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Research Article

Recycled Polypropylene, Coco Peat, and Rice Straw Composite Board as an Alternative Material for Fishing Vessel Upper Structure

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Abstract
While traditional shipbuilding relies heavily on materials such as steel, fiberglass, aluminum, and timber, the sustainability of wooden fishing vessels is increasingly challenged by severe timber supply shortages. This study investigates the feasibility of developing eco-friendly composite panels using agricultural waste, specifically coco peat powder and rice straw, combined with a recycled polypropylene (PP) thermoplastic matrix as a sustainable alternative for the upper structures of fishing vessels. The composite panels were designed to achieve a target density of 1 g/cm³ and fabricated using a hot-pressing process at 190°C and a pressure of 10 N/mm² for 10 mins, with various filler-to-matrix ratios investigated. The mechanical properties of the resulting composites were benchmarked against those of traditional maritime timber species classified as K1 and K2, in accordance with the shipbuilding structural guidelines specified in SNI 01-7210-2017. Mechanical characterization included tensile testing (ASTM D638-22), flexural testing (ASTM D790-17), and a modified compression test (ASTM D695-23). The experimental results revealed that formulation P4, comprising 20% coco peat powder, 30% rice straw, and 50% recycled PP, achieved a compressive strength of 55.72 N/mm², substantially exceeding the benchmark values for K1 (46 N/mm²) and K2 timber (19.21 N/mm²). Furthermore, P4 exhibited the highest flexural strength among the formulations investigated, reaching 41.72 N/mm² and outperforming the K2 timber benchmark of 32.62 N/mm². These findings highlight the potential of agricultural-waste-based composites as sustainable alternatives to conventional timber for the upper structures of fishing vessels.

Keywords: Coco peat, Composite, Fishing vessel, Recycled polypropylene plastic, Rice straw

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1 Introduction

The increasing need for fish for human consumption encourages an increased demand for the number of fishing vessels. According to data from the Indonesian Ministry of Maritime Affairs and Fisheries, in terms of dimensions, it is known that 90% of fishing vessels in Indonesia are dominated by those under 30 gross tons (GT). At the end of 2015, there were 3,160 fishing vessels in Indonesia weighing under 30 GT. The number of fishing vessels increased in 2016-2017 to 4,041 units. Generally, materials used to make ships include wood, aluminum, fiberglass, and steel. Wood is a material that is widely used by traditional fishermen as the main material for making boats [1]. However, the availability of wood is diminishing due to the high demand for wood for various purposes, driving deforestation, while the supply of wood from industrial plantation forests is still limited [2], [3]. The increase in demand for fishing vessels has forced shipyards to look for alternative raw materials other than wood for shipbuilding.

Alternative raw materials for shipbuilding that are currently commonly used are glass fiber-based materials. However, glass fiber-based materials have the potential to pollute the environment at the end of their use. Formaldehyde in fiberglass can generate high chronic toxic and carcinogenic risks to health [4]. In recent years, upcycling post-consumer thermoplastics reinforced with lignocellulosic agricultural residues has emerged as a sustainable strategy for fabricating eco-friendly wood-plastic composites (WPCs) [5]. However, due to the limitations already mentioned, the use of wood has begun to be replaced by the use of various natural fibers, for example, coco peat or rice straw. The chemical components of coconut fibers and rice straw consist of cellulose, hemicellulose, and lignin. Coconut coir fibers are a material that contains quite high amounts of lignocellulosic materials, namely 34,9% cellulose, 18% hemicellulose, and 29,8% lignin [6]. Rice straw has a cellulose content of around 28-36 %, 9-14% silica, 15-20% ash, and 12 -16 % lignin [7].

Polypropylene (PP), one of the most popular thermoplastics, was created in 1951 [8] and is one of the easiest to process and least expensive conventional thermoplastic polymers. The escalating global reliance on plastics has generated severe environmental challenges. Globally, annual plastic production exceeds 400 million metric tons (Mt), with approximately 350 Mt converting into plastic waste each year [9]. Moreover, its greatest benefit is its resistance to high temperatures, which makes PP particularly suitable for a variety of applications [10]. The advantage of PP plastic is that it can be recycled for the manufacture of other products. It can be used as a matrix in plastic composites and natural fibers [11].

Composite manufacturing techniques have been increasingly developed, for example, with the use of 3D printing technology. PP-based 3D printing filaments have been developed using basalt fiber [12], carbon fiber [13], and hemp fiber [14]. In addition, optimization of process parameters and precise control during the extrusion process have been developed to produce ready-to-use PP-based 3D printing filaments [15]. However, 3D printing technology has not been able to be applied by fishermen on the coast of Indonesia. Therefore, the technology for producing recycled PP composite boards using a hot-pressing machine still needs to be developed to produce composite boards that can be used for shipbuilding materials by Indonesian fishermen.

Various composites made from PP as a matrix and natural fibers as a filler were produced. Polypropylene-reinforced benzoyl-treated kenaf and sugar palm fiber composites were developed to produce a handgrip automotive prototype [16]. On the other hand, a composite of PP and kenaf fibers was utilized as the core of fiber-metal laminates to produce a hybrid composite [17]. Composites of PP and coconut fibers or rice straw as fillers have been widely developed. An airbag cover for automotive safety was produced from PP, and 5% coconut fiber in the form of a layered hot-pressed composite showed a tensile strength of 25.12 MPa and a bending strength of 35.94 MPa [18]. The use of 10% coconut fiber in the PP matrix is able to produce composites with higher tensile strength, bending strength, and impact resistance compared to PP without the addition of fiber. However, the use of 20% and 30% coconut fiber produces composites with lower mechanical properties than PP without the addition of coconut fiber [19]. On the other hand, PP composites with the addition of rice straw fiber (20%, 40%, 50%, 60%) showed a compressive strength between 84 Kgf/cm^2 or 8.24 MPa and 113 Kgf/cm^2 or 11.08 MPa, with a compressive strength ranging from 5.4 to 8.9 MPa [20]. However, so far, there are no references on the utilization of a mixture of coco peat and rice straw fiber, which have different chemical compositions in the PP matrix. Especially composites with a matrix of recycled PP.

To address this research gap, the hybrid utilization of coco peat and rice straw is proposed in this study. Coco peat offers high lignin content and hydrophobic characteristics that mitigate moisture absorption, whereas rice straw provides substantial cellulose and silica content that enhances structural stiffness. Combining these two complementary agricultural wastes within a recycled polypropylene (rPP) matrix provides a novel hybrid biocomposite engineered to meet the structural demands of traditional fishing vessel upper structures. The characteristics of composite boards are influenced by the composition of materials used. This study analyzes the combination of coco peat and rice straw to substitute wood material as a filler in recycled polypropylene (PP) plastic composite, which has not been widely discussed by other researchers. Variations in the composition of coco peat and rice straw were used and processed with recycled PP using a rheomixer machine at a certain temperature, rotor speed, and time to produce a compound. Furthermore, the compound was molded with a hot-pressing machine into composite boards. The mechanical properties of the produced plastic composite board were then compared with Mahang wood (K1) and Medang wood (K2) as wood standards based on the Indonesia Classification Bureau (BKI 2023) [21] and Indonesia National Standard (SNI 01-7210-2017) [22] concerning species of wood for shipbuilding in Indonesia. The results of this research are expected to be a reference for the development of environmentally friendly materials for shipbuilding.

2 Materials and Methods

2.1 *Materials*

The materials used in this study were rice straw (Figure 1a) from harvested rice fields in West Java, Indonesia, and coco peat (Figure 1b) from a coconut fiber processing plant in West Java, Indonesia, as fillers, and recycled polypropylene (recycled PP) plastic as the matrix. The recycled PP (Figure 1c) was collected from a used commercial water cup, sorted, washed, and shredded into small flakes with a maximum length of 5 mm. Initially, rice straw and coco peat were air-dried and crushed using a hammer mill machine. Afterward, a sieving process was carried out to obtain a rice straw and coco peat powder size that passed through a 60-mesh sieve. Maleic anhydride grafted polypropylene (MAPP) was used as a coupling agent. For comparison, flexural strength and compressive strength tests were also conducted on traditional woods commonly used as materials for fishing vessels: Mahang wood (K1) and Medang wood (K2).



