

Characteristic of FRP Shipbuilding Waste at the CV. Roni Marine Shipyard, Cilacap

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Abstract—The increasing production of fiberglass reinforced plastic (FRP) vessels in traditional shipyards contributes to higher waste generation. The lack of information regarding the quantity and characteristics of this waste makes it difficult to assess the sustainability of recycling FRP waste into composite boards. This study aims to estimate FRP waste based on vessel GT size and identify the physical forms of waste produced during the manufacturing process at the CV. Roni Marine Shipyard, Cilacap. The method used includes direct observation, vessel sampling by size, and classification and weighing of waste based on its type/shape. Results show that FRP composite waste in sheet/plate form accounts for the highest percentage (67%), followed by purse solid FRP composite waste (30%), and impure solid FRP composite waste (3%). The average amount of FRP waste generated per 1 Gross Tonnage (GT) of a vessel is 2.73 kg/GT. The highest amount of waste was produced during the frame installation stage. These findings are important for improving waste management efficiency and supporting the recycling of FRP waste into value-added products such as composite boards.

Keywords—FRP shipyard, FRP shipbuilding residual waste, FRP waste recycling.

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I. INTRODUCTION

The increasing production capacity in Indonesia's capture fisheries sector has directly led to a higher demand for fishing vessels, particularly those constructed from Fiberglass Reinforced Plastic (FRP). FRP has been widely selected as a primary material for fishing vessel construction due to its effectiveness and efficiency [1]. According to [2], many vessels in both the commercial and fisheries sectors have transitioned to FRP composites as an alternative to traditional materials such as wood and steel. Furthermore, the fishing vessel procurement assistance program initiated by the the Ministry of Marine Affairs and Fisheries (MMAF), Republic of Indonesia during the 2016-2017 period resulted in the distribution of approximately 3,325 units [3]. Notably, all assisted fishing vessels, ranging from less than 5 GT to 30 GT, were constructed using FRP materials [4].

Vessels made of FRP materials offer several advantages, including lighter weight, easier maintenance, resistance to environmental conditions, shorter production time, and greater cost efficiency compared to wood or metal, particularly for small-scale vessels [5]. However, the increasing production of FRP-based vessels has led to environmental concerns related to the generation of waste. FRP waste is categorized as

inorganic waste that requires a long time to decompose, as it is not naturally biodegradable. The accumulation of such inorganic waste has the potential to contaminate soil, thereby reducing soil quality and limiting its usability for agricultural or other purposes [6]. On a broader scale, fiber-based composite waste such as FRP exhibits high chemical stability, making it highly resistant to natural degradation processes. Therefore, more sustainable management approaches are required, such as recycling and material reuse strategies [7][8].

Based on previous research [9], one of the shipyards, UD Wahyu Asih, located in Kebumen Regency, attempts to reduce waste generated from FRP vessel manufacturing by incineration. However, the combustion of FRP waste produces smoke containing hazardous chemical substances and leaves solid residues in the soil [10]. These conditions may adversely affect both the environment and human health. The environmental impacts include air, soil, and water pollution. According to [11], contaminants from plastic and resin materials that infiltrate the soil can reduce soil functionality due to degradation processes and increase the concentration of heavy metals such as zinc (Zn), which negatively affects plant growth. This condition indicates that commonly used waste management practices, such as burning and landfilling, still have limitations as they potentially cause environmental pollution and have not been able to optimally reutilize materials that still possess economic value [12][13].

The large amount of FRP waste generated has the potential to cause economic losses for shipyards. In addition, FRP waste, particularly spilled resin, can lead to respiratory disorders [4]. Based on these considerations, it can be concluded that FRP waste remains a critical issue that poses risks to both living organisms and the surrounding environment, thus requiring proper management.

