Guidelines for Manufacturing Waterproof Partition Boards Using the Fibre Reinforced Plastics (FRP) Waste from the Boatbuilding Sector

A.D.H.T. Wijerathne[1], M.T.T. Ranjan[1*], U.I.K. Galappaththi[2]

[1]*Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University of Ruhuna, Sri Lanka*

[2]*Far-UK Ltd., Nottingham, United Kingdom*

***Abstract*: The manufacturing and disposal stages of Fibre Reinforced Plastic (FRP) boats become very significant since they generate environmentally hazardous waste. Although most boat manufacturers have upgraded their facilities to minimize waste, the amount of waste generated is directly proportional to the size of the FRP boats. One option for dealing with the waste generated by the FRP boatbuilding industry is to use FRP recyclate for the production of waterproof partition boards. Under the current research, eleven specific manufacturing guidelines for developing waterproof partition boards using recycled FRP waste were developed. Waterproof partition boards were made from crushed flakes from discarded FRP boats and manufacturing stage waste. The crushed FRP flakes of the disposed of boats and manufacturing stage waste were used as raw materials to produce partition boards, and a mechanical shredding process was employed to produce recyclates. The approximate thicknesses and the aspect ratios of the recyclates used to manufacture partition boards were 0.5–2 mm and 0.04–0.3, respectively.**

***Keywords*: Manufacturing guidelines, FRP recyclate, Composite wastes, Impact energy, Mix proportion**

I. INTRODUCTION

The boatbuilding industry is one of the oldest transportation mediums in the world. As a result, it gets considerably higher demand from the market, and customers are expecting superior quality, comfortability, and safety from modern boats. Therefore, boat manufacturers are focusing on integrating advanced materials and manufacturing technologies to improve the boatbuilding process compared to the traditional process. The traditional boatbuilding industry uses wood and metallic materials as the raw materials to produce boats, and there are significant issues to be addressed. However, with the development of materials science, those conventional materials for boatbuilding are being slowly shifted towards composite materials. As a result, FRP boats have been introduced to the market to cater to the market's demand. The FRP boats are made out of fibres as the reinforcing agent and a polymer matrix as the binder [1]–[3]. The excellent strength-to-weight ratio, resistance to environmental conditions and corrosion, cohesiveness, ability to mould complex shapes, low maintenance due to no leaks, no plank shrinkage as with wood, rot-proof nature, flexibility, lighter weight compared to metallic materials, etc. are strengthening the application of FRP in the boatbuilding industry [4]–[6].

In the global context, approximately 50% of the commercial fishing vessels are made out of FRP, and 95% of the total FRP amount is represented by Glass Fibre Reinforced Plastics (GFRP). Furthermore, the global demand for GFRP for all applications is nearly 8 million tons per year, approximately 1.5 million tons wasted each year. The largest portion of this waste is directed to landfilling, while 13% of it is recycled for developing raw materials for other manufacturing processes such as filling materials for concretes, decorating items, and furniture. In this context, increased recycling is required to manage future FRP demand and resource scarcity [7], [8].

In this situation, abandoning the boats to coastal regions or sending them to the landfilling sites can be observed as the end life management method of the FRP boats used in Sri Lanka. This is the main source of FRP waste generation in the boatbuilding sector, although the manufacturing phase produces most of the uncured material wastage [9]. Therefore, trimmed fibreglass particles, resin mixed fibreglass pieces, ground dust of the fibreglass, and FRP structures of abandoned boats can be identified as the main waste categories produced by the boatbuilding industry [10]. These waste materials have increased environmental pollution and endangered the living creatures on this planet. Therefore, it is required to ensure sustainability in the boatbuilding sector to achieve optimum use of resources and environmental protection. In this context, to manage the waste generated by the FRP boat manufacturing industry, the waste management hierarchy can be employed [11]–[13]. Based on the applicability of the waste management methods in terms of benefits and drawbacks, the mechanical shredding process can be recognized as the most reliable, user-friendly, and cost-effective method to produce FRP recyclates [14].

