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Tensile and Flexural Strength Fiberglass Mixed Green Mussel Shell Powder for Fishing Vessel Size below 5 GT

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Abstract

Green mussel (Perna viridis) is a marine organism that is widely cultivated and considered a leading commodity in the fisheries sector. The increase in mussel production has resulted in a significant amount of shell waste. Improperly managed mussel shell waste can have a negative impact on the environment. However, green mussel shell waste has great potential for reuse, one of which is as a composite material in fiberglass manufacturing. The high calcium content in mussel shells can serve as an additional reinforcement in fiberglass composites. The wood crisis as a raw material for boat construction, which also contributes to environmental deforestation, has led to the consideration of alternative materials such as fiberglass for boat building. This research is an experimental study on the utilization of green mussel shell (GMS) waste as a fiberglass mixture material for boat construction. An ideal composition between the GMS waste powder and fiberglass material is expected to enhance the mechanical strength of fiberglass fishing boats. The study shows that the addition of 20% GMS powder in fiberglass lamination improves mechanical properties, with a maximum tensile stress value of 113.23 MPa. Meanwhile, the maximum flexural strength is observed at 15% GMS powder composition, reaching 192.38 MPa. The addition of GMS powder has the potential to strengthen fiberglass, making it suitable for applications such as fishing boat hulls. However, adding more than 30% GMS powder decreases the material's strength, particularly in tensile testing. Further research is needed to explore the use of GMS powder for waste reduction and to provide insights into its applications in fiberglass boat manufacturing.

Introduction

Green mussels (Perna viridis) are marine organisms that are widely cultivated in Indonesia (Rudy, Firmani, & Farikhah, 2023). Due to the continuously increasing market demand, green mussel production in Indonesia has experienced rapid growth. According to the 2022 report by the Ministry of Marine Affairs and Fisheries (KKP), Indonesia's green mussel production reached more than 300,000 tons per year, making it one of the leading commodities contributing to the coastal community's economy in the fisheries sector. However, this increase in production also results in a significant amount of shell waste.

Green mussel shell waste (GMSW) is often not properly managed, which can lead to environmental pollution and negatively affect marine ecosystems. The accumulation of shell waste contributes to the buildup of organic matter and an increase in nutrient levels in the water. This condition can trigger excessive algal growth or eutrophication. Eutrophication may lead to a decline in water quality and threaten the survival of other marine organisms (Rasidi et al., 2022; Akinnawo, 2023; Rodgers, 2021; Tiwari & Pal, 2022).

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To address the problem of green mussel shell waste, there is significant potential to utilize it as a valuable alternative material. The use of green mussel shells has already been widely explored, such as in the production of handicrafts, flour for human food (Fitriah et al., 2018), animal feed nutrients (Istikharoh, 2023), materials for the medical industry and treatments for dental sensitivity (Halipah, 2016), additional growing media for earthworms (Darmawan, 2023), building construction materials such as concrete (Setiawan et al., 2022), and even composite materials (Ayu Ariska et al., 2023). Based on its chemical composition, green mussel shells contain a high level of calcium, including $CaCO_3$ (calcium carbonate), $CaPO_4$ (calcium phosphate), $Ca(HCO_3)_2$ (calcium bicarbonate), Ca_3S, and active calcium. This makes green mussel shell waste a potential raw material mixture, including for the production of fiberglass composites (Abdullah et al., 2021; Mufidun, 2016). Green mussel shells can be used as reinforcement in fiberglass composites, enhancing the material's strength and durability. Rich in calcium carbonate, the shells act as a reinforcing agent in fiberglass composites (Ayu Ariska et al., 2023; Rajan et al., 2022; Mohanty et al., 2024; Sundeep et al., 2023). The addition of green mussel shell powder can improve the tensile and flexural strength of fiberglass materials (Abdullah, 2023; Hosseini & Raji, 2023; Azhar et al., 2024).

