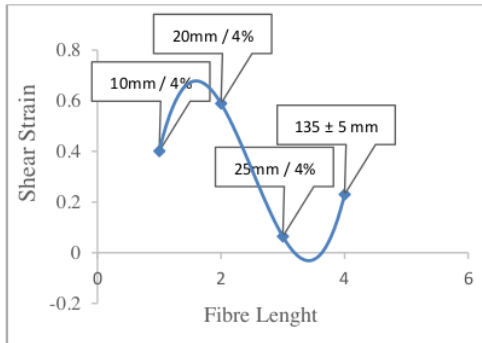


Fig. 3. Fibre Length and Strain Curves (4% Fibre Content)

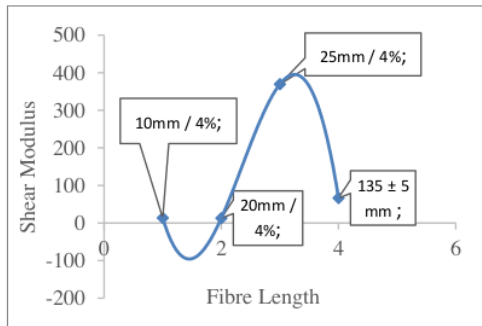


Fig. 4. Fiber Length and Shear Modulus Curves (4% Fibre Content)

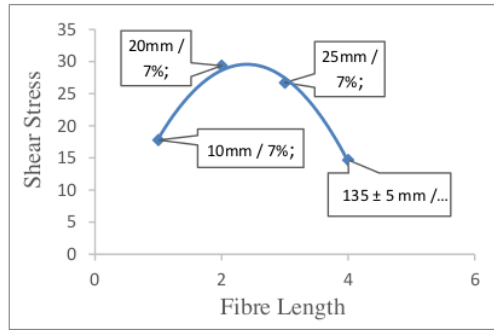


Fig. 5. Fibre Length and Tension Curve (7% Fibre Content)

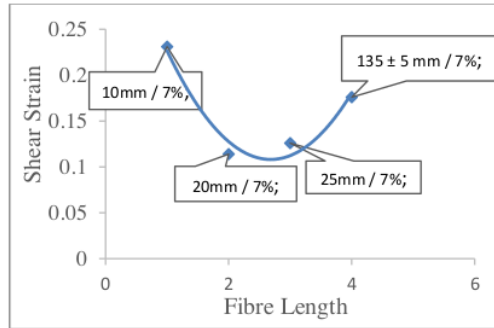


Fig. 6. Fibre Length and Strain Curves (7% Fibre Content)

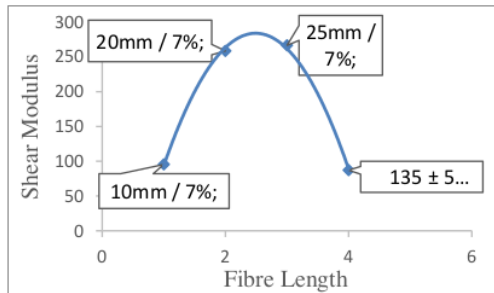


Fig. 7. Fiber Length and Shear Modulus Curves (7% Fibre Content)

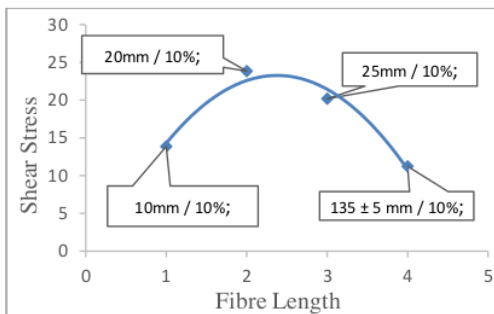


Fig. 8. Fibre Length and Tension Curve (10% Fibre Content)

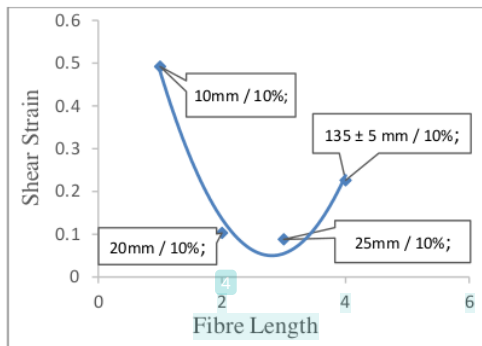


Fig. 9. Fibre Length and Strain Curves (10% Fibre Content)

