# Study of Mechanical Properties of Waru Fiber Reinforced Polymer Composites

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## ABSTRACT

This study aims to determine the appropriate matrix material and examine the mechanical properties of composite materials reinforced with waru fiber, using polyester, epoxy, and bisphenol as matrix materials. The composite material manufacturing process was carried out using the lay-up method with a composition of 70% resin and 30% waru fiber. Mechanical properties were determined using a tensile testing machine according to the ASTM D3039 standard. The mechanical properties of the polyester matrix composite material showed a strength of 30.76 MPa, an elastic modulus of 2131.53 MPa, and a strain of 2.71%. The epoxy matrix composite material exhibited a strength of 41.71 MPa, an elastic modulus of 2491.86 MPa, and a strain of 1.81%. The bisphenol matrix composite material had a strength of 22.05 MPa, an elastic modulus of 344.45 MPa, and a strain of 2.61%. The matrix material that is most suitable for the waru fiber reinforcement is bisphenol resin, which significantly enhances the composite material's strength by 4.26 times compared to the matrix material's strength. In contrast, the polyester and epoxy matrix materials showed a reduction in strength, which was lower than the strength of the matrix material itself.

***Keywords:*** Waru fiber; polyester resin; epoxy resin; bisphenol resin; tensile strength.

## INTRODUCTION

Polymer matrix composites reinforced with natural fibers (Natural Fiber Reinforced Polymer, NFRP) have become an increasingly popular material alternative in various industrial applications, including automotive, construction, and consumer products. This popularity is attributed to the superior properties of these composites, such as lightweight, eco-friendliness, biodegradability, and their ability to reduce dependence on non-environmentally friendly synthetic raw materials. Furthermore, the use of natural fibers as reinforcing materials offers additional benefits, including abundant availability, lower costs, and ecological sustainability.

Natural fibers such as flax, kenaf, bamboo, and jute have long been utilized in various traditional products. However, in recent decades, research on the application of natural fibers in polymer matrix composites has grown significantly. The combination of natural fibers with synthetic or natural polymers can produce materials with a well-balanced set of mechanical, thermal, and physical properties. Nevertheless, a major challenge in developing these composites lies in the incompatibility between natural fibers and the polymer matrix, which can affect the overall properties of the composite.

Composite materials offer a combination of strength, lightweight properties, corrosion resistance, and longer service life compared to other materials[1]. Industries such as construction, manufacturing, and automotive have widely adopted composites. In the material

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fabrication process, the use of natural fiber-reinforced polymer composites represents an innovative solution to address environmental issues and resource scarcity. In addition to being biodegradable, these composites exhibit high strength and lightweight properties [2].

Composite materials have been widely utilized across various industrial sectors, including construction, manufacturing, and automotive. In the production process, the use of polymer composites reinforced with natural fibers offers an innovative solution to address environmental challenges and resource limitations [3].

The waru tree, or Hibiscus tiliaceus, is an abundant source of natural fiber found in tropical regions, particularly in coastal areas. The fibers from the bark of the waru tree have attracted researchers' attention due to their potential as a reinforcement material for composites [4]. Studies have shown that composites based on waru bark fibers exhibit outstanding mechanical performance. These fibers are known for their lightweight, high strength, eco-friendliness, low density, high biodegradability, and cost-effectiveness [5]. One of the key advantages of waru fibers is their tensile strength, which is significantly higher than that of several other materials. Beyond industrial applications, these fibers are also utilized by communities for various purposes, such as building boats to reduce wood usage, making ropes, bags, musical instruments, and more [6].

Waru bark fiber-based composites offer numerous advantages that can be utilized across various industrial sectors, particularly in applications requiring high tensile strength. During the manufacturing process, resin serves as the matrix that binds and unifies the fibers, creating a strong and stable composite structure.

The selection of resin type significantly influences the composite's properties, including strength, stiffness, resistance to high temperatures, and moisture durability. Previous studies have explored the potential of waru bark fiber as a reinforcing material and the role of resin in enhancing the mechanical and physical properties of composites [7].

This research aims to investigate the potential of waru bark fiber-based composite materials with various types of resin as the matrix. The primary objectives of this study are to analyze the effect of resin type on the mechanical properties of the composites, such as tensile strength and stiffness, and to determine the potential applications of specific resin-based waru fiber composites in material fabrication.

## MATERIAL AND METHODS

This study was conducted at the Materials Engineering Laboratory, Department of Mechanical and Industrial Engineering, Syiah Kuala University, which is equipped with facilities to support the development and testing of composite materials. The research began with an in-depth and systematic literature review to gather relevant information that supports the implementation of the experiments.