To operate the mechanical shredding process sustainably, the recyclates should be used for effective product development [15]. Therefore, value addition to the FRP recyclates can be identified as the most vital aspect of FRP waste management [4]. According to the literature studies, ashtrays, litter bins, reinforced concrete, automotive moulding compounds, shower trays, kitchen worktops, roof tile production, timber beam strengthening methods, etc. can be recognized as value-added products for FRP recyclates [15]–[20]. Not only that but also, there are possibilities to design artificial wood that has the same performance as natural wood and high-performance reinforcement manufactured using recycled high-density polyethylene (HDPE). These examples justify the ability to produce different types of products using FRP recyclates.

However, the quality of these value-added products is significant as there are well-established products on the market. Therefore, the manufacturing process may require proper control and monitoring mechanisms. Otherwise, it will be very difficult to survive in a competitive market. At the same time, there should be a well-developed strategy to attract customers for the alternative products manufactured using FRP recyclates while there is an established market for the existing products. In this context, this study aimed to develop Manufacturing Guidelines (MG) for producing waterproof partition boards using FRP recyclates.

II. METHODOLOGY

As illustrated in Fig. 1, the process of drafting manufacturing guidelines involves a six-step approach.

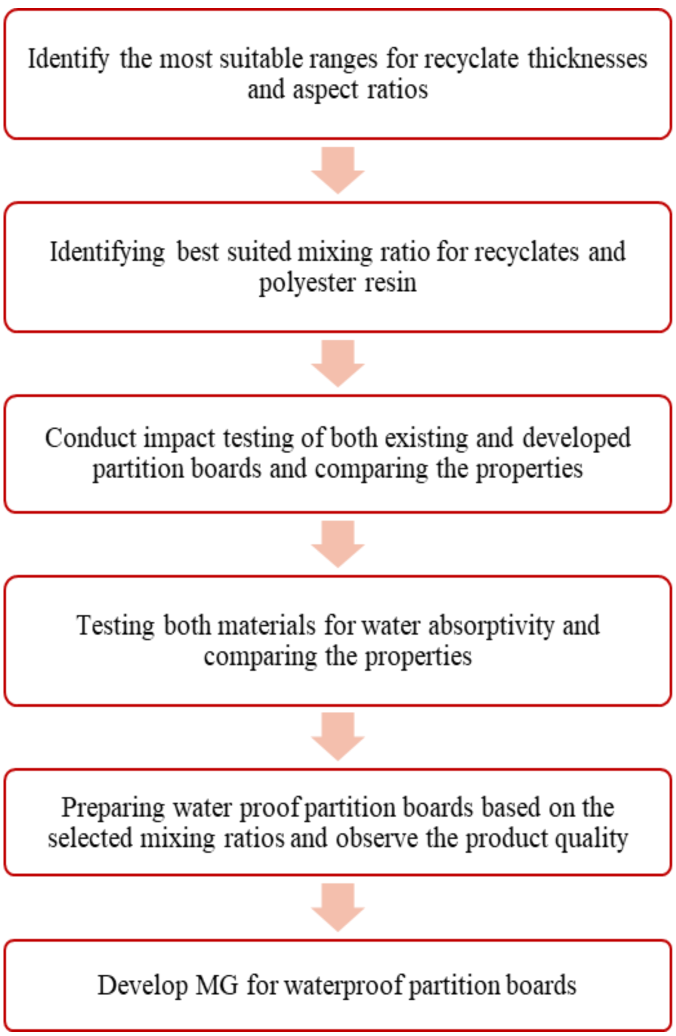


Fig. 1 Research Methodology

Initially, it was necessary to determine the best recyclate thicknesses and aspect ratios for use in waterproof partition board preparation. Based on observations and laboratory studies (refer to Fig. 2 and Fig. 3 for recyclates and a microscopic view of the recyclate), it was able to determine the approximate thickness and aspect ratio of the recyclates used to create partition boards as 0.5–2 mm and 0.04–0.3, respectively. The thickness variation and the aspect ratio distribution for randomly selected 30 samples are illustrated in Graph *1* and Graph 2 respectively. As the second step, different amounts of polyester resin were mixed with the selected recyclates to determine the best mixing ratio. The selection of an appropriate mixing ratio was based on cost and product quality considerations, including surface finishing and toughness variations. Based on the results of these tests, the ideal mixing ratio for producing partition boards was found to be 35% recyclates and 65% polyester resin by weight.

