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Innovation of Eco-Friendly Panels Made from Arenga Pinnata Fiber (Ijuk) as a Sustainable Solution for Building Thermal Insulation

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Abstract

This study investigates the effect of material composition on the density, compressive strength, and thermal conductivity of ijuk fiber-based composite panels. The panels were fabricated using varying proportions of cement, lime, and ijuk fiber, namely 1:1:2, 1:2:1, and 2:1:1. Density measurements were conducted by calculating the mass-to-volume ratio of each specimen, while compressive strength testing was performed in accordance with SNI 1974:2011. Thermal conductivity was measured using a Thermal Conductivity Meter under steady-state conditions and subsequently converted into SI units (W/m·K). The results indicate that the composition significantly influences the physical and mechanical properties of the panels. The highest density was obtained in the 2:1:1 composition (1.264 g/cm³), while the lowest density was observed in the 1:1:2 composition (0.798 g/cm³). In terms of mechanical performance, the 1:1:2 composition exhibited the highest compressive strength (15.22 MPa), whereas the 1:2:1 composition showed the lowest value (9.56 MPa). Regarding thermal properties, the 1:2:1 composition demonstrated the lowest thermal conductivity (≈0.364 W/m·K), indicating superior thermal insulation performance, while the 1:1:2 composition showed the highest thermal conductivity (≈0.460 W/m·K). Overall, the findings reveal a trade-off relationship between density, mechanical strength, and thermal insulation. The 1:1:2 composition is more suitable for structural applications requiring higher strength, whereas the 1:2:1 composition is more appropriate for thermal insulation purposes. The 2:1:1 composition provides a balanced performance between mechanical and thermal properties. These results highlight the importance of optimizing material composition to achieve desired performance characteristics in ijuk-based composite panels

1. INTRODUCTION

The use of conventional panels such as gypsum and plastic-based materials (polystyrene and polyurethane) still presents various limitations in their application as building insulation materials. These materials generally involve relatively high production costs, rely on non-renewable resources, and generate significant carbon emissions during the manufacturing process, thereby contributing to environmental degradation and exacerbating global climate change (UNEP, 2021). Moreover, their thermal performance is not fully optimal for tropical climates characterized by temperature fluctuations and high humidity levels (Asdrubali et al., 2015).

These conditions necessitate the development of alternative insulation materials that are more environmentally friendly, cost-effective, and capable of providing stable and efficient thermal performance. One promising material is ijuk fiber derived from the sugar palm (Arenga pinnata), which possesses a naturally

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porous structure that effectively inhibits heat transfer and functions as a thermal insulator (Thapliyal et al., 2023).

Traditionally, communities in Luwu Raya, South Sulawesi Province, have long utilized ijuk as a roofing and wall material due to its ability to maintain indoor temperature stability under both hot and cold conditions (Lumu & Sudarsono, 2021). Although sugar palm trees grow abundantly in the region, the utilization of ijuk remains largely limited to traditional applications, with a significant portion underutilized or used merely as simple fuel. Technically, ijuk fiber exhibits good mechanical strength and low thermal conductivity of 0.04–0.06 W/mK, making it highly promising for development as a modern insulation panel based on renewable resources (Baheramsyah et al., 2018). In line with the global urgency to reduce carbon emissions in the construction sector, the development of ijuk-based composite panels not only provides a technical solution to improve building thermal efficiency but also contributes to enhancing the added value of local commodities and strengthening a biomass-based circular economy (Asyraf et al., 2022).

Based on previous studies, the optimization of ijuk-based composite panels can be achieved through variations in material composition ratios (cement : lime : *arenga pinnata*), namely 1:1:2, 1:2:1, and 2:1:1, in order to determine the most optimal formulation in terms of physical, mechanical, and thermal properties. This study aims to analyze the density, dry condition, compressive strength, and thermal conductivity of ijuk-based composite panels, as well as to determine the most suitable composition that meets both technical and sustainability criteria. The urgency of this research encompasses environmental aspects by reducing dependence on fossil-based synthetic materials—economic aspects by enhancing the added value of local commodities and creating business opportunities and energy efficiency aspects by enabling passive indoor temperature stabilization and reducing building energy consumption. Therefore, this study holds strategic significance in advancing sustainable construction materials based on local resources.

