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Physico-Thermal Characteristics of Coconut Coir–Latex Composites for Thermal Insulation in Fishing Vessels

Polaris Nasution[1*], T Ersti Yulika Sari[2], Budhi Santoso[3]

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***Abstract*—** Maintaining fish quality on small fishing vessels requires effective thermal insulation materials for fish holds, especially under humid and splash-exposed marine conditions. Conventional polyurethane insulation is widely used, but its cost and material availability encourage the development of alternative bio-based insulation materials. This study aims to evaluate the physical and moisture-related characteristics of latex–coconut coir composites as lightweight insulation candidates for fishing-vessel applications. Composite panels were fabricated using six latex–coir formulations, namely 100/0, 90/10, 80/20, 70/30, 60/40, and 50/50. The specimens were characterized by measuring dry mass, water absorption after 24 h immersion, specific gravity, and density. Water absorption was evaluated using the general procedure of JIS A 5908, while specific gravity and density were determined using an Archimedes-based method according to ASTM D792 at 23°C. The results show that increasing coconut coir content reduces specimen mass from 820 g for neat latex to 525 g for the 50/50 composite, indicating the potential for lightweight insulation panels. However, the addition of coir increases moisture absorption. Neat latex shows the lowest water absorption of 0.846%, while the highest value occurs at the 80/20 formulation with 17.345%. At the 50/50 formulation, water absorption decreases to 10.410%, indicating a non-linear moisture uptake behavior. In contrast, specific gravity and density remain nearly constant, ranging from approximately 0.498 to 0.500 and 496.93 to 498.75 kg/m³, respectively. These findings indicate that moisture behavior is influenced mainly by porosity, fiber distribution, and latex–fiber interfacial sealing rather than bulk density. The study demonstrates that latex–coconut coir composites are feasible as lightweight bio-based insulation materials for fishing vessels, but further processing optimization and surface protection are required to improve moisture resistance in marine environments.

Keywords— Coconut coir, Natural fiber composite, Latex binder, Marine insulation, Fishing vessels, Lightweight panels, Water absorption, Specific gravity, Density, Moisture resistance

[*]*Corresponding Author: polarisb2000@yahoo.com*

I. INTRODUCTION

Maintaining the quality of captured or cultivated fish requires appropriate post-harvest handling. One of the most critical stages in this process is the storage of fish during fishing operations, from the time it is caught at sea until it reaches the port and ultimately the consumer [1]. The quality of fish storage is highly influenced by the performance of the thermal insulating material used in the fish hold or storage container [2]. Quality deterioration starts at capture; storage time and temperature are dominant drivers of spoilage in both wild and farmed fish [3]. Today, the demand for high-quality fish both for direct consumption and as raw material for processing industries is increasingly urgent [4]. Such fish must reach consumers in good condition, with their quality preserved inside well-insulated storage spaces. Sufficient ice and insulated containers significantly reduce post-harvest losses; inadequate ice and uninsulated boxes can increase losses by ~40% [5].

Polyurethane is a material commonly used as insulation in fish holds. However, fishermen are currently facing serious challenges related to the availability and cost of this insulation material [6]. The price of polyurethane-based insulation continues to rise, and its raw materials are not always easy to obtain. Fishermen’s concerns about cost and availability of polyurethane (PU) are well documented, especially for fish holds and coolboxes [7]. Polyurethane is a rigid plastic foam produced from a mixture of polyol and isocyanate, widely used as a thermal barrier in cold storage applications. In fish storage, the most common methods involve cooling with ice or the use of refrigeration systems in the cargo space [8]. To maintain the hold temperature within the desired range, thermal insulation is applied to the hold walls. The use of insulated fish holds has been shown to reduce the amount of ice required during fishing operations [9]. Properly insulated holds slow heat gain from the environment, allowing fish to be kept near 0 °C with less ice or smaller refrigeration capacity. Benefits include lower ice usage, reduced spoilage, and wider fishing range. For small vessels, insulated coolers/holds are central to maintaining freshness when only ice is available [10].

The demand for materials or products that are both cost-efficient and high-performing continues to increase. The use of natural fibers in a conventional manner is one approach to reducing material costs in production processes [11]. Note that high material costs can lower productivity and ultimately reduce profit margins.

Polaris Nasution is with the Department of Utilization of Fisheries Resources, Universitas Riau, Riau Province, Indonesia, 28132, E-mail: polarisb2000@yahoo.com

T Ersti Yulika Sari is with the Department of Utilization of Fisheries Resources, Universitas Riau, Riau Province, Indonesia. 28132, E-mail: t.ersti@lecturer.unri.ac.id

Budhi Santoso is with the Department of Naval Architecture, Politeknik Negeri Bengkalis, Bengkalis, 28711. E-mail: budhisantoso@polbeng.ac.id.

Rising raw material prices and pressure to maintain profitability are pushing firms to seek cost-efficient, high-performance materials and tighter cost control across production [12]. Multiple studies show that raw material and production cost efficiency is directly linked to profit margins and sales growth in manufacturing and small enterprises [13].

Therefore, alternative materials with similar or superior properties to conventional ones need to be explored, especially if they can offer lower costs. One such alternative is natural fiber. These fibers are inexpensive and readily available. Many types of natural fibers are currently used, including cotton, flax, sawdust, palm fibers, bagasse, and coconut fibers [14]. Despite lower absolute strength than glass fibers, their low density yields competitive specific strength and stiffness, often sufficient for automotive interiors, building panels, and packaging [15]. These materials generally exhibit advantageous mechanical properties such as low weight, low density, and high ductility, especially when compared to some conventional materials like steel, plastics, or ceramics. Natural fibers are also promising as thermal insulation materials because of their low thermal conductivity [16].

According to the *Coconut Statistics Yearbook*, Indonesia is the world's largest coconut producer, with a plantation area of 3.799 million hectares (35.96%), followed by the Philippines (31.99%) and India (18%). Within Indonesia, Riau Province (10.92%) ranks second after North Sulawesi (11.04%) in terms of coconut plantation area. However, only a small fraction of coconut husk is actually utilized; most of it is discarded as waste [17]. This coconut waste has significant potential as reinforcement in composite materials. Indonesia, the Philippines, and India dominate global coconut area and production, accounting for roughly 75–82% of world coconut area and output [18]. In addition to producing a new, environmentally friendly composite, coconut coir–polyester composites exhibit higher toughness than the polyester matrix and many other plastics, as well as good thermal insulation properties. These composites are tougher because coconut fibers have a variable cross-sectional area that influences their mechanical performance. The fibers typically contain about 30 wt% fiber and 70 wt% pith, with an oval cross-section and interlocking fiber cells [19].

