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Analysis of Relation Between Impact Strength and Torsional Strength in Palm Fiber-Reinforced Epoxy Resin Composite Materials

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Abstract-- *Composites are a combination of matrix or binder materials with reinforcement. The combination will produce a composite material that has different mechanical properties and characteristics from the constituent material, so that a desired composite material can be planned. The abundance of natural resources of palm fiber from palm trees but its utilization is still lacking, due to the mechanical properties of this fiber which is still in doubt about its reliability. For this reason, it is necessary to conduct research on epoxy resin composites with fibers as a filler so that the mechanical properties of each fiber and matrix composition can be known. The study used an experimental method that began with the manufacture of composite materials for the test specimens using an epoxy resin matrix reinforced with fibers with fiber volume fraction variations of 0%, 5%, 7% and 9%. Testing the mechanical properties of composite materials, which in this case is testing the torsional strength and impact strength of composite materials with variations in some fiber content, is then carried out simulations using the test data. The results of this study obtained an optimum average impact strength of 13.00 kJ/m on a composite material with a fiber content of 9% and obtained an optimum torsional strength with an average torque value of 271.14 N.m and an average stress value. shear of 2698.48 MPa on a composite material with a fiber content of 9%. The data obtained shows that the higher the percentage of fiber used, the greater the impact strength and torsional strength produced by the fiber-reinforced composite material.*

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1. INTRODUCTION

Composite materials are a very broad area of research and have proven to be a solution to various problems. In its development, various composite materials from natural fibers have been developed for use as sound-absorbing materials. One of them is a bamboo fiber-reinforced composite material for sound absorption. There is a significant increase in the sound absorption coefficient at a frequency of 1000 Hz of 0.972 for polyester materials reinforced with bamboo fibers[1].

Indonesia is rich in various natural fibers. Some natural fibers become organic waste if not utilized for something needed by humans. One potential application of natural fiber composite materials is for use in automotive components. Specifically, automotive components made of polymers, such as dashboards, interior walls, front and rear bumpers, and car bodies. Each of these automotive components has different functions and conditions, resulting in different mechanical properties required[2].

It is known that the addition of natural fibers will increase the strength of composites. The properties of composites depend on the filling fibers. Many types of fibers can be used as composite materials, and currently, composites with various natural fibers as fiber materials are being researched and developed. Indonesia is one of the countries with abundant forests and mountains, which are covered with various types of wild plants or trees, many of which produce natural fibers, one of which is the palm tree. The palm tree produces a fiber known as palm fiber, which is commonly used for various household purposes, including brooms, mats, ropes, water filters, roof vibration dampers, and others[3].

Palm fiber is a natural fiber that is abundant but has not been optimally utilized. Palm fiber can be used as an alternative reinforcement for composite materials. Palm fiber (Arenga Pinnata) is a special natural fiber compared to other natural fibers. The black fiber produced from the palm tree has many special characteristics, including durability, resistance to decomposition, and resistance to acids and sea salt. One form of processed palm fiber is palm rope, which is used to tie various marine fishing equipment and prevent termite infestation. Palm fiber is often used as a wrapping material for the bases of wooden building materials planted in the ground to slow down wood decay and prevent termite attacks[4].

The problem with palm fiber is that its use is still limited to household needs, and it is even exported in its raw state. Therefore, the use of palm fiber as a composite base material offers new hope for utilizing palm fiber as a commodity with higher added value. To obtain the desired quality and prevent failure in the use of composite materials, torsion strength and impact strength tests need to be conducted. Torsion testing on a specimen is carried out to determine the torsional strength or plasticity of a material. Meanwhile, impact testing is carried out to determine the ability of a material to withstand sudden loads. Impact testing simulates the operating conditions of materials that are often encountered where loads occur suddenly [5].

Research on composites has been conducted by creating polymer matrix composite materials reinforced with palm fiber, and then testing the fatigue failure cycle life of axial load polymer matrix composite materials with different percentages of palm fiber content. The material used as the matrix was Yukalac® 157 BTQN-EX unsaturated polyester resin (UPRs), and the catalyst used was methyl ethyl ketone peroxide (MEKPO) and palm fiber as reinforcement [6].