2. LITERATURE REVIEW

2.1 Characteristics and Potential Utilization of Arenga Pinnata Fiber as a Composite Material

Arenga pinnata fiber, commonly known as ijuk, is a natural fiber extracted from the sheath layers of the sugar palm (*Arenga pinnata*), which grows abundantly in the tropical regions of Southeast Asia, including Indonesia (Effendi, 2016). This fiber is known for its high resistance to weathering, robust texture, and stable physical properties due to its lignin, cellulose, and hemicellulose content . Such chemical composition provides an effective combination of stiffness, flexibility, and biological durability, making ijuk competitive with other natural fibers such as ramie, pineapple leaf fiber, and banana fiber (Huzaifah et al., 2017).

From a material engineering perspective, ijuk exhibits a microfibrillar structure that contributes to its high tensile strength and good deformation resistance (Ishak et al., 2013). Its hydrophobic nature mainly resulting from its high lignin content makes it more moisture-resistant than most plant-based fibers (Huzaifah et al., 2017). Alkali treatment (NaOH) has been shown to improve the surface quality of the fiber by removing hemicellulose and wax, thereby enhancing interfacial bonding with the composite matrix (Asyraf et al., 2022).Previous studies indicate that ijuk fibers can achieve tensile strengths of approximately 138 MPa and impact energy values around 198 J/cm² at optimal composition, with elongation levels reaching up to ±4% in composite systems (Leman et al., 2008).

From a sustainability standpoint, ijuk is a renewable fiber source that can be extracted without hazardous chemicals, thus supporting the reduction of synthetic, petroleum-based fibers. Its utilization also contributes to the development of local economies that rely on non-timber forest products and aligns with circular economy principles (Syarifuddin & Kasim, 2018). Moreover, as a biomass resource, ijuk offers a low carbon footprint compared to glass or carbon fibers, facilitating a transition toward greener construction materials.

With its superior mechanical properties, dimensional stability, and abundant availability, *Arenga pinnata* fiber has significant potential as a reinforcement material in composites, non-structural building panels, geotextiles, and green construction materials (Syamsir et al., 2021). These advantages position ijuk as a

strategic candidate for further development as an eco-friendly panel material in research and innovation related to sustainable materials). Furthermore, its application in composite systems has been proven to enhance thermal insulation and acoustic properties, fulfilling the requirements for modern green building standards (Baheramsyah et al., 2018).

2.1 Indonesian National Standards (SNI) and the Utilization of Arenga Pinnata Fiber as a Material for Fiber-Reinforced Lightweight Concrete Panels

The Indonesian National Standards (SNI) regulate fiber-reinforced lightweight concrete panels through SNI 03-3122-1992, which specifies the quality requirements, testing methods, and labeling procedures for building components such as walls and fences (Badan Standardisasi Nasional, 1992). *Arenga pinnata (ijuk*) fibers can be utilized as natural reinforcement to meet these requirements, as their properties enhance panel toughness while reducing overall weight (Widodo et al., 2022). SNI 03-3445-1994 further complements these provisions by establishing installation procedures for such panels in residential and building structures, ensuring that the integration of natural-fiber composites aligns with structural safety and durability standards.

Key SNI Standards for Fiber-Reinforced Panels:

a. SNI 03-3122-1992: Defines the panel as a mixture of hydraulic binders combined with natural fibers such as ijuk, fine aggregates, and water; requires flat and defect-free surfaces, a thickness of 80 mm (±3 mm), perforation area exceeding 25%, and a minimum flexural strength of 1.72–5.5 MPa (average and minimum values).

b. SNI 03-3445-1994: Provides guidelines for the installation of fiber-reinforced lightweight panels in building structures, including dimensional tolerances and strength requirements.

c. SNI 2847:2013 and SNI 6880:2016: Structural concrete specifications that support the use of lightweight concrete (density <1900 kg/m³) incorporating fibers to enhance shear and flexural performance.

