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Feasibility of Utilizing Recycled Carbon and Polyester Composites for Ship Hull Construction: An Experimental Approach

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Abstract **- The increasing environmental concerns surrounding fast fashion and the accumulation of waste materials have prompted a need for alternative, sustainable materials in various industries. This study aims to investigate the feasibility of utilizing recycled carbon and polyester composites for ship hull construction. An experimental approach is employed, focusing on tensile testing of material specimens, including carbon fiber and polyester, in accordance with ASTM D3039 standards. The method involves creating composite specimens, subjecting them to tensile tests, and analyzing the results through standard deviation to compare tensile strength and maximum load. The results demonstrate that the composites exhibit suitable mechanical properties for ship hull construction, with polyester showing an insignificant difference compared to carbon fiber composites. These findings provide a reference for future applications in shipbuilding, contributing to environmental sustainability efforts by repurposing waste materials.**

Keywords - Composite, Material, Manufacture, Experimental, Hull

I. INTRODUCTION

At this time, the fast fashion trend is a global issue that is often raised and discussed. Fast fashion refers to the availability of fashion that responds quickly to the latest fashion trends along with product availability [1] .Globally, 80 billion new pieces of clothing are purchased every year, which means that this accounts for 1.2 trillion dollars per year for the global fashion industry [2]Several types of fabric are used as the basic material for clothing, one of which is polyester [7]. This material is often used in the production of sportswear [8]. Polyester fiber is the most permeable and has the highest value water vapor permeability compared to cotton fiber and cotton blend and polyester fiber [3]. In some situations, thermal comfort that depends on the permeability of water vapor cannot be achieved only through the human body's ability to regulate temperature. In extremely cold or hot weather conditions, clothing is needed to help regulate body temperature by holding or allowing heat exchange between the body and the environment [4]. In the study conducted by Monika Bogusławska et al., polyester fibers showed better physiological response and performance among athletes compared to cotton and cotton-polyester blends. Therefore, the results can serve as a basis for the selection and processing of polyester in garment production. However, the effective selection in garment production following the current fast fashion trends can pose a threat to the environment in the future. Unsold clothing production in the industry can become solid waste, clogging rivers, greenways, and parks. This undoubtedly creates the potential for additional environmental health hazards in LMICs that are less robust [9]. The emergence of this trend has become a new problem in the balance of the ecosystem and the environment [6]. It should also be noted that polyester is a synthetic material often used in the textile industry or clothing production [10]. About two-thirds of all textile fibers are artificial, and more than half of these are made from polyester oil, which has grown by 25 percent in the last 20 years [5]. Polyester is made from synthetic polymers derived from chemicals such as ethylene glycol and terephthalic acid, or it can be considered polyester fiber [11]. Polyester is one of the matrix components frequently used in composite experiments [13].

Several industrial sectors have shifted to using composite materials extensively due to their long lifespan and excellent operational characteristics compared to other materials. [6]. Mall-volume ships have begun transitioning from wooden materials to fiberglass-reinforced plastic (FRP) [14]. The material is composed of a polymer matrix reinforced with fibers. This research offers a novel contribution to the field by focusing on the experimental validation of recycled carbon and polyester composites for ship hull applications. Unlike previous studies, which primarily

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concentrate on virgin composites, this work explores the use of recycled components, aligning with global sustainability goals and addressing the growing environmental concerns related to polyester waste. By assessing the tensile strength, modulus of elasticity, and other mechanical properties, this study provides critical insights into the feasibility of utilizing recycled composites in marine environments, thus contributing to more sustainable shipbuilding practices.

II. METHOD

A. Materials and Tools

The researchers conducted an experimental study to determine the feasibility of the proposed composite material by comparing it with several other material specimens. This experiment used several constituent materials, such as carbon fiber, fiber mat, and polyester.

B. Experiment Procedure

Before implementing the composite innovation on an actual ship, the material must undergo testing according to the applicable international standard, ASTM D 3039. The material is formed with various variations, with the main comparison being carbon fiber. This is because the primary material has strong properties, is lightweight, and has already been widely implemented in ships. The material variations are shown in Figure 1, where the applicable standards form the test materials.