Impact testing research was conducted by Muhamad Fitri and Mahzan. The purpose of this research was to examine the effect of fiber content, fiber size, and alkali treatment on the impact resistance of composite materials. The composite material used palm fiber as a reinforcing material, while polypropylene was used as the matrix for the composite material. Palm fiber was prepared for two conditions: fiber that was treated with alkali and fiber that was not processed. Fiber size varied in three sizes: 5mm, 7mm, and 10mm. During the preparation of composite materials, the fiber content was also varied into three different percentages: 5%, 7%, and 10% [7].

Another study on torsion testing aimed to determine the tensile, flexural, torsional, and metallographic characteristics of ST 41 steel material after the quenching process. The results of this study were in the form of material strength values, which were then compared with the minimum values required by BKI rules. Several research results, such as fracture cross-sections, can also represent the toughness characteristics of the material [8].

The purpose of this study was to analyze the effect of different percentages of palm fiber volume in test specimens on impact and punter strength so that the optimum impact and punter strength could also be determined.

2. METHODOLOGY

The method used in this study was experimental. This study describes the stages carried out during the testing process of epoxy resin composite materials reinforced with water hyacinth fibers. The research methodology was carefully designed to evaluate the mechanical properties of materials through impact and torsion testing. The process began with the preparation of test specimens, tailored specifically for both impact and torsion evaluations. Each specimen was fabricated according to standardized dimensions and specifications to ensure consistency and reliability in the results.

Once the specimens were prepared, the impact and torsion tests were conducted using calibrated testing equipment. The impact test measured the material's ability to absorb energy during sudden loading, while the torsion test assessed its resistance to twisting forces. These tests provided critical insights into the material's behavior under dynamic and rotational stresses.

Following the experimental phase, the impact strength and torsional strength of each specimen were calculated. Impact strength was determined by dividing the absorbed energy by the cross-sectional area at the point of fracture, whereas torsional strength was derived from the torque applied and the angle of twist observed during testing.

Finally, through comparative evaluation and optimization techniques, the optimum impact strength and torsional strength were identified. These values represent the best-performing material configurations under the given testing conditions, offering valuable guidance for future applications and material selection.

2.1 Tools and Materials Preparation

At this stage, tools and materials are prepared for use during specimen production. The tools prepared include a torsion test specimen molding tool in accordance with ASTM E143, an impact test specimen molding tool in accordance with ISO 179, digital scales, calipers, impact test tools, torsion test tools, and torsion testing software. The materials prepared are epoxy resin, hardener, and anti-stick paste/miracle gloss.

