The Effect of Coconut Fiber Usage and Clamshell Powder Replacement for Calcium Silicate Board's Bending Strength

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Abstract— **Calcium silicate boards (CSB) are being explored in the maritime industry due to the mechanical strength and its resintance to humidity. The common CSB comprises fiber, silica sand, and portland cement. Clamshell is one of marine waste, who has a high calcium carbonate (CaCO3) content. Coconut fiber, a natural fiber known for its high strength and durability, presents sustainable solutions for enhancing the material properties of CSB. This study explores the forming mechanism and mechanical properties of the CSB in the usage and varied volume fraction addition of coconut fiber with the varied portion replacement silica sand using clamshell powder. The bending test was performed, and the experimental results were analyzed using ANOVA, to understand the effect of the mixture composition on the bending strength of the CSB. The addition of volume fraction coconut fiber significantly improve the bending strength of the boards, while the replacement of silica sand using clamshell powder gives various result. The maximum bending strength was 13.87 ± 0.64 Mpa by 0% clamshell powder replacement in 9% coconut fiber, and significantly drop** at **8.26 ± 2.20 MPa by 50% clamshell powder with 50% silica sand. In fully portion replacement of silica sand, in which the addition of 100% clamshell powder, with 9% coconut fiber, the bending strength measured at 10.29 ± 1.31 MPa. The highest results exceeding the minimum requirement in ISO-8336 category A and B (saturated condition) , class 3 (>13 MPa) standards for interior wall installations. This study providing a more robust and eco-friendly materials alternatives that supports non or maritime industry needs in while resolve the environmental issue.**

Keywords:— Coconut Fiber, Clamshell Powder, Silica Sand, Bending Strength, Calcium Silicate Board.

I. Introduction

Maritime countries with extensive coastlines and abundant marine resources, such as Indonesia, have significant potential to produce marine animals like clams, fish, shrimp, and others. However, the coastal regions of Indonesia generate substantial amounts of clamshell and coconut waste, leading to significant environmental challenges. Clamshell waste is an organic waste product that has become a serious environmental problem. In 2019, Indonesia exported 77,732 kg of frozen clams. A significant amount of clamshell waste may be produced as a byproduct. Regions like Surabaya, particularly in Nambangan-Cumpat, produce as much as 12,823 tons of clam waste daily. Similarly, coconut production generates significant organic waste. Indonesia's coconut production exceeded 2 million tons in 2022, with East Java contributing 240,295 tons. Coconut's volume contains 35% coconut husk. It can potentially add 4.02 tons of organic waste. Coconut husks, consisting of pith and fiber, possess high stiffness, strength, and abrasion resistance, making them a valuable resource for several applications.

Studies have demonstrated that the combination of clamshell powder derived from blood shells (Anadara granosa) and natural fibers like coconut fiber plays a significant role in enhancing the mechanical properties of composite materials. The hand lay-up method found that a composite with a volume fraction ratio of 0:30 (clamshell powder to coconut fiber) achieved the highest average bending strength of 39.57 MPa (Utami, 2021). This study underscores coconut fiber's critical role in improving composites' structural integrity when used in optimal proportions. Furthermore, natural fibers like coconut fiber have shown potential for use in calcium silicate boards, supporting the development of green technology materials (Sheng, Zhang, et al., 2023). Calcium silicate boards, composed of silica sand, cement, natural fibers, and clay, are lightweight, environmentally friendly, and exhibit superior performance compared to conventional wallboard materials. Fiber-reinforced calcium silicate boards are considered promising materials due to their enhanced mechanical properties and sustainability.

The components of calcium silicate boards consist of silica sand, cement, natural fibers, and clay. Natural fibers can influence the quality of calcium silicate boards. Fiber-reinforced calcium silicate boards

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are considered one of the most potential new materials with better performance. In addition to being lightweight, calcium silicate board material is also environmentally friendly. This composite can be an alternative to regular wallboard materials. Despite the recognized potential of clamshell powder and coconut fiber in calcium silicate boards, there is a lack of comprehensive analysis regarding the optimal volume fraction of clamshell powder and coconut fiber to achieve maximum bending strength performance. The effect of different combinations of clamshell powder on coconut fiber for making calcium silicate boards must be examined to address these study gaps. The study's novelty is in creating a composite material that uses organic waste that is not being used, which helps create sustainable materials and reduces environmental pollution.