Figure 1: Rice straw (a), coco peat (b), and shredded recycled polypropylene (c).

2.2 *Raw materials preparation before mixing*

Coco peat and rice straw were dried under sunlight, followed by oven drying at 80°C for 12 hours to obtain a material with a moisture content of less than 5%. Afterward, the raw material was processed using a hammer mill followed by a disc mill to refine the material size. Coco peat and rice straw powder were screened so that the powder passed through a 60-mesh sieve. Coco peat and rice straw powder were put in a tightly closed container before further processing. Plastic waste (recycled PP) from a drinking water cup was chopped to 0.5 – 1 cm in width and length. Each raw material was weighed using a digital scale according to the composition (Table 1).

Table 1: Formulation of recycled polypropylene, coco peat, and rice straw composites.

Samples codes	rPP (g)	Coco peat (g)	Rice straw (g)	MAPP (g)
P1	25.0	25.0	0	1.25
P2	25.0	15.0	10.0	1.25
P3	25.0	12.5	12.5	1.25
P4	25.0	10.0	15.0	1.25
P5	25.0	0	25.0	1.25

*PP: polypropylene, MAPP: maleic anhydride polypropylene.

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2.3 *Coco peat and rice straw chemical component analysis and fiber length measurement*

The first step in making composite boards was preparing the raw materials. Coco peat and rice straw were sorted and air-dried. Coco peat and rice straw were then characterized, including water content (TAPPI T 264 cm-22 "Preparation of wood for chemical analysis") [23], ash content (TAPPI T 211 om-02 "Ash in wood, pulp, paper and paperboard") [24], extractive substance content (TAPPI T204 cm-97 "Solvent extractives of wood and pulp") [25], holocellulose content, lignin content, and alpha-cellulose content (TAPPI T 264 cm-22 "Preparation of wood for chemical analysis) [23]. Measurement of the length of rice straw and coco peat fibers was carried out first by taking a microscope photo of the cross-section of the composite. After that, the length of rice straw and coco peat fibers was calculated using ImageJ software.

2.4 *Material mixing*

Recycled PP plastic flakes, MAPP granules, coco peat, and rice straw powder were mixed manually. The total weight of the mixed materials was 50 g. Material compounding was carried out with a rheomixer (HAAKE Polylab OS, Thermo Scientific, USA) for 10 mins at 180°C and a rotor speed of 80 rpm. The formulation of plastic composites is presented in Table 1.

The selection of the five formulations was established based on an extreme-vertices mixture design at a constant 50 wt.% total filler content. Single-filler composites P1 (50% coco peat) and P5 (50% rice straw) served as bounding baselines, whereas formulations P2 (15:10), P3 (12.5:12.5), and P4 (10:15) systematically examined hybrid substitution ratios of 3:2, 1:1, and 2:3. Formulation P4 was determined to be optimal because it achieves an ideal balance between the skeletal reinforcement of high-aspect-ratio rice straw fibers and the interstitial pore-filling capability of finer coco peat particles, thus preventing catastrophic micro-void coalescence.

2.5 *Tensile test pieces preparation by injection molding*

The compound, which is a mixture of plastic with coco peat powder and rice straw powder produced from a rheomix machine, was molded into dumbbell-shaped test pieces, type V, according to ASTM D790 [26] by a mini injection molding machine (HAAKE Minijet Pro, Germany). As a sample holder, a cylinder was heated to 180°C before being filled with the composite compound. The cylinder filled with the compound was then put on a mold that had been heated to 40°C, in the injection machine. Afterward, the injection process was conducted at a pressure of 750 bar for 20 secs.

2.6 *Flexural and compression test pieces preparation by hot pressing*

The composite board was produced by a hot-pressing machine (Yasuda, Japan) using an internal mold dimension of $20\ \text{cm} \times 10\ \text{cm} \times 1\ \text{cm}$ ($200\ \text{cm}^3$) equipped with mechanical stops to enforce a nominal target density of 1.0 g/cm³. Exactly 200 g of the compounded mixture was placed into the mold, which was pre-lined with Teflon paper to facilitate uniform thickness distribution. Following fabrication, the actual densities of the composite formulations were verified experimentally via the Archimedes immersion method (ASTM D792), yielding values of 0.813 g/cm³ (P1), 0.875 g/cm³ (P2), 1.171 g/cm³ (P3), 1.042 g/cm³ (P4), and 1.042 g/cm³ (P5), reflecting slight differences in filler compressibility and true density. The mold containing the compound was then put into a hot press machine, which had previously been heated. The composite specimens were fabricated via a thermal pressing process sustained at 180°C and 10 N/mm² for a 15-minute duration, exploring various filler-to-matrix ratios. The composite boards produced were then conditioned at room temperature for 7 days before being cut according to the test standard size. The process of preparing raw materials and manufacturing composites is presented in Figure 2.

2.7 *Composite thermal properties analysis*

2.7.1. Thermal gravimetry analysis (TGA)

With about 6 mg of plastic composite, a thermogravimetric test was carried out using a thermogravimetric analyzer (Perkin Elmer TGA 4000, USA). The temperature increased from 25°C to 600°C with a temperature scan rate of 10°C per minute. The mass degradation was observed during changes in temperature and time while heating. The TGA consists



Figure 2: Raw material preparation processing, and composite manufacturing.

of a furnace with a programmer and temperature controller—a thermo-balance—and a sample vessel attached to a precision microbalance. Samples were weighed on a balance in a closed furnace. The samples used were plastic composites, so-called P1, P2, P3, P4, and P5.

2.7.2 Differential scanning calorimetry (DSC)

The differential scanning calorimetry (DSC) analysis (DSC 4000 Perkin Elmer, USA) of the plastic composite was performed. Plastic composite samples (P1, P2, P3, P4, and P5) of 5 mg were heated from -20°C to 350°C, then cooled from 350°C to 25°C, with a temperature scan rate of 10°C per minute.

The degree of crystallinity of the composite was calculated according to Equation (1):

$$Xc\ (\%) = (\Delta\ Hm)/(\Delta\ H°m)\times 1/f \times 100 \quad (1)$$

Where Xc is the degree of crystallinity (%), Δ Hm is the enthalpy of fusion of different blends, Δ Hºm is the enthalpy of fusion of 100% recycled PP, and f is the recycled PP fraction in the blend composition.

2.8 *Composite mechanical properties analysis*

2.8.1 Tensile tests

The tensile strength test was carried out using the Universal Testing Machine (UTM) (Shimadzu AGS-X, Japan). Tensile tests were carried out using specimens according to ASTM D638-22 (Standard Test Method for Tensile Properties of Plastics) type V [27]. The tensile test was carried out at a load speed of 30 mm/min and a load cell of 5 kN by 3 times replications.

2.8.2 Flexural test

In accordance with ASTM D790-17 [26], the flexural strength test was carried out using a universal testing machine (Shimadzu AGS-X, Japan) in three-point bending mode. The flexural test was carried out at a load speed of 10 mm/min and a load cell of 5 kN. The samples were tested with 3 replications. The sample size for the flexural test was 200 mm x 20 mm x 10 mm. The flexural test of samples of Mahang wood (K1) and Medang wood (K2) was conducted in the same dimensions and under the same testing conditions as the plastic composite.

2.8.3 Compression test

In accordance with ASTM D695-23 (Standard Test Method for Compressive Properties of Rigid Plastics) [28], compression tests were carried out using a universal testing machine (Shimadzu AG-IS Autograph, Japan). The compression test was carried out at a load speed of 1 mm/min and a load cell of 50 kN. The samples were tested with 3 replications. The sample size for the compression test was 40 mm x 10 mm x 10 mm. The compression test of samples of Mahang wood (K1) and Medang wood (K2) was conducted in the same dimensions and under the same testing conditions as the plastic composite.