One of the applications of fiberglass material is in the construction of fishing boats (Arif et al., 2022; Khairi et al., 2023; Rizwan et al., 2024). Fiberglass boats offer several advantages over wooden boats, particularly in terms of resistance to decay caused by fungi, heat, weathering, and chemical exposure. Wooden boats are more susceptible to such damage compared to fiberglass boats (Jamal et al., 2021; Rahman, 2019; Du Plessis, 2013). This study aims to utilize green mussel shell waste (GMSW) as a composite material in the production of fiberglass fishing boats, providing a solution for waste management while also exploring the potential of GMSW as a reinforcing material. The research focuses on enhancing the mechanical strength of fishing boats, particularly based on tensile and flexural strength test results.

Methods

This research employs an experimental design by adding green mussel shell (GMS) powder, sized at 50 mesh, to fiberglass material for the construction of a 5 GT fishing boat hull. The aim of this study is to compare the mechanical properties (tensile and flexural tests) of fiberglass material mixed with GMS powder in accordance with the research framework (see Figure 1). The study was conducted in Jakarta, with GMS powder samples collected from Cilincing District, North Jakarta City, and mechanical testing carried out at the National Research and Innovation Agency (BRIN) Laboratory in Serpong. The testing laboratory is accredited under SNI ISO/IEC 17025. The research was conducted from August to December 2024.

The comparative measurement results in this study are compared with the standard testing results applicable to hull material, such as ASTM D638 for tensile testing and ASTM D790 for flexural testing. Statistical analysis will be conducted to evaluate the data obtained from the comparative measurements. The analytical methods used will include Analysis of Variance (ANOVA) and correlation tests to determine if there are significant differences and correlations in mechanical values (tensile and flexural tests) across variations of independent and control variables.

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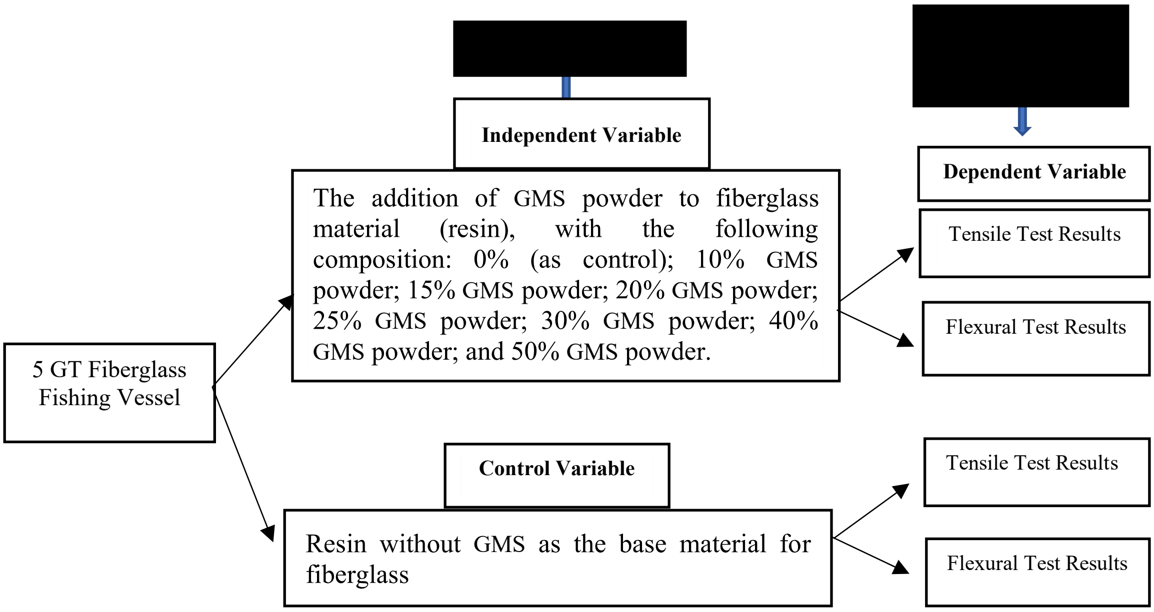