Fig. 2 Recyclates

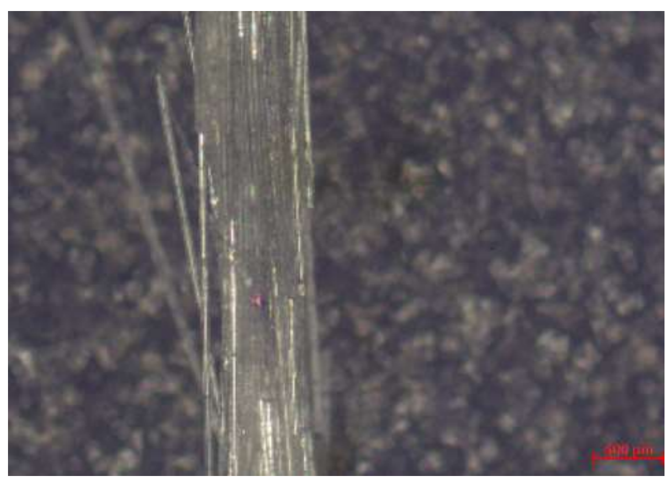
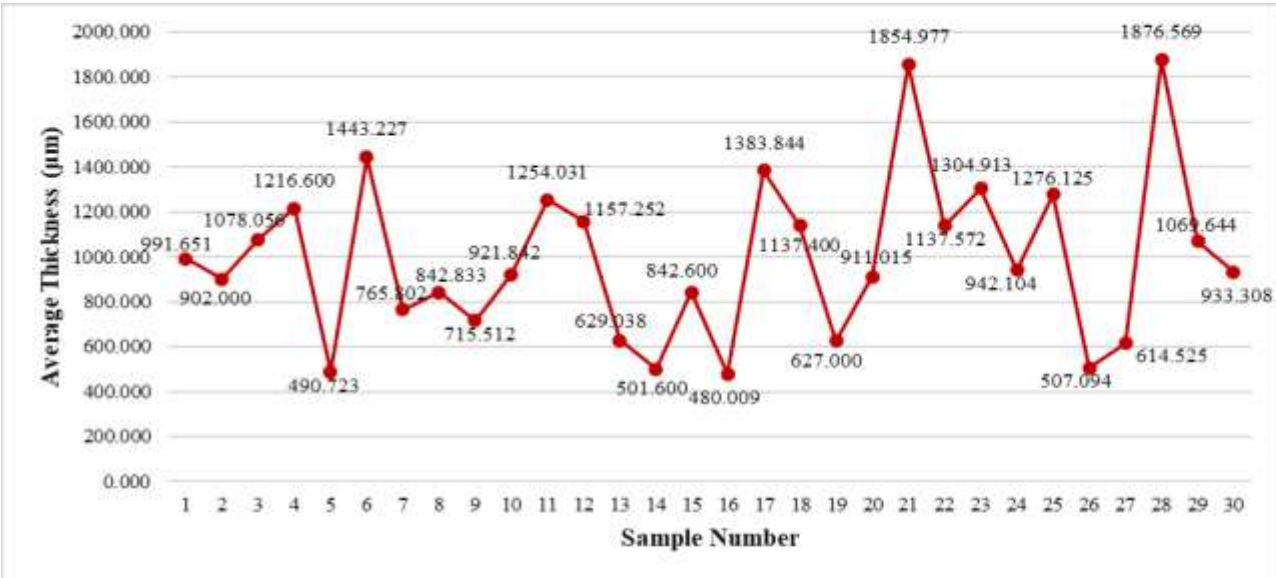
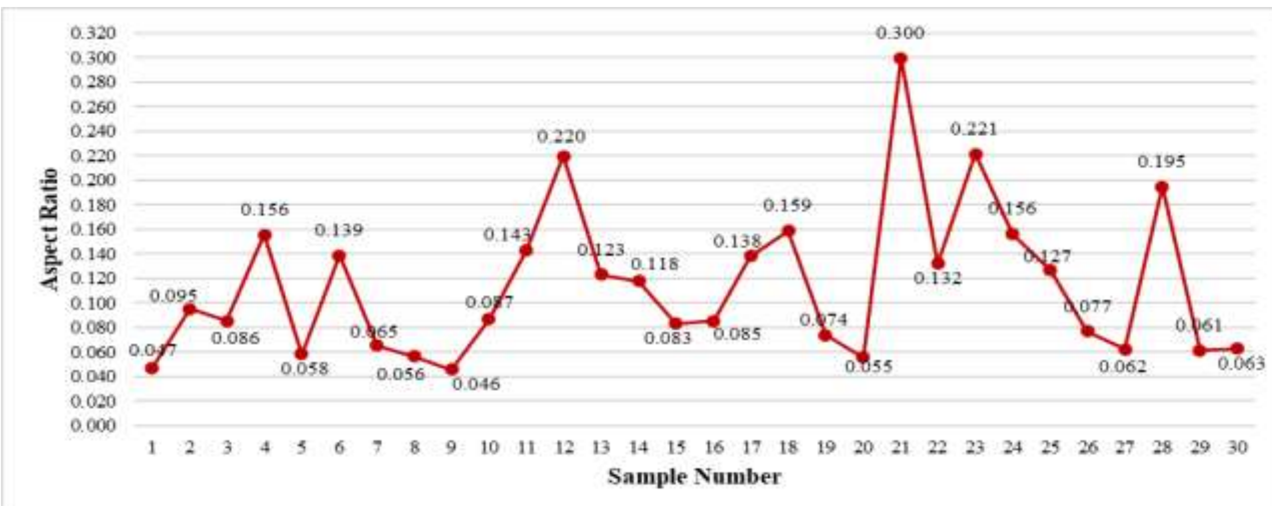