According to [15] efforts have been made to reduce waste from FRP shipbuilding processes by recycling it into composite boards. The results indicate

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that this method is relatively effective and efficient in supporting FRP waste management. However, this success raises new questions regarding the consistency of the effectiveness and efficiency of recycling FRP waste into composite boards. This is due to the lack of adequate information regarding the potential volume of FRP waste generated from shipbuilding processes. This limitation makes the sustainability of utilizing FRP waste as a raw material for composite boards questionable. If recycled FRP-based composite boards can be widely utilized in the future, their business feasibility must be carefully considered, particularly in terms of raw material availability.

Several previous studies have mainly focused on the utilization and recycling of FRP waste into value-added products. However, information regarding the quantity, characteristics, and sources of FRP waste generated during shipbuilding activities remains limited. Therefore, this study contributes by estimating FRP waste generation based on vessel Gross Tonnage (GT) and identifying waste generation at different stages of shipbuilding activities in a traditional shipyard. In addition, this study provides insight into the dominant characteristics of FRP waste generated during vessel construction processes.

The importance of assessing the availability of FRP waste is supported by previous studies that have shown that recycled composite materials still possess relatively good mechanical properties, making them suitable for use as alternative materials in various engineering applications [16][17]. Furthermore, FRP waste processed into fine particles or short fibers can be used as a reinforcing component in construction materials, such as concrete and composite panels, and has been proven to improve certain mechanical properties [18].

Therefore, this study was conducted to quantify and identify the amount and types of waste generated from shipbuilding activities. The obtained data can be further utilized to analyze the efficiency of FRP material usage in FRP shipbuilding. A previous study [19] conducted at the Bulukumba shipyards reported that approximately 14.47% of wood materials was wasted during the shipbuilding process, indicating inefficient material utilization. It is therefore hypothesized that a similar condition may also occur in FRP-based shipbuilding carried out in traditional shipyards.

The results of this study are expected to provide essential information supporting the sustainability of FRP waste recycling into composite boards, as well as serve as a basis for evaluating the efficiency of shipbuilding in traditional shipyards. Furthermore, successful FRP waste recycling efforts are anticipated to contribute to recommendations for effective and efficient methods for reducing FRP waste generated during shipbuilding activities.

II. METHOD

This study was conducted at the shipyard CV (*Commanditaire Vennotschaaap*) Roni Marine from April 2026. CV Roni Marine is located in Cilacap Regency, Central Java, and is a traditional shipyard

specializing in the construction of FRP-based vessels. The shipyard has a production capacity of approximately 5-25 FRP vessels per month. Its products have been widely utilized by fishermen across Java, Sumatra, Bali, and Lombok. In addition, CV. Roni Marine was involved in the government-assisted FRP vessel construction program organized by the Ministry of Marine Affairs and Fisheries (MMAF) in 2017. The equipment used in this study included a camera for documenting the forms of waste, a crane scale, and a measuring tape for determining the dimensions of the objects.

A. Research Procedures

This study was conducted in three stages. The first stage involved observing the FRP vessel construction process at the CV. Roni Marine shipyard Cilacap, to measure the principal dimensions, calculate the vessel's Gross Tonnage (GT), determine the number of vessels produced, quantify waste generated per vessel, identify the physical forms of the waste, and determine the amount of waste generated at each stage of the construction process. The second stage involved sampling all vessels under construction with a capacity of less than 3 GT, totaling 10 units, consisting of 4 vessels with a length overall (LOA) of 9 m, 5 vessels with an LOA of 9.5 m, and one vessel with an LOA of 11 m. From each LOA group, one vessel was randomly selected to obtain more detailed information regarding the types and physical forms of FRP waste generated during the construction process. The collected data were then processed by classifying the FRP waste based on its type (liquid or solid) and physical form. The final stage involved weighing the waste and analysing the processed data to determine the weight of waste generated per GT of the vessel during the FRP vessel construction process.