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2.9 *Composite morphology analysis*

The surface morphology and microstructural features of the composites were observed using a digital microscope (Keyence VHX 6000, Japan) with 200x magnification and a scanning electron microscope (Thermo Scientific PRISMA E, USA). The observation conditions using SEM were the following: acceleration voltage at 10 kV, pressure 5 x 10^{-3} pa, current 0.25 nA, with 500x magnification. Additionally, energy-dispersive X-ray spectroscopy (EDX) attached to the SEM was employed to analyze the elemental composition and distribution within the composites.

2.10 *Data analysis*

The mechanical property tests, namely tensile test, flexural test, and compression test, were conducted on 3 test pieces. The results obtained were compared for each composition, and then a statistical test was carried out. Analysis of variance (ANOVA) and Duncan's Multiple Range test were carried out at a confidence interval of $\alpha = 0.05$. Statistical analysis was carried out using Excel and SPSS applications.

Mechanical testing was conducted with three replicate specimens per group ($n = 3$) that complied with strict dimensional tolerance criteria. Analysis of variance (ANOVA) and Duncan's post-hoc tests demonstrated high statistical robustness, as evidenced by large F-values (F=447.592 for MOR, F=28.627 for compression) and low within-treatment variance (p-value < 0.001), confirming that the reported mechanical differences reflect genuine compositional effects.

3 Results and Discussions

3.1 *Chemical components of rice straw and coco peat*

Extractive substances in a material greatly affect the gluing process, the rate of curing of the adhesive, and the durability of the board that will be produced [29]. In this research, the chemical components in rice straw and coco peat as raw materials for manufacturing composite boards were analyzed by their content of extractive substances, lignin, cellulose, and hemicellulose. Lignin acts as an adhesive in wood, together with cellulose, to form lignocellulose, so that wood becomes hard and stiff [30]. Cellulose is a polysaccharide group that will be broken down into a monosaccharide group, namely glucose. This cellulose is surrounded by lignin, which inhibits the process of saccharification (breaking down polysaccharide groups into monosaccharide groups). The function of cellulose is to strengthen the plant cell walls, acting as a water binder [31]. The chemical components of coco peat powder and rice straw as the material for making plastic composite boards are presented in Table 2.

Ash is the remaining part of the combustion process, which no longer contains the carbon element, and the main element of ash is silica [33]. Silica also has the potential to be used as an antibacterial agent in composite boards [34]. Lignin, together with hemicellulose, forms a natural glue, which is an adhesive that provides strong mechanical properties [35], [36].

Lignocellulosic materials generally contain three main chemical components, namely cellulose, lignin, and hemicellulose. An interesting result is shown in Table 2, where rice straw contains hemicellulose and ash in quite significant amounts, namely 23.5% and 20.58%, respectively, although the amount of cellulose is still dominant, namely 26%. On the other hand, coco peat contains lignin in an amount of 33.83% and cellulose of 29.92%. The composition of these chemical components can affect the thermal and mechanical properties of the composite, which will be explained further in the following section.

Table 2: Chemical components of rice straw and coco peat.

Chemical components	Research result		Literature	
	Rice straw (%)	Coco peat (%)	Rice straw (%) [7], [29]	Coco peat (%) [6], [32]
Water content	8.04	9.06		
Ash content	20.58	12.17		
Extractive content	6.29	3.42		
Lignin	24	33.83	16.62; 12.3	41; 45
Cellulose	26	29.92	37.71; 36.0	27; 43
Hemicellulose	23.5	13.35	21.99	18; 20

Table 3: Thermal properties of recycled polypropylene, coco peat, and rice straw composites.

Sample	Tm [°C]	ΔHm [J/g]	Recycled PP fraction	Proportional Crystallinity [%]	Tc (°C)
Recycled PP	158.22	45.94	1	nd	115.22
P1	158.62	42.64	0.5	46.41	119.75
P2	160.12	37.54	0.5	40.86	120.11
P3	162.06	55.63	0.5	60.55	119.44
P4	159.40	31.64	0.5	34.44	119.79
P5	159.45	31.09	0.5	33.84	118.76

*Tm: Melting temperature, ΔHm: Melting enthalpy, PP: polypropylene, Tc: Crystallization temperature.

3.2 *Thermal properties of composites by DSC analysis*

The plastic composite board was tested for crystallinity and thermal properties using a Differential Scanning Calorimetry (DSC) apparatus. The melting temperature was initially measured after the sample was heated in the DSC apparatus. As shown in Figure 3a and Table 3, the melting temperatures (Tm) of all plastic composite types are presented in the range of 158.22-162.06°C. Plastic composite P3 shows the highest melting temperature (162.06°C) among other composites in this study. The difference in the amount of filler addition (coco peat and rice straw) into plastic composite boards only slightly changes the melting temperature of the plastic composite board.

The highest composite's melting temperature (162.06°C) was observed in composite P3, which contains the same amount of coco peat and rice straw powder. The lignin component in coco peat and silica (presented as an ash component) in rice straw show a synergistic interaction to increase the melting temperature of the recycled PP-based composite. Rice straw ash's high silica content offers superior thermal insulating qualities [37]. In line observations on bio-filled nanocomposites by [38], the incorporation of secondary inorganic/silicate fillers disrupts the regular crystalline order of cellulose while modifying surface roughness and mechanical load-transfer pathways. As reported by El Moustaqim *et al.,* the high value of glass transition temperature (Tg) would be related to the high molecular mass and a high degree of cross-linking in the lignin [39].

The proportional crystallinity in this study refers to the composite's crystallinity, compared to recycled PP crystallinity, based on the enthalpy of fusion from heating scans by DSC analysis. From the data in Table 3, the P3 composite shows the highest proportional crystallinity (60.55%). The crystallinity of the majority of commercial PP is intermediate, ranging from 40 to 60%. The melting point of commercial isotactic PP ranges from 160 to 166°C, depending on the atactic substance and crystallinity. In contrast, syndiotactic PP with a 30% crystallinity has a melting point of 130°C [40]. Meanwhile, in lignocellulosic materials, cellulose has higher crystallinity than lignin and hemicellulose, because it has extensive hydrogen bonding present in the crystalline regions [31].

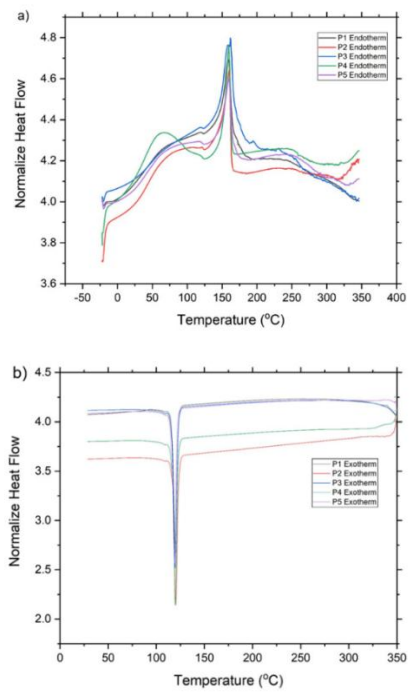


Figure 3: Differential scanning calorimeter thermogram of recycled polypropylene, coco peat, and rice straw composites by heating scan (a) and cooling scan (b).

The P3 composite comprises 50%wt recycled PP, 25%wt coir pith, and 25%wt rice straw. Therefore, when the proportion of coco peat and rice straw is equal in the recycled PP-based composite, the cellulose in coco peat and rice straw stimulates the composite crystallinity. On the other hand, the P5 composite shows the lowest proportional crystallinity, due to the higher content of amorphous fractions such as lignin, hemicellulose, and ash.

From the cooling stage analysis, the crystallization temperatures of P1, P2, P3, P4, and P5 plastic composites are shown in Figure 3b and Table 3. It was shown that at a range temperature of 118~120ºC. The melting point and crystallization point are still dominated by the melting temperature and the crystallization temperature of recycled PP, which is the matrix component in this plastic composite. This shows that the composition of coco peat and rice straw in the plastic composite board only slightly affects the melting and crystallization temperature of the plastic composite board.