Figure 1. Conceptual Framework of Experimental Research

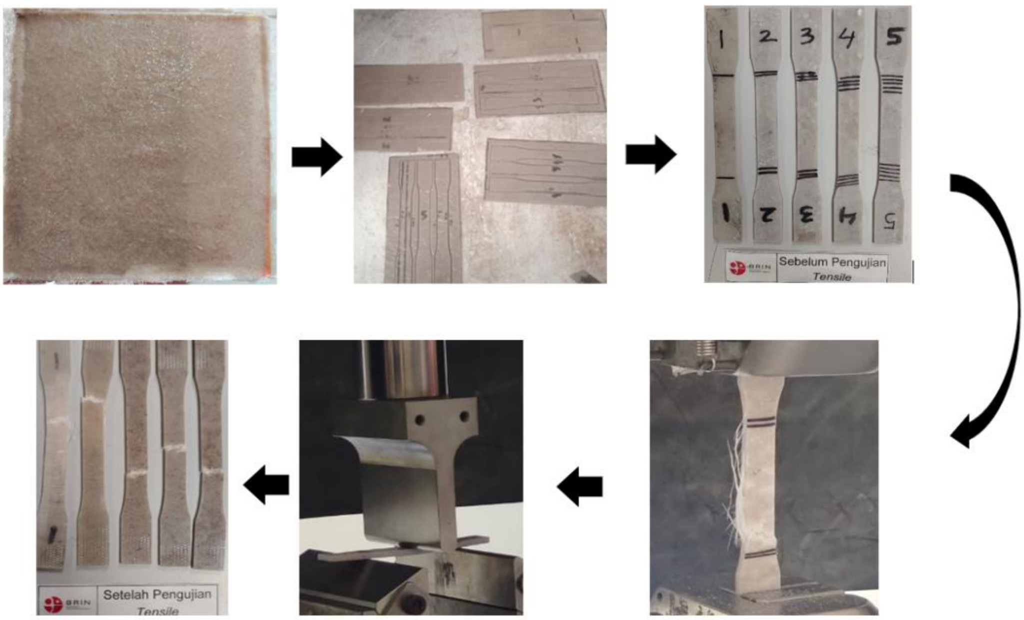

Figure 2. Flowchart of Sample Preparation and Testing

The fabrication of fiberglass specimens with the addition of GMS is carried out using the hand lay-up method in accordance with (SNI 8961:2021). The sample preparation begins with the preparation of tools and materials; lamination preparation; lamination process; and preparation of each tensile and flexural test specimen. In the preparation of tools and materials, the composition of the specimen includes Fiberglass Reinforced Plastic (FRP), unsaturated polyester resin (UP), Matt with a weight of 300 grams/m^2 and 450 grams/m^2, and Woven Roving with a weight of 600 grams/m^2. The GMSW powder is milled to a size of <50 mesh. During the lamination process, attention must be paid to the composition of GMS powder to be tested with Gel Time and a catalyst usage ratio of 0.01 to achieve a gel time of 9 minutes to 12 minutes. In this specimen, the Resin Gel Time is 11’50’’. In specimen preparation, the size for each sample is adjusted: 165 mm in length and 19 mm in width for tensile testing, and 90 mm in length and 13 mm in width for flexural testing.

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Results and Discussion

The results of the tensile test on several specimen compositions. Each specimen was tested three times, with the results shown in Figures 3 and 4.