B. Data Analysis

The data analysis method employed in this study is descriptive analysis. This method is used to systematically, factually, and accurately describe observational data. Through descriptive analysis, the collected data can be presented appropriately and in a manner that is easy to understand. The data were obtained from samples of FRP waste generated during fiberglass shipbuilding at CV. Roni Marine shipyard. In this sampling-based study, descriptive analysis was applied to explain the indications observed in the data and to provide an overview of the physical characteristics and volume of each type of FRP waste produced. In addition, the analysis was conducted by relating the volume of waste generated to vessel size expressed in terms of the Cubic Number (CUNO). The CUNO is calculated as the product of the vessel's overall length, breadth, and depth, thereby providing an overview of the relationship between vessel dimensions and the amount of FRP waste generated during the production process.

III. RESULTS AND DISCUSSION

A. Shape and Principal Dimensions of FRP Vessels

The CV. Roni Marine shipyard has several vessel molds with various principal dimensions, which are

adjusted according to fishermen's requirements. The shipyard is trusted to manufacture FRP vessels in accordance with the specifications, operational practices,

and local water conditions of fishermen, thereby ensuring optimal performance during operation.

Table 1 presents the average principal dimensions of the three vessel groups.

TABLE 1.
MAIN DIMENSIONS OF THE VESSEL

Vessel Group Based on LOA (GT)	Average Main Dimensions of the Vessel (m)			Average Ratio of the Main Dimensions of the Vessel		
	LOA	B	D	L/B	L/D	B/D
9 m (1.24 GT)	9.5	1.1	0.68	8.63	13.97	1.61
9.5 m (1.28 GT)	9	1.2	0.68	7.50	13.23	1.76
11 m (2 GT)	11	1.3	0.68	8.46	13.75	1.62

Based on Table 1, vessels produced by CV. Roni Marine shipyards have an LOA ranging from 9 to 11 m. According to [20], fishing vessel design must be adapted to the operational method of the fishing gear used. Interview results indicate that the vessels produced by CV. Roni Marine generally utilize gillnets, which are categorized as static gear. Therefore, the main dimension ratios of the vessels are compared with the reference values for static gear as proposed in [21].

The relationship between vessel size and its operational characteristics can be analyzed through the main dimension ratios, which reflect stability, maneuverability, loading capacity, and resistance [22]. According to [23], the L/B ratio is used to analyze resistance and vessel speed, the L/D ratio represents

longitudinal strength, and the B/D ratio indicates stability and resistance characteristics.

In general, as shown in Table 1, the L/B, L/D, and B/D ratios of the three vessel groups fall within the reference range for static gear according to [24]. The L/B and L/D ratios tend to approach the upper limit, indicating relatively low resistance but less optimal longitudinal strength. Meanwhile, the B/D ratio is within the mid-range, suggesting a moderate level of vessel stability.

In addition to comparing the main dimension ratios with the reference values for static gear, vessel volume was also compared using the Cubic Number (CUNO), as presented in Table 2.

TABLE 2.
COMPARISON OF VESSEL VOLUME WITH CUNO

Vessel Grouping based on LOA (GT)	Vessel volume (m ³)	CUNO (m ³)	Vessel volume ratio/CUNO
1.24 GT	4.97	7,1	0.7
1.28 GT	5.14	7,34	0.7
2 GT	8	11,44	0.7

Table 2 show that the ratio of vessel volume to CUNO is identical for all three vessel groups, with a value of 0.7. This indicates that the vessels share a similar hull form.

In addition to having comparable principal dimensions and hull forms, the three vessel groups also exhibit similar overall geometries, as illustrated in Figure 1.



Figure 1. FRP vessels produced by CV. Roni Marine shipyard: (a) vessel with a size of 1,24 GT, (b) vessel with a size of 1,28 GT and (c) vessel with a size of 2 GT

Figure 1 shows that all three vessel groups have a U-bottom hull form, characterized by a bottom structure resembling the letter “U”, thereby providing better

stability when operating in rough sea conditions. This hull form generally has a high block coefficient (C_b), indicating a greater cargo-carrying capacity [25]. The

vessel volume-to-CUNO ratio of 0.7 for all three vessel groups suggests that vessels produced by CV. Roni Marine have a relatively large-cargo-carrying capacity.