Fig. 3 Microscopic View of the Recyclate

Graph 1 Variation of the Average Thickness of the Recyclates

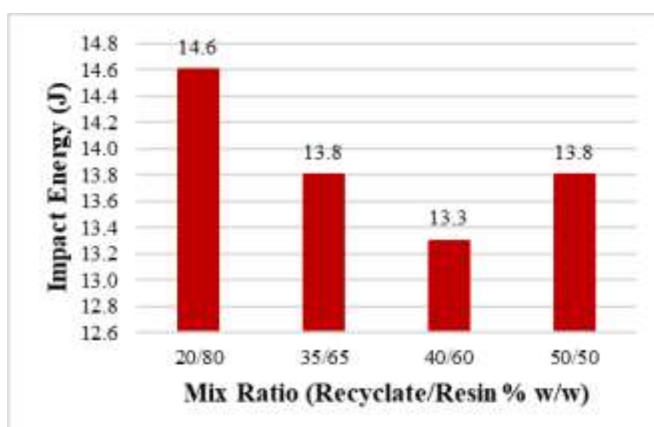


Graph 2 Variation of the Aspect Ratio of the Recyclates



Next, impact testing was performed according to the ASTM D 6110- 10 standard to determine the capacity of the partition boards to sustain sudden impact loads that may occur in the areas where they are mounted (commonly in washrooms, laundries, refrigerated spaces, and kitchens). The average impact energy for the four different samples are illustrated in the Graph 3. The impact parameters of existing partition board materials were then determined using literature data and compared to test findings for partition boards made from FRP recyclates. Then, the water absorptivity was examined for both current and new products in the fourth stage and identified the possible improvements to enhance the waterproof characteristics of the partition boards. The results of these two comparisons were used as decision-taking parameters for selecting the most suitable mixing ratio for partition board manufacturing.

