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Modulus of Rupture and Modulus of Elasticity in Recycling FRP

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***Abstract*— Fiber Reinforced Plastic (FRP) material has been widely used as a ship construction alternative to wood. FRP has many advantages such as lightweight material, easy maintenance, weather resistance, economical price, and shorter production time. FRP ship production is weak from the waste factor produced, such as production residue during shipbuilding, ship molds, and FRP shipwrecks. FRP waste can impact the environment, economy, and human health. These impacts include soil pollution, microplastics, skin diseases, and human respiratory disorders. FRP material tends to be burned by many shipyards but still leaves waste in the form of dust. FRP material is difficult to decompose and takes a long time to melt. One strategic effort to minimize the impact of FRP is to recycle FRP. This study aims to reduce FRP waste by making composite boards from FRP waste. The method used was experimental, involving the making of 12 specimens and testing the density, MOR, and MOE. Based on the results of the density value test, the average value obtained follows the JIS A 5905-2003 reference. The MOR and MOE values for each specimen do not comply with the Indonesian Classification Bureau (BKI) standards. In the ANOVA test calculation, no significant differences were obtained for MOR and MOE.**

Keywords— FRP waste, FRP composite, Modulus of Elastisity, Modulus of Rupture, Recycling FRP

I. INTRODUCTION[1]

Fiber Reinforced Plastics (FRP) is a material that is widely used in shipbuilding as an alternative to replace wooden ship materials. FRP material is included in the composite combination of synthetic resin and fibre [1]. FRP material has many advantages, such as being lightweight, easy to maintain, weather resistant, shorter production time, and prices tend to be more economical [2],[3],[4]. The use of FRP material in shipbuilding tends to be more accessible because it uses a ship mould that can be reused for the same size [5], so it can provide benefits for ship entrepreneurs [6]. Various traditional shipyards in Indonesia have used this FRP material. One of the traditional shipyards is UD Wahyu Asih Fiberglass. This shipyard can produce 15 FRP ships per month [7],[8],[9]. One of the traditional shipyards, UD Wahyu Asih Fiberglass, has used this FRP material. This shipyard can produce 15 FRP ships per month. The large production of FRP ships also has an impact on FRP waste.

FRP waste generally comes from the FRP shipbuilding process, FRP ship moulds, and FRP ships that are no longer used. This FRP waste is an inorganic waste that is difficult to decompose and can pollute natural conditions. FPB waste takes 30-50 years to melt in nature [10]. FRP waste handling at the UD Wahyu Asih shipyard is generally carried out by burning, and other FRP waste is still left in the form of ash from the burning residue. Burning waste in open locations can result in greenhouse gas emissions and air pollution [11]. The FRP waste-burning process generally requires high temperatures and heat to produce perfect combustion. The recorded temperature used to melt FRP is 2000°C [12].

The impacts of FRP waste can affect the environment, economy, and health. The impacts of FRP waste on the environment are non-biodegradability, microplastic pollution, landfill overflow and Energy-Intensive Production. Fibreglass is not biodegradable and can persist in the environment for hundreds of years,

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contributing to long-term waste accumulation in landfills. Over time, fibreglass can degrade into smaller particles, contributing to microplastic pollution in soil and water, which affects ecosystems and enters the food chain. As fibreglass waste increases, it strains landfill capacities, potentially leading to the need for new landfill sites, which disrupts natural habitats. The production and disposal of fibreglass require significant energy and resources, increasing the carbon footprint and contributing to climate change.

The Health impacts of FRP waste are airborne particles, skin irritation, and toxic chemicals. Airborne particles caused by cutting, grinding, or disposing of fibreglass can release fine glass fibres into the air, which can be inhaled. It poses respiratory risks, such as irritation, asthma, and even lung diseases, with prolonged exposure. Skin irritation from handling fibreglass can cause skin irritation and dermatitis, as the fine fibres can penetrate the skin. During production and disposal, fibreglass releases volatile organic compounds (VOCs) and styrene, which are hazardous to human health and contribute to air pollution. Selain itu, jika limbah tidak sempurna termusnakan, maka sisa limbah FRP akan menjadi timbunan sampah. Mengacu pada hal tersebut dibutuhkan suatu upaya untuk mengurangi limbah FRP. If the waste is not destroyed, the remaining FRP waste will become a pile of garbage. In this regard, an effort is needed to reduce FRP waste.

One effort to reduce FRP waste is through recycling. The results of recycling from FRP waste have been carried out by researchers, such as producing plastic pots [13] and making Wood Plastic Composite (WPC) [14]. These utilization efforts are a reference in the utilization of FRP waste. Through this reference, researchers aim to make composite boards from FRP waste at the shipyard and test the Modulus of Rupture (MOR) and Modulus of Elasticity (MOE). This composite board is reusable as a material on one part of the ship. The composite board is also reinforced by research into applying FRP composite boards, which can strengthen the structure of glulam beams for building construction [15]. Using FRP waste in composite boards is expected to be a solution to reduce FRP waste and as an appropriate product for fishing vessels.