However, the relatively high L/B ratio indicates that the vessels produced by CV. Roni Marine have a slender hull form and are therefore generally equipped with outriggers. According to [26], outrigger vessels typically have a B/D ratio ranging from 1.36 to 2.02. This is consistent with the data presented in Table 1, where the B/D ratio of the three vessel groups ranges from 1.61 to 1.76. A relatively low B/D ratio indicates lower inherent stability, and the use of outriggers may increase drag, thereby reducing vessel speed [27][28].

In addition to the hull form, the bow shape also plays an important role in determining sailing performances. Vessels produced by CV. Roni Marine are equipped with a raked bow design. This bow form is characterized by a stem that is inclined forward [29]. Previous studies [30] have shown that vessels with a raked bow exhibit better pitching performance than those with a spoon bow design.

The shipbuilding process at CV. Roni Marine employs the hand lay-up method, an open molding technique in which resin is manually applied to the reinforcing fibers and evenly distributed using rollers or brushes. The lamination process is carried out twice until a thickness of approximately 1.5 cm is achieved. This method offers several advantages, including ease of application and suitability for large, low-volume components [31]. Furthermore, traditional fishing vessels from Cilacap are typically decorated with bright colors and distinctive patterns that reflect the region's maritime cultural identity.

B. Vessel Construction Procedure

The FRP shipbuilding procedure at CV. Roni Marine shipyard in Cilacap consists of four main stages. The first stage is preparation, which includes mold inspection, workspace cleaning, and the preparation of materials and equipment. The FRP mold is cleaned and

polished using miracle gloss to facilitate easy release from the vessel model [32]. The second stage is hull fabrication, which begins with attaching the design template and vessel name onto the hull surface. This is followed by the application of a pigmented layer consisting of pigment, resin, aerosil increases the viscosity and strength of the resin, and the catalyst accelerates the curing process [33][34]. After the pigment layer had dried, the process continues with lamination using Chopped Strand Mat (CSM) 300 and Woven Roving (WR) 600 to improve the tensile and compressive strength as well as the structural integrity of the vessel. The number of laminate layers varies depending on the section, with three layers applied to the hull and six layers applied to the sheer. The next stage is the installation of frames. The frames function as structural supports for the hull, maintain the hull form, and support the deck beams to preserve structural stability [35]. The frames are installed transversely using a sandwich construction system with wood as the core material and are bonded using a mixture of talc and resin to prevent displacement. After the frame installation is completed, an additional lamination process is carried out to cover all frames, with varying numbers of layers applied to the hull and sheer sections. The final stage is finishing, which aims to refine and improve the previously formed structure [36]. At this stage, a mixture of pigment, resin, aerosil, and catalyst is applied in smaller quantities than those used during hull fabrication to improve surface smoothness and provide additional protection. Upon completion of all stages, the FRP vessel is ready for delivery to the customer.

C. Material Requirements

In the construction of FRP vessels, various primary materials are utilized to form a structure that is strong, lightweight, and resistant to corrosion. Based on the observation of the types and quantities of FRP materials used by CV. Roni Marine shipyard, the data are presented in Table 3.

TABLE 3.
THE TYPES AND TOTAL AMOUNTS OF MATERIALS USED FOR EACH VESSEL GT SIZE

Type material	Vessel Grouping based on LOA (GT)		
	1.24 GT (LOA 9.5 m)	1.28 GT (LOA 9 m)	2 GT (LOA 11 m)
Yukalac 157 resin	100 kg	120 kg	289 kg
CSM300	40 kg	48 kg	52 kg
WR600	15 kg	20 kg	27 kg
Mepoxe catalyst	2.5 kg	4 kg	6.1 kg
Color pigment	5 kg	5 kg	5 kg
Aerosil	1 kg	1.5 kg	2 kg
Talc	10 kg	10 kg	12 kg
Miracle Gloss	0.4 kg	0.5 kg	0.8 kg

Based on Table 3, the material requirements for FRP shipbuilding generally show an increasing trend in material consumption as the vessel's GT increases. The most significant increase is observed in the use of Yukalac 157 resin, which increases by 189%, from 100 kg to 289 kg. Other materials, including CSM300, WR600, Mepoxe catalyst, aerosil, talc, and miracle gloss, also show increased consumption. However, one material that remains unchanged is the color pigment.