Graph 3 Variation of the Aspect Ratio for Different Mix Ratios



The characteristics of the recyclate and resin combination, as well as the amount of FRP dust used, were adjusted to produce greater properties from the developed partition boards. As a result, impact testing revealed an improvement of 8%, as well as a reduction of 12% in water absorption from the FRP recyclates utilized in the test pieces (used recyclates to resin percentages were 35% and 65%, respectively by weight). Four alternative partition boards were made using the chosen mixing ratio (20% and 80%, 35% and 65%, 40%, and 60%, and 50% and 50% recyclate to resin amounts by weights) and recyclate size ranges, and the quality of the products was assessed. Fig. 4 illustrates the fabricated four partition boards. During the fabrication process, it was able to recognize a few drawbacks of manufacturing steps and possible amendments to the production process were incorporated while developing the MG. The generated dust particles were used as surface treatments on the waterproof partition boards throughout this operation. Because recycled flakes were employed as the reinforcing ingredient, an equal aspect ratio could not be achieved. Therefore, it was able to identify the most suitable proportions to add dust recyclates to achieve superior surface finishing from the partition boards. In this context, the mixture was non-homogeneous and hence displayed anisotropic behavior due to variations in the aspect ratio as well as the form of the recyclate flakes. Finally, to assure the quality and longevity of the partition boards, MG were developed based on practical experience and theoretical understanding obtained by undertaking above mentioned research studies.

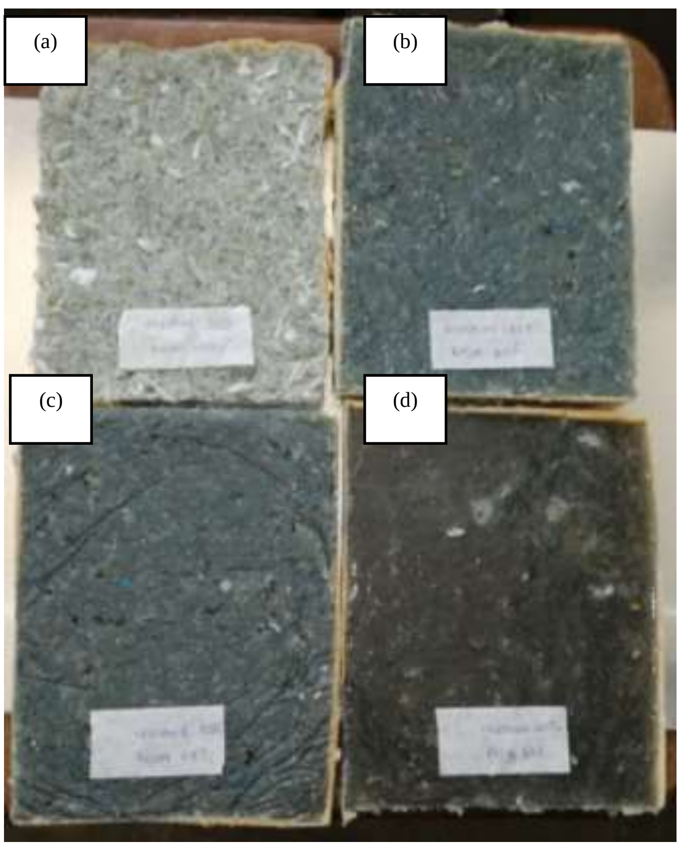


Fig. 4 Prepared Partition Boards Employing, (a) 50%–50% (b) 40%–60% (c) 35%–65% and (d) 20%–80% Recyclate and Resin Contents by Weight

III. MANUFACTURING GUIDELINES

There are several steps involved in the production of water-proof partition boards. To achieve the needed product quality, each of the MG listed below should be followed thoroughly and precisely.

MG 1- To ensure the surface quality of the product, the surfaces of the two parts of the mould, which are used to prepare the partition board, should be free of scratches, faults, or any other form of defect. Using acetone or thinner, the mould surface should be thoroughly cleaned to remove all dust, debris, and rust.

MG 2- To ensure safe and easy part removal, a few layers of suitable mould releasing agent (PVA-polyvinyl alcohol) should be added to the mould surface. If this mould releasing agent is not used, the demoulding procedure will be more difficult, and damage to both the product and the mould may result.