Figure 1. Stages in the Manufacturing Process of Latex–Coconut Coir Composite Specimens

A coconut fruit consists of the husk (coir), shell, meat, and water. The husk is a fibrous layer about 5 cm thick and forms the outermost part of the fruit. Coconut coir is one of the natural fibers with particularly interesting characteristics: it can act as reinforcement, while the voids between fibers provide acoustic and thermal insulation, thereby reducing the bulk density of the material [20]. Coir is a lignocellulosic fiber (≈36–43% cellulose, 32–45% lignin) from the coconut husk mesocarp, giving high durability, flexibility, and relatively low density [21]. When used as a reinforcement, coconut fiber can yield an alternative material suitable for a variety of components or structures, particularly as thermal insulation. Other notable properties of coconut coir include resistance to microorganisms, decay, and mechanical wear (abrasion and impact), as well as being lighter than many other fibers. Coconut fiber is also relatively resistant to biodegradation because only a limited range of decomposers can break down its structure. Several natural materials can serve as thermal insulation, such as coconut coir, rice husk, bagasse fibers, and other plant-based materials, in addition to polyurethane [22].

Rubber (Hevea brasiliensis) is another important agricultural commodity for Indonesia, with significant relevance both nationally and internationally. It is one of the main plantation products contributing to the country's economy. For many years, Indonesia has been a major player in global rubber production, at times surpassing other rubber-producing countries, including those in the species' native range in South America. Rubber plantations in Indonesia occupy extensive areas of land, especially in Sumatra and Kalimantan, and rubber has long been recognized as an export commodity that generates substantial foreign exchange income. Over the last two decades, Indonesian rubber exports have risen from about 1.0 million tons in 1985 to 1.3 million tons in 1995 and 1.9 million tons in 2004, with foreign exchange earnings reaching approximately US$ 2.25 billion in 2004, equal to around 5% of non-oil-and-gas export revenues. By 2005, the total rubber plantation area had exceeded 3.2 million hectares, distributed across various regions of Indonesia [23]. Rubber is consistently identified as one of Indonesia's main non-oil-and-gas export commodities, contributing significantly to foreign exchange and employment [24]. The rubber tree (Hevea brasiliensis) belongs to the group of latex-producing plants. This designation refers to plant species whose tissues contain extensive latex-bearing vessels. When the plant tissue is wounded, the latex exudes from these vessels. Latex itself contains a variety of components, including proteins, carbohydrates, sterols, and different types of lipids. Because of this composition, latex is highly susceptible to hydrolysis and can rapidly support microbial growth, which in turn leads to deterioration of the latex if it is not properly handled and preserved[25].

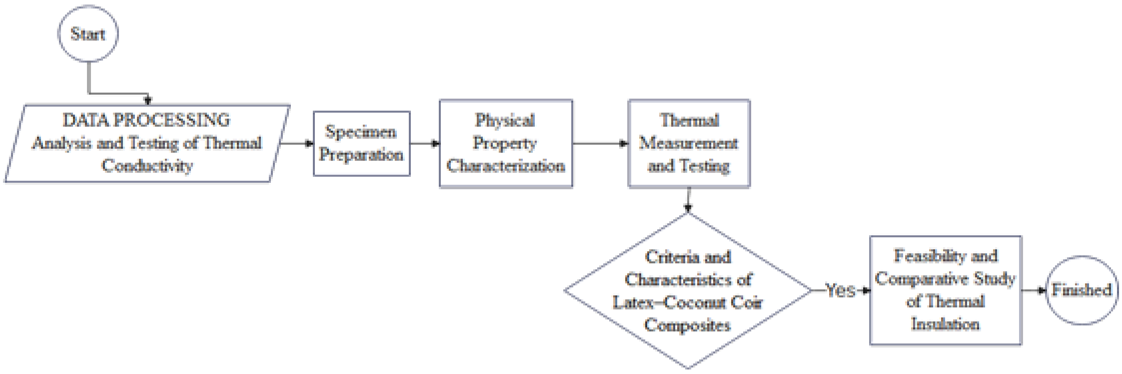

Figure. 2. Research Flowchart for Latex–Coconut Coir Composite Insulation Characterization.

Although polyurethane insulation is commonly used in fish holds, its increasing cost and limited availability create challenges for small fishing vessels. In addition, insulation materials for marine use must be lightweight and able to withstand humid and splash-exposed conditions.

Previous studies have discussed natural fibers such as coconut coir for insulation applications, but limited research has evaluated latex–coconut coir composites specifically for fishing-vessel insulation. Therefore, this study aims to evaluate the mass, water absorption, specific gravity, and density of latex–coconut coir composites with different composition ratios.

The novelty of this study lies in identifying the feasible latex–coir formulation window for marine insulation and explaining the relationship between composition, density stability, and non-linear water absorption behavior. These findings are expected to support the development of lightweight, locally available, and bio-based insulation panels for fishing-vessel fish holds.

II. LITERATURE REVIEW

A. Thermal Insulation in Fishing Vessels

Thermal insulation plays an important role in maintaining fish quality during fishing operations. Fish quality can deteriorate rapidly when storage temperature is not properly controlled. In small fishing vessels, fish are commonly stored in fish holds or cool boxes using ice as the main cooling medium. Therefore, the insulation material used in the fish hold must be able to reduce heat transfer from the surrounding environment into the storage space.

Polyurethane foam is widely used as an insulation material because it has low thermal conductivity and good insulating performance. However, polyurethane has several practical limitations, especially for small-scale fishermen. Its cost continues to increase, and the availability of raw materials may become a challenge. This condition encourages the development of alternative insulation materials that are more affordable, locally available, lightweight, and suitable for marine environments.

B. Natural Fiber Composites as Insulation Materials

Natural fiber composites have attracted attention as alternative engineering materials because they are lightweight, renewable, low-cost, and environmentally friendly. Natural fibers such as coconut coir, rice husk, bagasse, palm fiber, and other agricultural residues have been studied for insulation and composite applications. Their porous structure can reduce heat transfer, while their low density can help produce lightweight panels.

However, natural fibers also have limitations. Most lignocellulosic fibers are hydrophilic, meaning that they can absorb water from humid or wet environments. This characteristic is important for marine applications because insulation panels used in fishing vessels may be exposed to moisture, water splashes, and high humidity. Therefore, evaluating water absorption, density, and physical behavior is necessary before natural fiber composites can be considered for fish-hold insulation.

C. Coconut Coir as Composite Reinforcement

Coconut coir is a promising natural fiber for composite insulation materials. It is obtained from coconut husk and is widely available in coconut-producing regions. Coconut coir has low density, good toughness, and a porous fiber structure. The hollow lumen and voids within the fiber network can contribute to thermal insulation performance by reducing heat transfer through the material.

In addition, coconut coir is relatively resistant to decay and mechanical wear compared with several other natural fibers. These properties make coconut coir suitable as reinforcement in lightweight composite panels. Nevertheless, coconut coir contains cellulose, hemicellulose, and lignin, which make it capable of absorbing moisture. As a result, when coconut coir is used in marine insulation, the interaction between fiber content, porosity, and water absorption must be carefully studied.

D. Latex as Binder Matrix

Latex can be used as a binder matrix in natural fiber composites. In a latex–coconut coir composite, latex functions to bind the coir fibers, fill the gaps between fibers, and form a continuous matrix phase. Good latex penetration is important to improve fiber bonding, reduce open pores, and minimize water pathways inside the composite.