These findings indicate that the quantity of most materials increases with vessel size, whereas the amount of color pigment remains constant.

Furthermore, based on observations conducted during the shipbuilding process at the CV. Roni Marine shipyard, all materials were completely utilized. This condition reflects the effective and efficient use of materials by the workers, resulting in no remaining or wasted materials. A. solid waste that may pose environmental risks if not properly managed.

a. Waste Characteristic

This FRP shipbuilding processes two types of waste: pure material waste and FRP composite waste. Pure material waste originates from unused raw materials that have not been mixed, whereas FRP composite waste consists of materials that have already

been combined and are no longer reusable. Based on field observations conducted at the CV. Roni Marine shipyard, no pure material waste was identified due to efficient material utilization. In contrast, the FRP composite waste is presented in Figures 2 and 3.



Figure 2. FRP composite waste in solid form: (a) pure, (b) impure



Figure 3. FRP composite waste in form of sheets/plate

Based on the observational results, FRP composite waste can be classified into two forms: solid FRP composite waste (Figure 2) and sheet/plate FRP composite waste (Figure 3). Solid FRP composite waste consists of pure solid waste (Figure 2a), which originates from the hull fabrication and finishing stages and comprises a mixture of color pigment, aerosil, resin, and catalyst. In contrast, non-pure solid waste (Figure 2b) is generated during frame installation and consists of FRP-coated PVC pipe fragments. Sheet/plate FRP composite waste is generated during the lamination process in both hull fabrication and frame installation stages. This waste

consists of laminated material scraps, such as CSM300, WR600, and resin mixed with a catalyst. The lamination process is carried out twice with different numbers of layers. For vessels with a length overall (LOA) of 9-9.5 m, the total number of laminate layers is 18, whereas vessels with an LOA of 11 m have 22 layers.

b. Composition of Waste Types and Waste Forms in Relation to The Total Amount of Waste and Vessel GT.

The results of the weight measurements of each form the weight of each form of FRP waste are presented in Table 4.

TABLE 4.
WEIGHT OF EACH WASTE FORM ACCORDING TO VESSEL GT

Vessel Grouping based on LOA (GT)	Weight of each form of waste (kg)		
	Solid FRP Composite Waste (pure)	Solid FRP Composite Waste (impure)	Sheet/Plate-Shaped FRP Composite Waste
1.24 GT	1.06	0.13	2.11
1.28 GT	1.13	0.13	2.52
2 GT	1.45	0.17	3.54
Total Weight of Waste for Each From (kg)	3.64	0.43	8.17

D. Waste Generated During the FRP Shipbuilding Process

The FRP shipbuilding process generates Based on Table 4, each form of waste exhibits a different total weight. The largest amount of FRP waste was generated in the form of sheet/plate-shaped composite waste, with a total weight of 8.17 kg. Referring to Table 4, differences in waste weight were observed among the various vessel GT categories. As

vessel GT increases, the amount of waste generated also increases. This increase is attributed to the greater material requirements associated with larger vessel sizes. As more materials are used, the amount of FRP waste generated also increases. In addition to measuring the weight of each waste form, the proportion of each waste form relative to the total waste weight was also calculated, as presented in Figure 4.