II. METHOD

A. Mold Fabrication

At this stage, mold fabrication is carried out using acrylic material. The mold design is created using Autodesk Fusion 360 software, with mold dimensions referring to ISO-8336, as shown in Figure 1 below. Next, 5 mm thick acrylic material is prepared to be cut according to the mold pattern, as shown in Figure 1 above. Additionally, 1 mm thick acrylic material is ready to be cut without a pattern to serve as the base and lid of the mold. The acrylic material is cut using a laser cutting machine. After the cutting, the mold pieces are assembled, bolts are placed in the holes, and the mold is ready for use.

B. Coconut Fiber Preparation

Processing is conducted to obtain the desired coconut fiber, which will be used as reinforcement in the calcium silicate board.

1. The coconut husk is soaked in water for seven days to facilitate fiber extraction.
2. The coconut husk is brushed longitudinally with a wire brush to obtain the fibers.
3. The fibers are rinsed with water to clean them.
4. The coconut fibers are dried in the sun until completely dry.
5. fibers undergoing alkali treatment are soaked in a 5% NaOH solution for 72 hours.

C. Clamshell Powder Preparation

Processing is conducted to obtain the desired powder size. The clamshell powder will be used as a substitute for silica sand in the calcium silicate board.

1. The clamshell powder obtained from the clamshell grinding facility is prepared.
2. A 100-mesh wire sieve is prepared.
3. The powder is sifted to achieve the desired particle size (100 mesh).

D. Density Measurement

Density measurement is conducted to determine the density of the powder and sand. The results of this density test will be used to calculate the required amounts of clamshell powder, silica sand, and cement in the production of calcium silicate board. This study uses the pycnometer method to test clamshell powder's and silica sand's density. Through this method, the mass of the empty pycnometer, the mass of the pycnometer with powder, and the mass of the pycnometer with powder and water are measured using a digital balance. Then, the density is calculated based on the obtained data using the following equation.

$$Density = \frac{m}{v} \quad (1)$$

Where:
m = massa (g)
v = volume (mL)

E. Calcium Silicate Board Synthesis

The calcium silicate board used in this research is manufactured using the hand lay-up method.

1) Calculations were performed for the cement requirement, silica sand, and the mass of coconut fiber with volume fractions of 5%, 7%, and 9%. Clamp shell powder was substituted for silica sand in the Calcium Silicate Board at 0%, 50%, and 100%.
The fiber requirement is determined using the following equation:

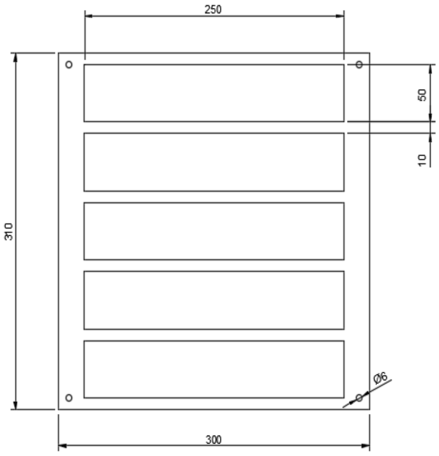

Figure. 1. The Design of Specimen Molds

Mass of coconut fiber = $(fv) \times V \times \rho_s$ (2)

Where:
Fv = volume fraction
V = volume of mold (mm^3)
ρ_s = density of coconut fiber (g/mL)

The volume fraction of cement is 25%. The cement requirement is determined using the following equation:

Mass of cement = $(fv) \times V \times \rho$ (3)

Where:
ρ = density of cement (g/mL)

The requirements for clamshell powder at 5% fiber and 100% replacing silica sand result in a volume fraction of 70%. The mass calculation for 100% clamshell powder replacing silica sand is as follows:

Mass of Clamshell Powder = $\frac{70}{100} \times \rho_{ck} \times V_c$ (4)

Where:
ρ_{ck} = density of clamshell (g/mL)
V_c = volume of mold (mm^3)

The requirements for clamshell powder at 5% fiber and 50% replacing silica sand result in a volume fraction of 35%. The mass calculation for 50% clamshell powder replacing silica sand is as follows:

Mass of Clamshell Powder = $\frac{35}{100} \times \rho_{ck} \times V_c$ (5)
Therefore, the mass of silica sand required when 50% of it is replaced by clamshell powder is as follows:

Mass of Silica Sand = $\frac{35}{100} \times \rho_{ps} \times V_c$ (6)

Where:
ρ_{ps} = density of silica sand (g/mL)

The requirements for clamshell powder are 5% fiber and 0% replacing silica sand or 100% packed silica sand without clamshell powder, resulting in a volume fraction of 70%. The mass calculation for 0% clamshell powder replacing silica sand or 100% silica sand is as follows:

Mass of Silica Sand = $\frac{70}{100} \times \rho_{ps} \times V_c$ (7)

The requirements for clamshell powder at 7% fiber and 100% replacing silica sand result in a volume fraction of 68%. The mass calculation for 100% clamshell powder replacing silica sand is as follows:

Mass of Clamshell Powder = $\frac{68}{100} \times \rho_{ck} \times V_c$ (8)

The requirements for clamshell powder at 7% fiber and 50% replacing silica sand result in a volume fraction of 34%. The mass calculation for 50% clamshell powder replacing silica sand is as follows:

Mass of Clamshell Powder = $\frac{34}{100} \times \rho_{ck} \times V_c$ (9)
Therefore, the mass of silica sand required when 50% of it is replaced by clamshell powder is as follows:

Mass of Silica Sand = $\frac{35}{100} \times \rho_{ps} \times V_c$ (10)

The requirements for clamshell powder are 7% fiber and 0% replacing silica sand or 100% packed silica sand without clamshell powder, resulting in a volume fraction of silica sand of 68%. The mass calculation for 0% clamshell powder replacing silica sand or 100% silica sand is as follows:

Mass of Silica Sand = $\frac{68}{100} \times \rho_{ps} \times V_c$ (11)

The requirements for clamshell powder at 9% fiber and 100% replacing silica sand result in a volume fraction of 66%. The mass calculation for 100% clamshell powder replacing silica sand is as follows:

Mass of Clamshell Powder =$\frac{66}{100} \times \rho_{ck} \times V_c$ (12)

The requirements for clamshell powder at 9% fiber and 50% replacing silica sand result in a volume fraction of 33%. The mass calculation for 50% clamshell powder replacing silica sand is as follows:

Mass of Clamshell Powder =$\frac{33}{100} \times \rho_{ck} \times V_c$ (13)
Therefore, the mass of silica sand required when 50% of it is replaced by clamshell powder is as follows:

Mass of Silica Sand = $\frac{33}{100} \times \rho_{ps} \times V_c$ (14)

The requirements for clamshell powder are 9% fiber and 0% replacing silica sand or 100% packed silica sand, without any clamshell powder, resulting in a volume fraction of silica sand of 66%. The mass calculation for 0% clamshell powder replacing silica sand or 100% silica sand is as follows:

Mass of Silica Sand = $\frac{66}{100} \times \rho_{ps} \times V_c$ (15)

2) Molds with dimensions according to requirements are prepared.

3) A basin container is prepared to mix all materials into a Calcium Silicate Board cement mixture.
4) Portland cement, fibers, silica sand, and clamshell powder are placed into the basin. Water is added according to calculations, and the mixture is thoroughly combined to form the Calcium Silicate Board cement mixture.
5) The Calcium Silicate Board cement mixture is poured into molds and leveled using a scraper.
6) The molds are clamped and tightened with bolts.
7) The Calcium Silicate Board is dried at room temperature.
8) The Calcium Silicate Board is removed from the molds when dry.
9) Bending tests are subsequently conducted on the specimens.