The literature review included an examination of previous studies, fundamental theories, and data related to the use of natural fibers as reinforcing materials in composites. This process aimed to provide a strong scientific foundation before proceeding to the experimental stage, which was designed in alignment with the research objectives. The preparation of waru fiber is carried out using the ripping method (fiber separation), which is a technique for separating natural fibers from the bark of the waru tree. In this method, the harvested waru bark is first cleaned of dirt and unwanted outer layers. Next, the bark is processed by tearing or flattening the fibers using specialized tools, such as knives or mechanical devices, so that the resulting fibers have the appropriate length and strength to be used as reinforcement in composites.

Figure 1. Waru fiber

The ripping method is effective in producing fibers of good quality, as it helps maintain the natural strength of waru fibers. The fibers are then dried or sun-dried to reduce moisture content, making them ready for use in composite production. This process ensures that the waru fibers are in optimal condition before being mixed with resin to create the composite material tested in this study. The tensile strength of untreated waru fibers is 207.3 MPa [8]. The resins used for the matrix are epoxy, polyester and bisphenol, the mechanical properties for each resin are as in Table 1, Table 2 and Table 3.

Table 1. Physical and mechanical properties of polyester resin

| Properties | Unit |
|---|---|
| Tensile strength | 55-65 MPa |
| modulus of elasticity | 3600-2800 MPa |
| Bending Strength | 182-192 MPa |
| Elongation | 1.9-2.3 % |
| heat deflection temperature | 63-71 ºC |
| Water Absorption After 24 Hours at Temperature 23oC | 15-19 mg |
| Density | 1.10-1.11 gm/cm3 |

Source : R A Mohammed [9]

Table 2. Mechanical properties of epoxy resin

| Properties | Unit | |
|---|---|---|
| Tensile strength | MPa | 68-80 |
| Deformation, ε | % | 5-7 |
| Bending Strength | MPa | 110-130 |
| modulus of elasticity | MPa | 2.9-3.2 |
| compressive strength | MPa | 110-130 |
| Impact energy, Charpy, | KJ/m2 | 30-50 |

Source : J. M. Petrović [10]

Table 3. Physical and mechanical properties of bisphenol resin

| Properties | Unit |
|---|---|
| Color of resin | Clear pale yellow |
| Density (km/m$^3$) | 1200 - 1250 |
| Viscosity at 250$^o$C (cps) | 550 |
| Tensile strength (MPa) | 11.14 |
| Modulus of elasticity (Gpa) | 0.48 |
| Bending strength (MPa) | 25.29 |
| Modulus of flexure (GPa) | 1.53 |
| Elongation (%) | 4.2 – 5.6 |
| Impact strngth (kJ/m$^2$) | 1.2 |
| Flash point ($^o$C) | > 2000 |

Source : M. Mittal and R. Chaudhary [11]

The next step in this study is to prepare the necessary equipment and materials. Once all the materials and equipment are available, the molding process for the specimens is carried out. The test composites are designed using waru bark fibers as the reinforcing material and three types of resin—epoxy, polyester, and bisphenol—as the matrix. The composite molding process is a crucial stage, as the outcome will determine the quality of the material testing and analysis.

In the composite preparation, the resin-to-fiber ratio is set at 70%, ensuring an optimal composition for testing. After the molding process is complete and the composite has dried in the mold, the material is removed and cut to the standard testing dimensions. Up to ten composite specimens can be produced from a single mold for material testing purposes.

The process of producing composite material test specimens is determined based on the ASTM D3039 standard, with the specimen shape as shown in Figure 2. Once the composites are produced, tensile testing is performed to evaluate their mechanical properties, and the test data are collected systematically. Each composite specimen is tested in stages and repeatedly to ensure accuracy and consistency of the results. After all the data are collected, the average values from the tests are calculated and analyzed. Based on this analysis, conclusions are drawn, and recommendations for the next steps in the research are made.

Figure 2. ASTM D3039 test specimen shape

In this study, resin serves as the matrix that binds the waru fibers, forming a strong and stable composite structure. Each type of resin has significant characteristics that influence the final properties of the composite. The three types of resin used in this study are epoxy, polyester, and bisphenol. While they share similar properties, the main difference lies in the specific application of each resin according to the requirements.

In addition to the resins, release wax is used as an important additive. This wax functions as a lubricant or anti-stick agent, facilitating the removal of the specimens from the mold without damaging the composite structure. The use of release wax ensures that the specimens remain in optimal condition for subsequent testing.