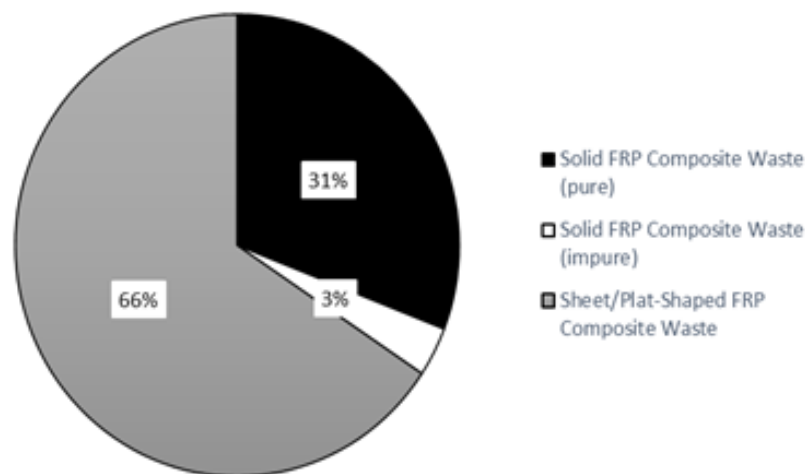


Figure 4. The weight composition of each type of waste relative to the total waste weight

Figure 4 shows that sheet/plate-shaped FRP composite waste constitutes the dominant waste form, accounting for 66% of the total waste weight (8.17 kg) (Table 4). This waste is generated during the hull skin manufacturing process and the frame installation stages. In contrast, the smallest proportion is solid (non-pure) FRP composite waste, which accounts for 3% of the total

waste weight (0.43 kg) (Table 4). This waste consists of PVC pipe fragments coated with FRP composite.

Furthermore, Table 5 presents the results of the calculation of waste generation per GT or vessel volume. This information can be used as a reference for estimating the amount of waste that will be generated by a vessel based on its GT or overall weight.

TABLE 5.
AMOUNT OF WASTE PER GT OF VESSEL

Vessel Grouping based on LOA (GT)	Σ Waste (kg)	Vessel GT	Vessel Weight (kg)	Σ Waste/Vessel GT (kg/GT)	Σ Waste/Vessel Weight (%)
9 m (1.24 GT)	3.30	1.24	5,098.56	2.66	0.06
9.5 m (1.28 GT)	3.77	1.28	5,269.32	2.95	0.07
11 m (2 GT)	5.16	2	8,208.20	2.58	0.06
Average				2.73	0.20

Based on Table 5, the amount of waste generated per GT is relatively similar across the three vessel groups. Although a slight increase is observed in the 1.28 GT vessel group, the increase does not indicate a significant difference. The average amount of waste generated per GT across the three vessel groups is 2.73 kg/GT, indicating that the amount of waste generated per GT is generally consistent among the vessel groups. Furthermore, the waste-to-vessel-weight ratio is also relatively similar across the three groups. The average waste-to-vessel-weight ratio for the three vessel groups is 0.20 %. This information provides a basis for estimating the total amount of FRP waste generated at the CV. Roni Marine shipyard in Cilacap. The estimated

amount of FRP waste generated at the shipyard is approximately 61.43 per month.

a. Waste Production at Each Stage of Shipbuilding

Observation of the amount of waste at each stage of shipbuilding is important as an effort to mitigate the presence of waste at those stages. The stages of shipbuilding at the CV. Roni Marine shipyard consists of four stages, namely the preparation stage, hull fabrication, frame installation, and finishing. Table 6, 7, and 8 present the results of the data analysis of weight generated at each stage of the FRP shipbuilding process at the CV. Roni Marine shipyard in Cilacap. Table 6 is presented as below.

TABLE 6.
THE WEIGHT OF THE 9 M (1,24 GT) SHIP WASTE DURING THE SHIPBUILDING PROCESS

Shipbuilding stage	Waste generated		Waste form	Waste type
	Weight (kg)	%		
Preparation	-	-	-	-
Hull construction	1.22	37.03	Solid FRP Composite Waste (pure) and Sheet/Plate-Shaped FRP Composite Waste	Solid
Frame installation (ribs)	1.54	46.74	Solid FRP Composite Waste (impure) and Sheet/Plate-Shaped FRP Composite Waste	Solid
Finishing	0.54	16.24	Solid FRP Composite Waste (pure)	Solid
Total Waste Weight (kg)	3.30			