Figure 1. Impact Test Specimen Mold

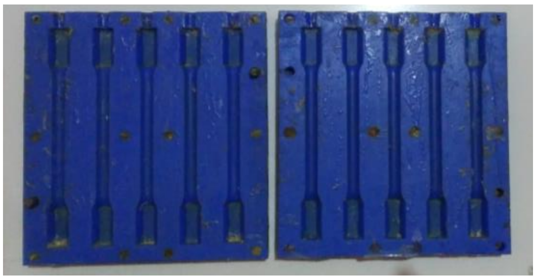

Figure 2. Torsion Test Specimen Mold

Figure 3. Torsion Testing Device

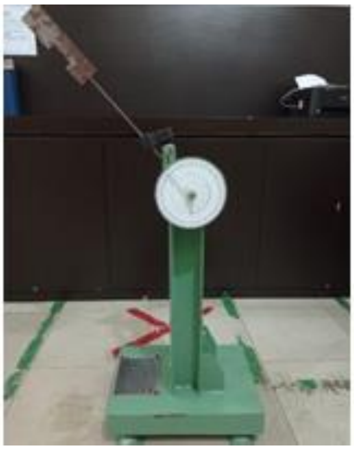

Figure 4. Impact Testing Device

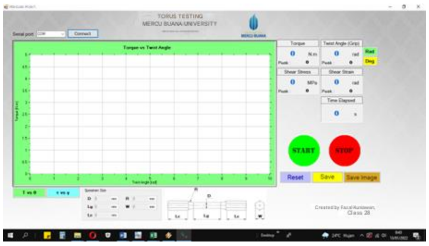

Figure 5. Torsion Testing Software

2.2 Palm Fiber Preparation

The palm fiber is washed three times using water to separate the dirt and short fibers from the long fibers, then dried for 3 days by airing it without exposing it to direct sunlight.

After the palm fiber is dry, the fibers are collected using a wire brush to obtain long palm fibers, which are then cut to the required length.

Figure 6. Fiber Washing

Figure 7. Fiber Drying

In this study, the ratio between resin and epoxy is 1:1 with the following conditions:

Tabel 1. Fiber Variation

Fiber Content	***Epoxy Resin Content***	***Hardener Content***
0%	50%	50%
5%	47.5%	47.5%
7%	46.5%	46.5%
9%	45.5%	45.5%

2.2 Specimen Preparation

Specimens will be prepared based on the ISO 179 standard for impact testing and the ASTM E-143 standard for torsion testing. [9].

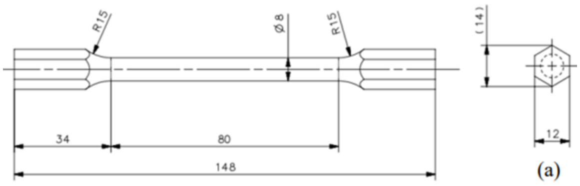

Figure 8. Torsion Test Specimen Dimensions

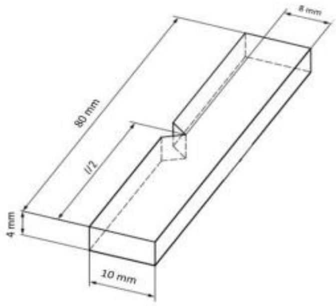

Figure 9. Impact Test Specimen Dimensions

The specimens were made using the hand lay-up technique with the molds shown in Figures 8 and 9. In this process, the fibers were arranged unidirectionally on each side of the mold.

Figure 1. The Fibers Arranged Continuously in One Direction

Arrange the fibers neatly in the mold according to the specified size, then pour the epoxy resin mixture into the mold so that it mixes with the palm fiber without damaging the fiber arrangement. Leave it for ±30 minutes.

Close the mold and ensure there are no gaps that could cause leakage, then pour the remaining epoxy resin mixture so that the mold is completely filled. Wait for the specimen to dry for approximately 24 hours at room temperature.

This study used volume fractions for the composition of composite materials, as described in the following table:

Table 2. Impact Test Specimen Composition

Fiber Content	*Resin Mass*	*Hardener Mass*	*Fiber Mass*
0%	11.360 g	9.016 g	0 g
5%	10.792 g	8.5652 g	0.64208 g
7%	10.5648 g	8.3848 g	0.8989 g
9%	10.3376 g	8.2045 g	1.1557 g

Table 3. Torsion Test Specimen Composition

Fiber Content	*Resin Mass*	*Hardener Mass*	*Fiber Mass*
0%	61.217 g	48.585 g	0 g
5%	52.340 g	41.540 g	3.114 g
7%	51.239 g	40.663 g	4.359 g
9%	50.137 g	39.792 g	5.605 g

2.3 Torsion Testing Preparation

Preparation of specimens and torsion testing equipment is carried out at this stage, ensuring that the torsion testing equipment is functioning properly, that the sensors are reading correctly, that each shaft on the torsion testing equipment is lubricated before use, that the torsion testing software is installed on the laptop or computer, and that a check is carried out by turning the clamp to see if the sensor is reading the clamp's movement. The next step is to prepare the specimens to be tested, then measure the dimensions using calipers and enter the data into the testing software.