The preparation of test specimens is carried out using resin matrices, namely epoxy, polyester, and bisphenol. The composite molding process is a crucial step in material testing and result interpretation, as it produces material that meets the testing requirements, thereby improving the accuracy, efficiency, and quality of the tests. The resin-to-fiber ratio for composite fabrication is 70%:30%.

Before the molding process begins, the mold must be coated with release wax to facilitate the removal of the specimens after drying. Next, the resin and fibers are weighed according to the specified ratio and poured into the mold. Once the composite has dried in the mold, the specimens are removed and cut to the desired dimensions. Several composite specimens can be produced from a single mold for testing purposes.


Figure 3. MTS landmark servohydraulic tensile testing machine

Tensile testing in this study was conducted using the MTS Landmark Servohydraulic Universal Testing Machine. This machine is designed to measure the tensile strength of materials with high accuracy, allowing for the effective testing of composite specimens. With servohydraulic technology, the machine provides precise control over the speed and load applied during testing, ensuring that the results are consistent and reliable. The purpose of this tensile test is to evaluate the composite material's ability to withstand tensile forces before undergoing deformation or failure, which is one of the key mechanical properties tested in this study.

## RESULTS AND DISCUSSION

In this section, the results of the testing and analysis of the composite materials made using waru fiber and various types of resins as matrices will be presented. The results obtained from the tensile tests will be discussed in detail, covering the influence of resin type on the mechanical properties of the composites, including tensile strength, stiffness, and resistance to environmental conditions. This discussion will also relate the experimental results to existing literature and provide an interpretation regarding the potential use of waru fiber-based composite materials in manufacturing.

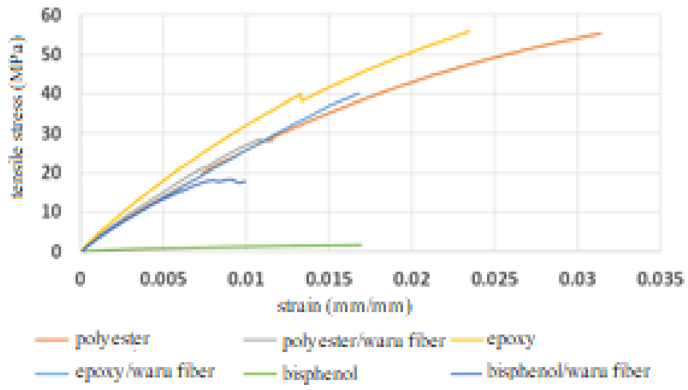


Figure 4. Strain relationship in several types of matrices

From Figure 4, the stress-strain relationship of the polyester, epoxy, bisphenol, polyester waru fiber, epoxy waru fiber, and bisphenol waru fiber specimens can be seen. The tensile strength for each is as follows: 55.828 MPa for epoxy resin, 55.416 MPa for polyester resin, and 1.669 MPa for bisphenol resin. For the composite materials, the tensile strengths are 39.947 MPa for epoxy waru fiber, 28.211 MPa for polyester waru fiber, and 17.907 MPa for bisphenol waru fiber. The maximum strength for each material is as shown in Figure 5 in the form of the following bar graph :

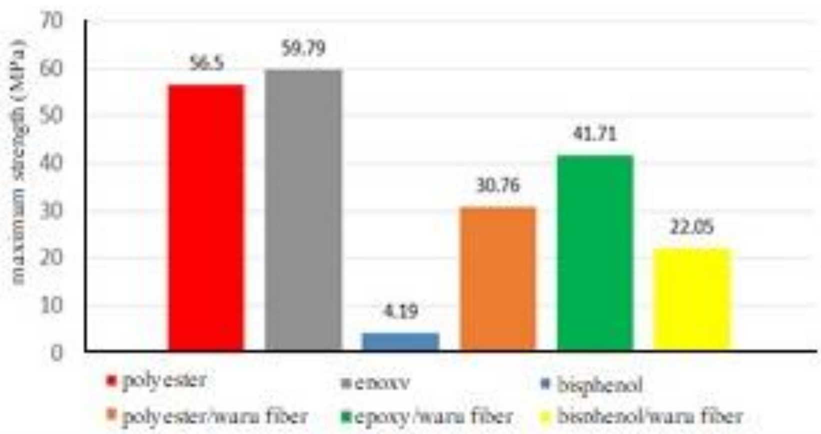


Figure 5. Maximum strength of each material

Meanwhile, the elastic modulus for each material is shown in Figure 6 below;