II. METHOD

The experimental method used in this study utilizes FRP waste in manufacturing composite boards. The experimental method is carried out objectively and controlled to obtain a specific conclusion adjusted to the hypothesis [16]. This experimental design uses a Completely Randomized Design (CRD), as in Table 1. This study uses specimens that will be compared according to the JIS A 5905-2003 rules [17] and the reference standards of the Indonesian Classification Bureau (BKI) [18], especially for density, MOR, and MOE values

TABLE 1
TREATMENT GROUP WITH COMPLETELY RANDOMIZE DESIGN FOR ALL SPECIMENS

Group	Treatment		
	Density targets = 1 gr/cm² (P1)	Density targets = 1,3 gr/cm² (P2)	Density targets = 1,5 gr/cm² (P3)
1	P_{11}	P_{21}	P_{31}
2	P_{12}	P_{22}	P_{32}
3	P_{13}	P_{23}	P_{33}
4	P_{14}	P_{24}	P_{34}

MOR is one of the mechanical properties or strengths of a material. The MOR value can explain the ability to withstand loads or forces on the material, and the force that occurs can change the size or shape [19]. The MOE or flexural strength is a constant value when comparing stress and strain below the proportion limit [19]. The stress can be in the form of a distribution of force per unit area. The strain itself is a change in length per unit of material length. A significant MOE value means that the material is resistant to changes in shape.

The stages of the composite board specimen manufacturing process include the following:

1) FRP waste is cut using a grinder and crusher to make the waste smaller (Figure 1)
2) The FRP waste pieces are mixed with resin, with a ratio of 50%:50%.
3) FRP waste and resin mixture is inserted into an iron plate mould.
4) The mixture is compacted with a press machine for 2 hours (Figure 2).
5) When the mould is dry, the mould is removed.
6) Each specimen is marked to distinguish between specimens.
7) The sides of the specimen are smoothed using a grinder.
8) The specimens are tested using a UTM machine to obtain Mor and MOE values (Figure 3).

The specimens were made into boards measuring 25 cm (l) x 25 cm (b) x 1 cm (h). The number of specimens produced was 12 composite boards, with a composition of 4 specimens for the target particle board density of 1 g/cm³ (P1), 1.3 g/cm³ (P2), and 1.5 g/cm³ (P3). The board weight for P1 is 647 grams, the P2 is 865 grams and 964 grams for the P3.

Figure 1. FRP waste has been crushed

Figure 2. Pressing the FRP waste

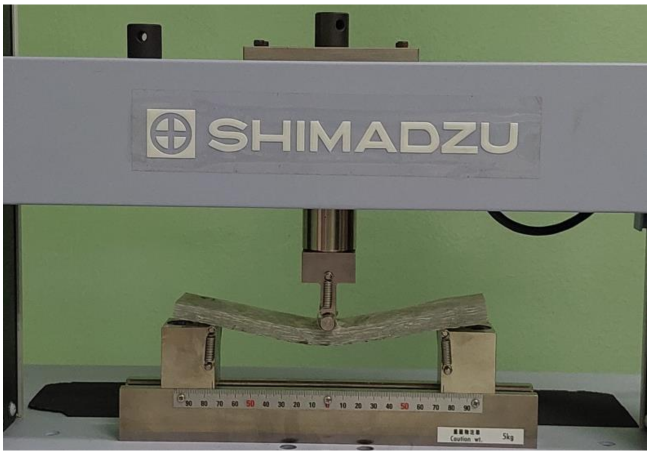

Figure 3. Testing the specimen with UTM

The density of the particle board uses the specimen reference standard in JIS A 5905-2003. The formula for obtaining the density value according to the reference from JIS A 5905-2003 is:

$$\text{Density } (\text{g/cm}^3) = \frac{\text{M}}{\text{V}} \quad (1)$$

while *M* is the weight of the particle board (g) and *V* is the volume of the particle board (cm^3). The reference value of

JIS A 5905-2003 for density must be greater than or equal to 0.8 g/cm3.

Specimen testing is carried out to obtain MOR and MOE using a Universal Testing Machine (UTM). The UTM machine uses the One Point Loading method with a 10 mm/minute loading speed. Referring to the JIS A 5905-2003 standard, MOE and MOR [21] testing is carried out with the following formula:

$$\mathrm{MOE} = \frac{\Delta PL^3}{4\Delta Ybh^3} \quad (2)$$

$$\mathrm{MOR} = \frac{3P\max L}{2bh^2} \quad (3)$$

While *MOE* is the Modulus of Elasticity (N/mm²) and *MOR* is the Modulus of Rupture (mm²), *Pmax* is the maximum load (N), and *ΔP* is the load below the proportion limit (N); *ΔY*for deflection at load P (mm); *L* for span distance (mm); *b* is the value of the width of the test sample (mm) and *h* is the value of the thickness of the test sample (mm).