This torsion test is intended to determine the values of shear stress, shear strain, and shear modulus in the material to be tested. To obtain the results of this study, the following torsion test formula is used[10]:

- Shear Stress Value:

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

Description:
τ_g = Shear Stress (MPa)
T_{max} = Torsional Moment (N.m)
π = 3.14
d = Radius (mm)

- Shear Strain:

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

Description:
γ = Shear Strain
θ = Twist Angle (º)
r_m = Average Radius of Test Specimen (mm)
L_u = Length of Test Specimen (mm)

- Shear Modulus:

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

Description:
G = Shear Modulus ($^{kg}/_{mm^2}$)
τ = Shear Stress ($^{kg}/_{mm^2}$)
γ = Shear Strain

2.4 Impact Testing Preparation

The impact testing equipment and specimens to be tested are prepared at this stage. The testing equipment is checked to ensure that all components are functioning properly. Ensure that the equipment is working properly. Prepare lubricant and lubricate the shaft before the impact testing equipment is started and also while the equipment is running (if necessary). Ensure that the indicator needle is in normal condition and functioning properly. Next, prepare the specimens to be tested. When testing, place the impact testing equipment in a stable position (always in a sturdy condition). Testing is carried out in stages for each group of specimens. After each test, always recalibrate to obtain accurate and precise measurement results for all grouped specimens.

$$AcN = Ec/Hbn \,.\, 10^3 \quad (4)$$

Description:
AcN = Charpy impact strength ($^{kg}/_{mm^2}$)
Ec = Corrected energy, absorbed by breaking the test piece (J)
h = Thickness of the test piece (mm)
bN = Remaining width of the test piece (mm)

3. RESULT AND DISCUSSION

3.1 Torsion Test Results

This test was conducted on specimens made using a torsion testing machine, which applies a bending force to the test specimens until they break. The results of the torsion test, based on the average of the specimens tested, can be seen in Table 3 below:

Table 4. Recapitulation of Torsion Test Results.

Percentage of Fiber Content	*Average Torque (N.m)*	*Average Shear Stress [MPa]*	*Average Shear Strain (rad)*	*Average Rotation Angle (rad)*
0%	107.05	1065.39	54.63	1092.70
5%	73.56	732.15	70.29	1406.07
7%	140.24	1395.74	34.12	682.40
9%	271.14	2698.48	16.92	338.45

Table 4, which shows a summary of the torsion test results for resin matrix composite materials reinforced with palm fiber, indicates that for palm fiber content percentages of 0%, 5%, 7%, and 9%, the average optimum torsion strength was produced by composite materials with a 9% palm fiber content, with an average torque value of 271.14 N.m and an average shear stress value of 2698.48 MPa. This data is illustrated in the following graph:

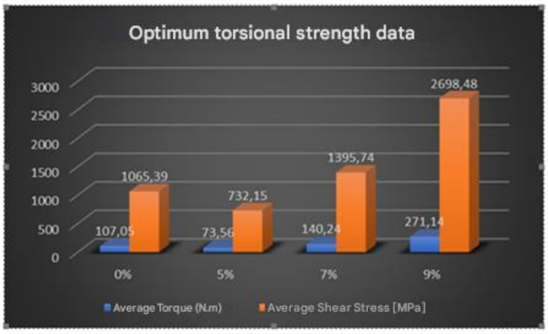

Figure 2. Optimum Torsional Strength Chart

3.2 Impact Test Results

Based on the results of the impact test that has been carried out, data was obtained on the energy absorbed by the test specimen for fiber composite materials with fiber volume fractions of 0%, 5%, 7%, and 9% using an epoxy resin matrix. Impact strength is a number that indicates the amount of energy required to break a specimen, which is known from the difference between the upper mass height and the lower mass height (fall height).