F. Bending Strength Testing

The bending test was performed using a Universal Testing Machine by ISO-8336 standards. Each variation was tested with three repetitions. This bending test was conducted at the Material Testing Laboratory, Politeknik Perkapalan Negeri Surabaya. The highest bending strength value obtained from the calcium silicate board tests will determine the acceptance of the composite as an alternative material for interior walls based on ISO-8336 standards. The equation for calculating the Modulus of Rupture (MOR) in the specimen is as follows:

$$\text{Bending strength} = \frac{3F l_s}{2be^2} \quad (16)$$

Where:
F = maximum load (N)
ls = support span length (mm)
b = specimen width (mm)
e = specimen thickness (mm)

G. Data Analysis

The data analysis was performed using the Analysis of Variance (ANOVA) statistical method to assess the impact of the variables.

III. Results and Discussion

A. Density Calculation Results

Density testing of clamshell powder, silica sand, and cement was conducted with three repetitions each. The density calculation using Equation 1 was performed after obtaining the density test results through the pycnometer method. Subsequently, the average density value from the three repetitions was taken as the density value of the reinforcing powder tested. Table 1 shows the density calculation results of clamshell powder as a component of the calcium silicate board. The calculation results of silica sand density can be seen in Table 2. The calculation results of cement density can be seen in Table 3 below.

According to Table 1, Table 2, and Table 3, the density of clamshell powder is 2.70 g/mL, the density of silica sand is 2.40 g/mL, and the density of cement is 2.57 g/mL. Variations in density values in each repetition are due to inconsistencies in filling the pycnometer, which causes air bubbles to be trapped inside the pycnometer, resulting in varying pycnometer masses. These air bubbles can be minimized by vertical agitation. Additionally, air bubbles can be reduced using the figure-eight stirring

TABLE 1.
RESULT OF CLAMSHELL DENSITY

Repetition	Density Value	Average Density Value
1	2.50 g/mL	
2	2.62 g/mL	2.70 g/mL
3	3.00 g/mL	

TABLE 2.
RESULT OF SILICA SAND DENSITY

Repetition	Density Value	Average Density Value
1	2.22 g/mL	
2	2.37 g/mL	2.40 g/mL
3	2.62 g/mL	

TABLE 3.
RESULT OF CEMENT DENSITY

Repetition	Density Value	Average Density Value
1	3.00 g/mL	
2	2.50 g/mL	2.57 g/mL
3	2.22 g/mL	

method. The second factor is changes in ambient temperature or pressure. Small changes in temperature or pressure can affect the density of liquids, ultimately influencing the calculation results. The results will also vary if the environmental conditions are inconsistent between test replications.

B. Requirement Calculation

The composition requirements for calcium silicate board fabrication can be determined using volume fraction calculations. This study calculated the necessary amounts of silica sand, coconut fiber, clamshell powder, and cement using Equations 2 to 15. Table 4 presents each specimen's required clamshell powder, silica sand, fiber, and cement quantities.

Where:

A: The volume fraction in CSB contains 5% coconut fiber and substitutes 100% of the silica sand composition with shellfish shells.
B: The volume fraction in CSB contains 7% coconut fiber and substitutes 100% of the silica sand composition with shellfish shells.
C: The volume fraction in CSB contains 9% coconut fiber and substitutes 100% of the silica sand composition with shellfish shells.
D: The volume fraction in CSB contains 5% coconut fiber and substitutes 50% of the silica sand composition with shellfish shells.
E: The volume fraction in CSB contains 7% coconut fiber and substitutes 50% of the silica sand composition with shellfish shells.
F: The volume fraction in CSB contains 9% coconut fiber and substitutes 50% of the silica sand composition with shellfish shells.
G: The volume fraction in CSB contains 5% coconut fiber and substitutes 0% of the silica sand composition with shellfish shells.
H: The volume fraction in CSB contains 7% coconut fiber and substitutes 0% of the silica sand composition with shellfish shells.
I: The volume fraction in CSB contains 9% coconut fiber and substitutes 0% of the silica sand composition with shellfish shells.