In the BKI standard, the reference value for MOR must be greater than 152 MPA. In contrast, the reference value for MOE must be greater than 6350 MPA. The calculation results obtained in the density, MOR, and MOR tests are continued in the data processing process.

The data processing process is carried out using Microsoft Excel. The analysis methods used in the study are descriptive and comparative analysis. Descriptive analysis aims to describe the magnitude of the MOR and MOE values produced. The comparative analysis compares the values obtained with the JSI A5905-2003 and the BKI standards. Based on this analysis, composite boards' best density was obtained as a reference for ship construction materials from recycled FRP waste. Further testing is carried out to determine if the variance analysis (ANOVA) results significantly differ between treatments. The design model uses the formula:

$$Yij = \mu + \tau i + \varepsilon ij \quad (3)$$

Where *Yij* is the experimental response value of the i treatment and j replication; *μ* is the general average value; *τi* is the effect of the i treatment; and *εij* is the error of the i treatment and j replication.

III. RESULTS AND DISCUSSION

Composite boards were tested for density, MOR and MOE. Each specimen has a very diverse value. The density value test is listed in Figure 4, the MOR value in Figure 5 and the MOE value in Figure 6.

The density value (Figure 4) refers to the formula equation (1); the highest value is obtained at 0.89 gr/cm3 at P1, 1.07 g/cm3 at P2, and 1.23 g/cm3 at P3. The lowest density value is obtained at 0.75 g/cm3 at P1, 0.97 g/cm3 at P2, 1.01 g/cm3 at P3. The average density value of each treatment obtained a value of 0.8 g/cm3 in P1, 1.02 g/cm3 in P2 and 1.11 gr/cm3 in P3. Based on the density values obtained, the average value of each treatment follows the JIS A 5905-2003 reference. The high density of the composite board produced requires more particles to make a board of the same size. The highest density is due to the addition of adhesive to increase the density of the board. The final value of the composite density is influenced by the density of the raw material, drying of the raw material, the compaction process, the adhesive content, and additional materials in making the composite board [22].

Differently, when viewed based on the repetition of each specimen, in treatment 1, 2 samples were obtained that were still below the JIS A5905-2003 reference value. The value obtained does not follow the JIS A 5905-2003 standard reference for the Hard Density Fiberboard (HDF) category with a minimum density value of 0.8 g/cm3. Values below the HDF reference in JIS A 5905-2003 are included in the Medium Density Fibreboard (MDF) category, which is more than 0.35 g/cm3. The BKI reference has no minimum or maximum density value. This lower value can be caused by the uneven particle distribution during board compaction using a press machine. The low-density value of the board is caused by several particles being thrown away during the board-making process [23].

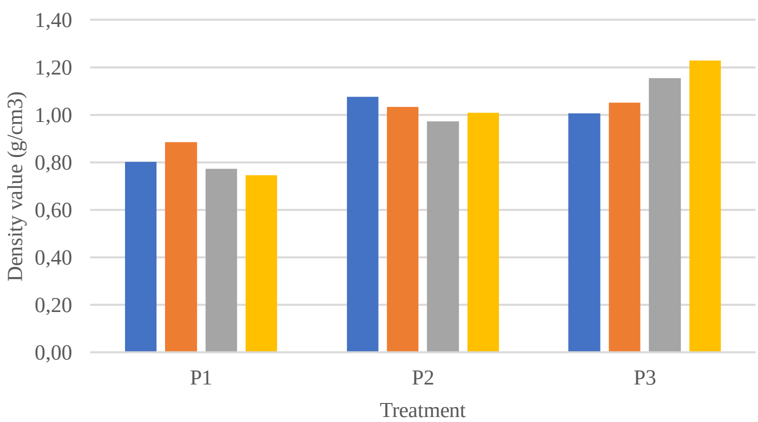

Figure 4. The Density of all spesicmens

The mechanical properties of a material can be reviewed based on the MOR value and MOE value. The MOR value indicates the value of the compressive strength of a material to withstand the load. MOR value testing is carried out until the material is damaged or broken. The MOR value on the specimen is presented in Figure 5.