3.3 *Thermal properties of composites by TGA analysis*

The degradation characteristics of a composite material when heated at a certain temperature range can be analyzed using a thermogravimetric analyzer. Figure 4 shows the TGA thermogram of plastic composite boards P1, P2, P3, P4, and P5 at a temperature range of 25°C to 600°C. The TGA thermogram shows the degradation steps at the set temperature and the maximum weight loss of the sample.

The thermogram of composites in Figure 4a shows that changes in mass can be divided into three areas. In the first area, starting from room temperature to 100°C, there is a reduction in mass due to the evaporation of water. The tested composite board showed good stability up to 250°C, indicated by a relatively flat TGA curve. In this region, the mass change is not significant, and the sample is thermally stable. Afterward, slightly diminishing curves between 250°C and 375°C occur, which indicate the presence of a decomposed component. More significant decomposition was detected in the temperature range of 400°C to 500°C, where almost all the organic matter in the coco peat and rice straw decomposed into carbon. In the last region, in the temperature range of 500°C to 600°C, the composite board undergoes slow thermal decomposition.

The addition of rice straw powder to recycled PP shows a positive influence on increasing composite boards' thermal stability, although the silica content will decrease at a temperature of 700°C [10], [41], [42]. This statement is in accordance with the graph in Figure 5, where the curves of the composite boards P3 and P5, which contain more rice straw powder, shift to the right, which means that the composite boards degrade at a higher temperature compared to the composite boards P1, which contain coco peat. It is well known that wood flour decomposes in the order of hemicellulose (200-300°C), cellulose (300-400°C), and lignin (200-900°C) [43]. Recent insights in [44] highlight that nanolignin possesses an exceptionally high specific surface area and multi-reactive functional groups, acting as a natural carbonizing agent to enhance flame retardancy and thermal stability in bio-based polymer composites.

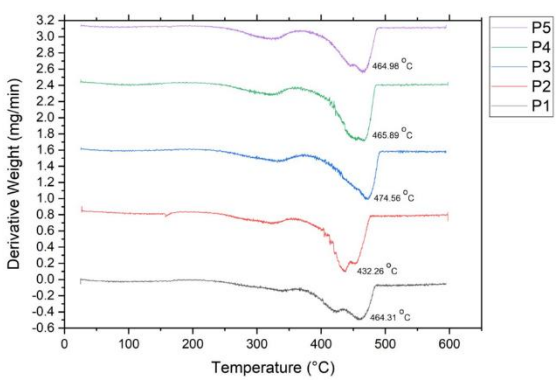


Figure 4: Thermal gravimetry analysis thermogram of recycled polypropylene, coco peat, and rice straw composites (temperature vs derivative weight).

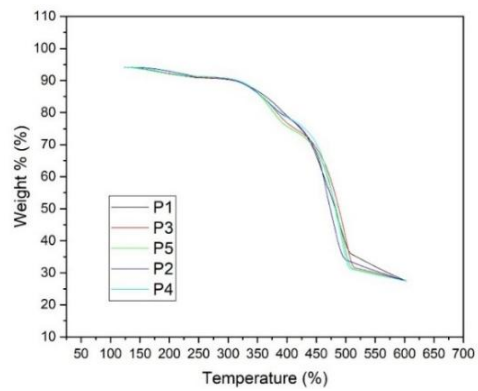


Figure 5: Thermal gravimetric analysis thermogram of recycled polypropylene, coco peat, and rice straw composites (temperature vs weight).

The P3 composite has higher stability among other composites in this study during heating, especially in a temperature range of 375~500°C, as indicated in Table 4, with the lowest mass loss (54.880%), the highest temperature to degrade 50% mass (450.96°C), and the highest residual yield at 500°C (21.153%). The P3 composite board also exhibited the best heat resistance compared to the other composite boards in this study. This was demonstrated by the highest degradation temperature, namely 474.56°C. As already mentioned before, P3 composite contains coco peat and rice straw in equal amounts.

Coco peat has a higher lignin content (33.83%) compared to rice straw (24%). In contrast, rice straw has higher silica content, as represented by ash content (20.58%), compared to coco peat (12.17%). Due to its complexity, which includes numerous interconnected phenolic rings with different branches and can be broken down into multiple stages, lignin degradation takes place over a broad temperature range [45]. Lignin degradation in the temperature range of 180 - 350°C occurred due to the elimination of volatile gases and low-molecular-weight compounds by the degradation of carbohydrates, α and β aryl-alkyl-ether linked components of lignins [45]. Shakiya *et al.,* explain rice straw degradation during TGA analysis in the temperature range of 30~900°C. Removal of moisture from rice straw occurs in the first region from 30 to 110°C, hemicellulose and cellulose decomposition occur at 190~400°C and lignin degradation (passive pyrolysis) starts from 190 to 900°C [46].

The TGA curve from this analysis provides information about the mass change in the plastic composite board material during the heating process. As the temperature increases, the plastic composite boards experience an increase in mass degradation due to the oxidation process. As reported by Mofokeng *et al.,* pure PP shows a single degradation step, while the composites show two degradation steps [47]. The recycled PP-coco peat-rice straw composite material shows three degradation steps, which are influenced by the cellulose, hemicellulose, and lignin content of coco peat and rice straw. It is noteworthy that while composite P3 displayed the highest proportional crystallinity (60.55%) and peak degradation temperature (474.56 °C) owing to the balanced nucleating synergy of lignin and silica at a 1:1 ratio, the superior mechanical performance was achieved in formulation P4. This highlights that in bulk composite boards, macroscopic load transfer is predominantly controlled by fiber aspect ratio, slenderness distribution, and structural interlocking, which exert a greater influence on flexural and compressive resistance than polymer crystallinity alone.

3.4 *Tensile strength properties of composites*

The tensile test pieces of plastic composite were kept at room temperature for 7 days before testing. The tensile test pieces were fabricated using an injection molding process under identical thermal and high-pressure conditions (750 bar at 180°C). This consistent cavity packing ensured uniform volumetric filling, minimized air void entrapment, and eliminated density fluctuations among the tested formulations, thereby allowing direct comparison of their absolute tensile strength and modulus without density-induced variance. Figure 6a shows the results of the tensile strength test of the plastic composite, which are not significantly different. This is because the test pieces were produced by injection molding with controlled temperature and pressure. The adequate pressure given during the injection molding process produces test pieces with compact interaction between the filler and the matrix, which minimizes air voids contained in the test piece (plastic composite), thus increasing the plastic composite density [48].

Table 4: Recycled polypropylene, coco peat, and rice straw composites' mass loss during heating by thermal gravimetric analysis.

Composites	Mass Loss (%) at 120-250°C	Mass Loss (%) at 250-375°C	Mass Loss (%) at 375-500°C	T5% (°C)	T50% (°C)	Residual yield (%) at 500 °C
P1	4.548	18.598	57.418	229.27	435.46	19.909
P2	3.828	17.002	58.691	247.52	434.95	19.342
P3	4.136	20.405	54.880	244.05	450.96	21.153
P4	3.753	16.822	61.355	252.40	446.68	19.399
P5	3.768	21.133	55.379	248.79	444.18	19.669

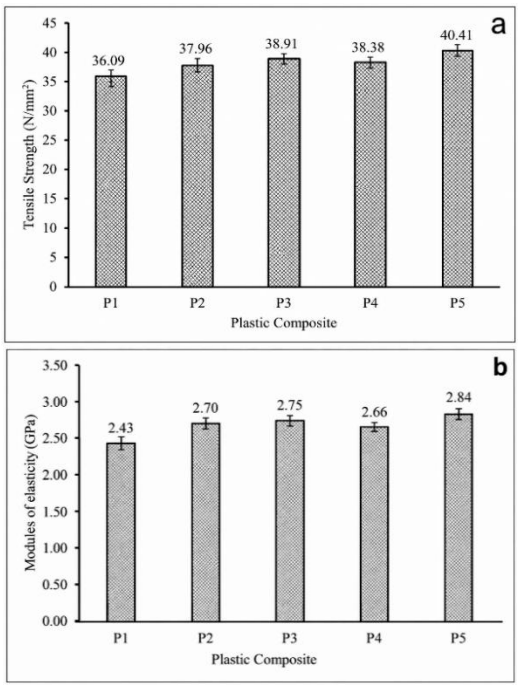


Figure 6: Tensile strength (a) and modulus of elasticity (b) of recycled polypropylene, coco peat, and rice straw composites.