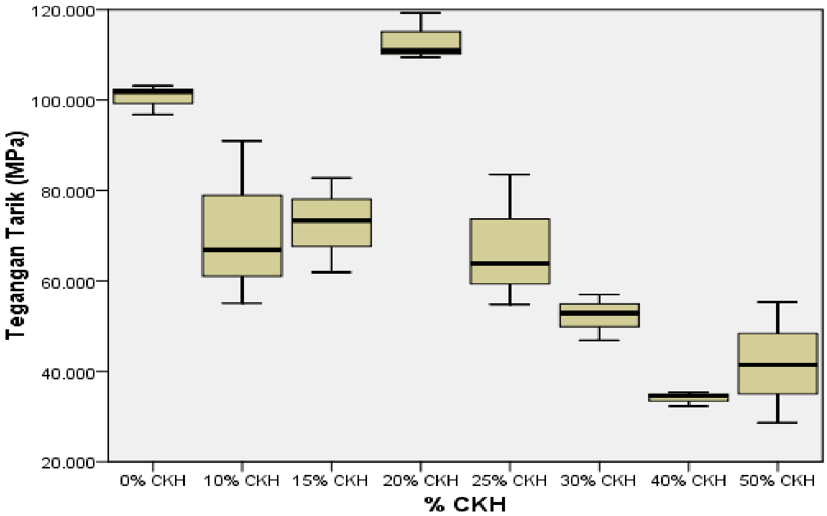

Figure 3. Tension Strength Results from Tensile Testing

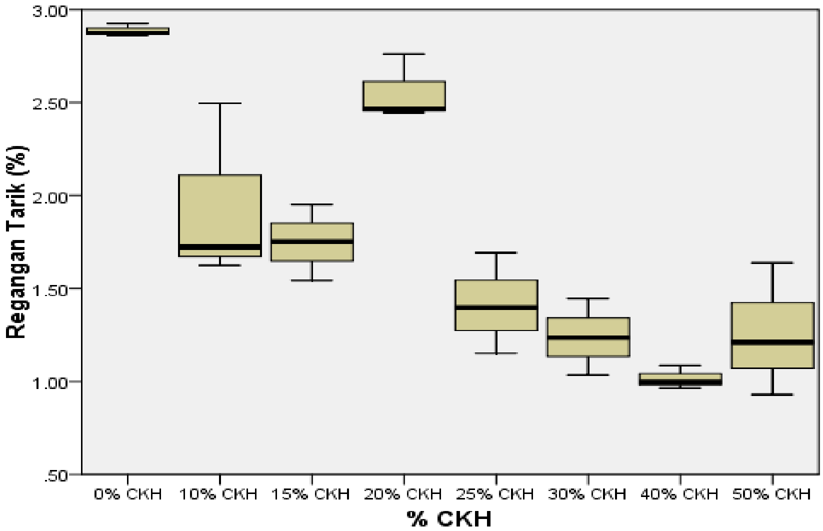

Figure 4. Strain Results from Tensile Testing

The results of the tensile strength test range from 28.61 to 119.30 MPa. In Figure 3, the highest average tensile strength value of 113.23 MPa is observed at the 20% GMS powder composition. At the 20% GMS powder composition, the tensile strength is higher than that of the control specimen (0% GMS powder), with the addition of GMS powder causing a tensile strength increase of about 12%. Meanwhile, for other GMS powder compositions, the tensile strength results are lower compared to the control specimen. The tensile strength values are directly proportional to the tensile strain (%) shown in Figure 4.

In the flexural test, each specimen was tested three times. The results of the flexural test are shown in Figures 5 and 6.

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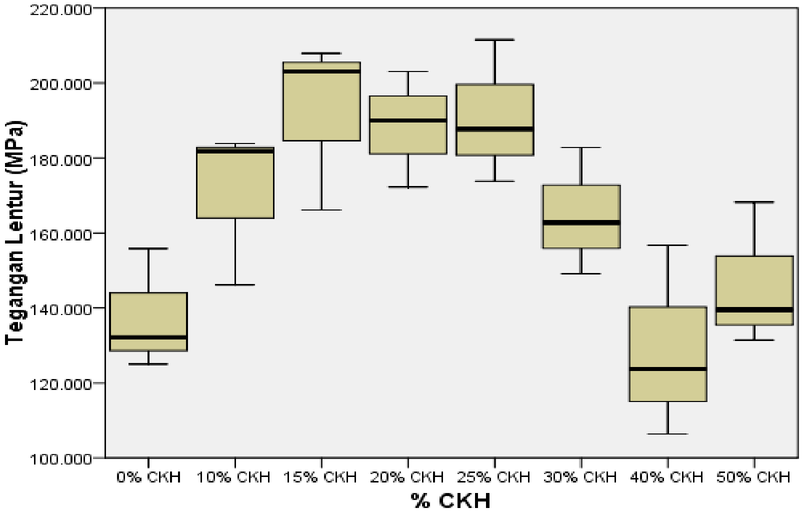