However, the amount of latex must be sufficient to coat and bind the coconut coir fibers. If the coir content is too high, latex may not be able to distribute evenly throughout the mold or penetrate the fiber network. This can produce weak specimens, poor interfacial bonding, and higher porosity. Therefore, identifying a feasible latex–coir composition is important for producing composite insulation panels with acceptable physical and moisture-related properties.

E. Research Gap

Previous studies have reported the potential of natural fibers and coconut coir as insulation materials, especially for building panels and general composite applications. However, limited studies have focused on latex–coconut coir composites for fishing-vessel insulation, particularly under conditions where lightweight properties and moisture resistance are both important.

Based on this gap, this study evaluates latex–coconut coir composites with different composition ratios as candidate insulation panels for fishing-vessel fish holds. The review of previous studies shows that the key parameters for this application are specimen mass, water absorption, specific gravity, and density. These parameters are directly related to the objective of this study, namely to assess the physical and moisture-related characteristics of latex–coconut coir composites for marine insulation applications.

III. METHOD

A. Coconut coir

Coconut coir, a biodegradable natural material, can be used as a thermal insulating medium with a thermal conductivity (λ) of about 0.05 W/m·K. It is suitable for use as room insulation to help maintain the internal temperature, and, importantly, the use of coconut-coir-based insulating composites can help prevent creep damage [26]. Coconut coir exhibits λ values that fall within an acceptable range for thermal insulation applications; optimum conductivity values at 24 °C are reported to be around 0.0488 W/m·K and 0.0483 W/m·K. The thermal conductivity of coconut coir increases over the test temperature range of 15.6 °C to 32 °C, and this trend is consistent with the behavior expected of insulating materials [27]. When coconut coir is added to polyurethane to form an insulating composite, coir contents of up to 30% by weight still produce a material that is viable as a thermal insulator, with a thermal conductivity of approximately 0.0521 W/m·°C. Loose coconut fiber: minimum λ ≈ 0.0488 W/m·K at 24 °C, within the range of conventional building insulation. Binderless coir panels (≈50 mm): RSI up to 0.909 m²·K/W, comparable to sprayed polyurethane at thinner sections [28].

Conduction is the most significant mode of heat transfer in solids. At the microscopic level, heat is conducted when rapidly vibrating atoms and molecules interact with their neighbors, transferring part of their energy (heat) to adjacent particles. The free movement of electrons also plays an important role in conductive heat transfer [29].

Thermal conductivity, commonly denoted by λ and also referred to as the conduction coefficient, characterizes this process. It is defined as the amount of heat, Q, that flows in a given time interval t through a material of thickness x W/(moC), in the direction normal to a surface area A, due to a temperature difference ΔT across that thickness [30].

The quantitative relationship that links the rate of heat transfer, the temperature gradient in the medium, and the conductive properties of the material is expressed by Fourier's law of heat conduction for the one-dimensional case [31].

$$Q = -\lambda . A \frac{T_2 - T_1}{\Delta x} \; ; q = -\lambda . A \frac{\Delta T}{\Delta x} \qquad (1)$$

The thermal conductivity of the specimen is calculated using the following formula:

$$\lambda = \frac{\Phi . d}{A.(T_1 - T_2)} = \mathrm{W/(m.{}^oC)} \qquad (2)$$

Where:

Φ :Average heater power, W
T_1 :Temperature of the first surface, °C
T_2 :Temperature of the second surface, °C
A :Specimen surface area, m²
d : Specimen thickness, m

The density of the fiber materials was determined by measuring their specific gravity in accordance with ASTM D-792. Specific gravity was obtained using a buoyancy test in water as the immersion medium. Samples and specimens were submerged in water, and their masses were recorded before and after immersion over a set time interval. Measurements were taken after 10 seconds of immersion to minimize water penetration into the fibers. The specific gravity was then calculated using the corresponding equation reported.

$$\text{Specific Gravity} = \frac{\text{Mass in Air}}{\text{Mass in Air- Mass in water}} \qquad (3)$$

To determine and calculate the density of the specimens, the ASTM D792–2008 *Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement* was applied, using the following equation [32]:

Density = (Specific gravity x 997.6) kg/m3 (4)

where 997.6 kg/m³ is the density of water at 23 °C.

According to ASTM C1045 and ASTM C518, and based on the terminology defined in C168, the measurement of thermal conductivity is carried out as follows:

$$\lambda = S.E\left(\frac{L}{\Delta T}\right) \quad (5)$$

One-dimensional heat flow through the test specimen can be disturbed by non-adiabatic conditions at the specimen edges and surfaces. These deviations become more pronounced when the apparatus is operated at temperatures far from ambient conditions. Therefore, if the hot plate is operated at more than 10 °C (20 °F) above or below the ambient temperature, the apparatus must be equipped with additional components and shielding to reduce lateral heat losses [33]. Side protection is added to minimize heat loss and to limit departures from one-dimensional heat flow in the specimen caused by non-adiabatic edge conditions at the heated surface and the test sample. Non-adiabatic edges or temperature inhomogeneities create lateral temperature gradients, generating 3-D heat flux that biases apparent conductivity/U-values [34].

Thermal conductivity is a bulk property of a material that characterizes its ability to conduct heat. In the following relationship, the proportionality factor k represents the thermal conductivity. The distance over which heat is conducted is denoted by Δx, measured perpendicular to the cross-sectional area A. The rate of heat transfer through the material is Q, flowing from temperature T1 to temperature T2, where T1>T2[35].

$$k = \frac{Q.\Delta x}{A\,(T_2 - T_1)} \quad (6)$$

Thermal conductivity is a key parameter in the cooling of equipment. When electronic devices generate heat, conductive heat transfer and thus the material’s thermal conductivity forms an essential part of the overall thermal management strategy. The temperature difference between the two plates is typically measured using foil-thermocouple junctions, with the measurement system designed to operate up to a maximum of about 200 °C [36].

According to Yoav Peles, the boundary conditions for heat conduction at an insulated wall can be expressed, following Fourier’s law, as [37]:

$$Q = kA\,\frac{dT}{dx} \quad (7)$$

Or, in terms of the heat conduction value:

$$Q = kA\,\frac{T_1 - T_2}{L} \quad (8)$$

Where:

Q = Rate of heat conduction (W)

k = Thermal conductivity (W/m·°C)

A = Surface area (m²)

T_1 = Average outside temperature (°C)

T_2 = Average inside temperature (°C)

L = Wall thickness (m)

$$\% = \frac{m_1 - m_0}{m_0}\,x\,100 \quad (9)$$

Where:

m_1 : Mass after drying

m_2 : Mass after immersion

To determine the permeability (water absorption) of a material, the specimen is exposed to a controlled environment so that water uptake occurs over a specified period of time. The mass of the material after water absorption is then compared with its initial dry mass, and from this difference the amount of absorbed water can be calculated, allowing the permeability of the material to be evaluated [38].