MG 3- A thin layer of gel coat should be placed on the mould, with a thickness of around 1 mm. The intention of applying a gel coat is to create a smooth, resilient surface that protects the product from water and UV radiation damage.

MG 4- Measure the required amounts of the raw materials. The required raw materials for the production process are as follows.

- Crushed FRP recyclates flakes
- FRP dust recyclates
- Polyester resin
- Methyl Methacrylate

The ultimate reinforcement to resin ratio should be taken into account when estimating the amounts necessary from the recyclate and resin. Furthermore, an additional 5% of all these raw materials must be taken to compensate for various types of waste produced during the manufacturing process. However, an excess amount of FRP dust recyclates may result to reduce the impact properties of the structure. The weight of the resin used should be taken into account when determining the amount of catalyst to utilize. In general, 15–25 g of catalyst is required for 1 kg of resin. Depending on the climate, the exact amount of catalysts required may vary. A higher amount of catalysts decreases the gelling time and also it may result in creating defects in the structure. Therefore, catalysts should be mixed very carefully.

MG 5- Allow the resin to degas approximately for 10 minutes before adding the catalyst to the resin container. Then, for a few minutes, whisk the mixture to mix the resin and the catalyst uniformly. The mixture is now ready to use.

Note: If there is a requirement to add colours to the boards, the pigment should be used accordingly.

MG 6- Add the required amount of crushed recyclate flakes to the mixture (resin and catalyst mixture) and stir well until the recyclates spread uniformly over the mixture. Add 5% of the crushed FRP dust to the mixture (compared to the weight of the flakes added).

Note: A separate mechanism may be required to undertake this process as the uniform distribution of recycled material is very essential to ensure product quality.

MG 7- Apply the prepared mixture into the mould and spread it evenly, pressing it down slightly. If the mould has any curvatures, make sure to fill all of the edges and curvatures perfectly.

MG 8- Place the upper half of the mould and clamp the two halves of the mould. And also, use the upper half of the mould to press the mixture.

MG 9- Keep the mould closed until the partition board gets cured. It may require 1 to 2 days depending on the length, width, and thickness of the partition board.

MG 10- After cured, carefully demould the product from the mould.

MG 11- Final processing activities such as trimming the edges and polishing the surfaces should be undertaken to improve the appearance of the partition board.

Note: The thickness of the product can be changed as per the requirements. Therefore, it may require altering the amount of the mixture used to fill the mould.

IV. RESULTS AND DISCUSSION

Based on the results of impact testing conducted for various reinforcement to resin ratios, it was chosen to employ a 35% to 65%, reinforcement (recyclate) to resin ratio for achieving optimal fracture toughness.

The more brittle fracture was observed as the resin amount was increased, whereas greater elastic fracture was observed in the specimen constructed with more reinforcement (refer to Fig. 5, Fig. 6, Fig. 7, and Fig. 8). The reason is the increment of reinforcing agent (recyclate) creates a hindrance or barrier to fracture propagation. Therefore, the fracture behavior will adopt a more elastic nature as the employed resin amount is decreased. Furthermore, the necking region could not be observed from the tested samples. According to this observation, it was clear that not only toughness but also fracture behaviour was necessary to attain high performance. On the other hand, as the used resin amount was increased, the quality of the surface of the partition board and the ability to flow the mixture were increased. According to the observations carried out, it was obvious that when the utilized resin amount was increased, the surface quality of the partition board was also increased. The improved flowability caused to reduce the void formation considerably and it was the main reason for this surface quality enhancement. On the other hand, the amount of FRP dust recyclate added to the mixture provided significant improvement for the surface and it was decided to use 5% of the FRP dust by weight compared to the flake recyclates. A higher amount of FRP dust can be a reason to decline the mechanical properties of the structure such as impact energy.