Table 5. Recapitulation of Impact Test Results

Number	*Percentage of Fiber Content*	*Average Impact Energy (J)*	*Average Impact Strength (kJ/m²)*
1	0%	0,25	7,40
2	5%	0,33	9,64
3	7%	0,39	11,45
4	9%	0,45	13,00

Table 4.12, which shows a summary of the impact test results for resin matrix composite materials reinforced with palm fiber, indicates that for palm fiber content percentages of 0%, 5%, 7%, and 9%, an optimum impact strength of 13.00 kJ/m² and an optimum impact energy of 0.45 were obtained at a 9% palm fiber content. The data is illustrated in the following graph:

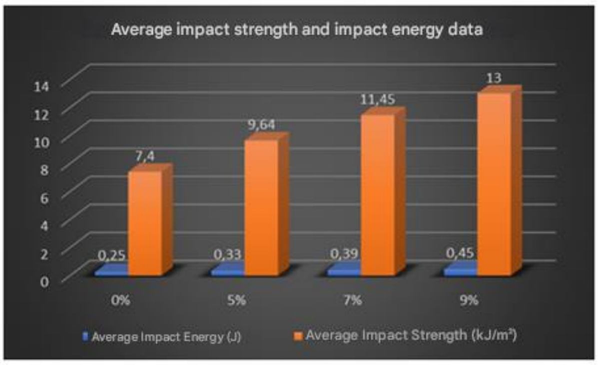

Figure 12. Optimum Impact Strength Chart

Based on the test results obtained, it can be seen that the addition of palm fiber increases the strength of the composite against shock loads. The higher the percentage of palm fiber, the higher the impact strength of the composite.

4. CONCLUSION

From the results of testing and analysis of impact testing and torsion testing data of composite materials reinforced with palm fiber with fiber content of 0%, 5%, 7%, and 9%, the following conclusions were obtained:

1. The torsion testing conducted on composite materials reinforced with palm fiber yielded the following results:
    a. This study shows that the fiber content of palm fiber composite materials has an effect on their torsional strength.
    b. Torsion testing with the highest average torque value of 271.14 N.m and the highest average shear stress value of 2698.48 MPa was found in composite materials with a 9% palm fiber content.
    c. Torsion testing with the highest average shear strain value of 70.29 rad and the highest average rotation angle value of 1406.07 rad was found in composite materials with a 5% palm fiber content.
2. Impact testing on pure resin material yielded an average impact strength of 7.40 kJ/m^2.
    a. Impact testing on composite material with 5% fiber content yielded an average impact strength of 9.64 kJ/m^2.
    b. Impact testing on composite materials with 7% fiber content yielded an average impact strength of 11,45 kJ/m^2.
    c. Impact testing on composite materials with 9% fiber content yielded an average impact strength of 13,00 kJ/m^2.
    d. The impact strength of composite materials reinforced with palm fiber had the highest impact strength of 13.00 kJ/m^2, which was found in composite materials with a fiber content of 9%. Meanwhile, the lowest impact strength of 7.40 kJ/m^2 was found in composite materials with a fiber content of 0%.
3. The results of this study obtained an optimum average impact strength of 13.00 kJ/m^2 in composite materials with a 9% palm fiber content and obtained an optimum torsional strength with an average torque value of 271.14 N.m and an average shear stress value of 2698.48 MPa in composite materials with a 9% palm fiber content. The data obtained shows that the higher the percentage of palm fiber used, the greater the impact strength and torsional strength produced by the composite material.

Based on the analysis that has been carried out, the author provides the following suggestions:

1. Suggestions for specimen preparation can be done in the following ways:
    a. The palm fiber needs to be straightened/combed first using a wire brush before being placed in the mold to facilitate the process of pouring resin into the mold.
    b. The composition of the matrix and binder must be accurate to obtain a specimen shape that is good/in accordance with the mold standard.
    c. The mixing process of resin and hardener should be done until evenly mixed for 10 minutes to ensure a good composition.
2. When collecting data during torsion testing, it is recommended that at least two people be involved to ensure more effective and accurate data collection and calculation.
3. Further research is also needed to investigate other mechanical properties besides impact and torsion strength, such as tensile strength, fatigue strength, and so on.

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