The heat released when ice melts inside an insulated box, in relation to the rate of heat transfer, is given by:

$$Q = U.A.\Delta T \quad (10)$$

And

$$Q = m.c.\Delta T \quad (11)$$

$$Q = \frac{m.L}{\Delta T} \quad (12)$$

$$U = \frac{1}{\frac{1}{h_{1}.A} + \frac{x_1}{k_{1}.A_1} + \frac{x_2}{k_{2}.A_2} + \frac{1}{h_{2}.A_2}}$$

Where:

Q = Rate of heat transfer (kcal)

c = Specific heat, for ice = 0.53 cal/kg·°C and for water = 1 cal/kg·°C

h_1 = Convective heat transfer coefficient inside the insulated hold = 20 W/m²·°C

h_2 = Convective heat transfer coefficient of cold water inside the hold = 5 W/m²·°C

IV. Results and Discussion

1. Rubber (Latex)

Rubber is one of Indonesia’s most important agricultural commodities, both nationally and internationally. In Indonesia, rubber plays a major role in supporting the national economy, contributing significantly to foreign exchange earnings. At certain periods, Indonesia has even led global rubber production, surpassing other producing countries, including those in the species’ original habitat in South America.

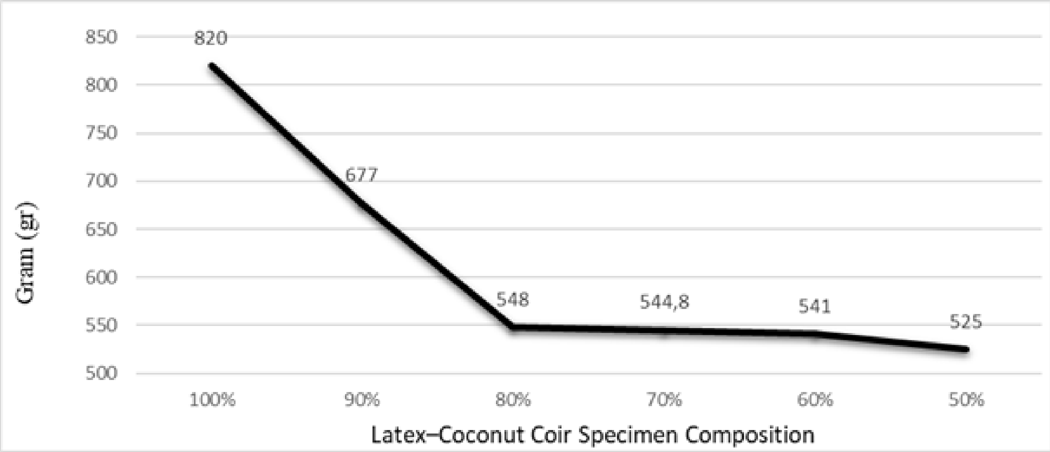

Figure. 3. Mass of Latex–Coconut Coir Composite Specimens

The rubber tree (*Hevea brasiliensis*) is a key estate crop and an important source of non-oil and gas foreign exchange for Indonesia, giving it strong economic prospects. For this reason, efforts to improve the productivity of rubber smallholdings and plantations continue to be pursued, particularly through advances in cultivation and agronomic practices.

As an export commodity, rubber has consistently contributed to Indonesia's foreign exchange. Over the last two decades, Indonesian rubber exports have shown a steady increase from about 1.0 million tons in 1985, to 1.3 million tons in 1995, and 1.9 million tons in 2004. In 2004, foreign exchange earnings from rubber reached approximately US$ 2.25 billion, representing around 5% of total non-oil and gas export revenues. Many regions in Indonesia provide suitable land for rubber cultivation, with large plantation areas located especially in Sumatra and Kalimantan. By 2005, the total rubber plantation area exceeded 3.2 million hectares, distributed across various provinces.

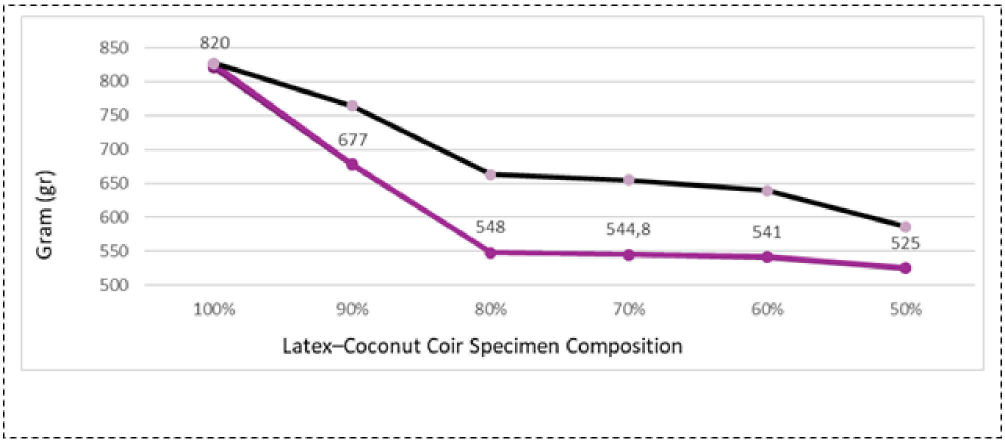

Figure. 4. Mass of Latex–Coconut Coir Composite Specimens

The rubber tree (*Hevea brasiliensis*) belongs to the group of latex-producing plants. This designation reflects the presence of an extensive latex-bearing vessel system within the plant tissue. When the bark or tissue is wounded, the latex exudes from these vessels.

Latex itself contains rubber particles coated with proteins and phospholipids, as well as other components such as carbohydrates, sterols, and various lipids. Because of this composition, latex is highly susceptible to hydrolysis and easily supports the growth of microorganisms, which can lead to rapid degradation. The protein layer on the surface of the rubber particles provides a negative charge, creating electrostatic repulsion between particles and thereby maintaining the stability of the latex colloid. When microorganisms are present, however, these proteins can be broken down, reducing the electrostatic repulsion and allowing rubber particles to interact, forming flocs or coagulated masses.

Coagulation is carried out to intentionally aggregate and compact the dispersed rubber particles in the latex into a single mass (coagulum). To achieve this, a coagulant such as formic acid or acetic acid is added. Fresh field latex typically has a pH of around 6.5. For coagulation to occur effectively, this nearly neutral pH must be lowered to approximately 4.7.

During the coagulation process, the latex system undergoes a transition from a sol state to a gel state with the aid of the coagulant. In the sol state, rubber particles are finely dispersed in the serum phase, whereas in the gel state, a three-dimensional network of rubber is formed within the latex. The addition of acid reduces the pH, bringing the system closer to the isoelectric point of the rubber particles; at this condition, the colloidal stability collapses and coagulation takes place.