Tensile strength is also affected by the bonds between materials. Furthermore, microfibrillated cellulosic fillers derived from agricultural biowaste promote smaller cell size distributions and facilitate intermolecular hydrogen bonding with polar polymer backbones [49]. In this study, the formulation uses MAPP as a coupling agent. MAPP is a modified polypropylene, made by attaching maleic anhydride molecules onto a standard polypropylene chain. This mixture acts as a bridge that helps coco peat and rice straw, as polar materials, attach to non-polar polypropylene. MAPP was used at a fixed concentration of 5% of the natural fiber weight (coco peat or rice straw) across all formulations, as the research did not focus on evaluating MAPP's effectiveness in the mixture of rPP, coco peat, and rice straw. The amount of MAPP used was slightly lower than the optimal amount recommended by [50] who specifically recommend 6% of the natural fiber weight in the composite. The decision to use 5% MAPP was made to reduce production costs while still achieving the required mechanical properties.

Holding the MAPP concentration constant at 5% of natural fiber weight across all formulations served to isolate the comparative effects of filler geometry and hybrid ratio, thereby eliminating compatibilizer dosage as a confounding variable. Although differences in specific surface area between coco peat and rice straw may cause localized variations in interfacial saturation, this fixed loading maintains cost-effectiveness while securing sufficient stress transfer across the polyolefin-biomass interface.

The presence of a small cavity can minimize the potential for initial cracks, which can potentially become fractures. Previous research [51] reported that, in general, the tensile strengths of the natural fiber-reinforced polymer composites increase with natural fiber content. The tensile strength test was carried out using ASTM D 638 standards. The tensile strength value for 10% fiber was 25.14 MPa, while for 20% fiber, the tensile strength value increased to 26.15 MPa. Misri *et al.,* produced hybrid composites from woven glass/sugar palm fibers reinforced unsaturated polyester, with an 18% fiber fraction for small boat application. For the sugar palm/glass fiber hybrid composite, the highest measured values for tensile stress and strain were roughly 43 MPa and 3.4%, respectively, while the lowest values were roughly 27 MPa and 2.3% [52].

Figure 6b shows the modulus of elasticity of plastic composite boards with varied compositions of coco peat and rice straw. The highest tensile strength and modulus of elasticity values were shown in the P5 plastic composite, while the lowest tensile strength and modulus of elasticity values were shown in the P1 plastic composite. Previous research [53] shows that the elastic modulus value decreases simultaneously with the reduction in fiber composition in the composite. A decrease in the amount of husk or natural fiber will reduce the elasticity value of the composite board. With a composition of 15% natural fiber, the value was 130.24 MPa, but with a composition of 10% fiber, the elasticity value was 1,916.46 MPa. On the other hand, the sugar palm fiber composite's value for tensile modulus was 1.586 GPa, while the sugar palm/glass fibers hybrid composite's tensile modulus value was 1.840 GPa [52].

This microstructural disparity explains why tensile strength was statistically insensitive to filler formulation (p-value = 0.101), whereas tensile modulus was significantly affected (p-value = 0.002). The high packing pressure (750 bar) in injection molding generated a cohesive rPP skin layer that dictated ultimate tensile yield strength uniformly across all samples. In contrast, the elastic modulus operates at low elastic strains and directly reflects filler stiffness; hence, replacing flexible coco peat with rigid, silica-containing rice straw fibers produced a continuous, statistically significant stiffening effect.

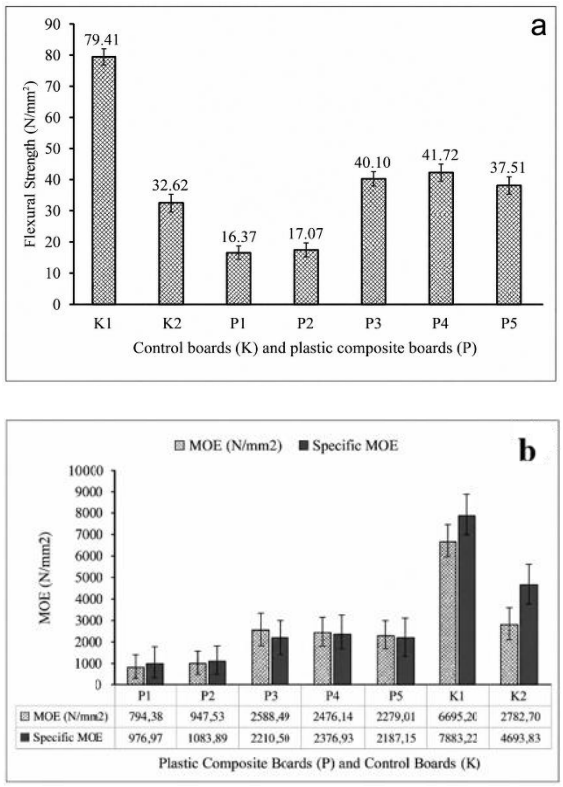


Figure 7: Flexural Strength (a) and modulus of elasticity by flexural test (b) of control boards (K1, K2) and plastic composite boards (P1, P2, P3, P4, P5).

3.5 *Flexural strength properties of composite*

When a composite board is given a load at the center of the composite board sample, which is placed on two supports, at certain spans (bending test), it will show the mechanical characteristics of the composite board in the form of flexural strength and stiffness (modulus of elasticity). The bending test was carried out by referring to the ASTM D-790-03 standard (Figure 7).

Although the MOE of composite P4 (2,476.14 N/mm²) is lower than that of K2 timber (2,782.70 N/mm²), its application in vessel upper structures remains highly feasible from a structural mechanics perspective. In boatbuilding engineering, the bending stiffness of a deck or partition panel is governed by its flexural rigidity (EI), which scales with the cube of panel thickness (h^3). The modulus deficit can be fully compensated by a modest 15–20% increase in panel thickness or by reducing frame stiffener pitch, providing equivalent deflection resistance with the added benefit of complete immunity to fungal rot and marine wood-boring organisms.

The measured average densities of the composite boards were 0.813 g/cm³ (P1), 0.875 g/cm³ (P2), 1.171 g/cm³ (P3), 1.042 g/cm³ (P4), and 1.042 g/cm³ (P5), while the control board exhibited densities of 0.852 g/cm³ for Mahang wood (K1) and 0.600 g/cm³ for Medang wood (K2). To eliminate the confounding effect of specimen density and isolate the fundamental reinforcement contributions of the constituent fibers, specific mechanical properties were evaluated alongside absolute values.

As illustrated in the comparative analysis (Figure 7b), the solid control boards (K1 and K2) demonstrated markedly superior stiffness, achieving specific MOE values of 7858.22 N/mm² and 4637.83 N/mm², respectively, owing to the continuous and oriented natural cell wall architectures inherent to natural wood. Among the composite formulations, the hybrid formulation P4 maintained the highest retention of specific modulus (2376.33 N/mm²). Interestingly, while composite P3 displayed the highest absolute MOE (2588.49 N/mm²) due to its higher compaction density, its specific MOE decreased to 2210.50 N/mm² upon normalization, revealing that the balanced 20% coco peat and 30% rice straw ratio in P4 offers superior intrinsic load distribution and matrix stiffening efficiency per unit mass.