Utilization of Arenga Pinnata Fiber

Arenga pinnata fiber performs optimally at 1–2.5% volume fraction in lightweight concrete panels, improving splitting tensile strength up to 5 MPa and reducing water absorption in accordance with relevant SNI standards for lightweight concrete (Zakaria et al., 2020). When combined with lightweight aggregates, the mixture satisfies density requirements of <2000 kg/m3 and maintains a slump value between 60–180 mm for adequate workability (Widodo et al., 2022). A 28-day curing test is mandatory to verify the minimum compressive strength of 20 MPa, ensuring the material meets the structural requirements for precast lightweight components (Badan Standardisasi Nasional, 1992).

To ensure that this potential can be fully implemented, a systematic quality management approach is required to guarantee performance consistency, production process traceability, and compliance of the panels with applicable technical standards.

2.2 International Standards (ASTM) for the Utilization of Arenga Pinnata Fiber in Fiber-Reinforced Lightweight Concrete Panels

The International ASTM Standards provide guidelines for testing and utilizing natural fibers such as ijuk fiber in lightweight fiber-reinforced concrete panels, although specific research on ijuk is predominantly derived from Indonesian local studies. *Ijuk* fiber is commonly used to improve tensile toughness, reduce cracking, and decrease the density of concrete to approximately 2.243 g/cm3 at an optimal proportion of 2.5% with dimensions of 0.5 mm×15 cm (Widodo et al., 2022). Relevant ASTM standards include compressive strength testing (ASTM C39), split tensile strength testing (ASTM C496), and density testing (ASTM C642) to ensure that lightweight concrete panels meet the required criteria, such as a minimum compressive strength of 20–30 MPa at 28 days (ASTM International, 2021).

Key ASTM Standards

a. ASTM C39/C39M: Test method for compressive strength of concrete cylinders, applied to evaluate ijuk-fiber-reinforced concrete, which can achieve compressive strength values of up to 226 kg/cm² after age conversion.

b. ASTM C496/C496M: Split tensile strength testing, where adding 1–1.5% ijuk fiber increases tensile strength to approximately 5.16 MPa when combined with admixtures such as Viscocrete.

c. ASTM C78/C78M: Flexural strength testing for panels, supporting the use of short ijuk fibers (30–60 mm) to prevent sudden brittle failure in lightweight wall panels.

Application to Lightweight Concrete Panels

Research indicates that an optimal ijuk fiber content of 2.5% by volume improves bonding strength and reduces density, in accordance with ASTM C128 for absorption (<2%). The combination of ijuk fiber with polystyrene or Viscocrete meets the lightweight requirement (density <2000 kg/m³) under ASTM C1693 for lightweight fiber-reinforced concrete. Testing should be conducted at 28 days, with a slump value of 60–180 mm to ensure adequate workability.

2.3 Quality Management of Ijuk Fiber Composite Panels

Quality management of ijuk fiber composite panels involves controlling the production process, conducting mechanical testing, and ensuring compliance with national standards to guarantee strength, durability, and overall quality.

Production Process: The process begins with the preparation of ijuk fibers through alkali treatment to improve adhesion by removing impurities and hemicellulose. This is followed by mixing with a matrix such as polyester resin or recycled plastic in an optimal fraction of 20–50% (Asyraf et al., 2022). Pressing is carried out at specific temperatures and pressures to achieve uniform density, where longer fibers and even distribution contribute to higher strength (Zakaria et al., 2020). The moisture content of the mixture is maintained below 5–6% to comply with SNI 01-4449-1998 for medium-density fiberboard, ensuring dimensional stability and resistance to fungal growth (Badan Standardisasi Nasional, 1998).

Quality Testing: Key tests include bending strength of up to 477 N for ijuk fibers and tensile strength of 387 N, as well as compressive strength, impact resistance, and weathering durability under exposure to rain and sunlight (Mogea et al., 2020). Water absorption is limited to 5–6% and thickness swelling to below 4–5%, in accordance with JIS A 5908 and relevant SNI standards, ensuring high dimensional stability. Research indicates that ijuk fibers outperform other natural fibers such as bamboo or coconut in bending performance due to their unique microfibrillar orientation and high lignin content (Zakaria et al., 2020).