TABLE 1.
COMPARISON OF COMPOSITION AND MASS OF LATEX–COCONUT COIR SPECIMENS

Nomor	Latex (Liquid)		Coconut Fiber (Bulk)	
	Composition	Liquid Weight	Composition	Bulk Weight
Specimen	(%)	(gr)	(%)	(gr)
1	100	2250	100	150
2	90	2025	10	15
3	80	1800	20	30
4	70	1575	30	45
5	60	1350	40	60
6	50	1125	50	75

2. Coconut Coir

Coconut coir fiber is derived from the seed (husk) of the coconut fruit, consisting of approximately 30% fiber and 70% pith by weight. The outer surface of the fiber is covered by a lignin-rich layer, with an average fiber diameter of about 0.255 mm. The cross-section of the elementary fiber cell contains a hollow central region known as the lumen. The shape and size of this lumen depend mainly on two factors: the thickness of the cell wall and the origin of the fiber. The presence of this hollow core contributes to the thermal insulation performance of the fiber and helps reduce its bulk density.

For use as reinforcement, the coconut coir fibers are randomly cut into lengths of approximately 2–5 cm to facilitate uniform dispersion within the mold during composite preparation. The fibers are then mixed with latex at various coir volume or mass fractions of 10%, 20%, 30%, 40%, and 50%. As a composite reinforcement, coconut coir is expected to provide thermal conductivity values in the range of 0.02–0.06 W/m·K, which is typical for materials used as thermal insulation. The thermal conductivity of the coir–latex insulating composites is measured in accordance with ASTM C518, under steady-state, one-dimensional heat-flow conditions.

3. Composite Specimens

The experimental work begins with the fabrication of test specimens made from 100% solid, dried latex, cast into panels with dimensions of 200 × 200 × 25 mm, corresponding to a volume of 1000 cm³. Subsequently, composite specimens are produced by incorporating coconut coir fibers at different proportions of 10%, 20%, 30%, 40%, and 50% by weight (or volume, as specified in the study design).

The preparation procedure follows a series of steps for mixing, placing, and curing the coir–latex mixture, with the process of specimen fabrication illustrated schematically in the following figure (process diagram).

A total of six composite panels were prepared with the following composition variations:

1. 100% pure latex
2. Composite of 90% latex and 10% coconut coir
3. Composite of 80% latex and 20% coconut coir
4. Composite of 70% latex and 30% coconut coir
5. Composite of 60% latex and 40% coconut coir
6. Composite of 50% latex and 50% coconut coir

For mixtures containing 40% latex or less (i.e., 60% or more coconut coir), the rubber latex could no longer be evenly distributed throughout the mold nor effectively penetrate the gaps between the coir fibers. As a result, the specimens became mechanically weak and the coir fibers detached easily due to insufficient binder content, as illustrated in Figure 4.2. Therefore, in this study, thermo-physical characterization of the composite material was only carried out on specimens with a maximum coir content of 50%, namely the composite containing 50% latex and 50% coconut coir.

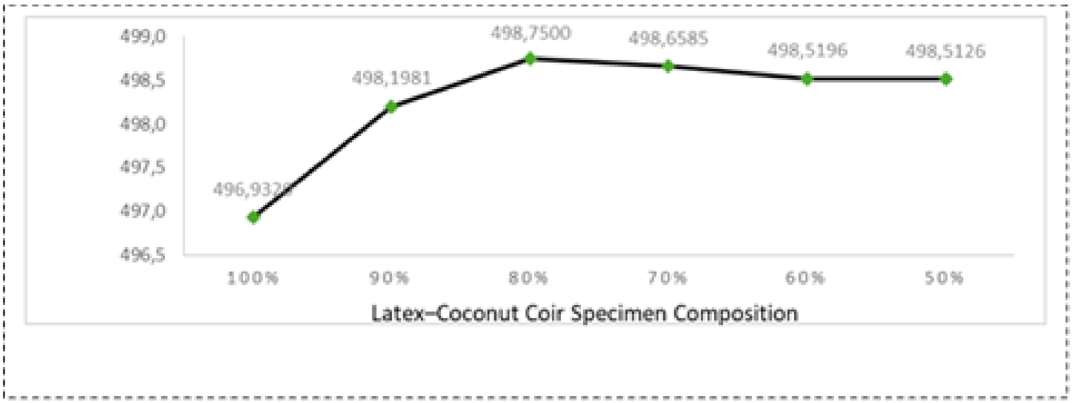

Figure. 5. Density (kg/cm^3)

4. Physical Characteristics of the Composite

a. Measurement of Specimen Mass

Composite specimens were evaluated through thermal and physical characterization to determine whether they satisfy the requirements of a thermal insulating material. The latex–coconut coir composition for specimens with dimensions of 200 × 200 × 25 mm is summarized in the following table1. Table 1 summarizes the formulation matrix used to manufacture six latex–coconut coir composite panels by systematically changing the coir fraction while reducing the latex fraction. The specimens represent a controlled series from neat latex (Specimen 1) to 50% latex–50% coir (Specimen 6), with intermediate compositions of 90/10, 80/20, 70/30, and 60/40 (latex/coir).

Figure. 6. Measurement of Specimen Weight and Water Absorption.

In the same sequence, the latex liquid weight decreases proportionally from 2250 g (100% latex) to 1125 g (50% latex), while the bulk coir weight increases from 15 g (10% coir) to 75 g (50% coir).

This stepped design ensures that each panel is produced using a consistent preparation basis, so any changes observed later in density, water absorption, and thermal conductivity can be attributed primarily to the latex-to-coir ratio rather than uncontrolled variation in specimen preparation.

Practically, the table also reflects the study’s manufacturability limit: composites above 50% coir were not pursued because mixtures with ≤40% latex (≥60% coir) could not be distributed uniformly and tended to become mechanically weak due to insufficient binder penetration.

Therefore, Table 1 defines the full experimental window used for subsequent physico-thermal characterization, where latex functions as the continuous binder phase and coconut coir is introduced as a lightweight, porous reinforcement intended to improve insulation performance.

b. Composition versus Specimen Weight

Table 2 Composition and Specimen Weight of Latex–Coconut Coir Composites. Summarizes how changing the latex–coir ratio affects the mass of the specimens in three conditions: (i) initial dry composite weight, (ii) apparent weight when immersed in water, and (iii) weight after soaking. As the coconut coir fraction increases from 0% (Specimen 1) to 50% (Specimen 6), the initial composite weight decreases from 820 g to 525 g, indicating that replacing part of the latex binder with coir produces a lighter composite, which is advantageous for insulation components in small fishing vessels where added weight should be minimized. The “weight in water” values are very close to the initial composite weights for each specimen, reflecting consistent buoyancy conditions during immersion and suggesting that the specimens were tested under comparable measurement procedures. After soaking, all specimens show an increase in mass, demonstrating water uptake during immersion. This effect becomes more pronounced at higher coir contents for example, Specimen 2 (90/10) increases to 764 g, while Specimen 6 (50/50) increases to 586 g which is consistent with the porous, hydrophilic nature of coconut coir that promotes moisture absorption. Overall, the table highlights a key trade-off in composite design: increasing coir content can reduce specimen weight (beneficial for lightweight insulation), but it also increases water absorption potential, which must be controlled through proper processing or surface treatment for marine applications.