The test results show that the flexural strength values of the P1 and P2 plastic composite boards were quite low compared to the P3, P4, and P5 boards, as presented in Figure 7a. Flexural strength tests were carried out by comparing plastic composite boards with control boards commonly used on traditional fishing boat upper structures. The control boards were indicated by the codes K1 and K2. The result of the flexural strength analysis on the K1 board was 79.41 N/mm^2, the K2 board was 32.62 N/mm^2, while the P4 plastic composite board was 41.72 N/mm^2. The test results showed that the flexural strength values of all composite plastic boards in this study were not as good as the flexural strength of K1 control boards. However, plastic composite boards of P3, P4, and P5 showed higher flexural strength values than those of the K2 control board. Thus, the plastic composite board with more rice straw composition produces composite boards with higher flexural strength values compared to boards with more coco peat composition. Lignocellulosic materials, including coco peat and rice straw, are susceptible to moisture due to hydroxyl groups in their cellulose chain, so they easily absorb

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water (hydrophilic). On the other hand, PP is a hydrophobic material. Therefore, to increase the cohesiveness and bond between wood particles and plastic, a coupling agent can be added to the wood-plastic composite board manufacturing process (Jian *et al.,* 2022). On the other hand, the uneven mixing of PP and filler during the mixing process can cause the strength of the composite to decrease [54]. Maleic anhydride grafted polypropylene (MAPP) in plastic composites serves to increase the adhesion and cohesiveness between coco peat or rice straw and recycled PP plastic. According to [55], a bond mechanism is formed between wood and plastic with the addition of maleic anhydride grafted polypropylene (MAPP).

Commercial natural fiber reinforced-polypropylene (PP) composites usually have a flexural strength between 30 and 85 MPa, which varies greatly depending on the kind of fibre, content loading (generally between 20 and 50 percent by weight), and the presence of coupling agents such as maleated polypropylene (MAPP). Natural fibre reinforcement greatly increases load-bearing capacity because neat polypropylene typically has a lower flexural strength (around 20 to 30 MPa).

PP composites incorporating 10% to 30% hemp fibers (10 mm in length) and a MAPP coupling agent (at 6% of the hemp fiber weight) exhibit flexural strengths ranging from 40.1 MPa to 77.7 MPa [50]. [56] developed a composite made from a virgin PP matrix with the addition of 10% to 30% of wood powder, rice husk powder, and a combination of wood powder and rice husk powder. The flexural strength of PP composites with wood powder, rice husk powder, or a combination of wood powder and rice husk powder ranges from 47.42-49.08 MPa, 39.52-51.00 MPa, 46.63 - 50.95 MPa, respectively.

In this research, the flexural strength values of composites P3, P4, and P5 (40.10 MPa, 41.72 MPa, and 37.51 MPa) were slightly lower than those of previous research composites due to the use of recycled polypropylene as the matrix. However, these flexural strength values were still higher than the flexural strength of Medang wood (K2), which was 32.62 MPa.

Similar to the flexural strength value of plastic composite boards, the modulus of elasticity (MOE) value of the P1 and P2 plastic composite boards was lower than that of P3, P4, and P5 plastic composite boards (Figure 7b). Based on the above results, the plastic composite board with the highest modulus of elasticity was the P4 plastic composite board with a composition of 20% coco peat, 30% straw, and 50% PP plastic, with the addition of 2.5% MAPP. The control board was indicated by the codes K1 and K2. The MOE test results on the K1 control board were 6696 N/mm^2, and the K2 control board test results had a MOE value of 2782 N/mm^2. The test results show that the MOE value of the control boards was better than that of all types of plastic composite boards. MOE shows the stiffness of a material. Control wood has a better MOE value because it is stiffer. Meanwhile, with plastic composites, the resulting boards are not as stiff as control wood because plastic is thermoplastic, easily softening in the presence of heat.

3.6 *Compressive strength properties of composite*

In the compressive strength test, two types of test boards were made, namely the plastic composite board and the control board. The plastic composite board that was produced by a hot-pressing machine was kept at room temperature for 7 days before testing.

The compressive behavior of the hybrid composite boards alongside traditional shipbuilding boards controls was evaluated in terms of both absolute compressive strength and normalized specific compressive strength (Figure 8). The measured average densities were 0.813 g/cm^3 (P1), 0.875 g/cm^3 (P2), 1.171 g/cm^3 (P3), 1.042 g/cm^3 (P4), and 1.042 g/cm^3 (P5), compared to 0.852 g/cm^3 for Mahang wood (K1) and 0.600 g/cm^3 for Medang wood (K2). In terms of absolute values, formulation P4 (20% coco peat, 30% rice straw, 50% rPP) exhibited the premier compressive strength at 55.72 N/mm^2, substantially outperforming both control K1 (46.00 N/mm^2) and K2 (19.21 N/mm^2). When normalized against material density to eliminate mass dependency, formulation P4 retained an exceptional specific compressive strength of 53.47 N/mm^2, which remains fully comparable to the benchmark boards K1 (53.99 N/mm^2) and superior to K2 (32.02 N/mm^2). Interestingly, while composite P3 displayed a high absolute compressive strength (45.26 N/mm^2), its specific value dropped to 38.65 N/mm^2 due to its elevated compaction density (1.171 g/cm3). This comparative normalization demonstrates that the synergistic combination of reinforcing rice straw fibers and interstitial coco peat filler in P4 provides optimal intrinsic load-bearing efficiency without relying solely on densification.

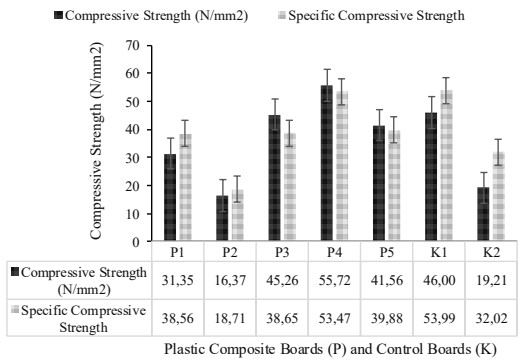


Figure 8: Compressive strength of control boards (K1, K2) and recycled polypropylene, coco peat, and rice straw composite boards (P1, P2, P3, P4, P5).

The compressive strength test of plastic composite boards was carried out using a Universal Testing Machine (UTM), which is equipped with additional tools (accessories) specifically used for compressive strength tests. Compressive strength test, in principle; The composite board is given a certain load and pressed until it cracks or even crumbles so that the maximum composite board's stress value (compressive strength) is obtained. It can be seen in Figure 8 that the compressive strength of the P4 plastic composite board was the highest, with a value of 55,72 N/mm^2, while the value of the K1 control board was 46 N/mm^2 and the K2 control board's compressive strength was only 19,21 N/mm^2. From these results, it is clear that the P4 plastic composite board was better than the K2 control board and the K1 control board. The value of the compressive strength test on the P4 composite board can be attributed to the uniformity of the plastic composite board compaction process when the hot-pressing process is carried out. The addition of 20% coco peat and 30% rice straw powder can enhance the plastic composite boards' toughness while bearing a load.

Commercially available wood-plastic composites (WPCs) and natural fiber-reinforced polypropylene (PP) composites typically feature compressive strength from 30 to 65 MPa, depending on fiber loading (30–50%), coupling agents, and fiber aspect ratio. Turkadze *et al.,* [57] reported that the compressive strength of composites made from PP and de-oiled tung powder (tung oil waste) ranges from 40.8 to 63.7 MPa. In this research, composites P3, P4, and P5 have comparable compressive strength, with values of 45.26 N/mm^2, 55,72 N/mm^2, and 41,56 N/mm^2, respectively.

Table 5 presents the analysis of variance (ANOVA) results of the mechanical test values of the plastic composite boards. The results showed that the values of flexural strength, compressive strength, and modulus of elasticity were significantly affected by the composition of the plastic composite board (p-value <0.05). Whereas, in the tensile strength test, the composition did not significantly affect the results of the plastic composite board test (p-value <0.05). The compound injection process with an even injection molding machine has an impact on the tensile strength test results.

Table 5: Analysis of variance (ANOVA) of plastic composites mechanical properties.

Properties	Mean square	F-value	p-value
Flexural Strength			
MOR	1396.865	447.592	0.000
MOE	1733051.830	8.423	0.001
Compressive Strength	646.258	28.627	0.000
Tensile Strength			
Tensile	6.970	2.596	0.101
ModElastic	0.079	9.588	0.002

* Values with a p-value lower than 0.05 are significantly affected, indicating the influence of the composition on the mechanical test results.