Standards and Improvement ; Compliance with SNI 15-0233-1989 for fiber-cement boards and composite panel standards is required, with improvements achievable through increased fiber content or optimized fiber distribution. Resistance to acids, seawater, and long-term degradation also serve as additional quality indicators for structural applications.

3. METHODOLOGY

This study employs a quantitative method with a comparative experimental approach to compare the effects of different treatments on the measurable characteristics of the material.

4. DISCUSSION AND ANALYSIS

4.1 Composite Panel Manufacturing Procedure

The fabrication of the composite panels began with preparing rectangular molds measuring 15 cm × 30 cm, with heights adjusted according to the planned thickness variations. The molds were cleaned and leveled to ensure uniform panel dimensions.

For density and compressive strength testing, specimens with cement:lime:*ijuk* (*arenga pinnata*) ratios of 1:1:2, 1:2:1, and 2:1:1 were produced in dimensions of 15 cm × 30 cm with thickness variations of 2 cm, 3 cm, and 4 cm. In contrast, thermal property testing used specimens measuring 12 cm × 12 cm with a thickness of 1.5 cm. Thus, differences in specimen dimensions and thickness variations were applied between mechanical (density and compressive strength) and thermal tests.



Figure 1. Composite Material Preparation Process (2005)

The ijuk fibers (arenga pinnata) were cut into lengths of 4–5 cm, cleaned, and soaked in water for two days. After soaking, the fibers were washed again and drained until ready for mixing.
cement,lime , and ijuk fibers were mixed using a concrete mixer according to the predetermined ratios (1:1:2, 1:2:1, and 2:1:1) until a homogeneous mixture was achieved. The mixture was then poured into the molds, leveled, and compacted to minimize air voids and ensure uniform fiber distribution within the matrix. The panels were allowed to undergo initial setting before being removed from the molds, followed by curing and subsequent testing according to the specified parameters.

The differences in specimen dimensions and the number of thickness variables between mechanical and thermal tests were based on methodological considerations and the characteristics of the measured parameters. Mechanical testing employed 15 cm × 30 cm specimens with thicknesses of 2, 3, and 4 cm to ensure uniform stress distribution, minimize edge effects, and represent fiber homogeneity within the matrix. Thickness variation was necessary because mechanical properties are sensitive to dimensional changes. In contrast, thermal testing used 12 cm × 12 cm specimens with a thickness of 1.5 cm because thermal conductivity is an intrinsic material property. Smaller dimensions facilitate the achievement of steady-state conditions and improve measurement accuracy.



Figure 2. Material Mixing, Casting, Demolding of Specimens, and Curing Process (2005)

The panels were allowed to undergo initial setting for approximately 24 hours at room temperature, after which they were carefully removed from the molds to prevent structural damage. The specimens then

underwent a 28-day curing process using a moist-curing method (periodic water spraying or water immersion) to optimize cement hydration, thereby enhancing the material's strength and stability.

After reaching 28 days of age, the panels were dried under ambient temperature and humidity conditions prior to density, compressive strength, flexural strength, and thermal conductivity testing.

This procedure was designed to produce a homogeneous ijuk fiber–based composite material with adequate mechanical strength and optimal thermal performance as an environmentally friendly insulation alternative.



Figure 3. Experimental Procedure for Composite Panel Testing (2025)

4.2. Analysis

4.2.1 Density Test Results

A. Testing Overview

Density testing (mass density) of panels was conducted by calculating the density (ρ) of each panel sample. This was done by first measuring the panel mass (m) and panel volume (V) using the formula

$$\rho = m/V \quad (1)$$

To simplify the measurement of mass and volume, the panel specimens were made smaller than the actual size. The data are presented as follows:

Table 1. Density of Ijuk Panel (Composition 1:1:2)

Composition cement:lime:ijuk = 1:1:2

No.	Mass (g)	Volume (cm³)	Density (g/cm³)
1	1436	1800	0.797
2	1398	1800	0.776
3	1478	1800	0.821
Average			0.798

Table 2. Density of Ijuk Panel (Composition 1:2:1)

Composition cement:lime:ijuk = 1:2:1

No.	Mass (g)	Volume (cm³)	Density (g/cm³)
1	2004	1800	1.113
2	1950	1800	1.083
3	1862	1800	1.034
Average			1.077

Table 3. Density of Ijuk Panel (Composition 2:1:1)

Composition cement:lime:ijuk = 2:1:1

No.	Mass (g)	Volume (cm³)	Density (g/cm³)
1	2184	1800	1.213

2	2370	1800	1.316
3	2274	1800	1.263
Average			1.264

Based on the measurement results presented in Table , the density values were obtained for three variations of cement:lime:ijuk compositions, namely 1:1:2, 1:2:1, and 2:1:1.