C. Bending Test Results

Bending tests in this research were conducted at the Materials Testing Laboratory, Shipbuilding Institute of Polytechnic Surabaya. The variations and variables included a fiber volume fraction of 5%, 7%, and 9%. The clamshell variations and variables consisted of 100% substituting the silica sand volume fraction, 50% substituting the silica sand volume fraction, and 0% substituting or not substituting the silica sand volume fraction. Bending tests were performed considering the external load applied to the material under conditions such as being used as a support by humans or encountering impacts from objects. These conditions can cause deflection in the material.

Bending strength is expressed in MPa. The bending tests were conducted with three repetitions. The results include data on the maximum load that calcium silicate boards can withstand. This data was then calculated using Equation 16 to obtain the bending strength values for each specimen. Table 5 shows the bending strength.

Based on the test results, the bending strength

TABLE 4.
RESULTS OF THE CLAMSHELL, SILICA SAND, FIBER, AND CEMENT REQUIREMENTS

Specimens	Mass of Fiber	Mass of Cement	Mass of Clamshell	Mass of Silica Sand
A	3,59 g	40,16 g	118.13 g	0
B	5,03 g	40,16 g	114.75 g	0
C	6,47 g	40,16 g	111.38 g	0
D	3,59 g	40,16 g	59.06 g	52.50 g
E	5,03 g	40,16 g	57,38 g	51,00 g
F	6,47 g	40,16 g	55.69 g	49.50 g
G	3,59 g	40,16 g	0	105 g
H	5,03 g	40,16 g	0	102 g
I	6,47 g	40,16 g	0	99 g

TABLE 5.
RESULT OF BENDING STRENGTH

Clamshell / Coconut Fiber	100%		50%		0%	
	MOR (MPa)	$\overline{MOR}$ (MPa)	MOR (MPa)	$\overline{MOR}$ (MPa)	MOR (MPa)	$\overline{MOR}$ (MPa)
5%	5,04 5,13 8,28	6,15 ± 1,84	8,46 8,19 5,58	7,41 ± 1,59	7,92 9,90 10,53	9,45 ± 1,36
7%	5,40 7,20 9,45	7,35 ± 2,03	7,26 6,48 5,61	6,45 ± 0,83	13,68 11,34 12,96	12,66 ± 1,20
9%	8,91 10,44 11,52	10,29 ± 1,31	6,15 8,10 10,53	8,26 ± 2,20	13,86 14,52 13,23	13,87 ± 0,64

values across each repetition varied. These variations were attributed to the hand lay-up method of manufacturing calcium silicate boards. This method can lead to imperfect manufacturing processes, such as inadequate mixing time of cement with different aggregates, insufficient binding of material aggregates in the calcium silicate board, or uneven pouring of cement mixture leading to air bubbles (porosity). Additionally, high room temperature and humidity can affect the strength of calcium silicate boards and increase porosity.

D. Relationship Between the Volume Fraction of Coconut Fiber and the Bending Strength of Calcium Silicate Board Material

The graph in Figure 2 illustrates the bending strength values of calcium silicate boards with the addition of coconut fiber, where the fiber volume fractions are 5%, 7%, and 9%. The calcium silicate board with 5% Fiber variation showed an average bending strength of approximately 7.67 MPa. Subsequently, the average bending strength of the calcium silicate board with 7% Fiber variation increases by about 25% to approximately 8.82 MPa. Furthermore, the average bending strength of the calcium silicate board with 9% Fiber variation increases by approximately 22.56% to 10.81 MPa.

The enhancement in bending strength is attributed to coconut fiber's ability to reinforce the microstructure of calcium silicate board material. Coconut fiber, known for its mechanical properties such as tensile strength and flexibility, aids in distributing stress uniformly and inhibiting crack propagation within the calcium silicate matrix. This finding aligns with research indicating that adding natural fibers to composite materials can enhance mechanical strength, including bending strength, by acting as physical barriers to crack propagation and improving overall material toughness.

Moreover, when used in geopolymer mortars, coconut fibers significantly improved tensile and flexural strength, comparable to synthetic fibers like glass fiber. However, the workability and compressive strength of the material tended to decrease with the addition of natural fibers (Wongsa et al., 2020). Higher fiber content facilitates better bonding between the fibers and matrix, significantly improving the material's bending strength.