TABLE 2.
COMPOSITION AND SPECIMEN WEIGHT OF LATEX–COCONUT COIR COMPOSITES

Specimen No.	Latex (Liquid) Composition (%)	Coconut Coir (Bulk) Composition (%)	Composite Weight (g)	Weight in Water (g)	Weight After Soaking (g)
1	100	0	820	826	827
2	90	10	677	678.5	764
3	80	20	548	548	663
4	70	30	544.8	545	655
5	60	40	541	541.5	639
6	50	50	525	525.5	586

The Composite Specimen Weight graph figure 4 shows how the specimen mass changes with the latex–coconut coir composition (from 100% to 50% latex). A clear overall trend can be observed: the dry composite weight decreases as the latex fraction is reduced (i.e., as the coconut coir content increases). The dry weight drops from about 820 g at 100% latex to 677 g at 90%, then decreases sharply to 548 g at 80%, and remains relatively stable around 544.8–541 g for the 70–60% latex range before reaching the lowest dry weight of 525 g at 50% latex. This pattern indicates that increasing the coir fraction produces a lighter composite, since part of the dense latex binder is replaced by coir, which is more porous and generally lower in density.

The dashed line with triangular markers represents the specimen weight after soaking, which is consistently higher than the dry weight for all compositions. This increase confirms water uptake during immersion, and it becomes more evident once coconut coir is introduced because coir has a porous, hydrophilic structure that can absorb moisture. The fact that the increase in soaked weight does not follow a perfectly linear trend suggests that water absorption is influenced not only by coir percentage, but also by factors such as fiber distribution, interfacial bonding between latex and coir, and the internal pore network formed during fabrication. Overall, the graph highlights an important design trade-off for marine insulation applications: higher coir content can reduce composite weight (beneficial for lightweight installation), but it also increases the potential for moisture absorption, which must be managed through processing control and/or protective treatments.

Table 3 summarizes the influence of the latex–coconut coir composition on the specimens' mass-related properties, including the dry composite weight, immersed weight, soaked weight, specific gravity, and density at 23°C. As the coir fraction increases from 0% (Specimen 1) to 50% (Specimen 6), the initial composite weight decreases markedly from 820 g to 525 g, indicating that partial replacement of latex with coconut coir produces a lighter panel, which is advantageous for insulation installation in fishing vessels where added weight should be minimized. In contrast, the weight measured after soaking is consistently higher than the initial weight for all specimens and becomes noticeably larger once coir is introduced, confirming water uptake due to the porous and hydrophilic nature of coconut coir; moisture can penetrate through fiber lumens and interfacial voids formed within the composite. This behavior is critical for marine environments, because increased moisture absorption may affect long-term durability and can potentially alter thermal performance. Despite the significant changes in composition and dry mass, the measured specific gravity remains nearly constant (approximately 0.498–0.500), and the reported density values also vary only slightly (about 497–499 kg/m³). This suggests that, within the studied formulation window, the bulk density is governed primarily by the overall consolidation and internal void structure during fabrication rather than by composition alone. Consequently, the results highlight a practical trade-off for vessel insulation materials: increasing coir content helps reduce component weight, but moisture uptake becomes more pronounced, emphasizing the need for optimized processing and/or protective surface treatments to maintain performance in humid and seawater-exposed conditions.

TABLE 3.
EFFECT OF LATEX–COCONUT COIR COMPOSITION ON SPECIMEN MASS, SPECIFIC GRAVITY, AND DENSITY (T = 23°C)

Specimen No.	Latex (Liquid) Composition (%)	Coconut Coir (Bulk) Composition (%)	Composite Weight (g)	Weight in Water (g)	Weight After Soaking (g)	Specific Gravity (–) (T = 23°C)	Density (kg/m³)*
1	100	0	820	826	827	0.4982	496.932
2	90	10	677	678.5	764	0.4994	498.1981
3	80	20	548	548	663	0.5	498.75
4	70	30	544.8	545	655	0.4999	498.6585
5	60	40	541	541.5	639	0.4998	498.5196
6	50	50	525	525.5	586	0.4998	498.5126

The density figure 5 graph indicates that changing the latex–coconut coir composition produces only a minor variation in specimen density. The lowest density is observed at 100% latex (approximately 496.9320), after which the density increases noticeably when the latex content is reduced to 90% (about 498.1981) and reaches its maximum at 80% latex–20% coir (approximately 498.7500). Beyond this point, as the coir fraction continues to increase (from 70% to 50% latex), the density shows a slight decrease and then stabilizes within a narrow range (around 498.51–498.66). This trend suggests that introducing coir up to an intermediate level (around 20%) may improve consolidation by partially filling internal voids and promoting a more compact structure. However, at higher coir contents, the composite may develop additional internal porosity or experience less uniform latex distribution, preventing further density increases. Overall, the results demonstrate that the composite density remains nearly constant across the tested formulations; therefore, differences in thermal insulation performance or moisture behavior are likely driven more by microstructural factors (porosity and latex–fiber interfacial bonding) than by density changes alone.

c. The water absorption test

The water absorption test was conducted to evaluate the moisture uptake behavior of the latex–coconut coir composite specimens, which is a critical property for thermal-insulation materials intended for humid or marine environments. In this procedure, the mass of each specimen was measured before immersion (dry weight) and after immersion for 24 hours (wet weight), following the general approach described in JIS A 5908 (2003). As illustrated in Figure 4.5, the specimens were first weighed using a digital balance, then fully immersed in water for a controlled duration of 24 h, removed from the water, and weighed again to determine the mass increase due to absorbed moisture.

The water absorption (moisture uptake/permeability indicator) was calculated, which expresses water absorption as the relative increase in mass after immersion. In practice, the difference between the wet and dry weights represents the amount of water retained within the composite's pore structure and at the fiber–latex interface. Because coconut coir is naturally porous and hydrophilic, the absorbed water may enter fiber lumens, microvoids, and interfacial gaps, especially when the latex matrix does not fully seal the internal structure. The resulting dataset (presented in the following table) therefore provides a quantitative basis to compare the moisture resistance of each formulation and to assess how increasing coir content influences the susceptibility of the composite to water uptake.