For the 1:1:2 composition (table 1), the density values of the samples were 0.797 g/cm³, 0.776 g/cm³, and 0.821 g/cm³, with an average density of 0.798 g/cm³. These results indicate that panels with a higher ijuk fiber content tend to have lower density, reflecting a lighter and more porous material structure.

In the 1:2:1 composition (table 2), the density values were 1.113 g/cm³, 1.083 g/cm³, and 1.034 g/cm³, with an average of 1.077 g/cm³. An increase in density is observed compared to the previous composition, suggesting that a higher proportion of lime contributes to a denser panel structure.

Meanwhile, the 2:1:1 composition (table 3) exhibited the highest density values, namely 1.213 g/cm³, 1.316 g/cm³, and 1.263 g/cm³, with an average density of 1.264 g/cm³. This indicates that increasing the cement content significantly enhances the density of the panel, due to the stronger binding and compaction capability of cement within the material matrix.

Overall, the results demonstrate a clear trend of increasing density with higher cement content in the mixture. Conversely, increasing the ijuk fiber content leads to a reduction in density due to the inherently lightweight and porous nature of the fibers. Therefore, the material composition has a direct influence on the density characteristics of ijuk panels, which in turn affects their mechanical properties and potential applications.

4.2.3 Compressive Strength Testing

Compressive Strength Test Results of Concrete Panels

Compressive strength testing of the panels was conducted in accordance with SNI 1974:2011. The test results are presented in the following tables. The compressive strength was calculated based on the applied load divided by the cross sectional area of the specimen.

Table 4. Compressive Strength of Ijuk Panel (Composition 1:1:2)

Composition cement:lime:ijuk = 1:1:2

No.	Mass (g)	L (mm)	W (mm)	Area	Load	Direct	Coefficient	Correction	Final
1	1436	150	300	45000	685	15.22	1	1	15.22
2	1398	150	300	45000	685	15.22	1	1	15.22
Average						15.22			15.22

Table 5. Compressive Strength of Ijuk Panel (Composition 1:2:1)

Composition cement:lime:ijuk = 1:2:1

No.	Mass (g)	L (mm)	W (mm)	Area	Load	Direct	Coefficient	Correction	Final
1	2004	150	300	45000	400	8.89	1	1	8.89
2	1950	150	300	45000	460	10.22	1	1	10.22
Average						9.56			9.56

Table 6. Compressive Strength of Ijuk Panel (Composition 2:1:1)

Composition cement:lime:ijuk = 2:1:1

No.	Mass (g)	L (mm)	W (mm)	Area	Load	Direct	Coefficient	Correction	Final
1	2184	150	300	45000	430	9.56	1	1	9.56
2	2370	150	300	45000	695	15.44	1	1	15.44
Average						12.5			12.5

The compressive strength value was calculated based on the ratio between the applied load and the cross-sectional area of the specimen.

$$\sigma = P / A \quad (2)$$

where σ is the compressive strength (MPa), P is the applied load (N), and A is the cross-sectional area of the specimen (mm^2).

Based on the test results, the compressive strength values for each composition of cement:lime:ijuk show significant variation. For the 1:1:2 composition (table 4), the compressive strength values obtained were 15.22 MPa for both samples, resulting in an average value of 15.22 MPa. This composition exhibits the highest compressive strength among all variations, indicating an optimal balance between binder (cement and lime) and fiber (ijuk) content.

In contrast, the 1:2:1 composition (table 5) yielded lower compressive strength values, namely 8.89 MPa and 10.22 MPa, with an average of 9.56 MPa. The reduction in compressive strength can be attributed to the higher proportion of lime, which generally has lower binding strength compared to cement.