The highest MOR value obtained was 11.93 MPA at P1, 23.84 MPA at P2, and 33.30 at P3. The lowest MOR value obtained was 1.77 MPA at P1, 10.62 MPA at P2, and 25.37 MPA at P3. The average MOR value for each treatment was 7.03 MPA at P1, 18.08 MPA at P2, and 28.87 MPA at P3. Compared with the BKI reference, the average MOR value of each specimen obtained did not comply with the BKI reference or was below 152 MPA. The higher density target can cause the low MOR value obtained compared to the BKI reference. Unlike the JIS A 5905-2003 reference, MOR has no minimum or maximum value requirement. The results of the variance analysis of the MOR value of the composite board are similar.

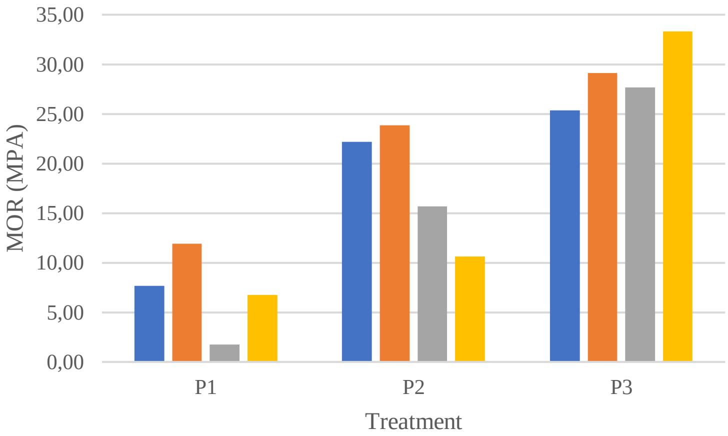

Figure 5. MOR value for all specimens

The MOE value indicates the resistance value of a material in maintaining its shape and stiffness. The MOE value indicates the elasticity value of the material being tested. If the resulting MOE value is high, the material is more elastic. The feasibility of material use can be known by detecting the mechanical properties of the composite product [24]. The results of the MOE value test are presented in Figure 6.

The highest MOE value obtained was 645.88 MPA at P1, 1749.62 MPA at P2, and 2198.27 at P3. The lowest MOR value was 273.65 MPA at P1, 744.97 MPA at P2, and 332.99 MPA at P3. The average MOR value for each treatment was 505.86 MPA at P1, 1124.84 MPA at P2, and 1436.59 MPA at P3. The JIS A 5905-2003 reference has no minimum or maximum criteria for the MOE value. Compared to the BKI reference, the average MOE value of each specimen obtained does not match the BKI reference or is below 6350 MPA. Low MOE values can be caused by fibre dimension conditions that do not support the board's ability to withstand loads, such as fibre length dimensions. The results of the analysis of the variance of the MOE values of the composite board were not significantly different.

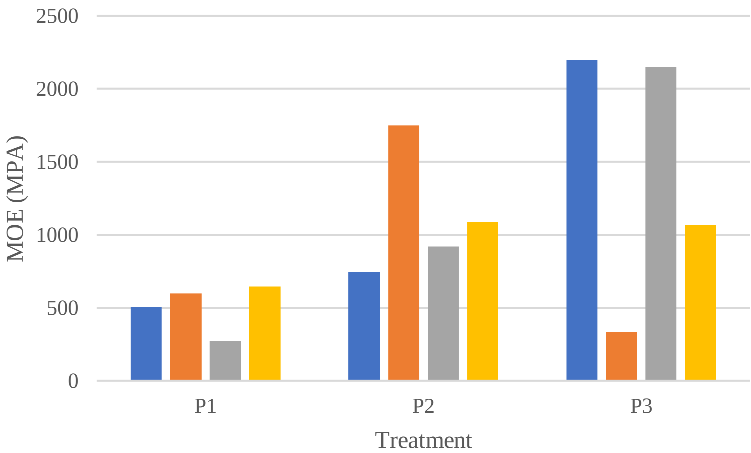

Figure. 6. MOE value for all specimen

Recycled FRP waste obtained density values that tend to follow the JIS A 5905-2003 reference, but the MOE and MOR values are under the BKI standard reference. This value is reinforced by FRP composites' weaknesses, such as relatively lower elastic modulus values and changes in mechanical properties over use time [25]. Other studies related to breaking stress and elasticity of FRP materials have obtained values that tend to be higher when compared to ferrous metal materials [26].

IV. Conclusion

Recycled FRP waste has various density, MOR, and MOE values. The highest density, MOR, and MOE values were obtained at P3 or a target density of 1.5 g/cm3. High values for density are 1.15 g/cm3, MOR is 33.30 MPA, and MOE is 2198.27 MPA. The magnitude of the target density value affects each specimen's density, MOR, and MOE values . The results of the comparative analysis based on the JIS A 5905-2003 reference obtained a higher average density value by the standard. The MOR and MOE values do not follow the BKI reference standard.

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