Based on the table above, it is known that the total waste generated by a 1.24 GT vessel during the FRP shipbuilding process reached 3.30 kg. This waste originates from several stages of the FRP shipbuilding stage, namely the preparation stage, hull fabrication, frame installation, and finishing. During the preparation stage, no waste was generated, as the activities as this stage only included checking the completeness of the vessel mold, cleaning the work area, and preparing all materials and equipment used. Therefore, no waste from residual materials was produced. During the hull fabrication stage, 1.22 kg of waste was generated, accounting for 37.03% of the total waste weight. The waste generated at this stage consists of solid (pure) FRP composite waste and FRP composite waste in sheet/plate form. Furthermore, the frame installation stage generated 1.54 kg of waste, accounting for 46.74% of the total

waste weight. This waste consisted of solid (non-pure) FRP composite waste and sheet/plate-shaped FRP composite waste. Meanwhile, the finishing stage generated the least amount of waste, weighing 0.54 kg and accounting for 16.24% of the total waste weight. The waste generated at this stage consisted of solid (pure) FRP composite waste. All waste generated during the shipbuilding stage was classified as solid waste. These data indicate that the frame installation stage contributed the largest amount of waste during the FRP shipbuilding stage. This information is important as a reference for planning waste reduction measures and improving material-use efficiency in subsequent stages of shipbuilding process.

Table 7 will explain the weight of waste generated by the 1.28 GT vessel during the FRP shipbuilding process.

TABLE 7.
THE WEIGHT OF THE 9.5 M (1,28 GT) SHIP WASTE DURING THE SHIPBUILDING PROCESS

Shipbuilding stage	Waste generated		Waste form	Waste type
	Weight (kg)	%		
Preparation	-	-	-	-
Hull construction	1.36	36.07	Solid FRP Composite Waste (pure) and Sheet/Plate-Shaped FRP Composite Waste	Solid
Frame installation (ribs)	1.88	49.73	Solid FRP Composite Waste (impure) and Sheet/Plate-Shaped FRP Composite Waste	Solid
Finishing	0.54	14.19	Solid FRP Composite Waste (pure)	Solid
Total Waste Weight (kg)	3.77			

Based on the table above, it can be seen that the total waste generated by the 1.28 GT vessel during the FRP shipbuilding process reached 3.77 kg. Several stages during the FRP shipbuilding process generated waste with varying weights. During the preparation stage, no waste was generated. During the hull fabrication stage, 1.36 kg of waste was generated, accounting for 36.07% of the total waste weight. The waste generated at this stage consisted of solid (pure) FRP composite waste and sheet/plate-shaped FRP composite waste. Furthermore, during the frame installation stage, the amount of waste reached 1.88 kg,

accounting for 49.73% of the total waste weight. The waste generated at this stage consisted of solid (impure) FRP composite waste and sheet/plate-shaped FRP composite waste. During the final stage, namely finishing, the 1.28 GT vessel 0.54 kg of waste was generated, accounting for 14.19%. The waste generated at this stage consisted of solid (pure) FRP composite waste. Overall, the shipbuilding process was dominated by solid waste originating from residual FRP materials generated during the shipbuilding process. Table 8 presents the weight of waste generated by the 2 GT vessel during the FRP shipbuilding process.

TABLE 8.
THE WEIGHT OF THE 11 M (2GT) SHIP WASTE DURING THE SHIPBUILDING PROCESS

Shipbuilding stage	Waste generated		Waste form	Waste type
	Weight (kg)	%		
Preparation	-	-	-	-
Hull construction	1.68	32.49	Solid FRP Composite Waste (pure) and Sheet/Plate-Shaped FRP Composite Waste	Solid
Frame installation (ribs)	2.80	54.32	Solid FRP Composite Waste (impure) and Sheet/Plate-Shaped FRP Composite Waste	Solid
Finishing	0.68	13.19	Solid FRP Composite Waste (pure)	Solid
Total Waste Weight (kg)	5.16			