The novelty in this research is the combination of coco peat and rice straw fibers in polypropylene matrices, which will be beneficial for obtaining higher flexural strength and compressive strength, as indicated by composite P4, which consists of 50% PP, 20% coco peat, and 30% rice straw. Composite P4 has higher flexural strength and compressive strength compared to P1 (PP and coco peat) and P5 (PP and rice straw). These mechanical properties are a primary consideration for the use of composites in vessel upper structures.

Materials used for the upper structures of fishing vessels undergo deformation and degradation over time. Fishing vessels operating in open seawater are subjected to intense sunlight during the day, the impact of saline waves, and low temperatures at night. These conditions affect the mechanical properties of the composite materials. Therefore, further research is required to evaluate changes in mechanical properties under varying temperature, climatic, and loading conditions.

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3.7 *Distribution of fiber dimensions in composites*

The dimensions of the fibers are one of the important components that greatly affect the mechanical performance of plastic composite boards. Previous researchers revealed that whereas wood particle size has no observable impact on specific gravity, aspect ratio has the biggest impact on WPC strength and stiffness [58]. The P1 and P2 composite boards consist of more coco peat than rice straw fibers. On the other hand, the fiber length frequency distribution histogram shows that the P4 composite board has various length distribution values. In the P4 composite board, the composition of long rice straw fibers is greater than that of coco peat. Based on the graphs in Figure 9 and Figure 10, the distribution of fiber lengths and slenderness ratio in the P4 composite board is the most even compared to other composite boards. The evenly distributed fiber lengths in the composite resulted in a composite board with better flexural strength and compressive strength, according to the results of the mechanical tests that have been carried out. According to [59], when the fibers in flax/polypropylene (PP) composites were longer than 6 mm, there was no significant improvement in the stiffness, tensile strength, or impact strength. In their study of wood pulp/PP composites, Thumm and Dickson found [60] that reducing the length of pulp fiber from 1.3 mm to 0.8 mm significantly decreased the composite's flexural strength. However, only the longest fiber (3.0 mm) showed a significant improvement in impact strength with an Izod notch.

This also has to do with how long the natural fibers are in the P4 composite, which gives the plastic composite board its longitudinal strength. A more uniform pore distribution is suggested by the lengthy, fibrous structure of the bast. The greater aspect ratio that bast produces encourages strong reinforcement and efficiently transfers stresses from the matrix to the resin [61], [62].

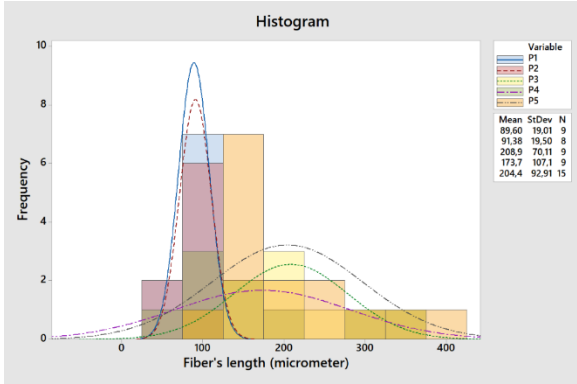


Figure 9: Histogram of fiber length.

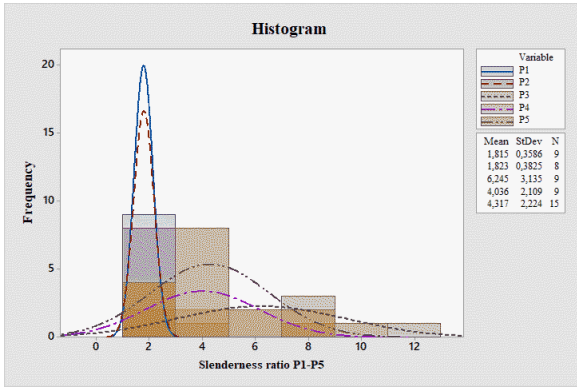


Figure 10: Histogram of slenderness ratio.

The challenge in industrial-scale production is ensuring the uniform dispersion of coco peat powder and rice straw fibers within the rPP matrix. To achieve uniform dispersion, the coco peat powder must have a consistent particle size, specifically passing through a 60-mesh sieve. On the other hand, the rice straw fibers must have a uniform length of approximately 0.5 cm, passing through a 4-mesh sieve. This combination of coco peat powder and rice straw fiber is expected to enhance the composite's mechanical properties, with the coco peat powder filling narrower gaps and the rice straw fibers acting as reinforcement. In addition to ensuring uniform particle size, the incorporation of coco peat powder and rice straw fibers must be carried out gradually once the rPP has melted.

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3.8 *Analysis of composite morphology and elemental*

The distribution of coco peat powder and rice straw in the recycled PP matrix was observed based on the cross-sectional image of the composite taken by a digital microscope at 200x magnification (Figure 11). As previously explained, in the P1 composite, the fiber length looks smaller with a lower slenderness ratio compared to other composites, because the matrix filler is coco peat in powder form, which is evenly dispersed in the recycled PP matrix (inside the red square in Figure 11a). However, voids are visible (inside the yellow circle in Figure 11a), which are caused by the incompatibility between the hydrophilic coco peat and the hydrophobic recycled PP matrix. A similar void appearance (in the yellow circle in Figure 11b) is seen in the cross-section of composite P2. Although composite P2 is still dominated by coco peat, there has been the addition of rice straw fiber (seen in the blue square in Figure 11b).

Composite P3 showed the best thermal properties compared to other composites in this study. From the cross-sectional appearance of composite P3 (Figure 11c), it can be seen that both coco peat and rice straw are present in proportional amounts. Composite P4 showed the best compressive strength and flexural strength compared to other composites in this study. The shape and size of the rice straw fiber, as seen in Figure 11d, can play a fairly good role under compressive load and flexural load, where coco peat in smaller sizes can fill the gaps in the recycled PP matrix. The P5 composite, whose filler consists only of rice straw fiber, is clearly visible in the recycled PP matrix (Figure 11e).

The presence of micro-voids and filler–matrix incompatibility, initially observed under optical microscopy, was further verified through high-magnification SEM analysis (Figures 12–14). The micrographs clearly reveal micro-gaps and debonding interfaces in formulation P1 due to the hydrophilic nature of coco peat against the hydrophobic rPP matrix, whereas formulation P4 shows a noticeably denser microstructure with improved filler encapsulation supported by MAPP coupling. A more detailed morphological examination of the composite was conducted using SEM at 1000x magnification. Figure 12 shows the gap in the composite due to lower interfacial bonding between coco peat and rPP (blue circle). Some coco peat granules still exist and are not well dispersed in the rPP matrix (red circle). The composite P4 has the highest flexural strength and compressive strength in this study. The morphology of the composite P4 (Figure 12) appears denser, indicating a stronger interfacial bond. The P4 composite board containing 20% coco peat and 30% rice straw within an rPP matrix, with the addition of 5% MAPP, exhibited greater strength than the other composite boards in this study.

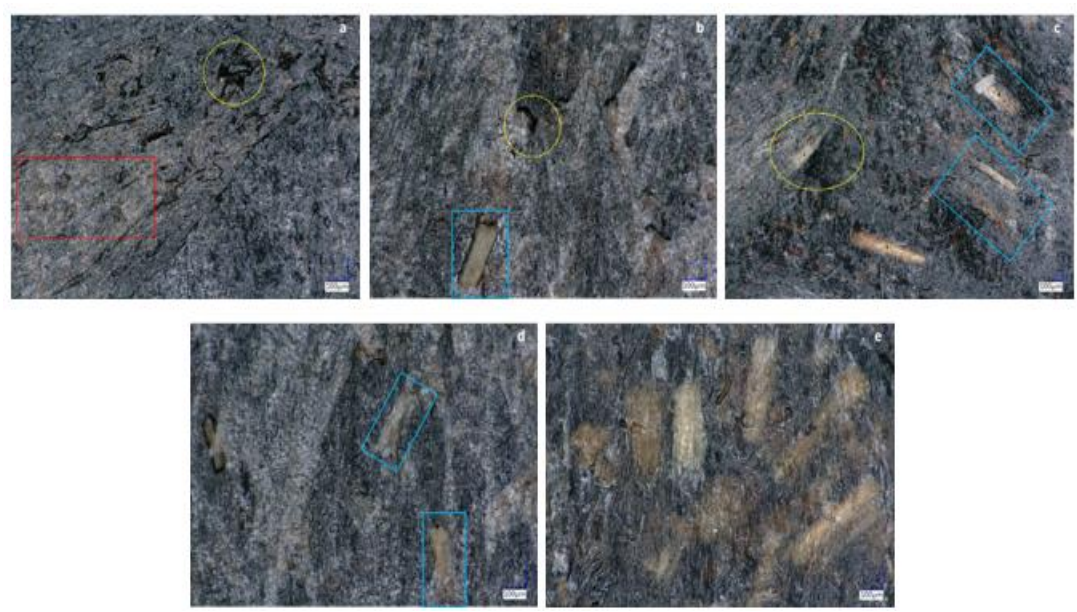


Figure 11: Morphology of composite boards P1 (a), P2 (b), P3 (c), P4 (d), P5 (e) observed by digital microscope with 200x magnification.