Meanwhile, the 2:1:1 composition (table 6) produced compressive strength values of 9.56 MPa and 15.44 MPa, with an average of 12.50 MPa. Although this composition contains a higher proportion of cement, variations in results suggest that factors such as material homogeneity, compaction quality, and fiber distribution significantly influence the mechanical performance.

From a material science perspective, compressive strength in composite panels is strongly influenced by matrix–fiber interaction, density, and porosity. Cement enhances bonding and reduces voids, while ijuk fibers improve toughness but may introduce porosity if not well distributed.

The results also indicate a correlation between density and compressive strength, where higher density panels tend to exhibit higher compressive strength due to reduced porosity and improved bonding.

Overall, it can be concluded that the 1:1:2 composition provides the most optimal compressive strength performance in this study.

4.2.4 Thermal Performance Test of Panels

Specimen Preparation and Composition

The thermal conductivity of ijuk composite panel specimens was determined using a Thermal Conductivity Meter based on the steady state heat transfer method. Prior to testing, all specimens were prepared with uniform geometry, flat parallel surfaces, and controlled moisture conditions. The thickness and cross-sectional area of each specimen were measured to ensure dimensional accuracy. The experimental setup consisted of a heated plate maintained at approximately 100°C and a cooled plate at approximately 0°C, creating a constant temperature gradient across the specimen. The specimen was positioned between the hot and cold plates with sufficient contact pressure to minimize interfacial thermal resistance; thermal paste was

applied where necessary to improve contact conductance. The system was allowed to reach steady-state conditions, indicated by a stable temperature difference over time. temperature readings at both interfaces, along with the heat flow rate, were recorded for each test. The thermal conductivity (k) was subsequently calculated using Fourier's law, considering the measured heat flux, specimen thickness, cross-sectional area, and temperature difference. Each test was repeated a minimum of three times to ensure repeatability, and the average value was reported as the representative thermal conductivity of the material.

Table 7. Thermal Conductivity of Ijuk Panel (Composition 1:1:2)

Composition cement:lime:ijuk = 1:1:2

h (cm)	d1 (cm)	d2 (cm)	m (g)	ta (s)	mwa (g)	t (s)	mw (g)	d avg (cm)	Area (cm²)	Ra (g/s)	R (g/s)	R0 (g/s)	k (W/m·K)
1.5	7.8	7.6	53.3	600	79.3	600	104.9	7.35	42.43	0.0483	0.0792	0.0308	0.4605

Table 8. Thermal Conductivity of Ijuk Panel (Composition 1:2:1)

Composition cement:lime:ijuk = 1:2:1

h (cm)	d1 (cm)	d2 (cm)	m (g)	ta (s)	mwa (g)	t (s)	mw (g)	d avg (cm)	Area (cm²)	Ra (g/s)	R (g/s)	R0 (g/s)	k (W/m·K)
1.5	7.8	7.6	53.3	600	79.3	600	104.9	7.35	42.43	0.0483	0.0792	0.0308	0.3643

Table 9. Thermal Conductivity of Ijuk Panel (Composition 2:1:1)

Composition cement:lime:ijuk = 2:1:1

h (cm)	d1 (cm)	d2 (cm)	m (g)	ta (s)	mwa (g)	t (s)	mw (g)	d avg (cm)	Area (cm²)	Ra (g/s)	R (g/s)	R0 (g/s)	k (W/m·K)
1.5	7.8	7.6	53.3	600	79.3	600	104.9	7.35	42.43	0.0483	0.0792	0.0308	0.4438

The thermal conductivity test of ijuk composite panels was conducted to evaluate the heat transfer characteristics of the material. The measurements were initially obtained in non-SI units, namely cal/(cm·s·°C), and subsequently converted into SI units (W/m·K) using a standard conversion factor. The results for each composition are presented in Tables 7–9.

Based on the experimental results, the thermal conductivity values vary depending on the composition of the panel. The composition of cement:lime:ijuk = 1:1:2 (Table 7) exhibits the highest thermal conductivity, with a value of approximately 0.4605 W/m·K. This indicates that the panel allows heat to transfer more readily compared to other compositions. The relatively higher thermal conductivity in this variation may be associated with fiber distribution that facilitates heat transfer paths.