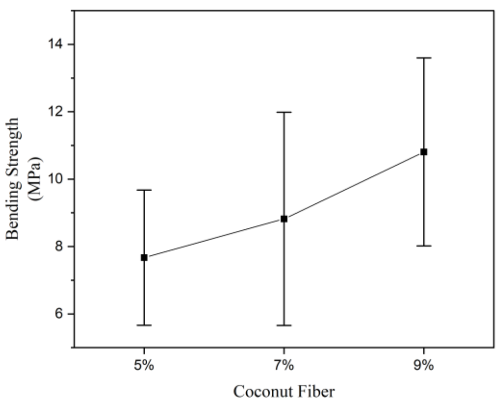

Figure. 2. Graph of Bending Strength of Calcium Silicate Board with Addition of Coconut Fiber

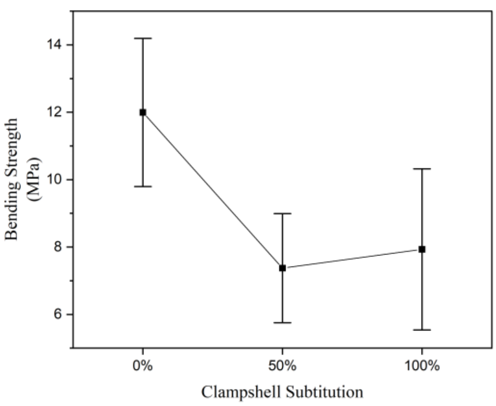

Figure. 3. Graph of Bending Strength of Calcium Silicate Board with Clamshell Substitution

E. Relationship Between the Volume Fraction of Clamshell Powder and the Bending Strength of Calcium Silicate Board Material

Figure 3 illustrates the bending strength values of the calcium silicate board under varying degrees of clamshell substitution. The calcium silicate board without clamshell substitution (0% replacing silica sand) showed an average bending strength of approximately 11.99 MPa. Conversely, the board with 50% clamshell substitution shows a notable decrease in average bending strength to approximately 7.37 MPa, marking a 38.53% reduction in strength. This decline is attributed to inadequate bonding between silica sand and clamshell, limiting enhancement of the board's mechanical properties.

Silica sand is prized for its superior physical and mechanical attributes, including a higher modulus of elasticity than a clamshell, which renders materials with a clamshell-filled matrix more prone to deformation and fracturing under load. Additionally, silica sand, predominantly composed of silicon dioxide (SiO_2), plays a pivotal role in calcium silicate board manufacturing by forming robust and stable bonds within the matrix. Silica sand facilitates the formation of calcium silicate hydrate (CSH), which is crucial for the board's strength and durability. Silica's high reactivity enables effective interaction with calcium compounds, resulting in a denser, more cohesive microstructure and enhanced flexural strength.

Conversely, when comparing the boards with 50% clamshell substitution and 100% clamshell substitution replacing silica sand, the average bending strength increases by approximately 7.59% to 7.93 MPa. These results satisfy the material requirements stipulated for calcium silicate boards under ISO-8336 standards.

F. Relationship Between Clamshell Powder as a Substitute for Silica Sand and the Addition of Coconut Fiber to the Bending Strength of Calcium Silicate Board Material

Based on the contour plot in Figure 4 illustrates the relationship between clamshell powder as a substitute for silica sand and the addition of coconut fiber on the bending strength of the Calcium Silicate Board (CSB). The X-axis represents the percentage of coconut coir fiber ranging from 5% to 9%. The Y-axis indicates the percentage of clamshell powder replacing silica sand, with variations at 0%, 50%, and 100%.