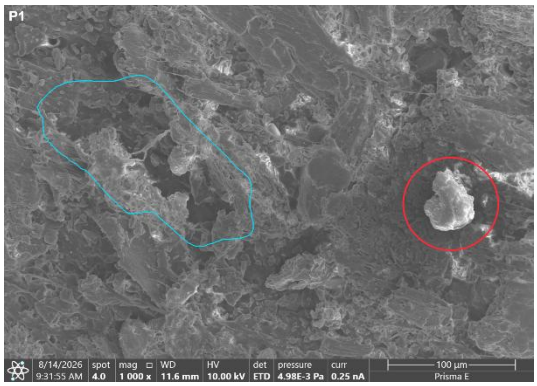


Figure 12: Morphology of composite board P1 observed by SEM at 1000x magnification.

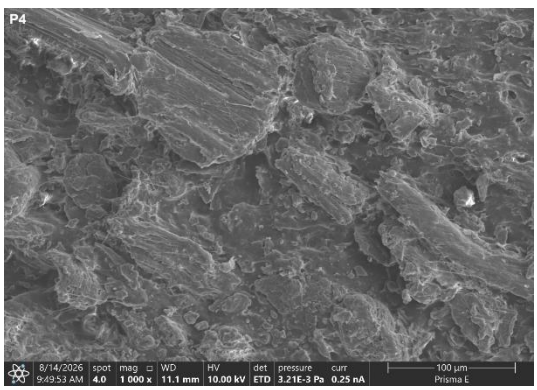


Figure 13: Morphology of composite board P4 observed by SEM with 1000x magnification.

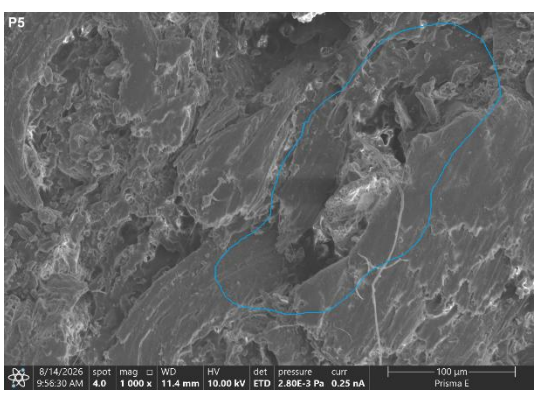


Figure 14: Morphology of composite board P5 observed by SEM at 1000x magnification.

Meanwhile, the P5 composite consisting of 50% rice straw in an rPP matrix with the addition of 5% MAPP yielded a composite board with inferior mechanical properties compared to the P4 composite board. This finding aligns with morphological observations of the P5 composite board (Figure 14), which revealed the presence of gaps, indicating poor interfacial bonding between the 50% rice straw and the rPP matrix.

While the dispersion of fibers (coco peat and rice straw) within the rPP matrix influences the composite's mechanical properties, its thermal properties are affected by mineral content—largely contributed by the rice straw. As reported by [63], rice straw contains 26% silica. Silica is widely known as a mineral with high heat resistance [64].

SEM observations equipped with EDS analysis reveal the relative silica content on the surface areas of the observed composites. Table 6 shows that the silica content in the composite P5 is the highest among the composites studied. This supports the earlier finding that the composite P5 exhibits the best heat resistance among the types of composites investigated.

Table 6: Elemental composition in the composite.

Element (weight %)	Composites				
	P1	P2	P3	P4	P5
C	64.15	60.77	69.42	68.72	60.83
O	28.35	31.00	23.76	24.99	30.24
Si	2.96	2.97	3.20	3.21	5.05
K	2.34	2.32	1.82	1.75	2.38
Cl	0.81	1.03	0.86	0.50	0.41
Ca	0.74	0.69	0.58	0.44	0.57
Na	0.30	0.33	0.12	0.14	0.25
Al	0.18	0.33	0.30	0.16	0.18
Mg	0.18	0.33	0.16	0.09	0.09

This research on the development of materials for fishing vessel upper structures based on recycled polypropylene (rPP), coco peat, and rice straw was successful in meeting material requirements for vessels by utilizing agricultural by-products and plastic waste. The mechanical and thermal properties exhibited by the P4 and P5 composites meet the standards for use as a material for fishing vessel upper structures.

Applying these composites to replace wood will reduce deforestation and open agricultural burning. Therefore, replacing traditional wood with these composite boards has a substantial positive impact on the environment. However, additional assessments such as water absorption, cyclic marine weathering

(salt spray), fatigue testing, and biofouling resistance are required before full-scale practical adoption in marine constructions. are necessary to provide long-term endurance in marine settings.

Although formulations P4 and P5 satisfy the baseline mechanical requirements established by BKI standards for dry wood benchmarks, these findings constitute a preliminary mechanical screening. Marine vessel superstructures endure severe cyclic marine exposure, salt-spray fog, dynamic wave impacts, and diurnal thermal fluctuations. Consequently, comprehensive environmental aging tests—specifically water absorption/swelling kinetics, cyclic fatigue, and marine biofouling resistance—are essential prerequisites before full-scale commercial installation.

The proposed manufacturing route in this research is highly feasible for industrial-scale implementation, as the raw material mixing and composite fabrication processes employed in this study utilize equipment commonly used in wood-plastic composite production such as extruders, hot presses, and compression molding machines. However, further evaluation through pilot-scale research is certainly required before advancing to the industrial scale.

4. Conclusions

Plastic composite board with code P4 (coco peat: rice straw: recycled polypropylene = 20%:30%:50%) was the best plastic composite board composition in this study based on test results. Combining coco peat and rice straw fibers in polypropylene matrices will be beneficial for obtaining higher flexural strength and compressive strength. The best value for P4 plastic composite board was 41 N/mm² in the flexural test and 55 N/mm² in the compression test. These mechanical property values were better than those of Medang wood (K2 control wood), but could not outperform Mahang wood (K1 control wood). The P4 plastic composite board can be recommended as an alternative material to produce upper structures of traditional fishing vessels in accordance with the BKI standard (2023) concerning wooden vessels.

P3 and P5 plastic composite boards, which contained rice straw, showed characteristics more resistant to heat degradation than P1 plastic composite boards (50% coco peat:50% recycled polypropylene). The silica content in rice straw is thought to play a role in the thermal resistance of recycled polypropylene plastic composite boards.

Substituting conventional timber with this recycled composite board offers significant environmental benefits by mitigating deforestation, open agricultural burning, and plastic accumulation. However, prior to full-scale practical implementation in marine structures, further evaluations, including water absorption, cyclic marine weathering (salt spray), fatigue testing, and biofouling resistance. are essential to ensure long-term durability in marine environments.

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Conflicts of Interest

The authors declare no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors utilized the ChatGPT tool to enhance the language and readability of the manuscript.

The authors used QuillBot and Grammarly to improve the manuscript's language, grammar, and readability. The authors reviewed and revised the manuscript and take full responsibility for its content.

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