Fig. 5 Fracture Behavior of the Specimen Prepared Employing 20%–80% Recyclate and Resin Contents by Weight

Fig. 6 Fracture Behavior of the Specimen Prepared Employing 35%–65% Recyclate and Resin Contents by Weight

Fig. 7 Fracture Behavior of the Specimen Prepared Employing 40%–60% Recyclate and Resin Contents by Weight

Fig. 8 Fracture Behavior of the Specimen Prepared Employing 50%–50% Recyclate and Resin Contents by Weight

Additionally, water absorptivity also declined drastically when the applied resin amount was increased. As the resin amount is increased, there is a sufficient amount of resin to fill the empty spaces inside the prepared product, and thus, there is no room for accumulating the water, and thus the water absorptivity and the thickness swell are reduced. If the particular product is absorbing more water, it will not function as a waterproof behavior and it may require adding more resin and FRP dust recyclates. However, there was a limitation to adding resin as it can result in to decline in the impact properties of the structure. Therefore, higher resin amounts should be tested before manufacturing the partition boards.

It was able to manufacture an 8 mm thick waterproof partition board by employing the above-mentioned 11 MG. Fig. 9 illustrates a sample of a manufactured waterproof partition board. The manufactured partition board had some voids, and the main reason for them was the air bubbles trapped inside the mixture. Difficulties in controlling the uniform mixture can result from this kind of defect and they will contribute to reducing the strength and water absorptivity of the product. To minimize these defect formation, a modified vacuum infusion technique or pressure controlled system should be introduced.

Fig. 9 Manufactured Waterproof Partition Board

The development of waterproof partition boards using FRP recyclates enhance the three pillars of sustainability not only in the boat building sector but also in the waterproof partition board manufacturing industry. As a result of replacing existing raw materials of the waterproof partition board manufacturing, the cost of production will be drastically reduced. Therefore, the product can be delivered to the market for a lower price than the existing products' prices. At the same time, new employment opportunities will be generated due to the new start-ups carried out by this method. However, there is a possibility of losing jobs for the people who are supplying existing raw materials to the partition board manufacturers. Additionally, the amount of waste sent through improper disposal methods will be declined and it will impact positively on the environment and human health.

As a major outcome of this research, the FRP wastes, which were previously abandoned without taking any advantage, are converted to a value-added product. Therefore, it creates economic benefits directly and indirectly for both industries. The cost of extracting virgin raw materials for partition board manufacturing can be reduced significantly while boat builders and users can receive additional income by selling the FRP waste to the recycling plants. At the same time, people who have engaged with recycling and producing waterproof partition boards using FRP recyclates may demand higher income since the cost of manufacturing is considerably low.

V. CONCLUSIONS

The objective of this study was to establish manufacturing guidelines for waterproof partition boards constructed from recycled FRP. The cost-effectiveness, structural stability, and surface-finish-friendliness of various reinforcement–resin ratios by weight were evaluated, and the 35–65 percent reinforcement–resin ratio by weight was determined to be the most cost-effective, structurally stable, and surface-finish-friendly mix proportion. As an outcome of the research, eleven MG for producing partition boards from FRP recyclates were developed. This study's conclusions are immediately beneficial to the boatbuilding industry's transition to sustainability. As a result, various types of value-added product development should be encouraged to efficiently manage the FRP boats' end-of-life while also effectively resolving the FRP waste generated during the production stage. Furthermore, to determine the environmental impact of producing value-added commodities from FRP waste, life cycle assessments (LCAs) should be performed.

REFERENCES

[1] J. Somarajan, S. Kodungallur, and C. G. Nandakumar, “Recycling of FRP boats,” Int. J. Adv. Res. Eng. Technol., vol. 9, no. 3, pp. 244–252, 2018.

[2] K. K. Chawla, Composite materials, Fourth Edi. Birmingham: Springer Nature Switzerland, 2019.

[3] S. Selvaraju and S. Ilaiyavel, “Applications of composites in marine industry,” Res. Artic., no. Ii, pp. 89–91, 2011.

[4] M. Önal and G. Neşer, “End-of-Life alternatives of glass reinforced polyester boat hulls compared by LCA,” pp. 134–141, 2018, doi: 10.1177/096369351802700402.