The highest bending strength occurs at 0% clamshell powder with approximately 7% to 9% fiber content, achieving bending strength values exceeding 14 MPa. A significant area with bending strength ranging from 12 MPa to 14 MPa is observed at coconut fiber percentages of 5% to 7% when no clamshell powder is used (0%). A broad range of medium bending strengths (8 - 10 MPa) covers a large area, indicating stable bending strength across various compositions. Even at the entire clamshell powder composition (100%) combined with 9% fiber, bending strength values exceeding 10 Mpa were achieved. Lower bending strengths (< 6 MPa) are found at high percentages of clamshell powder, around 80%, with low percentages of coconut coir fiber, approximately 6%.

These studies found that the volume fraction of coconut fiber and clamshell powder substitution affects the bending strength of calcium silicate boards, with higher coconut fiber content generally decreasing bending strength. At the same time, specific ratios can optimize mechanical properties. combining clamshell powder as a partial substitute for silica sand and adding coconut fiber can lead to specific mechanical property improvements. In suitable combinations, coconut fiber can compensate for strength deficiencies caused by replacing silica sand with clamshell powder.

G. Statistical Analysis

Data analysis was conducted statistically using Analysis of Variance (ANOVA) to determine the influence of the volume fraction of coconut fiber and clamshell powder substitution on the bending strength of the Calcium Silicate Board (CSB) made from silica sand, clamshell, and coconut fiber. The ANOVA results can be seen in Table 6.

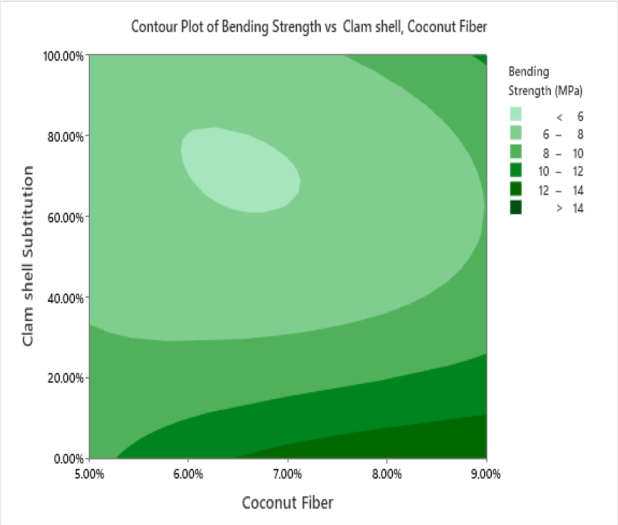

Figure. 4. Graph of Bending Strength of Calcium Silicate Board with addition of Coconut Fiber and Clamshell Substitution

TABLE 6.
ANALYSIS OF VARIANCE (ANOVA)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Clamshell	2	114.50	57.250	20.96	0.000
Coconut Fiber	2	45.32	22.661	8.30	0.002
Error	22	60.09	2.732		
Lack-of-Fit	4	18.13	4.532	1.94	0.147
Pure Error	18	41.97	2.331		
Total	26	219.92			

This analysis utilized a significance level (α) of 0.05. According to the ANOVA results in table 6, the P-value associated with the clamshell variable was 0.000, which falls below the predetermined significance level. Consequently, the null hypothesis (H0) is rejected, indicating a significant influence of substituting silica sand with clamshell powder on the bending strength of calcium silicate board.

Similarly, the calculated P-value for coconut fiber was 0.002, below the α threshold. Therefore, the null hypothesis is rejected, affirming a significant impact of coconut fiber addition on the bending strength of the calcium silicate board.

IV. CONCLUSION

The addition of volume fraction coconut fiber significantly improve the bending strength of the boards, while the replacement of silica sand using clamshell powder gives various result. The maximum bending strength was 13.87 ± 0.64 Mpa by 0% clamshell powder replacement in 9% coconut fiber, and significantly drop at 8.26 ± 2.20 MPa by 50% clamshell powder with 50% silica sand. In fully portion replacement of silica sand, in which the addition of 100% clamshell powder, with 9% coconut fiber, the bending strength measured at 10.29 ± 1.31 MPa. The highest results exceeding the minimum requirement in ISO-8336 category A and B (saturated condition) , class 3 (>13 MPa) standards for interior wall installations. This study providing a more robust and eco-friendly materials alternatives that supports non or maritime industry needs in while resolve the environmental issue.

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