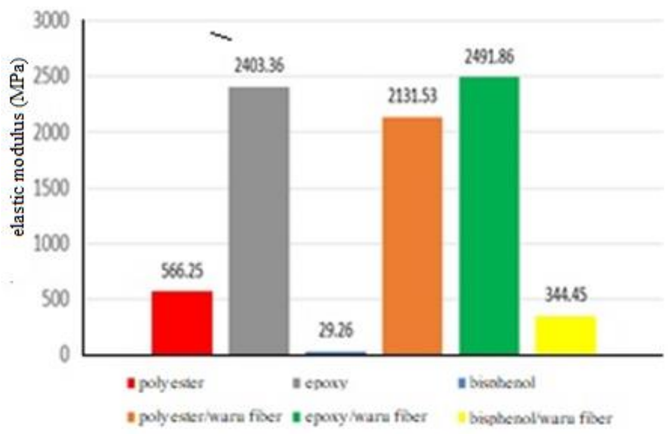


Figure 6. Elastic modulus of each material

The elastic modulus of each material is 566.25 MPa for polyester, 2403.36 MPa for epoxy, 29.26 MPa for bisphenol, while for the composite materials, the values are 2131.53 MPa for the polyester matrix composite, 2491.86 MPa for the epoxy matrix composite, and 344.45 MPa for the bisphenol matrix composite.

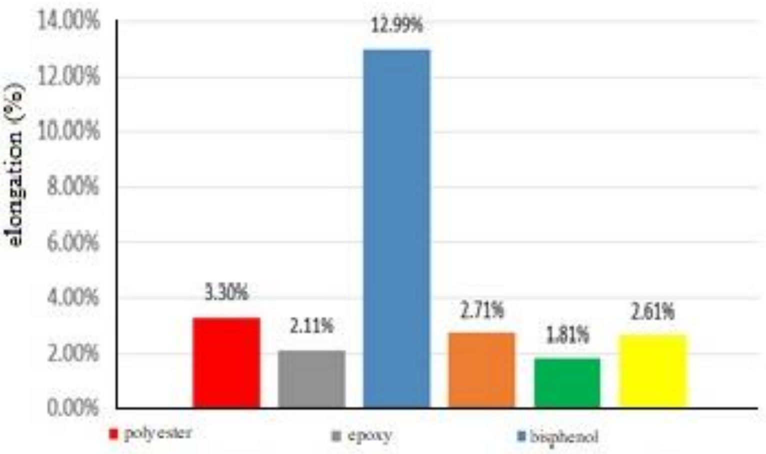


Figure 7. Maximum strain of each material.

Based on Figure 7, it shows that the strain occurring in each composite material is different. The figure indicates that the highest strain is observed in the bisphenol material, with a strain of up to 12.99 (%). Among the three types of resins used or the six types of materials tested, the lowest strain is found in the epoxy fiber waru composite material, with a strain of 1.81 (%).

The data obtained from the test results indicate that the strength of the composite material is lower compared to the strength of the pure resin used as the matrix. The elastic modulus behaves differently; it is significantly higher for the composite material when compared to the elastic modulus of the pure resin used as the matrix material. This can be confirmed by the strain occurring in each test material, where the strain is lower compared to the pure resin.

The elastic modulus showed an increase: the polyester matrix composite material exhibited a 2.76 times increase in the elastic modulus of polyester, the epoxy matrix composite material showed a 0.037 times increase in the elastic modulus of epoxy, and the bisphenol matrix composite material showed a 10.77 times increase in the elastic modulus of bisphenol. The lowest reduction in strain was observed in the epoxy matrix composite material, which was 0.3 times the strain of the epoxy

Of the three types of matrices used, namely polyester, epoxy, and bisphenol, only the bisphenol matrix composite material exhibited an increase in strength, a decrease in elastic modulus, and a reduction in strain. Meanwhile, the polyester matrix and epoxy matrix composite materials showed a decrease in strength compared to the strength of the matrix material itself. Therefore, bisphenol matrix material is more suitable for use with waru fiber reinforcement without treatment or surface modification.

## CONCLUSION

The discussion on the composite materials with polyester matrix, epoxy matrix, and bisphenol matrix leads to the following conclusions:

1. The mechanical properties of the polyester matrix composite material are a strength of 30.76 MPa, an elastic modulus of 2131.53 MPa, and a strain of 2.71%. The epoxy matrix composite material has a strength of 41.71 MPa, an elastic modulus of 2491.86 MPa, and a strain of 1.81%. The bisphenol matrix composite material has a strength of 22.05 MPa, an elastic modulus of 344.45 MPa, and a strain of 2.61%.
2. The matrix material that is most suitable for waru fiber reinforcement is bisphenol resin, which increases the composite material strength by 4.26 times the strength of the matrix material. In contrast, the polyester and epoxy matrix materials show a decrease in strength or are lower than the strength of their respective matrix materials.

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