Carbon fiber typically holds a tensile strength ranging between 3,500 MPa to 5,650 MPa, with a modulus of elasticity around 230 GPa and a density of approximately 1.75 g/cm³ [18]. Carbon fiber mats, often used in composite applications, generally have a lower tensile strength of around 1,000 to 2,500 MPa, with a modulus of elasticity between 70 to 100 GPa, and maintain a similar density of about 1.75 g/cm³ [18].

For composites made from used polyester reinforced with carbon fibers, the tensile strength typically falls within 300 to 600 MPa, depending on the carbon content, with a modulus of elasticity ranging from 10 to 50 GPa. The density of these materials is usually slightly higher than regular polyester composites, approximately 1.5 to 1.7 g/cm³ [18].

Lastly, used polyester alone, without carbon reinforcement, generally shows a tensile strength of 50 to 70 MPa, a modulus of elasticity around 3 to 6 GPa, and a density of approximately 1.4 g/cm³ [18]. These properties are crucial when assessing the suitability of these materials for applications such as shiphull construction.

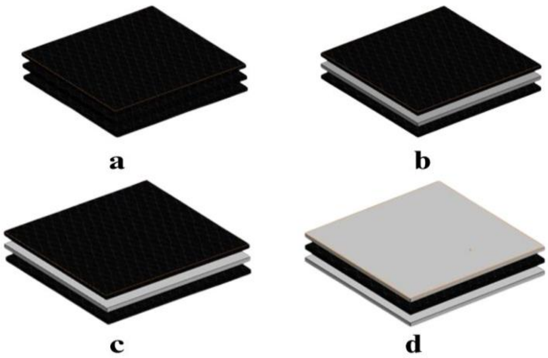

Figure 1. Carbon fiber (a) Carbon-Fibermat (b) Carbon-Usedpolyester (c) Used Polyester -Carbon (d)

Several steps are involved in the treatment and execution of the experiment, as shown in Figure 2. This includes the creation of specimens using a material mold made with a square frame measuring 25 cm x 25 cm, made of plywood. The mold is composed of layers of wood fibers, and the material specimen is pressed under high pressure.

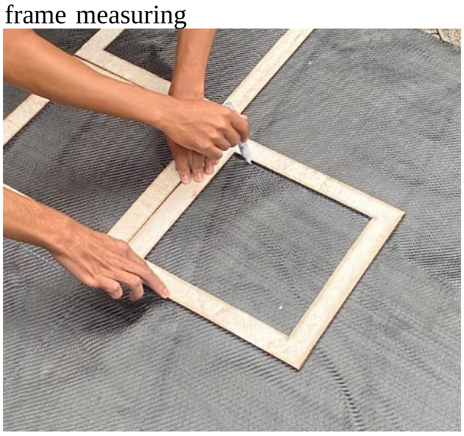

Figure 2. Preparation of test material specimens

C. Test Instrumentation

The tensile testing process on composite materials is carried out according to the ASTM D 3039 standard, "Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials." The test is carried out to obtain the tensile test value. The results obtained can determine the value of the material's characteristics or mechanical properties. The treatment and testing process are carried out according to the standards given in the laboratory.

Figure 3. Specimen Testing with Universal Testing Machine

D. Data Analysis

The author used a qualitative data analysis method in the experimental research conducted. The results obtained from the experiment were systematically, factually, and accurately described. The technique used aimed to measure and assess the relationships between variables by estimating the impacts that occurred and providing answers to the proposed hypotheses. Several data points were obtained in the Metallic Tensile Report, where each type of specimen was tested five times, and the results were collectively processed to achieve data averaging with standard deviation. The standard deviation is used to describe a data set or to carry out statistical tests, assuming that the data come from a population with a normal distribution [7]. The collected data will be analyzed or processed using the standard deviation, illustrating how much variation or dispersion exists within a data set. Standard deviation can be described as a measure of how far each value in a data set is from the average of that set.

Figure 4. Material Specimen

III. Results and Discussion

The data provided is descriptive and serves as a reference for future use. Several data points were obtained, including the maximum load. In the tensile test, the maximum load is defined as the maximum load that a material can withstand before failing or breaking during the tensile test. The tensile test is a mechanical test where a material sample is pulled until it breaks. The given data is descriptive, and the maximum load can be divided by the initial cross-sectional area to determine the maximum tensile strength or breaking strength.