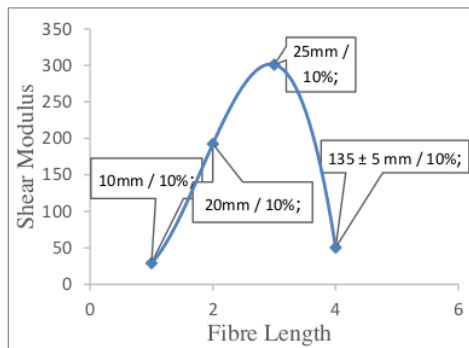


Fig. 10. Fiber Length and Shear Modulus Curves (10% Fibre Content)

Table 1. Results of Regression Method

Fiber Content (%)	Regression	Coefficient Determination
4% Fiber Length and Tension	$y = -5.862x^3 + 41.758x^2 - 82.593x + 52.514$	1
4% Fiber Length and Strain	$y = 0.234x^3 - 1.7605x^2 + 3.8315x - 1.904$	1
4% Fiber Length and Shear Modulus	$y = -169.28x^3 + 1194.1x^2 - 2397.7x + 1386.5$	1
7% Fiber Length and Tension	$y = -5.9003x^2 + 28.307x - 4.3828$	0.99
7% Fiber Length and Strain	$y = 0.0418x^2 - 0.2241x + 0.4088$	0.95
7% Fiber Length and Shear Modulus	$y = -85.638x^2 + 426.52x - 247.09$	0.99
10% Fiber Length and Tension	$y = -4.7322x^2 + 22.504x - 3.4878$	0.96
10% Fiber Length and Strain	$y = 0.1318x^2 - 0.7401x + 1.0893$	0.97
10% Fiber Length and Shear Modulus	$y = -50.773x^2 + 277.35x^2 - 313.4x + 115.99$	0.97

Figures 2, 3, 4, and Table 2 show the equation between the 4% fiber content to the shear stress, shear strain, and shear modulus, and we get a coefficient of determination of 1. This value indicates a regression accuracy rate of 100% or greater than 95%. So, this regression equation uses a 3rd-order polynomial regression. Equation of 7% fiber content to shear stress, shear strain, and shear modulus. Get the coefficient of determination in Figure 5 of 0.99,

Figure 6 of 0.95, and Figure 7 of 0.99. This value indicates the level of accuracy of linear regression of 95%. So, a polynomial regression of the 2nd order is used for this regression equation. At the same time, the equation between 10% fiber content to shear stress, shear strain, and shear modulus. Obtained 0.96 in Figure 8, 0.97 in Figure 9, and 0.97 in Figure 10. These values indicate a linear regression accuracy rate of 95%. So, a polynomial regression of the 2nd order is used for this regression equation.

#### 4. Conclusions

The torsion test results on the composite shaft reinforced with water hyacinth fibre showed that the fibre length and fibre content of the water hyacinth fibre composite material affected the torsional strength. Tests prove that short fibres have better torsional strength than long fibres. The longer the yarn is used, the less good the bonding process between the fibre and the resin, which affects the torsional strength of the material. Testing the specimen with the highest torque value of 1.418 Nm, namely at a fibre length of 20 mm with a variation of 7% fibre and 93% epoxy resin, testing the specimen with the highest shear stress value of 29.348 MPa, namely at 20 mm fibre length with 7% fibre variation and 93% epoxy resin and testing the specimen with the highest shear strain value of 0.589, namely at 20 mm fibre length with 4% fibre variation and 96% epoxy resin. And Testing of specimens with the highest shear modulus value of 369.40, namely at 20 mm fibre length with 4% fibre variation and 96% epoxy resin.

The regression equation was obtained from torsion testing of the composite shaft reinforced by water hyacinth fibre, the coefficient of determination is 0.99. The results of the torsion test for the water hyacinth fibre composite material obtained the highest strain value using a polynomial regression of the 3rd order with the equation  $y = 0.234x^3 - 1.7605x^2 + 3.8315x - 1.904$ , the coefficient of determination was 1, while the results of the torsion test for the water hyacinth fibre composite material were obtained the highest shear modulus value uses polynomial regression order-3 with the equation  $y = 0.234x^3 - 1.7605x^2 + 3.8315x - 1.904$ , the coefficient of determination is 1.

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