Figure 5. Tension Strength Results from Flexural Testing

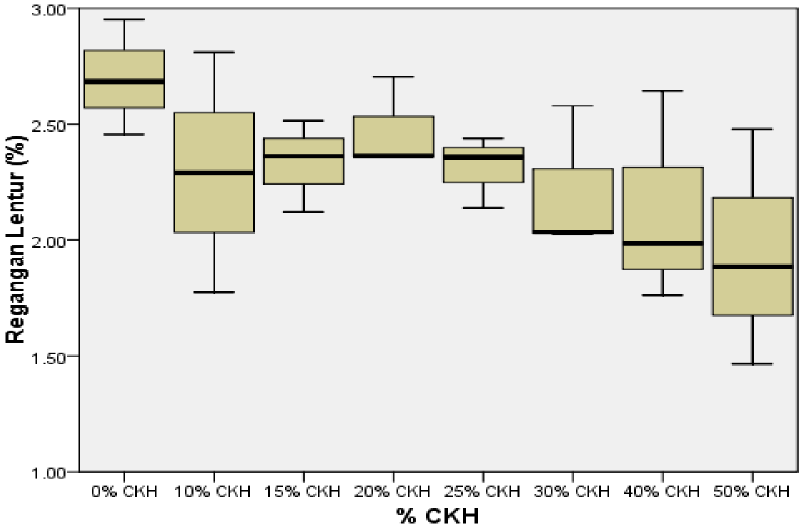

Figure 6. Strain Results from Flexural Testing

The flexural test results range from 106.35 to 207.92 MPa. In Figure 5, the highest flexural stress is observed in the specimen with a 15% GMS powder composition. At the 15% GMS powder composition, the flexural stress is higher than that of the control specimen (0% GMS powder), with the addition of GMS powder resulting in a 55% increase in flexural stress. Most specimens with GMS powder addition show higher flexural stress values compared to the control specimen, except for the specimen with 40% GMS powder, which has a lower value than the control specimen. The flexural strain results do not exhibit a uniform pattern with the flexural stress results, with the highest strain observed in the control specimen. Statistical testing was conducted in this study, including a difference test on various GMS powder composition variations and their effect on the material's mechanical strength, as shown in the table below.

Table 1. ANOVA Test Results

Mechanical Properties	p-value	Description
Tensile Strength	0,005*	Significant, there is a difference between groups
Flexural Strength	0,000*	Significant, there is a difference between groups
Tensile Strain	0,353	Not significant, no difference between groups

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Flexural Strain	0,000*	Significant, there is a difference between groups

*significance level <0,05

Table 1 shows that the tensile strength has a p-value of 0.005, indicating that there is a significant difference in the tensile strength across the GMS powder compositions. Therefore, it can be concluded that the variation in material composition affects the material's ability to withstand tensile forces before failure. For the flexural stress property, a p-value of 0.000 was obtained, suggesting that the variation in GMS powder compositions used in this study significantly affects the material's resistance to bending loads. Flexural stress is an important parameter in structures that are continuously subjected to bending loads.

In contrast to the previous results, the tensile strain shows a p-value of 0.353, indicating that there is no significant difference across the various GMS powder compositions. The GMS composition does not have a significant effect on the material's elasticity when subjected to tensile forces. In the flexural strain test, the p-value obtained is 0.000, meaning that different material compositions result in different deformation capabilities when the material is subjected to bending loads. This property is an important indicator for assessing the material's flexibility in applications that require high deformation before fracture.

Table 2. Correlation Test Results Between Tensile Strength and Tensile Strain

r Coefficient	**p-value**	**Description**
0,936	0,000*	Significantly correlated, with a strong positive relationship.

*significance level <0,05

The test results in Table 2 show that the correlation coefficient (r) is 0.936 with a p-value of 0.000 (significant result). This correlation value is close to 1, indicating a very strong and positive relationship between tensile stress and tensile strain. A positive value means that as the tensile stress increases, the tensile strain also tends to increase proportionally. This illustrates that the elasticity and strength properties of the material in the tensile test are closely related, so that an increase in tensile force will be followed by an increase in deformation until the fracture point.

Table 3. Correlation Test Results Between Flexural Strength and Flexural Strain

r Coefficient	**p-value**	**Description**
0,388	0,061	Not significantly correlated, weak positive relationship

In Table 3, the correlation coefficient (r) value of 0.388 with a p-value of 0.061 indicates that the relationship between flexural stress and flexural strain is weak and statistically insignificant. Although the correlation is positive, meaning that as the flexural stress increases, the flexural strain tends to increase as well, the strength of this relationship is low and cannot serve as a reliable basis for a convincing connection. This condition suggests that other variables, such as the material's microstructure, porosity, or fiber distribution in the composite, may be more dominant in affecting the flexural strain. Additionally, the variation in results across samples may also weaken the strength of the correlation.