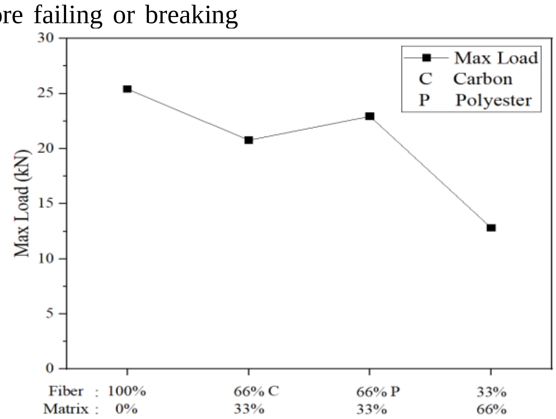

Figure 5. The comparison of Max load between materials

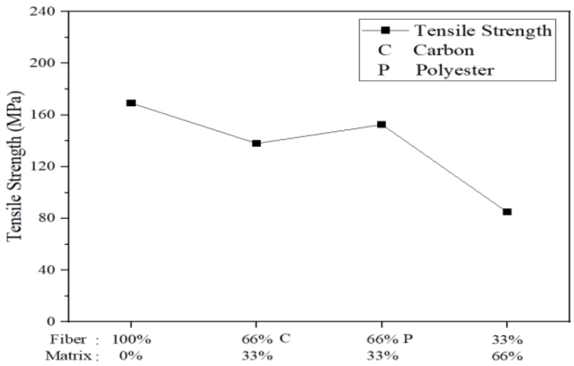

Figure 6. Comparison of Tensile Strength Between Materials

The tensile testing results reveal important insights into the mechanical properties of both virgin carbon composites and recycled polyester composites. Virgin carbon composites exhibited a tensile strength of 169 MPa and a maximum load of 25.42 kN, underscoring the material's high capacity for resisting tensile forces. In comparison, the recycled polyester composites demonstrated a slightly lower tensile strength of 152.5 MPa and a maximum load of 22.925 kN. Despite this reduction, the recycled composites still exhibited mechanical properties within the range required for ship hull construction.

The 10% difference in tensile strength between the virgin carbon and recycled polyester composites highlights the potential trade-offs when using recycled materials. However, the environmental and economic benefits of utilizing recycled composites mitigate this trade-off. The tensile strength of 152.5 MPa is still sufficient to meet many industry standards for marine applications, and the marginal reduction in mechanical performance can be compensated by strategic design modifications or layering techniques in ship hull construction.

After the data was collected from the tensile test results, the shipbuilding process was carried out using 66% carbon fiber and 33% polyester (c). The first phase of construction involved modeling the design of a trimaran-type ship with a width of 1.8 meters and a length of 5 meters. Resistance and stability analyses were conducted on the ship before production. Once the data and figures were obtained from the research using Rhino and AutoCAD applications, the next step was creating the mold design, in which the hull construction employed the molding method. A variation of wood mold construction, sometimes called a "plywood-shell mold," is occasionally utilized [8]. In the research, design, and production of this ship, the initial fabrication step was to create a positive mold using wood and plywood. The positive mold of the ship's hull followed the shape of the ship's body, adjusted to the line plan for each station. Before the lamination process using resin, fiberglass mat, woven roving (WR), catalyst, and aerosol powder, the mold was coated with mirror glass to facilitate the release of the final product from the mold. While this study demonstrates the feasibility of using recycled carbon and polyester composites for ship hull construction, several limitations must be addressed.

Furthermore, the maximum load values for both materials show that recycled polyester composites can endure substantial forces before failure. The recycled polyester's 22.925 kN max load, while lower than virgin carbon's 25.42 kN, demonstrates that it can still provide the necessary strength for structural components exposed to tensile stresses in marine environments. This slight reduction in max load is not expected to critically impact on the material's performance in typical ship operations, making recycled polyester composites a viable alternative to virgin materials, particularly when considering their sustainability advantages. On the other hand According to the regulations set by Biro Klasifikasi Indonesia (BKI) for ships made from fiberglass-reinforced plastics, the required material properties include a tensile strength of 98 N/mm², a tensile modulus of elasticity of 6.86 x 10^3 N/mm², a flexural strength of 150 N/mm², and a flexural modulus of elasticity of 6.86 x 10^3 N/mm² [17]. Once the figures and data for the composite material values are obtained, these values are compared to serve as a reference for determining whether this composite material can be implemented in the construction of ship hulls.