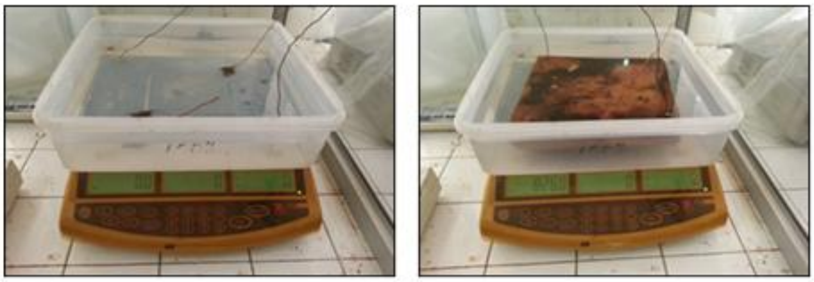

Figure. 7. Illustrates the water absorption (water moisture) %

TABLE 4.
WATER ABSORPTION AND COMPOSITE WEIGHT BEFORE AND AFTER SOAKING (24 H)

Specimen No.	Latex (Liquid) Composition (%)	Coconut Coir (Bulk) Composition (%)	Composite Weight (g)	Weight in Water (g)	Weight After Soaking (g)	Specific Gravity (–) (T = 23°C)	Water Moisture (%)
1	100	0	820	826	827	0.4982	0.846
2	90	10	677	678.5	764	0.4994	11.387
3	80	20	548	548	663	0.5	17.345
4	70	30	544.8	545	655	0.4999	16.824
5	60	40	541	541.5	639	0.4998	15.336
6	50	50	525	525.5	586	0.4998	10.41

Table 4. reports the mass change and water absorption behavior of the latex–coconut coir composites after 24 h immersion, together with the apparent weight in water and the calculated specific gravity at 23°C. The results clearly show that introducing coconut coir strongly increases moisture uptake compared with neat latex. Specimen 1 (100% latex) exhibits very low water absorption (0.846%), indicating that the latex matrix is relatively impermeable and limits water penetration. In contrast, once coir is added (Specimens 2–6), the weight after soaking increases substantially relative to the initial composite weight, reflecting water entering the composite through the coir's porous structure and through microvoids at the latex–fiber interface. The highest water absorption occurs at 80/20 (Specimen 3) with 17.345%, followed closely by 70/30 (Specimen 4) with 16.824%, and 60/40 (Specimen 5) with 15.336%. This trend suggests that at intermediate coir contents (approximately 20–40%), the composite likely develops a more connected pore network and greater exposed fiber surface area, enabling more rapid water ingress and retention. Interestingly, the water absorption decreases at the highest coir content tested: the 50/50 composite (Specimen 6) shows 10.410%, which may indicate improved packing of fibers, reduced open-pore connectivity, or more effective latex coating/bridging of voids during fabrication at this formulation, thereby restricting water pathways compared with the intermediate compositions. Across all specimens, the specific gravity remains nearly constant (~0.498–0.500), meaning the bulk density varies only slightly and does not directly explain the large differences in water uptake; instead, the dominant factor is the internal microstructure (porosity and interfacial bonding). From an application perspective, the table highlights an important design trade-off for fishing-vessel insulation materials: increasing coir content can help reduce weight and introduce insulating porosity, but

it also increases moisture sensitivity, so formulations near the peak absorption region (20–40% coir) may require improved processing or surface protection to maintain durability and thermal performance in marine environments.

Figure 4.6 illustrates the water absorption (water moisture) of latex–coconut coir composite specimens after 24 h immersion. A clear increase in absorbed moisture is observed once coconut coir is introduced into the latex matrix. The neat latex specimen (100% latex) shows very low water uptake (0.846%), indicating limited permeability. When the coir fraction increases, water absorption rises sharply to 11.387% at the 90/10 composition and reaches its maximum at the 80/20 composition with 17.345%. After this peak, the water absorption gradually decreases to 16.824% (70/30) and 15.336% (60/40), and then drops more noticeably to 10.410% at the 50/50 composition. This non-linear trend suggests that intermediate coir contents (approximately 20–40%) promote greater water ingress due to increased exposed fiber surface area and a more connected pore network within the composite, whereas at higher coir loading (50/50) the composite structure may become more compact and/or the latex binder may more effectively bridge and block open pathways, thereby reducing the overall permeability. Overall, the figure confirms that coconut coir significantly influences moisture behavior, and controlling porosity and interfacial bonding is essential to minimize water absorption for marine thermal-insulation applications.

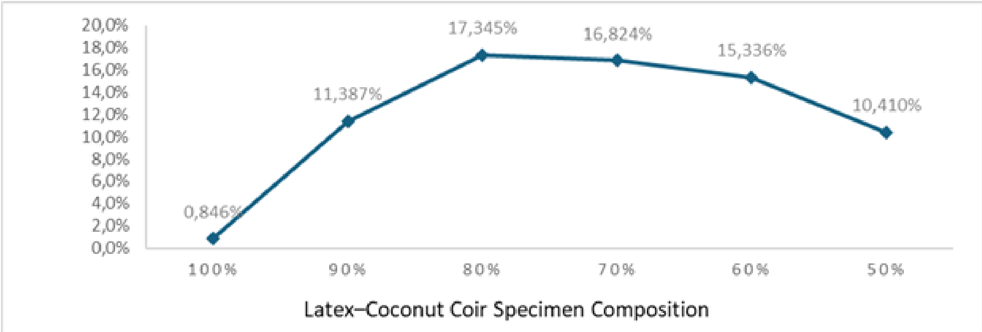

Figure. 8. Measurement of the Specific Gravity of Latex–Coconut Coir Composites

d. Determination of Weight in Water, Specific Gravity, and Density

The specimen density was determined in accordance with ASTM D792-08, which is based on the Archimedes principle. In this method, the density (and specific gravity) is obtained by comparing the specimen's weight measured in air and its apparent weight when submerged in water. The test was performed using an OHAUS BC Series analytical balance with an accuracy of ±0.005, ensuring sufficient resolution to capture small differences among compositions. A rigid container was prepared as the immersion tank, and a sinker wire (support wire) was installed to hold the specimen in a stable position during the submerged weighing. The sinker wire serves two important functions: (i) it prevents the specimen from drifting or touching the container walls, which could disturb the measurement, and (ii) it helps maintain the specimen in a fully submerged condition while allowing it to float freely under buoyancy.

To reduce potential error caused by water absorption during the density measurement, the specimen was not kept in water for a long period. Instead, the submerged weighing was taken after approximately 10 seconds of immersion, which helps minimize the amount of water entering the coir fibers and pores before the reading is recorded. During measurement, the specimen was ensured to remain completely immersed without trapped air bubbles on its surface, because air bubbles would artificially increase buoyancy and lead to an underestimated density. The balance reading was recorded once the specimen

reached a stable position in the water. The resulting weight-in-water data were then used to calculate specific gravity (ratio of specimen density to water density at the test temperature) and density for each formulation. This procedure provides a consistent basis for comparing the density behavior of latex–coconut coir composites as a function of composition, which is an important parameter for evaluating material suitability as lightweight thermal insulation for fishing vessels.

Table 5 presents the measured mass data and the calculated specific gravity and density of latex–coconut coir insulation composites at 23°C, together with the corresponding water moisture (water absorption) after 24 h soaking. The results show that, although the formulation varies substantially from 100% latex (Specimen 1) to 50% latex–50% coir (Specimen 6), the specific gravity remains nearly constant, ranging only from 0.4982 to 0.5000. Consistently, the calculated density values also exhibit only a very small variation, approximately 496.93–498.75 kg/m³, indicating that the bulk density of the composites is largely stable within the investigated composition window. This suggests that the overall density is governed more by the consolidation level and internal pore structure generated during fabrication than by the latex-to-coir ratio alone. In contrast to the relatively constant density, the water moisture values change significantly with composition: neat latex shows minimal uptake (0.846%), while the addition of coir increases water absorption sharply, reaching a maximum at the 80/20 formulation (17.345%) before decreasing at higher coir loading to 10.410% for the 50/50 composite.