Several other studies related to material testing have shown that the highest tensile stress occurs at a 20% GMS powder composition, with a value of 113.23 MPa, indicating an increase from the control value (0%), which was 100.57 MPa. At the 20% GMS powder concentration, it functions optimally as a reinforcement, helping to distribute the tensile load evenly within the matrix. However, after exceeding this 20% composition, a sharp decrease is observed. At the 30% composition, the value of σ decreases to 52.22 MPa, and continues to decline to 41.79

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MPa at the 50% composition. This decrease is likely caused by the aggregation of GMS powder particles, which disrupt the bonding between matrix components, forming voids and resulting in inefficient load distribution (Prayoga, 2020; Zhang, 2021).

For the flexural strength, the sample without green shell powder (control) has a flexural strength of 137.69 MPa. The flexural strength increases from the control sample at compositions of 10% to 30%, then decreases at the 40% composition and rises again at the 50% composition. The highest flexural strength occurs at the 15% composition. Overall, this study shows that GMS powder compositions of 15% to 25% provide the best improvement in the mechanical properties of the composite material. The flexural test is one of the mechanical testing methods used to determine the flexural properties of a material, particularly the flexural strength. This test is crucial in assessing how well a material can withstand forces that cause bending before failure (cracking or breaking) occurs. This testing is highly relevant in composite material studies, such as mixtures of epoxy resin and green shell powder, as it can demonstrate the effectiveness of filler reinforcement on the material's mechanical properties (Radhakrishnan et al., 2025; Sienkiewicz et al., 2022; Sivakumar et al., 2022; Kasinathan & Rajamani, 2022; Hiremath et al., 2024).

Previous research focused on the development of composite materials with the addition of natural nettle plant fibers at compositions of 10%, 15%, and 20%, and found that the highest flexural strength was achieved in the composite sample without the addition of natural fiber, with a flexural stress value of 80.823 Mpa (Suryawan et al., 2019). In a study conducted by Iswidodo et al. (2022), the use of coconut fronds in resin-based material mixtures as an environmentally friendly fiber for composites showed that a higher percentage of coconut fronds did not necessarily result in higher tensile strength. The 30% coconut frond and resin composition exhibited the highest tensile strength compared to other coconut frond compositions of 10% and 50%. Meanwhile, in flexural tests, the 50% coconut frond composition showed the highest strength compared to other compositions. Flexural strain illustrates how much a material can undergo elastic deformation before fracture due to bending loads. The decrease in flexural strain in composites with high powder content indicates that the material becomes stiffer and more brittle due to the non-homogeneous distribution of powder or particle aggregation, which causes weak points in the composite structure (Wang & Monetta, 2023).

The results of this study align with previous research, which states that the addition of shell powder can improve compressive and flexural strength, but it may reduce tensile strength due to uneven filler distribution (Zulfikar et al., 2023). Other studies also indicate that the optimal composition is at 10% shell powder, while adding more than that tends to reduce the mechanical properties (Saputra et al., 2024). Adding shell powder as a filler up to the optimal point significantly increases the mechanical strength of cement particle boards, but excessive filler leads to a decrease due to the formation of voids in the matrix (Zulfikar et al., 2023).

Research by Nayan & Hafli (2022) shows that increasing the volume fraction up to 40% results in high tensile strength; however, the microstructure reveals potential aggregation that reduces the material's homogeneity . Overall, the results of this study are consistent with various studies that indicate that the use of shell waste as a filler in composite materials contributes positively to the enhancement of mechanical strength up to a certain limit. Once the optimal limit is surpassed, there is a degradation in properties due to uneven particle distribution and ineffective interaction with the matrix.