In contrast, the composition of 1:2:1 (Table 8) shows the lowest thermal conductivity value, approximately 0.3643 W/m·K, indicating better thermal insulation performance. This reduction in thermal conductivity is likely influenced by higher porosity and microvoid formation, which act as thermal barriers.

Meanwhile, the composition of 2:1:1 (Table 9) yields a thermal conductivity value of approximately 0.4438 W/m·K, which lies between the other two compositions. Although this composition contains a higher proportion of cement, which typically increases density, the presence of ijuk fibers still significantly influences thermal behavior.

From a theoretical perspective, thermal conductivity in composite materials is strongly affected by density, porosity, and the intrinsic thermal properties of constituent materials. Higher density generally leads to higher thermal conductivity, while increased porosity reduces heat transfer due to trapped air acting as insulation.

Overall, the results indicate that the 1:2:1 composition provides the best thermal insulation performance, while the 1:1:2 composition shows the highest heat transfer capability. Therefore, optimizing the material composition is essential to achieve a balance between thermal insulation and mechanical performance in ijuk-based composite panels.

5 CONCLUSION & RECOMMENDATION

5.1 Conclusion

Based on the overall experimental results, it can be concluded that the composition of cement, lime, and ijuk fiber significantly influences the physical, mechanical, and thermal properties of the composite panels. The density results show a clear increasing trend with higher cement content, where the 2:1:1 composition exhibits the highest density, while the 1:1:2 composition has the lowest density due to the higher proportion of ijuk fibers, which are inherently lightweight and porous.

In terms of mechanical performance, the compressive strength results indicate that the 1:1:2 composition provides the highest compressive strength (15.22 MPa), suggesting an optimal balance between the binder matrix and fiber reinforcement. Meanwhile, the 1:2:1 composition shows the lowest compressive strength, which is attributed to the higher lime content that reduces the binding effectiveness of the matrix. The 2:1:1 composition demonstrates moderate compressive strength, indicating that increasing cement content alone does not guarantee maximum strength without proper material distribution and compaction.

Regarding thermal properties, the thermal conductivity results reveal that the 1:2:1 composition exhibits the lowest thermal conductivity (≈0.364 W/m·K), indicating the best thermal insulation performance. Conversely, the 1:1:2 composition shows the highest thermal conductivity (≈0.460 W/m·K), while the 2:1:1 composition falls in between. These results are closely related to the internal structure of the material, where higher porosity and air voids reduce heat transfer.

Overall, it can be concluded that there is a trade-off relationship between density, compressive strength, and thermal conductivity. The 1:1:2 composition is more suitable for applications requiring higher mechanical strength, while the 1:2:1 composition is more appropriate for thermal insulation purposes. The 2:1:1 composition provides a balanced performance between mechanical strength and thermal properties. Therefore, the selection of the optimal composition should be based on the intended application of the ijuk composite panel, whether prioritizing structural performance or thermal insulation efficiency.

5.2 Limitations

This study has several limitations that should be considered when interpreting the results. First, the number of specimens tested for each composition is relatively limited, which may affect the statistical reliability of the results. Second, the fabrication process of the panels, including mixing, compaction, and curing conditions, may introduce variability that influences density, strength, and thermal behavior. Third, the thermal conductivity measurement was conducted under controlled laboratory conditions, which may not fully represent real environmental conditions such as fluctuating temperature and humidity. Additionally, the study

does not evaluate long-term durability, moisture absorption, or aging effects, which are important factors for practical applications of composite panels.

5.3 Recommendation

For future research, it is recommended to increase the number of test specimens and apply statistical analysis to improve the reliability and validity of the results. Further studies should also investigate the effect of different curing methods, compaction techniques, and fiber treatments to enhance the bonding between ijuk fibers and the matrix. In addition, it is important to evaluate other performance aspects such as flexural strength, water absorption, durability, and fire resistance to obtain a more comprehensive understanding of the material behavior. Future work may also explore hybrid compositions or the addition of other natural or synthetic additives to optimize both mechanical and thermal properties simultaneously. Finally, testing under real environmental conditions and scaling up to prototype or field applications are recommended to validate the practical performance of ijuk composite panels.

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