[5] B. Ertuğ, “Advanced fiber-reinforced composite materials for marine applications,” Adv. Mater. Res., vol. 772, pp. 173–177, 2013, doi: 10.4028/www.scientific.net/AMR.772.173.

[6] ACMA - American Composites Manufacturers Association, Guidelines and recommended practices for fiber-reinforced-polymer (FRP) architectural products. 2016.

[7] F. Yan-chao, Z. Feng-qing, and X. U. Hong, “Recycling and utilization of waste glass fiber reinforced plastics,” vol. 07012, pp. 4–8, 2016.

[8] N. A. Shuaib and P. T. Mativenga, “Energy demand in mechanical recycling of glass fibre reinforced thermoset plastic composites,” J. Clean. Prod., vol. 120, pp. 198–206, 2016, doi: 10.1016/j.jclepro.2016.01.070.

[9] T. Al Abbar, F., & de Jong, D., Marohn, S., Scherders V., Vink, P., van Wuijckhuiijse, “Advice report: The prevention of fiber-reinforced-plastic boats from becoming orphan in Dutch waterbodies,” 2015. [Online]. Available: http://www.wageningenur.nl/upload_mm/2/c/0/59cad6bf-dff2-4f2f-9fb3-c11a435b68af_ACT_Finalversion_Group1542.pdf.

[10] J. Wellekötter, S. Baz, J. Schwingel, G. T. Gresser, P. Middendorf, and C. Bonten, “Recycling of composites - A new approach minimizes downgrading,” AIP Conf. Proc., vol. 2055, no. January, pp. 1–7, 2019, doi: 10.1063/1.5084841.

[11] C. F. Wait, “The reuse and recycling of glass fibre waste,” University of Birmingham, 2010.

[12] K. Ferrari, R. Gamberini, and B. Rimini, “The waste hierarchy: A strategic, tactical and operational approach for developing countries. the case study of Mozambique,” Int. J. Sustain. Dev. Plan., vol. 11, no. 5, pp. 759–770, 2016, doi: 10.2495/SDP-V11-N5-759-770.

[13] A. Rahman and M. Karim, “Green shipbuilding and recycling : issues and challenges,” Int. J. Environ. Sci. Dev., vol. 6, no. 11, pp. 838–842, 2015, doi: 10.7763/IJESD.2015.V6.709.

[14] A. Shajkumar, S. K. Samal, S. Mohanty, and S. K. Nayak, Chapter 23. The degradation and recycling of unsaturated polyester resin-based composites. Elsevier Inc., 2019.

[15] A. Yazdanbakhsh and L. C. Bank, “A critical review of research on reuse of mechanically recycled FRP production and end-of-life waste for construction,” Polymers (Basel)., vol. 6, no. 6, pp. 1810–1826, 2014, doi: 10.3390/polym6061810.

[16] S. Franke, B. Franke, and A. M. Harte, “Failure modes and reinforcement techniques for timber Beams-state of the art,” Constr. Build. Mater., vol. 97, pp. 2–13, 2015, doi: 10.1016/j.conbuildmat.2015.06.021.

[17] Y. O. Kustikova, “Application FRP-rebar in the manufacture of reinforced concrete structures,” Procedia Eng., vol. 153, pp. 361–365, 2016, doi: 10.1016/j.proeng.2016.08.128.

[18] F. Aydın, “Compressive Behavior of Concrete Filled Glass Fiber Reinforced Polymer (GFRP) Box Profiles,” Anadolu Univ. J. Sci. Technol., vol. 17, no. 3, pp. 605–617, 2016, doi: 10.18038/btda.86949.

[19] J. R. Correia, N. M. Almeida, and J. R. Figueira, “Recycling of FRP composites: Reusing fine GFRP waste in concrete mixtures,” J. Clean. Prod., vol. 19, no. 15, pp. 1745–1753, 2011, doi: 10.1016/j.jclepro.2011.05.018.

[20] M. C. S. Ribeiro et al., “Recycling approach towards sustainability advance of composite materials’ industry,” Recycling, vol. 1, no. 1, pp. 178–193, 2016, doi: 10.3390/recycling1010178.