For small boats (e.g., 5 GT), the material strength requirements are generally more flexible compared to large ships, but they must still be safe for maritime operations. Based on references

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from the Indonesian Classification Bureau (BKI) standards, technical literature, and general ISO guidelines for Fiberglass Reinforced Plastic (FRP) (e.g., ISO 12215-5), the commonly used minimum strength standards for small boats (especially hulls and main structures) are as follows: minimum tensile strength ≥ 50–55 MPa; minimum flexural strength ≥ 100 MPa; and minimum elasticity modulus (flexural or tensile modulus) ≥ 2000–3000 MPa. In this study, the tensile test results show that the 20% powder composition provides the highest tensile stress of 113.23 MPa, higher than the fiberglass without any mixture (100.57 MPa). Therefore, the 20% shell powder composite mixture can be recommended as a material for making small boats (<5 GT). Meanwhile, the highest flexural strength value of 192.38 MPa was obtained from the 15% shell powder composition, which is recommended as a mixture material for boat construction (<5 GT) based on BKI's minimum flexural strength standard.

The study by Ratik et al. in 2020 compared the tensile strength between pure fiberglass composites and those mixed with hemp fibers. The results showed that fiberglass composites had a tensile strength of 138.65 MPa, while the composites with hemp fibers only reached 25.17 MPa, indicating a significant decrease in tensile strength. Therefore, mixing fiberglass composites with hemp fibers is not recommended as a standard material for making small boats, as their tensile strength is below the BKI standard (Harefa, 2023; Galbi et al., 2021; Manik et al., 2021; Hafiz & Sulisetyono, 2022).

A study by Ahmad Nayan et al. in 2022 used shell powder as a reinforcement in epoxy composites. The test results showed that at a volume fraction of 40% and a particle size of 160 mesh, the average tensile strength reached 103 MPa. Observations using SEM revealed good fracture morphology in the composites with a filler size of 200 mesh and a filler composition of 40%. Shell powder in this study can be recommended as a material for making small boats (Nayan & Hafli, 2022).

A study by Rahmat Aziz evaluated the use of chicken feathers as a substitute for mat fibers in fiberglass composites. The tensile test results showed that composites with chicken feathers had the highest tensile strength of 3.51 kN. However, the conclusion of the study is that chicken feathers are not suitable as a replacement for mat fibers in fiberglass production. This material is also not recommended for making small boats (Zuhuri et al., 2023). The study by Mahardi and Andi Ard in 2020 examined hybrid composites consisting of unsaturated polyester, kenaf fibers, and $CaCO_3$ powder. The composite with 5% $CaCO_3$ by weight showed the highest flexural strength of 74.87 MPa (Waluyo & Maidhah, 2020). Shell powder can be recommended as a composite material for making small boats.

Conclusion

In this study, the tensile test results showed that the 20% shell powder composition provided the highest tensile strength of 113.23 MPa, which is higher than fiberglass without any mixture (100.57 MPa). Therefore, the 20% shell powder composite mixture can be recommended as a material for making small boats (<5 GT). Meanwhile, the highest flexural strength of 192.38 MPa was achieved with a 15% shell powder composition, which is recommended as a mixed material for making boats <5 GT based on the BKI flexural strength standard. In this study, the increased strength of samples reinforced with various compositions of green shell powder compared to the control sample occurred due to the strong bond between the fibers and the matrix. Thus, when the shell powder composition percentage is increased in the resin mixture, the fibers' ability to distribute the load decreases. In this study, the flexural strength with variations in the shell powder composition was able to exceed the flexural strength of the control sample, as the control sample was less effective in distributing the load evenly.

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In general, the statistical results indicate that variations in material composition have a significant effect on most mechanical properties, particularly on strength and flexibility under bending loads. This suggests that selecting the right composition can improve the mechanical performance of the material according to the structural application needs. Further research could be conducted, particularly on the environmental aspect of using GMS powder in the fiberglass boat manufacturing mixture, as it can reduce the impact of green shell waste. Additionally, it would provide valuable information to the public and shipyards about the need for fiberglass materials mixed with green shell powder. The gratitude is extended to the Center for Marine and Fisheries Education (Pusdik KP) of the Ministry of Marine Affairs and Fisheries for providing the 2023-2025 Master's Degree Scholarship Program and to all the members of the Polytechnic of AUP Jakarta.

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