Based on the table above, the total weight of waste generated by the 2 GT vessel during the shipbuilding process reached 5.16 kg. At the preparation stage, a 2 GT vessel does not produce any waste at all. During the hull fabrication stage, 1.68 kg of waste was generated, accounting for 32.49% of the total waste weight. The waste generated at this stage consisted of solid (pure) FRP composite waste and sheet/plate-shaped FRP composite waste. Furthermore, during the frame installation stage, 2.80 kg of waste was generated, accounting for 54.32% of the total waste weight. The waste generated at this stage consisted of solid (impure) FRP composite waste and sheet/plate-shaped FRP composite waste. During the final stage, namely finishing, 0.68 kg of waste was generated, accounting for 13.19% of the total waste weight. The waste generated at this stage consisted of solid (pure) FRP composite waste. Overall, the shipbuilding process was dominated by solid waste originating from residual FRP material generated during the shipbuilding process.

The three vessel groups, namely the 1.24 GT, 1.28 GT, and 2 GT vessels, generated different total

weights of waste. Each stage of the shipbuilding process shows that the three vessels produce different amounts of waste. However, a common characteristic was observed, namely that they all produce the largest amount of waste during the frame installation stage, with the waste generated in the form of FRP composite waste in solid (impure) form and FRP composite waste in sheet/plate-shaped form. Based on observations at the CV. Roni Marine shipyard, this condition occurs because the frame installation stage involves cutting PVC pipes that have been coated with FRP, as well as trimming laminated sections at the vessel's sheer. The laminated sections have thicknesses ranging from 18 to 22 layers. For vessels with an LOA of 9-9.5 m, an additional 12 laminate layers are applied, resulting in a total of 18 layers.

In contrast, vessels with an LOA 11 m receive an additional 16 laminate layers, resulting in a total of 22 layers. Consequently, this stage generates more waste than the other stages of the shipbuilding process. In addition, all three vessels only produce solid waste and no liquid waste was observed during the shipbuilding

process. The results of this observation indicate that the effectiveness of liquid material usage was relatively efficient, resulting in no unused liquid waste. Therefore, solid waste management, particularly during the frame installation stage, is an important aspect that should be considered to minimize environmental impacts.

Based on the study results referring to the size of FRP vessels, the average waste generated per GT of vessel is 2.73 kg/GT. If the CV. Roni Marine Shipyard produces 15 vessels per month, or 180 vessels per year, with an average vessel size of 1.5 GT, then the potential waste is estimated to reach 61.43 kg per month or 737.7 kg per year. According to a previous study [37], each composite board measuring 25x25x1 cm requires 0.51 kg of FRP waste. Therefore, the potential waste generated by CV. Roni Marine each month could be used to produce approximately 118 composite boards, or 1,418 composite boards measuring 25x25x1 cm annually. Referring to the number of composite boards that can be produced from recycled FRP waste from shipbuilding, mitigation efforts would be less effective if managed by a single shipyard alone. Therefore, a dedicated institution, organization, or cooperative involving multiple shipyards is needed to process FRP waste collectively, thereby improving the effectiveness and efficiency of recycling FRP waste into composite boards.

IV. CONCLUSION

FRP vessels with sizes of 1,24 GT, 1,28 GT, and 2 GT during the shipbuilding process did not show significant differences in waste volume. The amount of waste generated from the shipbuilding process at the CV. Roni Marine shipyard averaged 2.73 kg/GT or accounting for 0.66 kg/kg of vessel weight. The waste produced had two physical forms, namely solid FRP composite waste (pure weighing 3.64 kg and impure weighing 0.43 kg) and FRP composite waste in the form of sheets/plate-shaped amounting to 8.17 kg. Among all construction stages, frame installation generated the highest amount of waste due to intensive cutting and trimming activities during the lamination process. The results of this study may serve as preliminary information for supporting future FRP waste management and recycling efforts in traditional shipyard. Further studies are recommended to evaluate the potential use of FRP waste as an alternative material for composite applications.

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