Firstly, the experiments were conducted under controlled laboratory conditions, which may not fully represent the complex environmental factors encountered at sea, such as UV exposure, saltwater corrosion, and extreme temperatures. Testing these materials in real-world marine environments would provide more robust data on their long-term performance.

Additionally, while the mechanical properties of the recycled composites meet current standards, future research should investigate methods to enhance fiber-matrix bonding, which can further improve tensile strength and resistance to cracking. Advanced computational simulations, such as Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA), could provide deeper insights into how these composites perform under dynamic marine conditions, including the impact of hydrodynamic forces on hull integrity. Exploring the scalability of recycling processes and the economic implications of integrating recycled composites in large-scale shipbuilding will also be key areas for future research.

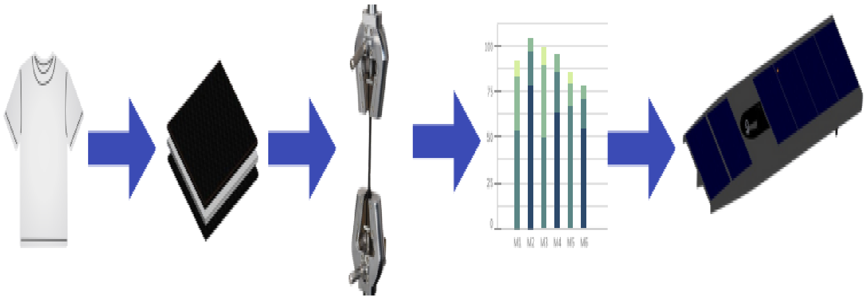

Figure 7. The Process of Implementing Composites on Hull

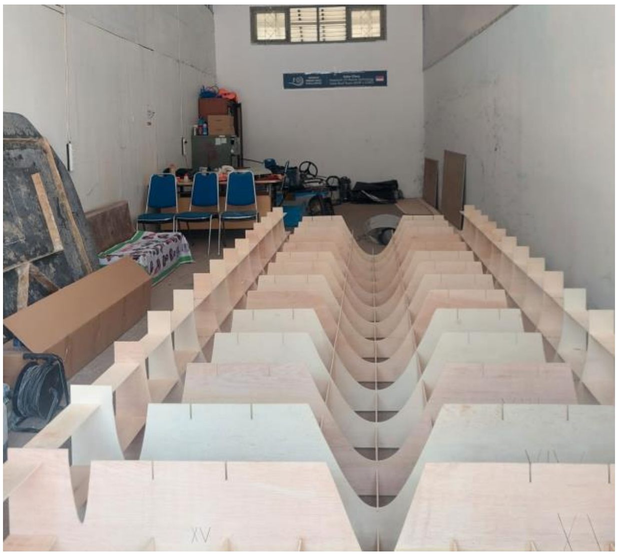

Figure 8. Hull Molding

Figure 9. Ship Hull Construction with Material Innovation

IV. CONCLUSION

The results of this study demonstrate that recycled carbon and polyester composites exhibit promising potential for use in ship hull construction. In the tensile strength tests, virgin carbon fiber composites recorded a tensile strength of 169 MPa and a maximum load of 25.42 kN. In comparison, recycled polyester composites exhibited a tensile strength of 152.5 MPa and a maximum load of 22.925 kN. Although the mechanical properties of recycled polyester composites are slightly lower than those of virgin carbon fiber, they still meet the required performance standards for non-critical marine applications.

The relatively lightweight nature of these composites, combined with their sufficient mechanical properties, makes them a viable option for reducing both material costs and the environmental footprint of ship construction. Using recycled composites aligns with global sustainability initiatives, particularly by reducing waste and promoting the circular economy within the shipbuilding industry.

Moreover, this research contributes to achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). By incorporating recycled materials, shipbuilders can reduce their environmental impact while maintaining the necessary mechanical performance for marine applications.

However, further research is needed to assess the long-term durability of these materials in real-world marine environments, particularly with respect to exposure to saltwater, structural fatigue, and other environmental factors. Optimization of composite formulations and additional testing under real-life conditions, such as exposure to varying water temperatures and UV radiation, should also be explored.

In conclusion, while recycled carbon and polyester composites may exhibit slightly lower mechanical properties than virgin carbon fiber, they present a sustainable and viable option for ship hull construction. This study provides a foundation for further exploration of these materials, paving the way for more sustainable and cost-effective solutions in the marine industry.

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