These findings highlight a key design implication for marine thermal-insulation panels: composition adjustments within 0–50% coir do not substantially alter density, but they strongly influence moisture behavior, meaning that optimization should focus on controlling porosity and latex–fiber interfacial sealing to minimize water uptake while maintaining lightweight characteristics.

TABLE 5.
SPECIFIC GRAVITY AND DENSITY OF LATEX–COCONUT COIR INSULATION COMPOSITES (T = 23°C)

Specimen No.	Latex (Liquid) Composition (%)	Coconut Coir (Bulk) Composition (%)	Composite Weight (g)	Weight in Water (g)	Weight After Soaking (g)	Specific Gravity (–) (T = 23°C)	Water Moisture (%)	Density (kg/m³)*
1	100	0	820	826	827	0.4982	0.846	496.932
2	90	10	677	678.5	764	0.4994	11.387	498.1981
3	80	20	548	548	663	0.5	17.345	498.75
4	70	30	544.8	545	655	0.4999	16.824	498.6585
5	60	40	541	541.5	639	0.4998	15.336	498.5196
6	50	50	525	525.5	586	0.4998	10.41	498.5126

The density plot for the latex–coconut coir insulation composites shows that the apparent density in water becomes slightly higher than the weight measured in air, and that the calculated density (and thus specific gravity) changes only modestly with composition. As coconut coir is introduced and increased up to 20% coir (80/20 latex/coir), the composite density rises from approximately 496.93 kg/m³ at 100% latex to a maximum of about 498.75 kg/m³. This increase suggests that, at low-to-moderate coir loading, the coir fibers may help fill internal voids and improve consolidation, producing a slightly more compact structure. When the coir content is further increased to 30–50%, the density decreases slightly and then stabilizes in a narrow range (approximately 498.66 → 498.52 kg/m³). This behavior indicates that higher fiber loading can promote additional microvoids, less uniform latex distribution, or reduced packing efficiency, which offsets the densification observed at lower coir contents. Overall, the figure confirms that the density of the composite remains nearly constant across the tested formulations, meaning that differences in performance (e.g., moisture absorption or thermal insulation) are more likely driven by microstructural features such as pore connectivity and latex–fiber interfacial sealing rather than by density changes alone.

5. Discussion

The experimental results show that the physical and moisture-related behavior of latex–coconut coir composites is strongly influenced by the latex–coir composition. In this study, the composite formulation was limited to a maximum of 50% coconut coir because mixtures with coir content above 50% could not be uniformly wetted by latex. Insufficient latex penetration caused weak bonding between fibers and increased the possibility of fiber detachment. This indicates that binder distribution is an important factor in determining the manufacturability of latex–coir insulation panels.

The addition of coconut coir reduced the specimen mass from 820 g for neat latex to 525 g for the 50/50 latex–coir composite. This mass reduction is beneficial for fishing-vessel insulation because lightweight panels can reduce additional load on small vessels. However, the use of coconut coir also increased water absorption due to the porous and hydrophilic nature of the fiber. Water can enter the composite through fiber lumens, microvoids, and imperfectly sealed interfaces between latex and coconut coir.

An important finding of this study is the non-linear water absorption behavior. Water absorption increased after coconut coir was added, reached the highest value at the 80/20 latex–coir formulation, and then decreased at the 50/50 formulation. This trend indicates that water uptake is not determined only by the amount of coconut coir, but also by the internal pore structure, fiber distribution, latex penetration, and interfacial sealing. At intermediate coir content, the composite may form more connected pores and exposed fiber surfaces, resulting in higher water absorption. At higher coir content, fiber packing and partial latex encapsulation may reduce open water pathways, leading to lower absorption.

The nearly constant specific gravity and density values across all formulations further support this interpretation. Although the composition changed from 100/0 to 50/50, the density remained within a narrow range. Therefore, bulk density is not the main factor controlling moisture behavior. Instead, microstructural characteristics such as porosity, pore connectivity, fiber arrangement, and latex–fiber bonding play a more dominant role.

The novelty of this study lies in identifying the feasible formulation window and explaining the composition–moisture relationship of latex–coconut coir composites for marine insulation applications. Unlike many natural-fiber insulation studies that focus on building panels or general-purpose composites, this study evaluates latex–coir composites in the context of fishing-vessel fish holds, where lightweight properties and moisture resistance are both critical. The results provide practical guidance that coir addition can reduce panel weight, but moisture resistance must be improved through better mixing, compaction, latex penetration, fiber treatment, or surface coating before application in humid and splash-exposed marine environments.

Future studies should include direct thermal conductivity testing, longer immersion periods, saltwater exposure, and cyclic wet–dry durability tests to confirm the long-term performance of latex–coconut coir composites as marine thermal insulation materials.

V. CONCLUSION

This study evaluated the physical and moisture-related characteristics of latex–coconut coir composites as lightweight bio-based insulation candidates for fishing-vessel applications. Composite panels were successfully fabricated using latex–coir formulations from 100/0 to 50/50. The results indicate that coconut coir can be incorporated into a latex matrix up to 50% while still producing manufacturable composite panels. However, formulations with coir content above 50% were not considered suitable because the latex binder could not be distributed uniformly and could not effectively penetrate the inter-fiber gaps, resulting in weak specimens and fiber detachment.

The addition of coconut coir reduced the specimen mass from 820 g for neat latex to 525 g for the 50/50 latex–coir composite. This result confirms that increasing coir content can support the development of lightweight insulation panels, which is beneficial for small fishing vessels where additional structural weight should be minimized. However, the incorporation of coir also increased water absorption due to the porous and hydrophilic nature of the fibers. Neat latex showed the lowest water absorption of 0.846%, while the highest water absorption occurred at the 80/20 latex–coir formulation with 17.345%. Interestingly, the water absorption decreased to 10.410% at the 50/50 formulation, indicating a non-linear moisture uptake behavior influenced by fiber distribution, pore connectivity, and latex–fiber interfacial sealing.

The specific gravity and density values remained nearly constant across all formulations, with specific gravity ranging from approximately 0.498 to 0.500 and density ranging from 496.93 to 498.75 kg/m³ at 23°C. This finding shows that the large differences in water absorption were not mainly caused by bulk density changes, but rather by microstructural factors such as porosity, fiber arrangement, and the effectiveness of latex in sealing the fiber network. Therefore, the novelty of this study lies in identifying the composition–moisture behavior relationship of latex–coconut coir composites for marine insulation applications, particularly the finding that moisture uptake is non-linear despite nearly constant density.

Overall, latex–coconut coir composites have potential as lightweight and locally available bio-based insulation materials for fishing-vessel fish holds. Nevertheless, their application in humid and splash-exposed marine environments requires further improvement, especially through better mixing, compaction, latex penetration, fiber treatment, or protective surface sealing. Future studies should include direct thermal conductivity testing, longer immersion periods, saltwater exposure, and cyclic wet–dry durability tests to confirm their long-term performance as marine thermal insulation materials.

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